Using Drones to Survey Shorebirds

The University of Queensland Final Report for The Moreton Bay Foundation

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With support from the Queensland Wader Study Group, Queensland Parks and Wildlife Service, and the Quandamooka Yoolooburrabee Aboriginal Corporation.

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Abstract

Context & Need

Migratory shorebird populations in Moreton Bay have declined by up to 79% [1]. To inform conservation measures aimed at arresting this decline we need data detailing the changing abundance and distribution of each species. However, attempts to survey shorebirds are hindered by the vastness of the intertidal habitats that they inhabit, and the difficulty of accessing these areas for field surveys. Drones present a potential method to conduct more extensive shorebird surveys, however they are yet to be used extensively, primarily due to a lack of information detailing how shorebirds react to drones and the time costs associated with manually reviewing survey images to locate and identify the birds. Here we address these issues for shorebirds in Moreton Bay, reducing barriers to the development of drone-based shorebird surveys.

Methods

To summarise previous research on how shorebirds react to drones, we conducted a review of the scientific literature. We found that existing literature did not encompass many of the shorebird species occurring in Moreton Bay and designed a fieldwork programme to address this knowledge gap. We conducted 204 drone approaches to bird flocks comprising mostly roosting shorebirds. Statistical analysis was conducted to assess the main factors associated with drone-induced bird disturbance. We synthesised these results into guidelines outlining ethically acceptable species-specific drone shorebird survey altitudes and recommendations to minimise drone-induced shorebird disturbance. To provide an accessible method of efficiently processing drone-based shorebird images we developed a state-of-the-art bird detection algorithm and embedded it into a web-based software application which requires no technical expertise to utilise.

Results

Different shorebird species responded very differently to an approaching drone. While some species were relatively undisturbed, Eastern Curlews were highly sensitive to an approaching drone. Mixed-species flocks reacted according to the most sensitive species in the flock, rather than according to the typical response of each component species. Because Eastern Curlew are present in many mixed-species shorebird flocks throughout Moreton Bay we conclude that, with current reasonably priced drones, **extensive drone-based shorebird surveys within Moreton Bay are neither practical nor ethical.** However, small scale drone-based surveys may still be appropriate when Eastern Curlew are not present, and researchers may use our guidelines to quantify the risk of disturbance before commencing work. We trained our bird detection algorithm on a dataset of drone images containing 7673 birds of 27 species. The trained network detects 99% of birds and only falsely detects birds 3% of the time. For example, if an image contained 100 birds the network would detect 103 birds, 99 of which would be correct. We are currently working to further optimise the network and ensure it will accurately detect species in many different contexts.

Policy Implications

Recreational and commercial drone use needs to be carefully regulated to ensure roosting shorebird flocks are not approached within distances that will disturb the most sensitive species likely to be present.

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Acknowledgements

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1 Introduction

Moreton Bay supports a diverse range of biodiversity, hosting over 120 species of coral [2], 140 square kilometres of mangroves [3], 40,000 shorebirds [4], herds of dugong hundreds strong [5], six of the world's seven species of sea turtle [6], and the highest recorded diversity and abundance of whales and dolphins in Australia [7]. Moreton Bay is particularly important for migratory shorebirds, supporting at least 28 species which rely on the nutrient rich mudflats to fuel migrations to their breeding grounds in the northern hemisphere. This includes critically endangered species such as the Eastern Curlew, Curlew Sandpiper, Great Knot, and Bar-tailed Godwit [8]. Unfortunately, in the last 15 years Moreton Bay's migratory shorebird population has declined by up to 79% [1]. While declines are largely attributed to habitat loss elsewhere along their migration [9], there are also substantial local threats from disturbance and habitat loss [10-13]. As such, it is crucial that we conserve Moreton Bay as high-quality habitat for migratory shorebirds.

To identify where we should focus shorebird conservation efforts, we need data detailing the abundance of each species and their distribution throughout Moreton Bay. However current attempts to survey shorebirds are hindered by the vastness of the intertidal habitats that they inhabit, and the difficulty of accessing these areas for field surveys. Consequently, almost all information about the distribution of shorebirds in Moreton Bay comes from high tide roost counts, which yields little information about where the birds are foraging. Drones are a potential solution to this difficulty, and indeed they are already being used monitor whales [14], turtles [15], and mangroves [16] in Moreton Bay.

One barrier to drone-based shorebird surveys is the lack of guidelines detailing whether and under what conditions drones can be used near shorebirds without causing undue disturbance. Shorebirds rely on feeding and roosting sites that are free from disturbance to ensure they intake enough energy for survival over the non-breeding period, and to prepare for and recover from their migratory flights [17]. Drone use near shorebird habitats may interrupt these feeding or roosting periods reducing the quality of Moreton Bay as a shorebird habitat and ultimately contributing to population declines [18-20]. This is concerning because drone use is increasing; between 2011 and 2015 it is estimated to have increased by 900% [21], and drones are now very widely used in agriculture [22], building and construction [23], delivery services [24], and for recreation. This increase may be particularly prominent in national parks such as Moreton Bay, where recreational users engage in aerial photography [25, 26]. Another barrier to drone surveys of birds is the significant time required to manually process survey images to determine the locations of birds. However, recent technological advancements mean that the rapid, autonomous, and accurate detection of birds in aerial images may now be possible [27, 28].

The Moreton Bay Foundation, Queensland Wader Study Group, Queensland Parks and Wildlife Service, and the Quandamooka Yoolooburrabee Aboriginal Corporation are supporting a University of Queensland project which aims to produce guidelines for the operation of drones near shorebirds and develop an accessible method of efficiently processing drone-based shorebird images. Through this project we aim to understand the potential for drones to disturb shorebirds, and to monitor them for conservation.

2 Investigating Drone Induced Shorebird Disturbance

2.1 Introduction

Our first step in investigating the possibility of using drones to aid shorebird surveys was to understand how shorebirds react to a drone during a survey. If shorebirds take flight as the drone approaches, it has two main impacts. Firstly, it can decrease the accuracy of the survey; drone-based shorebird surveys aim to capture an image of a shorebird habitat, but because shorebird habitats can be large this often involves capturing multiple images which together cover the entire habitat. If shorebirds take flight as the drone approaches, they may move within the habitat or leave it completely and be photographed more than once or not at all, resulting in an inaccurate survey. Secondly causing shorebirds to take flight can negatively impact the energy balance of the shorebirds. Interrupting shorebird feeding and resting through drone disturbance could reduce the probability that they survive migration and reproduce successfully, ultimately contributing to shorebird population declines [18, 19]. We studied three main factors which could potentially affect the amount of disturbance a drone causes to shorebirds during surveys: the type of drone and how it is flown, the composition of the shorebird flock, and the environmental conditions during the survey. In this section we conduct a review of the current literature and supplement this with our own fieldwork in Moreton Bay, with the aim of investigating how shorebirds react to an approaching drone, what factors impact this reaction, and ultimately develop guidelines detailing how to conduct drone-based surveys without significantly disturbing shorebirds.

2.2 Methods

Before we began conducting our own fieldwork, we reviewed existing research investigating how shorebirds react to a drone. To find relevant research we used Scopus, the largest database of peer-reviewed documents in the world. We searched for papers which either contained the words ‘bird’ and ‘drone’ or were cited by a paper containing those words. After reviewing the abstracts of over 1000 scientific papers, we retained 15 documents which investigated the interactions between drones and shorebirds and used these to inform our guidelines for the use of drones near shorebirds.

Because the existing research we found did not encompass all shorebird species occurring in Moreton Bay, we conducted our own fieldwork to address the study aims. All fieldwork was approved by the ethics committee of the University of Queensland (project number: 2021/AE000474), the Department of Environment and Science, and the Quandamooka Yoolooburrabee Aboriginal Corporation. All drone flights were conducted within the laws of the Civil Aviation Safety Authority. We approached mixed-species shorebird flocks with a drone at four roost sites within Moreton Bay: Toorbul (GPS: -27.0476, 153.1085), Thorneside (GPS: -27.4802, 153.2048), Wellington Point (GPS: -27.4851, 153.2414), and Cleveland (GPS: -27.5351, 153.2835). We used four common consumer drones (Table 1) and recorded the distance between the birds and the drone, the velocity and acceleration of the drone, as well as the wind speed, temperature, tide height, and cloud cover. We determined when each species present in the flock took flight during each approach. Figure 1 provides a visual overview of the method. We conducted statistical analysis to predict the probability of the birds taking flight based on the recorded parameters.

Table 1: Drone parameters

Specification	DJI Inspire 2	DJI Mavic 2 Pro	DJI Phantom 4 Pro	DJI Mavic Mini
Diagonal Size	605mm	354mm	350mm	213mm
Shape	Quadcopter	Quadcopter	Quadcopter	Quadcopter
Colour	Grey	Grey	White	Light Grey
Decibels at 2m	78dBA	74dBA	75dBA	70dBA

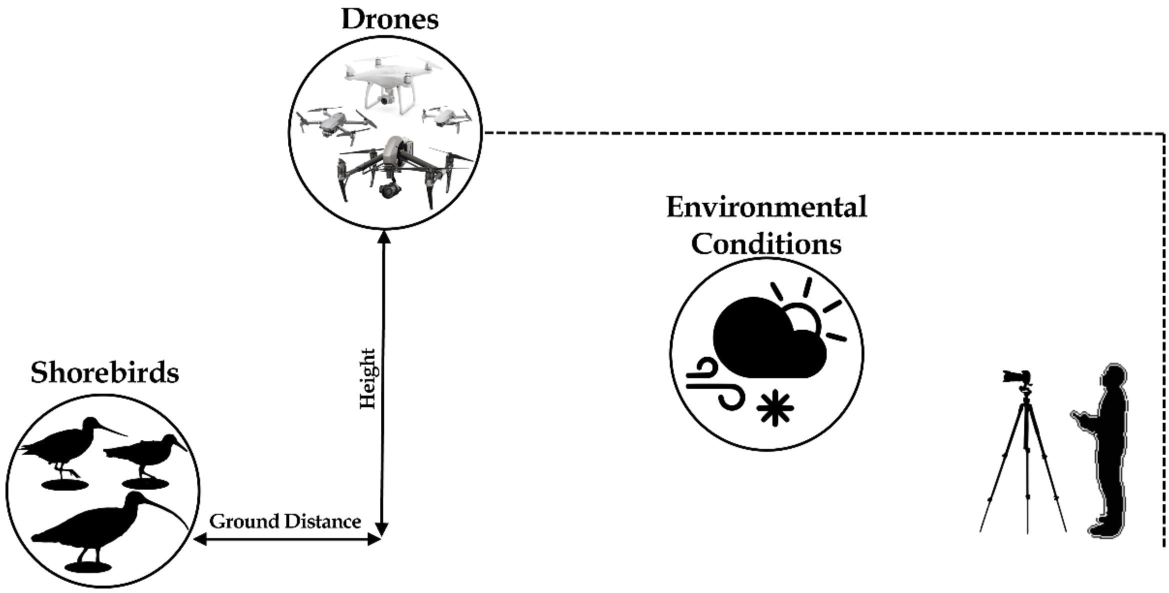

Figure 1: Method used to characterise drone-induced shorebird disturbance. We recorded the type and flightpath (shown by the dotted line) of the drone, the environmental conditions, and the composition and reaction of the shorebird flock.

2.3 Results

During 2020 and 2021 we conducted 204 approaches of flocks containing mostly shorebirds throughout Moreton Bay, with a focus on Eastern Curlew, which is a species of national and international conservation concern. The number of approaches per species is shown in Table 2.

Table 2: Approaches per species

Common Name	**Scientific Name**	**Approaches**
Eastern Curlew	*Numenius madagascariensis*	146
Bar-tailed Godwit	*Limosa lapponica*	95
Pied Oystercatcher	*Haematopus longirostris*	66
Pied Stilt	*Himantopus leucocephalus*	69
Gull-billed Tern	*Gelochelidon nilotica*	51
Caspian Tern	*Hydroprogne caspia*	44
Black Swan	*Cygnus atratus*	44
Whimbrel	*Numenius phaeopus*	33
Great Knot	*Calidris tenuirostris*	21

Figure 2 shows the probability of each of these 9 species of bird taking flight as they are approached from a 450-metre distance at altitudes between 0 and 120 metres above ground with a DJI Mavic 2 Pro or a DJI Phantom 4 Pro (both similar quadcopters with a 350mm diagonal size). The vertical and horizontal axis represent the altitude of the drone above the flock and the horizontal distance between the drone and the flock, respectively. The dots represent the actual data we gathered for all approaches with both drones, blue dots represent the position of the drone at 10 second intervals throughout each approach if the flock had not taken flight, and red dots represent the position of the drone when the flock did take flight. The background colour of the plot is the probability of the birds having taken flight at this point in the horizontal approach from 450 metres based on our statistical analysis. Blue indicates a low probability that the birds would take flight, and red represents a high probability that the birds would take flight. Shorebirds often occur in flocks containing multiple species. The species in these mixed flocks interact with each other, for example, the flight of one species that is highly sensitive to disturbance may cause other nearby species to take flight at the same time, despite those other species typically being less sensitive to disturbance. To ensure we were characterising the response of each species individually, rather than interactions between species, the data used to produce Figure 2 only includes approaches where the relevant species either did not take flight or was the first species to take flight in a mixed flock. We investigate the impact of interactions between species in mixed flocks later in this section.

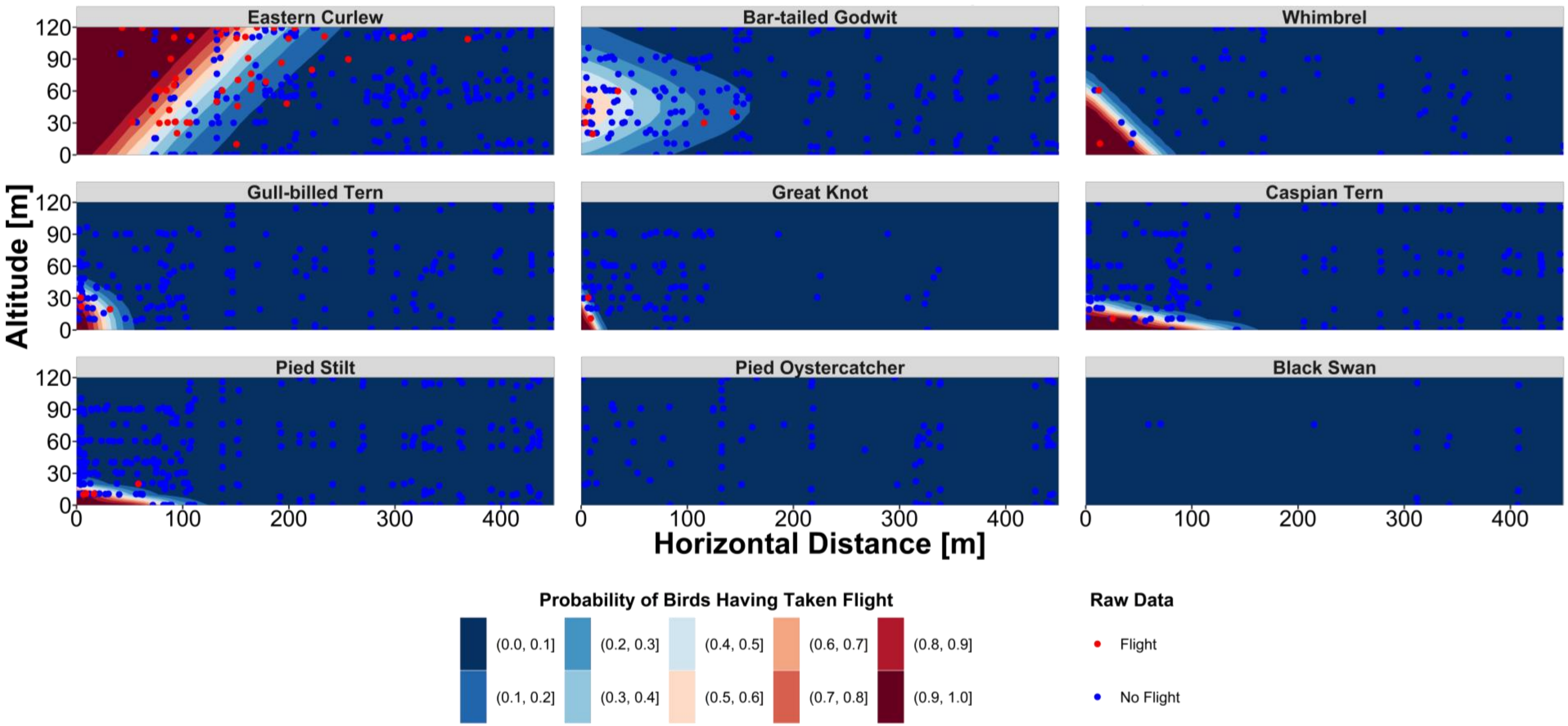

Figure 2: 350mm Wingspan Quadcopter Induced Bird Flight Probability

We identified four main factors impacting the response of the flock. The first was the species of bird, with Eastern Curlew being significantly more susceptible to drone-induced disturbance than other species (Figure 2). The second was the position of the drone, which generally showed that closer horizontal distance and lower altitudes induced more disturbance, except for Eastern Curlew which were more disturbed when the drone was flown at higher altitudes (Figure 2). The third was the type of drone, with the larger, louder DJI Inspire 2 drone inducing more disturbance than the smaller drones. This effect can be seen by comparing the response of birds to a 350mm diagonal quadcopter (Figure 2) to the response of birds when approached with an Inspire 2 (Figure 3).

As discussed earlier, the flight of one species in a mixed-species flock can cause other nearby species to take flight at the same time. This is the fourth factor that significantly impacts the response of the birds. We observed that species in mixed flocks containing Eastern Curlew often took flight at the same time as Eastern Curlew, rather than according to their response shown in Figure 2. Figure 4 shows the percentage of drone approaches where birds took flight at the same time as nearby Eastern Curlew. The red points in Figure 5 show the position of the drone when these flights occurred plotted over the typical response of each individual species. Together these plots show that the flight of nearby Eastern Curlew can induce flight in other nearby species despite the drone being outside that species typical drone-induced flight initiation distance according to Figure 2. Figure 4 also shows that species that are more sensitive to disturbance based on Figure 2 are more likely to take flight at the same time as Eastern Curlew. These results imply that mixed-species flocks react to a drone according to the species that is most sensitive to drone-induced disturbance, rather than according to the typical response of each individual species.

We combined the results from our literature review and fieldwork into a table which provides species-specific minimum drone survey altitudes for 22 species of shorebird (Table 3). We do not recommend drone surveys below an altitude of 30m. At this altitude most drone cameras will achieve a ground sampling distance (the distance of ground covered by each pixel) of less than 7mm. With this ground sampling distance bird species can be identified [29], therefore lower altitudes, which increase the risk of disturbance and collisions, are not ethically justifiable. We only consider results from non-nesting birds, as most studies use bird flight as an indicator of disturbance and nesting birds are unlikely to take flight even when significantly disturbed. For shorebird species not included in Table 3 there is no existing data detailing their response to a drone and we recommend alternatives to drone surveys should be sought until an appropriate survey altitude has been determined. We also outline some general guidelines in Figure 6 which are informed by our experiments and literature review. Reducing the size and noise of the drone, flying further from the birds, flying at lower speeds, and avoiding sudden changes in speed or direction can all reduce disturbance; along with avoiding flocks containing species that are sensitive to disturbance, and reducing drone flights when birds are preparing for and recovering from migration.

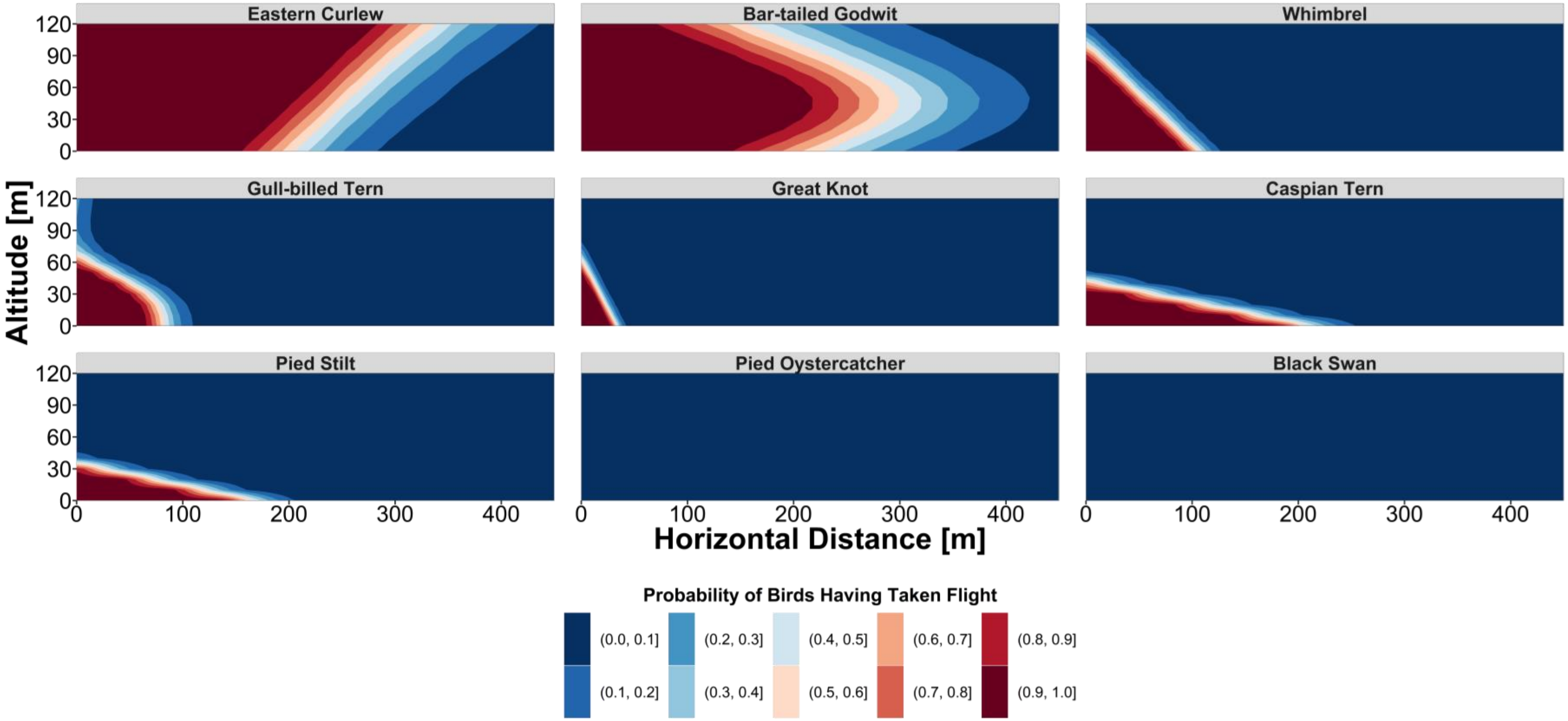

Figure 3: Inspire 2 Induced Bird Flight Probability

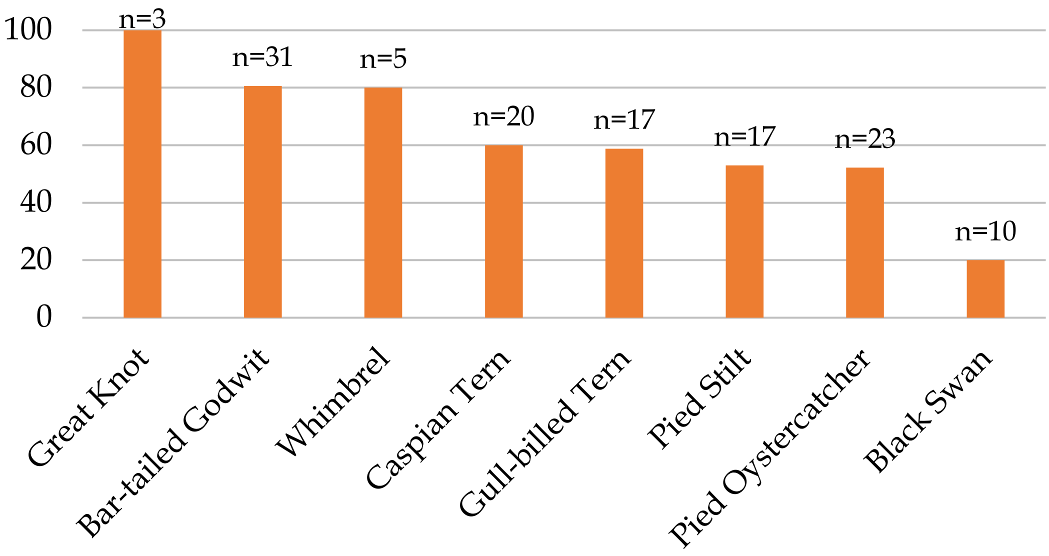

Figure 4: Percentage of drone approaches where birds flew in response to Eastern Curlew taking flight

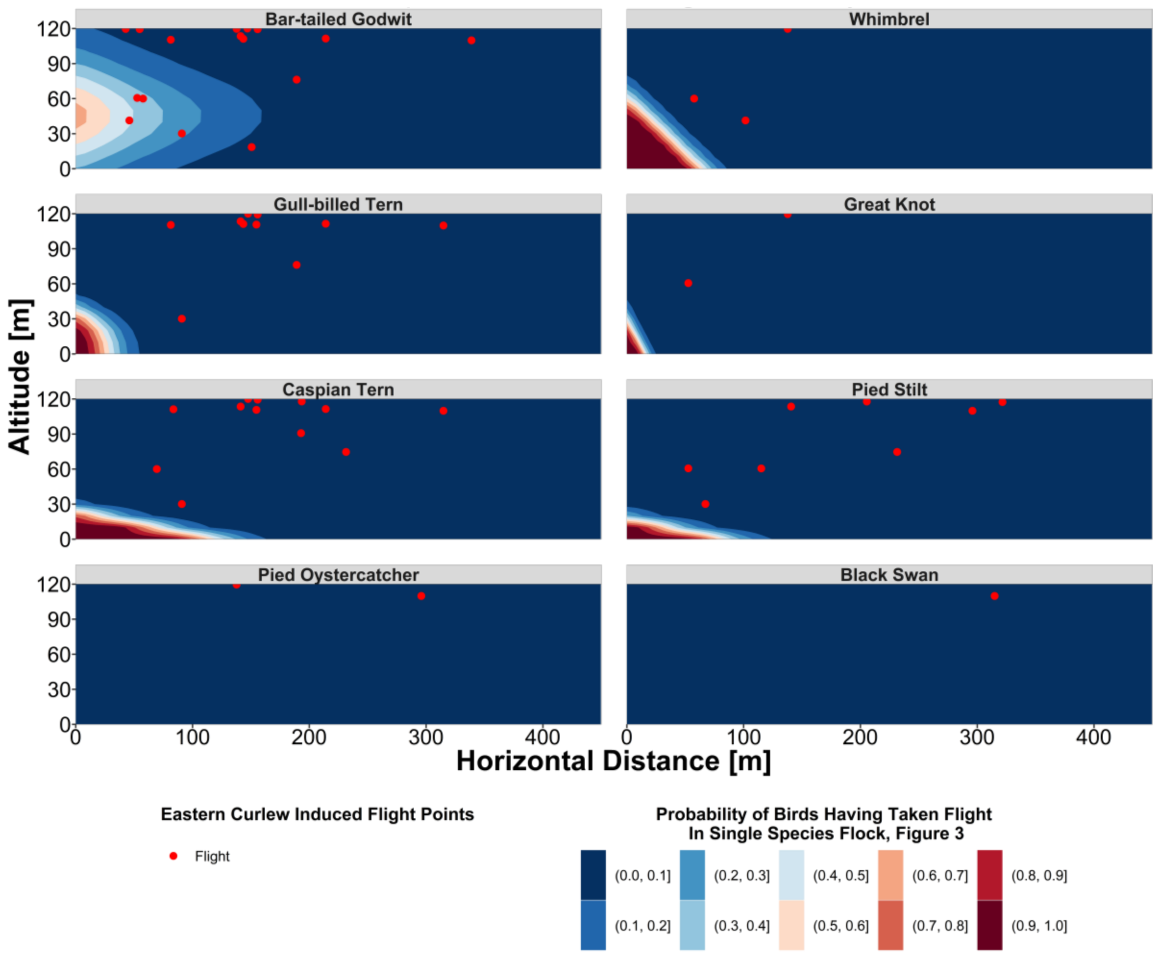

Figure 5: 350mm quadcopter induced bird disturbance when in a mixed flock containing Eastern Curlew. The background contours show the typical reaction of each species when it is not in a mixed-species flock, which is also shown in. Figure 2.

Table 3: Estimated Drone-Induced Shorebird Flight Initiation Altitude

Common Name	**Scientific Name**	**Minimum Altitude 350mm Quad**	**Justification**
Dunlin	*Calidris alpina*	Unknown: <75m	[30] non-nesting survey at 75m altitude.
Kentish Plover	*Charadrius alexandrinus*	Unknown: >30m	[31] nesting survey down to 5m altitude. [32] non-nesting flight initiation altitude >30m.
Little Ringed Plover	*Charadrius dubius*	Unknown: >30m	[32] non-nesting flight initiation altitude >30m.
Common Ringed Plover	*Charadrius hiaticula*	Unknown	[33] nesting survey at 20m altitude.
Piping Plover	*Charadrius melodus*	Unknown	[34] nesting survey at 15m altitude.
Collared Pratincole	*Glareola pratincola*	Unknown: >30m	[32] non-nesting flight initiation altitude >30m.
Pied Oystercatcher	*Haematopus longirostris*	30m	[35] flight initiation distance 14.6m at 4m altitude. [*] <10% probability of flight at 30m altitude.
Eurasian Oystercatcher	*Haematopus ostralegus*	Unknown: >50m & <75m	[30] non-nesting survey at 75m altitude. [32] non-nesting flight initiation altitude >30m. [36] [37] nesting flight initiation altitude > 50m.
Black-winged Stilt	*Himantopus himantopus*	40m	[32] non-nesting flight initiation altitude >30m. [38] non-nesting survey at 40m altitude. [39] nesting birds flushed below 30m altitude.
Bar-tailed Godwit	*Limosa lapponica*	75m	[30] non-nesting survey at 75m altitude. [*] <10% probability of flight at 60m altitude.
Black-tailed Godwit	*Limosa limosa*	Unknown	[36]
Eurasian Curlew	*Numenius arquata*	Unknown	[36] [40] recommend nesting survey at 50m.
European Golden Plover	*Pluvialis apricaria*	Unknown: <75m	[30] non-nesting survey at 75m altitude. [36]
Pied Avocet	*Recurvirostra avosetta*	>30	[32] non-nesting flight initiation altitude >30m. [39] nesting birds flushed below 30m altitude.
Red-necked Avocet	*Recurvirostra novaehollandiae*	Unknown	[35] flight initiation distance 10.8m at 4m altitude.
Common Redshank	*Tringa totanus*	30m	[32] non-nesting flight initiation altitude <30m. [36] [41] nesting birds flushed at 10m altitude.

Masked Lapwing	*Vanellus miles*	Unknown	[35] flight initation distance 31.2 ± 6.3m, 41.3 ± 5.9m at 4m, 10m altitude. Alarm initiation distance 56.8 ± 6.8m, 50.5 ± 3.4m at 4m, 10m altitude. [42] territorial calls within ~10 m.
Northern Lapwing	*Vanellus vanellus*	Unknown: >40m	[43] nesting survey down to 15m altitude. [44] 40m altitude incited flight in nesting birds.
Eastern Curlew	*Numenius madagascariensis*	Unknown: > 120m	[*] >90% probability of flight up to 120m altitude.
Whimbrel	*Numenius phaeopus*	80m	[*] <10% probability of flight at 80m altitude.
Great Knot	*Calidris tenuirostris*	50m	[*] <10% probability of flight at 50m altitude.
Pied Stilt	*Himantopus leucocephalus*	30m	[*] <10% probability of flight at 30m altitude.

**Justification from fieldwork conducted as part of this study, Figure 2.*

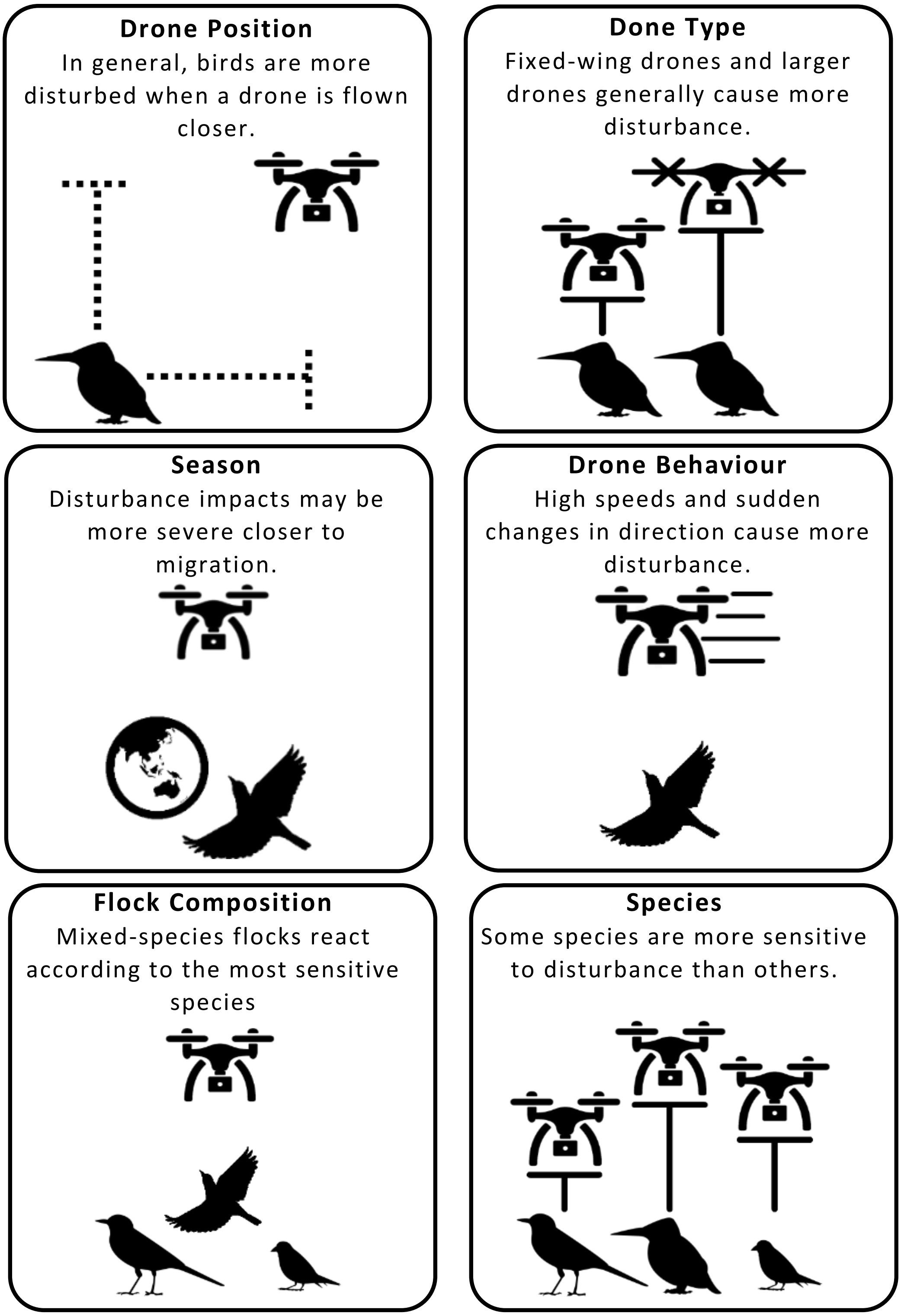

Figure 6: General guidelines for minimising drone induce bird disturbance.

2.4 Discussion

In this section we aimed to understand how shorebirds react to an approaching drone to develop guidelines for drone-based shorebird surveys in Moreton Bay. We found 15 previous studies which involved drones and shorebirds (Table 3), but only 5 of these focussed on drone-induced shorebird disturbance while 2 were in non-English languages making them less accessible [32, 35, 36, 40, 41]. The recommendations between these studies varied, with [32] finding that most shorebird species could be approached with a drone without inducing flight provided the drone was flown above 30 meters, but Jarrett, D., et al. (2020) [36] stated that because they induced too much disturbance "off-the-shelf quadcopters are unlikely to be an effective aide for the monitoring of non-breeding wetland birds". Finally, the interaction between drones and many shorebird species, such as the critically endangered Eastern Curlew and Great Knot, are not covered at all in the previous literature.

The inconclusiveness of this literature review prompted us to conduct our own fieldwork to determine the flight initiation distance of 9 bird species including 6 shorebirds. Weston, M.A., et al. (2020) [35] found Pied Oystercatchers were relatively undisturbed by a drone and we confirmed this, with no unsuccessful approaches even at 20 meters altitude. Previous studies also showed that breeding Caspian Terns [45] and Gull-billed Terns [32, 46] could be approached by a drone at altitudes above 30 meters, we found that an altitude of at least 50 meters is more appropriate when these species are not breeding. Bar-tailed Godwit did not show a clear flight initiation altitude, with some successful approaches even at altitudes as low as 10m, and some unsuccessful approaches at altitudes up to 60m, but no flights above 60m induced disturbance, aligning with [30] who found 75m to be an appropriate flight altitude for drone-based Bar-tailed Godwit surveys. No previous studies assessed the interaction between drones and Whimbrel, Eastern Curlew, Great Knot, or Pied Stilt. Here we show that Pied Stilt are unlikely to take flight when approached with a small drone flown at altitudes above 30 meters, while an altitude of 50 meters is recommended for surveying Great Knot, and at least 75 meters is necessary to approach Whimbrel without a high probability of inducing flight. Critically, we found that Eastern Curlew are highly sensitive to drone induced disturbance, out of 75 attempts, we were never able to approach to directly above Eastern Curlew with any of the four drone types tested at any altitude tested.

We also determined the main factors that impact how likely a bird is to take flight when approached with a drone. Previous research has shown that the response of birds to an approaching drone depends on their species [32, 35, 47] and we confirmed this effect and show that even species within the same genus can have very different sensitivities to drones. For example, Whimbrel took flight only when approached below 75 meters, but Eastern Curlew took flight at all tested altitudes. One of the most important findings was that bird flocks containing multiple species respond according to the most sensitive species in the flock, in this case the Eastern Curlew. None of the previous literature investigating the interaction between drones and shorebirds investigated this issue, but shorebirds often congregate in mixed-species flocks, so it is extremely important. We also show that larger, louder drones induce more disturbance than smaller drones, even between quadcopter drones with a similar shape. While this seems intuitive, most previous research focuses on a single type of drone, and there are mixed conclusions between those that do use multiple drone types. [48] and [49] did not see any clear impact of drone type, but [50] and [51] both found that fixed wing drones cause more disturbance than rotor-wing drones. We also confirmed that closer horizontal distance increased disturbance as in [35, 52] and that in most cases decreasing altitude increased disturbance [29, 32, 53]. However, surprisingly Eastern Curlew were more disturbed by the drone when it was flown higher. Overall, drone-induced bird disturbance was largely independent of environmental conditions with location, wind speed, cloud cover, and temperature having no major effects on the likelihood of the birds taking flight.

Unfortunately, because an approaching drone will cause mixed-species shorebird flocks containing Eastern Curlew to take flight, and Eastern Curlew are present in many mixed-species flocks throughout Moreton Bay, we conclude that **extensive drone-based shorebird surveys within Moreton Bay are not practical or ethical under the conditions we tested**. There is likely an altitude above the maximum altitude we tested where Eastern Curlew are no longer disturbed, however, to identify the species of a bird in a drone image each pixel must cover less than 1cm^2 of ground [29] and the cost of the equipment needed to achieve this resolution at a high altitude would be a significant barrier for many researchers. Also, most drone regulatory bodies require additional licences to fly above 120 meters, these licences cost money and require training, adding a skill and financial barrier. However, these barriers are not insurmountable, and drones may still present a valuable shorebird survey method in locations where Eastern Curlew are not present, as done by Castenschiold, J.H.F., et al. in 2022 [30] when they successfully surveyed European golden plover, Eurasian Oystercatcher, Dunlin, and Bar-tailed Godwit with a DJI Phantom 4 Pro flown at 75 meters altitude. Organisations such as the Queensland Wader Study Group may be interested in trialling drone-based shorebird surveys at specific sites which do not contain Eastern Curlew and we hope the information presented here can help inform the design of drone-based shorebird surveys.

In terms of regulations, the implication of these findings is that drone use near mixed-species shorebird flocks containing Eastern Curlew will cause them to take flight, interrupting critical foraging and roosting time and reducing the probability that these shorebirds survive migration and reproduce successfully. We recommend implementing measures to mitigate disturbance at critical shorebird habitats, these measures should be based on most sensitive species likely to be present and informed by the most disturbing drone type, in the context of this study that is an Inspire 2 (Figure 3). For example, for the Toorbul Site (GPS: -27.0476, 153.1085) the most sensitive species likely to be present is Eastern Curlew, which has a 10% probability of taking flight once an Inspire 2 sized quadcopter flown at 120 meters altitude approaches within 450 meters horizontal distance. We recommend that a 450-meter drone exclusion zone be implemented around the Toorbul Site. Unfortunately drone regulation is notoriously difficult, however there are several avenues for mitigating drone-induced disturbance. Regulatory bodies, such as the Civil Aviation Safety Authority in Australia, could use Figure 3 to incorporate drone restrictions near critical shorebird habitats similar to restrictions currently placed around airports. National parks could also distribute information and regulate drone park permits as well as implement informational signage near critical sites, and governing bodies such as local councils can also distribute information and implement signage.

3 Autonomous Detection of Birds in Aerial Imagery

3.1 Introduction

In section 2 we developed guidelines detailing how to operate a drone near shorebird without significantly disturbing the birds. This allowed us to address the second major issue associated with drone-based shorebird surveys, which is the time required to manually process survey images. A drone-based shorebird survey of a large intertidal habitat may produce hundreds of images containing thousands of shorebirds of multiple species. Manually reviewing each of these images to find the shorebirds and identify their species can be extremely time consuming. As a result, scientists have been investigating using machine learning applications to rapidly detect and identify wildlife in images produced by drone-based surveys [27, 28]. There are three main areas where we can improve on previous research investigating the use of machine learning to count birds in drone-based surveys. Firstly, previous machine learning applications are often designed to work in a certain context, e.g., the network may detect birds on ice shelves of Antarctica but not on the muddy shorelines of Moreton Bay. Secondly, the applications do not distinguish between different bird species, and thirdly the applications are not easily accessible for people without expertise in machine learning. Here we investigate whether we can develop an accessible machine learning application to detect birds in drone-based images and identify their species. In this section we include all bird species which were not easily disturbed by drones, rather than just focussing on shorebirds. This allowed us to gather more data and develop a more accurate machine learning based bird detector.

3.2 Methods

To train a machine learning algorithm to detect and identify an object within an image, it is necessary to use training images in which objects have been manually outlined. These are termed 'labelled images' and the group of all labelled images is called the 'dataset'. When shown this dataset of labelled images the machine learning network learns what the object looks like and can then find it in new images which have not been labelled.

To train our machine learning network we needed labelled images of birds taken from a drone. We used the flightpath outlined in Figure 7 to approach birds within Moreton Bay with a DJI Mavic 2 Pro and capture images. Prior to approaching each flock, we captured high resolution images of the birds from the ground to help identify and locate each bird. We used the guidelines developed in Section 2, to avoid inducing disturbance.

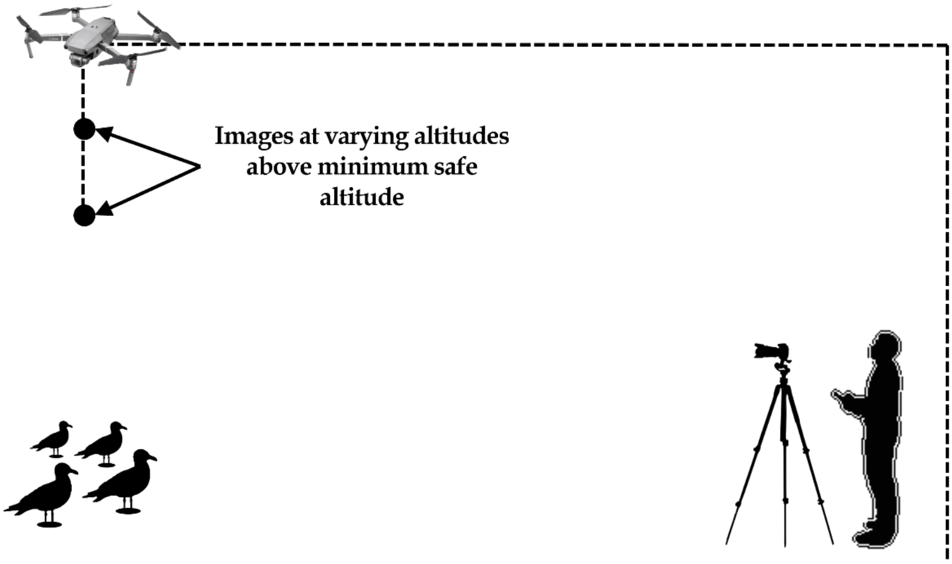

Figure 7: Bird detector image collection method

We then manually reviewed the images, located each bird, and assigned it a different coloured label which identified what species it was (e.g., see Figure 8).

Figure 8: An example of a labelled image used to train the machine learning network

There are many kinds of machine learning network for different purposes, we chose to use one called 'Faster-RCNN', a state of the art network which has been used to detect birds in aerial images before [27]. We split our dataset of labelled images into two parts, 80% of the dataset was used to train the machine learning network, called the 'training dataset', and the remaining 20%, called the 'testing dataset', was used to test the performance of the network once it was trained.

3.3 Results

During 2020, 2021, and 2022 we developed a dataset containing 7673 birds encompassing 27 species. Our current machine learning network detects birds very effectively but has not yet been extended to identify species. We are working on this capability, which we discuss in Section 3.4. Our network detects 99% of all birds in the testing dataset while only 3% of its detections are other objects incorrectly detected as a bird. For example, if an image contained 100 birds the network would detect 103 birds, 99 of which would be correct. Figure 9 shows example bird detections made by the trained network, we can see the network has accurately placed a box around each bird. This network is embedded in an application, which requires no machine learning expertise and is accessible and free to use. It is currently available for beta testing – please contact The Moreton Bay Foundation or the authors for details. This application generates an excel spreadsheet containing the GPS position of the birds and the time the image was taken, Table 4.

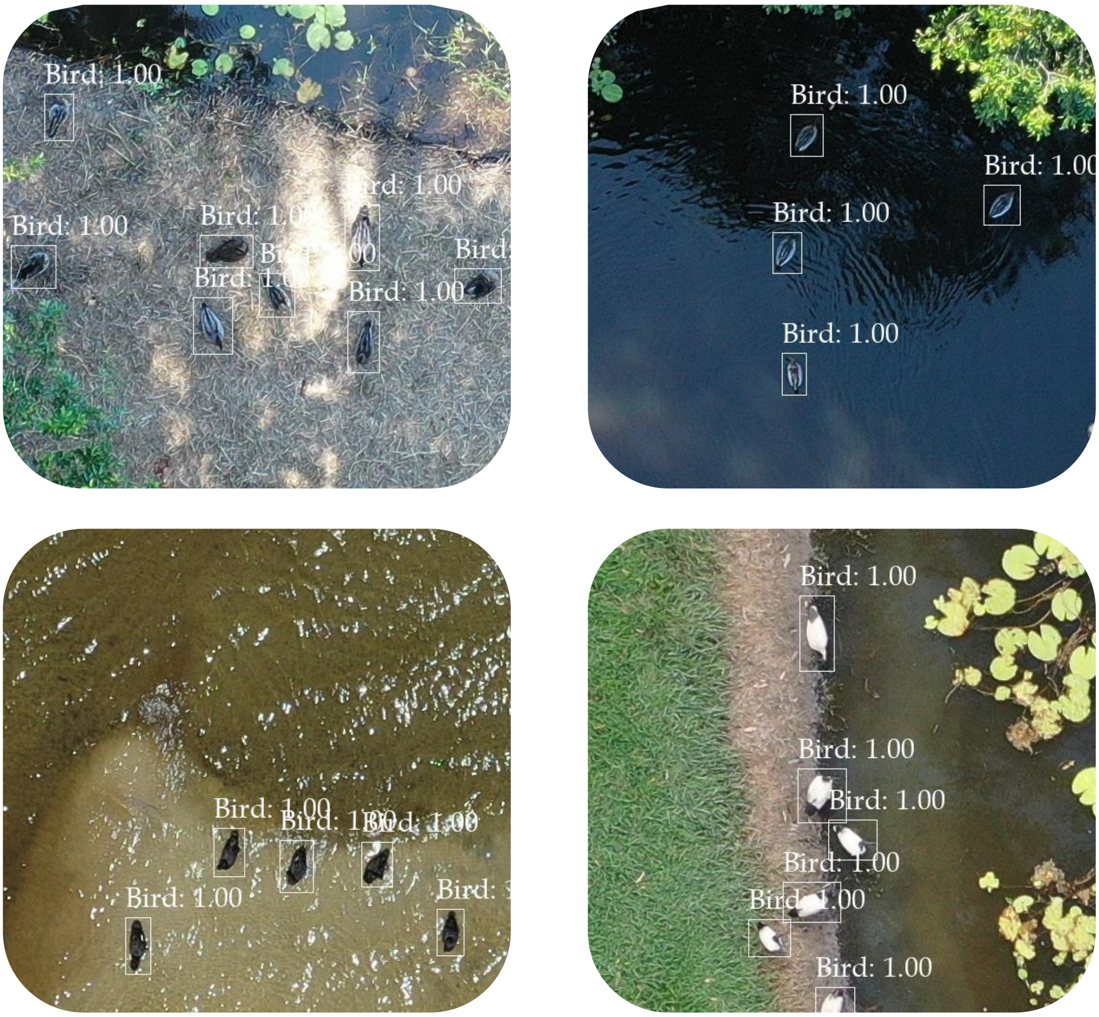

Figure 9: Example network detections

Table 4: csv generated by bird detection algorithm

label	datetime	latitude	longitude	score
bird	2022:03:23 10:44:53	-27.48392676	153.1154789	1
bird	2022:03:23 10:44:53	-27.48391738	153.1154629	1
bird	2022:03:23 10:44:53	-27.4839276	153.1154961	0.99

We demonstrated the field utility of this application by conducting a survey of the Minnippi Parklands, South-East of Brisbane (GPS: -27.4836, 153.1143), on 30th May 2022, detecting 43 birds, (Figure 10).

Figure 10: Drone-based bird survey of Minnippi Parklands, South-East Brisbane

3.4 Discussion

The goal of this section was to develop a machine learning based application that can be used without any machine learning expertise to accurately detect birds in drone-based images and identify their species across many different habitats. Our current network detects 99% of birds in drone-based images, and only falsely detects birds 3% of the time making it the best performing general bird detection network we are aware of [27]. Unlike previous research, this machine learning network has been embedded in an application which requires no machine learning expertise to use.

One problem with our current machine learning network is that the training dataset only encompasses bird species and environments within Moreton Bay, meaning that it will likely perform more poorly for species and environments not in Moreton Bay. For example, Figure 11 shows the result of applying our network to an image of penguins. While the network does detect all the penguins, it also falsely detects birds in the background because the training dataset did not contain images relevant to that substrate.

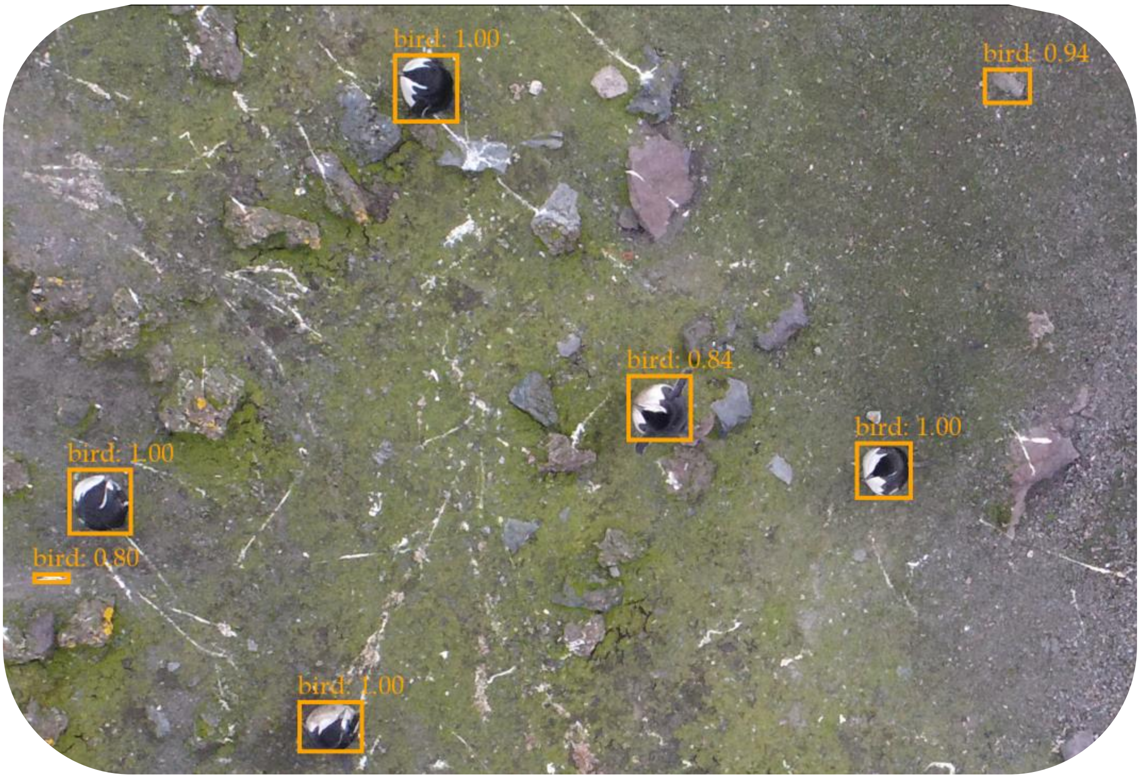

Figure 11: The trained network's detection of penguins on a substrate which was not in the training data. The network falsely detects birds in the top right and bottom left.

To ensure our network is accurate in many different habitats and for many species we have reached out to researchers from across the globe who have supplied images containing species and environments not found in Moreton Bay. Our dataset now contains over 2700 images, including flamingos from Chile provided by César Raul Luque-Fernández (Figure 12), penguins from Antarctica provided by Christian Pfeifer (Figure 13), and many other species.

Figure 12: A drone-based image of Chilean Flamingos by César Raul Luque-Fernández

Figure 13: Breeding chinstrap penguins, contributed by Christian Pfeifer

Another issue with our network is that it does not determine the species of detected birds, however we have begun to incorporate this feature. Figure 14 shows some of the results we have achieved so far. We are working with machine learning specialists at the University of Queensland to further optimise the network and ensure it will accurately detect species in many different contexts.

Figure 14: An example of the species-specific bird detector which is in development

4 Conclusion

This project aimed to define the barriers that limit the use of drones to survey shorebirds by producing guidelines for the operation of drones near shorebirds and developing an accessible method of efficiently processing drone-based shorebird images.

We identified four major factors that impact the response of birds to a drone. We found that different species reacted very differently to an approaching drone. The most sensitive species we approached was the critically endangered Eastern Curlew which we could not approach at any altitude with any drone, including the 249gram DJI Mavic Mini, without causing the flock to take flight. The position and type of drone also impacted the response of the birds, with larger, louder drones, and lower, closer approaches generally inducing more disturbance. Finally, we found that, in general, flocks containing multiple species reacted according to the most sensitive species within the flock, rather than according to the response of each component species. We then combined our own fieldwork with existing literature to produce a table specifying appropriate drone survey altitudes for 22 species of shorebird. Critically, we conclude that, with current reasonably priced drones, **extensive drone-based shorebird surveys within Moreton Bay are neither practical nor ethical.** However, small scale drone-based shorebird surveys may still be appropriate when Eastern Curlew are not present, and researchers may use our guidelines to quantify the risk of disturbance before commencing work.

To provide an accessible method of efficiently processing drone-based shorebird survey images we trained a state-of-the-art bird detection algorithm on a dataset of drone images containing 7673 birds of 27 species. We embedded this algorithm into a web-based software application which requires no technical expertise to use. The application detects 99% of birds and only falsely detects birds 3% of the time. For example, if an image contained 100 birds the network would detect 103 birds, 99 of which would be correct. We have begun to incorporate species-specific identification into the algorithm and are also working with international researchers to ensure the network performs well in contexts outside of Moreton Bay.

By supporting this project, the Moreton Bay Foundation, Queensland Wader Study Group, Queensland Parks and Wildlife Service, and the Quandamooka Yoolooburrabee Aboriginal Corporation have helped us understand the potential for drones to disturb shorebirds and reduce the barriers to ethical drone-based shorebird surveys. By investigating ways to gather more extensive shorebird abundance and distribution data we are taking steps towards informing more effective conservation measures to arrest the alarming declines in shorebird populations and ensure Moreton Bay continues to support a diverse range of biodiversity.

5 Budget

Unforeseen circumstances resulted in an $19,026.7 underspend for this project as of the 01/08/2022, however the project has been extended to allow these funds to continue to be used to improve bird conservation in Moreton Bay. $8603.93 of this was allocated in the proposed budget to hiring a research assistant to label drone-based bird images used to train the species-specific bird detection network. This was delayed due to difficulty determining appropriate survey altitudes for Eastern Curlew but is now underway. This leaves $10,422.77 to spend. We propose using this money to conduct drone-based bird surveys within Moreton Bay, culminating in an event demonstrating the drone-based bird survey capabilities we have developed to interested parties, such as The Moreton Bay Foundation, Queensland Wader Study Group, Queensland Parks and Wildlife Service, and Birdlife.

Table 5: Budget as of 01/08/2022

	BUDGETTED				ACTUAL				
EXPENSE	COST	TMBF	QWSG	UQ	COST	TMBF	QWSG	UQ	EXPLANATION
UAV and Aerial Imaging Hardware	$ 15,000.00	$ 13,500.00	$1,500.00	$ -	$ 3,427.73	$ 703.94	$ 2,723.79	$ -	Inspire 2 drone and accessories were refunded as the large drone caused high disturbance to birds. A smaller drone, the Mavic 2 Pro, was purchased at a much lower cost. Co-contribution was higher.
UAV Pilot & Radio Licence	$ 1,500.00	$ -	$1,500.00	$ -	$ 1,195.00	$ -	$ 1,195.00	$ -	Course was slightly less than anticipated
Machine Learning Hardware	$ 4,500.00	$ 4,000.00	$ 500.00	$ -	$ 4,588.78	$ 4,419.00	$ 169.78	$ -	Required slightly higher TMBF contribution than anticipated.
Object Detection Training Time	$ 550.00	$ -	$ 550.00	$ -	$ -	$ -	$ -	$ -	No paid training time was required
Laser-rangefinder/Lightmeter/Sound level meter	$ 450.00	$ -	$ 450.00	$ -	$ 341.54	$ -	$ 341.54	$ -	-
Ground Imaging Hardware	$ 914.00	$ 914.00	$ -	$ -	$ 1,290.82	$ 801.82	$ 489.00	$ -	Due to project extension renting became more expensive than purchasing, so items were purchased. Co-contribution was higher than anticipated.
Fieldwork Expenses	$ 500.00	$ -	$ 500.00	$ -	$ 80.89	$ -	$ 80.89	$ -	-
Prof Fuller (Level E, 0.05 FTE for 1 year)	$ 12,000.00	$ -	$ -	$12,000.00	$ 12,000.00	$ -	$ -	$ 12,000.00	-
Dr Woodworth (Level A, 0.05 FTE for 1 year)	$ 6,000.00	$ -	$ -	$ 6,000.00	$ 6,000.00	$ -	$ -	$ 6,000.00	Dr Brad Woodworth moved overseas for work. His position was replaced by Dr Tatsuya Amano
Reseach Assistant (HEW 4.1 for 1.5 months)	$ 10,000.00	$ 10,000.00	$ -	$ -	$ 1,396.07	$ 1,396.07	$ -	$ -	ONGOING
Moreton Bay Drone-Based Bird Surveys	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	Extension of proposed budget due to underspend on drone hardware
GST	$ -	$ -	$ -	$ -	$ 2,066.47	$ 2,066.47	$ -	$ -	GST was not included in the original budget
Total	$ 51,414.00	$ 28,414.00	$5,000.00	$18,000.00	$ 32,387.30	$ 9,387.30	$ 5,000.00	$ 18,000.00	-
Remaining	-	-	-	-	$ 19,026.70	$ 19,026.70	$ -	$ -	-

6 Timeline

Project Start: Jan-2019

MILESTONES	PROGRESS	START	END
TMBF Negotiations	100%	5/06/2020	23/12/2020
Disturbance Experiments	100%	1/02/2021	25/12/2021
Disturbance Analyis	100%	1/01/2022	30/04/2022
Bird Image Dataset Creation	100%	22/02/2021	31/05/2022
Bird Detector Training	100%	1/01/2022	31/05/2022
Bird Detector Application	100%	22/02/2021	31/05/2022
Drone Bird Guidelines	100%	1/05/2022	31/05/2022
Final Report	100%	1/02/2022	31/05/2022
Species Detector Dataset Creation	30%	1/04/2022	1/10/2022
Species Detector Devlopment	70%	1/04/2022	1/01/2023
Species Detector Application	50%	1/06/2022	1/03/2023
Drone Based Bird Surveys	0%	1/10/2022	1/01/2023
Updated Final Report	0%	1/01/2023	1/03/2023

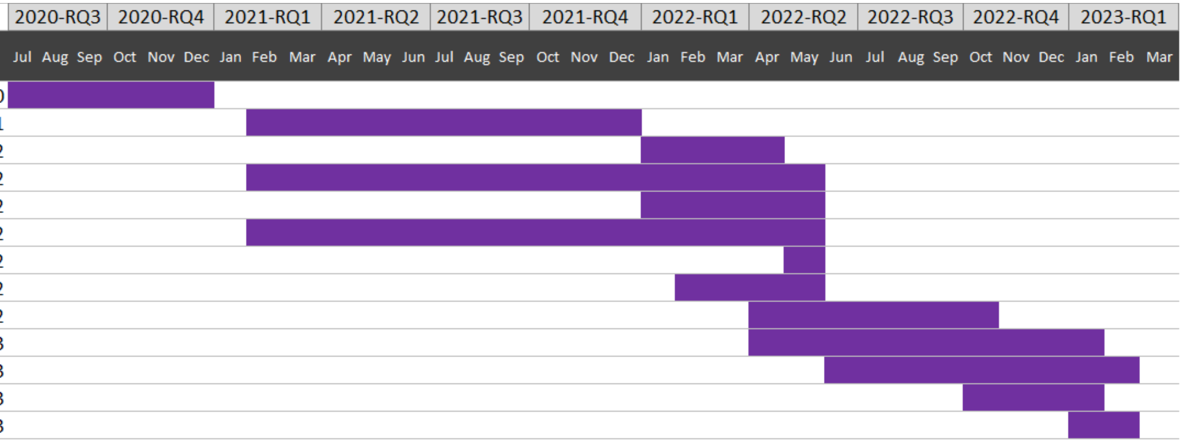

Figure 15: Project timeline including future work

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