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The use of drone to study the nesting behavior of milky stork: Some preliminary observations

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Abstract. *Mardiastuti A, Mulyani YA, Akbar A, Wicaksono B, Rahmawati T, Wulandari YP, Warsajaya. 2023. The use of drone to study the nesting behavior of milky stork: Some preliminary observations. Biodiversitas 24: 4549-4557.* The use of a drone to census waterbirds has been increasingly popular. However, study on the waterbird's behavioral response to the drone was still limited. The objective of this study is to reveal the response of the breeding milky stork *Mycteria cinerea* to the drone as a new and safer tool for collecting breeding behavior data. Factors that influence the success of the observation by using a drone were also identified and a set of recommendations was formulated. The research was conducted during the breeding season of the milky stork in Pulau Rambut, a small island in Jakarta Bay, between December 2022 and March 2023. Three types of drones were tested in the pilot study, and eventually, a small manually piloted drone (Syma X25 Pro) was found to be more appropriate for behavioral study. The bird response to the drone (no, neutral, temporary, negative response) was observed through a combination of various distances and angles of the drone to the nest trees. Despite the weather obstacles, this study suggested that the milky stork mostly (17 out of 20 trials) showed no response or neutral response to the drone. Some temporary responses were detected due to some accidental events, including a sudden launch of the drone. In conclusion, a small-size, easy-to-maneuver drone that produces low noise and mild wind can be used by using a manual pilot mode to study the breeding behavior of milky storks or other similar waterbird species.

Keywords: Behavior response, drones, Pulau Rambut, waterbird

INTRODUCTION

Drones, also known as 'unmanned aircraft systems' (UAS) or 'unmanned aerial vehicle' (UAV), have been emerging as powerful tools in wildlife research. The use of drones has tremendously increased in the past decades, as they have increased research efficiency and reduced research effort, time, as well as financial and operational costs (Koh and Wich 2012; Christie et al. 2016; Zink et al. 2023). Another benefit of using drones for wildlife research was the reduced disturbance compared to traditional surveys (Christie et al. 2016).

Chabot and Bird (2015) and Linchant et al. (2015) reviewed several types of drones for wildlife research. The most commonly used drone was a small fixed-wing type, which was able to fly fast in a longer time (~50 km/h for ~40 mins) and equipped with a high-quality camera. However, the fixed-wing type required ample space to take off and landing. Another alternative was using a multi-copter drone, usually a smaller drone that was able to maneuver and take images from various directions. The multi-copter drone was able to be launched and landed from a small area due to its vertical landing system, but it was only able to fly in a short time of ~40 min or less (Abro et al. 2022). A common multi-copter drone available in the market is a quadcopter (four-rotor) drone.

For birds, drones have been used for various objectives in diverse bird species or groups of bird species researches, including species identification in waterfowl flock (McEvoy et al. 2016), population estimation of shorebirds (Wilson et al. 2022) and waterfowl (Dundas et al. 2021), habitat selection of tern (Scarton and Valle 2020), as well as disturbance caused by drones on seabirds (Borrelle and Fletcher 2017), aquatic birds (Weston et al. 2020) and white stork (Zbyryt et al. 2021). To minimize the disturbance, some researchers (e.g., Ratcliffe et al. 2015; Vas et al. 2015; Mulero-Pázmány et al. 2017) have drafted a certain protocol to ensure that the research by using drones would not jeopardize the survival of the bird species under study.

Among the bird groups, to date, the waterbird population surveys by using drones have received more attention, as the waterbirds often occur in hard-to-access habitats (e.g., remote islands, wetlands, islands, offshore waters, mangrove forests), where only the drones may be able to overfly. The typical objective of the overflights is to survey the distribution and abundance of waterbirds in a certain area (Chabot and Bird 2015). Furthermore, Chabot and Bird (2015) stated that the use of small multirotor systems to perform nest checks is another emerging application for bird study. It is a safer and more convenient alternative to physical climbing to reach nests on trees.

Milky stork (*Mycteria cinerea*) is a large waterbird species that has already been protected by Indonesia. This rare species nests on tall mangrove trees, where access and visibility are quite a challenge when the traditional method is used. Furthermore, visits to the nesting trees might greatly disturb the individuals/pairs being studied or even the entire colony. The use of drones obviously would benefit the observers to study the breeding ecology of this species. Unfortunately, published paper on the use of drones to study the breeding behavior of waterbirds or storks in particular, is still very limited.

To the best of our knowledge, this research would be the first observation of the behavior of a milky stork by using a drone. The objective of this study is to reveal the response of the breeding milky stork to the drone as a new and safer tool for collecting breeding behavior data. Factors that influenced the success of the observation by using a drone will also be identified. Due to the time restriction related to the milky stork's breeding season, the breeding behavior of the milky stork in this study was limited to nest-building and incubating stages.

MATERIALS AND METHODS

Study area

This research was conducted on a small island (25 ha; 106.5°41'30"E, 5.5°58'30"S; Figure 1) known as Pulau Rambut, in Jakarta Bay Area. The island is a wildlife sanctuary dedicated mainly to waterbirds. The waterbird species that can be found nesting on the island are egrets, cormorants, herons, ibises, and storks, of which most of them prefer to use the mangrove trees as their nesting sites (Mardiastuti 1992). These waterbirds use the island as their roosting and nesting sites. As for foraging sites, the waterbirds fly to the Java mainland to seek fish and other food in wetland areas in the morning and fly back to the island in the evening. The distance between the island and the nearest coast (i.e., Java Island) is about 4 km.

Among the waterbird species that regularly breed in Pulau Rambut is the milky stork (*M. cinerea*; recently uplisted to Endangered by IUCN). Milky storks arrive in Pulau Rambut to breed normally in November or December, then stay on the island until the breeding season is over, around April. This timing coincides with the rainy season in Jakarta Bay area. During the non-breeding season, the milky stork cannot be found in Pulau Rambut. The roosting and foraging sites of this species are still unknown, probably spread out along the coastal area along the northern coast of Java Island and the eastern coast of southern Sumatra Island.

In Pulau Rambut, this species uses tall trees to nest. Due to their wide wing spread, they can only utilize the top canopy. Therefore, this species needs to select their specific nest spot very carefully as the top canopy is prone to the regular strong wind, as well as prone to aerial predators (i.e., white-breasted sea eagle *Haliaeetus leucogaster* and brahminy kite *Haliastur indus*). As this island is very important as the only known breeding site for milky storks, research on breeding behavior is very important to ensure the survival of the species.

Previous research on the breeding of milky stork has been conducted in the same site, either by using a binocular from an adjacent tree or by regularly climbing the nesting tree to check for egg and chick development (Imanuddin and Mardiastuti 2003). These methods obviously had some disadvantages of not being able to observe all behavioral aspects due to the dense canopy. Furthermore, climbing up the trees surely causes disturbance to the bird colony, as well as endangers the climber if the climbing equipment is less proper.

Before the actual research, a pilot study was conducted to ensure that the disturbance caused by the drone would be kept to a minimum. During the pilot study in the non-breeding season, three types of drones were used: (a) DJI Phantom 4 Pro Quadcopter, a larger drone (1.4 kg) equipped with a good camera but less ability to maneuver, (b) Syma X25 Pro, a smaller quadcopter drone (0.2 kg; 37.5x37.5x11.0) with a good ability to maneuver but with a lower quality of camera, (c) Blackhawk Pro-B222 (95.5 g; 18x15x45 cm), a semi-mini quadcopter grey-colored drone.

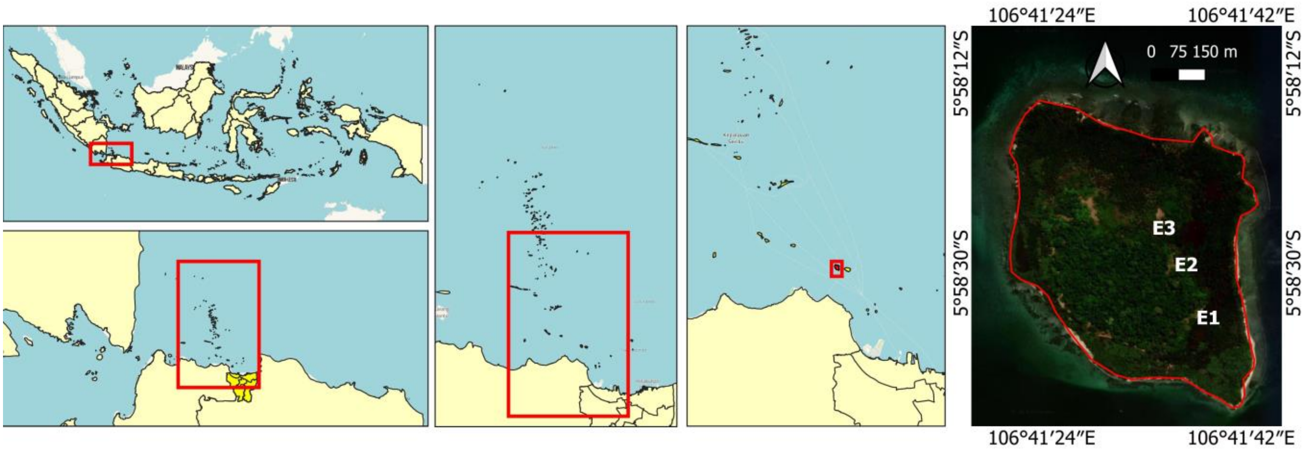

Figure 1. Location of Pulau Rambut Wildlife Sanctuary in the Jakarta Bay area, Indonesia; nesting trees were located in E1, E2 and E3, at the edges of mangrove forest

Table 1. Specification of the drone Syma X2 Pro used in this study

Parameter	Specification
Brand and model	Syma X25 Pro
Type	Indoor and outdoor; brushed racing quadcopter
Color	White
Flight time	15 min
Weight	170 g
Dimension	37.5 (length) x 37.5 (width) x 11.0 cm (height)
Range	100 m
Speed	18 km/h
Maximum flight altitude	200 m
Battery size	1000mAh
Gyroscope	6 axis gyro
Operating systems	Android and iOS
Operating mode	Controller
Sensor	CMOS
Megapixel camera	3 megapixel
Resolution	HD 1280x720, XGA 1024x768, FWVGA 864x480
Phooto/video-format	AVI, MOV, MP4
Image angle	120°
Storage	Micro-SD card up to 64GB
Gimbal	Yes
GPS	Yes
Headless mode	Yes
Return to home	Yes
Altitude position hold	Yes
Follow me	Yes
FPV function	Yes
Additional functions	Automatic landing mode
WiFi	Yes, 802.11 (a/ac/b/g/n), 2.4GHz
Kit Type	RTF (Ready To Fly; Controller included)

The DJI Phantom apparently produced a loud noise and a strong wind, causing many disturbances to the entire waterbird colony. Thus, the use of the DJI Phantom 4 Pro Quadcopter was terminated. Another trial by using the Blackhawk semi-mini drone was less successful because the drone could not withstand the strong wind above the tree canopy and eventually crash-landed. The study was then continued by using the Syma X25 Pro (See Table 1 for its specification), which provided satisfactory results in the pilot study.

This research was conducted between mid-December 2022 and early March 2023. Regular nesting behavior monitoring on foot, assisted by a binocular, was conducted to decide when the drone would be used to check the nest. The milky storks were observed to start their breeding and nest building in the fourth week of December 2022 in E3 on a big *Manilkara kauki* tree. Unfortunately, an unusually strong wind hit the Jakarta Bay area. In the next monitoring in early January 2023, the nesting site was moved to E1 and E2, on the *Rhizophora mucronata* stand, where the first observation using a drone was conducted in January 2023. The original plan was to conduct monitoring every week. However, the strong wind and high sea waves did not allow us to reach the site, and thus, monitoring by using a drone had to be adjusted to the weather.

E1 and E2 were located at the edge of a mangrove forest dominated by *R. mucronata*. Of the total of 42 nests censused in January 2023, only a small proportion of the nests in E1 and E2 (n=8; 19%) had a clear and visible view for behavioral study and drone flight. When a breeding individual or a pair was observed in a visible site, the birds were selected as focal samples. The characteristics of the nesting trees (n=3) of focal birds were recorded. Data collection for the nesting trees consisted of tree species, geo-position, tree height, tree diameter, clear bole height, crown diameter, and number of nests on the same tree.

Before deploying the drone, the behavior of the focal individual was observed in a 10-min period from a 40 m distance in the hidden site area by using a naked eye assisted with a Nikon Aculon binocular (7x35 mm) and a camera (Nikon Coolpix P1000 equipped with Nikkor 3000 mm tele-lens). After about 10 min habituation time and drone calibration, the Syma X25 Pro drone was deployed from a small clearing, about 5 m parallel from the hidden site and 40 m from the nest site. When the focal individual was flushed away during the habituation time, the observation was restarted or canceled if the bird did not return to its original position.

The drone was manually piloted. In order to ensure the response of the focal bird was minimum, the drone was positioned at about 20 m above the nest, then proceeded slowly downward as close as possible to the nest. The response of the focal individual of the milky stork to the drone was observed. The parameters tested were the distance and the angle of the drone to the nests. Initially, the drone velocity (i.e., 2, 4, 6, 8 m/sec) would also be tested. However, strong wind and heavy rain hampered the initial plan. Eventually, the speed used was around 4-6 m/sec, depending on the wind situation. Another planned parameter that could not work was the time of the day (morning, afternoon, and late afternoon observation). Observations were ended when (a) the drone's power was exhausted, which was about 12 minutes, (b) the focal bird flew away from the nest, or (c) the drone had to be called back due to a strong wind.

The only time slot to observe the milky stork was from 7 to 10 am. when the birds were still active in the nest, and the wind was not too strong. The milky stork relies on the thermal to fly, and thus, when the sun has risen and produced the thermal around 10 am, almost all of the milky storks leave the island to forage along the northern coast of Java.

As for the distance, we started from 30 m and as close as 2 m, with different angles. Due to the position of the nests on top of the canopy, the angles that were able to be tested with good visibility to the nests were 45°, 30° and 0° (directly above the nest). Wind, rain and the occurrence of the milky storks standing on their nests unfortunately did not permit us to conduct trials using the complete combination of distance and angles.

The behavior of an adult bird was categorized into four categories (Table 2). During the research, the breeding stage of most of the milky storks was egg-laying and incubating. At the end of the research period, some eggs were already hatched, but the chicks were always accompanied by their parents, and thus, data on the response of chicks alone were unavailable.

As the drone has limited flight time (i.e., effective of 12 min on average, out of 15 min maximum flight time), the duration for behavior observation was also limited. In addition, following the battery change, prior to the deploy of the next drone, there should be a minimum 15-minute time-out for the drone to ensure that the GPS and 'return to base' function of the drone would work properly.

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The total number of observers was four. Two observers (YAM, AM) were responsible for observing the bird behavior, while another two (YH, WJ) were in charge of the drone operation (i.e., YH operated the drone, while WJ provided some assistance in direction and took photos/ video). Only one individual bird was observed in one trial. If the bird showed no response or neutral response for at least 1 minute at the targeted distance and angle, the drone would be directed to find another target after adjustment of distance and angle or called back to base.

Considering that the complete combination of distances and angles could not be performed, behavioral data were analyzed qualitatively. Photos taken by the drone's camera as well as by the camera (Canon Lumix with a-300 mm built-in tele-lens) were used to assist analysis for a firmer conclusion.

RESULTS AND DISCUSSION

Characteristics of the nest trees

During the research, the milky storks nested on the *R. mucronata* trees in E1 and E2 (see Figure 1), at the edge between the mangrove forest and the dryland secondary forest. Ground counting revealed that the total number of trees that were used by the milky stork to nest was 30 trees, of which three trees were easily observed and thus selected as sampled trees (Table 3). The total number of nests, however, was difficult to monitor due to dynamic changes in the nest number caused by climatic disturbances.

During the observation, all nest trees were located in the mangrove forest, always inundated by seawater, even in a low tide. The sampled nesting trees were not too high, averaging 11.33 m. When the milky stork arrived in December 2022, they were observed to nest in a taller (25 m, crown diameter 18 m) *M. kauki* tree in E3. Unfortunately, an extraordinarily strong wind combined with continuous heavy rain ruined all of their nests. In mid-January 2023, the milky storks moved their nests to the smaller trees, which presumably were safer from the strong wind.

The selection of the nesting trees by the milky storks has been changed compared to the previous intensive research on this species (Mardiastuti 1992; Imanuddin and Mardiastuti 2003). This species used to nest on various tall tree species, including *Sterculia foetida*, *Ficus timorensis*, *M. kauki*, and *Terminalia catappa*. During the past years, only *R. mucronata* were used (Firdausy et al. 2021), probably due to the less availability of big trees with dense canopies, as well as was aimed to avoid the strong wind that might occur.

Behavioral response

When the study was conducted from January to March 2023, the weather in the Jakarta Bay area was unusually inhospitable. Prolonged heavy rain, coupled with the strong and constantly changed direction of the wind, has troubled the study, as well as the breeding attempts of the milky storks. Nests that had been built by the milky stork colony were completely destroyed by the strong wind in late January and again in mid-February, forcing the storks to move their breeding trees to rebuild their new nests. Despite the bad weather conditions and many unsuccessful flight trials (approximately 80 trials), we managed to record sufficient numbers of response behaviors (Table 4).

Table 2. Category and description of behavioral response used in this study

Category of behavioral response to drone	Description
No response	Ignoring the drone, stay still, as if there was no drone around and keep doing previous behavior
Neutral response	Looking at the drone, and noticed the existence of the drone, but showed no response and continue to conduct previous behavior
Temporary response	Flushed away and flying, but flying back to the nest after a short while
Negative response	Flushed away and flying out of sight, probably perched in other unseen trees, did not fly back for at least 10 minutes

Table 3. Characteristic of *Rhizophora mucronata* trees where the focal individuals of milky storks nest on them

Tree #	Tree height (m)	DBH* (cm)	Clear bole height (m)	Crown diameter (m)	Number of nests
1	12.0	24.8	7.0	5.0	3
13	10.0	19.8	3.2	3.2	1
29	12.0	26.4	4.0	9.0	6
Average	11.33	23.67	4.73	5.73	3.3

Note: *DBH: Diameter at Breast Height

Table 4. Behavioral responses of adult breeding milky stork and nestling to drone

Trial no.	Distance* (m)	Angle (°)	Category of behavioral response	Description of response behavior
1	25	45	No response	The entire colony continued perching, seemed unnoticed to the presence of the drone
2	22	0	No response	Adult**continued preening, took no notice to the drone
3	20	45	No response	Adult perched on the tree, no detectable movement
4	15	45	No response	Adult turn its head down several times; seemed to check on nest content then sit on nest
5	13	30	No response	Kept perching, no changes in posture
6	11	45	No response	Adult #1 kept sitting on nest; Adult #2 preening at nearby nest
7	10	45	Negative response	1 adult suddenly flew away, gliding to the west, turned around and 7 min later came back to the nearby tree but not to the previous spot
8	10	45	No response	Flapping its wings
9	10	0	Negative response	1 adult flying around nest tree
10	7	0	No response	An adult kept preening
11	7	0	Negative response	1 adult still flying around
12	7	0	No response	Perching
13	5	45	No response	Perching
14	5	45	No response	Flapping its wing
15	4	30	No response	Perching on nest; photo taken by drone confirmed that there 3 individuals, but only 1 can be directly seen from the hiding
16	3	45	No response	Perching
17a	3	30	No response	Perching
17b	3	30	No response	Perching
18	2	45	No response	Perching
19	2	30	No response	The adult parent continued to feed the chick, ignoring the presence of the drone; there were 2 chicks on the nest
20	2	0	No response	Perching

Note: *Distance from drone to the target nest; **There is no sexual dimorphism in milky storks; males and females are not able to be distinguished in the field

Direct observation of the response behavior (Figure 2) further confirmed that the use of a manually piloted small drone to study the breeding behavior of the milky stork did not disturb the bird. The drone was able to approach up to 2 m directly above the parents on nests without any sign of disturbance. Images produced by the drone (Figure 3) also further reaffirmed about this.

The use of drones to study the milky storks was already conducted in Riau, Sumatra (Ronny et al. 2017), with the main purpose of censusing the density of milky storks' nests. The research successfully estimated the nest density of the milky storks, grey herons (*Ardea cinerea*) and lesser adjutant (*Leptoptilos javanicus*) by using an autopiloted Walkera X350 Pro drone, 20 m above the ground. Another similar study was actually conducted in Pulau Rambut by Rahman et al. (2021), using autopiloted Matrice 300 RTK equipped with heat markings at flight altitudes above 65 m. The study was able to identify the nests of grey herons, purple herons (*Ardea purpurea*), and black-crowned night herons (*Nycticorax nycticorax*). The research did not find the milky stork nests because the timing of the study (i.e., in August) was not a breeding season for the milky stork in Pulau Rambut Wildlife Sanctuary.

In another country, in north-eastern Poland, Zbyryt et al. (2021) used drones to observe the behavioral response to other similar species, namely white storks (*Ciconia ciconia*), which could be compared to the results of this study. The breeding white storks flight initiation distances were between 20 to 1 m, and occasionally did not flush during drone approaches. The research also showed that the white storks that escaped from the nest would quickly return to their nests within 23 seconds, suggesting that drones are not a highly invasive tool for studying their breeding activity, even during the egg stage.

In Australia, McEnvoy et al. (2016) surveyed waterfowl (mostly ducks and swans) by using five different types of auto-piloted drone, i.e., delta-wing, glider-type, and three different sizes of multirotor drones. They also concluded that the level of disturbance caused by the drones was generally minimal. Meanwhile, for seabirds that nest on the land surface, Ratcliffe et al. (2015) found that when certain distances and heights were maintained, drone presence did not affect behavioral responses in gentoo penguins *Pygoscelis papua*. Another study by McClelland et al. (2016) on behavioral response in tristian albatrosses *Diomedea dabbenena* also revealed similar results. Rümmler et al. (2015), however, warned that some bird species or colonies may be more sensitive to drone presence than others, and thus, drone should be carefully used for seabirds. Earlier research by Mulero-Pázmány et al. (2017) showed that wildlife reactions toward drones depended on the drone's attributes (i.e., size, engine type, flight pattern) and the characteristics of wildlife under study (i.e., species, life-history stage, clumping pattern). Target-oriented flight patterns, larger drone sizes, and noisier drones would induce the strongest reactions in wildlife under study.

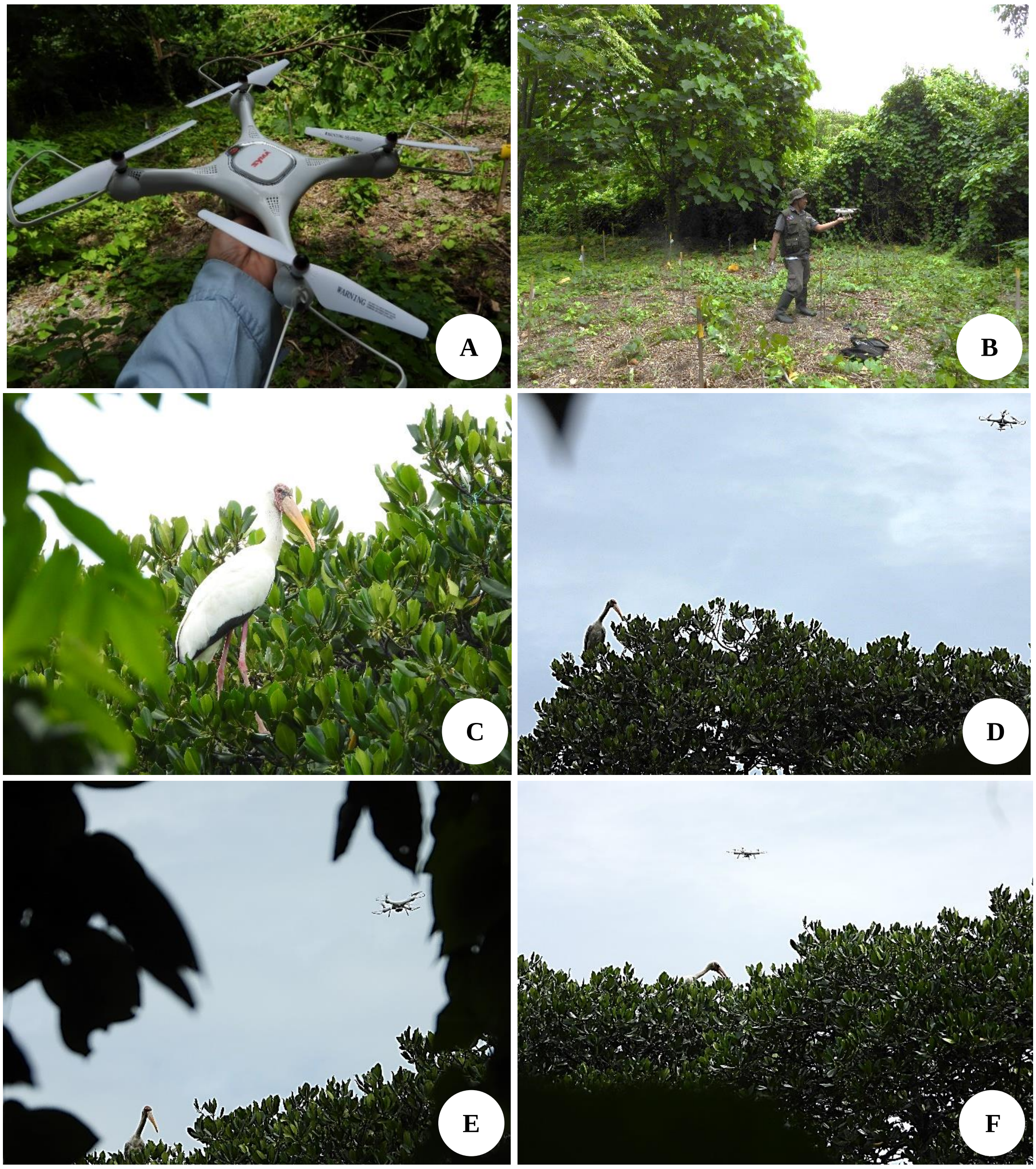

Figure 2. A. Drone being used - Syma X25 Pro; B. Deploying drone from the nearest clearing, about 40 m from the nest tree; C. An adult milky stork (*Mycteria cinerea*) nesting on *Rhizophora mucronata* tree; D. Trial #7 at 10 m and 45°; E. Trial #13 at 5 m and 45°; F. Trial #20 at 2 m and 0°

Table 5. Accidental events related to drone operations that caused negative responses to the adult milky storks

Event	Description of events; *Behavioral response of the milky storks*	Recommendations
Sudden and high velocity launch of a drone which produced a loud noise	When the wind was very strong, the drone had to launched with a high velocity; *some birds flying away and the trial had to be re-started when all flying birds returned to their nests*	No drone observation when the wind is strong
Sudden movement of drone operator toward the clearing	The drone operators need to move out from the hiding toward the clearing to launch the drone; *some birds flying away and the trial had to be re-started when all flying birds returned to their nests*	Walk very slowly to the launch site, avoid stepping on twigs which may cause some noise
Approaching and visiting on foot under the nest tree	The drone was crashed to the forest floor due to a sudden gust wind and need to be discovered; *almost all birds fly away, the trial was canceled and re-started the next day*	Wait until the milky stork leave the nest or, if possible, leave the island around mid-day

Figure 3. A. Photos taken by the drone: Trial #1 at 25 m and 45°; B. Trial #4 at 13 m and 30°; C. Trial #15 at 4 m and 30°; D. Trial #17a at 3 m and 30°; E. Trial #17b at 3 m and 30°, and F. a nest with three eggs at 2 m and at 0° (the continuation of Trial#17b)

Some causes of temporary response

During this research, there were some events, however, that accidentally caused some disturbance to the colony and to the bird target and caused a temporary response (Table 5). These events provided us with some excellent experiences, which would be very useful in formulating the protocols to observe the behavior of milky storks or similar species in the future. Other accidental events were the crashes of our drones. As mentioned in the next section, the semi-mini drone crashed down above the colony due to the strong wind. Although the drone was eventually discovered sinking in the mud, there was a possibility that it might landed first on a tree canopy. The Syma drone also crashed twice on the tree canopy, one of which forced us to stop due to engine damage. Direct observation of the 'no response' and a faint 'temporary response' suggested that the crash had a low impact on the milky stork and the waterbird colony.

McEnvoy et al. (2016) also noticed that the drone caused some disturbances when it was launched directly at a flock of birds at a low altitude during take-off, about 10-15 m away, probably due to the bird's cautiousness to the presence of the raptors. On the drone crash issue, Ratcliffe et al. (2015) acknowledged the risk of drone crashes in collecting data. In an environment surrounded by sea and frequently hit by strong winds like Pulau Rambut, the combination of the excellent skill of the pilot and his/her ability to sense the weather would be very important to get successful data. When the wind is too strong, it is better not to deploy the drone to avoid drone crashes.

Influencing factors

Factors that have been identified to influence the success of the research were (i) weather, (ii) size and color of the drone, and (iii) daily activity of the bird (Vas et al. 2015). Of all of these factors, the weather (i.e., wind) obviously was the most influential factor for this research. The breeding season of the milky stork had been recorded to coincide with the rainy season. As a consequence, rainy days are very often, while the west wind is always strong. In addition, during the past years, rainfall pattern has been unpredictable, possibly due to climate change. The rain and strong wind obviously influenced the drone operation.

The initial plan to employ various speeds (2, 4, 6, or 8 m/sec) turned out to be not feasible due to the condition of the island. The west wind was strong above the canopy (about 15 m above the ground) in most of the observation time, and hampering the pilot just to maintain the course of the drone. Although the National Weather Agency (*Badan Meteorologi, Klimatologi dan Geofisika*) reported that the wind velocity was 20 km/h in Jakarta Bay area, the local wind velocity was much stronger, estimated to be around 30-40 km/h due to the small island ecosystem without any windbreak. On some observation days, light or heavy rains poured for a long time and forced the pilot study to a complete stop.

The strong wind also gave an important lesson that a mini drone was not feasible to use. One of the drones, the Blackhawk, was swept away and lost. After an intensive search on the approximate crash site, both at the tree canopy and on the mud surface, the drone was found (accidentally stepped on, actually) in the mud between the rhizophores of mangrove trees about two weeks after the crashing date. The mini drone was badly damaged beyond repair.

Another important lesson from the crashed drone was the color of the drone. Reasons to select the semi-mini drone were its small size, cryptic color, less airstream produced, and its quietness. The small-light (less than 100 g) drone with a more natural grey color, combined with a quiet flight, presumably will minimize the disturbance to the stork. When being used, the grey color of the drone created some difficulties in manually tracking the flight by the bare eye because of the very similar color to the sky, which was greyish most of the time due to the tropical cloudy weather. This semi-mini drone is apparently more suitable to be used for indoor purposes and for a short target-shooting range, with very minimal weather influence.

As for the daily activity of the milky stork, it is closely linked to the weather. On a sunny morning when the wind is calm, the milky storks leave the island earlier, around 7 am. Observation on response obviously cannot be performed. On the contrary, on a cloudy morning, the storks might stay on the island until around midday. However, cloudy mornings usually coincided with a strong wind, which hampered the flight of the drone. Unfortunately, studies that discussed the impact of the weather on drones were very lacking. To the best of our knowledge, there has been no study to discuss manual-piloted drones and weather in the tropics.

Protocol to use a drone: some suggestions

Currently, several protocols and recommendations to study waterbirds by using drones to minimize or eliminate negative responses, especially those related to birds' behavioral responses, have been formulated. Many of the protocols were developed for bird census by using auto-piloted larger drones with a pre-determined flight path.

Among many available protocols, protocols that can be adapted for the milky stork were recommended by Mulero-Pázmány et al. (2017). From the results of this study, the protocol of Mulero-Pázmány et al. (2017) needs to be slightly adjusted (Table 6) to suit the situation of the breeding waterbirds in tropical countries. In other areas using other target species, some adjustment of protocol might be needed accordingly.

Table 6. Recommendation for adjustments on the existing protocol of using drones for waterbirds based on this research; recommended protocols were taken from Mulero-Pázmány et al. (2017)

Recommended protocols*	Revision/adjustment based on this study
“Use reliable drone operated by experienced pilots”	“Use reliable drone operated by experienced pilots” [*no change*]
“Favor low-noise or small drones against noisier or larger ones”	Use smaller drone with high maneuver capability, with low-noise and generate very small wind
“Mount the ground control station 100-300 m away from the study area”	“Mount the ground control station at least 40 m away from the study area” [*changed in the distance*]
“Conduct missions as short as possible”	“Conduct missions as short as possible” [*no change*]
“Fly at the highest altitude possible”	Fly at the safe distance above the birds’ nests, may slowly descent if the bird shows no response
“Avoid maneuvers above the animals”	Conduct maneuvers slowly, not abrupt
“Favor lawn-mower flight patterns”	Start with a direction of 90^o angle from the nests, then slowly fly above the nest
“Minimize flights over sensitive species or during breeding period”	During the breeding period, immediately cancel the operation when there are intense responses from the waterbirds
“Avoid drone silhouettes that resemble predator shapes”	Avoid drone silhouettes that resemble predator shapes (fixed-winged); quadcopters are preferred
“Avoid close-distance direct approaches and favor indirect ones”	When approaching the nest and observing the birds or nest in close distance, do it gradually from a farther distance
“Monitor target animals before, during, and after the flight”	“Monitor target birds before, during, and after the flight” [*no change*]
“For nest inspections, fly at times in which eggs/chicks are out of risk”	“For nest inspections, fly at times in which eggs/chicks are out of risk” [*no change*]
“If the flights are around aggressive raptor’s territories, perform them at day times when the temperature is low and birds are less prone to fly”	“If the flights are around aggressive raptor’s territories, perform them at day times when the temperature is low, and birds are less prone to fly” [*no change*]
-	Avoid drone operation during strong wind, to prevent the crash-landing drone on the nests

To conclude, this study suggested that drones can be used to study the breeding behavior of milky storks or other waterbird species that have similar ecological aspects (i.e., colony nesters, large-sized bodies, nesting on top tree canopy, cup-like nests). Drones that can be used should be small in size (but not too small in order to withstand strong wind above the canopy), easy to maneuver, produce very low noise and almost no wind generated from the rotor.

The drawback of the small-sized drone could be the fair quality of images produced by the drone, the short flight time, and its low ability against strong wind. Nevertheless, the breeding phase (e.g., number of eggs in the nest, approximate size of the nestling) can still be easily identified. Surely, there are some options to produce better results, for instance, by modifying the existing camera and battery.

Behavioral research by using small-sized drones still has some potential to disturb the nesting birds, especially during unplanned events such as sudden drone take-offs due to bad weather. In order to minimize the disturbance to the target bird, recommended protocols should be fully followed. The survival of the species under study should always be prioritized, knowing that many waterbird species are already endangered due to their decreasing population number.

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