國立臺灣大學共同教育中心國際學院生物多樣性國際碩士學位學程

碩士論文

Master's Program in Biodiversity

International College, Centre for General Education

National Taiwan University

Master's Thesis

台灣彰化曬池魚塭對供遷徙性水鳥的覓食重要性

The importance of semi-dry ponds as foraging habitat to migratory shorebirds in Changhua, Taiwan

蔡維哲

Wei-Che Tsai

指導教授：袁孝維 博士、林瑞興 博士

Advisors: Hsiao-Wei Yuan, Ph.D.,

Ruey-Shing Lin, Ph.D.

中華民國 113 年 7 月

July, 2024

doi:10.6342/NTU202404257

Acknowledgement

I would like to thank Prof. Hsiao-Wei Yuan and Dr. Ruey-Shing (Scott) Lin for their invaluable guidance and support throughout the two years of master's degree. Their availability and insightful advice were crucial as I explored the different possible trajectories of this thesis. I would like to thank Zhao-Hui Lin, Jhih-Wei Tsai, Pei-Cheng Wu, Ta-Chih Chen, and Shu-Yen Huang for conducting the bird surveys in Changhua and for providing me the data and necessary background information used in this thesis. I would also like to thank the committee members Dr. Jo-Szu (Ross) Tsai and Dr. Fu-Hsiung Hsu for their feedback which enriched the thesis. I would like to thank Carina Terry for their assistance in improving the clarity of each key point in the thesis. Lastly, I would like to thank my parents and family members for their unwavering support which enabled me to pursuit my passion and studies in biodiversity conservation.

doi:10.6342/NTU202404257

Abstract

Migratory shorebirds rely on inter- and supra-tidal habitats across their migration routes. In the East Asian-Australasia Flyway (EAAF), natural inter- and supratidal zones are being converted for human uses at alarming rates. Nearly 60% of the intertidal zones in Taiwan have been lost in the past 60 years; devastating populations in many shorebird species. Part of the converted landscape is salt pans and aquaculture ponds which can function as artificial wetlands. Migratory shorebirds use these artificial wetlands for feeding and roosting. We calculated the daytime feeding time budgets of shorebirds and the importance of drained (semi-dry) aquaculture ponds in pre-breeding (March, April), post-breeding (August, September, and November) and winter (December) months in Changhua, Taiwan. We found that drained aquaculture ponds provide significant food resources to shorebirds. The Tactile Continuous, Tactile Continuous Deep Water, Pause-Travel guilds, and Black-winged Stilt spent up to 40% of their daytime time budget feeding in the semi-dry ponds pre-breeding. In the post-breeding months, the Tactile Continuous, Tactile Continuous Deep-Water, Visual Continuous Deep-Water guilds, and Pied Avocet spent up to 40% of their time budget feeding in the semi-dry ponds. The Tactile Continuous guild and Black-winged Stilt also spent up to 40% of their time budget feeding in the ponds during winter. The Tactile Continuous (representative species: Red-necked Stint and Dunlin) and Tactile Continuous Deep-Water (representative species: Marsh Sandpiper) guilds and preferentially used aquaculture ponds over intertidal in August and November, respectively. April was the month in which semi-dry ponds provided important food resources to the greatest number of guilds, followed by August, and December. The semi-dry ponds and their surroundings regularly host significant populations of shorebirds

doi:10.6342/NTU202404257

numbering from thousands to tens of thousands, highlighting the urgency to conserve these artificial wetlands on a migration route in peril.

Keywords: migration, shorebirds, Charadriiformes, time budget, aquaculture ponds, habitat

關鍵字：遷徙、水鳥、魚塭、棲地

doi:10.6342/NTU202404257

Table of Contents

doi:10.6342/NTU202404257

List of Figures

doi:10.6342/NTU202404257

List of Tables

doi:10.6342/NTU202404257

Introduction

Flapping flight is one of the most energy-intensive behaviors for migratory birds, necessitating substantial fuel reserves, typically stored as fat, prior to departure from non-breeding grounds (Alerstam 1991; Lindström 1991). This strategy reduces the need for foraging stops en route to breeding grounds, thus shortening the journey. However, the increased weight elevates transportation costs and decreases agility (Fransson and Weber 1997). Additionally, the intense fuel deposition leads birds to reduce vigilance in favor of feeding, increasing their vulnerability to predation. To mitigate these risks, migratory birds often form flocks for collective vigilance (Metcalfe and Furness 1984).

The survival of migratory birds crucially depends on the availability of extensive suitable habitats along their flyways, spanning continents from Asia to the Americas (Kirby et al. 2008). The East Asian-Australasian Flyway (EAAF), known for its high number of threatened species, exemplifies a migratory route that requires international cooperation for effective conservation (Kirby 2010; Conklin et al. 2014). Insufficient habitat along these routes can cause significant declines in bird populations, even if other segments of the flyway are intact (Runge et al. 2014; Aharon-Rotman et al. 2016; Jackson et al. 2018).

Recent declines in species utilizing the Yellow Sea as a stop-over site have underscored the loss of critical habitats, exacerbated by the conversion of natural intertidal and supratidal zones into human-used areas (Melville et al. 2016). Conversely, certain land uses, like salt pans and fish ponds, can serve as artificial wetlands (Masero et al. 2000; Green et al. 2015; Bai et al. 2018; Jackson et al. 2018; Lei et al. 2018). The artificial wetlands can provide essential resources when natural intertidal zones are submerged during high tide.

doi:10.6342/NTU202404257

To understand how birds use different habitats, behaviour observation, which demands high observation effort, is needed. The importance of a habitat is often evaluated based on both the diversity and number of individuals in the area; thus, species identification is not the foremost determining factor. When observations include many species, related species are often grouped into guilds to increase the sample size and explanatory power. Shorebirds are often grouped into guilds based on their tarsus length (Green et al., 2015) or predominant feeding tactic (Zwarts et al., 1990, Jing et al., 2007) as these are the main factors that determine habitat use and prey choice.

In Taiwan, nearly 60% of intertidal zones was lost in the past 60 years compared to their extent in the 1920s. The construction of dams and weirs decreased the amount of sediment flowing into the ocean; thus, mudflats were replenished at a slower rate. The existing intertidal zones were mainly converted for agriculture and aquaculture (53%), and residential and commercial development (46%) (Chen et al. 2024).

With the loss of natural intertidal in mind, the necessity for nearby supratidal zones for resting and supplementary feeding further highlights the integral role that artificial habitats play within the broader landscape of migratory pathways (Dias et al. 2006; Rogers et al. 2006). Although shorebirds have adapted to these artificial wetlands—out of necessity due to displacement from preferred sites (disturbance hypothesis) or preference for the conditions found in these modified environments (preference hypothesis)—the significance of coastal artificial ponds as a food source remains significantly under-researched, despite their critical importance to shorebird conservation (Masero et al. 2000).

The practice of pond draining after the stock has been harvested, occurring every two to three years, exposes a high number of benthic organisms for shorebirds to capitalize on (Huang 2016). Shorebirds gather in large numbers and utilize the aquaculture ponds for

doi:10.6342/NTU202404257

high-tide roosting and feeding (Bai et al. 2018). However, whether the majority of birds remain to feed in these ponds during low tide (preference hypothesis) or only use the ponds during high tide and move to intertidal zones when they are available (supplementary hypothesis) is not yet clear (Masero et al. 2000). In southwest Taiwan, Huang found that clam ponds contain high densities of Amphipods (Arthropoda: Malacostraca), *Didontoglossa koysasensis* (Mollusca: Gastropoda), and *Neanthes glandicincta* (Annelida: Polychaete) with over 300 individuals per m^2 averaged across a whole year. Milkfish ponds also have high densities of Amphipods, Chironomidae (Arthropoda: Insecta), Hyrophilidae (Arthropoda: Insecta), *Stenothyra sp*. (Mollusca: Gastropoda), *Polydora cornuta* (Annelida: Polycheate), and *Capitella sp*. (Annelida: Polycheate). Whether these ephemeral resources constitute a significant portion of food for shorebirds is equally understudied.

Our study focused on the coastal ponds of Changhua, located near Taiwan's largest remaining tidal flat. Previous research has demonstrated that shorebirds utilize artificial supratidal semi-dry ponds (hereafter referred to as semi-dry ponds); however, the significance of these ponds as feeding sites remains under investigation. We aim to assess the importance of these semi-dry ponds as feeding sites by analyzing the number of shorebirds and the duration of their feeding activities. Specifically, we seek to determine to which species and during which seasons do these ponds serve as critical feeding habitats.

Methods

Study Site

Changhua County (彰化縣), located on the central west coast of Taiwan is renowned for its extensive mudflats and supratidal aquaculture ponds, which collectively

doi:10.6342/NTU202404257

support a large and diverse population of shorebirds (Liu 2011; Bai et al. 2018; Tsai 2020; Lin et al. 2023); the supratidal areas in Changhua are particularly vital for migratory shorebirds, recognized as key foraging and resting sites. This makes the coastal fish ponds of Changhua an excellent site for researching the importance of these habitats for shorebird feeding behaviors. This area faces similar threats to other wetlands across Taiwan. The natural wetlands are at risk due to the expansion of mangrove forests (Tsai 2020), and some aquaculture ponds are planned to house solar panels in the near future as part of a shift towards renewable energy production, aiming to generate 20 gigawatts of renewable energy by 2025 (Executive Yuan n.d.). The transition from traditional aquaculture to aquavoltaics is expected to reduce available habitats for shorebirds, potentially threatening their survival (Huang and Lin 2020). With the substantial loss of natural wetlands, these artificial wetlands have become crucial alternative habitats for shorebirds. Developing a better understanding of how and when shorebirds utilize these artificial wetlands is essential for future conservation planning and the protection of migratory flyways.

Many parts of the supratidal zone in Changhua have been diked off for aquacultural, agricultural, and industrial uses. In this study, we focused on two adjacent sub-regions, namely Yongxing (永興), and Wanggong (王功) in Fangyuan Township (芳苑鄉), which are almost exclusively comprised of aquaculture ponds (Fig. 1). The main animal stock in these ponds are clams (Fisheries Agency n.d.), but fishermen will often keep some milkfish and shrimps in the same ponds to clean up excess feed (personal communication with local fishermen). The intertidal zone in Changhua provides invertebrates that refuel migratory shorebirds, thus large numbers of them congregate here (Liu 2011; Bai et al. 2018; Tsai 2020, Chen et al. 2024). When the mudflat is submerged at high tide, most of the

doi:10.6342/NTU202404257

shorebirds will move inland into the diked off area to roost (Liu 2011) and feed (Bai et al. 2018), and a portion of them will opt to roost on exposed sandbars off the coast of Yongxing and Wanggong.

We used Google satellite images from March and April 2021 in ArcGIS Pro (ESRI 2022), and manually drew polygons around fish ponds, and then calculated the polygon area using the TWD97 / TM2 zone 121 projection (EPSG: 3826). The total area of semi-dry ponds surveyed ranged from 0.0355 km^2 in December to 0.193 km^2 in March, but the number of birds counted was not directly proportional to the area (table 1).

Data Collection

We carried out bird surveys in Yongxing and Wanggong during March, April, August, September, November, and December of 2022. The survey dates were strategically aligned with the spring tides, with high tide occurring near mid-day. This timing facilitated more effective counting, allowing bird counts to be conducted for three hours before and after the high tide. In order to identify the best locations to conduct time budget survey, we separated the survey into two parts: a complete census with entire area count, and a time budget survey (partial count) only conducted at select ponds. On the first day of the survey, we had a team of two which used a car as a hide and drove through all the roads at a speed lower than 40km/h in each of Yongxing and Wanggong at high tide. When we saw birds in the ponds or on the banks, we stopped the car and counted them in binoculars and spotting scopes. During the first day, the surveys in each region were completed within four hours, typically around two hours on each side of high tide to avoid double counting. We recorded the water coverage and count of each species. On the second day, we performed a time-budget survey, selecting the semi-dry pond with the highest shorebird counts and two others with the top five highest shorebird counts from the previous day. All of the ponds

doi:10.6342/NTU202404257

chosen had at least 50 individuals of shorebirds on day one, except in December when more than 1800 birds were found in a single pond while the other semi-dry ponds had less than 50 individuals each. We designed a route that could cover all these ponds within an hour (a round trip) and surveyed as many semi-dry ponds as feasible based on the route and recorded the number of individuals feeding, not feeding, and the water coverage in each pond. In March, each route was surveyed eight times, and in subsequent surveys, we conducted seven round trips. In other intertidal shorebird studies, birds were found to have predictable daily migration depending on water level of the intertidal zones, moving between high tide roost and intertidal feeding location about 160 minutes before and after high tide during spring tide (Zwarts et al., 1990). The seven to eight round-trip design of our survey was chosen to encompass the different tidal levels. In the species which prefer semi-dry ponds, we expect these shorebirds move inland early, and many would remain inland and a high proportion of them would be feeding even more than two hours after the high tide starts to recede. In the other species which prefer intertidal over semi-dry ponds, we expect them to only appear in semi-dry ponds during the two to four hours of high tide in the middle of the survey and are absent in the other hours. In addition to water level, temperature also affects the time budget of shorebirds. Birds are less likely to feed during the hotter hours except when they are constrained by time and need to do so to meet metabolic requirements (Zwarts et al., 1990). If a high proportion of birds is found feeding during round three and round four of the time budget survey, when the temperature is highest mid-day, it indicates their reliance on the semi-dry ponds. Given the daily migration pattern of shorebirds, we believe our survey sufficiently represents the day-time time budget of shorebirds.

doi:10.6342/NTU202404257

Since it is difficult to estimate water depth, we only classified water level into three categories based on proportion of pond bottom exposed: full (>90% covered by water), semi-dry (10-90% covered), and dry (<10% covered). The water level in aquaculture ponds can change very quickly. In about four hours the pond can change from completely covered (full, 100% cover) to having some parts of sediments exposed (semi-dry, <70% cover), and vice versa. The semi-dry ponds typically have more than half of sediment exposed and only a 10-40% water coverage. While the distribution of semi-dry ponds is somewhat random, due to the large area of the aquaculture areas, there always are some ponds being drained at any given moment (table 1), providing feeding opportunities for shorebirds.

Given the complexities of monitoring large and diverse shorebird flocks, where individual tracking is impractical, we opted for the instantaneous scan method to gather data on time budgets across different shorebird species. This decision aligns with our primary objective to analyze species-specific behaviors rather than the actions of individual birds. In this approach, we record the percentage of individuals displaying specific behaviors at given moments, providing a reliable estimation of the overall time budget for the flock (Gauthier et al. 1988; Green et al. 2015). This methodology rests on two foundational assumptions: firstly, that individuals within a flock are likely to exhibit similar behavior patterns, thus having comparable time budgets, and second, that the frequency of behavior within the flock's time budget is indicative of its prevalence at any observed moment. In simpler terms, the more frequent a behavior, the more likely it is to be observed during a scan. This proportionality allows for effective extrapolation of behavioral data across the flock. This method has proven essential for our surveys, allowing for efficient and accurate collection of behavioral data without the need for individual bird tracking.

doi:10.6342/NTU202404257

Guilds of Shorebirds

We grouped bird species base on their feeding tactics, mostly following Jing et al. (Jing et al., 2007). Jing et al. proposed grouping shorebirds into three categories base on their predominant feeding behaviours. The three groups are Tactile Continuous, Visual Continuous, and Pause-Travel. We further subdivided each of the Tactile Continuous and Visual Continuous guilds into a shallow-water and a deep-water group base on their tarsus length. Any species that has tarsi longer than 35mm were put into the deep-water groups. Pied Avocet, and Black-winged Stilt exhibit feeding behaviours distinct from the said groups; thus, each was given its own group. Whimbrel and Red-necked Phalarope were excluded from analysis because they each exhibit distinct feeding behaviours, but are too rarely recorded to merit their own guilds. In total, we classified the shorebirds into seven feeding tactic groups (table 2).

Analysis

Time Budget for Feeding

All analyses were conducted using R (R version 4.4.0, R Core Team 2024). To calculate the daytime feeding percentage of each bird guild in semi-dry fish ponds, we first identified the highest count from the semi-dry pond surveys. This count was then multiplied by the number of hours surveyed, eight for March and seven for other months, to serve as the denominator. The numerator was the sum of feeding individuals observed during all survey hours. This calculation yielded the proportion of individual-time spent using semi-dry ponds for feeding (fig 2). Each pond survey was treated as a separate sampling unit. We used bootstrapping, repeating the process 5000 times within each hour, to calculate the confidence intervals for the feeding percentage. The confidence interval was reported using the median, the 2.5th and the 97.5th percentiles. If the confidence

doi:10.6342/NTU202404257

interval of the feeding proportion overlapped with the 40% mark, it indicated that the guild devotes a significant portion of its time budget to feeding in semi-dry ponds. Additionally, we identified and highlighted the most abundant species within each guild that contributed most significantly to these results, referring to these as representative species.

The 40% mark was chosen as threshold for significant use as it is typical of those shorebirds species which rely on salt pans and aquaculture ponds (Lei et al. 2018; Green et al. 2015). The average percentage feeding in artificial wetland across low tide and high tide when birds need to fatten during March and April is around 40% (Masero et al. 2000)

Feeding Importance Index

We calculated a feeding importance index by multiplying the feeding percentage and its associated confidence interval (CI) with the entire area count for each guild. If the maximum count observed during the semi-dry pond survey exceeded the entire area count, we used the higher number instead. By developing this index, we created a comprehensive method to evaluate feeding importance while incorporating both time budget and the number of individuals (fig. 2). The importance index is based on three assumptions: 1) the time budget of sampled individuals, when the sample includes more than 10% of the entire area count, is representative of their conspecifics, 2) ponds not sampled on day two also provide similar feeding opportunities, and 3) a high time budget devoted to feeding in semi-dry ponds indicates significant usage of these habitats, making the sample representative. We identified the month with highest feeding index and the months with confidence interval overlapping with that of the highest month as highly important.

The accuracy of the importance index hinges on the reliability of the feeding percentage estimates for the different guilds. Thus, errors associated with estimating feeding percentages for different guilds also influence the importance index. Additionally,

doi:10.6342/NTU202404257

the index is dependent on the count of each guild. Consequently, identical index values, derived from the same count and feeding percentage, could represent different proportions of their respective flyway populations.

Due to these limitations, the importance index is only suitable for comparing habitat usage by a guild across different months within the same study; it is not applicable for comparing indices between different guilds or aggregating them. Great Knot, Eurasian Curlew, Far Eastern Curlew, Bar-tailed Godwit, Green Sandpiper, Common Snipe, Ruff, and Oriental Pratincole were excluded from the analysis because they were only observed either roosting on banks on day one or inside the semi-dry ponds on day two, but not on both days. This restriction further underscores the contextual use of the importance index in our study.

Results

Use Patterns of Semi-dry Ponds

In the guilds that highly rely on semi-dry ponds, the counts obtained in the selected ponds during the time budget survey (partial count) matched or sometimes exceed the entire area count over a larger area (complete census) (table 3). For the Tactile Continuous guild, more than 60% of the entire area count was seen in semi-dry ponds, except in November: 71.0% (740/1042) in March, 114% (2825/2486) in April, 100% (4439/4425) in August, 62.0% (920/1485) in September, 35.3% (414/1172) in November, and 84.2% (3507/4165) in December.

The Tactile Continuous Deep-Water guild also was mostly found in the semi-dry ponds during March, April, November, and December: 181% (132/73) in March, 126%

doi:10.6342/NTU202404257

(272/216) in April, 1.7% (3/179) in August, 6.0% (21/350) in September, 137% (112/82) in November, and 288% (23/8) in December.

The Visual Continuous guild was rarely seen in semi-dry ponds with the partial counts never exceeding 10% of the complete census count: 1.3% (7/536) in March, 5.4% (60/1119) in April, 6.0% (57/948) in August, 1.7% (11/639) in September, 0% (0/533) in November, and 1.2% (10/861) in December.

The partial count of Visual Continuous Deep-Water guild equates to about half of complete census count in March and September with only a small fraction of individuals in semi-dry ponds during the other months: 48% (115/239) in March, 10.5% (8/76) in April, 17.2% (29/169) in August, 59% (188/316) in September, 6.9% (5/72) in November, and 1.8% (1/57) in December.

Large numbers of the Pause-Travel guild were found during the partial counts; with the exception of November, the partial count usually equates to a quarter of more of the complete census: 38.7% (974/2518) in March, 25.7% (607/2362) in April, 70.3% (3401/4838) in August, 62.6% (3201/5110) in September, 0.6% (29/5106) in November, and 16.2% (1380/8537) in December.

The partial count and complete census count of Pied Avocet differed widely, the ratio between the two ranged from only 3% to over 300%: 320% (307/96) in March, >100% (38/0) in April, 3.4% (6/178) in August, 34.6% (18/52) in September, 36.8% (77/209) in November, and 9.9% (15/151) in December.

Similar to the occurrence of Pied Avocet, the ratio between partial count and complete census of Black-winged Stilt also had a large range: 230% (1476/642) in March, 98.6% (864/876) in April, 10.5% (61/581) in August, 4.3% (49/1129) in September, 38.1% (261/685) in November, 7.7% (44/573) in December.

doi:10.6342/NTU202404257

Time Budget and Importance Index

Tactile Continuous (representative species: Red-necked Stint, and Dunlin)

Tactile Continuous was the most abundant guild recorded in the semi-dry ponds, numbering from hundreds to thousands during each survey. The highest counts in semi-dry ponds were recorded during the months April (2825), August (4439), and December (3507) (table 3, fig 3a). This guild spent significant daytime time budget feeding in semi-dry ponds during April, August, September, and December (fig. 3b). The feeding importance index was highest in August and December, indicating the use of semi-dry ponds for post-migration fueling by this group (fig. 3c). In August, this group spent up to 50% (median: 50%, CI: 32.1%, 70%) of their time budget feeding in semi-dry ponds, and more than half of them remain in semi-dry ponds to feed during the hours when the intertidal is available, indicating a preference of semi-dry ponds over intertidal.

Tactile Continuous Deep Water (representative species: Marsh Sandpiper)

The Tactile Continuous Deep-Water guild was recorded numbering from tens to hundreds during each survey. The highest counts in semi-dry ponds were recorded during the months March (132), April (272), and November (112) (Table 3, fig. 4a). This guild spent up to 40% (median: 40.3%, CI: 26.6%, 55.7%) of their day feeding in semi-dry ponds during April and 60% in November (fig. 4b). A large portion of them remain in semi-dry ponds to feed when the intertidal is available in November, indicating a preference for ponds. The feeding function of semi-dry ponds was high in both pre- and post-migration months April, and November (fig. 4c). Although September also has high feeding index, it was derived from a sample smaller than 10% of entire area count (table3).

Visual Continuous (representative species: Terek Sandpiper)

doi:10.6342/NTU202404257

The Visual Continuous guild was much rarer than the other guilds, and semi-dry ponds never contained more than 10% of entire area count during our surveys (table 3); only April and August had more than 10 individuals recorded in semi-dry ponds. This guild spent very little time feeding in semi-dry ponds. They spent less than 20% of their time feeding during all of the surveyed months (fig. 5b).

Visual Continuous Deep Water (representative species: Common Redshank, Common Greenshank)

The Visual Continuous Deep-Water group was found in highest number in semi-dry ponds during March (115) and September (188) (table 3, fig. 6a). Only a few dozen individuals were counted during the remaining months. This guild spent more than 40% of their time budget feeding in semi-dry ponds during August (median: 25.8%, CI:12.9%, 41.5%) and December (median: 28.6%, CI:14.3%, 57.1%) (fig. 6b). A large portion of their time budget in April was also devoted to feeding in semi-dry ponds, but the confidence interval did not overlap with the 40% mark. The feeding importance index was consistently higher in March, April, and August, but the in the latter two months, only a small fraction of entire area count was found in semi-dry ponds (fig. 6c). In November and December, less than 10% of entire area count was found in the semi-dry ponds, thus the result for both time budget and importance index were inconclusive for these months (table 3).

Pause-travel (representative species: Kentish Plover)

The pause-travel guild was recorded from hundreds to thousands in semi-dry ponds throughout the year except in November. The highest counts were recorded in August (3401), September (3201), December (1380) (table 3, fig. 7a). In November, few were seen in semi-dry ponds, instead, they were mostly found roosting on the bank and other dry locations in the region (table 3). This guild spent more than 40% of their daytime time

doi:10.6342/NTU202404257

budget feeding in semi-dry ponds in April (median: 25.8%, CI: 11.3%, 41.6%) and nearly 40% in December (median: 24.5%, CI: 11.9%, 38.5%) (fig. 7b). Unlike all of the other guilds, the importance index was highest in December (fig. 7c).

Pied Avocet

The high count of Pied Avocet in semi-dry ponds was recorded in March numbering at over 300 individuals. Only a few dozen individuals were recorded during the other months (table 3, fig. 8a). August was the only month in which Pied Avocet spent more than 40% of their daytime time budget feeding in semi-dry ponds (median: 26.2%, CI: 7.1%, 47.6%) (fig. 8b). The feeding index was consistently low throughout the year (fig. 8c).

Black-winged Stilt

Large numbers of Black-winged Stilts were recorded in semi-dry ponds in March (1476), April (864), and November (261) (table 3, fig. 9a). They spend over 60% of their time budget feeding in semi-dry ponds in April (median: 41.7%, CI: 25.6%, 63.8%) and over 40% in December (median: 29,3%, CI: 13.9%, 46.8%) (fig. 9b). The feeding importance index was significantly higher pre-migration in April than during other months (fig. 9c).

Discussion

Pre-Breeding Time Budget

In most of the guilds, there was a strong seasonal variation in their usage of semi-dry ponds. The Tactile Continuous guild spent up to 40% of their daytime time budget foraging in semi-dry ponds during April, August, September, and December. Similarly, the Tactile Continuous Deep-Water guild spent over 40% of their daytime time budget foraging

doi:10.6342/NTU202404257

in these ponds during April, and November; the Visual Continuous Deep Water guild during August; the Pause-Travel guild during April, and nearly 40% in December; Pied Avocet during August; and Black-winged Stilt during April, and December. The high proportion of time budget devoted to feeding in semi-dry ponds demonstrated the ponds provide significant amount of food to these groups pre-breeding in April and post-breeding from August to November (table 4). The notably high feeding proportion of Tactile Continuous, Pause-Travel and Black-winged Stilt in December will be discussed later. In contrary to the other guilds, the Visual Continuous guild foraged in semi-dry ponds minimally and does not show any seasonal variation.

The high portion of time budget dedicated to feeding during the pre-breeding season was likely due to the urgency of migration. Under most circumstances, birds do not encounter a situation in which food is so abundant that their fat deposition is limited because their body cannot process more food (metabolically-limited). Rather, the amount of energy intake available for fat deposition is limited by foraging time (foraging-time limited) (Lindström 1991). Given the urgency of migration, the birds would use semi-dry ponds to increase foraging time, even if they provided less food resources than intertidal, in addition to foraging in the intertidal zone to supplement their diet (Masero et al. 2000). The Tactile Continuous, Tactile Continuous Deep-Water, Visual Continuous-Deep-water, Pause-Travel guilds and Black-winged Stilt dedicated a significant portion of their time budget to feeding in the semi-dry ponds in April, but less than half of them remain in those ponds when the intertidal is available during the earlier and later hours of time budget survey; this supports the supplementary hypothesis.

Post-Breeding Time Budget

doi:10.6342/NTU202404257

In the post-breeding months, August through November, the birds were under less of a time constrain and were less likely to be using time-optimized migration strategy, meaning they can keep a lower fat reserve than pre-migration (Hedenström and Alerstam 1997; Alerstam 2011). Most speices' post-breeding migration were spread out over a longer period compared to their pre-breeding migration (Supplementary S1) and there was less of an urgency to feed; thus, as expected, the time budget dedicated to feeding in semi-dry ponds tends to be lower than during the pre-breeding period, except for a short period of post-migration fueling.

A notable exception was found in the Tactile Continuous and Tactile Continuous Deep-Water guilds. In August, the Tactile Continuous guild exhibited a preference, spending up to 60% of their time budget, for feeding in semi-dry ponds. More than half of individuals chose to stay and feed in ponds even when the intertidal was available in round one, two, six and seven (fig. 3a). Nearly all individuals in the Tactile Continuous guild recorded in August were Red-necked Stints (table 3). The Red-necked Stint is a small sized shorebird known for making long non-stop flights to wintering grounds after departing from the yellow sea (Mu et al. 2020); thus, they likely arrived in Taiwan with lower fuel load than larger species and were in need of refueling. Most of the Red-necked Stints found in our study site during August do not winter in Changhua, instead they use this location as a stop-over site before flying to Southern Taiwan or Australia to winter (Supplementary S1, Fink et al. 2023). The high portion of time budget dedicated to feeding in semi-dry ponds in December can be attributed to the post-migration feeding of Dunlins as the time coincides with their arrival in late November and December (table 3, Fink et al. 2023). In November, the time budget of Tactile Continuous Deep-Water guild also supported the preference hypothesis (fig. 4a). This guild was mostly comprised of Marsh Sandpiper in November.

doi:10.6342/NTU202404257

The high time budget dedicated to feeding might be due to some individuals had just arrived as suggested by the higher count in semi-dry ponds on day two than entire study area on day 1 (table 3). The Visual Continuous Deep-Water guild also had high proportion of time budget dedicated to feeding in December, but we will not discuss it as it was calculated from observation of a single individual.

It was surprising that the Tactile Continuous, Pause-Travel guilds and Black-winged Stilt dedicated a high portion of their daytime time budget to foraging in semi-dry ponds in December, since they were unlikely to be in high demand of fuel in the subsequent months during winter. One possible explanation is that there was a sudden increase of preferred food in the ponds, thus the birds utilized the semi-dry ponds more. The representative species of these guilds, Red-necked Stint, Dunlin, Kentish Plover and Black-winged Stilts, primarily consume polychaetes, crustaceans, and insects during non-breeding season (del Hoyo et al. 2023, Maleko et al. 2023). Polychaetes might be in high abundance in certain ponds during December which was the month we surveyed closest to January when polychaetes are often found to be abundant. In a benthic survey from Qigu lagoon in South Western Taiwan, Chiu found that the highest abundance and richness of polychaetes was in January and lowest in October among the months January, April, July, and October (Chiu 2010). The availability of polychaetes can also be unpredictable and might not directly correlate to seasons. In a clam-shrimp mixed culture benthos study in Yunlin, about 30km south of our study site, polychaetes were found to be in low abundance from October through January when the abundance suddenly increased, but in the following rotation, polychaete abundance increased in October (Lu and Shyu 1991). In shrimp monocultures, benthic organisms were found to decrease at first when the sediment become polluted by organic material build-up, but hardy polycheate species that can survive the pollution

doi:10.6342/NTU202404257

would soon take advantage of the available nutrients and suddenly increase in abundance becoming the dominant species (Lu and Shyu 1991). This was unlikely what happened at our study site as the farmers need to harvest their animals and empty the ponds before the sediment become overly polluted.

Feeding Importance Index

Our analysis found the months in which semi-dry ponds are the most important are April (for three guilds, Tactile Continuous Deep Water, Visual Continuous Deep Water, and Black-winged Stilt), August (for two guilds, Tactile Continuous, and Visual Continuous Deep Water), December (for two guilds, Tactile Continuous, Pause-Travel), March (for one guild, Visual Continuous Deep Water), September and November (both for one guild, Tactile Continuous Deep Water) (table 5).

The Wetlands Convention, RAMSAR, recommends that wetlands which support 1% population of a shorebird species should be considered internationally important (United Nations 1971, Bamford and Watkins 2003). Using the flyway minimum population estimates (MPE) on the EAAF, we found semi-dry ponds meet this criterion for four species: Red-necked Stint (MPE: 315,000), Kentish Plover (MPE: 100,000), Black-winged Stilt (MPE: 25,000-100,000), and Pied Avocet (MPE: 25,000-100,000) (Bamford and Watkins 2003). Although the Black-winged Stilt's population is now probably several times higher than the 2003 estimate, this still highlights the importance of semi-dry ponds to migratory shorebirds on this threatened flyway. Further, even the months with lower feeding importance indices also have high proportion of birds in the area roosting in the semi-dry ponds: March (3751/5146, 72.89%), April (4674/7135, 65.51%), August (7996/11318, 70.65%), September (4408/9081, 48.54%), November (898/7859, 11.43%), and December (4980/14352, 34.70%); This demonstrates that in addition to providing

doi:10.6342/NTU202404257

important foraging grounds, semi-dry ponds also serve as important roosting area where birds can rely on other individuals for vigilance and devote more time budget to other activities (Metcalfe and Furness 1984).

A limitation of our research was that all surveys were conducted during spring tide. Since the different tidal cycle (spring or neap tide) exposes different parts of the intertidal, and different shorebirds preferentially use different parts of intertidal for foraging (Jing et al. 2007), we could not identify if the importance of semi-dry ponds also changes with tidal cycle. There could also be a complex interaction between tidal cycle and date since the arrival of shorebirds is time dependent, but the tidal cycle does not occur at the same time every year. Another limitation in the time budget survey is that since it is typically easier to identify feeding behaviors in tactile continuous and tactile continuous deep-water guilds compared to others, the semi-dry pond usage by other guilds is more likely to be underestimated.

Conclusion

In this thesis, we quantified the function of semi-dry ponds as foraging grounds and analyzed its seasonal variation. Overall, April, was the most important months for three guilds, followed by August and December each having two guilds that use semi-dry ponds for feeding. The supratidal aquaculture ponds in Changhua can support more than 1% of the population of many migratory shorebird species and should be considered important habitats. In the inevitable case of degrading and disappearing wetland habitats, we recommend increasing the number of drained ponds during the months in which they can

doi:10.6342/NTU202404257

provide birds with foraging grounds. This need is especially critical during April, August and December.

Tables

Table 1. Number, and area of pond surveyed. The number of shorebird individuals was the sum of max count of each species.

Date (Y-M-D)	Number of Semi-dry Ponds Surveyed	Area of Semi-dry Ponds in km^2	Number of Species	Number of Shorebird Species	Number of Shorebird Individuals
March 21, 2022	16	0.532	17	8	557
March 22, 2022	16	0.193	33	18	3752
April 18, 2022	16	1.04	22	17	2274
April 19, 2022	7	0.084	26	24	4693
August 11, 2022	20	1.38	27	20	8408
August 12, 2022	8	0.107	31	23	7996
September 12, 2022	19	1.49	30	23	5936
September 13, 2022	7	0.0851	31	26	4452
November 10, 2022	11	0.678	16	10	507
November 11, 2022	8	0.107	22	11	898
December 8, 2022	4	0.173	12	4	1943
December 9, 2022	3	0.0355	23	18	4985

doi:10.6342/NTU202404257

Table 2. Guild assignment of each species and their year total. Day one (entire area count) total was the sum of all surveys. Day two (time budget survey) total was the sum of max counts from each survey. For detailed break-down, see table 3.

Guild	Common Name	Scientific Name	Day One Year Total	Day Two Year Total
Tactile continuous	Red-necked Stint	*Calidris ruficollis*	7008	7995
	Dunlin	*Calidris alpina*	6738	4312
	Curlew Sandpiper	*Calidris ferruginea*	546	285
	Sanderling	*Calidris alba*	281	115
	Sharp-tailed Sandpiper	*Calidris acuminata*	70	52
	Long-toed Stint	*Calidris subminuta*	60	44
	Broad-billed Sandpiper	*Calidris falcinellus*	32	27
	Red Knot	*Calidris canutus*	29	14
	Little Stint	*Calidris minuta*	11	1
subtotal			14775	12845
Tactile continuous deep water	Marsh Sandpiper	*Tringa stagnatilis*	869	501
	Black-tailed Godwit	*Limosa limosa*	9	40
	Wood Sandpiper	*Tringa glareola*	30	22
subtotal			908	563
Visual continuous	Terek Sandpiper	*Xenus cinereus*	349	50
	Ruddy Turnstone	*Arenaria interpres*	3484	46
	Grey-tailed Tattler	*Tringa brevipes*	752	43
	Common Sandpiper	*Actitis hypoleucos*	51	6
subtotal			4636	145
Visual continuous deep water	Common Redshank	*Tringa totanus*	465	190
	Common Greenshank	*Tringa nebularia*	464	156
subtotal			929	346
Pause-travel	Kentish Plover	*Anarhynchus alexandrinus*	20874	6540
	"Lesser" Sand-Plover	*Anarhynchus mongolus/atrifrons*	2181	1516
	Greater Sand-Plover	*Anarhynchus leschenaultii*	1567	643
	Little Ringed Plover	*Charadrius dubius*	311	336
	Pacific Golden-Plover	*Pluvialis fulva*	786	266
	Greater/ "Lesser" Sand-Plover	*Anarhynchus mongolus/atrifrons/ leschenaultii*	1408	222
	Northern Lapwing	*Vanellus vanellus*	12	64
	Black-bellied Plover	*Pluvialis squatarola*	1332	5
subtotal			28471	9592
Pied Avocet	Pied Avocet	*Recurvirostra avosetta*	686	461
subtotal			686	461
Black-winged Stilt	Black-winged Stilt	*Himantopus himantopus*	4486	2755
subtotal			4486	2755

doi:10.6342/NTU202404257

Excluded from analysis	Whimbrel	*Numenius phaeopus*	228	42
	Red-necked Phalarope	*Phalaropus lobatus*	22	19
	Eurasian Curlew	*Numenius arquata*	954	
	Far Eastern Curlew	*Numenius madagascariensis*	2	
	Great Knot	*Calidris tenuirostris*	257	
	Bar-tailed Godwit	*Limosa lapponica*	14	
	Common Snipe	*Gallinago gallinago*		5
	Green Sandpiper	*Tringa ochropus*		1
	Ruff	*Calidris pugnax*		1
	Oriental Pratincole	*Glareola maldivarum*		1
subtotal			1477	69

Table 3. High count of each species during surveys.

		Month											
		March		April		August		September		November		December	
Guild	**Common Name**	Mar. 21	Mar. 22	Apr. 18	Apr. 19	Aug. 11	Aug. 12	Sep. 12	Sep. 13	Nov. 10	Nov. 11	Dec. 8	Dec. 9
Tactile continuous	Red-necked Stint	0	304	1249	2225	4238	4326	1303	870	95	50	123	220
	Dunlin	1025	397	661	316	0	1	11	4	1067	359	3974	3235
	Curlew Sandpiper	1	1	360	200	165	80	19	4	0	0	1	0
	Sanderling	16	38	82	15	2	18	106	14	10	1	65	29
	Sharp-tailed Sandpiper	0	0	58	50	4	0	8	1	0	0	0	1
	Long-toed Stint	0	0	37	6	0	11	23	3	0	4	0	20
	Broad-billed Sandpiper	0	0	8	0	7	3	15	24	0	0	2	0
	Red Knot	0	0	29	13	0	0	0	0	0	0	0	1
	Little Stint	0	0	2	0	9	0	0	0	0	0	0	1
subtotal		1042	740	2486	2825	4425	4439	1485	920	1172	414	4165	3507
Tactile continuous deep water	Marsh Sandpiper	69	130	195	213	179	2	337	21	81	112	8	23
	Black-tailed Godwit	0	0	9	39	0	1	0	0	0	0	0	0
	Wood Sandpiper	4	2	12	20	0	0	13	0	1	0	0	0
subtotal		73	132	216	272	179	3※	350	21※	82	112	8	23
Visual continuous	Terek Sandpiper	19	0	70	32	89	16	141	2	5	0	25	0
	Ruddy Turnstone	511	6	657	5	543	24	436	2	510	0	827	9
	Grey-tailed Tattler	0	0	388	22	311	15	53	6	0	0	0	0
	Common Sandpiper	6	1	4	1	5	2	9	1	18	0	9	1
subtotal		536	7※	1119	60※	948	57※	639	11※	533	0※	861	10※
Visual continuous deep water	Common Redshank	29	0	37	6	136	24	187	160	30	0	46	0
	Common Greenshank	210	115	39	2	33	5	129	28	42	5	11	1
subtotal		239	115	76	8	169	29	316	188	72	5※	57	1※
Pause-travel	Kentish Plover	1080	568	266	55	3603	2211	4093	2639	4312	11	7520	1056
	"Lesser" Sand-Plover	0	302	1196	431	407	597	133	143	263	0	182	43
	Greater Sand-Plover	6	25	568	118	636	445	56	55	208	0	93	0
	Little Ringed Plover	4	4	0	2	141	124	78	154	22	2	66	50
	Pacific Golden-Plover	198	74	205	0	5	2	78	7	99	16	201	167
	Greater/ "Lesser" Sand-Plover	727	0	0	0	42	22	639	200	0	0	0	0
	Northern Lapwing	0	0	0	0	0	0	0	0	1	0	11	64
	Black-bellied Plover	503	1	127	1	4	0	33	3	201	0	464	0
subtotal		2518	974	2362	607	4838	3401	5110	3201	5106	29※	8537	1380
Pied Avocet	Pied Avocet	96	307	0	38	178	6	52	18	209	77	151	15
subtotal		96	307	0	38	178	6※	52	18	209	77	151	15
Black-winged Stilt	Black-winged Stilt	642	1476	876	864	581	61	1129	49	685	261	573	44
subtotal		642	1476	876	864	581	61	1129	49	685	261	573	44
Total		5146	3751	7135	4674	11318	7996	9081	4408	7859	898	14352	4980
Excluded from analysis	Whimbrel	0	0	1	0	0	0	177	42	33	0	17	0
	Red-necked Phalarope	0	0	17	19	2	0	3	0	0	0	0	0
	Eurasian Curlew	51	0	2	0	0	0	0	0	295	0	606	0
	Far Eastern Curlew	0	0	0	0	0	0	0	0	2	0	0	0
	Great Knot	57	0	198	0	0	0	1	0	1	0	0	0
	Bar-tailed Godwit	4	0	0	0	0	0	0	0	4	0	6	0
	Common Snipe	0	0	0	0	0	0	0	0	0	0	0	5
	Green Sandpiper	0	0	0	0	0	0	0	1	0	0	0	0
	Ruff	0	1	0	0	0	0	0	0	0	0	0	0
	Oriental Pratincole	0	0	0	0	0	0	0	1	0	0	0	0
subtotal		112	1	218	19	2	0	181	44	335	0	629	5

※: less than 10% of area total count

doi:10.6342/NTU202404257

Table 4. Feeding time budget table summary. **TC:** tactile continuous, **TCDW:** tactile continuous deep water, **VC:** visual continuous, **VCDW:** visual continuous deep water, **PT:** pause-travel, **PIAV:** Pied Avocet, **BWST:** Black-winged Stilt. ※ indicates the partial count equates to less than 10% of entire area census.

	Mar	Apr	Aug	Sep	Nov	Dec
TC		40%	60%	40%		40%
TCDW		40%	※	※	60%	
VC	※	※	※	※	※	※
VCDW		38%	40%		※	40% ※
PT		40%			※	38.5%
PIAV			40% ※			
BWST		60%				40%

Table 5. Importance table summary. For abbreviations, see table 4. ※ indicates the partial count equates to less than 10% of entire area census.

	Mar	Apr	Aug	Sep	Nov	Dec
TC			high			high
TCDW		high	※	high※	high	
VC※	※	※	※	※	※	※
VCDW	high	high	high		※	high※
PT					※	high
PA※			※			
BWST		high				

doi:10.6342/NTU202404257

Figures

doi:10.6342/NTU202404257

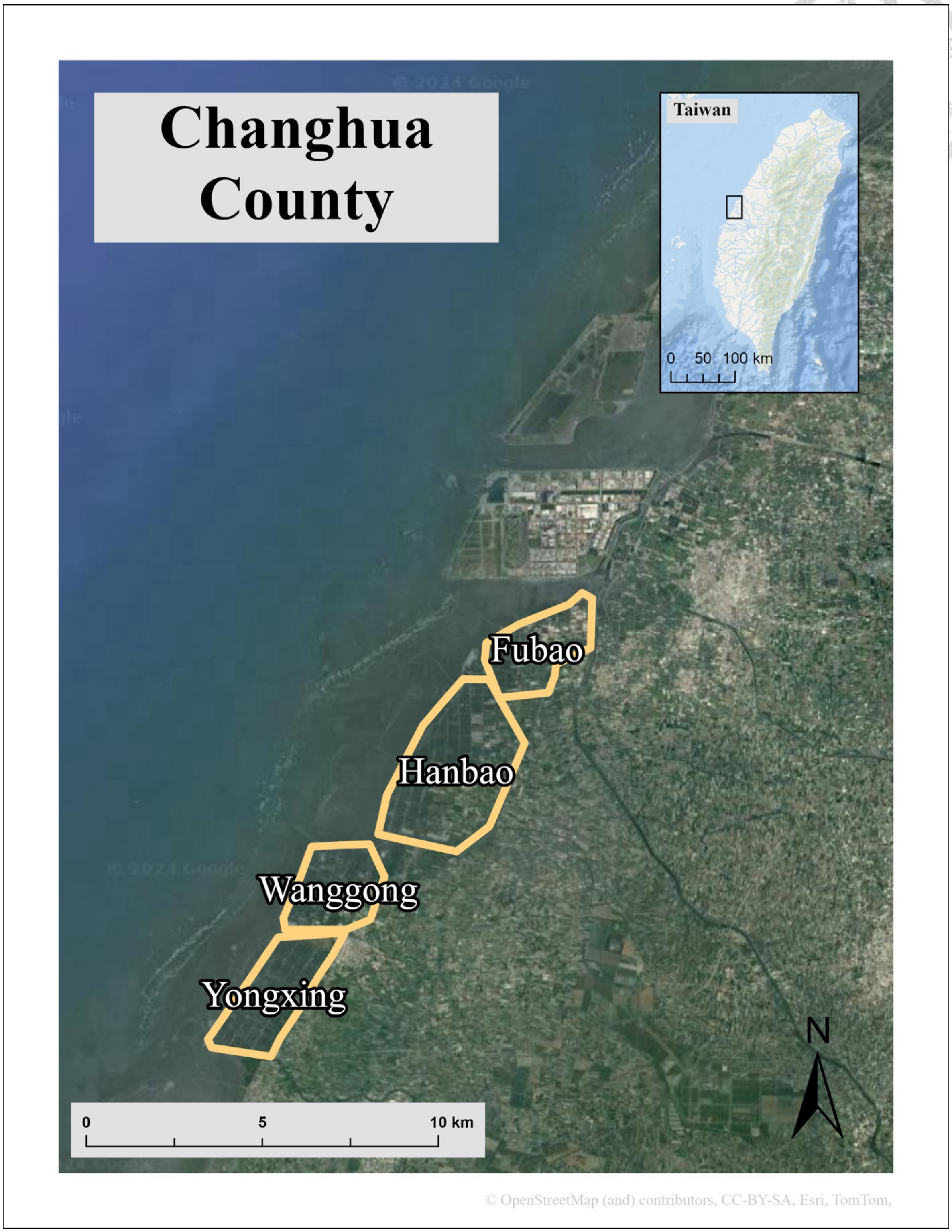

Fig. 1. Map of Study area in Changhua, Taiwan.

doi:10.6342/NTU202404257

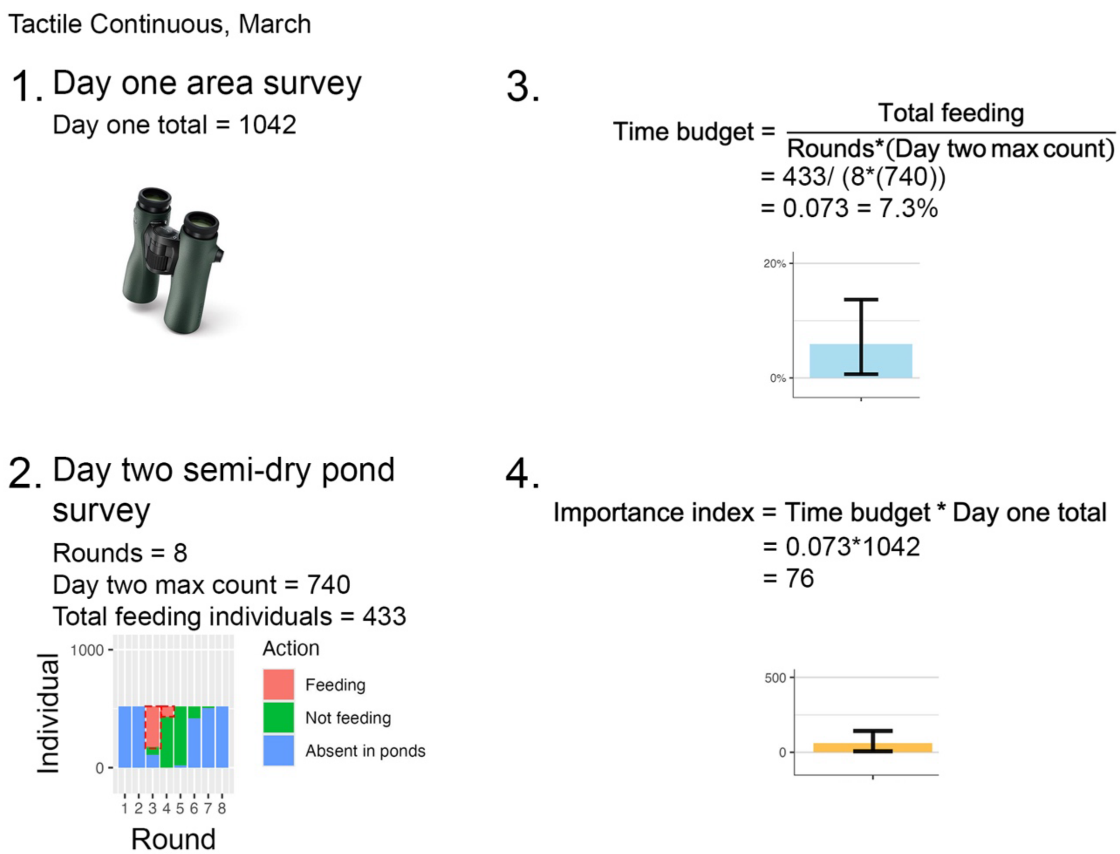

Fig. 2. Survey and analysis flowchart.

doi:10.6342/NTU202404257

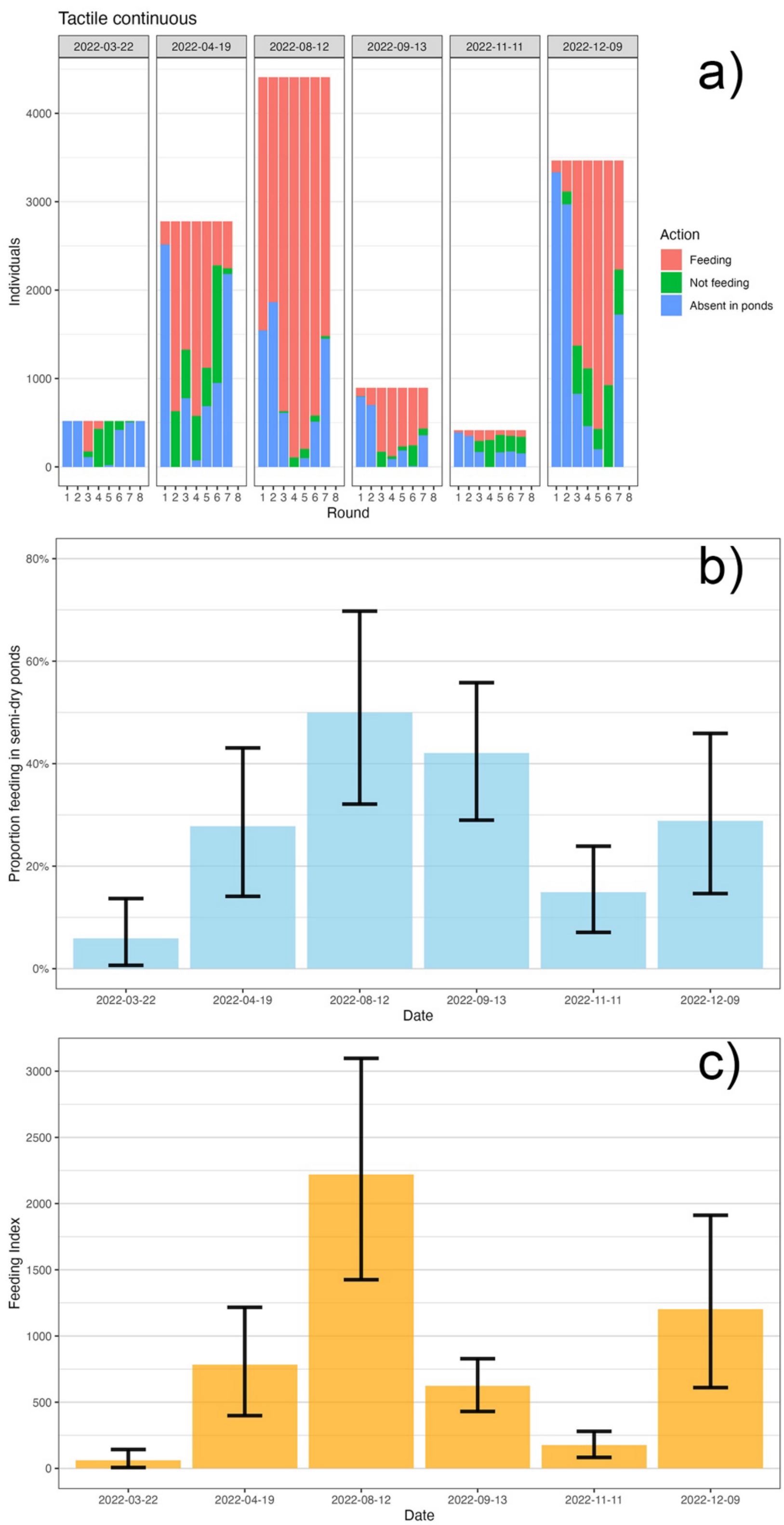

Fig. 3. Tactile Continuous guild a) counts during each round of survey, b) feeding time budget, c) feeding importance index.

doi:10.6342/NTU202404257

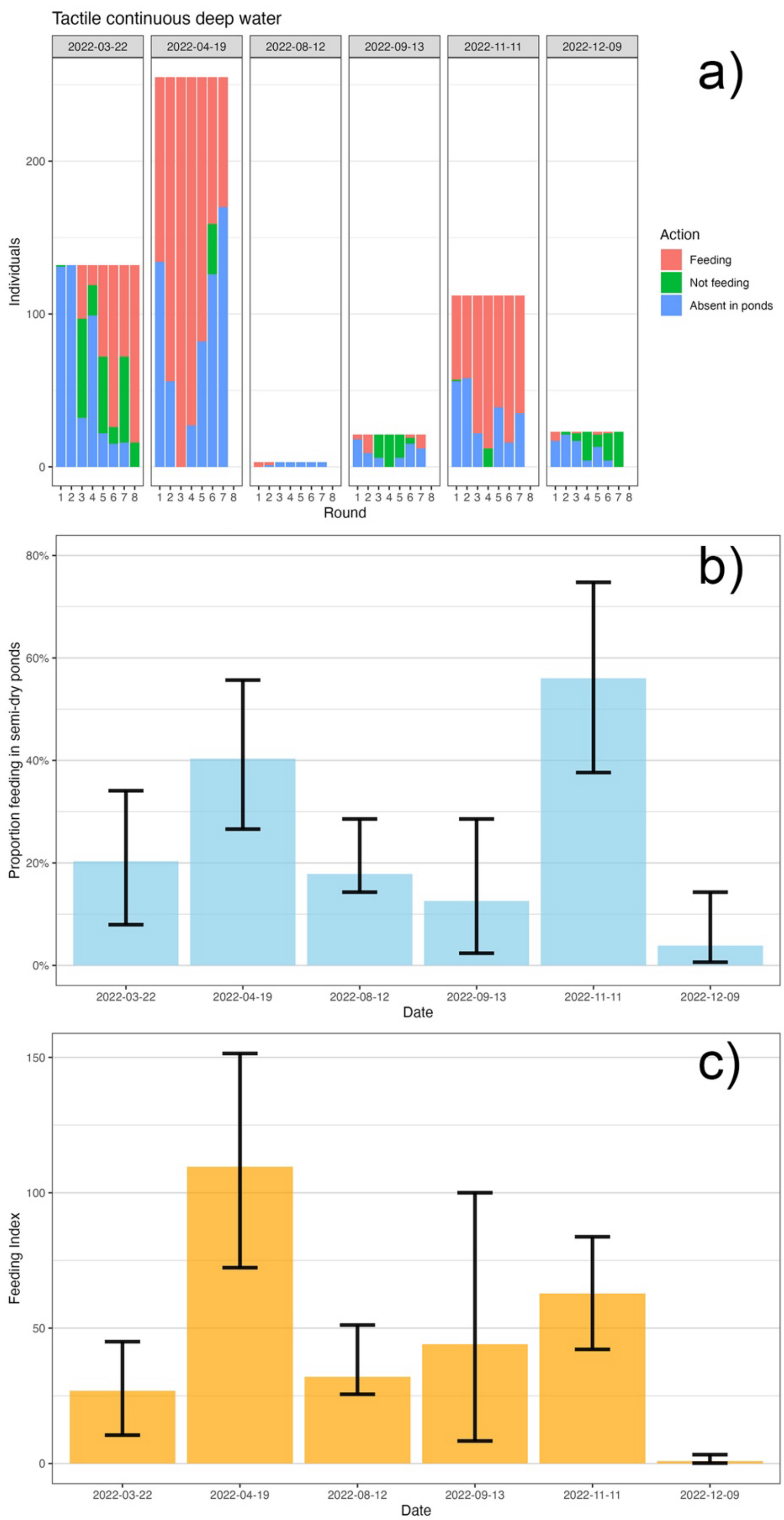

Fig. 4. Tactile Continuous Deep Water guild a) counts during each round of survey, b) feeding time budget, c) feeding importance index. Time budget and feeding importance index in August and September were calculated from small samples.

doi:10.6342/NTU202404257

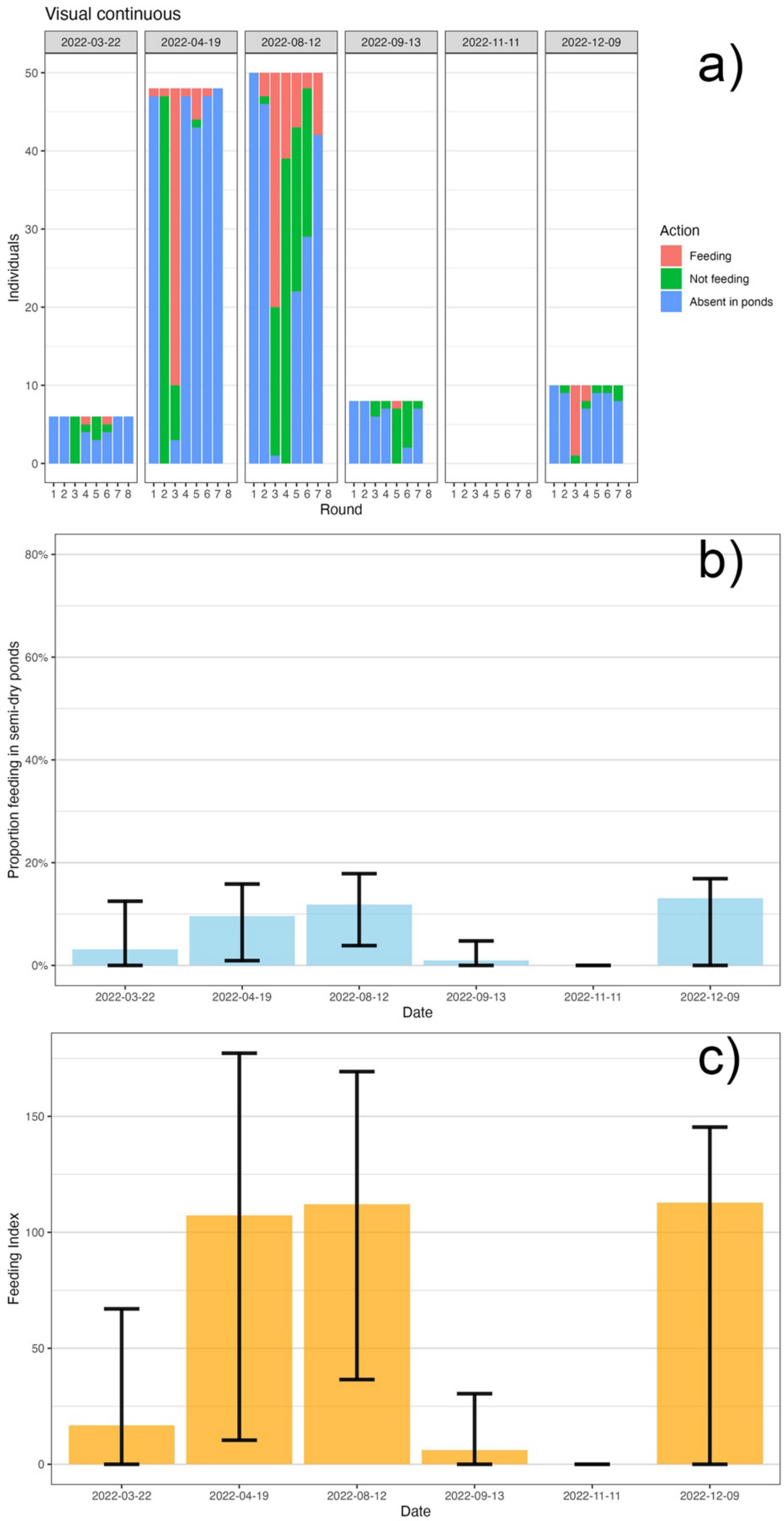

Fig. 5. Visual Continuous guild a) counts during each round of survey, b) feeding time budget, c) feeding importance index. Time budget and index calculated from small sample.

doi:10.6342/NTU202404257

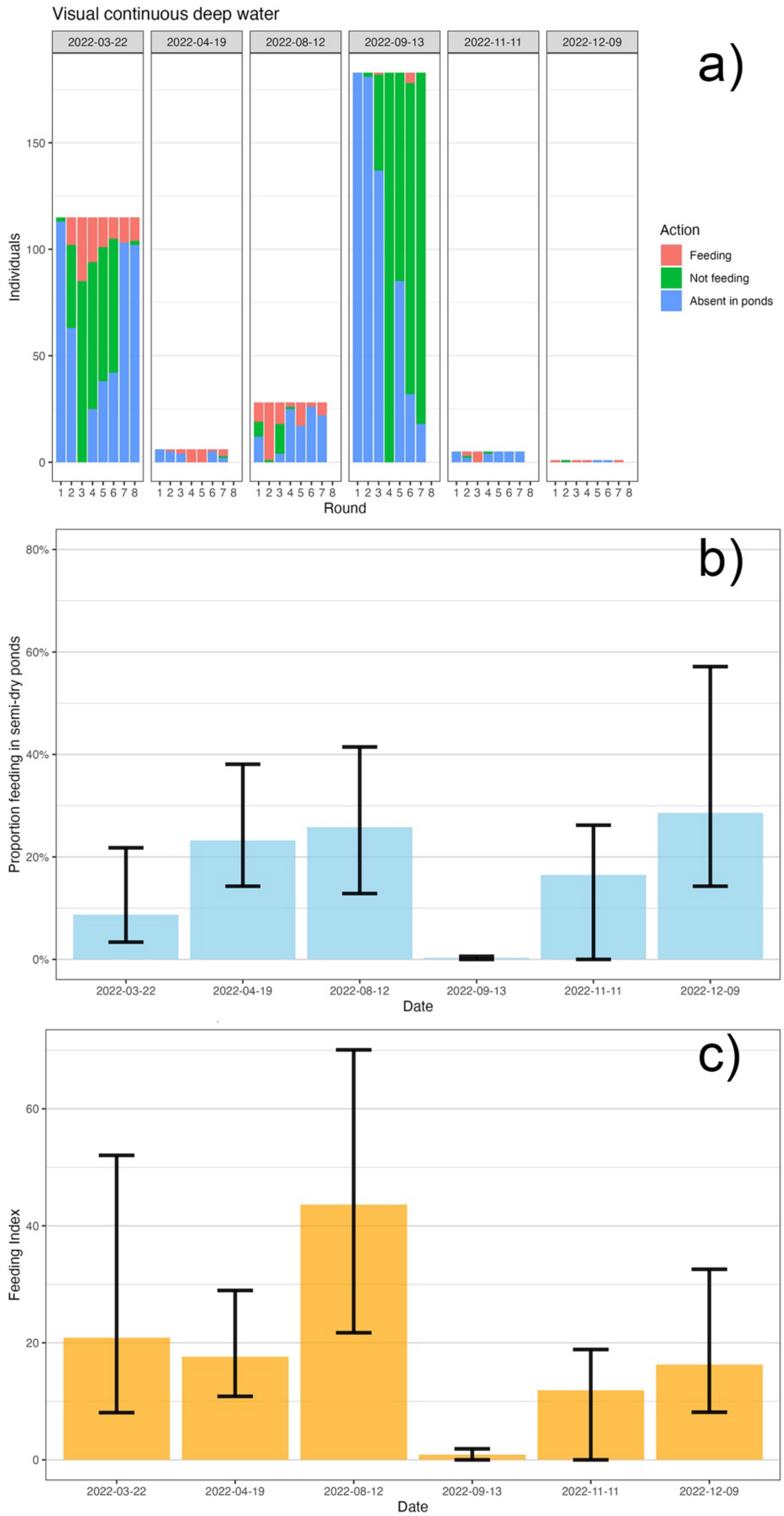

Fig. 6. Visual Continuous Deep Water guild a) counts during each round of survey, b) feeding time budget, c) feeding importance index. Time budget and feeding importance index in December were calculated from a small sample.

doi:10.6342/NTU202404257

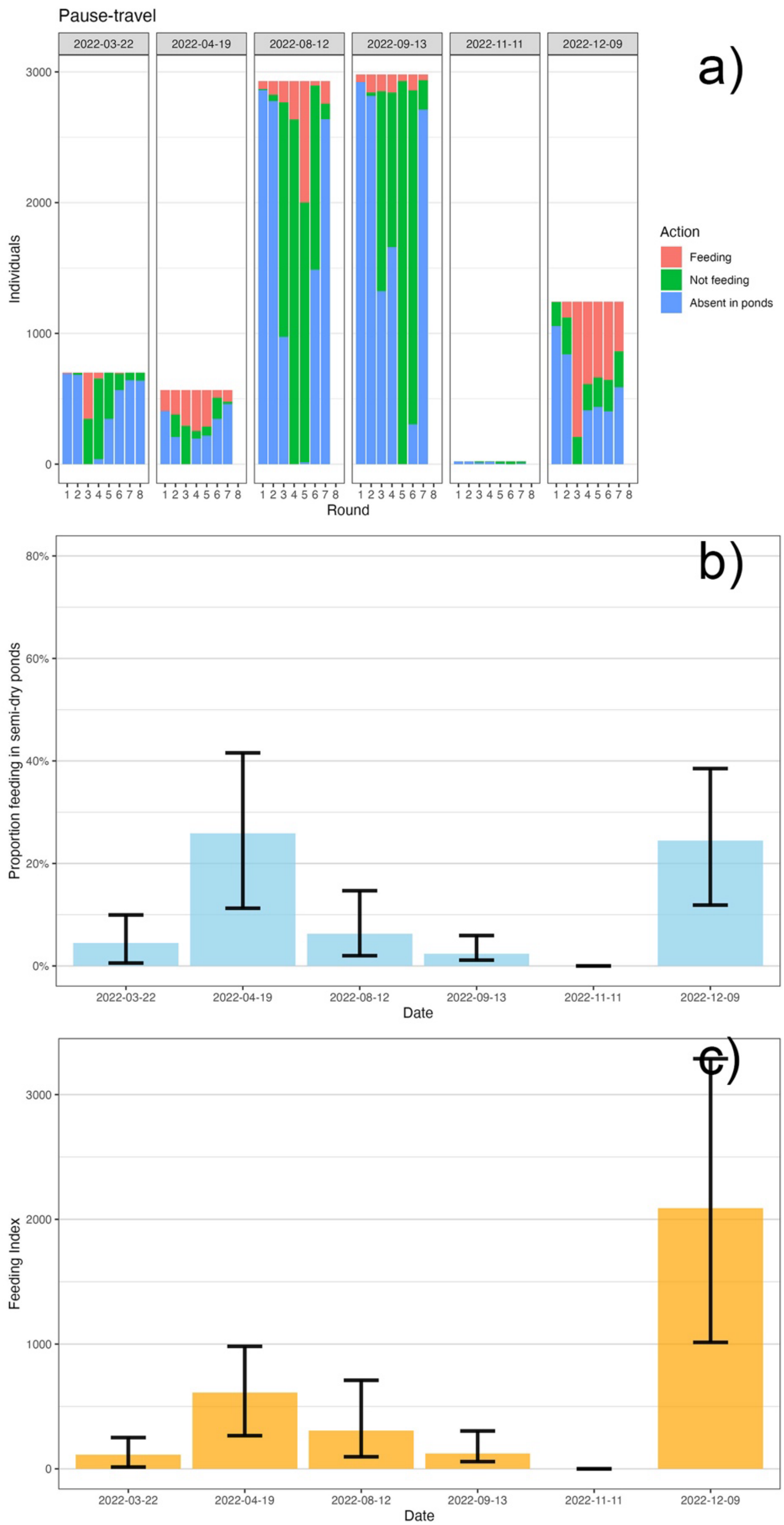

Fig. 7. Pause-Travel guild a) counts during each round of survey, b) feeding time budget, c) feeding importance index.

doi:10.6342/NTU202404257

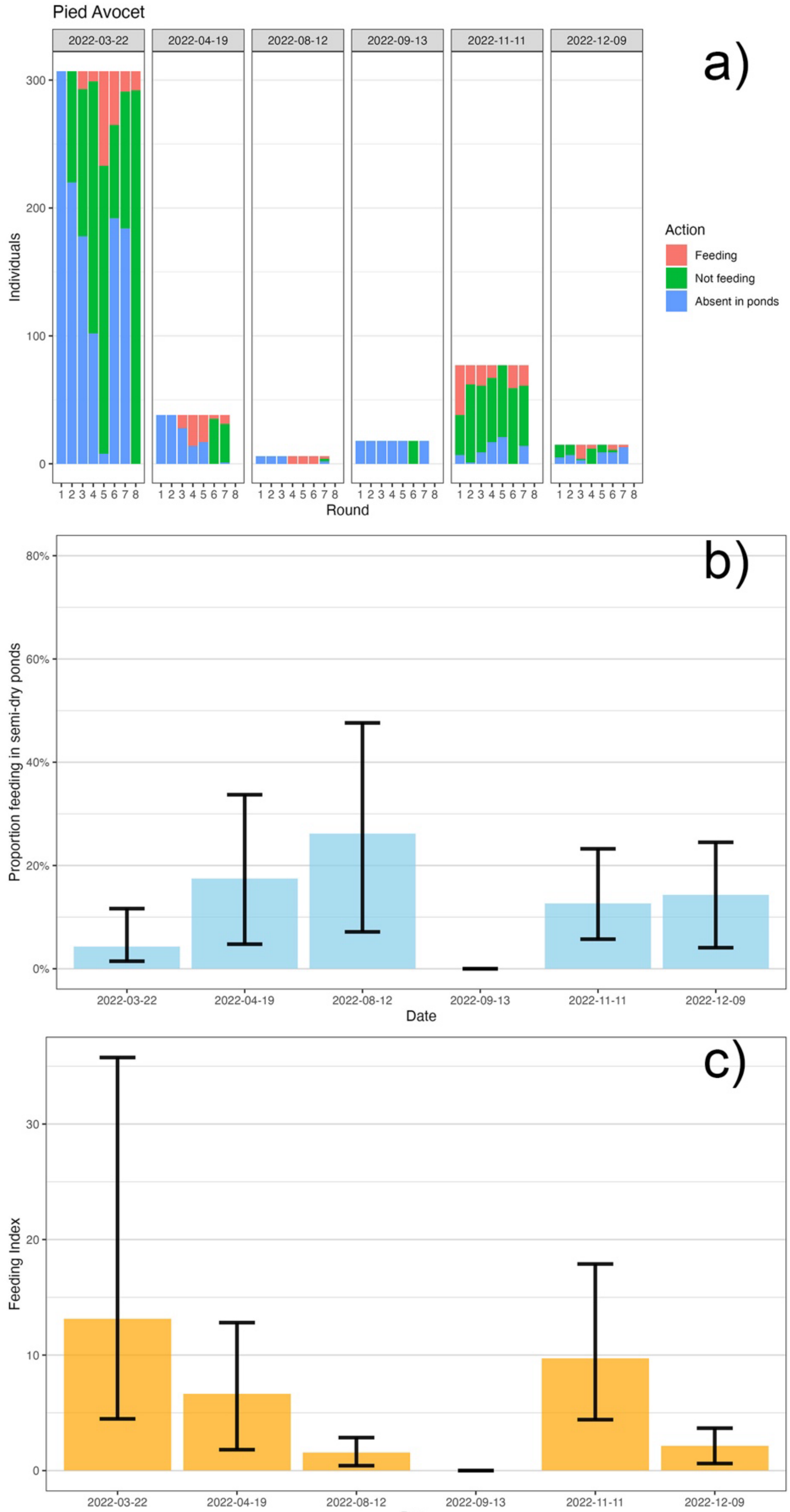

Fig. 8. Pied Avocet a) counts during each round of survey, b) feeding time budget, c) feeding importance index.

doi:10.6342/NTU202404257

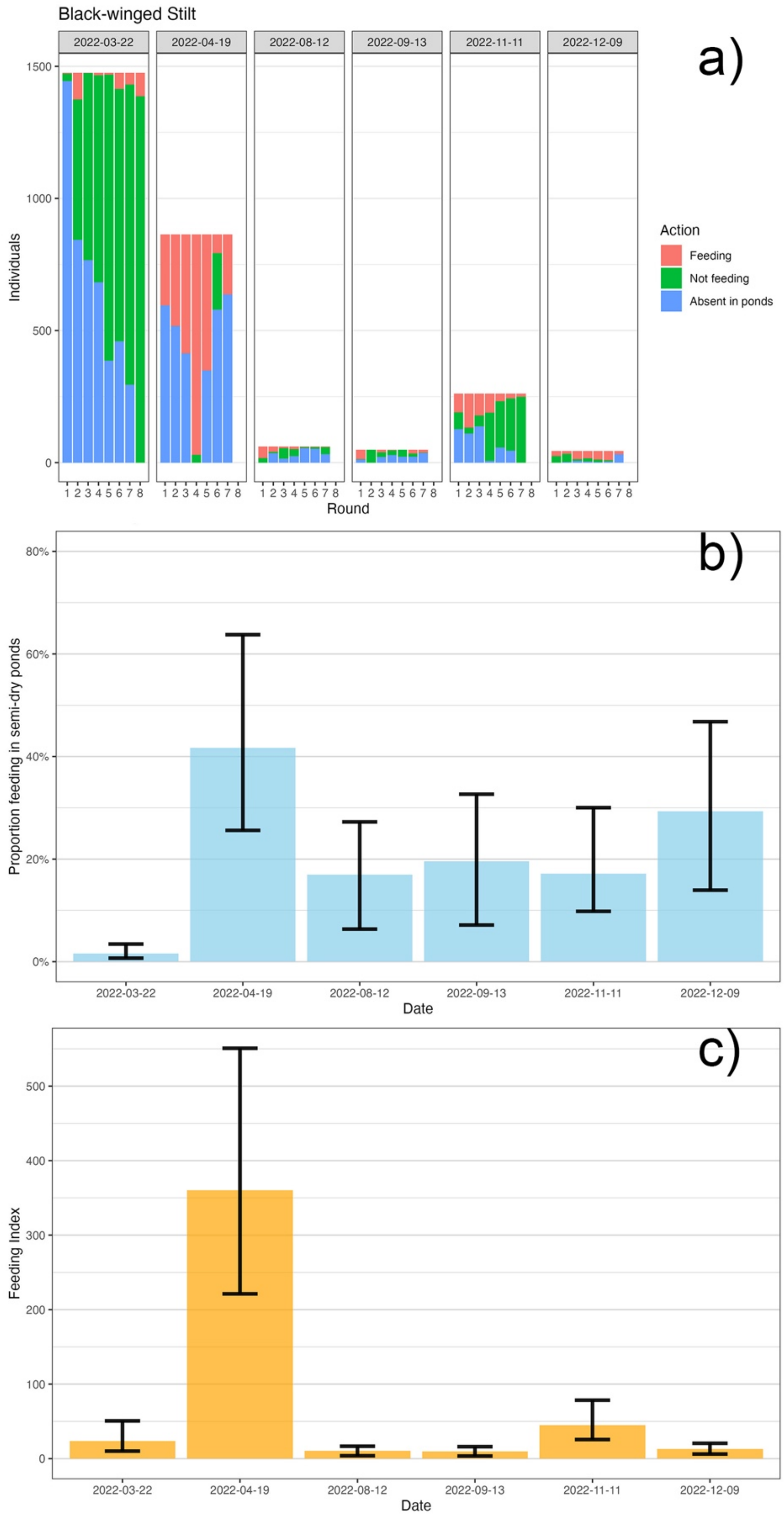

Fig. 9. Black-winged Stilt a) counts during each round of survey, b) feeding time budget, c) feeding importance index.

doi:10.6342/NTU202404257

References

Aharon-Rotman Y, Bauer S, Klaassen M. 2016. A chain is as strong as its weakest link: Assessing the consequences of habitat loss and degradation in a long-distance migratory shorebird. Emu. 116(2). doi:10.1071/MU15029.

Alerstam T. 1991. Bird Flight and Optimal Migration. Trends Ecol Evol. 6(7):210–215.

Alerstam T. 2011. Optimal bird migration revisited. J Ornithol. 152(1 SUPPL):S5–S23. doi:10.1007/s10336-011-0694-1.

Bai ML, Chih WC, Lai YC, Lee PF, Lien YY. 2018. Aquaculture ponds as important high-tide habitats for waterbirds along the west coast of Taiwan. Ornithol Sci. 17(1). doi:10.2326/osj.17.55.

Bamford M, Watkins D. 2003. Population estimates and important sites for shorebirds in the East Asian-Australasian Flyway. Australasian Wader Studies Group.

Chen W-J, Chang A-Y, Lin C-C, Lin R-S, Lee P-F. 20242. Losing tidal wetlands in the midpoint of East Asian-Australasian Flyway in the pasting 100 years. Wetlands 44(59). doi: 10.1007/s13157-024-01814-7

Chiu Y-C. 2010. A study on polychaetes community compositions and its relation to the environmnetal factors in the intertidal zone of Cigu Lagoon, Taiwan. (in Chinese). Master's Thesis. National University of Tainan.

Conklin JR, Verkuil YI, Smith BR. 2014. Prioritizing migratory shorebirds for conservation: Action on the East Asian-Australasian Flyway. WWF-Hong Kong

del Hoyo J, Wiersma P, Kirwan, Collar N, Boesman PFD, Sharpe CJ. 2023. Kentish Plover (Anarhynchus alexandrinus), version 1.2. In Birds of the World (B. K. Keeney, Editor). Cornell Lab of Ornithology, Ithaca, NY, USA. https://doi.org/10.2173/bow.kenplo1.01.2

Dias MP, Granadeiro JP, Lecoq M, Santos CD, Palmeirim JM. 2006. Distance to high-tide roosts constrains the use of foraging areas by dunlins: Implications for the management of estuarine wetlands. Biol Conserv. 131(3):446–452.

ESRI. 2022. ARC GIS pro version 3.0.2.

Executive Yuan. Accelerate the push for renewable energy -maximize the development of green electricity to achieve gradual energy transformation (in Chinese). [accessed 2024 Jan 16]. https://www.ey.gov.tw/Page/5A8A0CB5B41DA11E/46de50e1-7381-4634-93e7-4cd320ec308b.

Fink D, Auer T, Johnston A, Strimas-Mackey M, Ligocki S, Robinson O, Hochachka W, Jaromczyk L, Crowley C, Dunham K, Stillman A, Davies I, Rodewald A, Ruiz-Gutierrez

doi:10.6342/NTU202404257

V, Wood C. 2023. eBird Status and Trends, Data Version: 2022; Released: 2023. Cornell Lab of Ornithology, Ithaca, New York. doi: 10.2173/ebirdst.2022

Fisheries Agency Ministry of Agriculture. Aquaculture stock inquiry platform (in Chinese). [accessed 2024 May 24]. https://fadopen.fa.gov.tw/fadopen/service/qryProduceSectionSummaryYearlyReport.htmx.

Fransson T, Weber TP. 1997. Migratory fuelling in blackcaps (Sylvia atricapilla) under perceived risk of predation. Behav Ecol Sociobiol. 41:75–80.

Gauthier G, Bédard Y, Bédard J. 1988. Habitat Use and Activity Budgets of Greater Snow Geese in Spring. J Wildl Manage. *52*(2), 191–201. https://www.jstor.org/stable/3801222

Green JMH, Sripanomyom S, Giam X, Wilcove DS. 2015. The ecology and economics of shorebird conservation in a tropical human-modified landscape. Journal of Applied Ecology. 52(6):1483–1491. doi:10.1111/1365-2664.12508.

Hedenström A, Alerstam T. 1997. Optimum fuel loads in migratory birds: Distinguishing between time and energy minimization. J Theor Biol. 189:227–234. doi:10.1006/jtbi.1997.0505.

Huang S-Y. 2016. A study on the Benthic Fauna of Shallow-water Milkfish Ponds and Hard Clam Ponds in Qigu. Taiwan Journal of Biodiverisyt. 18(4):281–294.

Huang S-Y, Lin R-S. 2020. When solar photovoltaic met biological conservation -the development of solar photovoltaic at Budai salt pans. Nature Conservation Quarterly. 110:18–27. [accessed 2023 Apr 10]. https://www.tesri.gov.tw/Uploads/userfile/A15_1/2020–09-02_1341018692.pdf.

Jackson MV, Carrasco LR, Choi CY, Li J, Ma Z, Melville DS, Mu T, Peng HB, Woodworth BK, Yang Z, et al. 2018. Multiple habitat use by declining migratory birds necessitates joined-up conservation. Ecol Evol. 9(5):2505–2515. doi:10.1002/ece3.4895.

Jing K, Ma Z, Li B, Li J, Chen J. 2007. Foraging strategies involved in habitat use of shorebirds at the intertidal area of Chongming Dongtan, China. Ecol Res. 22(4):559–570. doi:10.1007/s11284-006-0302-7.

Kirby J. 2010. Review 2: Review of Current Knowledge of Bird Flyways, Principal Knowledge Gaps and Conservation Priorities. Convention on the Conservation of Migratory Species of Wild Animals

Kirby JS, Stattersfield AJ, Butchart SHM, Evans MI, Grimmett RFA, Jones VR, O'sullivan J, Tucker GM, Newton I. 2008. Key conservation issues for migratory land- and waterbird species on the world's major flyways. Bird Conserv Int. 18: S49–S73. doi:10.1017/S0959270908000439.

doi:10.6342/NTU202404257

Lei W, Masero JA, Piersma T, Zhu B, Yang HY, Zhang Z. 2018. Alternative habitat: The importance of the Nanpu Saltpans for migratory waterbirds in the Chinese Yellow Sea. Bird Conserv Int. 28(4):549–566. doi:10.1017/S0959270917000508.

Lin DL, Tsai CY, Pursner S, Chao J, Lyu A, Amano T, Maron M, Lin RS, Lin KH, Chiang KK, et al. 2023. Remote and local threats are associated with population change in Taiwanese migratory waterbirds. Glob Ecol Conserv. 42. doi: 10.1016/j.gecco.2023.e02402.

Lindström Å. 1991. Maximum Fat Deposition Rates in Migrating Birds. Scandinavian Journal of Ornithology. 22:12–19. https://www.jstor.org/stable/3676616?seq=1&cid=pdf-.

Liu C-H. 2011. Where do the Shorebirds at Han-Bou Wetland Come from? Investigating the Migration Route and the Stopover Length by Flag Resighting. Master's Thesis. Tung Hai University.

Lu M-Y, Shyu C-Z. 1991. Study on the benthic fauna in shrimp culture ponds (in Chinese). Conference paper. Shrimp pond environment research and improvement.

Maleko PN, Billerman SM, Pyle P. 2023. Black-winged Stilt (Himantopus himantopus), version 2.0. In Birds of the World (S. M. Billerman, Editor). Cornell Lab of Ornithology, Ithaca, NY, USA. https://doi.org/10.2173/bow.bkwsti.02

Masero JA, Perez-Hurtado A, Casas MC, Arroyo GM. 2000. Complementary use of intertidal mudflats and adjacent salinas by foraging waders. Ardea. 88(2):177–191.

Melville DS, Chen Y, Ma Z. 2016. Shorebirds along the Yellow Sea coast of China face an uncertain future - A review of threats. Emu. 116(2):100–110. doi:10.1071/MU15045.

Metcalfe NB, Furness RW. 1984. Changing Priorities: The Effect of Pre-Migratory Fattening on the Trade-Off between Foraging and Vigilance Vigilance. Behav Ecol Sociobiol. 15: 203–206.

Mu T, Tomkovich PS, Loktionov EY, Syroechkovskiy EE, Wilcove DS. 2020. Tracking the migration of red-necked stint Calidris ruficollis reveals marathon flights and unexpected conservation challenges. J Avian Biol. 51(11). doi:10.1111/jav.02585.

R Core Team. 2024. _R: A Language and Environment for Statistical Computing_. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/.

Rogers DI, Piersma T, Hassell CJ. 2006. Roost availability may constrain shorebird distribution: Exploring the energetic costs of roosting and disturbance around a tropical bay. Biol Conserv. 133(2):225–235. doi: 10.1016/j.biocon.2006.06.007.

Runge CA, Martin TG, Possingham HP, Willis SG, Fuller RA. 2014. Conserving mobile species. Front Ecol Environ. 12(7):395–402. doi: 10.1890/130237.

doi:10.6342/NTU202404257

Tsai C-Y. 2020. Avian community in relation to mangrove structure in the Changhua costal area. Master's Thesis. National Taiwan University.
United Nations. 1971. Convention on Wetlands of International Importance especially as Waterfowl Habitat. Ramsar (Iran), 2 February, 1971. UN Treaty Series No. 14583

Zwarts L, Blomert AM, Hupkes R. 1990. Increase of feeding time in waders preparing for spring migration from the Banc d'Arguin, Mauritania. Ardea, 78(1–2), 237–256. https://doi.org/10.5253/arde.v78.p237

doi:10.6342/NTU202404257

Appendix -Supplementary data

S1 eBird reporting rate

In this study, we focused on four adjacent sub-regions, namely Yongxing (永興), Wanggong (王公), and Hanbao (漢寶) in Fangyuan Township (芳苑鄉), and Fubao (福寶) in Fuxing Township (復興鄉), which are almost exclusively comprised of fish ponds. Ebird is a citizen science platform on which scientists and nature enthusiasts alike, can submit their avian observations. When submitting data to ebird, users are prompted to input metadata, following a semi-structured design. The eBird database is managed by the Cornell lab of Ornithology and local volunteer experts (Sullivan et al 2014). In 2015, the Cornell Lab of Ornithology collaborated with the Taiwan Biodiversity Research Institute (then named Endemic Species Research Institute) to popularize eBird in Taiwan by establishing a Taiwan portal (Praveen et al. 2018). Following the establishment of this local portal and the translation of eBird website to traditional Chinese, the participation from Taiwanese bird-watchers soon skyrocketed.

We used the eBird Basic Dataset from March 2024 (eBird Basic Dataset, EBD_relMar-2024) and chose the date range from 2019 to 2023 as these years had more eBird checklists in the study region compared to the years prior (fig. S1). By comparing the proportion of checklists containing a species and calculating its reporting rate at different time points, we can infer its relative abundance (Roberts et al. 2007, Walker and Taylor 2017). Checklists were filtered based on the following criteria: the checklist was labelled "complete", survey protocol was "travelling", "stationary", or "historical", distance travelled must be less than 15 km, duration, if provided, must be between 6 minutes and 260 minutes, number of taxa reported on the checklist must be between 6 and 60. A checklist is labelled as "complete" when the observer reports all of the species they can identify. The number of species reported is a proxy for search effort and observer skills (Horns et al. 2018). By following these criteria, we removed unusually high and low search efforts and target specific searches. We called the checklists which meet filtering criteria qualified checklists (fig. S2-4). We calculated reporting rate of the seven representative species (most abundant species in each guild) during each Julian week in all four sub-regions from 2019 to 2023. If a month had five weeks instead of four, the 5th week was binned into the 4th. Each week must have at least 5 qualified checklists to calculate reporting rate.

The reporting rate of Red-necked Stint showed a consistent pattern across the five years (fig. S5). There were two upticks in a year. The sudden increase of reporting rate around the week of April 1st indicating the arrival of spring migration, which started to dwindle a month later around May 1st. Starting in the week of August 8th, there was another spike in reporting rate, but again dwindles a month later around the week of September 15th. Dunlin's reporting rate is lowest in the middle of the year between May 15th and August 15th. This species' reporting rate gradually increases in the autumn months and peaks between November 8th and March 8th of the following year (Fig. S6). Marsh Sandpiper's reporting rate did not show as much of a dramatic change as Red-necked Stint did. There were nearly no reports of Marsh Sandpiper between week of May 8th and week of July 15th, but the reporting rate was relatively consistent through the rest of the year (fig. S7). Terek Sandpiper's pre-breeding (spring) reporting rate peaked between April 8th and May 8th (fig. S8). In the post-breeding (autumn) season, the reporting rate started to increase again around the week of July 22, but, unlike the pre-breeding weeks, there wasn't

doi:10.6342/NTU202404257

a point at which reporting rate dropped across all of the years and instead seems to taper off slowly and at different times across the years. Common Redshank's pre-breeding reporting rate was highest between April 22nd and May 22nd and dropped off slowly during June, then there was another peak at July 15th which dropped significantly by October 1st (fig. S9). Common Greenshank's reporting rate is low between May 15th and June 15th, but remains relatively consistent through the rest of the year (fig S10). Pied Avocet's pre-breeding reporting rate peaked around April 1st and dropped off sharply by May 8th during all of the years, but the post-breeding reporting rate is less consistent with higher reporting rate sometime between July 15th, and September 8th (fig. S13). Kentish Plover (fig. S11), and Black-winged Stilt (fig. S12) both have high numbers of resident population, thus it was difficult to discern any pattern in the reporting rate in different seasons for these two species.

The representative species chosen here showed a consistent time of arrival in the study area across the five years 2019 to 2023. The pattern of sharp peaks in the April of Red-necked Stint, Terek Sandpiper, Common Redshank, and Pied Avocet indicated the high time pressure in their flight schedule. The consistent peaks reporting rate showed their reliance on Changhua wetlands, calling for conservation of the remaining natural and artificial wetlands in the area.

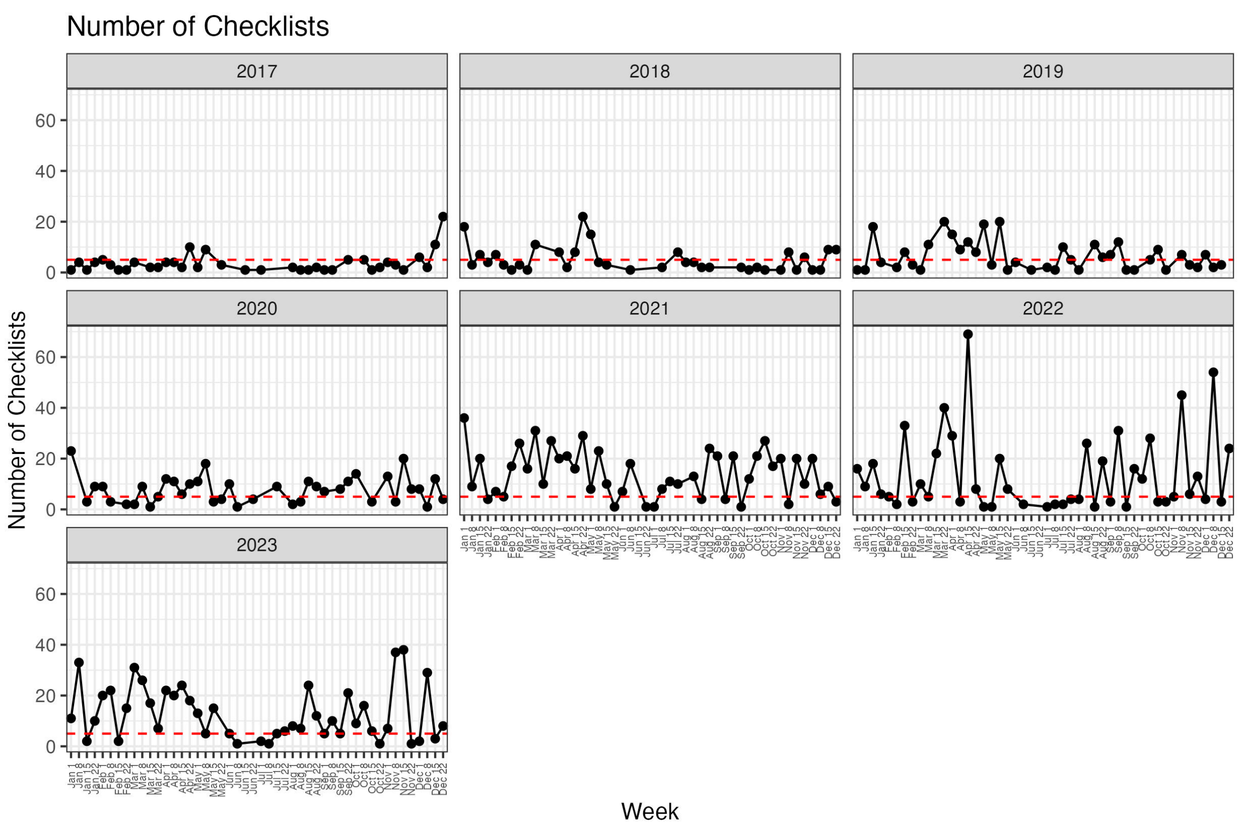

Fig. S1. Number of qualified checklists in a week from 2017 to 2023. The red dash line denotes the minimum number of checklists (5) required to calculate reporting rate.

doi:10.6342/NTU202404257

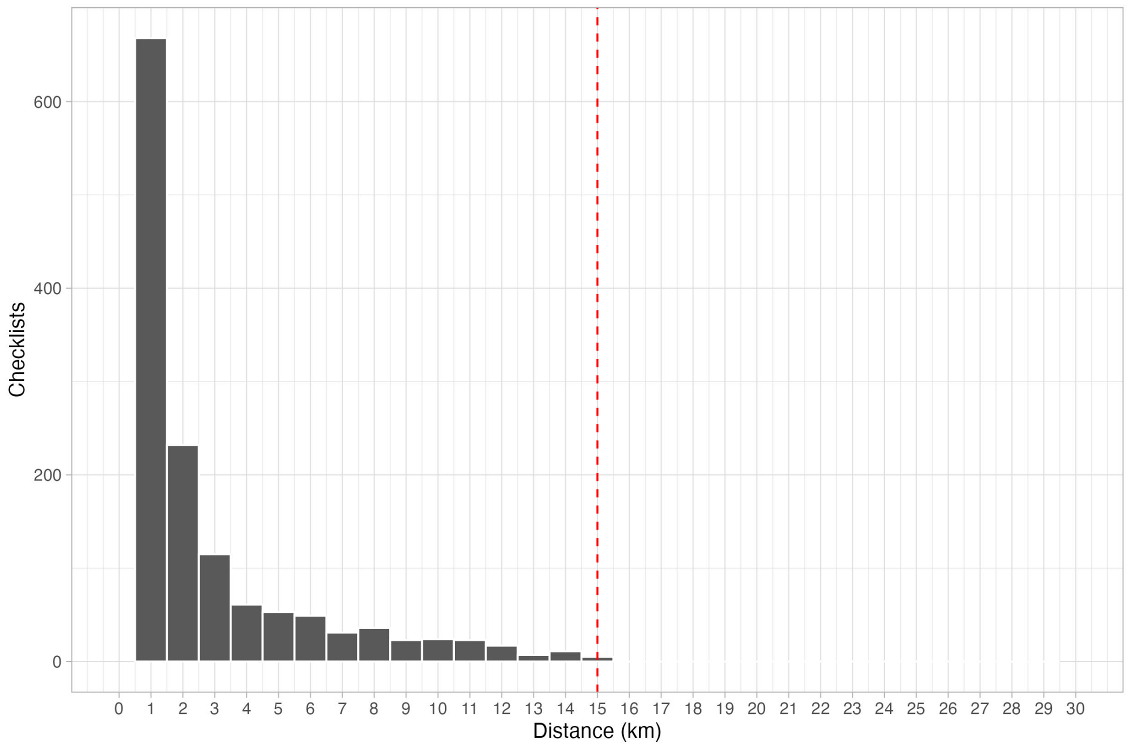

Fig. S2. Histogram of checklists and distance effort from 2017 to 2023, checklists with stationary protocol not shown. The red dash line denotes filtering criteria

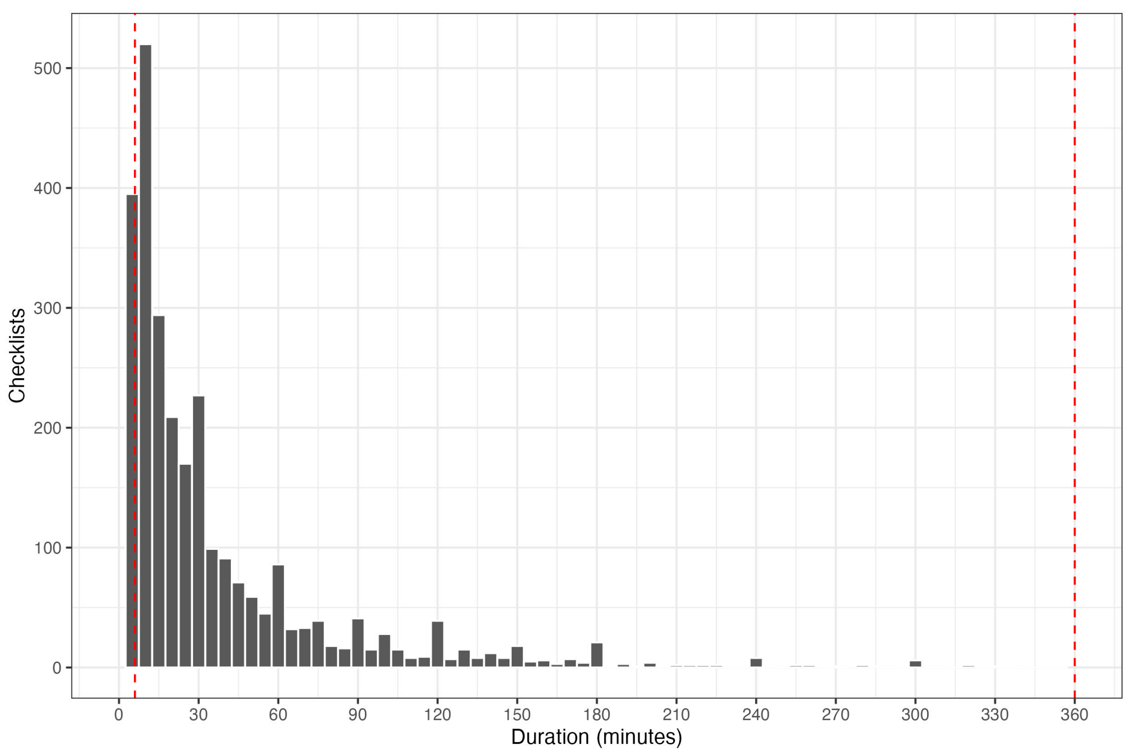

Fig. S3. Histogram of checklists and duration of checklist from 2017 to 2023. The red dash lines denote filtering criteria.

doi:10.6342/NTU202404257

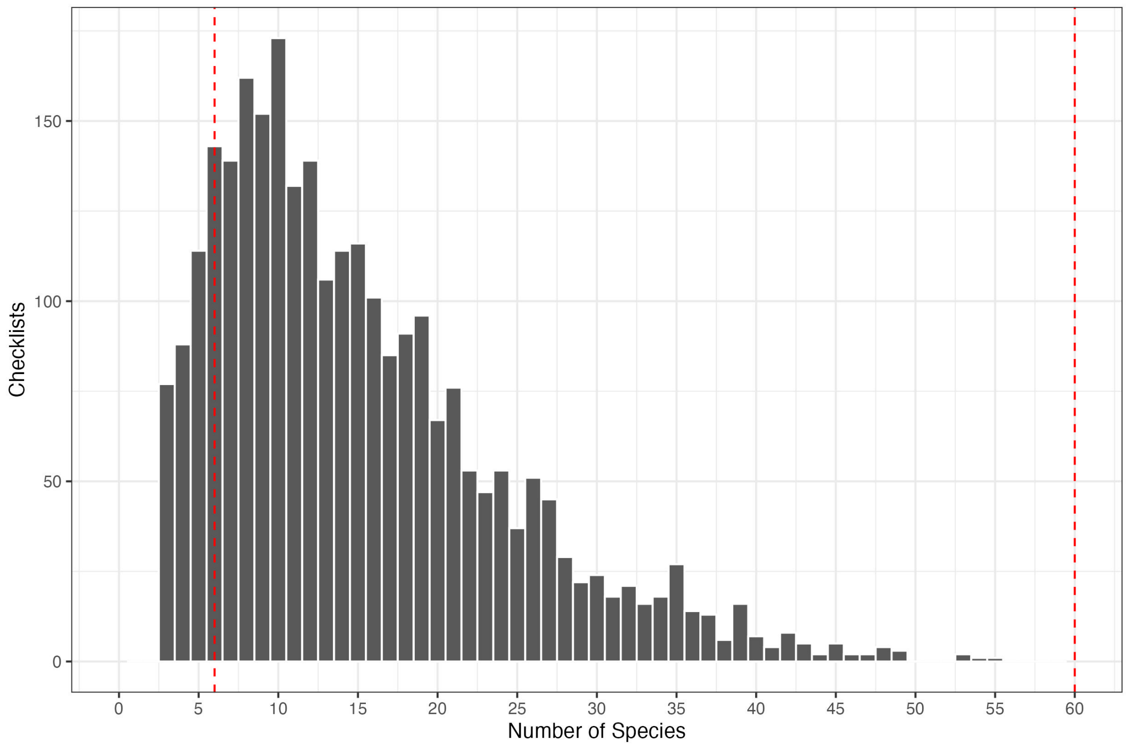

Fig. S4. Histogram of checklists and the number of taxa reported in them from 2017 to 2023. The red dash lines denote filtering criteria.

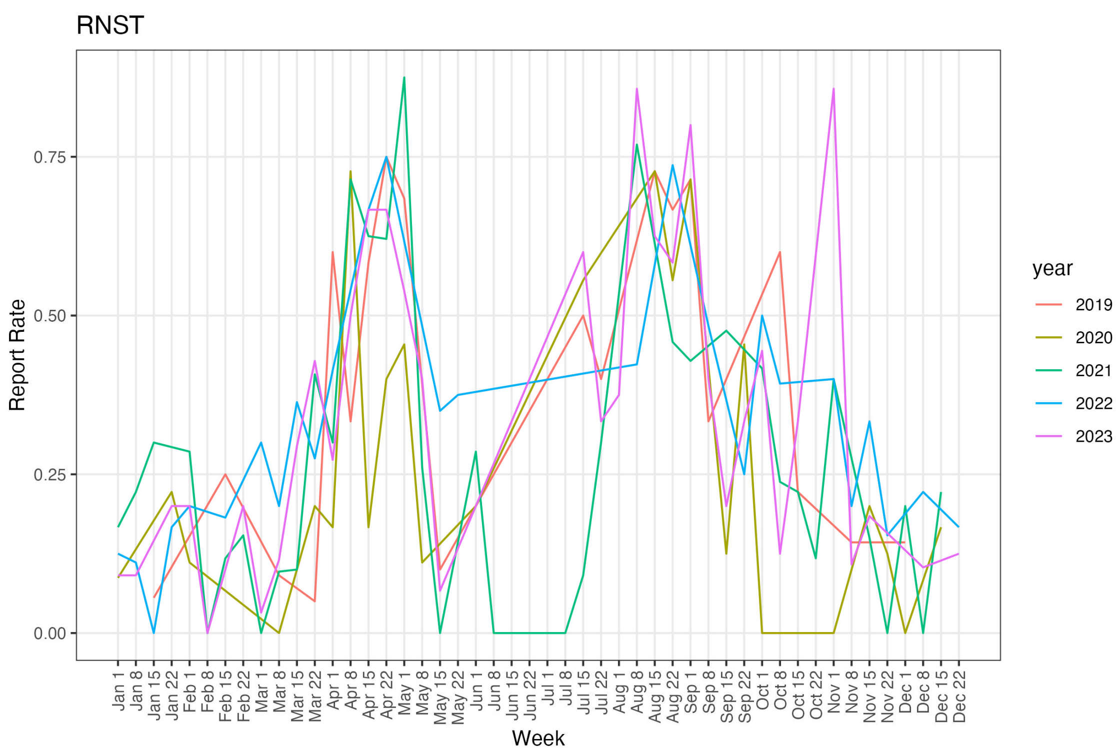

Fig. S5. Reporting rate of Red-necked Stint

doi:10.6342/NTU202404257

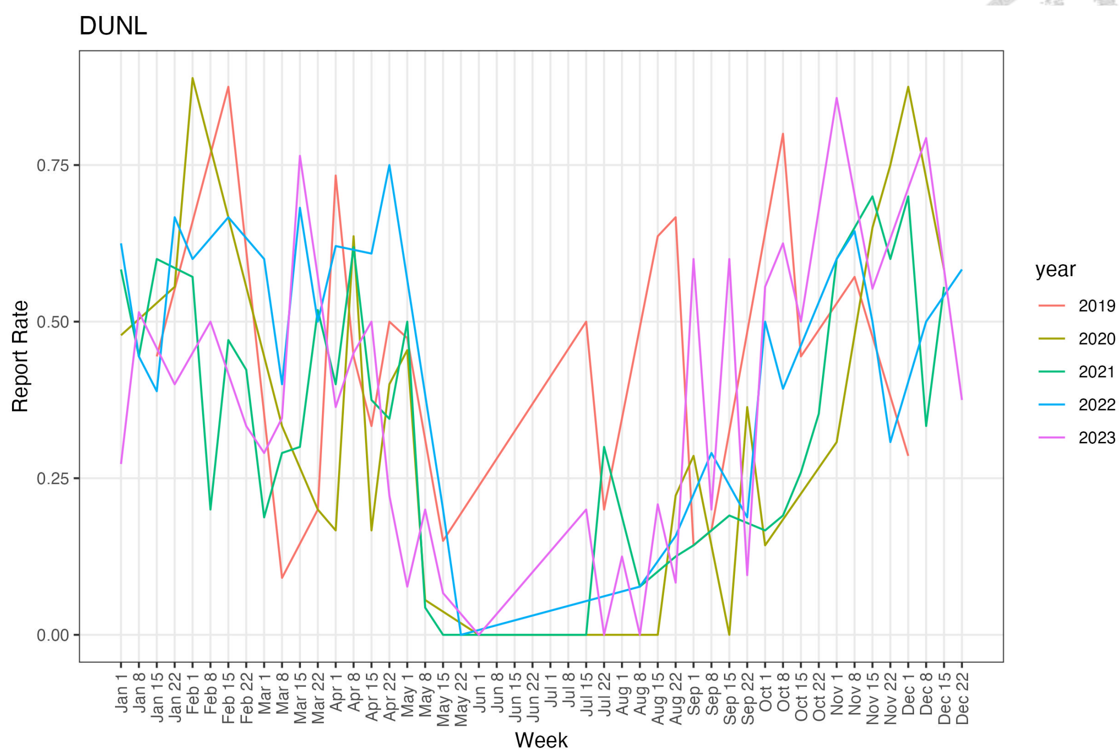

Fig. S6. Reporting rate of Dunlin

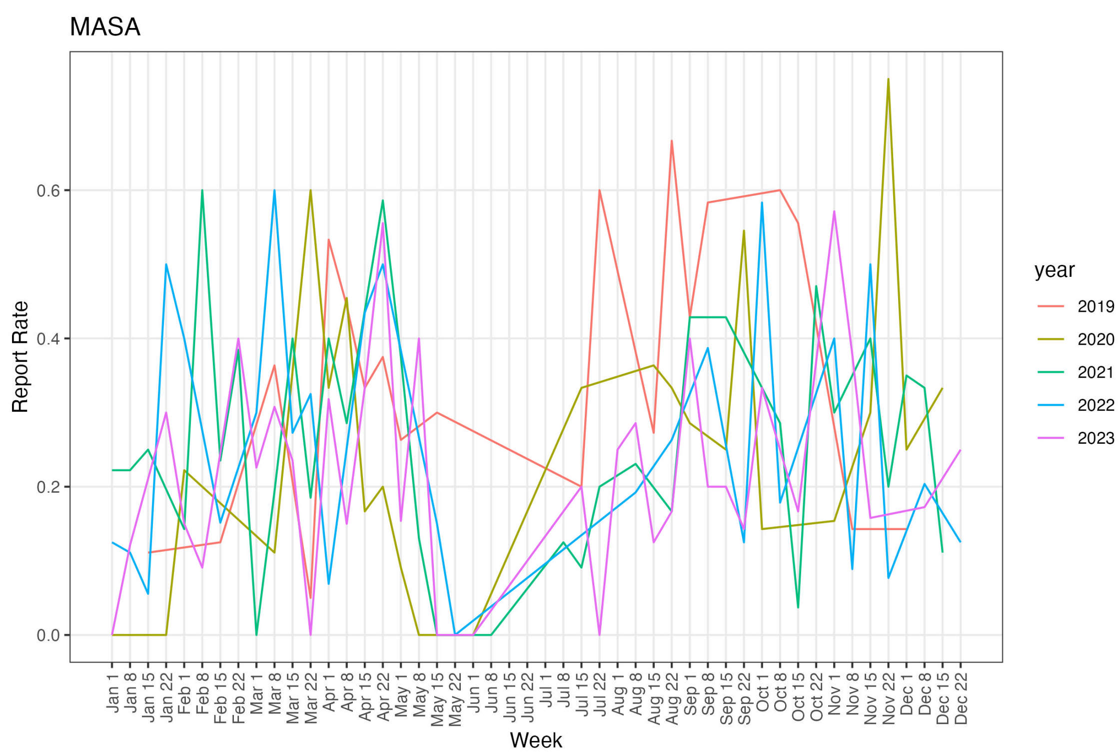

Fig. S7. Reporting rate of Marsh Sandpiper

doi:10.6342/NTU202404257

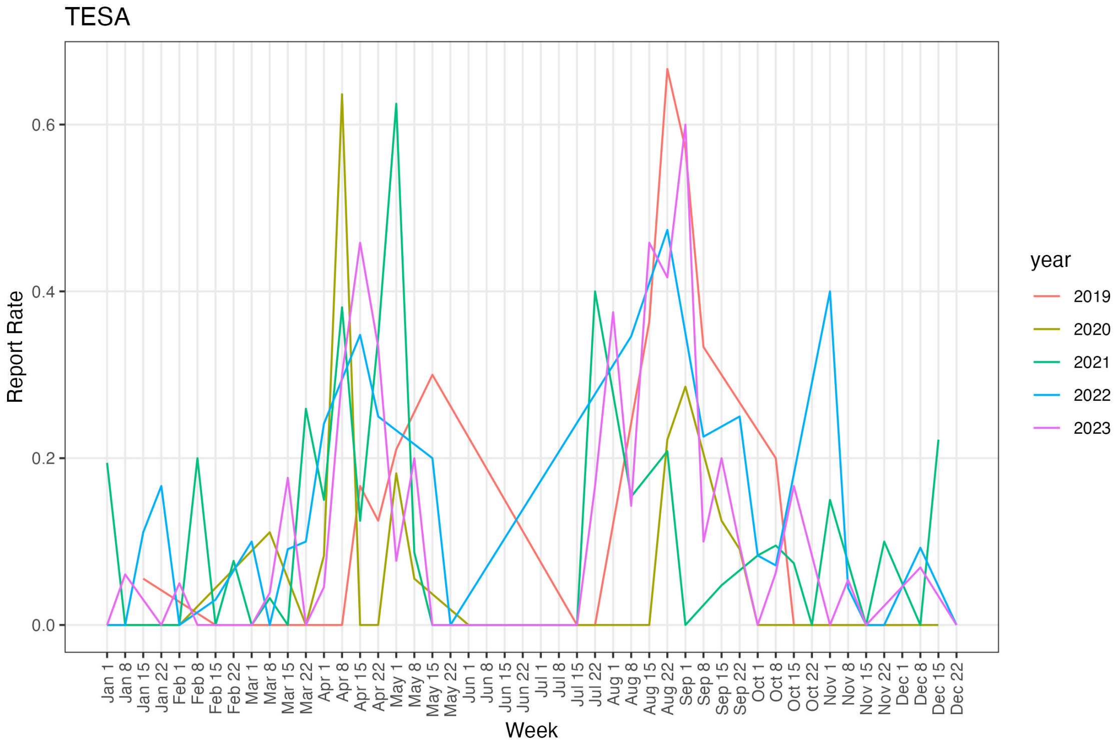

Fig. S8. Reporting rate of Terek Sandpiper

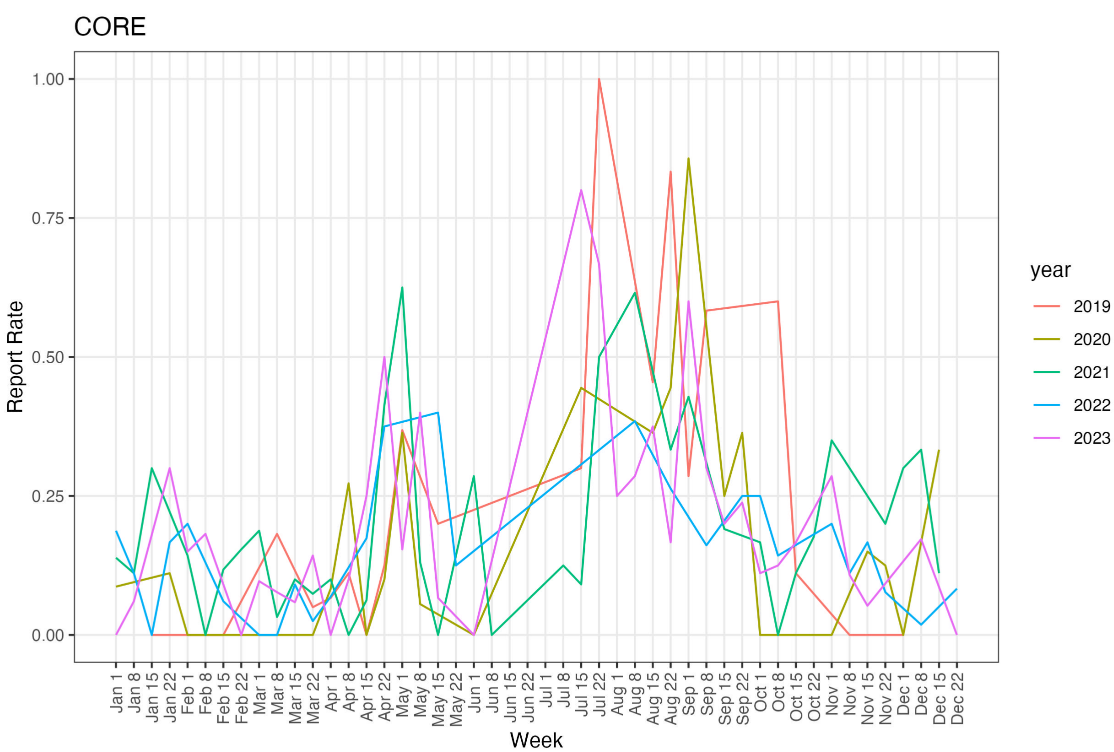

Fig. S9. Reporting rate of Common Redshank

doi:10.6342/NTU202404257

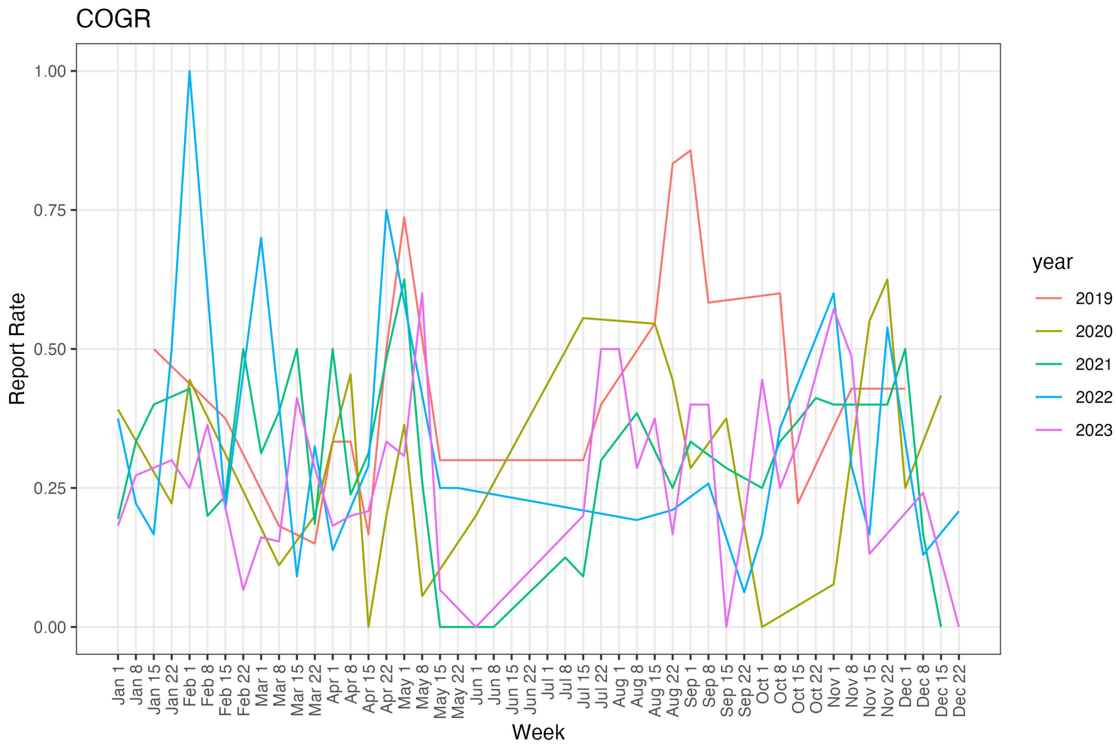

Fig. S10. Reporting rate of Common Greenshank

Fig. S11. Reporting rate of Kentish Plover

doi:10.6342/NTU202404257

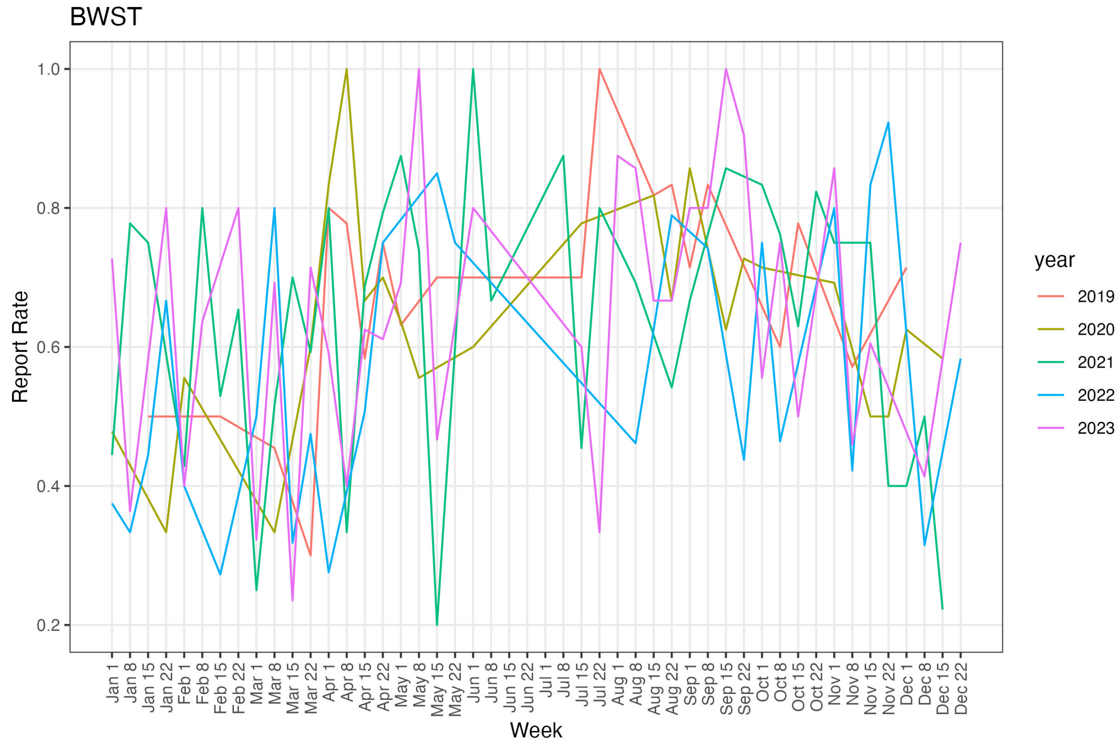

Fig. S12. Reporting rate of Black-winged Stilt

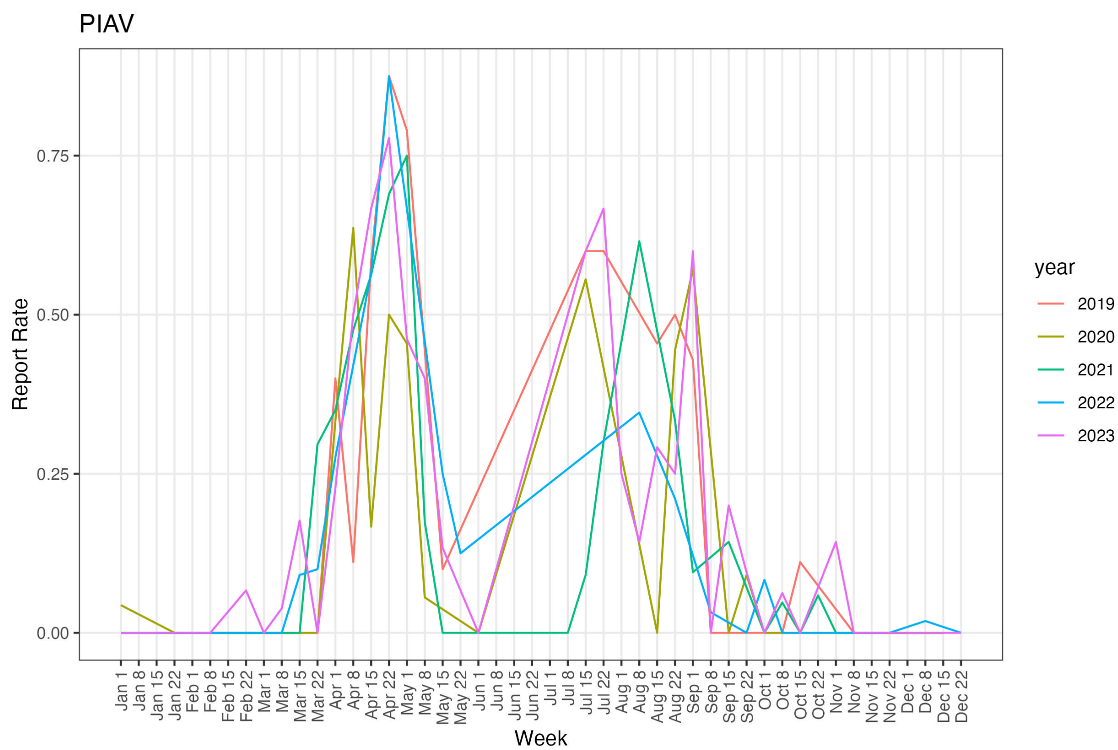

Fig. S13. Reporting rate of Pied Avocet.

doi:10.6342/NTU202404257

S1 References

eBird Basic Dataset. Version: EBD_relMar-2024. Cornell Lab of Ornithology, Ithaca, New York. Apr 2024.

Horns JJ, Adler FR, Şekercioğlu FH. 2018. Using opportunistic citizen science data to estimate avian population trends. Biological Conservation 221: 151-159.

Praveen J., P., Quader S, Lin R-S, Tsai J-S, Limparungpatthanakij W, Perez C, Ling YY, Bakewell D, Sullivan BL, Iliff MJ, Davies IJ, Wood CL. 2018. eBird in Asia: standardised tools for birdwatchers. Birding Asia 29:105-108.

Sullivan, BL, Aycrigg JL, Barry JH, Bonney RE, Bruns N, Cooper CB, Damoulas T, Dhondt AA, Dietterich T, Farnsworth A, Fink D, Fitzpatrick JW, Fredericks T, Gerbracht J, Gomes C, Hochachka WH, Iliff MJ, Lagoze C, La Sorte FA, Merrifield M, Morris W, Phillips TB, Reynolds M, Rodewald AD, Rosenberg KV, Trautmann NM, Wiggins A, Winkler DW, Wong W-K, Wood CL, Yu J, Kelling S. 2014. The eBird enterprise: an integrated approach to development and application of citizen science. Biological Conservation 169:31-40.

doi:10.6342/NTU202404257