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**Butterfly assemblages of conventional and organic tea
plantations in Yuchi Township,
Nantou County, Taiwan**
南投魚池鄉慣行及有機茶園之蝶類群聚
資料集

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Abstract

This is a research on butterfly assemblages of conventional and organic tea plantations in Yuchi Township, Nantou County, Taiwan. We conducted surveys once every two weeks from July to December in 2019, and March to December in 2020. A total of 909 butterfly occurrence datasets were recorded from 188 sampling events.

Six sampling plots had 92 species pertaining to five families with 65 species in three conventional tea plantations and 76 species in three organic tea plantations. This paper contributes to the study design, systematic survey methods, and species database of butterfly assemblages between different tea farming manipulations.

摘要

本研究是關於慣行及有機茶園之蝶類群聚組成，我們每 2 個禮拜 1 次從 2019 年 7-12 月 - 2020 年 3-12 月於南投魚池鄉進行蝶類調查。188 次調查活動，累計 909 筆蝶類出現紀錄。6 個樣區累計記錄到 5 科 92 種蝴蝶。3 個有機茶園記錄到 76 種蝴蝶，而 3 個慣行茶園則有 65 種蝴蝶。在本篇說明計畫在不同農法茶園的取樣設計、調查方法，及蝶種名錄。

Keywords: sampling event, butterfly assemblages, organic tea plantation, conventional tea plantation

關鍵詞：取樣事件、蝶類群聚、有機茶園、慣行茶園

Introduction

Lepidopterans represent one of the most extensively studied insect taxa worldwide, with butterflies and skippers being particularly well-known as environmental indicators and contributors to biodiversity (Sreekumar and Balakrishnan 2001).

During the past decades, conventional farming manipulation and monoculture cultivation have driven huge declines in butterfly assemblages, especially in suburban areas (Jonason et al. 2011). Recently, the general public is increasingly aware of agroecology, green economics, and food safety,

therefore food source, processes, and ecological equilibrium have become issues of concern, including farming types, modes of production, traceability cards, and carbon footprints, etc. (Probst et al. 2012). Organic agriculture or eco-friendly farming that regulate pesticide residue, improve human health, and protect butterfly assemblages in arable lands are also being adopted (Rödiger and Hamm 2015).

In Taiwan, tea manufacturing is one of the highest value-added agriculture industries. Around the island stand four major tea plantation areas, among which Yuchi Township, located in Nantou County of central Taiwan, is known for producing tea varieties and manufacturing black tea. Each tea plot here typically comprises 1-3 hectares with trees hedges bordering among different cultivation lands. Tea trees per se are not the main food plant of most butterfly species, while organic tea plantations without pesticides provide

proper nectar resources and shelters for butterfly assemblages that harbor higher species diversity (Tam and Bonebrake 2016; Han et al. 2021).

Project details

Project title: Ecological survey of establishment and promotion of organic tea demonstration plantations.

Funding: Tea Research and Extension Station, Council of Agriculture, Executive Yuan.

Taxonomic coverage

General taxonomic coverage description: A total of 909 butterfly occurrence datasets were recorded from 188 sampling events. There are 92 species pertaining to five families (Table 1), of which *Eurema blanda arsakia* was the most frequently recorded species in both farming types of tea plantations. Of all the butterfly species recorded in Taiwan, 23.1% had been covered in this research. Six sampling plots had

92 species pertaining to five families with 65 species in three conventional tea plantations and 76 species in three organic tea plantations.

Temporal coverage

Description: Every two weeks from July 2 to December 16, 2019, and from March 4 to December 28, 2020.

Methods

Study extent: Six different tea plantations (sizes: 0.8-2.5 ha) in Yuchi Township, Nantou County (Table 2, Figure 1). A 200-meter transect was set within each sampling plot.

Sampling description: We focused on butterflies as the target taxa, which consists of five families: Papilionidae, Nymphalidae, Lycaenidae, Nymphalidae, and Paleidae. Sampling followed the transect procedure, whenever objects detected within the distance of 5 meters from researchers were recorded (Pollard and Yate 1993). Insect nets were

also added to help identify unknown individuals. The first of each species encountered was collected and kept as dry specimens in the Endemic Species Research Institute (Taiwan Biodiversity Research Institute).

Quality control description: The first encountered individual of each species was collected and preserved as dry specimen and voucher specimen.

Step description:

1. We carried out the surveys once every two weeks from July to December in 2019 and March to December in 2020, respectively.
2. During the surveys, conductors detected and identified butterfly species with the naked eye, and used insect nets. Datasets included date, number of sampling plots, temperature (°C), relative humidity (%RH), start time, duration, species, and abundance.
3. The first individual of each species was collected, and temporarily placed in triangular paper envelopes, then made

into dry specimen for preservation.

Datasets

Dataset description

Object name: Archive Butterfly
Community of Yuchi Tea Garden in
2019-2020

Character encoding: UTF-8

Format name: Darwin Core Archive
format

Format version: 1.0

Distribution: [https://ipt.taibif.tw/archive.
do?r=yuchi_2019-2020_butterfly](https://ipt.taibif.tw/archive.do?r=yuchi_2019-2020_butterfly)

Publication date of data: 2022-04-13

Language: Chinese

Licenses of use: Creative Commons
Attribution (CC-BY) 4.0 License

Metadata language: Chinese

Date of metadata creation: 2022-04-06

Hierarchy level: Dataset

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Table 1. List of butterfly taxa recorded in conventional and organic tea plantations.

表 1. 2019 年 7-12 月 - 2020 年 3-12 月於 6 個茶園記錄所記錄之蝶類名錄

Family	Scientific name
Hesperiidae	<i>Badamia exclamationis</i> (Fabricius, 1775)
Hesperiidae	<i>Borbo cinnara</i> (Wallace, 1866)
Hesperiidae	<i>Hasora taminatus vairacana</i> Fruhstorfer, 1911
Hesperiidae	<i>Parnara bada</i> (Moore, 1878)
Hesperiidae	<i>Parnara guttata</i> (Bremer & Grey, 1853)
Hesperiidae	<i>Pelopidas agna</i> (Moore, [1866])
Hesperiidae	<i>Pelopidas mathias oberthueri</i> Evans, 1937
Hesperiidae	<i>Potanthus confucius angustatus</i> (Matsumura, 1910)
Hesperiidae	<i>Potanthus motzui</i> Hsu, Li & Li, 1990
Hesperiidae	<i>Tagiades trebellius martinus</i> (Plötz, 1884)
Hesperiidae	<i>Telicota bambusae horisha</i> Evans, 1934
Hesperiidae	<i>Telicota ohara formosana</i> Fruhstorfer, 1911
Lycaenidae	<i>Acytolepis puspa myla</i> (Fruhstorfer, 1909)
Lycaenidae	<i>Callenya melaena shonen</i> (Esaki, 1932)
Lycaenidae	<i>Catochrysops panormus exiguus</i> (Distant, 1886)
Lycaenidae	<i>Celastrina lavendularis himilcon</i> (Fruhstorfer, 1909)
Lycaenidae	<i>Chilades pandava peripatria</i> Hsu, 1989
Lycaenidae	<i>Deudorix epijarbas menesicles</i> Fruhstorfer, 1912
Lycaenidae	<i>Heliophorus ila matsumurae</i> (Fruhstorfer, 1908)
Lycaenidae	<i>Jamides alecto dromicus</i> (Fruhstorfer, 1910)
Lycaenidae	<i>Jamides bochus formosanus</i> Fruhstorfer, 1909
Lycaenidae	<i>Jamides celeno lydanus</i> Fruhstorfer, 1901
Lycaenidae	<i>Lampides boeticus</i> (Linnaeus, 1767)
Lycaenidae	<i>Megisba malaya sikkima</i> Moore, 1884
Lycaenidae	<i>Nacaduba beroe asakusa</i> Fruhstorfer, 1916
Lycaenidae	<i>Prosotas nora formosana</i> (Fruhstorfer, 1916)
Lycaenidae	<i>Rapala varuna formosana</i> Fruhstorfer, 1912
Lycaenidae	<i>Spalgis epeus dilama</i> (Moore, 1878)
Lycaenidae	<i>Zizeeria karsandra</i> (Moore, 1865)

- Lycaenidae *Zizeeria maha okinawana* (Matsumura, 1929)
- Lycaenidae *Zizina otis riukuensis* (Matsumura, 1929)
- Nymphalidae *Telchinia issoria formosana* (Fruhstorfer, 1914)
- Nymphalidae *Argynnis hyperbius* (Linnaeus, 1763)
- Nymphalidae *Athyma cama zoroastes* Butler, 1877
- Nymphalidae *Athyma perius* (Linnaeus, 1758)
- Nymphalidae *Athyma selenophora laela* (Fruhstorfer, 1908)
- Nymphalidae *Cupha erymanthis* (Drury, [1773])
- Nymphalidae *Cyrestis thyodamas formosana* Fruhstorfer, 1898
- Nymphalidae *Danaus genutia* (Cramer, [1779])
- Nymphalidae *Discophora sondaica tulliana* Stichel, 1905
- Nymphalidae *Elymnias hypermnestra hainana* Moore, 1878
- Nymphalidae *Euploea eunice hobsoni* (Butler, 1877)
- Nymphalidae *Euploea mulciber barsine* Fruhstorfer, 1904
- Nymphalidae *Euploea sylvester swinhoei* Wallace, 1866
- Nymphalidae *Euploea tulliolus koxinga* Fruhstorfer, 1908
- Nymphalidae *Euthalia irrubescens fulguralis* (Matsumura, 1909)
- Nymphalidae *Hypolimnas bolina kezia* (Butler, 1877)
- Nymphalidae *Ideopsis similis* (Linnaeus, 1758)
- Nymphalidae *Junonia almana* (Linnaeus, 1758)
- Nymphalidae *Junonia iphita* (Cramer, [1779])
- Nymphalidae *Junonia lemonias aenaria* (Fruhstorfer, 1912)
- Nymphalidae *Junonia orithya* (Linnaeus, 1758)
- Nymphalidae *Kaniska canace drilon* (Fruhstorfer, 1908)
- Nymphalidae *Melanitis leda* (Linnaeus, 1758)
- Nymphalidae *Melanitis phedima polishana* Fruhstorfer, 1908
- Nymphalidae *Neope muirheadii nagasawae* Matsumura, 1919
- Nymphalidae *Neptis hylas luculenta* Fruhstorfer, 1907
- Nymphalidae *Neptis nata lutatia* Fruhstorfer, 1913
- Nymphalidae *Neptis sappho formosana* Fruhstorfer, 1908
- Nymphalidae *Parantica aglea maghaba* (Fruhstorfer, 1909)
- Nymphalidae *Parantica swinhoei* (Moore, 1883)

- Nymphalidae *PentHEMA formosanum* (Rothschild, 1898)
Nymphalidae *Symbrenthia brabira scatinia* Fruhstorfer, 1908
Nymphalidae *Symbrenthia lilaea formosanus* Fruhstorfer, 1908
Nymphalidae *Tirumala limniace limniace* (Cramer, [1775])
Nymphalidae *Tirumala septentrionis* (Butler, 1874)
Nymphalidae *Vanessa indica* (Herbst, 1794)
Nymphalidae *Ypthima baldus zodina* Fruhstorfer, 1911
Nymphalidae *Ypthima atra taiwana* Lamas, 2010
Nymphalidae *Ypthima multistriata* Butler, 1883
Papilionidae *Graphium agamemnon* (Linnaeus, 1758)
Papilionidae *Graphium doson postianus* (Fruhstorfer, 1902)
Papilionidae *Graphium sarpedon connectens* (Fruhstorfer, 1906)
Papilionidae *Papilio bianor thrasymedes* Fruhstorfer, 1909
Papilionidae *Papilio dialis tatsuta* Murayama, 1970
Papilionidae *Papilio hermosanus* Rebel, 1906
Papilionidae *Papilio memnon heronus* Fruhstorfer, 1902
Papilionidae *Papilio polytes polytes* Linnaeus, 1758
Papilionidae *Papilio protenor protenor* Cramer, [1775]
Papilionidae *Papilio xuthus* Linnaeus, 1767
Pieridae *Appias lyncida eleonora* (Boisduval, 1836)
Pieridae *Catopsilia pomona pomona* (Fabricius, 1775)
Pieridae *Cepora nadina eunama* (Fruhstorfer, 1903)
Pieridae *Delias pasithoe curasena* Fruhstorfer, 1908
Pieridae *Eurema blanda arsakia* (Fruhstorfer, 1910)
Pieridae *Eurema brigitta hainana* (Moore, 1878)
Pieridae *Eurema laeta punctissima* Matsumura, 1909
Pieridae *Hebomoia glaucippe formosana* Fruhstorfer, 1908
Pieridae *Ixias pyrene insignis* Butler, 1879
Pieridae *Leptosia nina niobe* (Wallace, 1866)
Pieridae *Pieris canidia* (Linnaeus, 1768)
Pieridae *Pieris rapae crucivora* Boisduval, 1836

Table 2. The six studying sites at the tea plantations.

表 2. 6 個取樣茶園

Studying site (locationID)	Farming types	Area (ha)	Latitude, Longitude	Altitude (m)
ORG_A	Organic farm	1.0	23.8861001 120.9276700	717
ORG_B	Organic farm	2.0	23.9158842 120.9418720	621
ORG_C	Organic farm	2.5	23.89260081 120.9229122	679
CON_A	Conventional farm	0.8	23.8824373 120.931744	654
CON_B	Conventional farm	1.4	23.9226900 120.9435618	707
CON_C	Conventional farm	1.7	23.8821442 120.9346025	785

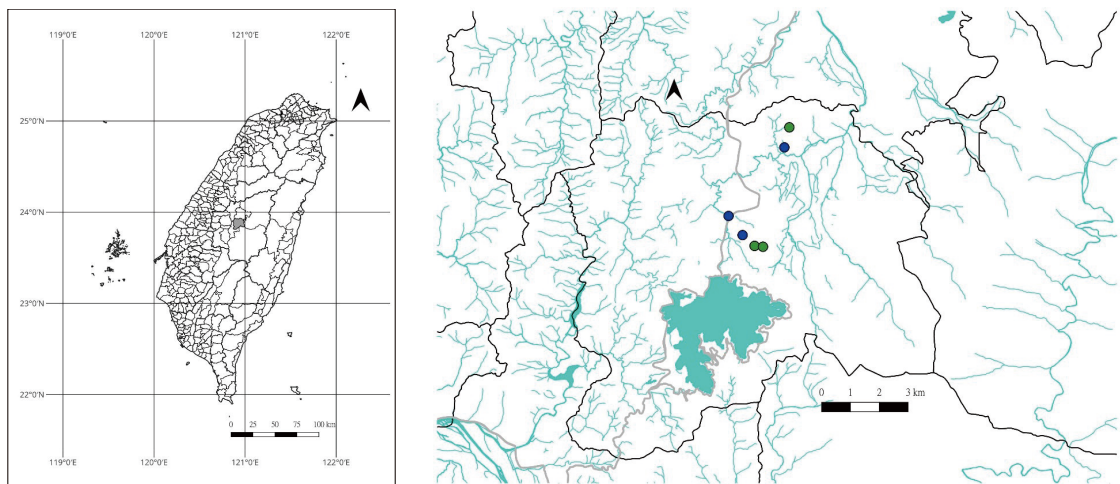


Figure 1. Survey locations of the six studying sites at the tea plantations. Blue line: the river system; Green spot: the three study sites at the conventional tea plantations; Blue spot: the three study sites at the organic tea plantations.

圖 1. 6 個茶園樣區分布圖。藍色線條：水系及河道；綠色圓點：慣行田的 3 個樣區；藍色圓點：有機田的 3 個樣區。

A Case Study of Using Low-cost Siphon Equipment to Enhance Shorebird Foraging Habitats

利用低成本虹吸裝置改善岸鳥覓食棲地

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Abstract

This study presents how to apply the siphon equipment, which is low-cost and low-carbon, to a dry salt pan in Taiwan to optimize foraging habitats for migrating shorebirds. The study area is situated in a subsidence zone with poor hydrological

facilities due to inadequate maintenance and long-term subsidence. Consequently, some salt pans have become completely dry or excessively flooded. As a key component, The siphon diversion equipment, was made by a 3-inch Polyvinyl Chloride (PVC) connecting pipes. Bird surveys were conducted before and after the water diversion. The results showed that during the experimental period from April 15 to April 21, 2022, the total volume of water diversion was approximately 2,788.5 m³ in the Salt Pan 9-1 (area about 14 ha), providing suitable foraging habitats for migrating shorebirds. The siphon equipment was cost-effective, it cost only NT\$4,549 (around US\$150) in materials and took a single day for assembly. This case study shows comprehensive information on the environmental characteristics, fabrication process, operational procedures, and associated costs of the siphon water diversion equipment. The findings suggest that siphons can serve as a practical, low-cost, and environmentally friendly tool for habitat management under specific environmental conditions.

摘要

本研究描述一個低成本、低碳排的虹吸引水裝置，以其應用於嘉義布袋廢曬鹽田，用以改善遷徙鸕鶿的覓食棲地。研究地點位於一地層下陷、無引水設施，且面臨乾旱的鹽田。因鹽田剛好緊鄰潮溝，溝內水位高於鹽田底部，故運用虹吸原理進行引水。虹吸管根據重力和大氣壓力的物理原理來促進液體流動，本研究的虹吸水泵利用 3 吋的聚氯乙烯（PVC）水管組成。在引水前後進行鳥類調查。結果顯示 2022/4/15 - 4/21 試驗期間，在面積 14 ha 的 9-1 號鹽田引入水體積約為 2,788.5 m³，為遷徙鸕鶿提供適宜的覓食棲息地。該虹吸裝置成本為 4,549 新台幣（約 150 美元），材料費用和組裝時間為 1 天。本案例提供虹吸引水裝置的環境特性、製作方式、操作過程和相關成本的完整資訊。結果顯示在特定的環境條件下，虹吸可以是一種成本效益高、低碳的棲地管理工具。

Keywords: shorebird habitat, low-cost siphon equipment, water diversion

關鍵字：鸕鶿類棲地、低成本虹吸裝置、引水

Introduction

The loss and degradation of natural habitats significantly threaten global biodiversity, particularly in coastal and near-coastal environments, which face severe development pressures (Halpern et al. 2019). The East Asian-Australasian Flyway, of which Taiwan is a part, has experienced some of the most rapid and extensive coastal habitat loss globally in recent decades (Murray et al. 2014; Duan et al. 2021). Consequently, waterbirds increasingly rely on artificial wetlands created or modified by human activities as alternative or supplementary habitats when natural habitats are reduced (Ma et al. 2004, 2010; Sebastián-González et al. 2010; Li et al. 2013; Fan et al. 2021). Appropriately improving habitats in suitable locations could alleviate the pressure on waterbirds' habitat loss.

Non-natural wetlands come in

different types, and their suitability or unsuitability for waterbirds can vary depending on their characteristics (e.g., depth, vegetation, surrounding land use) and location (e.g., geographic region, climate). However, once water becomes scarce or dries up entirely, these wetlands can no longer provide suitable habitats for waterbirds, or only a limited number of species can use them. Changes in water levels in the same wetland can also significantly influence the presence and abundance of different waterbird species or functional groups (e.g., waders, ducks, geese) using the wetland (Roshier et al. 2002; Ma et al. 2010; Gray et al. 2013; Wang et al. 2020). Therefore, when managing artificially created wetlands as waterbird habitats, adjusting water levels is often a crucial conservation measure (Cheek, 2009; Wang et al., 2020).

The United Nations Convention

on Biological Diversity's Kunming-Montreal Global Biodiversity Framework (GBF) includes restoring 30% of degraded global habitats as an important goal (access at <https://www.cbd.int/gbf/>). However, the actual implementation of the GBF's various goals faces global and local challenges, with the lack of funding being a major obstacle (Xu et al. 2021). Moreover, conservation actions that require large or long-term fossil fuel energy inputs and increase carbon emissions can conflict with addressing the global climate crisis. Thus, when designing habitat restoration measures, the optimal option within a suite of measures should be the least resource-intensive while avoiding increases in carbon emissions.

Since the Budai Salt Pans were abandoned in 2001, they have progressively evolved into a pivotal bird habitat in southwest Taiwan (Lin et al. 2023). Per the Taiwan New Year Bird Count, a citizen science project

initiated in 2004, the Budai Salt Pans are noted to harbor the highest concentration of waterbirds among over 170 sampling circles, each with a 3-kilometer radius, across Taiwan (Lin et al. 2023). Nevertheless, the hydrological infrastructure within these salt pans has been progressively deteriorating due to the combined effects of neglect post-closure and long-term subsidence (Wang et al. 2020). Consequently, several salt pans have completely dried up or maintained excessive water depth for prolonged periods, impairing their ability to facilitate water exchange.

This paper reports on a case study of the application of a low-cost, non-fossil fuel energy-based siphon diversion equipment in a dry salt pan, including the environmental conditions before its use, the design of the suction pump, and changes in species and numbers of waterbirds observed before and after its deployment.

Methods

Study Area

The study site is located along the southwest coast of Taiwan, spanning from 23°22'24.9"N to 23°18'39.1"N latitude and 120°08'57.9"E to 120°11'23.4"E longitude (Figure 1). The area is situated in a subsidence zone with an elevation lower than sea level ranging from -1.8 to -0.5 m (Kuo and Wang 2018). The region experienced an average annual of 1384 mm between 2018 and 2022, with the highest precipitation occurring from May to August, accounting for approximately 80% of the total annual rainfall (data collected from the Budai weather station of the Central Weather Bureau in Taiwan). The salt pans at the study site are characterized by a flat topography with predominantly muddy substrate, poor soil quality, and high salt content. During the rainy season (from May to October), the area accumulates water, while during the non-rainy season (from November

to April), parts of the area frequently experience drought due to evaporation and lack of water replenishment (Yeh and Tsao 2020).

Siphon test

As a result of flood risk management measures implemented by the local authorities, the test site, Salt Pan 9-1 (Figure 1), frequently experiences several months of drought before the onset of the rainy season (Figure 2). For instance, the cumulative rainfall between January 1 and April 30 in 2021 and 2022 amounted to 34 mm and 343 mm, respectively. However, a significant rainfall event on April 23, 2022, accounted for 48% of the total rainfall from January 1 to April 30, 2022. During March and April, wintering waterfowl have typically departed the area, coinciding with the peak migration season for shorebirds. Therefore, increasing the water coverage of Salt Pan 9-1, which spans approximately 14 hectares, would be advantageous in providing suitable foraging habitats for

migrating shorebirds. The western side of Salt Pan 9-1 adjoins a tidal drainage system, and even during low tide, the water level remains higher than the flat areas of the salt pan, making it an ideal location for installing siphon diversion equipment. The equipment was installed on April 14, 2022, and pre-testing was conducted on April 15. The continuous water diversion started on April 16 at 10:00 a.m.

For this test, we selected 3-inch Polyvinyl Chloride (PVC) pipes considering the convenience of material handling and acquisition and the goal of maximizing water intake. Once the apparatus was installed, we used a Handheld 1-D electro-magnetic current meter (Model: AEM1-DA) designed for river use to measure the flow velocity at the outlet of the siphon tube. The water level in the drainage system used for water diversion remains relatively stable due to controlled water gate operations, resulting in minimal fluctuations during

regular times. Therefore, assuming that the water flow rate inside the siphon tube remains relatively stable during the experimental period. We conducted two measurements of the flow velocity of the siphon at the test site.

Subsequently, the flow rate was calculated using the formula $Q = A \times V$, where Q represents the flow rate in cubic meters per second (m^3/sec), A denotes the cross-sectional area of the pipe in square meters (m^2), and V represents the flow velocity in meters per second (m/sec). The cross-sectional area of the pipe was calculated using the formula $A = ID^2 \div 4 \times \pi$, where ID stands for the pipe's internal diameter.

Bird Survey

We adopted a before-and-after design to compare shorebirds' composition and behavioral differences at Salt Pan 9-1 before and after the water diversion. On April 8 and April 21, 2022, we conducted a complete count of the bird species and their quantities within

Salt Pan 9-1. Using a scan sampling method, we recorded the behavior of each observed bird at the moment of sighting to determine whether they were foraging. For example, probing of the bill into the water or mud by sandpipers, feeding on invertebrates by plovers, and foot-trembling behavior exhibited by plovers were considered valid foraging behaviors. We also utilized bird data collected on April 8, 2021, using the same methodology to present the composition and utilization patterns at Salt Pan 9-1 during two consecutive years of drought. Given that the primary objective of this experiment was to enhance the foraging function for sandpipers and plovers during their peak migration period, the comparison of species and quantities focused explicitly on Scolopacidae (sandpipers) and Charadriidae (plovers). We performed a chi-square test of homogeneity to determine if there was a significant difference in foraging proportions of the

sandpipers and plovers before and after the water diversion. Statistical analyses were performed with R packages (stats).

Results

Siphon Diversion Equipment

The siphon diversion equipment pump designed in this study is based on the environmental characteristics of the test site. Its main components and materials consisted of a 3-inch Polyvinyl Chloride (PVC) connecting pipe, extending from the water source to the drainage point. The water intake end was equipped with a 3-inch interface check valve that allowed water to enter but not exit, while the water outlet end was fitted with a 3-inch ball valve. At the highest point of the equipment, an extended fill pipe was connected to a 3-inch ball valve. Various connections and bends in the equipment incorporated a 3-inch PVC tee, three 45-degree bends, and a 90-degree bend, all made of PVC. The quantities and prices of the components

used in this experiment are presented in Table 1.

The purchased 4-meter-long 3-inch PVC pipe was cut into appropriate lengths for each section during assembly. After pre-assembly, the water intake section was positioned at the site, and necessary adjustments were made. Finally, solvent cement (PVC glue) was used to adhere to all connections securely. The installation of the siphon equipment was completed within a single day, and its proper functioning was confirmed (Figure 3).

At the commencement of the operation, ball valve B at the water outlet was kept closed while ball valve A was opened. Water was then introduced into the pipe until completely filled to serve as the siphon liquid, after which ball valve A was shut. This procedure ensured that the entire interior of the siphon pipe was filled with water. Following this, ball valve B was opened, permitting the liquid within the pipe to

flow out owing to atmospheric pressure. The resulting increase in internal pipe pressure triggered suction, causing the foot valve to open. Consequently, due to this elevated pressure, water from the channel was drawn into the siphon pipe, facilitating a continual water diversion.

Field test

Water diversion commenced on April 15, from 11:00 a.m. to 6:00 p.m. The continuous water diversion started on April 16 at 10:00 a.m. and lasted until early April 23. On that day, due to rainfall of 163.5mm in the Budai area, the water level within the salt pan rose by 10 cm, prompting the closure of the siphon pipe and ceasing its operation. During the water diversion period, there was a noticeable increase in the water coverage of Salt Pan 9-1 (Figure A1). In addition, we measured the flow velocity of the siphon at the test site. The average recorded velocity was 1.3 m/s. With a 3" PVC pipe diameter of 77 mm, the calculated average flow rates were

21.785 m³/h. From April 15 to April 21 (bird survey day), the total duration of water diversion was 128 hours, resulting in a total volume of 2788.5 m³. The surface area of Salt Pan 9-1 was approximately 140,000 square meters. Under the assumption of no leakage or evaporation, the total water diversion volume would lead to a water level rise of approximately 2 cm.

Shorebird responses

There was a significant difference in the foraging proportions of sandpipers ($\chi^2=254.6$, $p<0.001$) and plovers ($\chi^2=2178.5$, $p<0.001$) before and after the water diversion. Before the diversion at Salt Pan 9-1 on April 8, 2022, eight sandpiper species and three plover species were recorded. Among the sandpipers, 575 (76%) were observed foraging, and 177 (24%) not foraging. For the plovers, 775 (29%) were observed foraging, while 1,936 (71%) were not foraging. On April 21, 2022 (seven days after the diversion on April

15, 2022), six sandpiper species and three plover species were recorded, and all individuals were observed foraging. The sandpipers accounted for 981, while the plovers accounted for 1,720 (Figure 4).

Before the diversion on April 8, 2022, the sandpiper species with more than 10% of the total population were ranked as follows: the Curlew sandpiper (44%), Red-necked stint (23%), and Rroad-billed sandpiper (21%). Among the plovers, the Pacific golden plover (81%) and Mongolian plover (19%) were the two species representing more than 10% of the total population. After the diversion on April 21, 2022, the sandpipers with more than 10% of the total population were ranked as follows: the Broad-billed sandpiper (64%), Curlew sandpiper (13%), and Sharp-tailed sandpiper (10%). The Pacific golden plover (93%) was the only plover species representing more than 10% of the total population (Table 2).

In April, 2021, which experienced drier conditions compared to 2022, Salt Pan 9-1 recorded six sandpiper species, totaling 548 individuals. The majority consisted of 330 Curlew sandpipers and 114 Red-necked stints, accounting for 60% (328) of the observed sandpipers. Two plover species were observed with a total of 785 individuals, with the Pacific golden plover being the predominant species at 779. Only six Lesser sand plover individuals (0.8%) were observed foraging (Table 2). These findings indicate that Salt Pan 9-1 primarily serves as a resting site for plovers, especially the Pacific golden plover, under dry conditions.

Discussion

This case study explores a salt pan habitat affected by drought, lacking water diversion structures. Despite limited funds, our management team identified a need for a foraging habitat for migrating shorebirds. We constructed siphon

equipment for 4,549 New Taiwan Dollars (around 150 USD) and assembled it in one day. This solution channeled water from nearby tidal drainage, creating a temporary foraging area for the birds. To our knowledge, this case represents the first documented instance in Taiwan of using a siphon for water management in a waterbird habitat. Our study details the habitat's characteristics, siphon construction, operation, costs, and the impact on sandpipers and plovers before and after the siphon's introduction.

Salt Pan 9-1 spans 14 hectares. When water was introduced, it mainly flowed to the southern and eastern lower areas of the pan. This increased wet or shallow water zones but mainly moistened the region. The very shallow water depth (less than 5 cm) allowed small sandpipers and plovers to forage easily. This change likely improved their foraging due to increased food availability within the salt pan, as studies suggest (Zhang et al. 2016; Wang and

Kuo 2018). The Pacific golden plover, for instance, typically rests during the day and feeds at night (Crawford and Herbert 2009). In past dry conditions, like on April 8, 2021, and April 8, 2022, Salt Pan 9-1 served as a daytime resting place for these birds. However, after the water diversion on April 21, 2022, there was a notable increase in foraging Pacific golden plovers (see Table 2). This change transformed Salt Pan 9-1 into a daytime feeding habitat.

Waterbirds exhibit remarkable mobility, and when suitable temporary habitats emerge within their primary distribution range or migration routes, they swiftly take advantage of the plentiful food sources, underscoring the significance of such stopover sites in their management (Roshier et al. 2002; Golet et al. 2018; Huang 2021). Nevertheless, it remains uncertain whether the rapid surge in food resources within Salt Pan 9-1 originates from the introduced water source or the rapid

proliferation of organisms. During the study period, sandpipers and plovers were at their peak migration season through the Budai Wetland. As a result, there were rapid fluctuations in bird species and occurrence numbers. Therefore, species composition may not be a good indicator to represent changes in food resources before and after water diversion.

Siphons have been long used for water management and irrigation due to their efficiency, low maintenance, and cost-effectiveness (Wichelns et al. 1997). For siphons to work, the water level at the inlet must be higher than the outlet. In our study, we designed the siphon tube with two closure methods: 1. Direct closure method: close ball valve B. This causes both valves A and B to shut and stops the water flow. The benefit is its ease of reuse by simply reopening valve B. The downside is valve B's potential location in muddy conditions, making it harder to access. 2. Air-entry method:

introduce air into the tube by opening valve A, which stops the siphon effect. This valve is nearer to roads, allowing quicker shutdowns in emergencies. However, before using the siphon again, it needs refilling. For equipment protection, close both valves during downtime. This keeps out organisms and reduces maintenance. To monitor water levels, a gauge can be added. This helps adjust water depths to attract various waterbirds. If the budget allows, adding more siphons can boost water diversion rates. While we used PVC for our siphon assembly, high-density polyethylene (HDPE) is also an option. HDPE joints are easier to assemble and disassemble, simplifying transportation and storage. Unlike PVC, which requires strong adhesive and is permanent, HDPE is more flexible. But, HDPE is significantly pricier than PVC.

The East Asian-Australasian Flyway, which includes Taiwan, has lost significant coastal habitats

recently. Taiwan's western coast alone has lost 60% of its natural mudflats in six decades (Wanjuan Chen, personal communication). This decline affects migratory waterbirds. As a solution, there has been a move towards wetland restoration and the use of artificial wetlands. While not perfect replacements, artificial wetlands can provide temporary refuges for these birds. Effective management of these habitats depends on understanding ecosystem needs, wildlife behaviors, and specific goals, especially in water level regulation (Gray et al. 2013). Practical challenges include budgetary and time constraints, while reducing carbon footprints remains crucial. Our study details an efficient water diversion technique for these artificial habitats.

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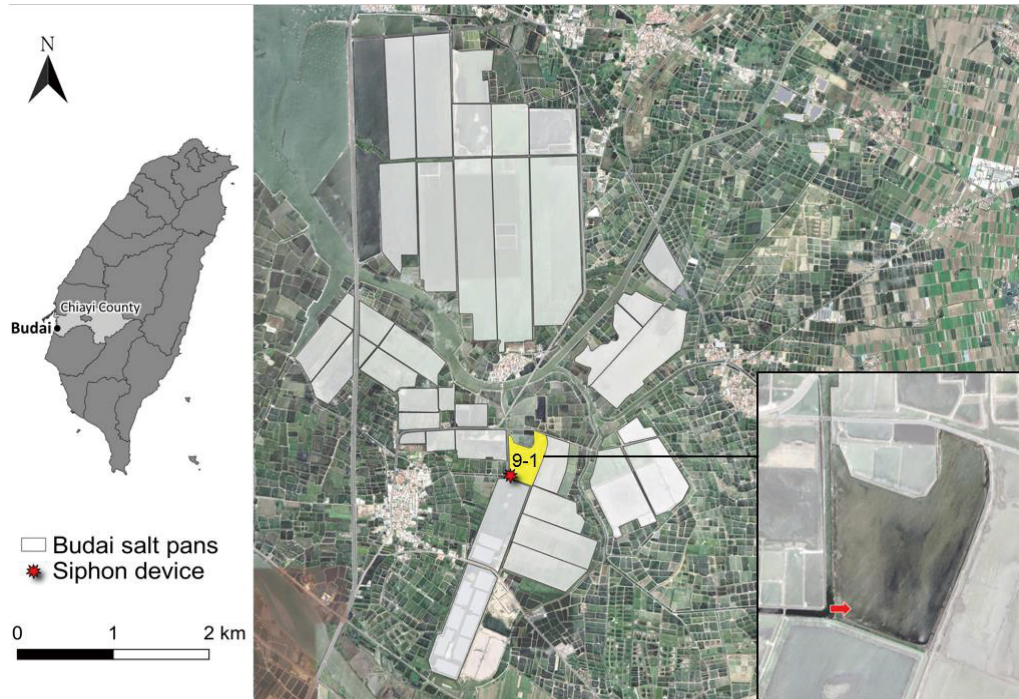


圖 1. 虹吸引水設施於布袋鹽田的設置地點 (Salt Pan 9-1)。

Figure 1. The location of the siphon equipment in Budai Salt Pans (Salt Pan 9-1).

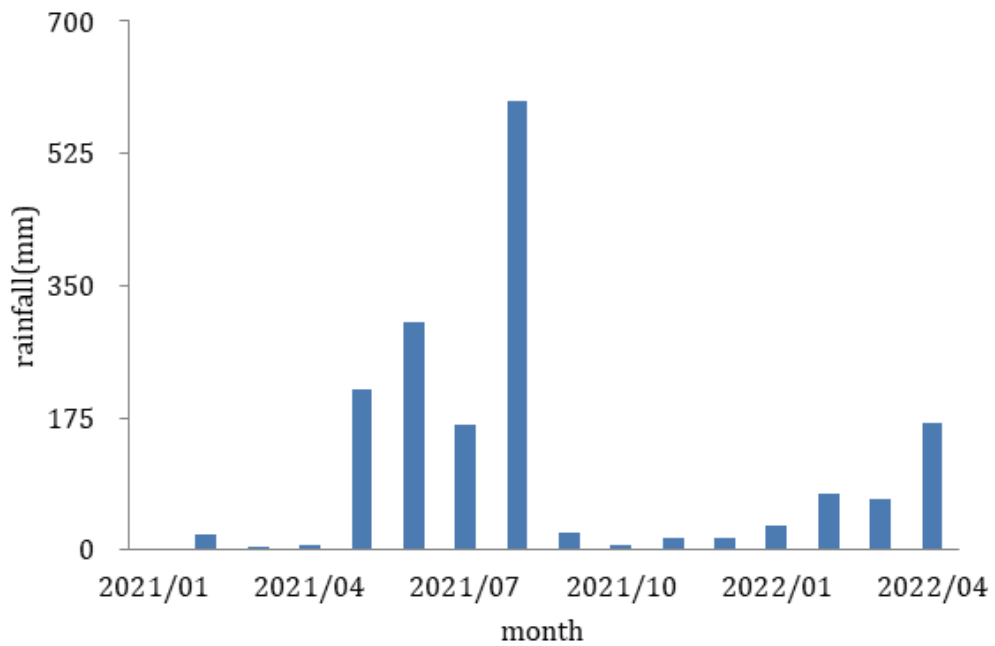


圖 2. 布袋氣象觀測站的月雨量 (2021/01-2022/04)。

Figure 2. The monthly rainfall of Budai weather station from January, 2021, to April, 2022.

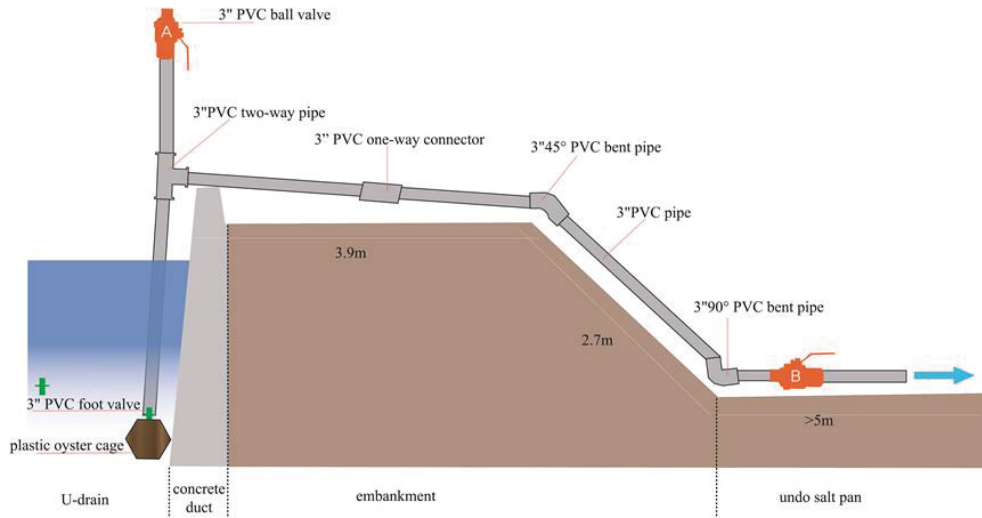


圖 3. 虹吸管設計圖與案場結構剖面示意圖。

Figure 3. The design of the siphon equipment and the schematic cross-sectional diagram of Salt Pan 9-1.

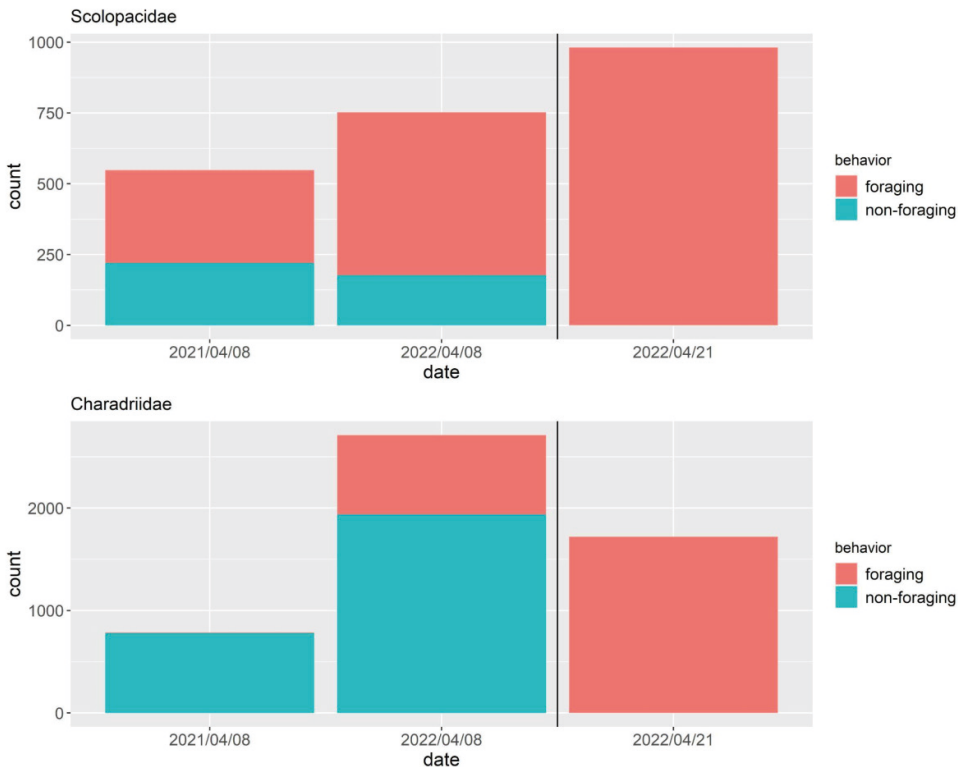


圖 4. Salt Pan 9-1 引水試驗前 (2021/04/08, 2022/04/08)、後 (2022/04/21) 鷸科與鴝科的數量變化。行為分為覓食與非覓食兩類。黑色線段代表引水當日 (2022/04/15)

Figure 4. The change in the number of Scolopacidae and Charadriidae before (April 8, 2021, and April 8, 2022) and after (April 21, 2022) the water diversion at Salt Pan 9-1. The behavior is divided into “foraging” and “non-foraging” categories. The black line represents the day of water diversion (April 15, 2022).

表 1. 本研究使用的虹吸引水設備組成零件的數量與價格 (新台幣)

Table 1. The quantity and cost (expressed in New Taiwan Dollars) of the siphon components utilized in this study.

Component	Unit price	Quantity
3-inches PVC pipe	400	4
3-inches two-way PVC pipe	210	1
3-inches 90-degree PVC bent pipe	128	1
3-inches 45-degree PVC bent pipe	104	4
3-inches PVC one-way connector	115	3
3-inches PVC ball valve	650	2
3-inches PVC foot valve	400	1
Plastic oyster cage	150	1

表 2. Salt Pan 9-1 引水試驗前 (2021/04/08, 2022/04/08)、後 (2022/04/21) 調查結果的鶺鴒科與鴿科種類及數量。

Table 2. The species list and their number of Scolopacidae and Charadriidae in the survey results before (April 8, 2021 and April 8, 2022) and after (April 21, 2022) the water diversion at Salt Pan 9-1.

Date	Family	Scientific name	Common name	Foraging	Non-foraging
2021/4/8	Charadriidae	<i>Pluvialis fulva</i>	Pacific Golden-Plover	0	750
		<i>Charadrius mongolus</i>	Lesser Sand-Plover	6	29
	Scolopacidae	<i>Calidris ruficollis</i>	Red-necked Stint	94	20
		<i>Calidris alpina</i>	Dunlin	22	0
		<i>Tringa stagnatilis</i>	Marsh Sandpiper	46	0
		<i>Calidris acuminata</i>	Sharp-tailed Sandpiper	1	0
		<i>Tringa nebularia</i>	Common Greenshank	35	0
		<i>Calidris ferruginea</i>	Curlew Sandpiper	130	200
2022/4/8	Charadriidae	<i>Pluvialis fulva</i>	Pacific Golden-Plover	405	1800
		<i>Charadrius mongolus</i>	Lesser Sand-Plover	370	135
		<i>Charadrius alexandrinus</i>	Kentish Plover	0	1
	Scolopacidae	<i>Tringa stagnatilis</i>	Marsh Sandpiper	44	0
		<i>Calidris acuminata</i>	Sharp-tailed Sandpiper	10	0

		<i>Tringa totanus</i>	Common Redshank	1	0
		<i>Tringa nebularia</i>	Common Greenshank	14	2
		<i>Calidris ruficollis</i>	Red-necked Stint	73	100
		<i>Calidris alpina</i>	Dunlin	14	0
		<i>Calidris falcinellus</i>	Broad-billed Sandpiper	159	1
		<i>Calidris ferruginea</i>	Curlew Sandpiper	260	74
2022/4/21	Charadriidae	<i>Pluvialis fulva</i>	Pacific Golden-Plover	1613	0
		<i>Charadrius mongolus</i>	Lesser Sand-Plover	73	0
		<i>Charadrius alexandrinus</i>	Kentish Plover	34	0
	Scolopacidae	<i>Calidris falcinellus</i>	Broad-billed Sandpiper	627	0
		<i>Calidris ferruginea</i>	Curlew Sandpiper	132	0
		<i>Calidris acuminata</i>	Sharp-tailed Sandpiper	98	0
		<i>Calidris ruficollis</i>	Red-necked Stint	69	0
		<i>Tringa stagnatilis</i>	Marsh Sandpiper	38	0
		<i>Tringa nebularia</i>	Common Greenshank	17	0



附圖 1. Salt Pan 9-1 引水試驗期間的水域覆蓋度變化。(a) 2022/04/15: 引水試驗第 1 天。(b) 2022/04/21: 引水試驗第 7 天。

Figure A1. The change in water coverage during the water diversion period at Salt Pan 9-1. (a) April 15, 2022: the first day of the water diversion. (b) April 21, 2022: the seventh day of the water diversion.

模擬氣候變遷下臺灣原生生質能潛力樹種 無患子的分布動態

Modelling range dynamics for native bioenergy potential tree species *Sapindus mukorossi* in Taiwan under climate change

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摘 要

生質能的擴大使用與開發為我國邁向淨零排放的關鍵策略之一，進一步瞭解暖化對生物質潛在分布構成的影響，有助未來資源利用的空間規劃與配置。本研究以具生質能潛力之原生樹種無患子 (*Sapindus mukorossi*) 為例，運用集成生態棲位模型，進行無患子適宜生育地分布的模擬，並搭配政府間氣候變遷專門委員會所發布的共享社會經濟途徑 (shared socio-economic pathways, SSPs) 暖化情境，分析該物種現時至 21 世紀末 (2071~2100 年代) 適宜生育地的分布動態。研究結果顯示，與溫度相關的氣候變項是驅使無患子生育地適宜性發生改變的主因，未來無患子將可受益於輕度暖化 (SSP126)，擴張其適宜生育地範圍；重度暖化 (SSP585)

則不利西南側適宜生育地的維持，雖適宜生育地範圍朝高海拔擴張，不致削弱總體分布面積，然生育地空間分布型態的改變，可能影響未來資源利用的可行性，建議及早擬定或調整栽植計畫，以提供氣候變遷下相對應的經營管理策略。

Abstract

Expanding and developing the use of bioenergy is one of the key strategies for Taiwan to achieve net-zero emissions. Further understanding the impact of global warming on the potential distribution of biomass significantly informs future resource spatial planning and allocation. This study focused on *Sapindus mukorossi*, a potential biomass species, we applied the ensemble ecological niche model to simulate the species range dynamic under the shared socio-economic pathways (SSPs) warming scenario, spanning from the current time to the end of the 21st century (2071-2100). The results show that temperature-related climate variables are the primary drive shifts in habitat suitability for *S. mukorossi*. In a low emission scenario (SSP126), *S. mukorossi* is anticipated to benefit, leading to an expansion of its suitable habitat range. However, under a high emission scenario (SSP585), the maintenance of suitable habitats on the southwestern is constricted. Although suitable habitat ranges may expand towards higher altitudes without reducing the overall habitat area, changes in habitat spatial patterns could potentially affect the availability of future resource utilization. We recommend early formulation or adjustment of planting plans to provide corresponding operational and management strategies for climate change.

關鍵詞：共享社會經濟途徑、生物質資源、永續性、生態棲位模型

Keywords: shared socio-economic pathways, bioenergy resource, sustainability, ecological niche model

緒 言

鑑於化石燃料資源日益枯竭，以及溫室氣體高度排放，導致氣候變遷與生態環境損害等問題，逐步降低並淘汰化石燃料的使用，以及積極尋求清潔且具永續性的替代能源，儼然是近代能源發展的重要趨勢 (Chang *et al.* 2012, Sahoo *et al.* 2022)。生質能 (bio-energy) 是由生物質 (biomass) 所提取的能源，使用生質能可視為封閉式的碳循環，即總體能源轉換達到零碳排，為一兼顧環保與永續經營的能源型態 (張 2016)。在謹慎合宜的規範與管理下，提升生質能的利用占比，可望減緩氣候變遷帶來的威脅，並健全社會生態環境 (Souza *et al.* 2017, Von Cossel *et al.* 2019)。在眾多不同形式的生質能資源中，又以木本油料樹種的利用較受矚目 (Papini and Simeone 2010)，它們通常可在 6~20 年間開始結果，並持續保持數十年的生產力 (Dai *et al.* 2017)，在不影響森林蓄積的前提下，由此類非木材的森林副產物獲取生質能原料，應能降低因能源需求對環境所造成的衝擊，可謂具前瞻性的一種

再生能源。

植物生長與收穫很大程度取決於適宜氣候條件的存在與否，氣候變遷已被證實會改變生質能植物的生育地適宜性 (habitat suitability)，並使其空間分布發生再分配 (Hu 2017, Liu *et al.* 2021)。為確保生質能原料供給的永續性，有必要進一步瞭解氣候變遷對其適宜生育地空間分布帶來的影響，據以制訂相關的因應對策。生態棲位模型 (ecological niche model, ENM) 可基於物種存在位置與其對應環境變量間的關聯性，預測物種潛在分布或生育地適宜性 (Guisan *et al.* 2013)，搭配未來氣候資料，更有助理解氣候變遷情境下的空間分布動態 (Elith and Leathwick 2009)。生態棲位模型多樣，然迄今尚未有任何單一模型具通用性 (Segurado and Araujo 2004)，集成式的 ENM 是依據多種演算法構建多模型，再藉由共識原則進行整合，獲取最終的預測結果 (Araújo and New 2007)，如此不僅可消彌各種模型間的不確定性，並可提供更穩健、可靠的性能 (Marmion *et al.* 2009)，近來集成模型

已廣泛應用於植物生態的研究 (Ardestani *et al.* 2021, Rahmanian *et al.* 2021, Kunwar *et al.* 2023)。

臺灣高度倚賴化石燃料，據統計近百年來增溫約 1.4°C，遠高於全球平均值 (盧等 2012)，足見受氣候變遷影響甚鉅。為呼應全球「2050 淨零排放」的趨勢，我國政府自 111 年陸續公布「臺灣 2050 淨零排放路徑及策略總說明」及「12 項關鍵戰略行動計畫」與「淨零排放路徑 112-115 年綱要計畫」，並於 112 年 2 月公布施行《氣候變遷因應法》，展現邁向淨零排放目標之決心。其中，2050 淨零排放的路徑規劃及關鍵戰略中，均明確提出擴大使用生質能、以生質能取代化石燃料等新潔淨或前瞻能源的開發指引。無患子是臺灣重要的原生園林與造林樹種，該物種不僅固碳能力強，其種仁油脂含量豐富且優質 (Zhang *et al.* 2012, Chhetri *et al.* 2008)，兼具對環境友善與可再生特性，極具生質能源料開發與利用潛力 (Jia and Sun 2012, Chakraborty and Baruah 2013, Liu *et al.* 2017)。有鑑於此，本研究以無患子做

為目標種，整合物種存在紀錄與環境資料，並搭配政府間氣候變遷專門委員會 (Intergovernmental Panel on Climate Change, IPCC) 第 6 次評估報告所提出之氣候變遷情境，進行生態棲位建模，研究目的在於 (1) 瞭解影響無患子生育地適宜性的重要環境因子，並模擬其適宜生育地潛在分布；(2) 探討不同程度的暖化情境下，無患子現時至 21 世紀末 (2071~2100 年代) 的潛在分布動態，期研究成果可作為氣候變遷下生質能源資源開發與利用，以及空間調適策略擬定之參考資訊。

材料與方法

研究區概述

臺灣位處歐亞大陸與菲律賓海板塊交會處，西側毗鄰臺灣海峽，東面臨太平洋。臺灣地狹人稠，面積約 36,000 km²，人口數約 2,300 萬。地勢東高西低，地形陡峭，多由山地與丘陵組成，據林業及自然保育署第 4 次森林資源調查報告顯示，島內約有 6 成土地為森林所覆蓋；非森林土地利用類型，以農業用地為大宗 (約

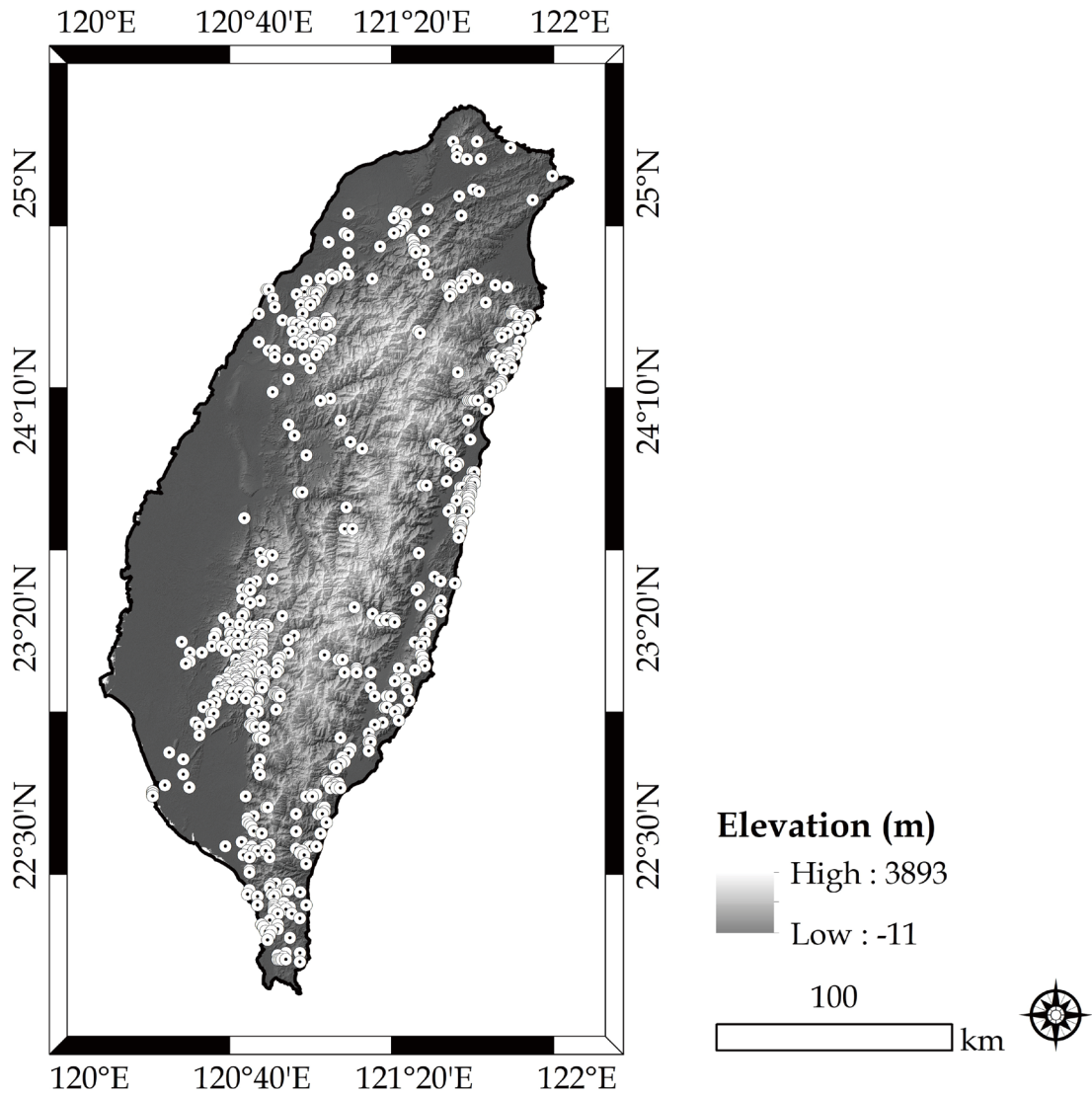


圖 1. 研究區地理位置與目標種發生紀錄（圓形標記）。

Fig. 1 Geographical location of the study area and the species occurrence records (circular markers).

22%)、建築用地次之(約6%)，多分布於西部平原至沿海一帶(如圖1)。臺灣氣候東西向介於季風西風帶與貿易東風帶之間，南北向受中緯度與熱帶天氣系統的雙重影響，全境可歸類為副熱帶季風氣候，然受複雜地形所影響，氣候隨區域不同而有顯著的差異(林2010)，而在全球暖化的大趨勢下，臺灣過去百年暖化現象亦十分明顯，增溫速率相當於每10年上升0.14°C(盧等2012)。臺灣自產能源匱乏，高度倚賴進口，據111年能源統計資料(經濟部能源局2022)顯示，以化石燃料(含煤及煤產品、原油及石油產品、天然氣)做為能源供給的占比高達92.5%、核能4.9%，具再生性能源(含生質能及其廢棄物、慣常水力、地熱、太陽光電及風力)為2.6%，其中生質能及其廢棄物僅1.21%。

研究方法

(一) 物種存在資料

無患子存在紀錄下載自林業及自然保育署生態調查資料庫系統(<https://>

ecollect.forest.gov.tw/)所收錄的「生物資源資料庫」資料集，該資料集為該署主導之多年期全國性自然資源普查成果，所獲取紀錄計有1,164筆，調查期間為1998-2007年，座標格式為經緯度(WGS84)，為確保地理坐標的精確度，先刪除小數點不足3位的資料，接續配合生態棲位模型所使用預測變項之空間解析力，設定各存在紀錄間的鄰近距離至少大於1 km，以R套件“spThin”(Aiello-Lammens *et al.* 2015)進行存在紀錄的空間篩選與剔除，以減少空間自相關及地理取樣偏差的影響，最後保留存在紀錄計607筆(圖1)。另以相同的方法，在同一資料集下抽取非目標種存在紀錄，並在剔除與目標種共存同一分析單元之紀錄後，將其視為偽非存在紀錄(或背景點)，計9,502筆，供後續生態棲位建模使用。

(二) 環境資料與變遷情境

氣候與土壤變項可謂預測植物生育地適宜性的良好變項(Hageer *et al.* 2017, Wan *et al.* 2019)，同時地形所導

致的環境異質性，意味生育地條件的不同 (Dubayah and Rich 1995)，而土地利用 / 覆蓋亦直接影響生育地的品質和數量 (Titeux *et al.* 2016)，為生態棲位不可切割的一部份，有必要一併納入建模與未來預測的考量。因此，生態棲位建模所使用之預測變項包含氣候、土壤、地形、土地利用 / 覆蓋等 4 類 29 項。其中，19 項現時生物氣候變項 (Bio1-BIO19)，乃自 CHELSA V2.1 資料庫 (<https://chelsa-climate.org/>) 取得，其資料生成期間涵蓋 1979-2013 年，空間解析度近 1×1 km (Karger *et al.* 2017)。土壤類變項，則從 ISRIC 資料庫 (www.isric.org/explore/soilgrids) 下載粗碎屑含量、粘粒含量、砂粒含量、粉粒含量、土壤 pH 值、陽離子交換能力等 6 項。地形類變項，除由內政部取得數值高程模型 (digital elevation model, DEM) 外，並以 ArcGIS 10.8 軟體產製獲取坡向、坡度等變項。土地利用 / 覆蓋變項，取自 Chen *et al.* (2022) 基於 Land-Use Harmonization 2 (Hurtt *et al.* 2020) 及 ESA-CCI 資料集 (www.esa-landcover-cci.org) 所建構

的 2015 年全球土地利用 / 覆蓋圖資，包含森林、草地、農地、都市、荒地與水體等 6 種類別 (1×1 km 空間解析力)。由於各預測變項資料來源與空間解析力略有不同，本研究將上述 29 個預測變項 (表 1) 統一重取樣為 1×1 km，另為克服變項在統計上的多重共線性問題，以 R 套件 “*virtualspecies*” 執行 Pearson 相關分析 (Leroy *et al.* 2016)，排除相關性高的變項，當相關係數大於 0.7 以上時，擇一與生物學關連性高者予以保留 (Dormann *et al.* 2013)。

對於未來的預測，本研究假設氣候及土地利用 / 覆蓋兩類變項會隨 IPCC 第 6 次評估報告所發布的共享社會經濟途徑 (shared socio-economic pathways, SSPs) 發生改變，其餘則維持不變。本研究採用其中的 SSP126 和 SSP585 等 2 種碳排放情境，各別代表輕度和重度暖化，其中 SSP126 情境為永續導向的綠色途徑，相較於基準年 (1850~1900 年)，21 世紀末全球增溫可望在控制在 2°C 以下；SSP585 情境則是假設社會經濟發展仍

表 1. 生態棲位建模所使用之預測變項

Table 1. Predictor variables used in ecological niche modeling.

Category	Variable	Code
Bioclimatic	Annual mean temperature	BIO1
	Mean diurnal range (mean of monthly (max temp - min temp))	BIO2
	Isothermality (BIO2/BIO7) ($\times 100$)	BIO3
	Temperature seasonality (standard deviation $\times 100$)	BIO4
	Maximum temperature of warmest month	BIO5
	Minimum temperature of coldest month	BIO6
	Temperature annual range (BIO5-BIO6)	BIO7
	Mean temperature of wettest quarter	BIO8
	Mean temperature of driest quarter	BIO9
	Mean temperature of warmest quarter	BIO10
	Mean temperature of coldest quarter	BIO11
	Annual precipitation	BIO12
	Precipitation of wettest month	BIO13
	Precipitation of driest month	BIO14
	Precipitation seasonality (coefficient of variation)	BIO15
	Precipitation of wettest quarter	BIO16
	Precipitation of driest quarter	BIO17
	Precipitation of warmest quarter	BIO18
	Precipitation of coldest quarter	BIO19
Soil	Coarse fragments volumetric	CRF
	Soil texture fraction clay	CLY
	Soil texture fraction sand	SND
	Soil texture fraction silt	SLT
	Soil pH x 10 in KCl	pH
	Cation exchange capacity	CEC
Topography	Elevation	ELEV
	Slope	Slope
	Aspect	ASP
Land-use/Land-cover	Land-use/Land-cover	LULC

由化石燃料所驅動，全球增溫將達到 3.3~5.7°C 間 (IPCC 2021)。未來的氣候資料自前述 CHELSA v2.1 下載 21 世紀末 (2071~2100 年的平均值) 兩種情境下可使用之生物氣候資料 (Karger *et al.* 2017)，包含 GFDL-ESM4、IPSL-CM6A-LR、MPI-ESM1-2-HR、MRI-ESM2-0 與 UKESM1-0-LL 等 5 種之大氣環流模型 (general circulation model, GCM)；另從 Chen *et al.* (2022) 取得相同年代的未來土地利用 / 覆蓋變項，SSP126 與 SSP585 情境分別根據 IMAGE 和 REMIND-MAGPIE 兩種預測土地利用 / 覆蓋變遷的綜合評估模型 (integrated assessment model, IAM) 所產製。本研究使用 5 種 GCM 各別搭配 2 種 IAM 為無患子未來的生育地適宜性進行預測，並取其結果之平均數做為最終結果。

(三) 生態棲位建模

藉由 R 套件 “sdm” 執行 ENM (Naimi and Araújo 2016)，推估無患子的生育地適宜性，使用 5 種常見的演算法，包括廣義線性模型 (generalized

linear model, GLM)、廣義相加模型 (generalized additive model, GAM) 等 2 種迴歸統計模型，以及增強迴歸樹 (boosted regression tree, BRT)、隨機森林 (random forest, RF)、最大熵 (maximum entropy, MaxEnt) 等 3 種機器學習演算法。首先，分別就物種存在與非存在紀錄 (或背景點) 兩類點位逢機選取 80% 做為訓練資料集，剩餘 20% 做為測試資料集。接續，演算過程採 10 折交叉驗證法 (10-fold cross-validation) 進行模型建構與驗證，5 種演算法共可建構 50 個模型。準確度評估以接受者操作特徵 (receiver operating characteristic) 曲線下面積 (area under the curve, AUC) 與真實技能統計值 (true skill statistics, TSS) 兩個常見指標進行，其中 AUC 值域介於 0.5~1，當值愈高代表模型預測之準確性愈佳，TSS 則落於 +1 至 -1，接近 1 表示模型幾乎完美，反之亦然 (Allouche *et al.* 2006)。當 AUC 與 TSS 分別高於 0.7 及 0.4 以上，即達合理之可接受標準 (Swets 1988, González-Ferreras *et al.* 2016)。最終，本研究僅選擇保留

AUC 高於 0.8 且 TSS 高於 0.5 的模型，並以各模型 TSS 做為權重，計算加權平均數，產製集成概率圖，用以表示無患子之生育地適宜性，當概率愈大，愈適宜無患子生存，反之則不適宜。

各預測變項對模型的重要性是透過 R 套件 “sdm” 中的 “getVarImp” 函數來衡量，它是比較所建構的模型在各別排除某一變項後，其 AUC 與原模型間的落差，亦即該變項改進 AUC 的程度；另反應曲線 (response curves) 是觀察適宜性集成概率與變項間之關係。待求得全區現時生育地適宜性後，以最大 TSS 所對應的適宜性做為閾值 (Liu *et al.* 2016)，並轉換獲取適宜 (1) 與非適宜 (0) 的二元化 (binary) 生育地圖，接續將此劃定標準套用於未來變遷情境下之生育地適宜性預測結果，以利後續動態分析與比較。

(四) 生育地分布動態分析

參照 Kumari *et al.* (2022) 對生育地動態的歸類法，以 ArcGIS 10.8 軟體之 “Spatial Analyst Tools” 模組獲取現時與未來情境之生育地分布動態圖，

其中型態屬擴增 (gain) 者，代表該像元現時狀態係非適宜生育地，但未來情境下可轉為適宜生育地 (0, 1)；反之，現時狀態為適宜生育地，但未來情境下轉為非適宜生育地之像元 (1, 0)，則定義為損失 (loss)。穩定 (stable) 是現時與未來均為適宜生育地者 (1, 1)；而現時與未來均屬非適宜生育地者 (0, 0)，則歸屬為不存在 (absence)。擴增與損失像元數除以現時適宜生育地像元數，可分別獲得擴增率 (percentage gain) 與損失率 (percentage loss)，而擴增率減去損失率，可表示總體生育地範圍變化 (range change)。

結 果

由相關分析保留預測變項計 12 個，據此以 5 種運算法建構無患子 ENM，結果顯示除 GLM 的 TSS 指標 (0.42) 表現略低外，其餘 4 種演算法獲取模型之性能相對優良，並以 RF、MaxEnt 表現更佳 (圖 2)。進一步僅保留模型性能達預設標準之模型 (即 AUC>0.8 且 TSS>0.5)，計有 40 個，可用以做為後續模型集成使用，其平

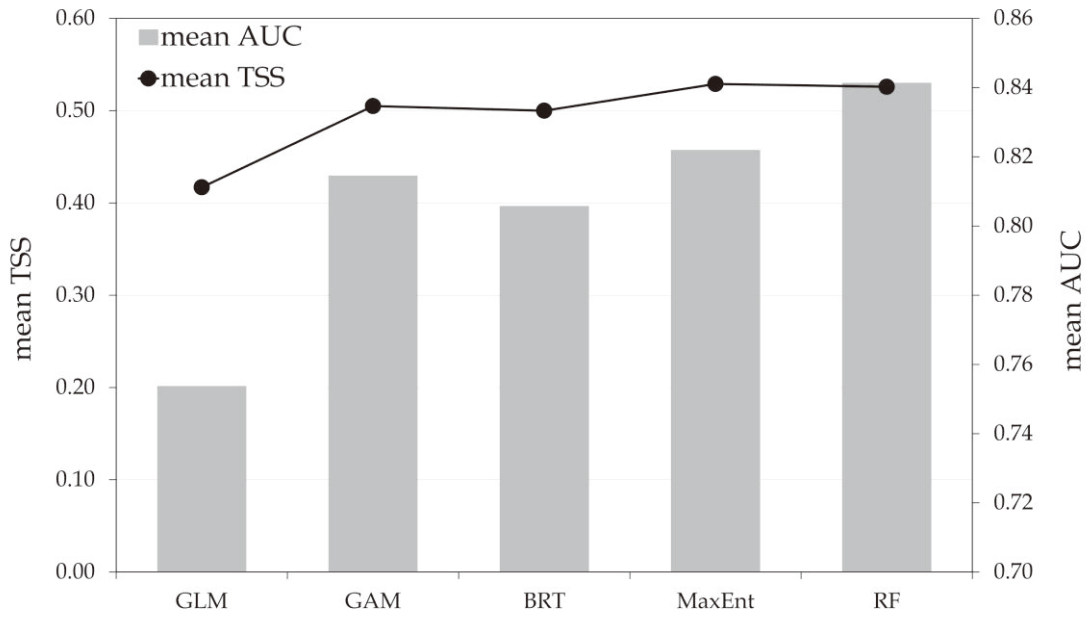


圖 2. 各演算法獲取模型之接受者操作特徵曲線面積 (area under a ROC curve, AUC)、真實技能統計值 (true skill statistic, TSS)。

Fig. 2. The area under the receiver operating characteristic curve (AUC) and the true skill statistic (TSS) obtained by each algorithm for the model.

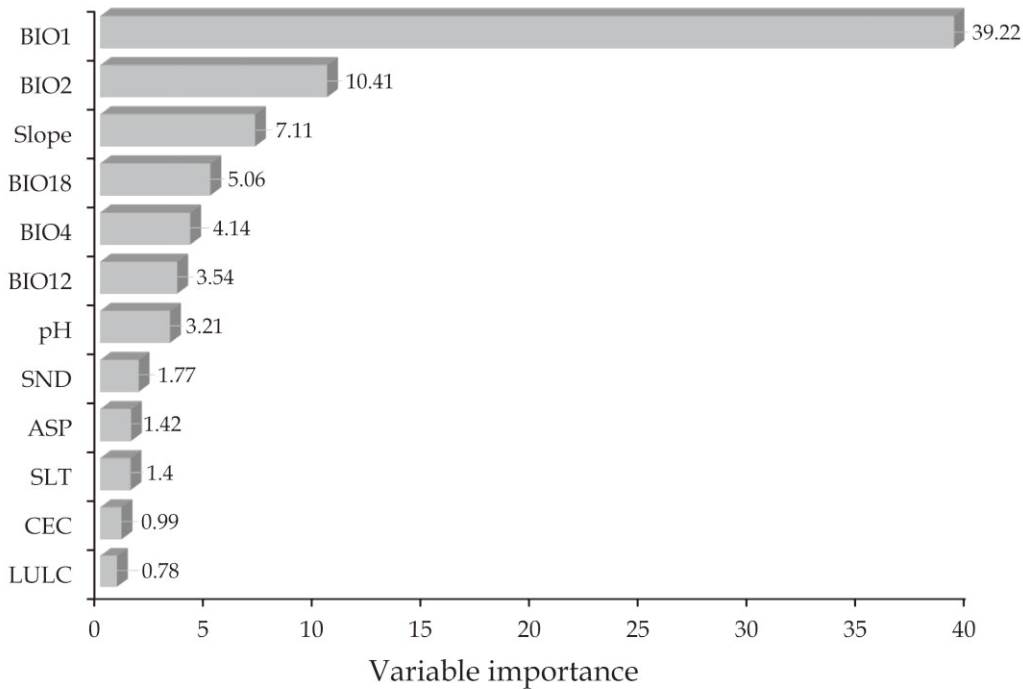


圖 3. 各預測變項對集成模型的重要性。

Fig. 3. Importance of each predictive variable to the ensemble model.

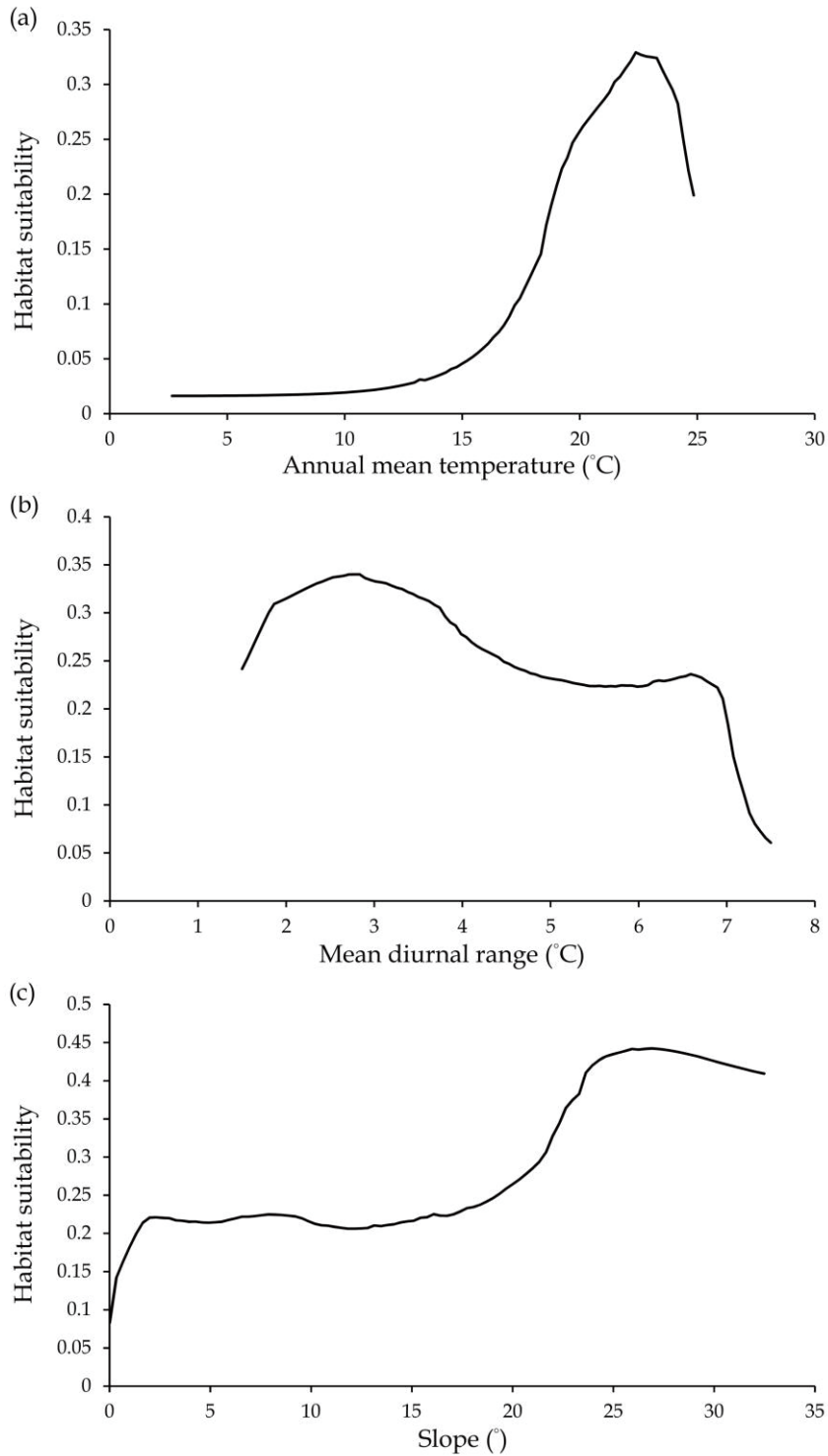


圖 4. 無患子對集成模型主要變項之反應曲線，(a) 為年均溫；(b) 平均溫度日較差；(c) 坡度。
 Fig. 4. Response curves for the topmost important variables in an ensemble model; (a) annual mean temperature; (b) mean diurnal range, and (c) slope.

均 AUC 為 0.82、平均 TSS 為 0.51。

各預測變項對集成模型的重要性如圖 3 所示，圖 3 顯示重要性最大者為年均溫 (39.22)，其次為平均溫度日較差 (10.41)，再者為坡度 (7.11)。相較於氣候類變項，除坡度外，其餘非氣候類變項重要性大多低於 4，對模型的影響力相對較小。進一步觀察集成模型所推導生育地適宜性對主要影響變項的反應曲線 (圖 4) 可發現，無患子生育地適宜性將隨年均溫上升而提升，並在 22.4~23.3 °C 間達到最適範圍，隨後適宜性急遽下降 (圖 4a)；而最適宜無患子生存之溫度日較差範圍介於 1.9~3.7 °C 間，隨後緩慢下降並持平，直至日較差大於 6.9 °C 後，適宜性快速驟降 (圖 4b)，不利其生存；此外，相較於平地，具適當坡度的生育地環境，更適宜無患子生存，其生育地適宜性可在坡度 25° 左右達到最高 (圖 4c)。

集成模型最大 TSS 所對應之生育地適宜性閾值為 0.22，依該閾值獲取之適宜生育地分布 (圖 5) 來看，無患子適存範圍多位處淺山地區，現

時除主要分布於阿里山山脈、玉山山脈、中央山脈南緣，以及海岸山脈等地帶外，竹苗地區丘陵亦有較大範圍的局部分布，估算面積約為 7,663 km²，ENM 為預測氣候變遷對物種適宜生育地影響的有效工具，在本研究所執行的 5 種演算法中，以基於機器學習演算法的 RF 與 MaxEnt 兩種模型模擬性能最佳，此與過往許多研究結果一致 (Kaky *et al.* 2020, Ardestani and Ghahfarrokhi 2021)，其中 RF 由多棵決策樹的共識預測所獲得 (Mi *et al.* 2017)，而 MaxEnt 具正則化 (regularization) 程序，本質上均能避免模型複雜化所造成的過度擬合 (Phillips and Dudík 2008)，進而提升模型的通用性 (generality) 或移轉性 (transferability)。最終生育地適宜性模型，本研究選擇僅保留高性能模型，以 TSS 做為權重，採加權平均進行集成預測，有助降低單一模型預測差異性與不確定性，並提升準確度與穩健性 (Araújo and New 2007, Marmion *et al.* 2009)，如此對後續分布動態的模擬，應足具說服力。

以預測變項對模型影響力來說，

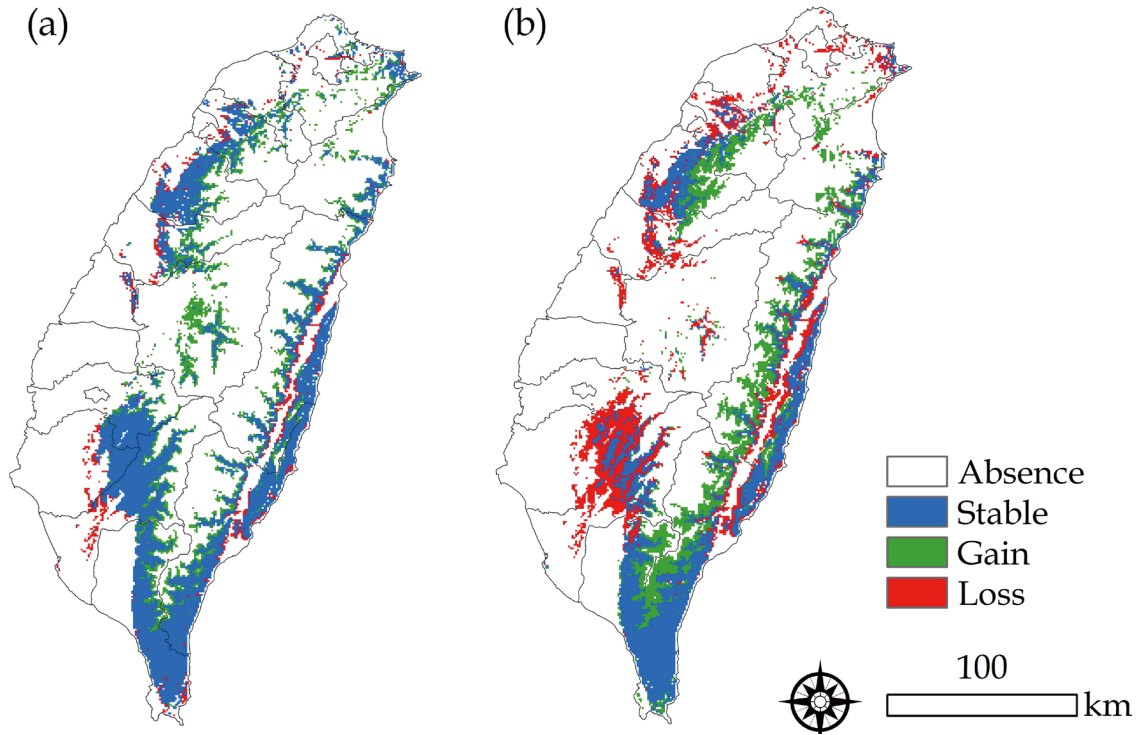


圖 5. 無患子在未來氣候變遷情境下的適宜生育地分布動態，(a) SSP126、(b) SSP585。

Fig. 5. Climate-related range shift of *Sapindus mukorossi* under future climatic scenarios. (a) SSP126, (b) SSP585.

表 2. 現時至未來氣候變遷情境下無患子的適宜生育地分布動態統計

Table 2. Summary of the range change statistics for *Sapindus mukorossi* under future climatic scenarios compared to current climatic conditions.

Scenarios	Area (km ²)				Species range change (%)		
	Absence	Stable	Gain	Loss	Percent gain	Percent loss	Range change
SSP126	25,681	6,875	2,529	789	33.00	10.29	22.70
SSP585	25,107	4,698	3,103	2,966	40.49	38.70	1.79

氣候類明顯大於非氣候類變項，尤其與溫度相關的年均溫、平均日較差兩變項 (圖 3)，更是決定無患子生育地適宜性的關鍵因素。由詳細的生態棲位特徵 (圖 4) 可歸納出，無患子偏好相對溫暖、日夜溫差小，以及適當坡度的生育地環境，故未來暖化所促使山區環境的增溫與日較差的縮減 (Lin *et al.* 2015, Tsai *et al.* 2023)，有機會為無患子創造新的適宜生育地 (Dai *et al.* 2017)，致整體適宜生育地有朝高海拔方向微幅擴張的趨勢，惟過高的年均溫仍將逾越其生態耐受性，進而限縮緯度或海拔相對低的原有生育地 (圖 5)，尤以重度暖化的 SSP585 情境更為明顯，類似的生育地分布模擬研究 (Li *et al.* 2021, Liu *et al.* 2022) 亦提出相同的論點，其中 Li *et al.* (2021) 更強調無患子僅能在 SSP126 情境下增加適宜生育地，再進一步的暖化皆不利其生存，並對未來栽植或利用的空間配置增加不確定性。

相較喪失或遭受限縮的生育地，可穩定維持並持續擴張生育地的區位，更有利於物種的栽植與多樣性的

保存。然重度暖化下，緯度或海拔相對低的西南側適宜生育地顯著受到限縮 (圖 5)，推測可能與高溫對光合作用的抑制有關 (Yue *et al.* 2019)，這意味該區位可能不再適合無患子的生存與繁殖，該區位有必要優先強化這些損失區內的種原採集及保存工作 (Liu *et al.* 2022)。此外，當前若有栽植或計畫栽植無患子，建議及早規劃轉植其他可受惠於該暖化情境之樹種，抑或積極選育更為耐熱的品種 (Wang *et al.* 2014)，避免未來出現生長不良、收穫不佳，或衍生更多必要的撫育成本。

結 論

本研究集成多種演算法，建構無患子生態棲位模型，藉以模擬氣候變遷下的適宜生育地分布動態。基於研究結果可獲得以下結論：一、無患子適宜生育地特徵包含相對溫暖、日夜溫差小及適當坡度等，未來氣候條件的改變，將有利於山區適宜生育地範圍的擴張；二、大部分的現時適宜生育地範圍，在輕度暖化情境 (SSP126) 下，可望持續維持，並朝高海拔方向

微幅擴張，然重度暖化 (SSP585) 恐明顯限縮西南側的適宜生育地範圍，改變其既有的空間分布型態，故當前的栽植或利用計畫，有必要將氣候變遷併同納入考量，據以調適氣候變遷所帶來的影響。最後，生質能原料的生產與利用，仍須建構在合理空間規劃下，可能涉及環境影響、社會經濟，以及資源利用等層面，決策者須權衡其中的利弊 (Dale *et al.* 2011)。本研究基於 ENM 所推估的適宜生育地分布動態資訊，可供選擇栽植區位時之參考，至於進一步發展為生質能原料供應鏈系統，亦即收穫、運輸、儲存與分配等一系列過程 (Nunes *et al.* 2020)，則須考量到地形特徵、交通運輸、人力調度、以及與既有土地利用的衝突等諸多因素 (Immerzeel *et al.* 2014, Gasparatos *et al.* 2022)，這些均有待更深入的分析、整合與探討。

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Testing a simple and non-intrusive method for monitoring the breeding season of barn swallows in an urban area in Kaohsiung, Taiwan

測試以一種簡單且非侵入性的方式監測台灣高雄市區的家燕繁殖

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ABSTRACT

Monitoring of biodiversity with citizen scientists is increasing worldwide, including Taiwan. We present a simple and non-intrusive method for monitoring urban swallows that is ideal for nationwide student or citizen science monitoring projects. In 2019, we continuously monitored the breeding phenology and success of 57 barn swallow (*Hirundo rustica*) nests in an urban district in Kaohsiung City, southern Taiwan. We used minimal equipment (mirror on stick, flashlight, pen, and paper) to survey the eggs, nestlings, and fledglings inside the nests during the entire breeding season. Among the 46 active nests, 21 and 25 nests were associated with one or two breeding attempts,

respectively. The two peaks of egg-laying occurred in April and from early to mid-May until early June. The mean clutch size for the first and second breeding attempt was 4.1 eggs and 3.8 eggs, respectively, and the mean fledgling number was 1.8 and 1.3 fledglings, respectively. The overall fledgling success rate was 40.8%. The number of nestlings correlated positively with the number of fledglings ($r^2 = 0.46$). The main result of this pilot study is that it is possible to conduct long-term monitoring of urban swallow populations with little training and minimal equipment and only a moderate investment of time and effort as long as the nests are accessible. We suggest that the implementation of a nationwide monitoring network of urban swallows would have several benefits, such as useful data on breeding phenology and breeding success, but also to entice more people to become citizen scientists and to educate people about the ecosystem services of birds.

摘要

包括台灣在內，公民科學家對生物多樣性的監測在世界各地不斷增加。我們提出了一種簡單且非侵入性的方式監測城市的燕子生態，非常適合全國學生或公民科學計畫。在 2019 年，我們持續監測了台灣高雄市區 57 個家燕 (*Hirundo rustica*) 巢穴的繁殖物候和成功情況。在整個繁殖季節，我們使用最少的設備（黏在長棍上的鏡子、手電筒、筆和紙）來調查巢內的蛋、雛鳥和幼鳥。在 46 個活躍巢穴中，分別有 21 個和 25 個巢穴與一次或兩次繁殖嘗試相關。兩個產蛋高峰期分別發生在 4 月和 5 月上旬至 6 月上旬。第 1 次和第 2 次繁殖嘗試的平均窩卵分別為 4.1 枚蛋和 3.8 枚蛋，平均幼鳥數量分別為 1.8 隻和 1.3 隻。整體幼鳥離巢成功率為 40.8%。雛鳥數量與幼鳥數量呈正相關 ($r^2 = 0.46$)。這項前導研究的主要結果顯示，但凡燕巢可接近，研究人員只需極少的訓練和最少的設備；並且投入適度的時間和精力，就可以對城市裡的燕子族群進行長期監測。根據上述結論，

我們建議實施全國性城市燕子監測網絡。其益處有許多，例如產生有關繁殖物候和繁殖成功的有用數據，並且還可以吸引更多成為公民科學家，並教育人們有關鳥類生態系統服務的知識。

key words: citizen science, monitoring, urban biodiversity, breeding phenology, breeding success.

INTRODUCTION

The phenology of breeding seasons is an important aspect of the study of bird behavior and reproduction (Lovette and Fitzpatrick 2016). Due to rapid man-made changes to the biosphere, changes in breeding distribution and phenology as well as changes in population numbers can now be used as indicators of the biological effects of climate change, land-use change, chemical or light pollution, and other important changes due to human activity (e.g., Both *et al.* 2009; Barbet-Massin *et al.* 2012; Cooper *et al.* 2014; García-Pérez *et al.* 2014; Walther 2016; Dominoni *et al.* 2020; Wang *et al.* 2021).

To be able to monitor important avian population changes in Taiwan, the

Taiwan Breeding Bird Survey (BBS) was initiated in 2009 and has already revealed important distribution and population changes (Ko *et al.* 2016; Ko *et al.* 2017; TESRI 2021; Lin *et al.* 2023). The BBS is a perfect example of the emergence of citizen science in Taiwan, which ideally engages interested citizens in the entire scientific process, such as the rationale for the study, generating questions or hypotheses, developing the methods, collecting and analyzing the data, and publishing and disseminating the results (ECSA 2015; Heigl *et al.* 2019). However, many citizen science projects are more limited in scope, and often the citizen scientists mostly collect data although in a scientifically rigorous way. Besides the BBS, other typical examples

from Taiwan are recording migratory bird populations (TESRI 2019), bird poisoning events (Hong *et al.* 2018), avian influenza cases (Wu *et al.* 2023), or roadkills (Hsu *et al.* 2018; Chyn *et al.* 2019).

After living in Taipei City for three years, the first author (BAW) realized that urban swallows (Hirundinidae) are very easy to monitor because (1) they are not scared by the presence of people (with some nests less than a meter away from where people are), (2) most of their nests are very accessible, and (3) they are found almost across the entire island of Taiwan except the high mountains. Since urban swallows are so easy to monitor and so ubiquitous, they should be an ideal study species for student or citizen science monitoring projects. Before embarking on a citizen science project, however, one needs to field test whether monitoring urban swallows is indeed feasible with a reasonable amount of time and manpower and

without disturbing or harming the birds. Therefore, we here present a simple and non-intrusive monitoring method which (1) we field tested to demonstrate its feasibility and (2) could be the starting point for many citizen science projects to monitor the breeding phenology of swallow species, which are widespread and common in Taiwan but also in other countries (for citizen science projects that monitored British, Chinese and Malaysian swallows, see Kettel *et al.* 2021, Jiang *et al.* 2019, and Mansor *et al.* 2021).

On the main island of Taiwan (from hereupon called Taiwan), five species of swallows (Gray-throated Martin *Riparia chinensis*, Barn Swallow *Hirundo rustica*, Pacific Swallow *Hirundo tahitica*, Striated Swallow *Cecropis striolata*, and Asian House-Martin *Delichon dasypus*) have been recorded as regular breeders (Ding *et al.* 2023). They usually breed in cities, villages, cliffs, sand banks, tunnels, and under bridges (Severinghaus

et al. 2017).

In our urban study area in Kaohsiung, we recorded only the barn swallow and the striated swallow as breeders. The barn swallow is found throughout Taiwan from 0-2300 m a.s.l., and its usual breeding season lasts from April to August (Severinghaus *et al.* 2017). The striated swallow is found throughout Taiwan in the plains to the mid-elevation mountains, and its usual breeding season lasts from April to July (Severinghaus *et al.* 2017).

While Severinghaus *et al.* (2017) notes that the barn swallow's open bowl-shaped nests are built on a vertical wall under the eaves of buildings and on beams and light fixtures, the preferred location in Taiwanese cities is often inside the porches or colonnades of city houses (called verandahs by Wang and Hung 2019 and Wang *et al.* 2021). Many Taiwanese city houses (especially older ones built in the decades after World War II) have a space in front of the entrance

door which is open to the street and also usually open to the neighboring houses, but is covered either by a roof or by a ceiling from the story above it (Fig. 1). This space protects the house entrance from heat, offers an open but shaded place for people to sit or walk, and also protects people and belongings from rain. The distance from the entrance door to the front of the roof or ceiling is usually several meters, and the roof or ceiling covers the entire width of the building. If many of these porches are seamlessly connected, people can use them to walk along the street protected from sunshine and rain; in that case, these spaces could also be called colonnades.

These spaces offer the swallows a very well-protected site for breeding because they combine vertical walls for the nest's attachment (usually at 2-4 m height), protection from heat and rain, and an open pathway for flying from the nest into the street (Fig. 1). Given their location, there are also almost no

predators (but see Wang and Hung (2019) for a recent and novel predator as well as our Discussion below).

For the striated swallow, Severinghaus *et al.* (2017) notes that nests are usually built in hallways, colonnades, porches, and under the beams of houses, schools, or other man-made structures. However, the nest is not open, but a closed tunnel in the shape of a long-necked jug (Fig. 2). Because it is impossible to see the inside without special equipment, we did not monitor the breeding season of the striated swallow.

In contrast, the open nests of urban barn swallows (Figures 1 and 2) are extremely easy to observe even without any equipment or with just binoculars. Barn swallow nests can be extremely close together in suitable locations and include nests constructed by the birds themselves or nesting opportunities provided by people (Fig. 2). Residents provide such nesting opportunities

because “barn swallows have traditionally been well-loved by local residents” (Severinghaus *et al.* 2017, see also Pagani-Núñez *et al.* 2016; Jiang *et al.* 2019; Wang and Hung 2019).

The main purpose of this study is to conduct a pilot study which demonstrates that the documentation of the breeding phenology and breeding success of the barn swallow in Taiwanese cities, towns, and villages is possible with little training and minimal equipment and only a moderate investment of time and effort. This study may then serve as a blueprint for a nationwide citizen science monitoring effort.

MATERIALS AND METHODS

The study was conducted within a fully urbanized district of Kaohsiung, which is located in southern Taiwan as the second largest city that features the busiest harbor in Taiwan (Republic of China). The climate is categorized as

tropical savanna climate with monthly mean temperatures ranging from 20 to 29°C and high relative humidity ranging from 71 to 81%. The warmer season lasts from April to November and the cooler season from December to March. Annual rainfall is around 1885 mm and falls mainly from June to August. For Gushan District, the Annual Climatological Data Report for 2018 by Taiwan's Central Weather Bureau gives the annual mean temperature as 25.4°C and the annual precipitation as 2576 mm. The highest temperature is in July (29.3°C) and the lowest temperature in February (19.2°C). The highest precipitation is in August (1299 mm) which accounts for almost half of the entire annual precipitation.

We carried out our 18 surveys from 7 April to 17 August 2019 in the local area called Hamasing which is at the southern end of Gushan District of Kaohsiung. This district is adjacent to the harbor and National Sun Yat-sen University (Table 1, Fig. 3). Hamasing

was created when land was reclaimed by the Japanese colonial government in the 19th century when it was the site of the local government.

For each of the 18 surveys, we walked along all the streets within this district from 7:00-9:00 hours. This district has many houses with roofed colonnades where swallows chose to build their nests. Once a nest was spotted, its location was noted on a map. In order to look inside the nests with minimal disturbance to the breeding parents, we attached a mirror to a 1.8 m long metal stick which enabled us to count the eggs and nestlings in each nest (Fig. 4). Even without this mirror, citizen scientists could observe the later stages of the breeding cycle when the nestlings are so large that they are clearly visible inside the nest using binoculars (and often without binoculars). With the mirror, we looked inside each nest to record the number of eggs, nestlings, and fledglings present (Fig. 4). Sometimes, a

flashlight was needed to better illuminate the nest. Wang and Hung (2019) and Wang *et al.* (2021) used a similar method, but replaced the mirror with a smartphone camera.

For the purpose of this study, nestlings were defined as any live juvenile birds present in the nest, no matter what their developmental status was such as hatchling or nestling, as long as they could not actively fly (Figures 1 and 5, left panel; see Brown and Brown (1999), Turner (2006), and Fernaz *et al.* (2012) for detailed descriptions). Consequently, fledglings were defined as having reached the developmental stage “when the feathers and wing muscles are sufficiently developed for flight” (Wikipedia 2023). Thus, a nestling became a fledgling when it became clearly capable of flying about on its own (Fig. 5, right panel). These fledglings were actively flying out of and back into the nest, especially at night to rest.

If adults were present in the nest,

we waited until they left the nest before checking the nest. We often observed that adults would return quickly to the nest after our observations, and we never observed that a nest was abandoned due to our very short disturbance (usually less than ten seconds, rarely longer than one minute). Likewise, no nest abandonments were observed during a similar multi-year study conducted in Taipei (2013-2018 breeding seasons, unpublished data of first author).

The Mann-Whitney U test was used when we investigated differences between the first and the second breeding attempt (which was the binary variable in this case). For linear relationships, we used both the non-parametric Spearman rank test and the parametric simple linear regression. Any P-value < 0.05 was considered statistically significant.

RESULTS

Breeding phenology

During the 2019 breeding season,

we monitored 57 barn swallow nests, of which 46 nests (80.7%) were actively used. The date of 21 April was when at least five nests had at least one nestling. Overall, we clearly observed two peaks of egg-laying: most eggs were laid for the first clutch in April, and fewer eggs were laid for the second clutch from early to mid-May until early June (Fig. 6). We call these two periods “first breeding attempt” and “second breeding attempt.” While most breeding pairs closely followed this phenology, there were of course a few pairs which began laying eggs earlier or later than these two periods. Although the incubation is given at 14-15 days in Severinghaus *et al.* (2017), we observed the peaks for nestling numbers at 30 days after the peak for egg numbers (namely, 7 April and 31 May for eggs and 7 May and 30 June for nestlings).

Breeding success

Among the 46 active nests, 21

nests (45.7%) were associated with two breeding attempts and the remaining 25 nests with only one breeding attempt. Among these 25 nests, ten and 15 nests were associated with only the first and only the second breeding attempt, respectively. Thus, there were only 31 active nests during the first breeding attempt but 36 active nests during the second breeding attempt.

Not all nests actively used by barn swallows produced eggs (or they produced eggs, but the eggs disappeared before we could record them; see Discussion). During the first breeding attempt, 31 out of the 46 nests contained freshly laid eggs (67.4%). The mean clutch size was 4.1 ± 0.9 (± 1 std. dev., range 2-5; Fig. 7). Of the total of 126 eggs laid, 57 produced fledglings that successfully left the nest (45.2%). Out of the 31 nests with eggs, 13 nests produced no fledglings at all (41.9%). The mean fledgling number across the 31 nests was 1.8 ± 1.6 (range 0-4).

During the second breeding attempt, 32 out of the 46 nests had new eggs in them (69.6%). The mean clutch size was 3.8 ± 1.0 (range 1-5; Fig. 8). Of the total of 134 eggs laid, 49 produced fledglings that successfully left the nest (36.6%). Out of the 36 nests with eggs, 20 nests produced no fledglings at all (55.6%). The mean fledgling number across the 36 nests was 1.3 ± 1.4 (range 0-4).

The differences between the clutch sizes and the fledgling number per nest were not statistically significant between the first and the second breeding attempt (Mann-Whitney U test, $P > 0.05$).

In total, 260 eggs resulted in 106 successful fledglings (40.8%). The mean clutch size across both breeding attempts was 3.9 ± 1.0 (range 1-5). Of the 67 nests, 33 produced no fledglings at all (49.3%). The mean nestling number across the 67 nests was 2.5 ± 1.6 (range 0-5), and the mean fledgling number was 1.5 ± 1.5 (range 0-4).

Across both breeding attempts, the

number of eggs (or clutch size), nestlings and fledglings were all positively and significantly correlated with each other, whether tested with the non-parametric Spearman rank test (all $P < 0.03$) or the parametric simple linear regression (clutch size vs. nestlings, std. coeff. = 0.43, $F = 14.3$, $r^2 = 0.18$, $P = 0.0003$; clutch size vs. fledglings, std. coeff. = 0.30, $F = 6.1$, $r^2 = 0.09$, $P = 0.02$; nestlings vs. fledglings, std. coeff. = 0.09, $F = 54.7$, $r^2 = 0.46$, $P < 0.0001$).

DISCUSSION

The results of our pilot study clearly demonstrate that the documentation of the breeding phenology and breeding success of the barn swallow in Taiwanese cities, towns, and villages is possible with little training and minimal equipment and only a moderate investment of time and effort. Our study thus generated some basic natural history data about an urban swallow population in southern Taiwan. To our

knowledge, this is the first study of the breeding phenology of the barn swallow in Kaohsiung which is at the southern tip of Taiwan. Over the breeding season, we observed a decreasing number of eggs and nestlings (Fig. 6), a decrease in clutch size (especially fewer clutches of five eggs, Figures 7 and 8), a decrease in overall fledgling success (from 45.2% to 36.6%) and the number of successful fledglings per nest (1.8 to 1.3), and an increase in the proportion of completely failed nests (from 41.9% to 55.6%). However, these trends are not very strong and not statistically significant. Such declining rates of breeding success for successive breeding attempts are known in many bird populations (e.g., Wang *et al.* 2021).

However, high ambient temperature may also play a role. Because of the southern location and the additional urban heat effect, the swallows in Kaohsiung should experience some of the highest temperature levels of any

urban swallows in Taiwan. It has been well established that high ambient temperatures can cause physiological stress and hyperthermia in nestlings, which lead to various detrimental effects including death (Mertens 1977a; Mertens 1977b; Murphy 1985; Salaberria *et al.* 2014; Catry *et al.* 2015; Rodríguez and Barba 2016; Imlay *et al.* 2019). For example, in experimentally heated nests, heated nestlings were lighter on their 15th day after hatching than control nestlings, but only when outside temperatures were also relatively high (Rodríguez and Barba 2016). Consequently, Rodríguez and Barba (2016) argued that ambient temperatures $> 34^{\circ}\text{C}$ begin to cause negative effects on nestling physiology. This upper-temperature threshold was supported by other studies; e.g., nestling survival declined when internal nestbox temperatures exceeded 35°C (Ardia 2013), and various indicators of nestling growth and survival were reduced by temperatures $> 32^{\circ}\text{C}$ (Geraert *et al.*

1996; Quinteiro-Filho *et al.* 2010; Cunningham *et al.* 2013). Even adult wild birds lost body weight when maximum air temperatures exceeded 35.5 °C (Du Plessis *et al.* 2012). Interestingly, a study of two Chinese populations showed that nestling survival decreased with increasing temperatures at the tropical site, but not at the temperate site (Tian *et al.* 2022), which supports the detrimental effect of very high temperatures on barn swallow nestlings. The possibly detrimental role of high temperatures on nestling growth and survival should also be investigated in Taiwan, possibly even by citizen scientists (see our four suggestions below).

The normal clutch size for barn swallows in our study was 3-5 eggs with a mean of 3.9 ± 1.0 , which is very similar to the mean of 4.4 ± 1.1 and 4.1 ± 1.1 reported by Wang *et al.* (2021) for the first and second breeding attempt, although their clutch size decreased

to 2.8 ± 1.7 during the third breeding attempt. The clutch sizes for a southern and a northern Chinese population were 4.33 ± 0.87 eggs and 4.62 ± 0.80 eggs, respectively (Tian *et al.* 2022). The clutch sizes for the first and second breeding attempt were 4.8 ± 0.9 eggs and 4.3 ± 0.5 eggs in a South Korean study, respectively (Choi and Kwak 2019).

The few clutches smaller than three eggs in our study seem to be anomalies. The two clutches of two eggs each during the first breeding attempt (Fig. 7) were likely abandoned or predated because the eggs had disappeared after only 1-2 weeks. During the second breeding attempt (Fig. 8), one nest contained one egg from 17 July until the end of the surveys; we assume that this egg was abandoned. Furthermore, there were two clutches of two eggs each which disappeared after only one week, but one clutch of two eggs actually produced two fledglings.

Clutch size predicted the number of

nestlings and fledglings, although with much unexplained variation (82% and 91%, respectively). Thus, clutch size was not a good predictor of the number of nestlings or fledglings. However, the linear relationship between the number of nestlings and fledglings explained 46% of the variation, so clearly the number of hatched young was a somewhat decent predictor of the number of successfully fledged young.

The mean number of nestlings and fledglings in our study was 2.5 ± 1.6 and 1.5 ± 1.5 , respectively. These numbers are substantially lower than the respective means of 3.0 ± 1.8 and 3.0 ± 1.9 for nestlings and 2.7 ± 1.7 and 2.2 ± 1.8 for fledglings reported by Wang *et al.* (2021) for their first and second breeding attempts (their numbers further decreased for the third breeding attempt). Again, this difference may be due to the higher temperatures at our study site.

Severinghaus *et al.* (2017) provides some natural history information on

Taiwanese barn swallows. First, they state that the barn swallow commonly has two clutches per year, one in April and a second one in July. While our first clutch was also in April, the second clutch was from early to mid-May until early June, much earlier than stated in Severinghaus *et al.* (2017). Again, this difference might be due to the higher temperatures in southern Taiwan. Wang *et al.* (2021) even reported up to three clutches in Taipei in northern Taiwan where temperatures are lower than in Kaohsiung. In southern China, the breeding season of barn swallows lasted from February to July in one study (Tian *et al.* 2022) and from April to July in another study, with up to three breeding attempts per season (Pagani-Núñez *et al.* 2016). In northern China, it lasted from May to August (Tian *et al.* 2022). Severinghaus *et al.* (2017) further wrote that “incubation takes 14-15 days” and “nestlings fledge at about 20 days, but remain near the parents post-fledging.”

We also observed such lengths of time in most cases.

This study should mainly be seen as a pilot study or a proof-of-concept study. Therefore, the main result is that it is possible to conduct long-term monitoring of urban swallow populations with little training and minimal equipment (mirror on stick, flashlight, pen, and paper) and only a moderate investment of time and effort as long as the nests are accessible, as was in our case. Indeed, the second author (HY) had no prior experience in ornithological fieldwork but was trained by the first author within a short period of time. After that, he conducted the field work completely independently from the first author. In essence, the second author was a “citizen scientist” in the true sense of the word; a regular citizen who became interested enough to spend the time and effort in order to be able to record something interesting about the natural world.

With this pilot study as well as the

experiences gained by the first author during his multi-year study conducted in Taipei (unpublished data), we were able to demonstrate that the documentation of the breeding phenology and breeding success of barn swallows and possibly other swallow species is easily possible by citizen scientists. Therefore, we suggest that the implementation of a nationwide monitoring network of urban swallows would have the following benefits.

1. The Taiwan BBS monitors population changes, but it generates no data on breeding phenology and breeding success. Monitoring bird populations such as swallows would augment the BBS with data on breeding phenology and breeding success, which can then be linked to variables related to weather, climate change, urban environment, and so on. Thus, inferring causal changes for bird population changes may become stronger, such as the influence of artificial light (Dominoni *et al.* 2020; Wang *et al.*

2021), breeding date (Pagani-Núñez *et al.* 2016), climate change (Cooper *et al.* 2014; García-Pérez *et al.* 2014) or nest-site selection (Safran 2006) on breeding phenology and breeding success.

2. Since swallows are extremely easy to monitor, they should be an ideal study species for student or citizen science monitoring projects, even including children and high school students. To be able to monitor a bird species without much prior knowledge and with little equipment can entice more people to become enthusiastic citizen scientists, which then often leads to these people to become interested in birdwatching, conservation work, and environmental advocacy. Children and teenagers are especially interested in observing natural phenomena, and interactions with nature are important for their mental and physical development and well-being (Taylor *et al.* 2001; Louv 2009; Moss 2012; Zhang *et al.* 2014). Still, school children in Taiwan spend

way too much time in the classroom and too little outside experiencing the real world as it is (CNA 2020).

3. Swallows are insectivores which consume large amounts of insects, including noxious ones, such as flies, mosquitoes, and plant pests. Therefore, they could be used for educational purposes, such as illustrating the ecosystem services of birds (Whelan *et al.* 2015; Sekercioglu *et al.* 2016; Michel *et al.* 2020) and a healthy urban environment (Dearborn and Kark 2009; Goddard *et al.* 2009; Ahern *et al.* 2014). Many Taiwanese people have a positive attitude towards nesting swallows (see Introduction), and therefore swallows would make a great “mascot” or “messenger” for attracting people to learn about birds and perhaps also become citizen scientists who collect data about breeding behavior.

4. Of course, the purely observational approach used in this study is not useful if more detailed data need to

be gathered, e.g., blood samples or the changing weight of the nestlings, but the advantages are that it is very easy to learn and quick to conduct with minimal disturbance to the breeding birds, which is essential for citizen scientist studies. Nevertheless, one could imagine that the monitoring could be expanded to gather more scientific data. For example, we suggested several times above in the Discussion that temperature is an important factor influencing breeding phenology and success. However, we did not collect any data to support this supposition. Citizen scientists could perhaps quickly measure the ambient temperature every time they visit the nest, or, even better, continuous temperature monitors could be installed and maintained by the citizen scientists (Croston *et al.* 2018). Another factor which influences breeding success and even adult survival is parental visitation rates (Öberg *et al.* 2015) and nest predation (Wang and Hung

2019). Again, citizen scientists could record visitation rates for a period of time (e.g., 30 minutes) or could install and maintain data-loggers (Pierce and Pobprasert 2013; Öberg *et al.* 2015). In short, monitoring by citizen scientists of swallow nests allows many possibilities to collect interesting and valuable scientific data.

CONCLUSION

These benefits should also apply to many other countries which have easily observable urban swallow populations, e.g., China, Malaysia, and South Korea (Pagani-Núñez *et al.* 2016; Choi and Kwak 2019; Jiang *et al.* 2019; Mansor *et al.* 2021; Tian *et al.* 2022; Zhao *et al.* 2022; Kim *et al.* 2023). Notably, China has barn swallow populations in most cities (Zhao *et al.* 2021) as well as a burgeoning community of dedicated birdwatchers (Walther and White 2018), and successful citizen science projects have already been conducted, e.g., for

the scaly-sided merganser (*Mergus squamatus*) (Zeng *et al.* 2018). Citizen science is now used worldwide to monitor biodiversity at various spatial and temporal scales (e.g., Dickinson *et al.* 2010; Hochachka *et al.* 2012; Sullivan *et al.* 2014; Chandler *et al.* 2017; Hong *et al.* 2018). We here add a simple and non-intrusive citizen science method for monitoring the breeding phenology and breeding success of urban swallows, which we hope will find widespread adaptation in many places and situations.

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Table 1. English and Chinese names of the streets in Gushan District, Kaohsiung, which we regularly monitored for barn swallow nests during our study.

表格 1. 我們在研究期間定期監測的家燕巢位於高雄市鼓山區街道的英文和中文名稱。

English street name	Chinese street name
Binhai 1 st Road	濱海一路
Binhai 2 nd Road	濱海二路
Chang-an Street	長安街
Gunan Street	鼓南街
Gu-po Street	鼓波街
Guyuan Street	鼓元街
Linhai 1 st Road	臨海一路
Linhai 2 nd Road	臨海二路
Lisyong Street	麗雄街
Yanping Street	延平街



Fig. 1. A typical porch (or colonnade) of a Taiwanese city house in Xinyi District, Taipei. The vertical walls inside these colonnades are preferred nesting places for swallows (white arrow). Insert: Four barn swallow nestlings a few days before they fledge (16 May 2013). Photos taken by the first author.

圖 1. 台北市信義區台灣城市住宅的典型門廊（或柱廊）。這些柱廊內的垂直牆壁是燕子的首選築巢地（白色箭頭）。插入：離巢前幾天的四隻家燕幼鳥（2013 年 5 月 16 日）。照片由第一作者拍攝。



Fig. 2. Left: A closed-tunnel nest of the striated swallow attached to the corner of a colonnade's roof. Right: Two open bowl-shaped nests of the barn swallow attached to the vertical wall just below a colonnade's roof. Sometimes, people provide the swallows with a nesting platform or basket, such as the nest on the right. Photos taken by the first author in Gushan District, Kaohsiung (left panel, 12 August 2020) and Xinyi District, Taipei (right panel, 3 June 2013).

圖 2. 左圖：赤腰燕在封閉隧道內的巢穴，附著在柱廊屋頂的一角。右圖：兩個開放的碗狀家燕燕巢附著在柱廊屋頂下方的垂直牆上。有時，人們會為燕子提供築巢的平台或籃子，例如右側的巢穴。第一作者在高雄市鼓山區（左圖，2020 年 8 月 12 日）和台北市信義區（右圖，2013 年 6 月 3 日）拍攝的照片。



Fig. 3. Map of the study area in Gushan District, Kaohsiung. Both sides of each street within the red line were monitored for barn swallow nests, including all the streets along the border. Map made by the second author.

圖 3. 高雄市鼓山區研究區域地圖。家燕巢穴的監測範圍為紅線內每條街道兩側（包括邊界沿線的所有街道）。地圖由第二作者製作。



Fig. 4. The first author holding a mirror attached to a long metal stick to peer inside one of the barn swallow nests found inside a city house's colonnade. Photo taken by the second author in Gushan District, Kaohsiung (12 August 2020).

圖 4. 第一作者拿著一面附在一根長金屬棒上的鏡子，觀察在城市房屋柱廊內發現的一個家燕燕巢的內部。照片由第二作者在高雄市鼓山區拍攝（2020年8月12日）。



Fig. 5. Barn swallow nestlings (left panel, 8 May 2013) and fledglings (right panel, 17 May 2013) as defined for the purpose of this study (see Methods for details). Photos taken by the first author in Xinyi District, Taipei.

圖 5. 為本研究目的而定義的家燕雛鳥（左圖，2013 年 5 月 8 日）和幼鳥（右圖，2013 年 5 月 17 日）（詳見方法）。照片由第一作者在台北市信義區拍攝。

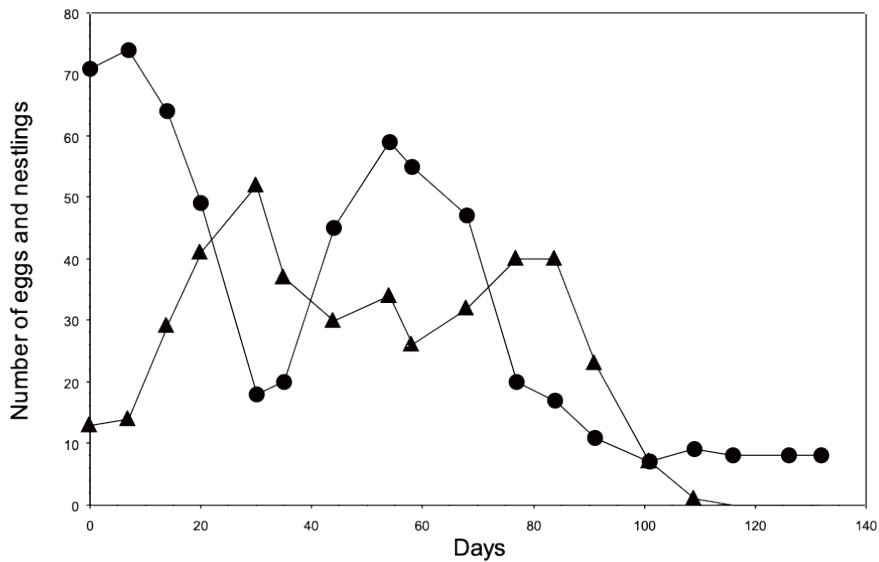


Fig. 6. The number of eggs (full circles) and nestlings (full triangles) observed in 46 active barn swallow nests from 7 April to 17 August 2019 in Gushan District of Kaohsiung (days 0-23 represent April, days 24-54 represent May, days 55-84 represent June, days 85-115 represent July, and days 116-132 represent August).

圖 6. 2019 年 4 月 7 日至 8 月 17 日高雄市鼓山區 46 個活躍燕巢觀察到的蛋（實心圓圈）和雛鳥（實心三角形）數量（第 0-23 天代表 4 月，第 24-54 天代表 5 月，天數 55-84 日代表 6 月，85-115 日代表 7 月，116-132 日代表 8 月）。

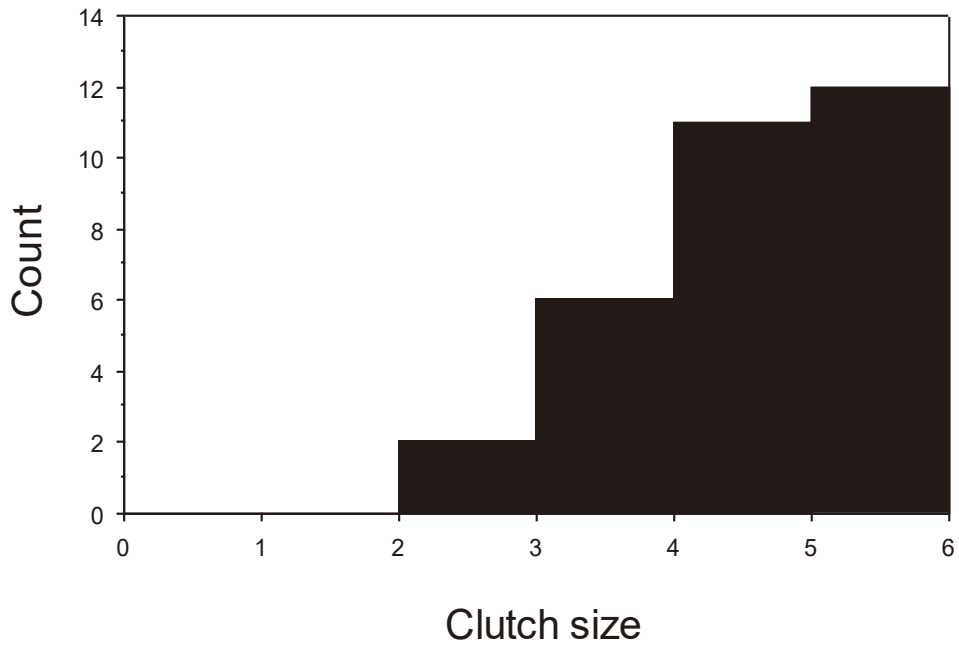


Fig. 7. Histogram of the clutch sizes of the 31 nests of the first breeding attempt.

圖 7. 第一次繁殖嘗試的 31 個燕巢窩卵數直方圖。

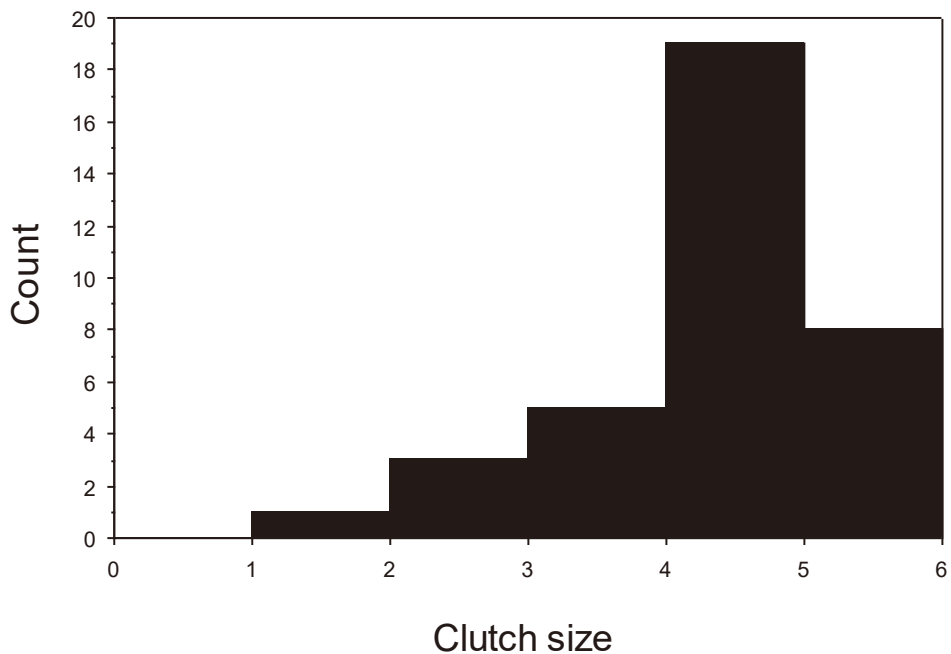


Fig. 8. Histogram of the clutch sizes of the 36 nests of the second breeding attempt.

圖 8. 第二次繁殖嘗試的 36 個燕巢窩卵數直方圖。

Dataset of long-term bird monitoring in Qigu wetlands, Taiwan

七股濕地長期鳥類監測調查資料集

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Abstract

Qigu, located on the southwest coast of Taiwan, is one of the internationally significant sites in the East Asian-Australasian Flyway. Various types of waterbirds inhabit this region due to its distributed natural wetlands and periodically drained fish farms. Qigu also supports approximately 15-20% of the wintering population of the globally endangered black-faced spoonbills (*Platalea minor*) and has been designated as an Important Bird Area (IBA) by BirdLife International. Taiwan Endemic Species Research Institute (TESRI) (currently known as Taiwan Biodiversity Research Institute, TBRI) initiated a long-term systematic bird monitoring project in Qigu in 2015. In the period from April, 2015, to March, 2021, monthly bird censuses were conducted at six

sampling sites within Qigu, resulting in 432 sampling events and 11,533 occurrence records. A total of 100,601 bird individuals, representing 120 species across 36 families, were counted and documented. The most dominant family is Ardeidae, followed by Scolopacidae, Anatidae, Recurvirostridae, and Charadriidae.

Keywords: Aves, bird census, southwest coast of Taiwan, Important Bird Area, fish farms

摘要

七股地處臺灣西南沿海，有豐富的天然濕地與定期曬池魚塭分布，為許多遷徙性水鳥提供良好棲地，是東亞澳遷徙線上之重要節點。國際瀕危鳥種黑面琵鷺每年約有 15-20% 的度冬族群棲息於七股，國際鳥盟亦將此地劃設為重要野鳥棲地。特有生物研究保育中心（農業部生物多樣性研究所前身）於 2015 年 4 月開始執行七股濕地之長期鳥類監測計畫，於 6 個調查樣點進行每月 1 次之鳥類調查，截至 2021 年 3 月累計進行 432 次樣點調查，取得 11,533 筆鳥類調查紀錄，包含 36 科 120 種 100,601 隻次。其中最優勢的科別為鷺科，其次依序為鷸科、鴨科、長腳鷸科及鶺鴒科。

關鍵詞：鳥類、鳥類監測調查、西南沿海、重要野鳥棲地、魚塭

Introduction

The East Asian-Australasian Flyway (EAAF), stretching from eastern Russia to New Zealand, is one of the globally recognized flyways for migratory waterbirds (Boere and Stroud 2006). The EAAF is used by approximately 201 species of waterbirds (Kirby *et al.* 2008), and the total number of shorebirds within this flyway is estimated to be at least 8 million (Bamford *et al.* 2008). However, populations of many waterbird species in this major flyway are undergoing rapid decline (Wilson *et al.* 2011; Clemens *et al.* 2016). Long-term systematic monitoring for waterbirds within the EAAF is therefore necessary for population tracking and conservation decision-making (Hansen *et al.* 2016).

Qigu, located on the southwest coast of Taiwan, is one of the internationally significant sites in the EAAF (Bamford *et al.* 2008). This region is full of natural wetlands and periodically drained fish farms, therefore providing habitats for

various types of waterbirds (Huang and Hsueh 2014). Qigu supports approximately 15-20% of the wintering population of the globally endangered black-faced spoonbills (*Platalea minor*) (Yu *et al.* 2021; Taiwan Black-Faced Spoonbill Conservation Association 2021), and has been designated as an Important Bird Area (IBA) by BirdLife International (Chan *et al.* 2004).

Although the importance of Qigu in supporting migratory waterbirds has been well-recognized, long-term population data for most species in this region are still insufficient. Therefore, Taiwan Endemic Species Research Institute (TESRI) (currently known as Taiwan Biodiversity Research Institute, TBRI) initiated a long-term systematic bird monitoring project in Qigu in 2015. In the period from April, 2015, to March, 2021, (72 months in total), monthly bird censuses were conducted at six sampling sites within Qigu, resulting in 432 sampling events and 11,533

occurrence records. A total of 100,601 bird individuals, representing 120 species across 36 families, were counted and documented (Fig. 1 & Fig. 2). All of these records were organized into an open dataset using Darwin Core (DwC) Archive format. This monitoring project is still in progress, and the dataset may be updated in the future.

Project details

Project title: Long-term bird monitoring project in Qigu wetlands

Funding: Funding from the Endemic Species Research Institute, Council of Agriculture, Executive Yuan, R.O.C. (Taiwan).

Study area description: The study area of this project is the southwestern part of Qigu District (in Tainan City), which is located on the southwest coast of Taiwan (23.07206°N to 23.10149°N, 120.03645°E to 120.08831°E). The landscape of this region is composed of various natural and artificial wetlands

(e.g. fish farms), and therefore provides suitable habitats for waterbirds, especially those migrating along the East Asian–Australasian Flyway (EAAF). Based on the weather data of the past 10 years (2013-2022) from the Qigu weather station (23.14719°N, 120.08619°E), the average temperature here is 24.1°C. The month with lowest temperature is January (17.3°C), while the month with highest temperature is July (29.2°C). The average annual precipitation is 1510.2 mm, and the seasonality of precipitation is typically obvious. From May to September, the monthly precipitation is above 160 mm, but it declines to less than 80 mm from October to April.

Design description: This project is meant to establish baseline data of the avian community in the Qigu wetlands by means of long-term periodic bird censuses at selected sampling sites.

Taxonomic coverage

General taxonomic coverage

description: A total of 120 bird species, spanning 36 families and 16 orders, are included in this dataset. The most dominant family (the family with the most individuals recorded) is Ardeidae (27,654), followed by Scolopacidae (15,777), Anatidae (12,074), Recurvirostridae (9,617), and Charadriidae (8,326). The family with the most species recorded is Scolopacidae (25 species), followed by Ardeidae (11 species), Charadriidae (8 species), Anatidae (7 species), and Laridae (7 species) (Table 1). The most dominant species is little egret (*Egretta garzetta*), followed by great egret (*Ardea alba*), black-winged stilt (*Himantopus himantopus*), Kentish plover (*Charadrius alexandrinus*), and Eurasian tree sparrow (*Passer montanus*).

Spatial coverage

General spatial coverage: The dataset includes sampling events in the southwestern part of Qigu District (in

Tainan City), which is located on the southwest coast of Taiwan.

Coordinates: 23.07206°N to 23.10149°N (latitude); 120.03645°E to 120.08831°E (longitude).

Temporal coverage:

April 29, 2015-March 8, 2021

Methods

Study extent description: Six representative sites within southwestern Qigu District were selected as the sampling sites of this monitoring project (as shown in column “locality” of the DwC Occurrence Extension), including Lighthouse Fish Farms (LHF), North Fish Farms (NFF), East Fish Farms (EFF), Qigu Levee (QGL), American Fish Farm Ruins (AFR), and American Fish Farms (AFF) (Fig. 3). Bird censuses were conducted once a month at these six sampling sites from April, 2015, to March, 2021. The main habitat type within these sampling sites are fish farms for clams (*Meretrix lusoria*) or milkfish

(*Chanos chanos*), while the habitat environment still slightly differs between sites (more details in Table 2).

Sampling method description: The monthly bird censuses at LHF, NFF, EFF, and QGL were conducted using transect method (as shown in column “samplingProtocol” of the DwC Event Core). These transects are usually trails beside fish farms (at LHF, NFF, EFF) or along the levee (at QGL), with the length ranging from 0.826 km to 3.129 km. In contrast, monthly censuses at AFR and AFF were conducted using counting flocks method, which means counting flocks of birds within a predefined area. The sampling areas of AFR and AFF are 9.8 ha and 22.4 ha, respectively (Table 2). Bird censuses were all conducted during daytime (mostly between 9 a.m. and 5 p.m.), with no strict limitation on the starting time and duration of each census.

Quality control description: All of the monthly bird censuses were carried

out by one to three experienced and well-trained bird observers. To keep the quality steady, only five observers (including two main observers and three occasionally assistant observers) have been involved during the time coverage of this dataset (April, 2015, to March, 2021). All of the occurrence records were integrated and examined after each census. Any uncommon or abnormal records will be confirmed, and modifications will be made if necessary. The taxonomy information in this dataset is organized based on the eBird Taxonomy v2022 (Clements *et al.* 2022) and the 2023 TWBF Checklist of the Birds of Taiwan (Ding *et al.* 2023).

Method step description: All of the six sampling sites and the corresponding census methods were determined at the beginning of this project. For the transect censuses (at LHF, NFF, EFF, and QGL), a team of observers walked along a predefined transect and recorded the birds nearby. For the

counting flocks censuses (at AFR and AFF), observers counted and recorded the birds within a predefined area, which is typically composed of several fish farms. Observers used binoculars (typically 10x42) and/or monoculars (20-60x) to detect and observe birds in all censuses, and recorded bird species as well as the number of individuals. Birds seen or heard by the observers were all recorded, except for those birds only flying through sampling area without perching or foraging behaviors. The weather condition determined by visual observation was also recorded for each census (presented as a categorical variable in the DwC Measurement or Facts Extension). Each monthly census at each of the six sampling sites is regarded as a sampling event (as shown in column “eventID” of the DwC Event Core). It should be noted that from April, 2015, to around June, 2018, all of the bird occurrences within a single sampling event were recorded at the

same coordinate, which is the centroid coordinate of the sampling site. However, the bird occurrences were recorded at the coordinate of several distinct locations, which correspond to different sections along the transect or different districts within the site, since around June, 2018 (the time points slightly differ between sampling sites, see Table 2 & Table 3 for details). The change of recording protocol can be observed through columns “locationID,” “decimalLatitude,” and “decimalLongitude” of the DwC Occurrence Extension.

Dataset

Dataset description

Object name: Darwin Core Archive Dataset of long-term bird monitoring in Qigu wetlands, Taiwan

Character encoding: UTF-8

Format name: Darwin Core Archive format

Format version: 1.0

Distribution:

<https://www.gbif.org/dataset/346c95bec7b3-41dc-99c9-e88a18d8884a> (GBIF)
<https://doi.org/10.15468/4a97qb> (DOI)
https://ipt.taibif.tw/resource?r=cgbs_tesri_2021 (TaiBIF IPT)

Publication date of data: 2023-07-20

Language: English

Licences of use: This work is licensed under a Creative Commons Attribution (CC-BY) 4.0 License (<https://creativecommons.org/licenses/by/4.0/legalcode>).

Metadata language: English

Date of metadata creation: 2023-07-20

Hierarchy level: Dataset

Darwin Core Terms used in the dataset:

eventID, parentEventID, eventDate, eventTime, samplingProtocol, sampleSizeValue, sampleSizeUnit, country, countryCode (**DwC Event Core**); occurrenceID, type, basisOfRecord, locationID, locality, decimalLatitude, decimalLongitude, coordinateUncertaintyInMeters, geodeticDatum,

verbatimCoordinateSystem, coordinatePrecision, order, family, scientificName, vernacularName, individualCount, taxonRank, recordedBy (**DwC Occurrence Extension**); measurementID, measurementType, measurementValue, measurementUnit, measurementDeterminedDate, measurementDeterminedBy, measurementMethod, measurementRemarks (**DwC Measurement or Facts Extension**).

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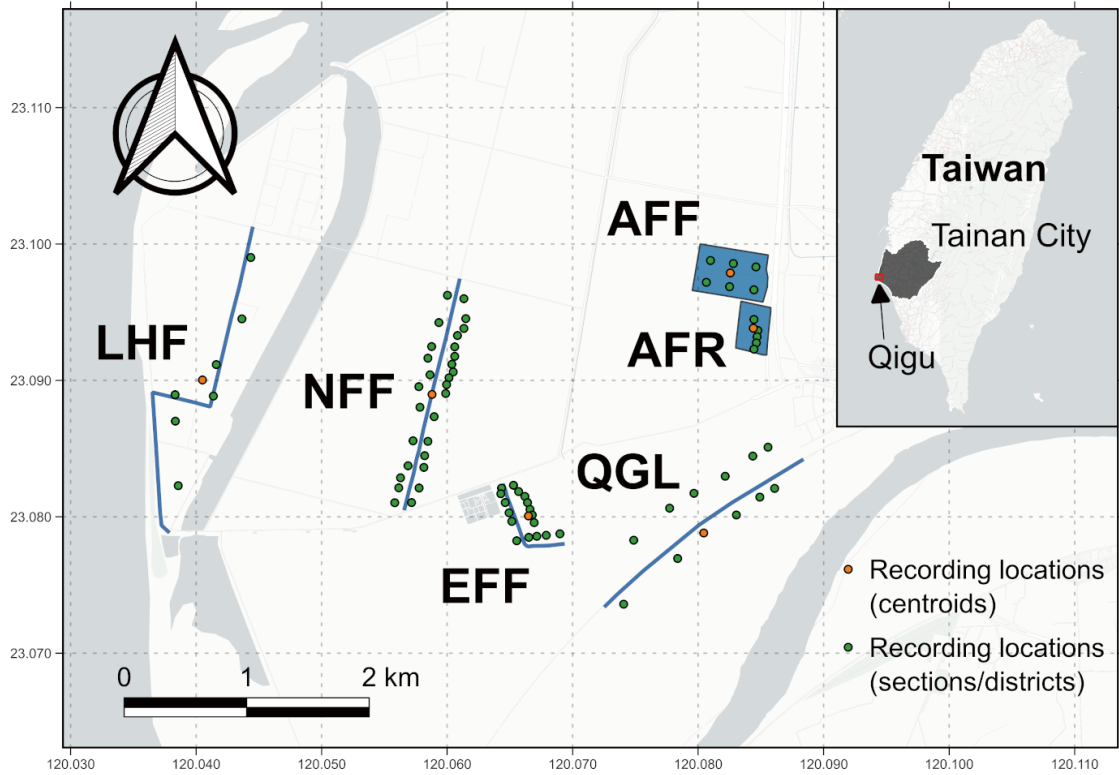


Fig. 3. Distribution of sampling sites and recording locations.

圖 3、調查樣點及記錄座標位置圖。

Table 1. List of orders and families in the dataset with numbers of species and individual counts.

表 1、資料集內目、科、每科物種數及個體隻次列表。

Order	Family	No. of Species	Individual Count
Anseriformes	Anatidae	7	12,074
Galliformes	Phasianidae	1	88
Podicipediformes	Podicipedidae	1	1,349
Columbiformes	Columbidae	3	2,681
Cuculiformes	Cuculidae	1	11
Gruiformes	Rallidae	5	962
Charadriiformes	Recurvirostridae	2	9,617
	Charadriidae	8	8,326
	Rostratulidae	1	40
	Jacanidae	1	1
	Scolopacidae	25	15,777
	Glareolidae	1	56
	Laridae	7	3,855
Suliformes	Phalacrocoracidae	1	6
Pelecaniformes	Ardeidae	11	27,654
	Threskiornithidae	3	5,040
Accipitriformes	Pandionidae	1	9
	Accipitridae	4	172
Bucerotiformes	Upupidae	1	1
Coraciiformes	Alcedinidae	1	45
Piciformes	Picidae	1	9
Falconiformes	Falconidae	1	12
Psittaciformes	Psittacidae	1	1
Passeriformes	Dicruridae	2	402
	Laniidae	2	432
	Corvidae	1	209
	Alaudidae	1	116
	Cisticolidae	4	1,012
	Hirundinidae	4	1,279

Pycnonotidae	1	1,337
Zosteropidae	1	446
Sturnidae	5	2,187
Muscicapidae	3	74
Estrildidae	2	932
Passeridae	1	4,275
Motacillidae	5	114

Table 2. List of sampling sites and associated information.

表 2、調查樣點列表及相關資訊。

Site Code	Site Name	Habitat Type	Census Method	Length/Area	Centroid Coordinate (WGS 84)	Census Period	Recording Location
LHF	Lighthouse Fish Farms	fish farms (clams, milkfish, shrimps); abandoned fish farms	transect	3.129 km	23.09003°N, 120.04050°E	2015/04~ 2018/06	1 location: LHF
		2018/07~ 2021/03				7 locations: LHF01, LHF02, LHF03, LHF04, LHF05, LHF06, LHF07	
NFF	North Fish Farms	fish farms (clams)	transect	1.904 km	23.08897°N, 120.05879°E	2015/04~ 2018/09	1 location: NFF
						2018/10~ 2021/03	29 locations: NFFc01, NFFc02, NFFc03, NFFc04, NFFc05... NFFc30 (There is no NFFc08 because it was combined with NFFc07.)
EFF	East Fish Farms	fish farms (clams)	transect	0.826 km	23.08006°N, 120.06647°E	2015/04~ 2018/07	1 location: EFF
						2018/08~ 2021/03	17 locations: EFFa01, EFFa02, EFFa03, EFFa04, EFFa05... EFFa17
QGL	Qigu Levee	abandoned fish farms; farmland	transect	1.997 km	23.07881°N, 120.08044°E	2015/04~ 2018/06	1 location: QGL
						2018/07~	7 locations:

		(shallots)				2019/02	QGL01, QGL02, QGL03, QGL04, QGL05, QGLAF, QGLFL
							9 locations: QGL01, QGL02, QGL03, QGL04, 2019/03~ QGL05, 2021/03 QGLAF1, QGLAF2, QGLFL1, QGLFL2
AFR	American Fish Farm Ruins	abandoned fish farms	counting flocks	9.82 ha	23.09383°N, 120.08439°E	2015/04~ 2018/06	1 location: AFR
							5 locations: 2018/07~ AFR00, AFR01, 2021/03 AFR02, AFR03, AFR04
AFF	American Fish Farms	fish farms (milkfish fingerlings)	counting flocks	22.4 ha	23.09788°N, 120.08256°E	2015/04~ 2018/07	1 location: AFF
							6 locations: 2018/08~ AFFf01, AFFf02, 2021/03 AFFf03, AFFf04, AFFf05, AFFf06

Table 3. Coordinates (WGS84) of recording locations.

表 3、紀錄點位的經緯度座標 (WGS84)

Recording Location	Latitude (degree)	Longitude (degree)	Recording Location	Latitude (degree)	Longitude (degree)
LHF	23.09003	120.04050	EFFa03	23.08104	120.06462
LHF01	23.08228	120.03857	EFFa04	23.08029	120.06493
LHF02	23.08701	120.03834	EFFa05	23.07966	120.06515
LHF03	23.08895	120.03832	EFFa06	23.07824	120.06554
LHF04	23.08885	120.04137	EFFa07	23.08231	120.06528
LHF05	23.09116	120.04160	EFFa08	23.08185	120.06569
LHF06	23.09451	120.04364	EFFa09	23.08149	120.06619
LHF07	23.09901	120.04435	EFFa10	23.08104	120.06640
NFF	23.08897	120.05879	EFFa11	23.08054	120.06660
NFFc01	23.09624	120.06002	EFFa12	23.08013	120.06678
NFFc02	23.09424	120.05934	EFFa13	23.07957	120.06693
NFFc03	23.09248	120.05876	EFFa14	23.07849	120.06650
NFFc04	23.09163	120.05846	EFFa15	23.07857	120.06714
NFFc05	23.09041	120.05863	EFFa16	23.07864	120.06789
NFFc06	23.08954	120.05774	EFFa17	23.07875	120.06898
NFFc07	23.08803	120.05783	QGL	23.07881	120.08044
NFFc09	23.08557	120.05728	QGL01	23.07359	120.07406
NFFc10	23.08374	120.05688	QGL02	23.07828	120.07486
NFFc11	23.08286	120.05628	QGL03	23.07694	120.07836
NFFc12	23.08212	120.05614	QGL04	23.08063	120.07772
NFFc13	23.08103	120.05582	QGL05	23.08172	120.07966
NFFc14	23.09599	120.06133	QGLAF	23.08445	120.08435
NFFc15	23.09453	120.06148	QGLAF1	23.08510	120.08556
NFFc16	23.09381	120.06133	QGLAF2	23.08297	120.08215
NFFc17	23.09329	120.06082	QGLFL	23.08144	120.08491
NFFc18	23.09246	120.06060	QGLFL1	23.08208	120.08609
NFFc19	23.09176	120.06060	QGLFL2	23.08013	120.08304
NFFc20	23.09118	120.06037	AFR	23.09383	120.08439
NFFc21	23.09062	120.06048	AFR00	23.09447	120.08444

NFFc22	23.09019	120.06014	AFR01	23.09366	120.08475
NFFc23	23.08969	120.05995	AFR02	23.09320	120.08469
NFFc24	23.08904	120.05988	AFR03	23.09275	120.08463
NFFc25	23.08734	120.05896	AFR04	23.09229	120.08444
NFFc26	23.08553	120.05846	AFF	23.09788	120.08256
NFFc27	23.08448	120.05820	AFFf01	23.09832	120.08460
NFFc28	23.08362	120.05814	AFFf02	23.09857	120.08280
NFFc29	23.08211	120.05776	AFFf03	23.09879	120.08098
NFFc30	23.08104	120.05716	AFFf04	23.09664	120.08444
EFF	23.08006	120.06647	AFFf05	23.09687	120.08250
EFFa01	23.08210	120.06433	AFFf06	23.09719	120.08065
EFFa02	23.08169	120.06427			

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4. Corresponding author is required to sign a Copyright Transfer Agreement for the paper accepted for publication to the journal publisher, the Taiwan Biodiversity Research Institute.

II. Manuscript Preparation:

1. Research paper: Manuscript should be written in a sequence of 1) Title, 2) Authors' full name 3) Author(s) affiliations(s) and address(es), 4) Abstract, 5) Key words, 6) Introduction, 7) Materials and methods, 8) Results, 9) Discussion, 10) Conclusions, 11) Acknowledgements, 12) Literature Cited. Of them 1 to 5 should be written in dual languages, Chinese and English.

2. Data paper: Manuscript should be written in a sequence of 1) Title, 2) Authors full name, 3) Author(s) affiliations(s) and address(es), 4) Abstract, 5) Key words, 6) URL of the website where the dataset and metadata are available. The dataset and metadata should be built in the international standard formats of Darwin Core (DwC) and Ecological Metadata Language (EML). For species occurrence open data repositories, Global Biodiversity Information Facility (GBIF) is suggested. Author(s) must confirm the correctness and authenticity of the data prior to submission. The data should be readable and its meaning obvious for the data user(s). Importantly, if anomalies, outliers, and/or missing values are included in the data, a distinct number or symbol should be used to clearly identify those values. Metadata should be written at least in 1) Dataset content, 2) Coverage (including Taxonomic, Spatial and Temporal aspects), 3) Methods, 4) Intellectual property rights disclaimer. To promote the free dissemination of biodiversity open data, author(s) should not assert any proprietary rights to the dataset and metadata. For example, This {DATA(BASE)} is made available under the Open Data Commons Public Domain Dedication and License v1.0. (<http://www.opendatacommons.org/licenses/pddl/1.0/>) This {DATA(BASE)- NAME} is made available under the Open Data Commons Attribution

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3. Cover page should contain title of manuscript, author name(s), author's (s') affiliation(s), corresponding author's name, telephone number, fax number and e-mail address, and a short running title.

4. Title should be less than 30 words. Capitalize the first letter of each word except articles, conjunctions and prepositions.

5. Author's name should be first name first followed by surname. For multiple authors, use a comma to separate the names but the last two names by "and."

6. Running title should be less than 50 letters including spaces.

7. Abstract must be a single paragraph not exceeding 500 words.

8. Key words should be no more than 5 words.

III. Manuscript Format:

1. Manuscript must be typed using standard software (Microsoft Word) with top, bottom, left and right. Mark page numbers on the bottom.
2. Manuscript should be typed in a uniform character size. There is no need to differentiate paragraph, title, subtitle or contents by using large or small characters.
3. Measurements should use International System of Units (kg, mg, km, m, cm... etc.). All numerals or quantities should be expressed in Arabic numbers. Years in the text should use A.D. universally.
4. Figures and tables in the text should be sequenced by Arabic numbers (e.g. Fig.1 and Table 1). Both graphs and photos use same "Fig." designation.
5. Common name of an animal or plant that appears in title and first appears in abstract and text should be accompanied with scientific name. All scientific names in manuscript should be in italics.
6. When citing a reference in text, use surname and year, e.g. (Clough 1998) for single author; use "and" to link authors, e.g. (Pimm and Gittleman 1992) for double authors; and use "et al." e.g. (Baker et al. 1996) for multiple authors. When citing multiple references, separate them with semi-colons in chronological order.
7. Use the following system for arranging references in literature cited.

For journals:

Clough, B. 1998. Mangrove forest productivity and biomass accumulation in Hinchinbrook Channel, Australia. *Mangroves and Salt Marshes* 2: 191-198.

Pimm, S. L. and J. L. Gittleman. 1992. Biodiversity: Where is it? *Science* 255: 910-940.

Baker, C. S., F. Cipriano and S. R. Palumbi. 1996. Molecular genetic identification of whale and dolphin products from commercial markets in Korea and Japan. *Molecular Ecology* 5: 671-685.

For books and symposiums:

Soule, M. E. and B. A. Wilco. 1980. *Conservation biology: An evolutionary-ecological approach*. Sinauer Associates, Sunderland, Massachusetts.

Jinchu, H. and W. Fuwen. 1990. Development and progress of breeding and rearing giant pandas in captivity within China. pp. 322-325. In: H. Jinchu (ed). *Research and progress in biology of the giant panda*. Sichuan Publishing House of Science and Technology, Sichuan, China.

8. Table should be typed on a separate sheet and be headed by a title of dual languages (Chinese and English). It consists of only horizontal lines and typed with English terms (if possible) and Arabic numerals. If foot notes are required, mark with superscripts 1, 2, *, #, etc.
9. Figure should be drawn with black ink on a separate white tracing paper with a figure legend of the dual languages below. Computer graph made from laser printer is acceptable.

10. Photograph should be a glossy black and white shot with sufficient resolution to be clearly legible after reduction. When multiple photos are employed, the author should arrange them in plates. Micrographs should include bars indicating scales of magnification. Photos should be pasted on white A4 paper loosely with the figure legend below.

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