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臺北都會區棲地特性與繁殖鳥種多樣性及 性狀組成的相關性

The associations between habitat characteristics and breeding bird species richness and functional trait composition in the Taipei Metropolitan Area

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摘要

都市化與外來種正改變全球之生物群聚組成、降低物種多樣性並造成生物同質化。本研究探討臺北都會區繁殖鳥種多樣性及性狀組成與都市棲地特性的相關性，以期為生物友善的都市規劃與原生鳥種多樣性損失的調適提供科學依據。本研究在都市化梯度上選取六類棲地進行鳥類調查，並利用空間迴歸模型、RLQ 及四角分析探討地景與樣區尺度的棲地變數與鳥種多樣性及性狀組成間的關係。結果顯示原生、外來鳥種豐富度和個體數量均隨農業覆蓋比例與地景異質度增加而增加。原生鳥種豐富度與個體數量與植被高度成正相關，這應與樹木提供天然食物與棲枝有關。相對地，外來鳥種偏好不透水層覆蓋較高的區域及河濱草坪，而在植被高度較高的區域數量相對較少，此現象可能與優勢外來種，如野鴿、家八哥偏好地面覓食的習性有關。RLQ 及四角分析顯示，在不透水層覆蓋較高的區域，有較多築巢於人為建築、取食人類食物及食性廣度較寬的鳥種；而在植被高度較高的區域，則出現較多食果性與在樹冠層覓食鳥種。綜合而言，若要維持鳥類在物種與性狀的多樣性，建議臺北都會區應保留農田、森林與草地等半自然地景覆蓋，結合較高的地景異質度規劃，與提升都市綠地植被高度，以提供原生鳥類所需的棲地與資源。同時，應減少都市人為活動所提供的食物來源，降低優勢外來鳥種的利用與族群擴張，達到外來種管理與原生鳥類保育的效益。

關鍵詞：原生鳥種、外來鳥種、多樣性、性狀特徵、都市梯度。

Abstract

Urbanization and the biological invasions are reshaping community composition, reducing biodiversity, and driving global biotic homogenization. This study investigated how urban habitat characteristics were associated with the species diversity and

trait composition of breeding birds across a range of urban environments in the Taipei Metropolitan Area. Our aim was to provide scientific evidence to support biodiversity-friendly urban planning and strategies to mitigate the loss of native avian diversity. Bird surveys were conducted across six habitat types along an urbanization gradient, and spatial regression models, RLQ, and fourth-corner analyses were applied to assess the effects of habitat variables on bird diversity and traits at both landscape and local scales. The results showed that the species richness and abundance of both native and alien birds increased with greater agricultural cover and landscape heterogeneity. Native bird species richness and abundance also increased with vegetation height, likely due to the greater availability of natural food resources and perching sites provided by taller trees. In contrast, alien bird species preferred areas with high impervious surface cover and riparian lawns, while avoiding habitats with taller vegetation. This pattern reflected the ground-foraging behavior of dominant alien species, such as *Columba livia* and *Acridotheres tristis*. RLQ and fourth-corner analyses further revealed that areas with higher impervious surface cover were associated with bird species that nest in artificial structures, feed on human-provided food, and exhibit broader dietary breadth. Conversely, areas characterized by taller vegetation supported a higher proportion of frugivorous and canopy-foraging species, reflecting the structural complexity and resource availability provided by mature vegetation. To maintain taxonomic diversity and trait composition of urban bird communities, this study highlights the importance of maintaining semi-natural landscapes, such as agricultural lands, forests, and grasslands, within the Taipei metropolitan area and promoting landscape heterogeneity. Enhancing vegetation structure complexity in urban green spaces can support native bird communities. Moreover, reducing anthropogenic food sources in urban areas can limit the resource use and population expansion of dominant alien bird species, thereby achieving the dual benefits

of invasive species management and native bird conservation.

Keywords: native bird species, alien bird species, diversity, functional trait, urban gradient.

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緒言

都市化透過土地利用方式的改變，重構了生態系的結構與功能，除了導致天然棲地喪失與破碎化，同時也創造出高度人為結構與不透水鋪面的新型棲地，對於全球生物多樣性帶來負面的效應 (McKinney 2008; McDonald *et al.* 2013; Aronson *et al.* 2014; Hastedt and Tietze 2023)。隨都市化程度的增加，物種多樣性降低 (Sol *et al.* 2014)，一些原生鳥種消失 (Davis *et al.* 2013)，外來鳥種則增加 (Sol *et al.* 2012; Cadotte *et al.* 2017)。此外，都市環境的高度相似，使得少數適應都市環境的原生及外來鳥種優勢地存活，造成物種組成同質化 (Marzluff 2001; McKinney 2006)。然而，隨著人口往都市集中，增加都市發展的需

求，實踐生物多樣性友善的都市規劃有助於調適對原生物種多樣性與生態系統功能帶來的負面影響 (McKinney 2006)。

外來種因人類活動引入其自然分布範圍之外，可能透過種間競爭、疾病感染、捕食威脅原生物種生存，造成生態影響 (Simberloff *et al.* 2013)，也導致全球社會的經濟損失 (Vilà *et al.* 2010; Kumschick *et al.* 2013)。外來種成功入侵一個新環境，需經歷運輸、引入新環境 (釋放至野外)、族群建立、擴散等四個階段 (Blackburn *et al.* 2011)。並非所有的外來種引入皆會成功入侵，下列情況可能促進此現象，例如：多次的引入事件、外來種極度適應人類活動且擅於利用人為變更後環境中的資源、新環境中缺少生物控

制互動關係，以及被入侵環境之物種多樣性較低 (Sax and Brown 2000)。都市環境經常成為外來種成功入侵的環境，主要因為環境受到人為高度變更，創造新的生態棲位，減弱生物抵抗，加上較密集的人類活動提高外來種引入的機率 (Sol *et al.* 2017)。釐清都市地區原生、外來鳥種分布與相關的棲地因子，有助於評估現有的外來入侵種問題，並為後續的外來種防治與都市管理提供科學依據 (Cadotte *et al.* 2017; Dyer *et al.* 2017; McKinney and Kark 2017)。

多項全球研究指出，鳥類特定的功能性狀與其在都市環境中的適應能力呈正相關，有助於在天然資源受限的都市中成功存活。觀察到的關鍵功能性狀包含體型、食性、棲地選擇等。體型較大 (Callaghan *et al.* 2019; Palacio 2020) 或較小 (Neate-Clegg *et al.* 2023) 的鳥種曾被報導較為適應都市環境。廣食性鳥種通常較能適應都市環境 (Palacio 2020; Neate-Clegg *et al.* 2023; Yang *et al.* 2023)。此外，偏好取食特定的食物資源，例如：脊椎動物與腐

食 (Palacio 2020)、種子 (La Sorte *et al.* 2018)，或偏向雜食性的鳥種 (Yang *et al.* 2023)，也展現出對都市環境的高度適應力。另外，都市環境特別適合生態棲位較寬廣的鳥種 (Callaghan *et al.* 2019; Neate-Clegg *et al.* 2023)，以及善用人工建物築巢的鳥種 (Neate-Clegg *et al.* 2023; Yang *et al.* 2023)，但對於地面築巢的鳥種則較不利 (Ikin *et al.* 2012; Neate-Clegg *et al.* 2023)。在覓食棲位上，偏好於植被 (La Sorte *et al.* 2018)、地面 (Palacio 2020) 及空中 (La Sorte *et al.* 2018; Palacio 2020) 等不同棲位覓食的鳥種較為適應都市環境。然而，這些與都市鳥類適應性相關的功能性狀可能因都市環境的異質性及生物地理區而有所差異 (Neate-Clegg *et al.* 2023)，這強調了區域性研究的重要性。

臺灣地區過去因鳴禽文化、寵物飼養、宗教放生、賽鴿等活動引入許多外來鳥種 (Su *et al.* 2014)。根據臺灣地區繁殖鳥類大調查在 2011-2019 年間的成果顯示，相較於原生鳥種，外來鳥種在全臺的數量呈現快速成長的

趨勢 (Lin *et al.* 2023)。臺北都會區是臺灣最大的都會區，在近三十年內經歷了 49% 的人口快速成長以及 63.6% 的建地擴張 (Huang and Chiu 2020)。然而，都市周圍仍保留了河濱草地、農田、森林等多樣的土地覆蓋，使其適宜作為探討都市化對鳥類群聚影響的研究區域。

過去在臺灣都會區鳥類多樣性研究，多著重於都市公園綠地 (Lin *et al.* 2008; Chang and Lee 2016; Chang *et al.* 2017; Shih 2018)，因此可能低估周圍其他類型棲地 (如農田) 在鳥類保育上的重要性 (許等 2019; Hastedt and Tietze 2023)。此外，研究若未區分原生種及外來種 (Shih 2018)，可能導致物種多樣性被高估，進而產生對生物多樣性的誤判。Chang *et al.* (2017) 分析了臺北市 283 處綠地的鳥種多樣性，並區分原生與外來鳥種，發現當綠地內部具有較高的草坪覆蓋、常態化差異植生指標 (Normalized Difference Vegetation Index，後稱 NDVI) 及水域覆蓋，觀察到較多的原生鳥種數，而在 NDVI 值較高，但灌叢覆蓋較低

的綠地中，外來鳥種出現機率增加。Shih (2018) 針對臺北市 30 處公園綠地調查發現，整體鳥種數隨水域存在與棲地異質度的增加而增加。在鳥種性狀方面，都市綠地的外來種及高度適應人類的鳥種偏好出現在開闊林地及地面短草坪的環境 (Chang *et al.* 2017)，且多數都市鳥種以雜食及地面覓食為主 (Shih 2018)。這些研究說明了都市綠地中不同土地覆蓋與棲地結構，對鳥類多樣性與性狀的影響。

本研究以臺北都會區環境梯度上的繁殖鳥類群聚為對象，探討地景與樣區尺度多項棲地變數與鳥類多樣性的相關性，並區分為原生、外來鳥種。為了解鳥類群聚組成、棲地特性及鳥種性狀的相關性，透過四角 (Fourth-corner method) 及 RLQ 分析法，整合環境變數 (R)、鳥種組成 (L) 及物種特性 (Q) 等資料，鑑別那些鳥種性狀隨棲地特徵變化而改變 (Dray *et al.* 2014)。預期在鳥種多樣性方面，隨都市環境中不透水層覆蓋的增加，原生鳥種減少，而外來鳥種則增加；相反地，隨植被覆蓋的增加，原生鳥種增

加，外來鳥種減少；而地景異質度則同時促進原生與外來鳥種多樣性。在鳥種性狀方面，則預期隨不透水層覆蓋的增加，外來種、體型較大、食性與棲地廣度較高、偏好地面覓食與築巢於人為建物等鳥種較為適應；相對的，隨植被覆蓋增加，外來種減少、偏好於樹冠層及灌草叢層覓食與築巢、取食果實的鳥種增加。

方法

一、研究區域

位於臺灣北部的臺北都會區(24°N, 121.5°E)，包含臺北市、新北市及基隆市。根據中央氣象署統計，臺北地區近三十年間平均氣溫為 23.3°C，平均降雨量為 2329.5 mm (<https://www.cwa.gov.tw/V8/C/C/Statistics/monthlymean.html>)。臺北盆地是臺灣人口最稠密的區域，都市化發展高度集中，覆蓋大量建物、道路、商業大樓及公共設施，在不同行政區間公園綠地、濱水綠廊則面積分布不均。淡水河及支流大漢溪、基隆河於臺北盆地交會，為了防洪及休閒用，

河川濱岸多維持短草坪覆蓋。臺北盆地周圍山麓覆蓋常綠闊葉森林，淡水河下游關渡、社子島一帶分布農田及濕地，農業生產主要為水稻田及早作。

本研究於臺北盆地內進行，沿都市化梯度選取六類棲地，分別為：闊葉森林、農田、河濱草坪、都市公園、公寓住宅區與商業區。由於都市內土地覆蓋區塊面積較小且呈高度鑲嵌狀，本研究將鳥類調查樣區面積設為 60 × 60 m²。於臺北市及新北市各類棲地中，分別挑選 12 個樣區，共計 144 處。潛在的樣區篩選主要參考衛星影像與現地勘查，綜合考量棲地類型及行政區分布進行挑選。然而，由於都市土地分區規劃（如森林及商業區）與農地面積有限，部分棲地類型的樣區位置出現聚集分布的情形，最終樣區間平均最近距離為 410±176 m（圖 1）。雖然樣區面積不大，但仍可有效在每個調查時段內偵測鳥類於樣區內出沒，即使是都市發展程度較高的商業區及公寓住宅區，仍可於行道樹冠、人行道、灌叢、草坪區塊及建物外牆與陽台上觀察到鳥類活動。

二、鳥類調查

我們在 2020 年 8 月至 2022 年 7 月期間進行鳥類調查，第一年收集位於臺北市 60 處樣區，第二年收集位於新北市及臺北市 84 處樣區的資料。各樣區每月進行 1 次調查，每次 10 分鐘，記錄樣區內 $60 \times 60 \text{ m}^2$ 聽到或看到的鳥種，持續收集 12 個月。調查由 3-4 位有經驗的調查員執行，在日出後至上午 10 點前鳥類活動高峰期間內完成，並避免下雨或強風的天候。高空飛越樣區 (高於 20 m) 的鳥種不予採計。最後完成 143 樣區資料收集，1 個都市公園樣區因轉作為捷運建設而無法調查。為檢視兩年度間調查到的鳥種數、數量間是否具有差異，以廣義線性模型 (Generalized Linear Models) 考慮棲地類型、年度的效應，結果顯示兩年間調查到的鳥種數及數量沒有顯著差異 ($p > 0.05$)，故合併兩年之調查結果。

研究期間共記錄到 108 種鳥種，依據 2023 年臺灣地區鳥類名錄 (Ding *et al.* 2023) 定義為留鳥、夏候鳥、外來種、冬候鳥及過境鳥。為探討繁殖

鳥類性狀與都市棲地變數間的相關性，我們保留留鳥、夏候鳥、外來種，排除 31 種冬候及過境鳥種。進一步以廣義線性模型比較繁殖鳥種於繁殖季節 (3-9 月) 與非繁殖季 (10-2 月) 間調查到的鳥種數、數量是否具有差異，結果顯示考慮棲地類型影響下，在不同季節間的鳥種數具有顯著差異 ($p < 0.001$)，繁殖季較非繁殖季偵測到較多的種類，但數量沒有顯著差異 ($p > 0.05$)。最後我們以繁殖季節調查成果的 71 種 11,200 隻次為代表，進行後續分析。

三、棲地變數

為說明都市化梯度的棲地變化，我們利用不同圖資呈現各樣區在地景尺度 (landscape scale) 及樣區尺度 (local scale) 的棲地變數。考慮鳥類的行動能力，樣區周圍半徑 500 m 為不同鳥種活動範圍常採用的分析尺度 (Rutz 2006; Vangestel 2011; McPherson *et al.* 2019)。因此，地景尺度計算樣區周遭 500 m 半徑圓內不同土地覆蓋類型比例及地景異質度 (landscape

heterogeneity)；樣區尺度則估算每個 $60 \times 60 \text{ m}^2$ 樣區範圍內的植被高度 (vegetation height) 與樹木覆蓋比例 (tree cover)，詳如表 1。圖資來源包括六類土地覆蓋類型，包含水體 (water body)、河川 (river)、不透水層 (impervious surface，如道路、建築物、公共設施)、農田 (agricultural land)、森林 (forest) 與草地 (grassland)。前四項取自臺灣國土測繪中心以航空照片 (解析度為 $0.25 \times 0.25 \text{ m}^2$) 繪製的電子地圖及土地利用圖資。植生部分，區分為森林與草地兩類，判別方式依據衛星影像的植生指標與常態化數位地表模型 (Normalized Digital Surface Model，後稱 nDSM)。首先，利用 PlanetScope 影像 (解析度 $3 \times 3 \text{ m}^2$) 計算 NDVI 值取得植生分布範圍，接著結合 Maxar 太空技術公司 AW3D 產品計算之 nDSM (解析度 $0.5 \times 0.5 \text{ m}^2$)，作為地面物件相對高度的指標。相關研究常採用植被高度 2 m 作為分類閾值 (Takahashi *et al.* 2005; Viana-Soto *et al.* 2022)，將植生高度 2 m 以上分類為森林，低於 2 m 以下者主要為灌叢

與草本植物，在本研究都市環境中則歸類為草地。利用 FRAGSTATS 軟體統計六類土地覆蓋比例與以 Shannon-Wiener 多樣性指數計算地景異質度 (McGarigal *et al.* 2023)。樣區尺度計算每個 $60 \times 60 \text{ m}^2$ 樣區內的植被高度 (m) 與樹木覆蓋 (%) 等棲地變數。六類棲地環境的棲地變數平均值如表 2。

四、鳥類性狀

我們依據臺灣鳥類性狀資料集 (Fu *et al.* 2024) 彙整樣區內各繁殖鳥種的性狀特性 (表 3)，涵蓋外來種 (alien status)、體重 (body weight)、喙長 (bill length)、自然翼長 (wing length)、食性種類 (diet)、食性廣度 (diet breadth)、覓食位置 (foraging stratum)、巢位 (nest location)、棲地廣度 (habitat breadth) 等項。外來種依據 2023 年臺灣地區鳥類名錄 (Ding *et al.* 2023) 定義為二元資料，體重、喙長及自然翼長為連續性數值。食性種類為比例資料，包括：無脊椎生物 (invertebrates)、陸生脊椎生物 (terrestrial vertebrates)、魚 (fish)、果實 (fruits)、種子 (seeds)、花蜜、葉

或其他植物部位 (nectar and leaves) 等項，腐肉 (carrion) 及人類食物 (food remnants) 在該資料集合併為一項，在此依據原始資料區別為兩項，8 項加總合計為 100%。依據各鳥種食性類別數量計算食性廣度 (diet breadth)，代表鳥種在食性上的專一程度，數值越低代表較專一，越高代表資源利用彈性較寬。覓食位置區分為 5 類分別為：空中 (aerial)、水域 (aquatic)、樹冠 (canopy)、灌草叢 (understory)、及地面 (ground)，為 5 項加總合計為 100% 的比例資料。築巢位置區分 6 項，包括：人為設施 (artificial structure)、洞穴 (cavity)、樹木 (tree)、灌草叢 (understory)、土坡 (soil slope)、地面 (ground) 等，依據鳥種是否使用該位置築巢定義為二元資料。棲地廣度 (habitat breadth) 的計算，先依據鳥種是否出現於國際自然保護聯盟 (The International Union for Conservation of Nature, IUCN) 8 項棲地類型，包含森林、灌叢、草地、內陸濕地、岩壁區、海洋潮間帶、陸域人為環境、水域人為環境，定義為二元資料。再以出現

的棲地類別數量計算棲地廣度，數值高代表該鳥種利用的棲地類別較多樣。

一、統計分析

(一) 相關性分析

為確認棲地變數間、性狀間的相關程度，進行 Pearson 相關性分析 (Hazra and Gogtay 2016)。當相關係數高於 0.7 時，顯示變數間具有高度相關，為降低共線性問題，僅保留其中一項作為代表變數以檢視其效應 (Dormann *et al.* 2013)。分析結果顯示，樣區內植被高度、樹木覆蓋與地景尺度森林覆蓋之間的相關係數均高於 0.7 (表 4)。由於植被高度能反應植生的垂直結構發展，並與演替階段密切相關 (Poorter *et al.* 2024)，因此在後續分析中，以樣區內植被高度作為上述三項變數的代表。此外，觀察到草地覆蓋與地景異質度相關係數高於 0.75，依據文獻中此兩棲地變數與反應變數間的相關性，我們在分析多樣性時，保留地景異質度，在分析鳥種性狀時則保留草地覆蓋。性狀之間的相關性，

除體重、喙長、翼長間高度相關 (r 均 > 0.83)，取食魚類與水域覓食間相關係數 ($r = 0.69$) 接近 0.7 外，其餘任兩性狀相關性均小於 0.7，高度相關性狀間僅保留體重與水域覓食進行後續分析。

(二) 棲地變數與鳥種多樣性的關係

我們利用廣義線性模型分析棲地變數對鳥類多樣性指數的影響 (R Core Team, 2024)。模型分別以原生、外來及所有鳥種數與數量作為反應變數，並依據資料特性使用 Poisson 分布或資料轉換後採 Gaussian 分布。各模型確認變異數膨脹因子 (Variance Inflation Factors, VIFs)，若 VIF 值大於 10 顯示模型變數間存在嚴重的共線性 (Menard 2002)。為確認空間自相關的潛在影響，我們利用 `spdep` 套件讀入樣區座標圖層，以 `nb2listw` 函數計算空間權重矩陣 (spatial weights)，再以 `lm.morantest` 函數執行 Moran's I 檢測 (Bivand *et al.* 2013)。結果偵測到原生鳥數量具有顯著的空間自相關效應 (Moran I = 2.02, $p < 0.05$)。為處理此問

題，我們改以空間迴歸分析 (Bivand *et al.* 2013)，執行 Spatial Lag Regression (SAR) 與 Spatial Error Models (SEM)。此分析以 `spatialreg` 套件 `lagsarlm` 和 `errorsarlm` 函數進行，SAR 在模型中考慮空間權重矩陣為變數，SEM 則在殘差內考慮空間權重矩陣的影響 (Gaetan and Guyon 2010)。最後比較 SAR 及 SEM 兩模型間赤池資訊量準則 (Akaike Information Criterion, AIC)，取 AIC 較低者為最佳模型。鳥種數及數量以開平方根或對數 (logarithm) 轉換改善常態分布，並以向後消去法 (backward elimination) 進行模式變數篩選，逐步將最不顯著的變數移除，直到所有不顯著項目均移除。

(三) 棲地變數與鳥種性狀相關性分析

我們利用 RLQ 和四角分析探討都市棲地變數與鳥種性狀的相關性 (Dray *et al.* 2014)。此分析需建置三種表格，分別為表格 R (各樣區 - 環境特性)、表格 L (各樣區 - 出現鳥種) 與表格 Q (所有鳥種 - 性狀)。

RLQ 分析應用序列分析摘要三張表格中的聯合結構 (joint structure)，而四角分析則說明每一棲地變數與性狀之間成對的相關性 (Legendre *et al.* 1997; Dray and Legendre 2008)。進行 RLQ 分析前，先將三表格進行初步序列分析處理，表格 L 樣區內物種數量以對數轉換後進行對應分析 (Correspondence Analysis)，量化數值的棲地變數表格 R 則進行主成分分析 (Principal Components Analysis)，同時包含量化及類別性狀的表格 Q 則進行 Hill-Smith 分析 (Hill and Smith 1976)。最後，合併 RLQ 及四角分析兩方法共同執行 RLQ 整體顯著性檢測，採用 49999 次重複 Monte-Carlo 模擬檢定，同時檢視棲地變數、性狀與 RLQ 序列分析兩軸之間的相關性 (Dray *et al.* 2014)。由於四角分析同時進行多個檢定，增加第一型錯誤的機率，為處理多重檢定問題 (multiple testing problem)，採 False Discovery Rate (FDR) 方法進行校正 (Benjamini and Hochberg 1995)。檢測之虛無假說包括：模型 2 檢測棲地變數未影響鳥

種組成；模型 4 檢測鳥種性狀為隨機分布，鳥種分布與鳥種對樣區的偏好相關，與性狀無關。當模型 2 與 4 的虛無假說被拒絕，再進行模型 6 的檢測 (ter Braak *et al.* 2012)，模型 6 為模型 2 與 4 的結合，虛無假說為鳥種性狀與棲地變數間沒有相關 (Dray *et al.* 2014)。RLQ 與四角分析使用 R 軟體 ade4 套件進行分析 (Dray and Dufour 2007)。

結果

一、鳥種組成

結果顯示，在臺北都會區都市梯度上於繁殖季 3-9 月間共記錄到 71 種鳥種、11,200 隻次 (附錄)，其中原生種 58 種 8,343 隻次 (74.5%)，13 種外來種 2,857 隻次 (25.5%)。在原生種中，麻雀 (*Passer montanus*, 26.1%)、白頭翁 (*Pycnonotus sinensis*, 14.6%)、斯氏繡眼 (*Zosterops simplex*, 14.0%)、家燕 (*Hirundo rustica*, 9.9%)、珠頸斑鳩 (*Streptopelia chinensis*, 7.2%)、紅嘴黑鵯 (*Hypsipetes leucocephalus*,

6.5%) 為優勢物種，佔原生種總隻次 78.3%。在外來種中，野鴿 (*Columba livia*, 32.5%)、家八哥 (*Acridotheres tristis*, 24.4%)、白尾八哥 (*Acridotheres javanicus*, 16.8%)、黑領棕鳥 (*Gracupica nigricollis*, 9.8%)、亞洲輝棕鳥 (*Aplonis panayensis*, 9.4%) 為優勢物種，佔外來種總隻次 92.9%。

二、棲地變數與原生、外來鳥類多樣性的相關性

樣區及地景尺度各棲地變數均與都市鳥種多樣性指數呈現顯著相關 (表 5)。農業覆蓋及地景異質度與原生、外來及所有鳥種數、數量呈正相關 ($\text{all } p < 0.05$)，隨農業覆蓋與地景異質度的增加而增加。不透水層覆蓋與外來鳥種、所有鳥種之種類數及數量呈現正相關 ($\text{all } p < 0.05$)，與原生鳥種的數量間也有相同的趨勢 ($p < 0.001$)，均隨不透水層覆蓋增加而增加。此外，河川覆蓋與外來鳥種數及數量呈正相關 ($\text{all } p < 0.001$)，亦影響所有鳥種數量 ($p < 0.05$)。水域覆蓋則是與原生及所有鳥種數量呈負相關 ($p < 0.01$)，在

水域覆蓋較高的區域，觀察到的隻次數較少。樣區內植被高度與原生、外來鳥種的相關性不同，隨植被高度的增加，原生鳥種數及數量增加 ($\text{all } p < 0.05$)，但外來鳥種數及數量減少 ($\text{all } p < 0.001$)；兩者加總後，植被高度則與所有鳥種數及數量沒有顯著相關。

三、棲地變數與鳥種性狀相關性

RLQ 第 1 軸解釋棲地變數與鳥種性狀整體變異程度為 58.7%，第 2 軸解釋 37.8% 的變異，兩軸共解釋 96.47% 的變異 (表 6)。此外，第 1 軸解釋棲地變數變異的 70.2%，鳥種性狀變異的 78.6%。模型 2 與模型 4 檢測結果均顯著 ($\text{all } p < 0.001$)，顯示都市環境中棲地變數、鳥種性狀影響鳥種組成；此外模型 6 亦為顯著 ($p < 0.001$)，顯示性狀與棲地變數間具有相關性。

四角分析呈現任一棲地變數與性狀間兩兩相關性，在 132 項中共有 7 項呈現顯著性 (圖 2)。於人為建物、設施上築巢 ($r = 0.205, p < 0.05$)，取

食人類食物 ($r = 0.194, p < 0.05$) 與較高的不透水層覆蓋呈現低度正相關。水域覓食的鳥種與較高的農田覆蓋呈低度正相關 ($r = 0.206, p < 0.05$)，而鳥種的食性廣度則與農田覆蓋呈低度負相關 ($r = -0.146, p < 0.05$)。樹冠間覓食的鳥種與河川覆蓋 ($r = -0.195, p < 0.05$)、草地覆蓋 ($r = -0.188, p < 0.05$) 呈低度負相關。植被高度與樹冠層間覓食的鳥種呈現中度正相關 ($r = 0.356, p < 0.01$)。

結合 RLQ 與四角分析都市鳥類群聚的結果如圖 3，所有棲地變數與部分鳥種性狀呈現顯著而相關係數低至中度的相關性結果，包括：利用人為建物設施築巢、取食果實及人類食物、在地面或樹冠覓食，以及食性廣度等。與 RLQ 第 1 軸相關的結果顯示，當研究區域內具有較高的植被高度 ($r = 0.342, p < 0.001$)、較低的草地覆蓋 ($r = -0.163, p < 0.05$) 及河川覆蓋 ($r = -0.185, p < 0.01$) 時，傾向有較多取食果實 ($r = 0.236, p < 0.05$)、於樹冠覓食 ($r = 0.363, p < 0.001$) 與較少地面覓食 ($r = -0.236, p < 0.05$)

鳥種。與 RLQ 第 2 軸相關的結果則顯示，當棲地具有較多水域覆蓋 ($r = 0.107, p < 0.01$) 與農田覆蓋 ($r = 0.240, p < 0.001$)、較少不透水層覆蓋 ($r = -0.305, p < 0.001$) 時，具有較少利用人為建築築巢 ($r = -0.178, p < 0.05$)、取食人類食物 ($r = -0.168, p < 0.05$) 及食性廣度 ($r = -0.180, p < 0.05$) 較窄的鳥種。

討論

本研究以標準化方法調查臺北都會區多樣環境下的繁殖鳥類群聚，並區分原生與外來鳥種。結果顯示，外來鳥種在都市環境中入侵的現象普遍存在，且原生與外來鳥種在棲地偏好上展現出明顯差異，主要影響因子包括植被高度、不透水層覆蓋及河川覆蓋。原生鳥種類與數量隨植被高度增加而上升，而外來鳥種則不偏好較高的植被；此外，外來鳥種偏好不透水層覆蓋及河川覆蓋較高的環境，例如河濱草坪等開闊區域。同時，隨農業覆蓋及地景異質度增加，原生與外來鳥種的多樣性均同步上升。在性狀

層面上，結果顯示不透水層覆蓋較高的區域，常見築巢於人為建築、取食人類食物以及具較寬廣食性廣度的鳥種；相對地，植被高度較高的區域則有較多食果性及在樹冠層覓食的鳥種。綜合而言，本研究驗證了全球都市生態學中有關生物多樣性損失的趨勢，並進一步呈現臺北都會區鳥類群聚對都市棲地結構的反應。這些結果不僅對外來種管理具有重要意涵，也為推動生物友善的都市規劃與調適原生鳥種多樣性損失，提供了關鍵的科學依據 (Petersen *et al.* 2020; Patankar *et al.* 2021)。

一、棲地變數與原生、外來鳥類多樣性的相關性

原生鳥種類與數量隨植被高度增加而增加，這與樹木、灌叢提供原生鳥種食物、巢位及棲息位置等資源有關 (del Hoyo *et al.* 2019)，且增加棲地結構的複雜度 (Evans *et al.* 2009)。本研究中各項植被變數間呈現高度相關，暗示無論在樣區或地景尺度上，樹木覆蓋對原生鳥種的利用有正面效

益，與其他都市研究指出較高的樹木高度、樹木覆蓋有利維持原生鳥種多樣性的結果相符 (MacGregor-Fors 2008; Villaseñor *et al.* 2021)。相較之下，外來鳥種偏好不透水層覆蓋較高的環境與濱岸草坪，而在植被高度較高的區域種類、數量減少 (Chang *et al.* 2017; Arévalo *et al.* 2022; Lin *et al.* 2025)。這現象可能與研究區域內優勢外來鳥種，如野鴿、家八哥、白尾八哥及黑領棕鳥等，多以地面覓食為主要生活習性相關。對這些鳥種而言，不透水層覆蓋高的都市地面與廣闊的濱岸草坪提供充足的覓食空間，然而，由於鳥種性狀的限制，他們較不適應在密林環境中活動。

臺北都會區多樣環境中，隨農業覆蓋、地景異質度增加，觀察到較高的原生與外來鳥種多樣性，顯示資源豐富、棲地異質的環境有利兩者的生存 (McKinney and Kark 2017)，符合解釋原生群聚受外來種入侵影響的「生物接受假說」(Biotic acceptance hypothesis, Stohlgren *et al.* 2006)。農田地景除了作物區之外，經常鑲嵌不同

類型區塊 (Batáry *et al.* 2020)，包括：灌溉用的池塘與溝渠、果園、樹林、草地與廢耕地。這些相鄰的棲地輪流供應生物在生活史不同階段所需的食物、巢位資源，加上生長季期間供應高產量的穀物外，也吸引密度較高的節肢動物，因而支持著較高的物種多樣性 (Batáry *et al.* 2020; Li *et al.* 2020; Petersen *et al.* 2020)。目前臺北地區農業經營除了旱田，還包括水稻，水田及旱田相鄰的灌溉水域，這些棲地吸引水域覓食鳥種出現，提高整體鳥種多樣性。

此外，地景異質度與鳥種多樣性呈正相關 (Lorenzón *et al.* 2016; Lu *et al.* 2024)，強調了地景結構的效應。較高的地景異質度代表多樣化的土地利用彼此鑲嵌，相較於同質地景提供較廣的生態棲位，有利於廣布種生存 (Katayama *et al.* 2014)；也支持不同資源需求的鳥種同時出現，例如農田鑲嵌樹林區塊，出現偏好灌草叢及樹冠覓食的鳥種，造成較高的多樣性。在本研究中，地景異質度與草地覆蓋呈現高度正相關，因此在地景異質度較

高的樣區也可能觀察到較多高草叢與短草地間覓食的鳥種。

值得注意的是，原生鳥種的數量隨不透水層覆蓋增加而上升，這與一般認為都市化導致原生鳥種數量減少的假說不符。此現象可能歸因於少數高度適應人為環境的原生鳥種，如珠頸斑鳩，在都市人類活動中獲得額外食物資源，或由於相對較低的天敵捕食壓力，從而促進這些少數原生鳥種在都市環境中的生存與優勢分布 (Palomino and Carrascal 2006; Paz *et al.* 2024)。這些結果反應了都市棲地特性形塑鳥類群聚，以及外來種與少數原生鳥種在都市環境的適應策略。

研究指出，都市公園內水域濕地環境，搭配栽植多樣的水生植物，有助於提供原生水鳥棲息、築巢及覓食的環境，進而提升其多樣性與群聚組成 (Lin *et al.* 2008; Chang *et al.* 2017; Shih 2018; Dong *et al.* 2023)。然而，本研究結果顯示水域覆蓋與原生鳥種數量呈負相關，可能與試驗設計的取樣範圍及棲地類型有關。本研究主要聚焦於都市化梯度，選取的樣區涵蓋

闊葉森林、農田、河濱草坪、都市公園、公寓住宅區與商業區等六類陸域棲地，並未納入濕地樣區。因此，偏好水域環境的原生鳥種在本研究資料中代表性較低，導致結果與部分先前針對都市公園濕地的研究有所差異。

二、棲地變數與鳥種性狀的相關性

都市研究常以建築物與道路等土地覆蓋比例作為都市化程度的指標 (Syrbe and Chang 2018; Hastedt and Tietze 2023)，其中不透水層覆蓋度高而植被覆蓋低通常代表高度都市發展 (Sol *et al.* 2020)。鳥類在一個地區出現機率，主要受到其演化出的性狀與當地植被結構影響，進而形成當地的生物群聚 (Lizée *et al.* 2011; Ikin *et al.* 2012)。過去針對不同都市環境 RLQ 研究指出，在高度都市化區域，鳥類群聚呈現以下特徵：於地面、灌草叢間覓食及築巢鳥種較少 (Ikin *et al.* 2012)；樹冠層覓食鳥種較多 (Stukenholtz and Stevens 2022)；地面築巢、食蟲者、森林鳥種較少，但築巢高度較高及都市鳥種增加 (Mayorga

et al. 2020)、以及空中食蟲者較多 (Chin *et al.* 2022)。

與此相較，本研究觀察到在不透水層覆蓋度較高的區域，利用人為建築築巢、取食人類食物以及食性廣度較寬的鳥種明顯較多。隨著都市環境中天然食物與巢位的減少 (Geslin *et al.* 2016; Narango *et al.* 2018; Seress *et al.* 2025)，這些性狀有助於鳥類成功適應高度都市化的環境。例如，取食人類食物與食性廣度較寬的鳥種，如野鴿、珠頸斑鳩及家八哥，能有效利用都市中全年可得且來源多樣的動物 (Jones and Reynolds 2008; Ducatez *et al.* 2015)，包括人為餵食、垃圾、行道樹與綠籬提供的季節性果實、草坪種子、土壤中的蚯蚓，以及路殺動物屍體等 (Jones and Reynolds 2008; Coogan *et al.* 2018)。此外，部分鳥種如家燕、鳩鴿科 (Columbidae)、八哥類 (Sturnidae) 及亞洲輝椋鳥，則善用屋簷、陽台、紅綠燈銜管與外牆縫隙等人造結構築巢，這些場所既能提供遮蔽，也降低了人為干擾風險，確保繁殖成功 (Melles *et al.* 2003; Reynolds

et al. 2019)。

本研究透過常態化數位地表模型成果，獲取大範圍的植被高度資訊，相較反應植被水平結構的樹木覆蓋，植被高度更能呈現植生在垂直結構上的發展，且隨演替階段推進而增加 (Akay *et al.* 2009; Poorter *et al.* 2024)。較高的植被代表成熟大樹的存在 (Peper *et al.* 2001)，不僅能生產大量的果實，亦提供樹冠層、樹幹及中層等多樣化的生態棲位 (MacGregor-Fors 2008; Minor and Kobe 2019)，進而吸引以果實為食及偏好於樹冠層覓食的鳥種 (Shanahan *et al.* 2011)。

Galbraith *et al.* (2015) 的研究觀察到都市中人類餵食行為改變了鳥類群聚組成，Sol *et al.* (2012) 也指出無論是主動或非主動提供的食物，皆可能吸引一些都市原生鳥種及外來鳥種加以利用。本研究雖未直接評估人類餵食的具體影響，但透過對繁殖鳥種性狀的分析，觀察到在不透水層覆蓋較高的區域，取食人類食物的鳥種數量有上升的趨勢，間接證實都市區域人為活動對鳥種性狀與群聚組成的潛在

影響。為更全面評估此影響，後續都市鳥類生態研究可考量納入人類餵食行為與活動人數等人為干擾指標進行分析。

在研究區域內，外來鳥種已佔繁殖鳥種總隻次的 25.5%，顯示外來鳥種入侵都市環境的普遍現象，但在綜合考量所有鳥族群聚的四角分析中，並沒有觀察到「外來種」此一性狀與任何單一棲地變數間具有顯著相關性。這結果可能反應本區域可觀察到的 13 種外來鳥種在其他性狀上仍展現變異性，因此無法單以「外來種」一項作為整體代表，解釋所有外來鳥種與單一棲地變數之間的關係。例如，部分優勢外來種 (如野鴿與八哥類) 偏好在地面覓食，然亦有偏好樹冠層覓食的鳥種，如鵲鴝 (*Copsychus saularis*) 與白腰鵲鴝 (*Copsychus malabaricus*)，或偏好水域覓食的埃及聖鸚 (*Threskiornis aethiopicus*)，出現於研究區域的都市公園至農田地景，導致其棲地偏好無法以單一變數概括。這現象也暗示研究區域內各類型棲地皆有外來鳥種入侵的潛在風險

(Petersen *et al.* 2020)，應加以留意與管理。

三、都市環境鳥類保育的建議

本研究分析臺北都會區繁殖鳥類群聚與棲地特性之間的相關性，發現原生鳥種與外來鳥種對都市化梯度上的棲地偏好呈現顯著差異，以及都市人為活動對鳥種性狀與群聚組成的潛在影響。這些發現為未來的都市規劃與鳥類保育提供了具體的科學依據：

提升原生鳥種多樣性之棲地策略：

1. 維持並加強半自然地景覆蓋：本研究觀察到農業覆蓋、植被高度及地景異質度較高時，原生鳥種種類與數量顯著增加。這強調了臺北都會區應積極規劃並保留農田、森林及草地等半自然地景，結合較高的地景異質度規劃。這些地景不僅能提供原生鳥類豐富的食物來源、築巢地點及庇護所 (Matthies *et al.* 2017; Arévalo *et al.* 2022; Lu *et al.* 2024)，亦有助於維護其親緣與功能 β 多樣性，減緩對高度都市化環境不適應物種的消失 (Fu *et al.* 2025)。

增加都市綠地植被高度：原生鳥種偏好植被高度較高的區域。因此，建議在都市公園、河濱草坪及其他空間，補植多樣性的樹木與灌叢，增加植被結構的複雜度 (Paker *et al.* 2014)。高大、成熟的樹木可提供樹冠層覓食、食果性鳥種所需的覓食空間與食物，同時也提供築巢與棲息位置 (Shanahan *et al.* 2011; Minor and Kobe 2019)。在復育樹種的選擇上，應優先考量本地原生植物，以支持其長期演化適應下對昆蟲及果實資源有依賴的原生鳥種 (Burghardt *et al.* 2009; Aronson *et al.* 2014; Narango *et al.* 2018; Seress *et al.* 2025)。

外來鳥種管理策略：

1. 精準管理外來種偏好棲地：本研究發現外來鳥種偏好不透水層覆蓋高的區域及河濱草坪，且數量隨植被高度增加而減少。鑑於外來鳥種在臺北都會區已佔繁殖鳥種總隻次的 25.5%，並普遍分布於各類型棲地，建議針對這些區域增加植被覆蓋，來限制偏好開闊地面覓食的外來種如野

鴿與家八哥的活動空間 (Grarock *et al.* 2014; Paker *et al.* 2014)。

限制人為食物來源供應：研究結果顯示，不透水層覆蓋較高的區域出現較多取食人類食物及食性廣度較寬的鳥種。由於優勢外來鳥種（如野鴿）高度依賴人類供應的食物，建議透過限制人類餵食行為及加強垃圾管理，減少外來鳥種在都市中獲取食物的機會。這有助於管控野鴿及其他依賴人類食物鳥種的族群量 (Krimowa 2012; Lim *et al.* 2023; Chen *et al.* 2025)，進而減少人為活動對鳥族群聚組成的潛在影響。

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表 1 樣區尺度 (樣區 $60 \times 60 \text{ m}^2$ 內) 與地景尺度 (樣區周圍 500 m 半徑範圍) 的棲地變數與定義
 Table 1 Definitions and scales of habitat variables used in the analysis, including local-scale (within $60 \times 60 \text{ m}^2$ plots) and landscape-scale (500 m radius buffer) habitat variables

Scale	Variable	Acronym	Definition
Local (Within $60 \times 60 \text{ m}^2$ plot)	Vegetation height (m)	In Veg height	The median vegetation height within each plot was used as a proxy for local vegetation structure. Taller vegetation generally indicated the presence of mature trees, while shorter vegetation suggested more open ground or less developed vegetation cover.
	Tree cover (%)	In Tree	Tree cover was defined as the proportion of vegetation equal to or taller than 2 meters within each plot. Higher values indicated greater canopy cover.
Landscape (500m buffer around each plot)	Forest cover (%)	Forest	Forest cover was defined as the proportion of vegetation with a height equal to or greater than 2 meters.
	Grassland cover (%)	Grassland	Grassland cover was defined as the proportion of vegetation with a height less than 2 meters, including areas dominated by tall grass or lawn.
	River cover (%)	River	River cover was defined as the proportion of rivers, streams, and other water flows.
	Water body cover (%)	Water body	Water body cover was defined as the proportion of area occupied by lakes or ponds, whether naturally formed or artificially excavated.
	Agricultural cover (%)	Agriculture	Agricultural cover was defined as the proportion of land used for rice and other paddy crops, dry farming, and fruit tree cultivation.
	Impervious surface cover (%)	Impervious surface	Impervious surface cover was defined as the proportion of area occupied by roads, buildings, schools, and other public facilities.

表 2 臺北都會區六類樣區類型在樣區尺度與地景尺度之棲地變數平均值

Table 2 Mean values of local-scale or landscape-scale habitat variables across six habitat types in the Taipei Metropolitan Area

Habitat type	Local scale		Landscape scale						
	Vegetation height (m)	Tree cover (%)	Forest (%)	Grassland (%)	River (%)	Water body (%)	Agricultural area (%)	Impervious surface (%)	Landscape heterogeneity
Forest	10.16	96.24	67.85	6.80	0.23	0.40	0.01	24.71	0.74
Agricultural lands	1.03	6.09	9.69	24.71	10.42	0.80	22.75	31.64	1.17
Riparian lawns	1.38	6.80	8.05	25.55	21.48	1.24	0.07	43.61	1.16
Urban parks	6.10	58.49	11.51	9.20	1.42	0.56	0.00	77.31	0.69
Multi-story buildings	3.49	7.94	8.17	9.18	1.10	0.41	0.72	80.42	0.61
Commercial areas	0.96	1.89	4.42	6.79	0.80	0.21	0.02	87.76	0.44

表 3 各繁殖鳥種功能性狀，包含型態、食性種類、覓食位置、巢位、棲地廣度、外來種 / 原生種等性狀類別與資料格式

Table 3 Functional traits of breeding bird species, including trait types and data format for morphology, diet, foraging stratum, nesting location, habitat breadth, and alien (or native) status

Traits	Types	Description	Data format
Alien status	Alien or native	Alien birds referred to species that were introduced to Taiwan and were not native to the region.	Binary
Morphology	Body weight	Body weight of each bird species.	Continuous
	Bill length	The distance from the tip to the base of the bill	
	Wing length	The distance from the carpal joint to the tip of the longest primary feather on the unfattened wing	
Diet	Invertebrates	Included hexapods, spiders, annelids, molluscs, crustaceans, multipods, and plankton.	Proportional values
	Terrestrial vertebrates	Mammal, bird, reptile, amphibian	(0~100%).
	Fish	Fish	The sum of all items
	Carrion	Animal carcasses	equals to
	Food remnants	Human food remnants, supplemental food	100%
	Fruits	Fruits	
	Seeds	Seeds	
	Nectar and leaves	Nectar, flowers, leaves, or other plant material.	
Diet breadth		Number of items present in the diet	Count
Foraging stratum	Aerial	Foraging in aerial.	Proportional values
	Aquatic	Foraging under the deep, shallow water, around the water surface, or mudflat.	(0~100%).
	Canopy	Foraging in the canopy, or middle layer in trees, on the trunk.	The sum of all items
	Understory	Foraging in the shrubs, or tall grass.	equals to
	Ground	Foraging on the bare soil, or lawn.	100%
Nest location	Artificial structure	Nesting in artificial structures, buildings, or facilities.	Binary
	Cavity	Nesting in unused tree holes, rock crevices, or hollows.	Binary
	Tree	Nesting within the foliage, on the branches or the trunk.	Binary
	Understory	Nesting on the shrubs or tall grass.	Binary

	Soil slope	Nesting in the soil slope without vegetation.	Binary
	Ground	Nesting on the ground.	Binary
Habitat breadth		The number of habitat categories per species was defined based on IUCN habitat classifications, including forest, shrub land, grassland, inland wetland, rocky area, marine intertidal area, terrestrial artificial area, and aquatic artificial area.	Count

表 4 棲地變數間相關性分析結果

Table 4 Pearson correlation coefficients among habitat variables Highly correlated variables ($r > 0.7$) are assessed and shown in bold to reduce multi-collinearity before inclusion in regression models and trait-based analyses.

Variables	Local scale		Landscape scale						
	Vegetation height	Tree cover	Forest (%)	Grassland (%)	River (%)	Water body (%)	Agricultural area (%)	Impervious surface (%)	Landscape heterogeneity
Vegetation height (m)	1	0.86	0.70	-0.42	-0.31	-0.15	-0.20	-0.21	-0.23
Tree cover (%)		1	0.79	-0.37	-0.32	-0.10	-0.20	-0.30	-0.15
Forest (%)			1	-0.26	-0.28	-0.10	-0.12	-0.58	-0.04
Grassland (%)				1	0.50	0.37	0.10	-0.41	0.75
River (%)					1	0.22	-0.03	-0.32	0.62
Water body (%)						1	0.10	-0.22	0.4
Agriculture (%)							1	-0.44	0.21
Impervious surface (%)								1	-0.61
Landscape heterogeneity									1

Highly correlated variables ($r > 0.7$) are assessed and shown in bold to reduce multi-collinearity before inclusion in regression models and trait-based analyses.

表 5 以空間迴歸分析棲地變數與原生、外來及所有鳥種多樣性指數的相關性
 Table 5 Results of spatial regression analysis examining the effects of habitat variables on native, alien, and overall bird diversity metrics

Response variable	Bird species	Local scale		Landscape scale			
		Vegetation height	Impervious surface cover	Agricultural cover	River cover	Water body cover	Landscape Heterogeneity
Species richness	Overall	-	0.83*	1.17***	-	-	2.06***
	native birds	0.10**	-	0.17***	-	-	0.24***
	alien birds	(-0.24)***	0.59***	0.18***	0.22***	-	0.29***
Abundance	Overall	-	0.33***	0.12**	0.12*	(-0.12)**	0.33***
	native birds	0.12*	0.29***	0.13*	-	(-0.14)**	0.38***
	alien birds	(-0.33)***	0.83***	0.20*	0.47***	-	0.41***

The table presents estimates for significant predictors only (* p < 0.05, ** p < 0.01, *** p < 0.001). Metrics for overall bird species (native + alien) are shown in bold.

表 6 RLQ 分析結果，摘要環境變數 (R), 鳥種組成 (L), and 鳥種性狀 (Q) 在 RLQ 分析第一、二軸解釋能力

Table 6 Summary of RLQ analysis results, showing the explained variance of environmental variables (R), species composition (L), and species traits (Q) along the first and second RLQ axes.

Total inertia: 1.318			
Projected inertia (%):			
	Ax1	Ax2	
	58.68	37.79	
Eigen values decomposition L:			
	eig	covariance	correlation
eig1	0.773	0.879	0.339
eig2	0.498	0.706	0.322
Inertia & coinertia R:			
	inertia	max	ratio
eig1	1.647	2.346	0.702
eig1+2	3.332	3.576	0.932
Inertia & coinertia Q:			
	inertia	max	ratio
eig1	4.094	5.210	0.786
eig1+2	6.937	8.777	0.790
Correlation L:			
	corr	max	ratio
eig1	0.339	0.696	0.486
eig2	0.322	0.524	0.615

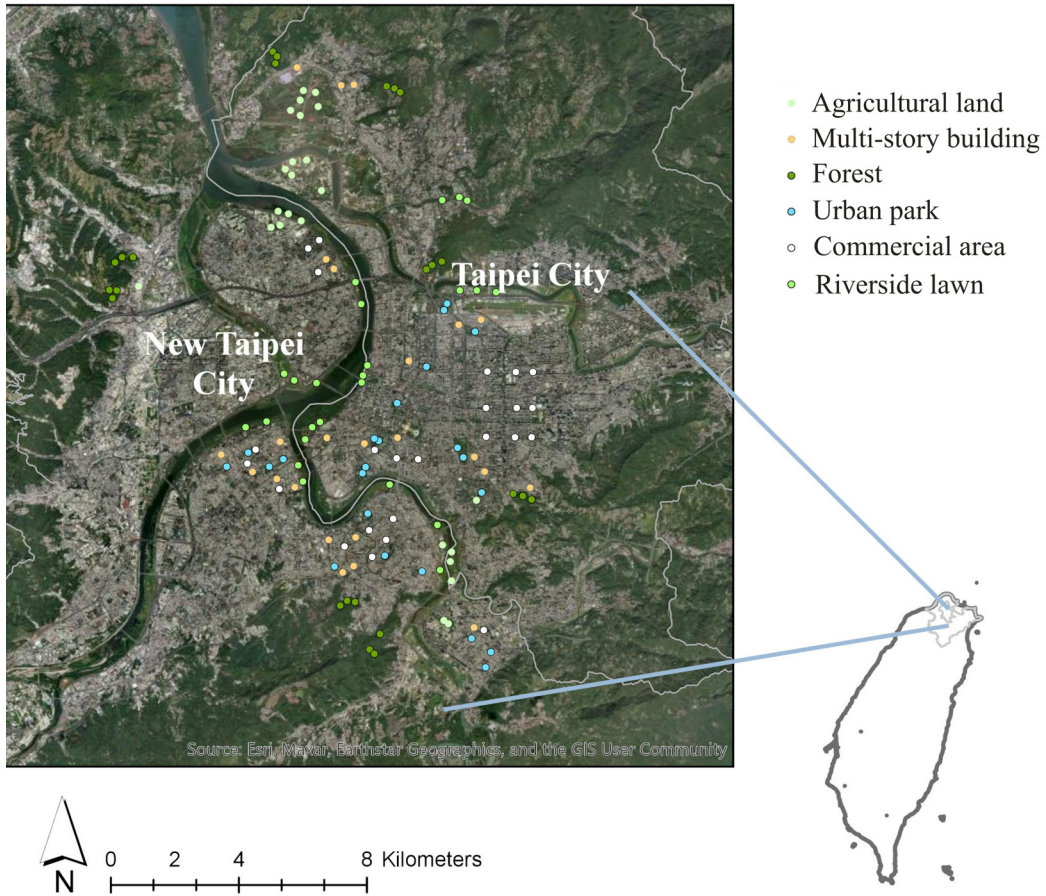


圖 1 臺北都會區研究樣區分布圖，位於臺北市及新北市境內。在都市梯度上選取六類棲地代表，含闊葉森林、農田、河濱草坪、都市公園、公寓住宅區與商業區。

Fig. 1 Location of the study area within the Taipei Metropolitan Area, including both Taipei City and New Taipei City. Six habitat types were selected along an urbanization gradient, including forest, agricultural land, riparian lawn, urban park, residential area (multi-story buildings), and commercial area.

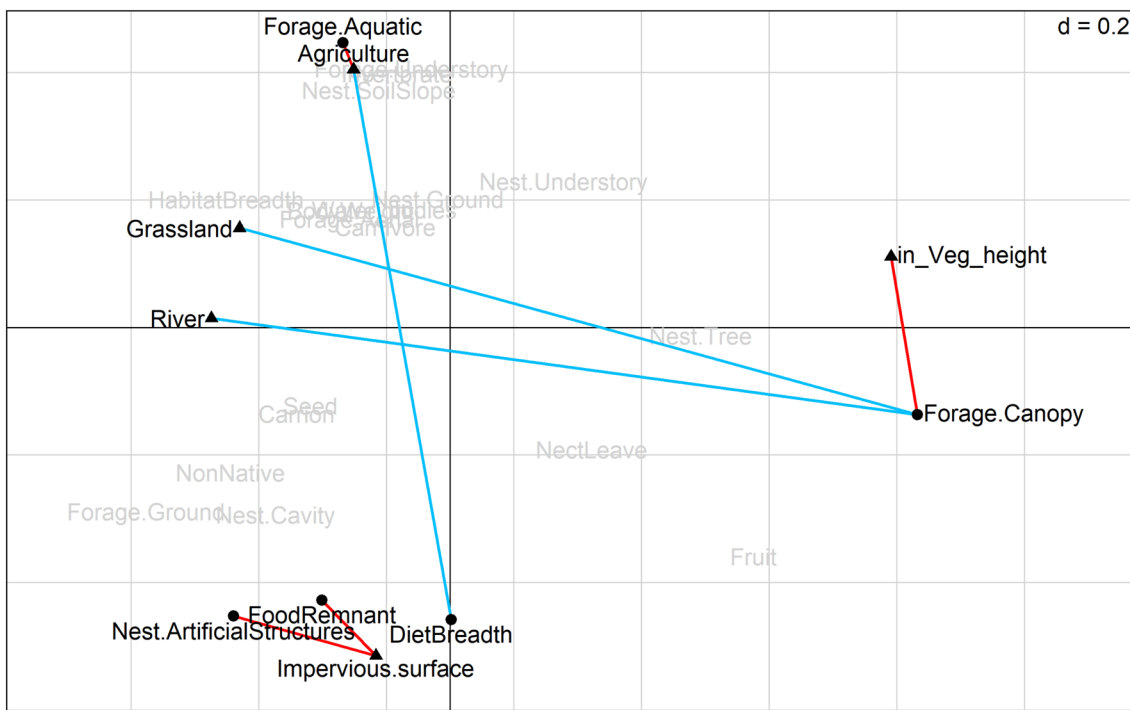


圖 2 以四角分析呈現臺北都會區鳥類群聚各棲地變數與鳥種性狀間的相關性。紅線表示棲地變數與性狀間具有正相關性，藍線表示兩者為負相關；棲地變數標註為三角形，鳥種性狀標註為圓形。

Fig. 2 Biplots from the fourth-corner analysis illustrating significant associations between habitat variables and functional traits of bird communities in the Taipei Metropolitan Area. Positive associations are shown in red and negative associations in blue. Habitat variables and species traits are represented by triangles and circles, respectively.

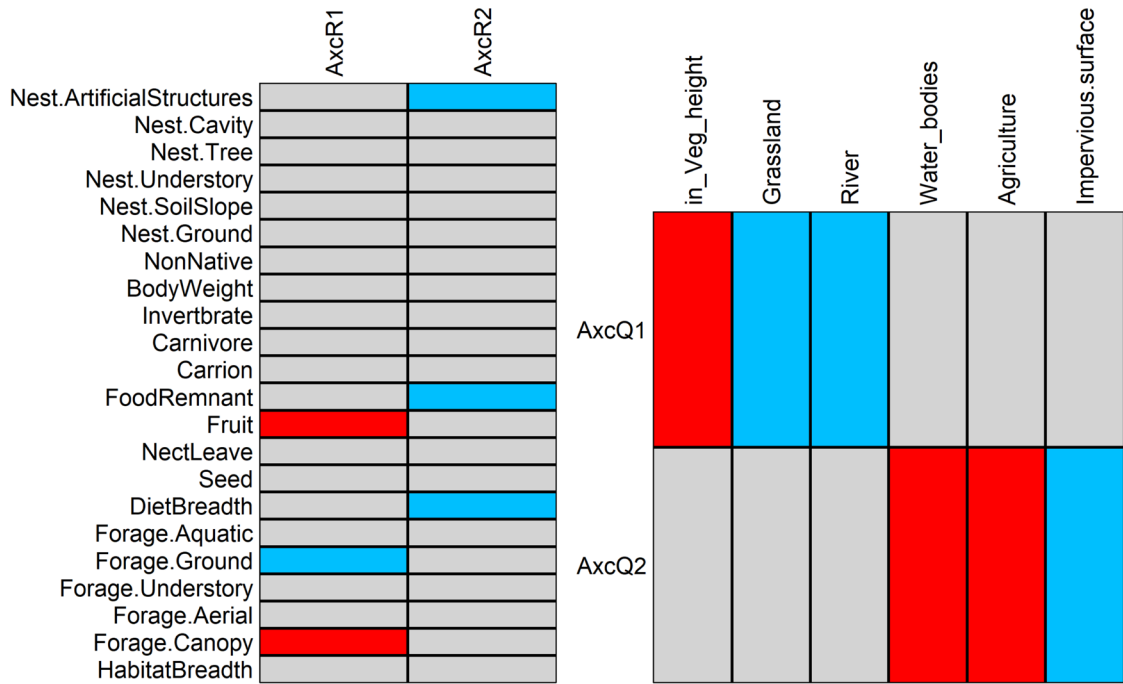


圖 3 結合 RLQ 及四角分析的結果，左、右圖分別顯示與 RLQ 兩軸具顯著相關性的性狀與棲地變數，紅色表示正相關，藍色表示負相關。AxcR1、AxcR2 代表與 RLQ 分析第 1、2 軸相關的棲地變數；AxcQ1、AxcQ2 代表與 RLQ 分析第 1、2 軸相關的性狀。

Fig. 3 Results from the combined RLQ and fourth-corner analyses displaying significant associations between habitat variables and functional traits of bird communities in the Taipei Metropolitan Area. The left panel shows functional traits significantly associated with the first (AxcQ1) and second (AxcQ2) RLQ axes, while the right panel shows the corresponding habitat variables (AxcR1 and AxcR2). Red and blue cells indicate positive and negative associations, respectively. Only statistically significant associations are displayed.

附錄 本研究記錄到的繁殖鳥種與相對數量

Appendix Breeding bird species recorded and their total abundances in this study.

Family	Family (Chinese)	Species	Chinese names	Native/Alien	Abundance	%
Accipitridae	鷹科	<i>Accipiter trivirgatus</i>	鳳頭蒼鷹	Native	10	0.089
Accipitridae	鷹科	<i>Accipiter virgatus</i>	松雀鷹	Native	1	0.009
Accipitridae	鷹科	<i>Elanus caeruleus</i>	黑翅鳶	Native	1	0.009
Accipitridae	鷹科	<i>Milvus migrans</i>	黑鳶	Native	1	0.009
Accipitridae	鷹科	<i>Spilornis cheela</i>	大冠鷲	Native	2	0.018
Alaudidae	百靈科	<i>Alauda gulgula</i>	小雲雀	Native	6	0.054
Alcedinidae	翠鳥科	<i>Alcedo atthis</i>	翠鳥	Native	1	0.009
Anatidae	雁鴨科	<i>Anas zonorhyncha</i>	花嘴鴨	Native	1	0.009
Apodidae	雨燕科	<i>Apus nipalensis</i>	小雨燕	Native	59	0.527
Ardeidae	鷺科	<i>Bubulcus ibis</i>	黃頭鷺	Native	225	2.009
Ardeidae	鷺科	<i>Egretta garzetta</i>	小白鷺	Native	16	0.143
Ardeidae	鷺科	<i>Gorsachius melanolophus</i>	黑冠麻鷺	Native	53	0.473
Ardeidae	鷺科	<i>Ixobrychus sinensis</i>	黃小鷺	Native	1	0.009
Ardeidae	鷺科	<i>Nycticorax nycticorax</i>	夜鷺	Native	27	0.241
Caprimulgidae	夜鷹科	<i>Caprimulgus affinis</i>	南亞夜鷹	Native	1	0.009
Charadriidae	鴉科	<i>Charadrius dubius</i>	小環頸鴉	Native	9	0.080
Cisticolidae	扇尾鶯科	<i>Cisticola exilis</i>	黃頭扇尾鶯	Native	2	0.018
Cisticolidae	扇尾鶯科	<i>Cisticola juncidis</i>	棕扇尾鶯	Native	11	0.098
Cisticolidae	扇尾鶯科	<i>Prinia flaviventris</i>	灰頭鶯	Native	17	0.152
Cisticolidae	扇尾鶯科	<i>Prinia inornate</i>	褐頭鶯	Native	52	0.464
Columbidae	鳩鴿科	<i>Chalcophaps indica</i>	翠翼鳩	Native	5	0.045
Columbidae	鳩鴿科	<i>Columba livia</i>	野鴿	Alien	928	8.286
Columbidae	鳩鴿科	<i>Spilopelia chinensis</i>	珠頸斑鳩	Native	603	5.384
Columbidae	鳩鴿科	<i>Streptopelia orientalis</i>	金背鳩	Native	188	1.679
Columbidae	鳩鴿科	<i>Streptopelia tranquebarica</i>	紅鳩	Native	80	0.714
Columbidae	鳩鴿科	<i>Treron sieboldii</i>	綠鳩	Native	1	0.009
Corvidae	鴉科	<i>Corvus macrorhynchos</i>	巨嘴鴉	Native	3	0.027
Corvidae	鴉科	<i>Dendrocitta formosae</i>	樹鴉	Native	167	1.491
Corvidae	鴉科	<i>Pica serica</i>	喜鴉	Alien	143	1.277
Corvidae	鴉科	<i>Urocissa caerulea</i>	臺灣藍鴉	Native	27	0.241
Dicruridae	卷尾科	<i>Dicrurus aeneus</i>	小卷尾	Native	1	0.009
Dicruridae	卷尾科	<i>Dicrurus macrocercus</i>	大卷尾	Native	38	0.339
Estrildidae	梅花雀科	<i>Estrilda melpoda</i>	橙頰梅花雀	Alien	3	0.027
Estrildidae	梅花雀科	<i>Lonchura atricapilla</i>	黑頭文鳥	Native	12	0.107

附錄 本研究記錄到的繁殖鳥種與相對數量 (續)

Appendix Breeding bird species recorded and their total abundances in this study (continued)

Leiothrichidae	噪眉科	<i>Alcippe morrisonia</i>	繡眼畫眉	Native	6	0.054
Leiothrichidae	噪眉科	<i>Garrulax taewanus</i>	臺灣畫眉	Native	1	0.009
Leiothrichidae	噪眉科	<i>Pterorhinus chinensis</i>	黑喉噪眉	Alien	2	0.018
Megalaimidae	鬚鴛科	<i>Psilopogon nuchalis</i>	五色鳥	Native	226	2.018
Monarchidae	王鷓科	<i>Hypothymis azurea</i>	黑枕藍鷓	Native	37	0.330
Motacillidae	鵲鴿科	<i>Motacilla alba</i>	白鵲鴿	Native	3	0.027
Muscicapidae	鷓科	<i>Copsychus malabaricus</i>	白腰鵲鴿	Alien	5	0.045
Muscicapidae	鷓科	<i>Copsychus saularis</i>	鵲鴿	Alien	36	0.321
Muscicapidae	鷓科	<i>Myophonus insularis</i>	臺灣紫嘯鷓	Native	1	0.009
Passeridae	麻雀科	<i>Passer montanus</i>	麻雀	Native	2178	19.446
Phasianidae	雉科	<i>Bambusicola sonorivox</i>	臺灣竹雞	Native	6	0.054
Picidae	啄木鳥科	<i>Yungipicus canicapillus</i>	小啄木	Native	2	0.018
Psittaculidae	舊世界鸚鵡科	<i>Agapornis fischeri</i>	費氏愛情鳥	Alien	1	0.009
Pycnonotidae	鵲科	<i>Hypsipetes leucocephalus</i>	紅嘴黑鵲	Native	540	4.821
Pycnonotidae	鵲科	<i>Pycnonotus sinensis</i>	白頭翁	Native	1218	10.875
Rallidae	秧雞科	<i>Amaurornis phoenicurus</i>	白腹秧雞	Native	14	0.125
Rallidae	秧雞科	<i>Gallinula chloropus</i>	紅冠水雞	Native	9	0.080
Rallidae	秧雞科	<i>Zapornia fusca</i>	緋秧雞	Native	1	0.009
Sturnidae	八哥科	<i>Acridotheres cristatellus</i>	八哥	Native	104	0.929
Sturnidae	八哥科	<i>Acridotheres javanicus</i>	白尾八哥	Alien	480	4.286
Sturnidae	八哥科	<i>Acridotheres tristis</i>	家八哥	Alien	698	6.232
Sturnidae	八哥科	<i>Aplonis panayensis</i>	亞洲輝椋鳥	Alien	267	2.384
Sturnidae	八哥科	<i>Gracupica nigricollis</i>	黑領椋鳥	Alien	281	2.509
Sturnidae	八哥科	<i>Sturnia malabarica</i>	灰頭椋鳥	Alien	7	0.063
Sylviidae	鶯科	<i>Sinosuthora webbiana</i>	粉紅鸚嘴	Native	1	0.009
Threskiornithidae	鸚科	<i>Threskiornis aethiopicus</i>	埃及聖鸚	Alien	6	0.054
Timaliidae	畫眉科	<i>Cyanoderma ruficeps</i>	山紅頭	Native	31	0.277

附錄 本研究記錄到的繁殖鳥種與相對數量 (續)

Appendix Breeding bird species recorded and their total abundances in this study (continued)

Family	Family (Chinese)	Species	Chinese names	Native/Alien	Abundance	%
Timaliidae	畫眉科	<i>Erythrogenys erythrocnemis</i>	大鸞嘴	Native	7	0.063
Timaliidae	畫眉科	<i>Pomatorhinus musicus</i>	小鸞嘴	Native	50	0.446
Vireonidae	綠鵙科	<i>Erpornis zantholeuca</i>	綠畫眉	Native	13	0.116
Zosteropidae	繡眼科	<i>Zosterops simplex</i>	斯氏繡眼	Native	1168	10.429

利用 MaxEnt 模型預測氣候變遷情境下短柱山茶的潛在分布

Predicting potential distribution of *Camellia brevistyla* under climate change scenarios using MaxEnt model

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摘要

氣候變遷正在重塑全球物種分布格局，為具經濟或生態價值的原生物種帶來嚴峻的挑戰，精準掌握其潛在分布與動態發展，可為制定調適與保育策略提供基礎資訊。本研究以臺灣原生油料樹種短柱山茶 (*Camellia brevistyla*) 為目標種，整合物種出現紀錄與氣候、土壤、地形、土地覆蓋等環境變項，利用 MaxEnt 模型預測現時與 21 世紀末 (2071-2100 年) 兩種氣候情境 (SSP126 與 SSP585) 下的適宜生育地範圍，並進一步藉由交集分析，將時空動態劃分為脆弱生育地、新增適宜生育地與氣候庇護所等 3 種類型。研究結果顯示，氣候為影響短柱山茶生育地分布的主要因子，其中季節性溫度變異愈明顯，愈適合該物種生存，相反地，平

均日較差愈大與最冷月溫度愈高則相對不適宜。從空間分布來看，現時適宜生育地多集中於北部與東北部，兩種情境的預測結果顯示，SSP126 情境下，北部區塊的部分生育地將轉為脆弱生育地，但仍可維持一定面積的氣候庇護所；而 SSP585 情境下，大多數生育地可能轉為脆弱狀態，僅存少數氣候庇護侷限於東北部區塊。綜合上述結果，本研究提出了幾點有關該物種在保育與經營管理面上的調適建議供參。

Abstract

Climate change is reshaping global species distribution patterns, posing profound challenges to native species of economic or ecological importance. Accurately characterizing their potential ranges and spatiotemporal dynamics provides essential baseline information for developing effective adaptation and conservation strategies. This study focuses on *Camellia brevistyla*, a native oil-bearing tree species in Taiwan. Species occurrence records and environmental predictors, including climate, soil, topography, and land cover, were integrated into a MaxEnt model to project suitable habitats under current conditions and two future climate scenarios (SSP126 and SSP585) for the late 21st century (2071-2100). A spatiotemporal overlay analysis was performed to classify habitat dynamics into vulnerable habitats, increased suitable habitats, and climate refugia. Results indicate that climatic variables are the primary drivers of habitat suitability. The species shows higher habitat suitability in areas with greater temperature seasonality, whereas suitability declines with increasing mean diurnal range and higher minimum temperatures of the coldest month. Spatially, suitable habitats are primarily concentrated in northern and northeastern Taiwan. Under the SSP126 scenario, while portions of northern habitats are projected to become vulnerable, substantial climate refugia are ex-

pected to persist. In contrast, under the SSP585 scenario, most suitable habitats are likely to transition into vulnerable habitats, with only limited refugia remaining in the northeastern region. Based on these findings, we propose adaptive strategies to support the conservation and sustainable management of *C. brevistyla* under future climate change.

關鍵詞：經濟樹種、共享社會經濟途徑、脆弱生育地、氣候庇護所、調適

Keywords: economic tree species, shared socio-economic pathway, vulnerable habitat, climate refugia, adaptation

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緒言

氣候變化專門委員會 (Intergovernmental Panel on Climate Change, IPCC) 的報告顯示，2011 至 2020 年全球地表溫度比 1850 至 1900 年高出 1.09°C，其中陸域的升溫幅度約 1.59°C，明顯超過海域的 0.88°C (IPCC 2021)。氣候變遷會使許多物種的原生棲地或生育地環境發生變化，影響現有的生物多樣性分布與組成，甚至導致一些脆弱物種的滅絕 (Urban *et al.*

2015; Pecl *et al.* 2017)，除受脅物種外，另有學者更專注於具備生態系服務價值 (ecosystem services) 的重要物種，這些物種群族的衰退，將對人類的日常生活造成更直接的影響 (Mooney *et al.* 2009; Warren *et al.* 2013; Soroye *et al.* 2020)。

山茶科 (Theaceae) 的山茶屬 (*Camellia*) 為常綠灌木或小喬木，在全球有 200 餘種，主要分布於東亞地區，本屬植物的種子可透過物理壓榨或化

學浸出獲取油脂，俗稱苦茶油，也被譽為「東方橄欖油」，由於富含對人體健康有益的單元不飽和脂肪酸，故是具有經濟潛力的食用油作物 (Su *et al.* 2014)。不僅如此，茶籽榨油後產生的副產品苦茶粕，亦含茶皂素、多醣體等功能性成分，除可作為農工業中的乳化劑、天然清潔劑、殺蟲劑和殺菌劑等使用外 (Zhao *et al.* 2011)，也具備抗腫瘤、抗氧化、延緩老化和降低心血管疾病等保健潛力 (Chen *et al.* 2009; Jin and Ning 2012; Wei *et al.* 2014; Chiang *et al.* 2019)，利用層面廣泛。基於氣候變遷對生物多樣性的影響，近代世界各地的研究發現，茶樹屬的物種也面臨了威脅，並可能導致相關產品的質與量雙雙受損 (Ahmed *et al.* 2018; Jayasinghe and Kumar 2021)。

為因應氣候變遷所帶來的衝擊，預測物種的潛在分布被視為是擬定調適策略的首要任務 (Thomas 2010)。隨著統計方法和地理資訊科學的快速發展，物種分布模型 (species distribution models, SDM) 已被廣泛應用於預測物種的分布格局，並評估氣候變遷對物

種分布的影響 (Newbold 2018)。透過 SDM 預測生育地適宜性，不僅有助於劃定脆弱物種保育和經營管理的關鍵區位，並可針對物種的生態生理或習性行為提出具體的調適方案。在各種 SDM 中，最大熵模型 (Maximum Entropy, MaxEnt) 是基於資訊熵理論所發展的一種機器學習演算法，具有預測性能好、運算效率佳與模擬精度高等優點 (Phillips *et al.* 2006)，過去也曾受學者青睞，用以預測肯亞、斯里蘭卡、中國和土耳其等地山茶屬物種受氣候變遷的影響，同時提出有些物種確實存在生育地限縮的潛在風險 (Jayasinghe and Kumar 2021; İzmirli and Gül 2023)。

臺灣的原生山茶屬植物約有 12 種，其中短柱山茶 (*C. brevistyla*) 為常綠小喬木，主要分布於中低海拔山區 (蘇 2015)，目前也有做經濟栽培，一般樹齡需達 4 年才有種子收穫，種植 6 年以上才開始有較佳的產量，栽培至 10 年後可達穩定的產量，主要栽培於苗栗以北，俗稱小果油茶，屬高經濟價值的樹種，此外，其植株根系深

且廣，具有保水作用，故近年的調整耕作制度活化農地計畫和檳榔廢園轉作計畫，均將油茶列為獎勵栽植樹種(林等 2019)。

臺灣是位處東亞太平洋上的亞熱帶島嶼，受氣候變遷影響甚鉅，根據百年以上的資料(1911-2009年)顯示，臺灣增溫約 1.4°C，遠高於全球平均值，足見氣候暖化趨勢已相當明顯(盧等 2012)。有鑑於此，瞭解氣候變遷對短柱山茶適宜生育地的影響至關重要，然而，目前國內外均尚未有相關的研究報告，本研究即鎖定該物種為目標種，應用 SDM 探究影響物種空間潛在分布的主要因子，進一步搭配 IPCC 最新的第 6 次評估報告所提之氣候情境，預測適宜生育地範圍的動態發展，研究成果可提供未來經營管理或研擬調適策略之參考。

材料與方法

研究區概述

臺灣本島位於亞洲東部、太平洋西北側，西側緊鄰臺灣海峽(圖 1)，

土地面積約 36,000 km²。地形以山地與丘陵為主，地勢起伏陡峭，平原與都市用地則集中於西部沿海，整體地勢呈現東高西低的格局，主要山脈有中央、玉山、阿里山、雪山及海岸等 5 大山系；河川大多發源於中央山脈，水系密布，主要分布於西半部。據中央氣象署網站(<https://www.cwa.gov.tw/>)顯示，臺灣橫跨熱帶與副熱帶季風氣候區，因地形阻隔與天氣系統交互作用，各區域氣候特徵具明顯差異。冬季受東北季風主導，北部及東半部氣溫降幅較顯著，降雨亦較頻繁；夏季轉由西南季風與太平洋高壓控制，中南部常有局地性強降雨發生。全年最低溫在 1 月下旬至 2 月初，平均為 18°C，最高溫發生在 7 月，平均約 33°C；每年 12 月至翌年 1 月是全臺雨量最少的月份，主要降雨來源集中於 5、6 月梅雨季與 7-9 月颱風季。

物種出現紀錄

物種調查資料取自生態調查資料庫系統(ecollect.forest.gov.tw)，資料範

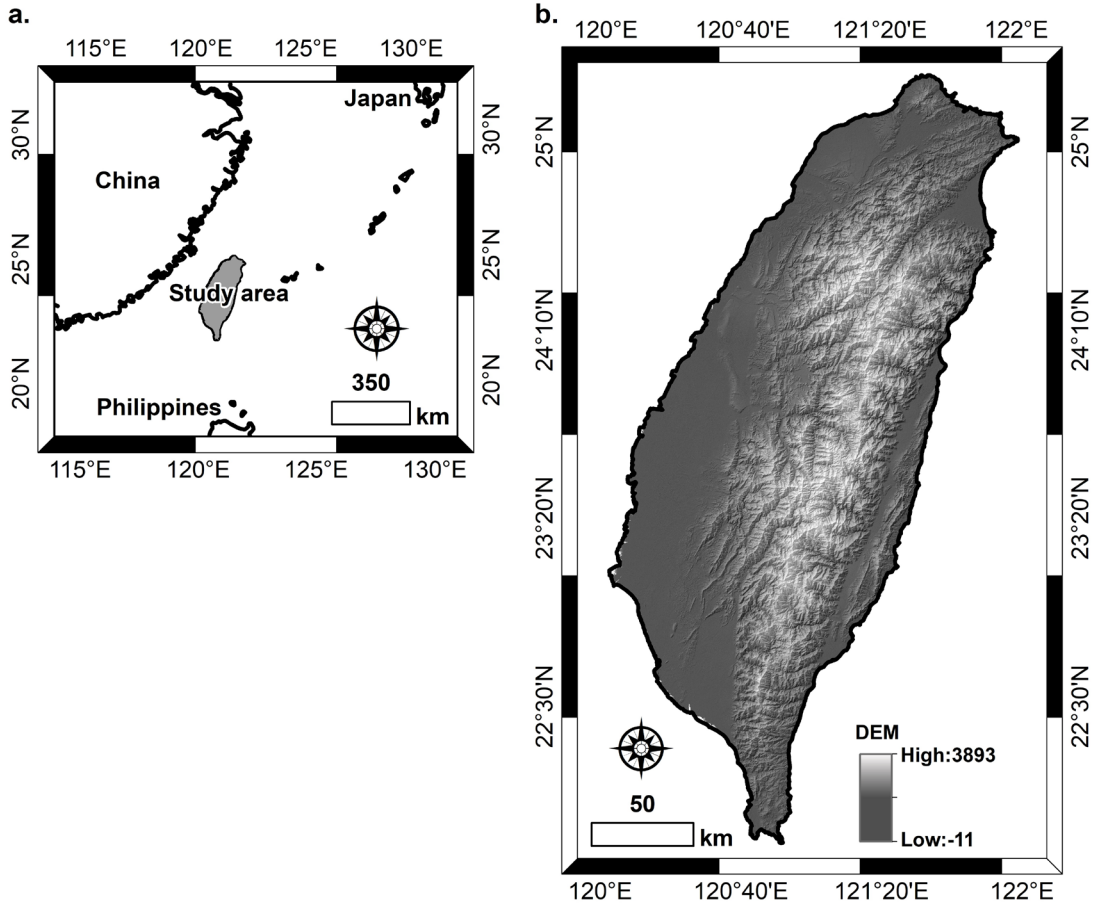


圖 1 研究區之 (a) 地理位置與 (b) 數位高程模型。
Fig. 1 (a) Geographic location and (b) digital elevation model (DEM) of the study area.

圍涵蓋林業及自然保育署發布的「生物資源資料庫」、「森林永久樣區調查」與「國家植群多樣性調查及製圖」等資料集，係屬政府主導之全國性自然資源普查計畫成果。所有資料皆由該署依政府資料開放授權條款公開釋出，屬合法且可自由取得的生態基礎資訊，可確保研究數據之可靠性與應用正當性。本研究抽取短柱山茶的出現紀錄，座標格式為經緯度，僅使用 1981-2015 年期間的資料，以盡可能與環境資料的時間間隔相匹配。考量到地理座標的精確度，先刪除小數點不足 3 位，或座標錯誤（如位於水域）等不合理紀錄，並進一步在 R 4.1.3 平台上，以套件「spThin」進行空間過濾 (Aiello-Lammens *et al.* 2015)，減少空間自相關及地理取樣偏差的影響，為符合預測變項之空間解析力，設定各出現紀錄間的鄰近距離至少在半徑 1 km，經處理後留下 279 筆的出現紀錄 (圖 2a)。

環境資料與變遷情境

氣候、土壤、地形與土地覆蓋

通常被認為是評估植物生育地適宜性的重要因子 (Titeux *et al.* 2016; Hageer *et al.* 2017; Esen 2022)，因此，本研究所使用的預測變項即圍繞在這 4 類因子。現時的氣候資料是由 CHELSA V2.1 (chelsa-climate.org) 取得，涵蓋 1981-2010 年的全球氣象資料，共獲取 19 個 (BIO1-BIO19) 近 1×1 km 空間解析力之生物氣候變項 (Karger *et al.* 2017)，其源自每月的溫度 (°C) 和降水量 (mm)，包括年度趨勢、季節性變化及極端氣象特徵 (worldclim.org/data/bioclim.html)；土壤資料是從 ISRIC-World Soil Information (isric.org) 下載，包括與土壤質地有關的砂粒、粉粒及粘粒含量，另有土壤 pH 值和陽離子交換能力等 5 個變項。數位高程模型則由政府資料開放平臺 (data.gov.tw) 取得，並使用 ArcGIS 10.8 (ESRI Inc.) 軟體中的 Surface Tool 工具進行處理，產生坡度和坡向等變項。土地覆蓋方面是取自 Chen *et al.* (2022) 基於 Land-Use Harmonization 2 (Hurt *et al.* 2020) 及 ESA-CCI 資料集 (www.esa-landcover-cci.org) 所建構的 2015

年全球土地覆蓋圖，包含森林、草地、農地、都市、荒地與水體等 6 種類別。所有變項的空間解析力使用 ArcGIS 10.8 的 Resample Tool 工具重取樣為 $1 \times 1 \text{ km}$ 。為克服統計上的多重共線性問題，除土地覆蓋變項外，以 R 軟體套件「virtual species」執行 Pearson 相關分析 (Leroy *et al.* 2016)，排除相關性高的連續性變項，當相關係數大於 0.7 以上時擇一保留 (Dormann *et al.* 2013)。

對於未來的預測，本研究假設氣候與土地覆蓋變項會隨 2021 年 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。本研究採用 SSP126 和 SSP585 兩種途徑，也分別代表低度與高度碳排放情境，氣候類變項由前述 CHELSA V2.1 獲取 21 世紀末 (2071-2100 年的平均值) 兩種情境的生物氣候資料，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覆蓋變項，SSP126 與 SSP585 情境分別根據 IMAGE 和 REMIND-MAGPIE 兩種預測土地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 各別搭配兩種 IAM 為短柱山茶建模，並取其結果之平均數作為最終生育地適宜性，這種方式可排除模型間的不確定性 (Araújo and New 2007)。此外，由於土壤和地形因子的相對穩定性，假設這些相關變項維持恆定。

潛在生育地預測

為預測短柱山茶的適宜生育地，使用 MaxEnt 軟體 (版本 3.4.3) 進行演算，首先，將該物種的出現紀錄隨機分為兩部分，其中 80% 的資料用於模型訓練，其餘 20% 作為測試資料集，用來評估最終的預測模型。訓練資料集被隨機分成 10 折進行交叉驗證，並隨機選擇 10,000 個背景點位來訓

練模型，準確度評估依接受者操作特徵 (receiver operating characteristic) 所產生之曲線面積 (area under the curve, AUC) 與真實技能統計值 (true skill statistics, TSS) 評估模型的性能。其中 AUC 值域介於 0.5-1，當值愈高代表模型推估出來的準確性愈佳，TSS 則落於 +1 至 -1，接近 1 表示模型幾乎完美，反之亦然。當 AUC 與 TSS 分別高於 0.8 及 0.6 以上時，可表示預測達「良好」水準，若高於 0.9 及 0.8 以上即達「優越」水準 (González-Ferreras *et al.* 2016)。

為避免模型過度擬合，利用 R 軟體套件「SDMtune」(Vignali *et al.* 2020) 的「gridSearch」函數判別 MaxEnt 超參數的最佳組合，其中考量超參數包含「regularization multiplier (範圍為 0.5 到 5，增量為 0.5)」、「maximum number of iterations (範圍為 300 到 900，增量為 200) 以及「feature classes (l、h、lq、lp、hp、lqt、lqp、lqpt，其中的 l 為 linear，h 為 hinge，q 為 quadratic，p 為 product

和 t 為 threshold)。最佳模型是根據交叉驗證過程中的 TSS 來決定，可用於預測短柱山茶的生育地適宜性。最後，藉由獨立的測試資料集，再一次計算 TSS，瞭解最佳模型的預測能力。此外，MaxEnt 的內建工具可獲得預測變項在模型擬合過程中的重要性，以及生育地適宜性與變項間之反應曲線 (response curves)。

時空動態分析

MaxEnt 的預測結果為值域介於 0-1 的連續概率值，其值愈高代表環境條件愈適合該物種生存，可用以表示物種的生育地適宜性。適宜生育地範圍的劃定是採用靈敏度 (sensitivity) 和特異性 (specificity) 之和達到最大值時 (即最大 TSS)，所對應的概率作為閾值，據此將連續性的適宜性圖轉換為二元地圖 (適宜 / 非適宜生育地)，並進一步估算適宜生育地面積。隨後，根據 Dai *et al.* (2019) 評估生育地動態的方法，使用 ArcGIS 的 Combine 工具進行空間交集分析，產生 3 種生育

地動態類型，即「脆弱生育地」：現時為適宜生育地，預計未來氣候情境將轉為非適宜生育地；「新增適宜生育地」：現時為非適宜生育地，但未來氣候情境將轉為適宜生育地；「氣候庇護所」：現時與未來氣候情境皆維持適宜生育地狀態。

結果

以 Pearson 相關係數 < 0.7 為標準，可保留溫度季節性、平均日較差、最冷月最低溫、降水季節性、坡度、坡向、年降水量、土地覆蓋、粉粒含量、陽離子交換能力與砂粒含量等 11 個預測變項 (圖 3)，用於建構預測模型。從 10 折交叉驗證的總體平均測試 AUC 為 0.89 ± 0.01 ，依常用的標準，所建構的模型達「優越」水準的性能。根據 MaxEnt 最佳化超參數組合的判別結果，regularization multiplier 設定為 1，maximum number of iterations 設定為 900，feature classes 指定為 lqt。該最佳模型根據測試資料集計算出的 TSS 為 0.72，由此顯示，無論是訓練

資料集或測試資料集的準確度評估結果，本研究所建構的模型都具備良好的預測能力。利用最佳 MaxEnt 模型預測短柱山茶的適宜生育地，研究結果顯示，該物種的適宜生育地多集中於北部與東北部，形成兩大區塊，南部則較為零星 (圖 2b)，面積估算約 $5,479 \text{ km}^2$ ，占全島面積 15% 左右。

MaxEnt 模型擬合過程中，各變項的重要性如圖 3 所示，前 3 個氣候類的變項明顯高於其他，依序為溫度季節性 (31%)、平均日較差 (30%) 和最冷月最低溫 (23%)，累計達 84%，其餘各變項皆不足 6%，對模型的影響力相對較小。進一步觀察 3 個主要影響模型變項與生育地適宜性構成的反應曲線 (圖 4) 可發現，溫度季節性的提升，將同時伴隨短柱山茶生育地適宜性的增加 (圖 4a)；相反地，平均日較差則呈現負相關的趨勢，並且適宜性的峰值落在 $2-3^\circ\text{C}$ ，隨後便呈現快速下降 (圖 4b)；此外，最冷月最低溫的適宜性峰值落在 $1-5^\circ\text{C}$ ，超過該範圍都呈現下降趨勢 (圖 4c)。

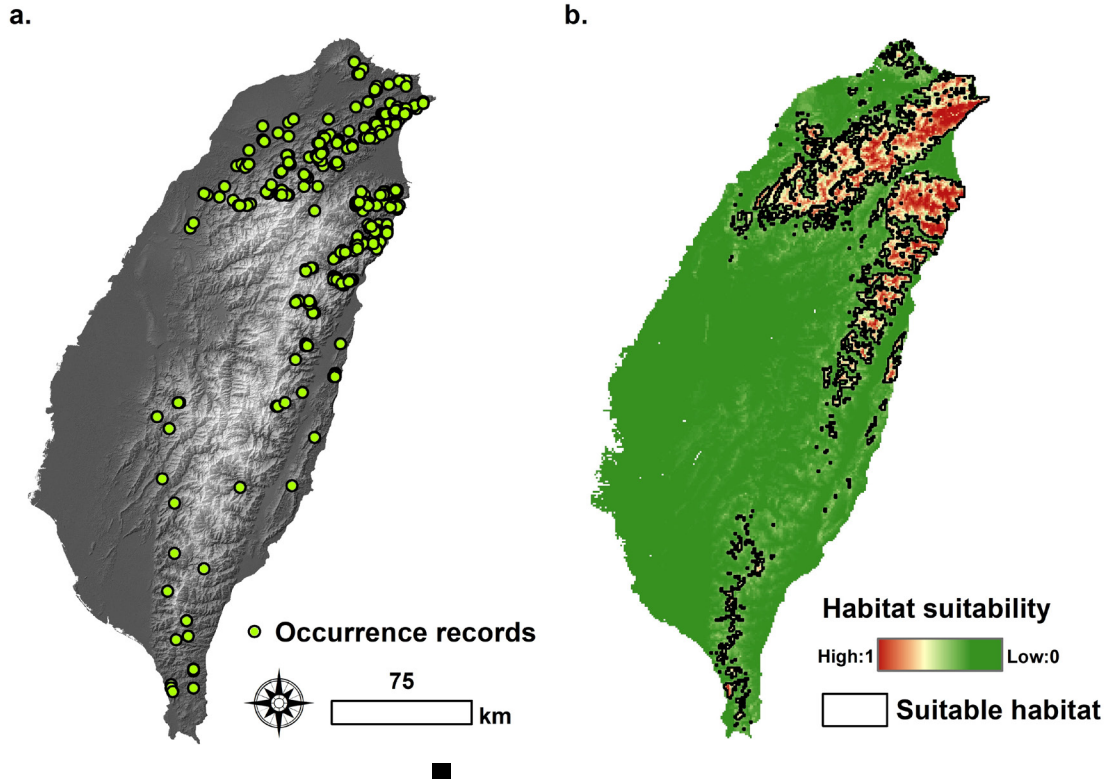


圖 2 (a) 短柱山茶的出现紀錄；(b) 根據最佳化 MaxEnt 模型所預測的結果。

Fig. 2 (a) Occurrence records of *C. brevistyla*; (b) predicted distribution based on the optimized MaxEnt model.

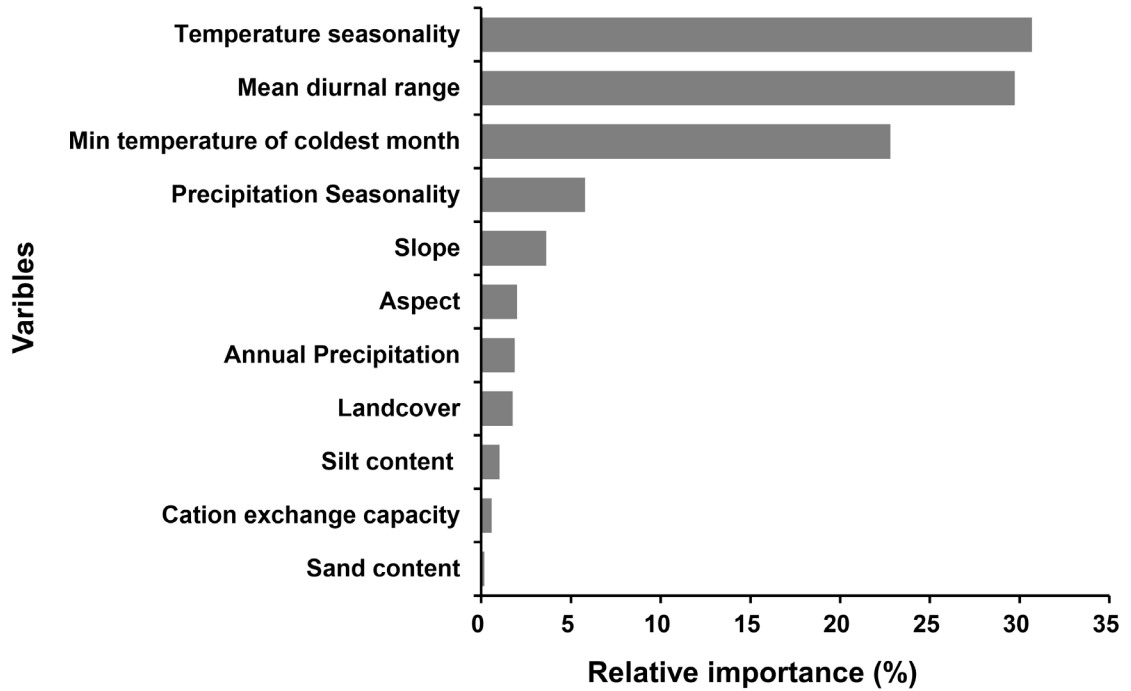


圖 3 各預測變項對 MaxEnt 模型之相對重要性 (%)。

Fig. 3 Relative importance (%) of predictor variables in the MaxEnt model.

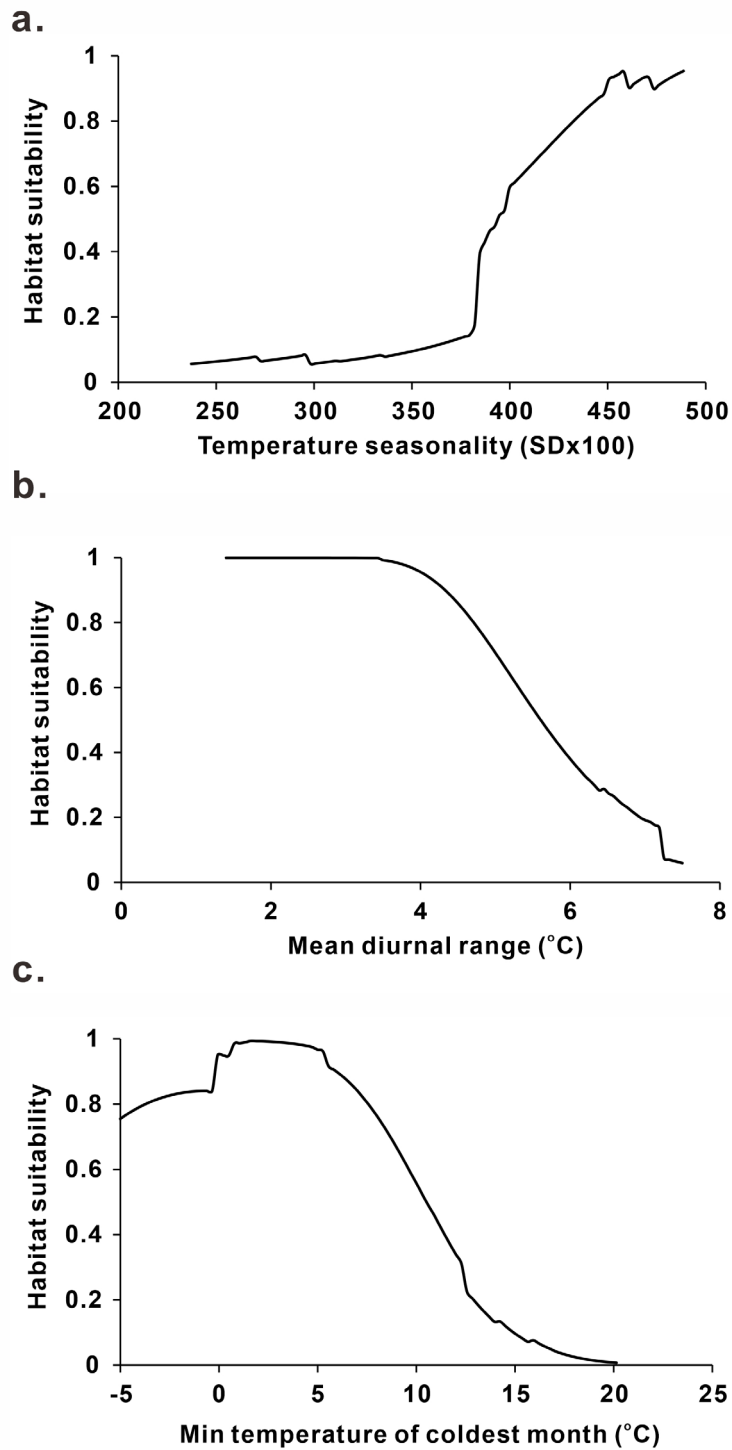


圖 4 主要影響模型變項之反應曲線。

Fig. 4 Response curves of the primary variables influencing the model.

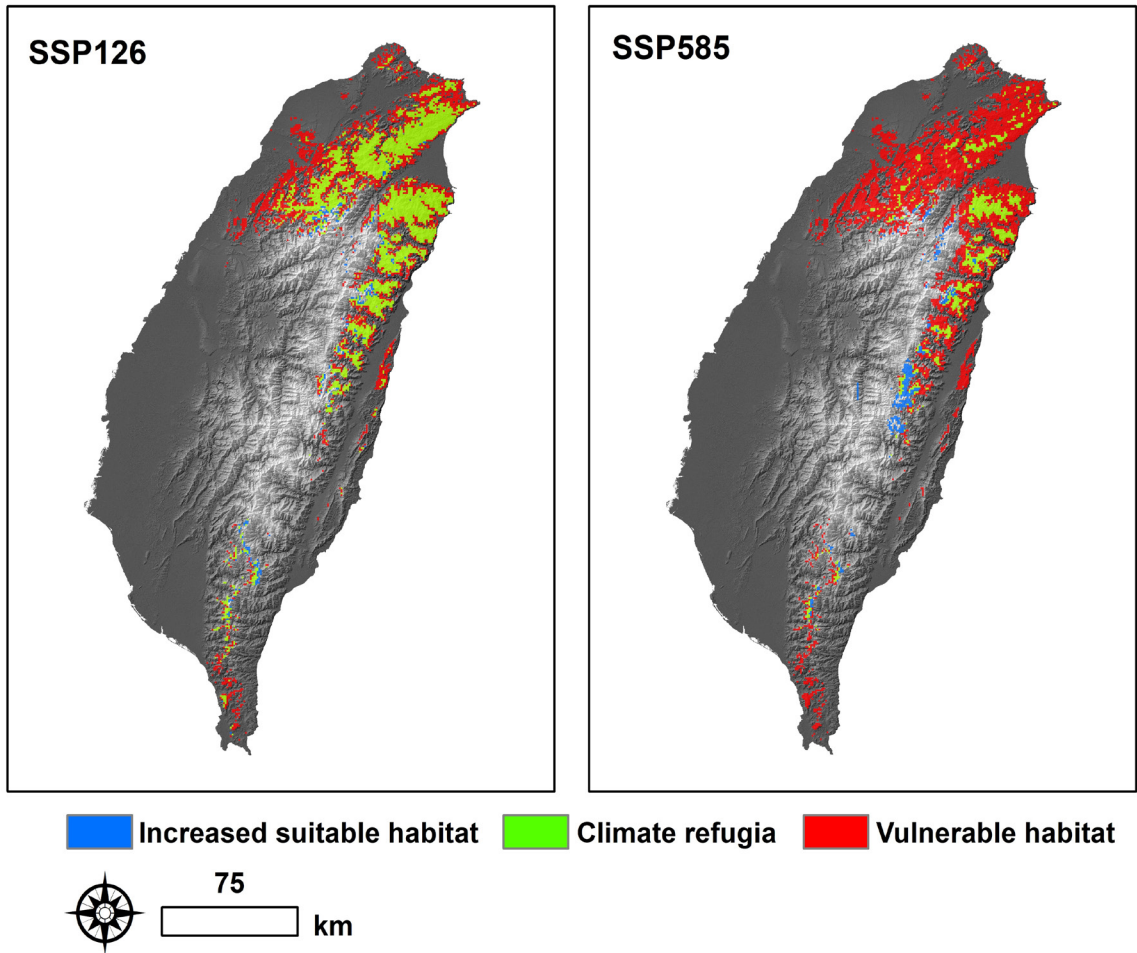


圖 5 兩種碳排情境下現時至 21 世紀末短柱山茶的適宜生育地動態。

Fig. 5 Projected dynamics of suitable habitats for *C. brevistyla* from the current to the end of the 21st century under two carbon emission scenarios.

短柱山茶的生育地動態分析結果顯示（圖 5），無論是低碳排或高碳排放情境，直至 21 世紀末，均以氣候庇護所與脆弱生育地為主要型態，可新增適宜生育地相當少數。就低碳排的 SSP126 情境而言，估計有 2,893 km² 的範圍可為氣候庇護所，而幾乎所有的邊緣生育地，都被預測轉為脆弱狀態，面積約為 2,586 km²。相形之下，高碳排放的 SSP585 情境，適宜生育地將產生劇烈變動，脆弱生育地可能在北部區塊大幅增加，估計面積達 4,583 km²，氣候庇護所則明顯縮減至 896 km²，且僅侷限分布在東北部區塊。

討論

氣候變遷是改變許多物種地理分布的關鍵因素 (Bellard *et al.* 2012)，因此，預測物種對氣候變遷的反應，尤其是適宜生育地的分布，有助預先規劃調適策略 (Teixeira *et al.* 2013)。MaxEnt 是預測氣候變遷對物種生育地分布影響最常用的工具之一，本研究開發了最佳超參數組合之 MaxEnt 模型用於預測短柱山茶的適宜生育地，

在模型訓練過程中，經交叉驗證所建構之模型，雖 AUC 均達「良好」性能的水準 (AUC > 0.8)，惟僅依訓練資料集進行內部測試，仍可能存在過度參數化的問題 (Lobo *et al.* 2008)，故進一步計算獨立測試資料集之 TSS，以確認此最佳化模型確實具備高性能表現，由此顯示，本研究中擬合出的模型並未受到過度擬合的影響，也確保了後續的氣候情境模擬是建立在穩固的科學基礎上。

氣候向來是驅動植物生長、發育與地理分布的關鍵因子，本研究的結果亦顯示，溫度季節性、平均日較差和最冷月最低溫等氣候類變項，對短柱山茶的適宜生育地分布具顯著影響，此與過往山茶屬栽培物種的研究結果相互應，顯示氣候不僅影響物種空間分布，更直接牽動其產量與品質 (Jayasinghe and Kumar 2019; Jayasinghe and Kumar 2021)。回顧與山茶屬植物 SDM 有關的研究，氣候因子的重要性屢獲驗證，如 Zhao *et al.* (2021) 指出溫度年較差為影響 *C. sinensis* 適宜生育地的最關鍵變項；Liu *et al.* (2023)

預測中國4大油茶植物的適宜生育地，強調不同物種對預測變項的反應存在差異性，其中與短柱山茶應用性質較相近的 *C. oleifera*，主要受最冷季均溫與溫度季節性所支配；Gu *et al.* (2025) 在中國山茶組 (sect. *Camellia*) 55 物種的大規模研究更進一步指出，最冷月最低溫是驅動其分布範圍的重要因子；Xu *et al.* (2025) 對 15 種山茶亞屬植物的分析亦顯示，最冷季降水量與溫度季節性為相對重要的環境變項，短柱山茶的分布更同步受到平均日較差的顯著影響。綜合上述研究結果可見，儘管不同研究在預測變項的選擇上略有差異，但普遍共識認為溫度變異性（溫度年較差、日較差或季節性）與冬季氣候（最冷月或最冷季溫度）為決定山茶屬植物分布格局的核心因子。

細部的氣候棲位特徵顯示（圖 4），短柱山茶偏好季節性溫度變異明顯的環境，且變異愈大適宜性愈高，顯見四季分明的溫度型態，更有利其生長。相對的，平均日較差愈大或最冷月溫度愈高的環境則較不適宜，這也反映出該物種偏好日夜溫差穩定的

冷涼環境。與多數溫帶木本植物相同，山茶屬植物具備以芽休眠越冬的適應性機制，日本山茶 (*C. japonica*) 與短柱山茶在系統發育上關係密切 (Yin *et al.* 2021)，其研究案例已證實了低溫對其休眠解除具關鍵作用，晚秋與冬季氣候過暖，可能導致開花不穩定或延遲 (Berruti *et al.* 2012; Berruti *et al.* 2015)。此外，楊及郭 (2017) 的研究中也指出，短柱山茶種子能耐 1-4°C 溫度，屬於溫帶異儲型，其種子經 3 個月低溫層積處理，可完全打破休眠並促進發芽，進一步佐證其生理機制與冷涼環境相互契合，由此推論，若氣候暖化持續加劇，導致冬季低溫不足或日夜溫差擴大，勢必對短柱山茶族群的更新與存續構成潛在威脅。

根據模型預測結果（圖 2）顯示，短柱山茶適宜生育地主要分布於臺灣北部山區，此分布格局與過去的植群調查報告（楊 1997；陳 2004）所記錄的實際分布範圍大體一致。然臺灣未來氣候不僅朝暖化加劇的方向發展，且山區、北部的升溫幅度，預期將高於平地、南部地區 (Lin *et al.* 2015)，

此暖化空間特徵恰與短柱山茶現有的核心適宜生育地高度重疊，勢必加劇脆弱生育地的擴增；此外，未來熱浪頻率增加，可能導致日較溫差擴大 (Kueh *et al.* 2017)；旱澇災害風險的提升，也將致使降水型態變得更趨極端 (Huang *et al.* 2012)。從這些氣候變遷特徵看來，臺灣未來的氣候條件恐不利短柱山茶的存續，誠如本研究模型所預測，低碳排 (SSP126) 情境下，生育地的脆弱化仍以邊緣區位為主，至 21 世紀末，尚能維持一定面積的氣候庇護所；但對高碳排情境而言 (SSP585)，退化趨勢顯著加劇，多數現存生育地都將轉為脆弱狀態，尤以北部區塊最為明顯，僅存少數氣候庇護所侷限於東北部。值得注意的是，幾項研究對氣候變遷下山茶屬的分布預測提出了不同觀點，如 Xu *et al.* (2025) 指出短柱山茶在中國仍有機會於 SSP126 情境下擴張生育地範圍，但在 SSP585 情境下，則將面臨大幅生育地縮減；Jiang *et al.* (2025) 則認為 *C. oleifera* 可在未來氣候條件下，往北擴張其適宜生育地範圍，顯示同屬

不同物種在不同地理區域或排放情境下，其分布動態可能存在差異 (Liu *et al.* 2023; Gu *et al.* 2025)。然無論如何，臺灣北部與東北部受限於地理空間條件，即便在低碳排情境下，短柱山茶亦難發生生育地擴張的現象，反而更傾向於持續面臨生育地退化的風險。

為因應氣候變遷對短柱山茶的衝擊，本研究提出幾點調適建議：第一、目前臺灣現行的保育評估系統及國際自然保育聯盟 (International Union for Conservation of Nature, IUCN) 的標準，該物種被列為「無危 (Least Concern)」(IUCN 2001，臺灣植物紅皮書編輯委員會 2017)，然而，該物種可能是容易受到氣候變遷影響的「脆弱物種」，故有必要強化其保育意識。第二、由於臺灣山區已有完善的保育網絡，調整自然保護區以維持適宜生育地的空間自是有限，因此，建議加強氣候庇護所的長期監測工作，以防止族群面臨衰退。第三、由於北部區塊在高碳排情境下 (SSP585)，適宜生育地有大幅衰退的風險，未來苦油茶的栽培區可考慮著重在東部的氣候庇

護所範圍，蘇 (2014) 的培育試驗中也曾證實過，東部為短柱山茶最佳的栽植區域。最後，除了物種保育與產業經營模式的調整外，本研究也建議同步投入其他物種的研究與開發，以消彌因氣候變遷所造成的損失。

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***Capparis cantoniensis* Lour. (Capparaceae), a newly
recorded plant species in the Matsu Islands**

馬祖新紀錄植物 – 廣州山柑

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Abstract

A newly recorded species, *Capparis cantoniensis* Lour. (Capparaceae) is documented from the Matsu Islands, representing not only a new addition to the regional flora but also the first record of the family Capparaceae in this archipelago. This species exhibits a broad distribution across tropical and subtropical Asia, including the Andaman Islands, Assam, Bangladesh, southeastern China, the eastern Himalayas, Hainan, Java, Laos, the Lesser Sunda Islands, Maluku, Myanmar, the Philippines, Sulawesi, Sumatra, Thailand, and Vietnam. Within China, it has been recorded in the provinces of Fujian, Guangdong, Guangxi, Guizhou, Hainan, and Yunnan. Despite the close geographical proximity of the Matsu Islands to the southeastern coast of China, the presence of *C. cantoniensis* had not previously been reported from this region. In this study, we provide a detailed morphological description, accompanied by diagnostic line drawings and high-resolution photographs taken from specimens *in situ*, to support accurate identification and future floristic research.

Key words: *Capparis cantoniensis*, Capparaceae, Matsu

摘要

本文報導廣州山柑 (*Capparis cantoniensis* Lour.) 為馬祖列島的新紀錄種，同時亦為該地區首次記錄之山柑科植物，對區域植物誌具有重要補充意義。該物種廣泛分布於熱帶與亞熱帶亞洲地區，包括安達曼群島、阿薩姆、孟加拉、東喜馬拉雅、中國東南部、海南、爪哇、寮國、小巽他群島、摩鹿加群島、緬甸、菲律賓、蘇拉威西、蘇門答臘、泰國與越南等地。在中國境內，已知分布於福建、廣東、廣西、貴州、海南與雲南等省。儘管馬祖列島地理上鄰近中國東南沿海，過去未

有關於此物種的紀錄。本研究提供詳細的形態描述，並附有特徵線繪圖與原生環境之彩色照片，以利日後之鑑定與植物區系研究之應用。

關鍵詞：廣州山柑、山柑科、馬祖

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Introduction

The Matsu Islands, located in the northwestern Taiwan Strait, comprise five main islands, Dongyin, Beigan, Nangan, Dongju, and Xiju, as well as numerous smaller islets. Geographically, they are situated approximately 211 km west of Keelung, Taiwan, and about 16 km from the coast of Fujian, China. Due to their proximity to the mainland, the islands share a high degree of floristic and faunal similarity with southeastern China (Ota and Lin 1997). Previous botanical surveys have documented a total of 677 vascular plant taxa, including infra-spe-

cific ranks, and encompass 472 genera and 131 families (Huang 2002; Kuo 2004; Tzeng *et al.* 2012; Tzeng *et al.* 2014). In recent years, additional newly recorded and naturalized plant species have been reported from the region (Jung 2017; Lu and Wang 2023; Liou *et al.* 2025). The family Capparaceae, belonging to the order Brassicales within the Rosids, includes around 430 species distributed across 15 genera, with a predominantly Northern Hemisphere distribution (POWO 2025). *Capparis* Tourn. ex L. is one of the largest genera of the family Capparaceae and is important of its economic and medicinal value (Rivera *et al.*

2003; Jiang *et al.* 2007; Chedraoui *et al.* 2017). The genus consists of 146 species distributed in tropical and subtropical Old World to Mongolia (POWO 2025). It occupies mostly xeric habitats and is characterized by the presence of thorns and saccate outer sepals (Jacobs 1960; Jacobs 1965; Hall *et al.* 2002, 2004). The genus is divided into four sections based on leaf persistence and sepal morphology. Species with well-developed and persistent leaves belong to either Sect. *Capparis*, Sect. *Monostichocalyx*, or Sect. *Busbeckea*. Among them, when the sepals are all free in bud, one sepal of the outer pair is distinctly saccate, so the species are assigned to Sect. *Capparis*. However, if both sepals of each pair are equal, then they are placed in Sect. *Monostichocalyx*. When the outer pair of sepals is connate in bud, the species are classified under Sect. *Busbeckea*. In contrast, species with small leaves up to 2 × 0.3 cm and soon caduceous are placed in Sect. *Sodada* (Jacobs 1965). During re-

cent floristic investigations in the Matsu Islands, *Capparis cantoniensis* Lour. is recorded for the first time in this archipelago. Based on the sepal morphology, *Capparis cantoniensis* is classified under Sect. *Monostichocalyx*. This finding not only represents a new record of the species for the Matsu flora, but also marks the first documentation of the genus *Capparis* and the family Capparaceae in the region. Therefore, it contributes significantly to our understanding of the floristic composition and biogeographic affiliations of the Matsu Islands.

Systematic treatment

Capparis cantoniensis Lour. Fl. Cochinch. 1: 331. 1790. 廣州山柑.(Fig. 1-2)

Type: CHINA. Kwang Tung Province, Canton & Vicinity, 9 March 1917, *Levine 1247* (Neotype E 00327222 digital image!; Isonotypes A 00277170 digital image!, GH 00042251 digital image!, K 000380489 digital image!, L 0035314 digital image!, US 00100536 digital im-

age!).

Shrubs, scandent, 2-6 m tall, branch cylindrical, grey to light green, nearly glabrous, internode 1-4 cm; branchlet cylindrical, light green, pale yellow pubescent; twig cylindrical, light green, straight, with ridge angle when young, pale yellow pubescent. Stipular spines firm, flat or recurved, 3-5 mm, on flower twigs, small or absent, apex often brown orange. Leaf alternate, distichous, nearly leathery, leaf blade elliptic, oblong, oblong-lanceolate, or sometimes ovate, 7-10 × 2-4 cm, apex often acuminate and shortly mucronate, base cuneate to broadly cuneate, reddish brown when dry, adaxially pale green when dry, glabrous or when young mid-vein on both surfaces apically sparsely shortly pubescent but glabrescent, mid-vein abaxially raised and adaxially impressed, secondary veins 8-12 on each side of mid-vein and inconspicuous; petiole 4-5 mm, trichomes like those on twigs. Inflorescences axillary and subumbellate or axillary and terminal,

thus forming a panicle, to 9-flowered; peduncle 1-3 cm, trichomes like those on twigs; bracts early falling, subulate, 1-2 mm; bractlets small, sometimes absent. Pedicel 8-12 mm, trichomes like those on twigs. Sepals 4-5 × ca. 3 mm; sepals of outer whorl navicular, outside shortly pubescent, particularly near base, inside glabrous, margin membranous and glabrous; sepals of inner whorl elliptic to obovate, slightly smaller, margin white, membranous, and with white cilia. Petals white, obovate to oblong, 5-6 × 2.0-2.5 mm, inside basal and central parts white pubescent. Stamens 20-30; filaments 1.0-1.5 cm; anthers 0.7-0.8 mm. Gynophore 6-8 mm, glabrous; ovary nearly ellipsoid, ca. 1.5 × 1 mm, glabrous. Fruit spheroid to ellipsoid, 1-1.5 cm in diam., smooth; pericarp thin, leathery. Seeds 1 to several per fruit, globose or nearly ellipsoid, 6-7 mm.

Specimens examined: Lien-chiang County (Matzu Islands), Beigan Township, Wusha, alt. 50-150 m, 17 Aug.

2023, *W.Y. Wang* 3259; Wusha, alt. 20-80 m, 27 Mar. 2024, *W.Y. Wang* 3375 (TAIF)

Distribution: The native range of this species extends from India, including the Andaman Islands, and the eastern Himalayas, through Myanmar to southeastern China and Hainan, and further south to the Indo-Chinese Peninsula and the Isthmus of Kra (Jacobs 1965; Fici *et al.* 2022). It is also native to Bhutan, China, Indonesia, Laos, Myanmar, the Philippines, Thailand, Vietnam, and the Malaysian region (Zhang and Tucker 2008; Fici *et al.* 2022). In China, the species is distributed across several provinces, including Fujian, Guangdong, Guangxi, Guizhou, Hainan, Yunnan (Zhang and Tucker 2008), and Hong Kong (Hu 2007).

Habitat and Ecology: *Capparis cantoniensis* inhabits forests and forest edges, frequently in the shade, and seems to prefer moist places (Jacobs 1965). The population was recorded in Wusha, Beigan Township, Matsu Islands, growing in

crevices of rocky slopes, forest margins, and roadsides at elevations ranging from 20 to 150 m (Fig. 3). The canopy layer is composed of *Casuarinae quisetifolia* L., *Elaeagnus oldhamii* Maxim., *Triadicasebifera* (L.) Small, *Acacia confuse* Merr., *Ficussuperba* var. *japonica* Miq., and *Celtisbiondii* Pamp. The invasive species present include *Leucaenaleu cocephala* (Lam.) de Wit. Additional associated flora includes *Allium grayi* Regel, *Arisaemahete rophyllum* Blume, *Asparagus cochinchinensis* (Lour.) Merr., *Dianella ensifolia* (L.) DC., *Commelina auriculata* Blume, *Melodinus angustifolius* Hayata, *Trachelospermum jasminoides* (Lindl.) Lem., *Bidens alba* var. *radiata* (Sch. Bip.) R.E. Ballard ex Melchert, *Dendranthema indicum* (L.) Des Moul., *Stellaria media* (L.) Vill., *Celastrus hindsii* Benth., *Sedum drymarioides* Hance, *Mallotus repandus* (Rottler) Müll. Arg., *Ajuga nipponensis* Makino, *Salvia bowleyana* Dunn, *Jasminum sinense* Hemsl., *Corydalis decumbens* (Thunb.) Pers.,

Corydalis koidzumiana Ohwi, *Corydalis tashiroi* Makino, *Pittosporum tobira* (Thunb.) W.T. Aiton, *Sageretia thea* (Osbeck) Johnston., *Galium spurium* f. *vaillantii* (DC.) R.J. Moore, *Rubia akane* Nakai, *Dodonaea viscosa* Jacq., *Wikstroemia indica* (L.) C.A. Mey., *Davallia tyermanii* (T. Moore) H.J. Veitch, and *Carex kago shimensis* Tak. Shimizu.

Phenology: Flowering occurs from August to October, with fruiting happening from March to June.

IUCN Red list category: *Capparis cantoniensis* is widely distributed across Bhutan, China, Indonesia, Laos, Myanmar, the Philippines, Thailand, Vietnam, and the Malesian region (Zhang and Tucker 2008; Fici *et al.* 2022). In contrast, on the Matsu Islands, the species is currently known only from a single locality in Wusha, with an area of occupancy estimated to be less than 2 km² and a population size of approximately 50 to 100 individuals. Based on the IUCN

Red List Categories and Criteria (IUCN 2024), these parameters technically meet the thresholds for Critically Endangered (CR) under criteria [B1a+C1+D1+D2]. Nevertheless, according to the IUCN regional assessment guidelines, categories may be adjusted when the extinction risk of a local population is likely to be mitigated by immigration from outside the region. Considering that *C. cantoniensis* is widely distributed in neighboring regions where the Matsu site currently experiences minimal anthropogenic pressure, the final regional assessment for the Matsu Islands population is best placed under Vulnerable (VU).

Acknowledgments

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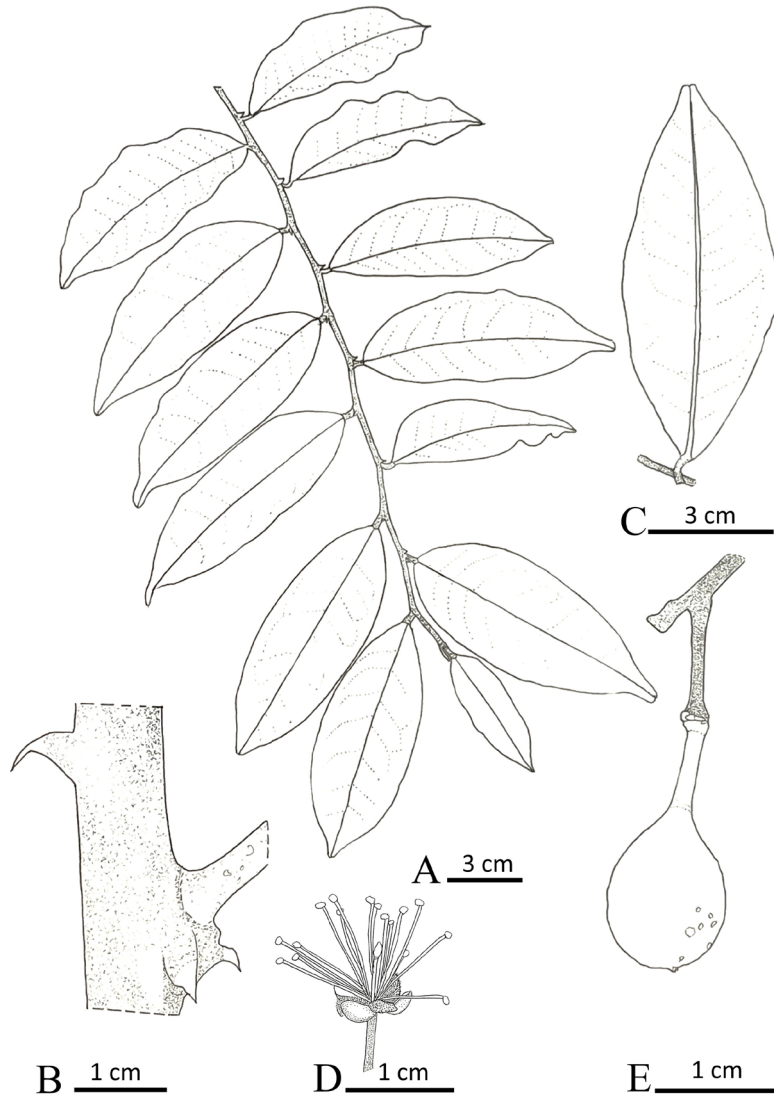


Fig. 1 Illustration of *Capparis cantoniensis* Lour., A. Branches and leaves; B. Branches with barbed thorns; C. Leaf; D. Flower; E. Fruit. (Illustrated by C.K. Yang)

圖 1 廣州山柑線繪圖。A 枝條及葉；B 枝條具倒鉤刺；C 葉；D 花；E 果實

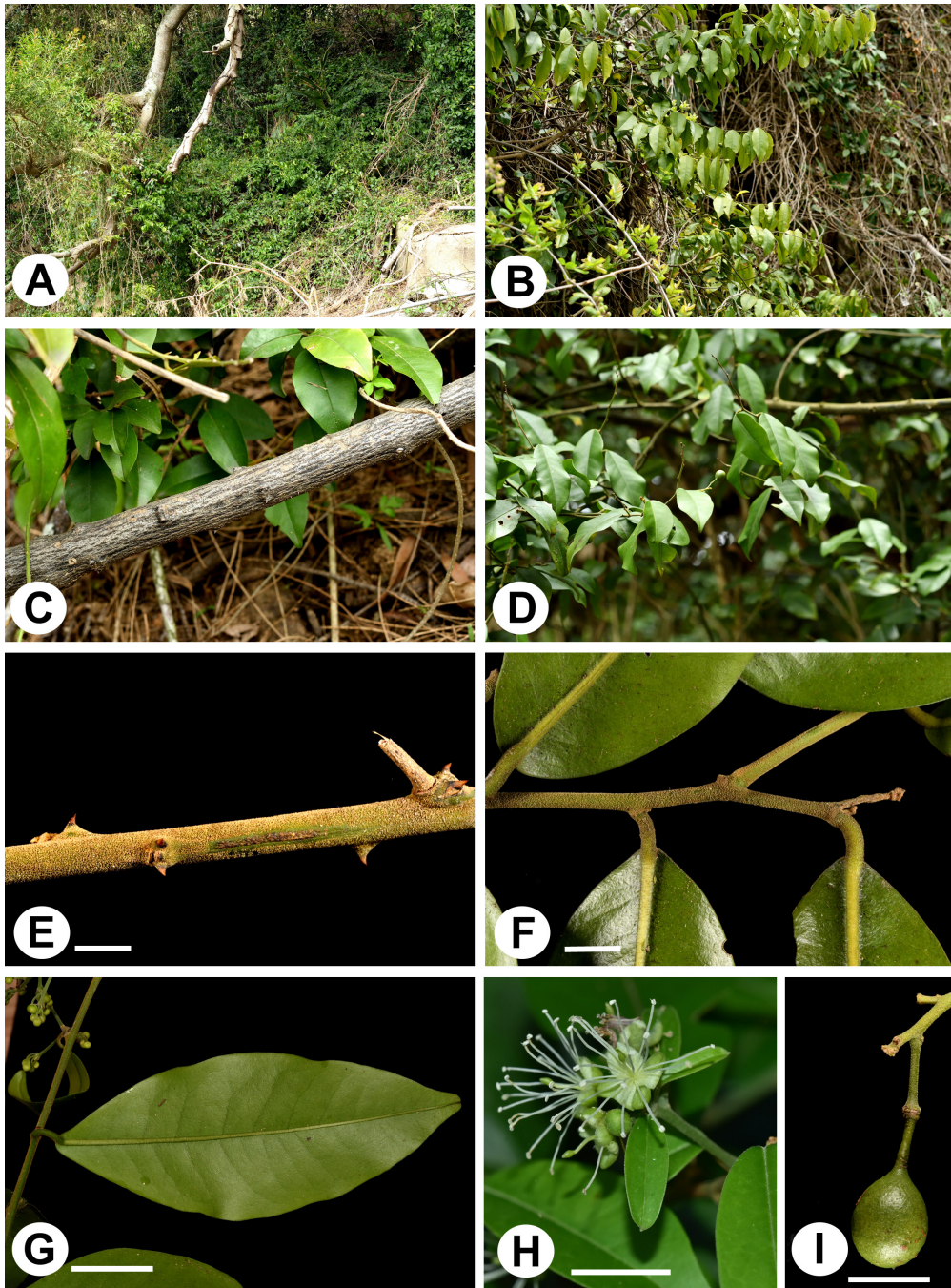


Fig. 2 Habitat and morphology of *Capparis cantoniensis* Lour., A. Habitat; B. Habit; C. Stem; D. Leaves and fruit; E. Branches with barbed thorns and pubescence; F. Young branches and petiole with pubescence; G. Abaxial of leaf; H. Inflorescence; I. Fruit. Scale bars: E = 5 mm; F = 5 mm; G = 3 cm; H = 1 cm; I = 1 cm

圖 2 廣州山柑 (*Capparis cantoniensis* Lour.)。A. 生育地；B. 植株；C. 莖；D. 葉及果實；E. 枝條；F. 幼枝及葉柄密被毛；G. 葉遠軸面；H. 花序；I. 果實。

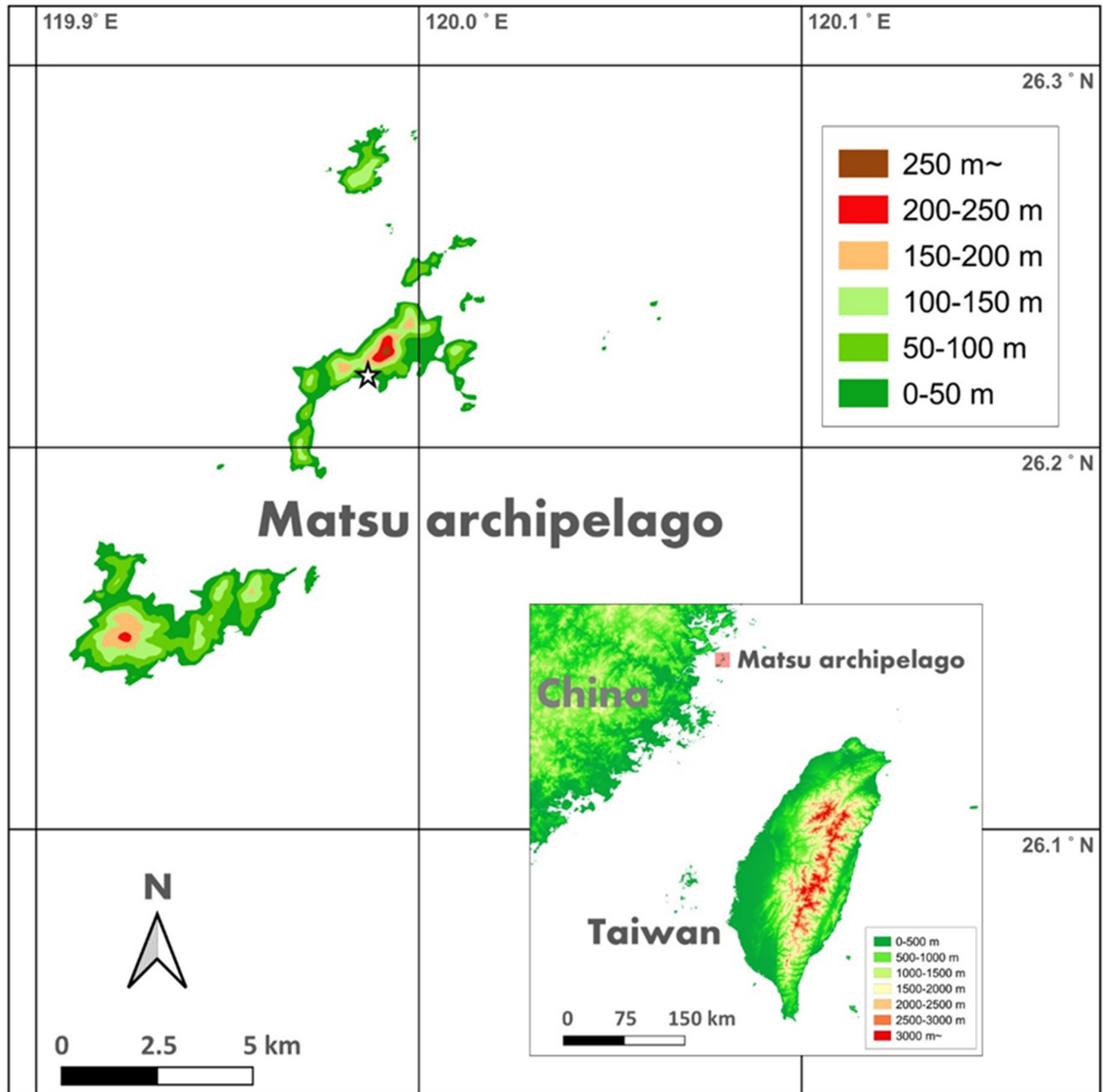


Fig. 3 Locality of *Capparidaceae* in the Matsu Islands.

圖 3 廣州山柑 (*Capparidaceae* Lour.) 在馬祖的分布圖

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Argemone ochroleuca—A newly naturalized species of
Argemone (Papaveraceae) in Taiwan
臺灣薊罌粟屬（罌粟科）的新歸化種—淡
黃薊罌粟

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Abstract

A newly naturalized species of *Argemone* L., *A. ochroleuca* Sweet, has been discovered in central, northern, and eastern Taiwan. This discovery increases the number of *Argemone* species up to two species in Taiwan. Due to its morphological similarity to *A. mexicana* L., this species has often been misidentified as *A. mexicana* in the past. This

paper provides color photographs of the external morphology, pollen, and distribution map of *A. ochroleuca* and *A. mexicana* in Taiwan. In addition, this paper also provides a key to *Argemone* in Taiwan.

Key words: Taiwan, newly naturalized plant, *Argemone ochroleuca* Sweet, pollen, key

摘要

近年於臺灣中部、北部與東部地區發現一新歸化薊罌粟屬植物——淡黃薊罌粟 (*Argemone ochroleuca* Sweet)，將臺灣薊罌粟屬增加至 2 種。本種與薊罌粟 (*A. mexicana* L.) 的形態相似，因此過往常被誤認為薊罌粟。本文提供淡黃薊罌粟與薊罌粟的外部形態彩色照片、花粉照片與在臺分布圖。此外，提供臺灣薊罌粟屬植物的檢索表。

關鍵詞：臺灣、新歸化植物、淡黃薊罌粟、花粉、檢索表

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Introduction

Argemone L. belongs to Papavera-
ceae (The Angiosperm Phylogeny Group
2016; Zuntini *et al.* 2024). Globally, *Ar-
gemone* includes approximately 30 taxa,
primarily distributed across America
(Schwarzbach and Kadereit 1999).

In recent years, an unidentified spe-
cies of *Argemone* was discovered in cen-
tral, northern, and eastern Taiwan. After
reviewing relevant literature, this species
was identified as *Argemone ochroleuca*
Sweet. This species is newly naturalized
in Taiwan, because it is a species wide-
spread in various regions in central and
eastern Taiwan. This species closely re-
sembles *Argemone mexicana* L. (Fig. 1,
2, 3), previously recorded *Argemone* spe-
cies in Taiwan (Liu 1976; Liu and Yang
1996), and their overlapping distributions
have often led to misidentification. This
study compares the external morpholo-
gy and pollen characteristics of the two
species from wild populations, and pro-
vides their distribution maps and a key to

Argemone in Taiwan for clarifying their
differences.

Materials and Methods

Sample collection and photography

The fresh samples used in this study
were collected from Yunlin County in
Taiwan. Externally morphological and
microscopic features were recorded di-
rectly at the collection sites and subse-
quently processed using photographing
software. After photographing, plants
containing flowers or fruits were collect-
ed and brought back to the Department
of Biological Resources, National Chiayi
University, where they were made spec-
imens to serve as voucher specimens.
After the preparation of the voucher
specimens is completed, they will be de-
posited in the Herbarium of Taiwan For-
estry Research Institute (TAIF).

Morphology of pollen

Fresh pollen grains were collected
from the field by using clean tweezers to

remove anthers, which were then temporarily stored in micro-centrifuge tubes containing 75% ethanol. Pre-photography processing was primarily based on the protocol by Halbritter (1997). The samples were put into a vial containing acidified 2,2-dimethoxypropane (1 drop of 0.2 M hydrochloric acid added to 30 mL of 2,2-dimethoxypropane). This step required 30 minutes of processing. After removing acidified 2,2-dimethoxypropane, acetone was added for preservation. Samples were gold-coated for 90 seconds and subsequently examined using a scanning electron microscope (SEM, HITACHI S-3400N). After photographing, the images were post-processed using the photographing software.

Pollen size was measured using Image J 1.50d software (Schneider *et al.* 2012). For each species, 10 pollen grains were randomly selected, followed by calculating the polar axis length (P), equatorial plane length (E), and the P/E ratio. One intact pollen grain was also selected,

and 10 ornamentations were randomly measured in width. A one-way ANOVA was then performed to assess significant differences in pollen characteristics between *A. ochroleuca* and *A. mexicana*. All statistical analyses were performed using R version 4.5.1 (R Core Team 2025). Pollen terminology was primarily based on Halbritter *et al.* (2018).

Horizontal and vertical *Argemone* species distribution in Taiwan

The horizontal and vertical species distribution maps of Taiwan for *A. ochroleuca* and *A. mexicana* were generated using QGIS ver. 3.36.0. (QGIS.org. 2024). Data were obtained originally from iNaturalist (accessed 18 Mar. 2025), selecting records from 2018 to 2024 that had achieved "Research Grade" status. The downloaded data included latitude and longitude information, while elevation data were obtained using Google Earth (accessed 18 Mar. 2025). The vertical and horizontal distribution maps were

created based on this dataset, following the QGIS project template for horizontal and vertical species distribution mapping of Taiwan developed by Lin (2018).

Result and Discussion

Taxonomic treatment

Argemone L. 薊罌粟屬

Annual or perennial glaucous herbs, rarely shrubs, with yellow, foetid milky latex. Leaves alternate, mostly pinnatifid, usually aculeate-dentate. Flowers solitary, terminal; sepals 2 or 3, coherent at apex, caducous; petals double the number of sepals, corrugate in bud; stamens numerous, short than corolla, filaments free; ovary ovoid, with 3-7 parietal placentas; style short, stigma 3-7 lobed, lobes opposite placentas; ovules numerous. Capsules 3-7 valved at apex; seed numerous, globose, reticulate-ribbed.

About 10 taxa native to America; 2 taxa naturalized in Taiwan.

Key to *Argemone* in Taiwan

Plant whitish-green; petals 6, rarely 9, pale yellow..... *A. ochroleuca*
Plant green; petals 6, light yellow.....
.....*A. mexicana*

1. *Argemone mexicana* L., Sp. Pl. 508. 1753; Fawcett *et al.*, Fl. Jamaica 3: 222. 1914; Liu, Fl. Taiwan 2: 654. *pl.* 437. 1976; Liu & Yang, Fl. Taiwan 2nd 2: 720. *pl.* 339. 1996; Zhang & Christopher, Fl. China 7: 262. 2008. 薊罌粟 (Fig. 1, 2)

Type: LINN 670.1 (Lectotype) (Fig. 3)

Erect annual or occasionally short-lived herb, 0.3-1 m tall, green slightly glaucous. Leaves sessile, pinnatifid, oblong-obovate or lanceolate-obovate, 7-28 cm long, 2.5-10 cm wide, spinulose-dentate, white-pruinose on both surfaces, more or less amplexicaul at base. Flower buds subspherical, prickles many, green. Flowers sessile or very short pedicelled, floral diameter 5.5-6 cm; sepals mostly 3, green, 2.7-2.9 cm long, ca. 0.7 cm wide; petals obovate, bright yellow,

2-3 cm long, ca. 1.5 cm wide; stamens many; stigma dark red, 5-lobed. Capsules oblong, 2.5-4 cm long, ca. 1.4 cm wide, 3-6 valved above, clothed with erect-patent sharp bristles. Seed spherical, deep brown, 1.5-2 mm long, 1.5-2 mm wide, obviously tessellate on surface. Flowering from December to May. Fruiting from January to May.

Naturalized in central, western, southern, and eastern Taiwan and Penghu Islands.

Voucher specimens: TAIWAN, Yunlin County, Shuilin Township, 11 Jan. 2025, *Y. Z. Lu* 788 (TAIF¹). Kaohsiung City, Tianliao District, Hsiaokunshui, 05 Jan. 2019, *Z. H. Chen* 1811 (TAIF); Tashu Township, 04 Feb. 2002, *S. Z. Yang* 26262 (TAIF); Shoushan, 05 Apr. 1996, *C. S. Yang* 452 (TAIF). Taitung County, Taitung, 01 Mar. 1913, *Tadasaburo Soma* s.n. (TAIF). Penghu County, Penghu, 01 Sep. 1917, *Tanaka* s.n. (TAIF); Fen Kuei, Shihli Li, 22 Jun. 1994, *C. H. Chen* 704

(HAST²); Nanliao, 22 Jul. 2015, *S. W. Chung* 12248 (TAIF).

¹ This code is the herbarium of the Taiwan Forestry Research Institute, Taiwan.

² This code is the herbarium of Biodiversity Research Museum, Herbarium, Academia Sinica, Taiwan

2. *Argemone ochroleuca* Sweet, Brit. Fl. Gard. 3: 242. 1828; Chintala & Patanaik, Zoos' Print 22(12): 2949. 2007; Patel, Phytoneuron 52: 1 2013. 淡黃薊罌粟 (Fig. 4, 5)

Type: British Flower Garden vol. 3, t. 242, 1828 (Holotype) (Fig. 6)

Argemone mexicana L. var. *ochroleuca* (Sweet) Lindley, Edwards's Bot. Reg. 16: t. 1343. 1830.

Argemone mexicana L. subsp. *ochroleuca* (Sweet) Schwarzb, Fl. Valle Tehuacán-Cuicatlán 131: 8. 2015.

Erect annual herbs, up to 1 m tall, whitish-green, densely glaucous with

reddish tinge. Leaves sessile, semi-amplexicaul, oblanceolate, 16-22 cm long, 4-8 cm wide, sinuate to pinnatifid, basal leaves deeply lobed; lobes oblong, glaucous. Flower buds oblong, prickles few, tinged red. Flower sessile or very short pedicelled, floral diameter 6-7 cm; sepals mostly 3, green, 2.5-2.6 cm long, ca. 0.7 cm wide; petals 6, rarely 9, obcuneate-obovate, pale yellow, ca. 3 cm long, 1.5-1.8 cm wide; stamens many, 8-10 mm long; filaments pale yellow; anthers oblong, recured, dark yellow; stigmas 5-lobed, deeply dissected, dark red. Capsules ovoid or lanceolate-ovoid, 3-4 cm long, 1.3-1.4 cm wide, 3-6 valved above, clothed with erect-patent sharp bristles. Seed spherical, black, 1.5-2 mm long, 1.5-2 mm wide. Flowering from December to May. Fruiting from January to May.

Naturalized in central, northern, and eastern Taiwan (Fig. 8).

Voucher specimens: TAIWAN, Changhua County, Tatsun Township, 16 Mar. 2019, *C. M. Wang* 17791 (TNM³); Shetou Township, Shetou, 21 Mar. 2026, *Y. Z. Lu* 1265 (TAIE⁴); Tienwei Township, Tienwei, 02 Apr. 2001, *C. M. Wang* 04807 (TNM); Tianzhong Township, 13 Jan. 2025, *Y. Z. Lu* 792 (TAIF); Hsichou Township, Hsitso Village, 31 Jul. 2016, *C. M. Wang* 17029 (TNM). Yunlin County, Erhlun Township, Kanghou Village, 31 May 2022, *C. M. Wang* 19391 (TNM); Taihsi Township, Provincial #155, 13 Apr. 2012, *C. H. Chen, C. M. Wang, C. Y. Li* 10866 (TNM).

³ This code is the herbarium of National Museum of Natural Science, Taiwan.

⁴ This code is the herbarium of Taiwan Biodiversity Research Institute, Taiwan

Note: *A. ochroleuca* closely resembles *A. mexicana* in external morphology. However, the most notable difference between the two species lies in the color of their plant and petals. *A. ochroleuca* has

a whitish-green plant and pale yellow petals; *A. mexicana* has a green plant and bright yellow petals.

Morphology of pollen

According to SEM observation, pollen grains of *A. ochroleuca* and *A. mexicana* are very similar (Fig. 7). They are monad, subcircular in shape, and have a microrugulate surface ornamentation. Each pollen grain possesses 3-apertures, with gemmate structures on the aperture surface. However, pollen grain of *A. ochroleuca* sometimes has 4-apertures. These results are consistent with Chaturvedi *et al.* (2010).

Polar axis length (P) of *A. ochroleuca* ($28.28 \pm 0.52 \mu\text{m}$, Mean \pm Standard Error) is longer than *A. mexicana* ($22.86 \pm 1.28 \mu\text{m}$), and they show a significant difference. Equatorial diameter length (E) of *A. ochroleuca* ($32.50 \pm 1.17 \mu\text{m}$) is longer than *A. mexicana* ($30.65 \pm 0.90 \mu\text{m}$), and they show a significant difference. P/E ratio of *A. ochroleuca*

($0.86 \pm 0.03 \mu\text{m}$) is longer than *A. mexicana* ($0.68 \pm 0.06 \mu\text{m}$), and they show a significant difference. Ornamentation width of *A. ochroleuca* ($0.46 \pm 0.04 \mu\text{m}$) is longer than *A. mexicana* ($0.31 \pm 0.04 \mu\text{m}$), and they show a significant difference. Hence, polar axis length, equatorial diameter length, and ornamentation width can distinguish *A. ochroleuca* and *A. mexicana*. Pollen traits of *A. ochroleuca* and *A. mexicana* are summarized in Table 1.

Horizontal and vertical species distribution in Taiwan

Figure 8 is a distribution map of *A. ochroleuca* and *A. mexicana* in Taiwan. Both species are mainly found in low-altitude areas in central Taiwan. *A. mexicana* is also distributed in eastern and southern Taiwan, as well as in the Penghu Archipelago. *A. ochroleuca* has also been recorded in northern and eastern Taiwan.

Acknowledgments

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Fig. 1 Plants of *Argemone mexicana* L. in Taiwan.

圖 1 臺灣的薊罌粟植株。

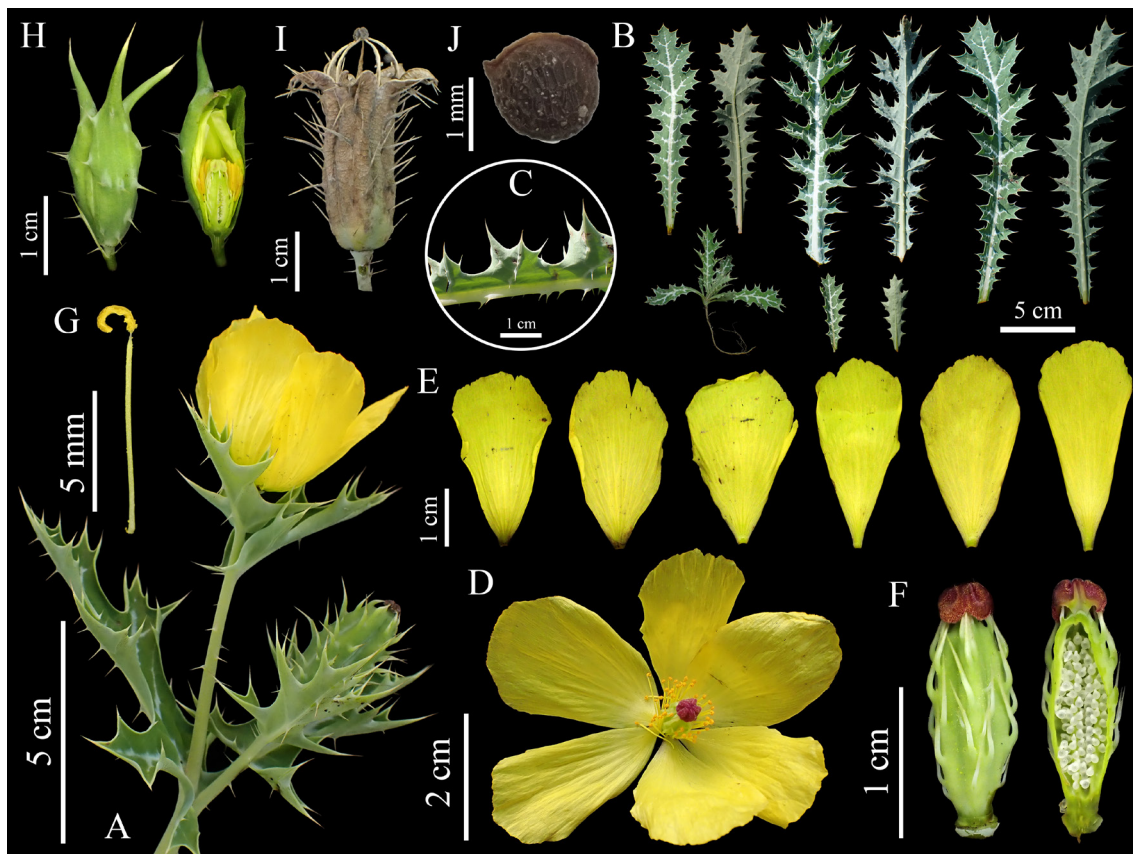


Fig. 2 *Argemone mexicana* L. (A) Habit. (B) Leaves and plantlet. (C) Side of leaf. (D) Flower. (E) Petals. (F) Pistil, outside view (left) and sectional view (right). (G) Stamen. (H) Bud, outside view (left) and sectional view (right). (I) Fruit. (J) Seed.

圖 2 薊罌粟。(A) 植株。(B) 葉片和小苗。(C) 葉片側面。(D) 花。(E) 花瓣。(F) 雌蕊，外觀(左)與剖面(右)。(G) 雄蕊。(H) 花苞，外觀(左)與剖面(右)。(I) 果實。(J) 種子。



Fig. 3 Lectotype of *Argemone mexicana* L. (LINN 670.1). Image from the Linnean Collections.

圖 3 薊罌粟之選模式 (LINN 670.1)。圖片取自 the Linnean Collections (https://linnean.access.preservica.com/uncategorized/IO_48d1ed21-2176-4873-8041-f31d4b3070cd/ [retrived on 16 April 2026])。



Fig. 4 Plant of *Argemone ochroleuca* Sweet in Taiwan.

圖 4 臺灣的淡黃薊罌粟植株。

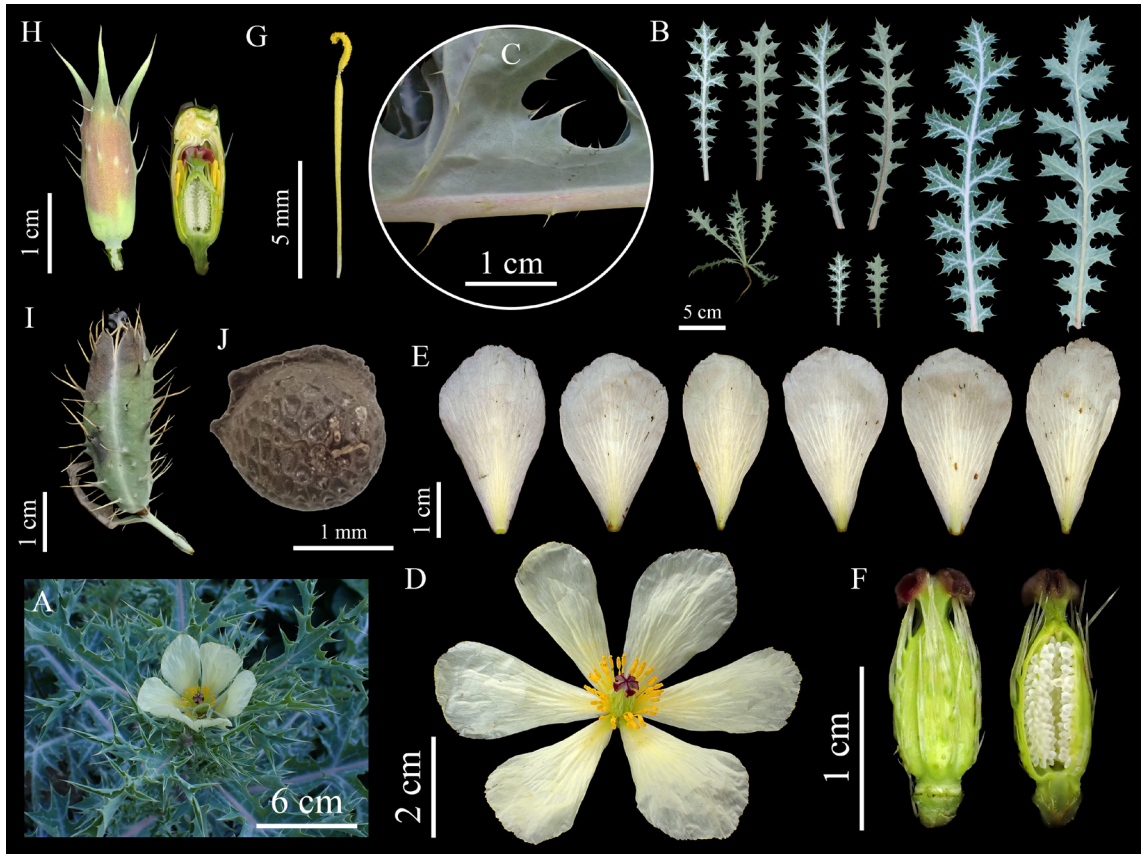


Fig. 5 *Argemone ochroleuca* Sweet. (A) Habit. (B) Leaves and plantlet. (C) Side of leaf. (D) Flower. (E) Petals. (F) Pistil, outside view (left) and sectional view (right). (G) Stamen. (H) Bud, outside view (left) and sectional view (right). (I) Fruit. (J) Seed.

圖5 淡黃薊罌粟。(A)植株。(B)葉片和小苗。(C)葉片側面。(D)花。(E)花瓣。(F)雌蕊，外觀(左)與剖面(右)。(G)雄蕊。(H)花苞，外觀(左)與剖面(右)。(I)果實。(J)種子。



Fig. 6 Holotype of *Argemone ochroleuca* Sweet (British Flower Garden vol. 3, t. 242, 1828). Image from the Biodiversity Heritage Library.

圖 6 淡黃薊罌粟之全模式 (British Flower Garden vol. 3, t. 242, 1828)。圖片取自 Biodiversity Heritage Library (<https://www.biodiversitylibrary.org/item/224660#page/178/mode/1up> [retrieved on 27 November 2024])。

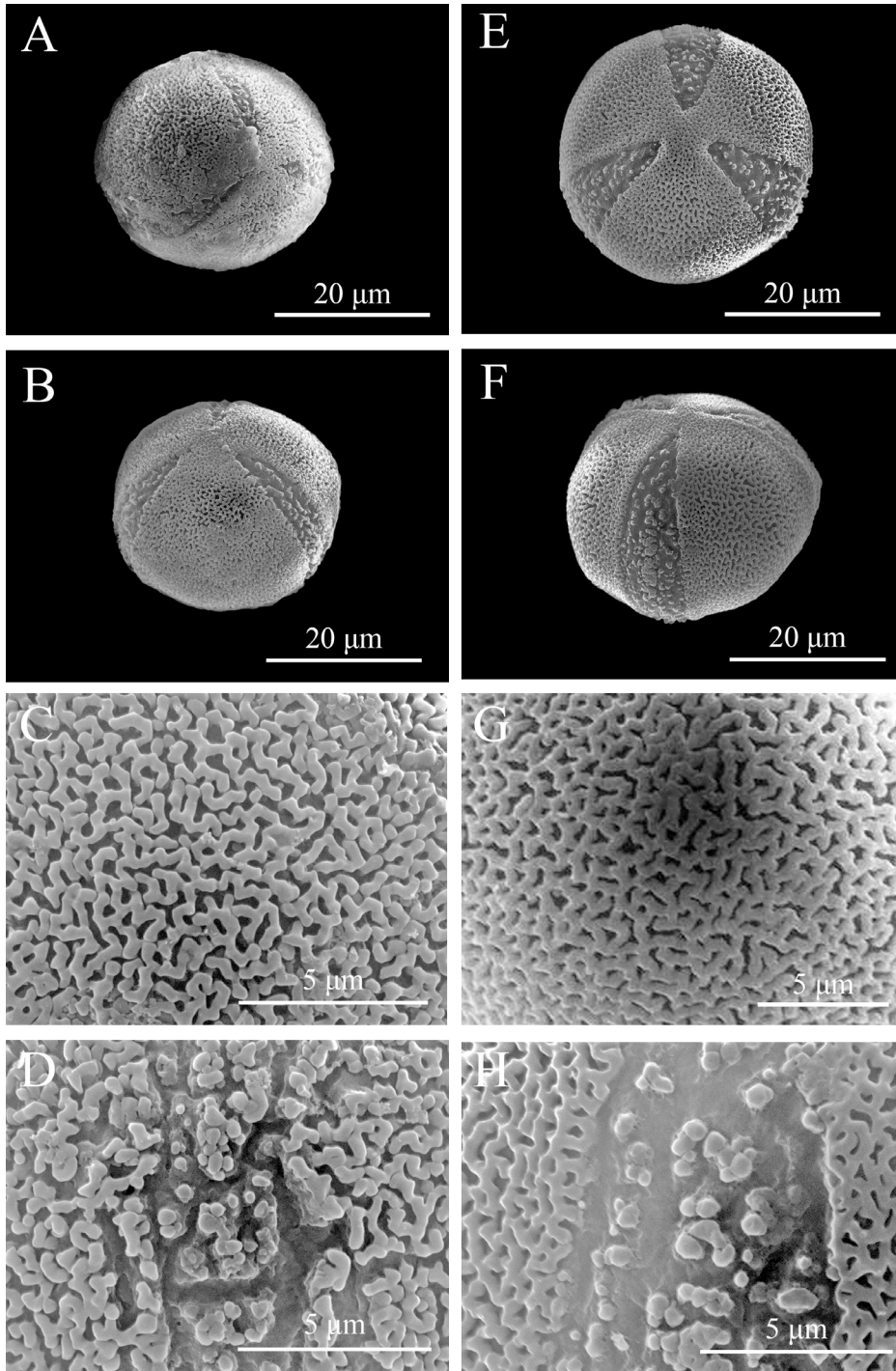


Fig. 7 Pollen morphology of *Argemone mexicana* L. (left) and *Argemone ochroleuca* Sweet (right). (A)(E) Polar view. (B)(F) Equatorial view. (C)(G) Ornamentation. (D)(H) Aperture.

圖7 薊罌粟(左)與淡黃薊罌粟(右)的花粉外部形態。(A)(E)極面。(B)(F)赤道面。(C)(G)表面紋飾。(D)(H)萌發溝。

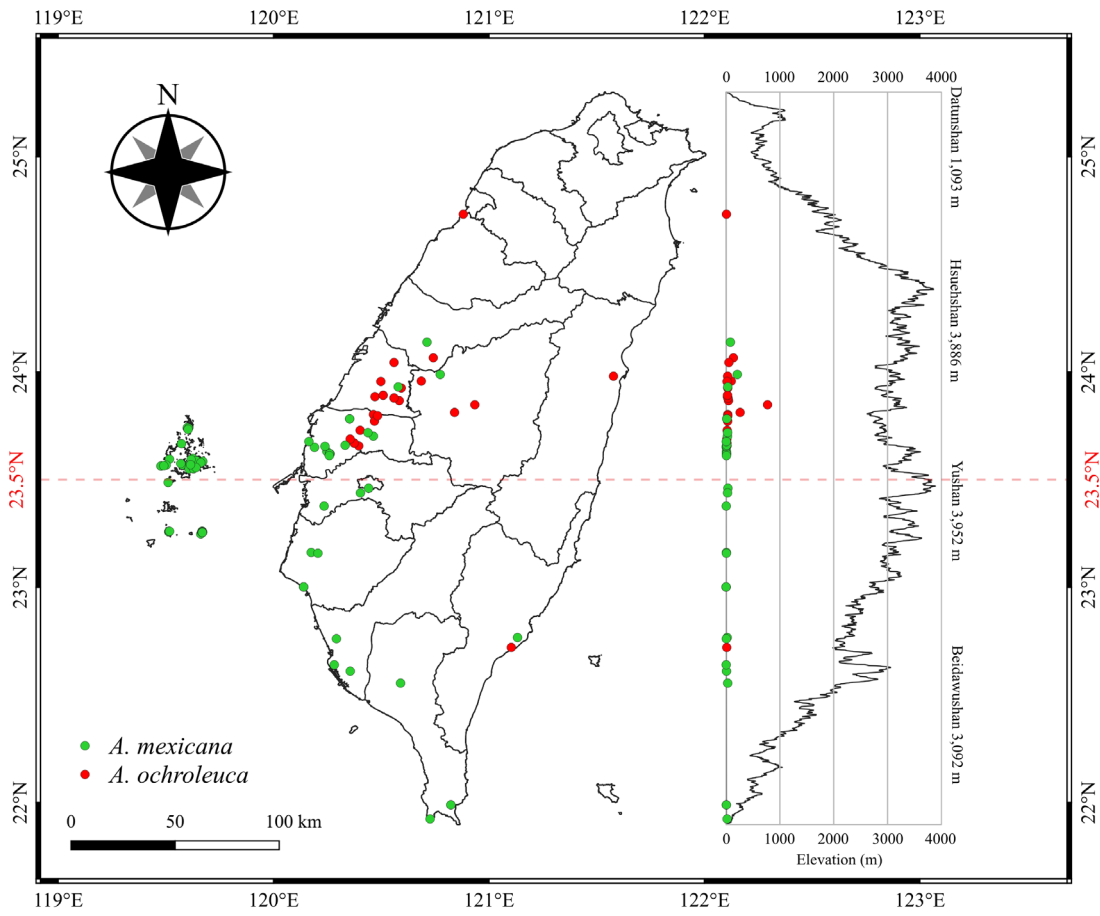


Fig. 8 Distribution of *Argemone ochroleuca* Sweet and *Argemone mexicana* L. in Taiwan.

圖 8 淡黃薊罌粟與薊罌粟在臺灣的分布。

Table 1 Pollen trait of *Argemone ochroleuca* Sweet and *Argemone mexicana* L. (* indicates a significant difference)

表 1 淡黃薊罌粟與薊罌粟的花粉特徵。(* 表示具有顯著差異)

Taxon	Shape	Ornamentation	Polar axis length (P) (μm) ($n = 10$)*	Equatorial length (E) (μm) ($n = 10$)*	diameter P/E ($n = 10$)*	Ornamentation width (μm) ($n = 10$)*
<i>A. ochroleuca</i>	Subcircular	Microrugulate	28.28 \pm 0.52	32.50 \pm 1.17	0.86 \pm 0.03	0.46 \pm 0.04
<i>A. mexicana</i>	Subcircular	Microrugulate	22.86 \pm 1.28	30.65 \pm 0.90	0.68 \pm 0.06	0.31 \pm 0.04

Note: The values in the table are Mean \pm SE.

註：表中數值為平均值 \pm 標準誤差。

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