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目 錄 contents

封面圖說 /
瓶鼻海豚 *(Tursiops truncatus)*（林思瑩 提供）

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出版 / 農業部生物多樣性研究所
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彰雲海岸濕地土壤重金屬含量分析

Heavy metal monitoring in the soil of Changhua and Yunlin coastal wetlands

劉靜榆

Ching-Yu Liou

農業部生物多樣性研究所 552005 南投縣集集鎮民生東路 1 號

Taiwan Biodiversity Research Institute, Nantou, Taiwan

通訊作者：lcy@tbri.gov.tw

Corresponding authors: lcy@tbri.gov.tw

摘要

為瞭解彰雲海岸濕地之污染現況，本研究依地理位置、河口現況及潮間帶寬度設置採樣站，設置 28 個固定採樣站，於 2022–2023 年進行採樣。在每個固定採樣站檢測水體之鹽度、pH 值、溶氧飽和度、NO_3 等，各進行 3 次樣點檢測，共 177 筆現場水質、水文檢測資料。每固定採樣站採集上下層土壤各 1 個樣本，帶回實驗室進行後續處理。土壤粒徑分析砂粒、粘粒、坋粒百分比，2 年上下層共 121 筆資料進入分析。土壤重金屬含量檢測以 X- 射線螢光光譜儀進行 32 種重金屬濃度檢測，每樣本各 3 次重複，2 年上下層共 393 筆資料進入分析，以定量數據來計算採樣站間、不同土層以及不同年度間之差異。檢驗分析結果，發現彰化縣福寶、舊濁水溪口、八洲排水道口、三豐新街海堤採樣站土壤硫化情形嚴重，

呈現厭氧狀態，溶氧量偏低。據觀察 2023 年 4–5 月有些地區藻華情形嚴重，絲狀綠藻繁生，溶氧過飽和。除芳苑、麥寮、線西，多數採樣站 pH 值偏低。雲林湖口濕地鹽度顯著高於平均海水鹽度。彰化縣線西採樣站 Cu 之上層土壤顯著高於下層土壤，且高於其他採樣站，舊濁水溪口採樣站之上下層土壤 Cu 數值皆偏高，雲林縣金湖採樣站之上下層土壤 Cr 值顯著高於其他採樣站。有畜牧廢水排入的採樣站，例如彰化福寶、三豐採樣站，其溶氧度偏低，且土壤重金屬如 Cu、Zn、Fe、S、Co、Sr、Rb、V、Sc 等含量偏高。彰雲海岸有大量的工業區和畜牧養殖廢水排入，綜合分析兩年的採樣數據，採樣站之間的差異很大，年度的差異較為不顯著，顯示許多採樣站的污染是長期累積，對於海岸生態確實已經發生影響。年度的差異以舊濁水溪口較為顯著，2 年間的土壤粒徑改變，砂粒比例顯著增加，有多種重金屬有顯著下降。

關鍵詞：重金屬含量、土壤、彰雲海岸濕地

Abstract

To investigate heavy metal pollution in the Changhua and Yunlin coastal wetlands, 28 sampling stations were established based on estuary and geographical locations, followed by conducting all samples from 2022 to 2023. Salinity, pH value, dissolved oxygen saturation, and NO_3 of samples were seasonally measured at each station three times, resulting in 177 records of water quality and hydrological readings over two years. Soil samples were collected from both upper and lower layers at each station and brought back to the laboratory for soil particle size analysis, including percentage of sand, silt, and clay, yielding a total of 121 data records. Additionally, a total of 393 soil samples from both upper and lower layers over two years were collected for measuring the concentrations of 32 heavy metals using an X-ray fluorescence spectrometer. Quantitative data were then utilized to calculate differences between sampling stations, different soil layers, and different years. The results show severe sulfurization in the soils from various stations, including Fubao, the old Zhuoshui estuary, Bazhou Drainage, and Sanfeng in Changhua county, exhibiting anaerobic conditions with low dissolved oxygen levels. Significant algal blooms were observed in certain areas in April and May 2023, characterized by the proliferation of filamentous green algae and oversaturation of dissolved oxygen. Relatively low pH values were recorded in most of the stations, except for Fangyuan, Mailiao, and Xianxi stations. The salinity in Hukou wetland was significantly higher compared to the average seawater salinity. The upper soil layer at the Xianxi sampling station in Changhua county exhibited significantly higher levels of copper (Cu) than its lower soil layer, and also showed surpassing levels compared to the other stations. The old Zhuoshui estuary station was found with elevated copper (Cu) values in both upper and lower soil layers. Chromium (Cr) values in both upper and lower soil layers at Jinhu station in Yunlin county were significantly higher than those at other stations. Livestock wastewater is discharged to Fubao and Sanfeng stations, leading to low dissolved oxygen levels of water, and the soil at these locations exhibited high concentrations of heavy metals, such as Cu, Zn, Fe, S, Co, Sr, Rb, V, Sc, and others. It is also evident that industrial and livestock farming wastewater is discharged to the Changhua and Yunlin coasts. Data revealed substantial differences between sampling stations, while annual variations were relatively non-significant between years, suggesting that pollution in many stations has accumulated over the long term and is significantly impacting coastal ecology. The annual differences were obviously evident at the old Zhuoshui estuary. Over the two-year period, there was a noticeable increase in the proportion of sand particles and a significant decline in the concentrations of several

heavy metals.

Key words: heavy metal content, soil, Changhua and Yunlin coastal wetlands

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緒言

彰雲海岸大型工業區林立，從北到南分別有全興工業區、彰濱工業區、芳苑工業區及臺塑麥寮六輕工業區、雲林離島式基礎工業區等，長年工業廢水排放是否影響潮間帶土壤中重金屬含量？近年來臨海地區及潮間帶新增不少光電設施，除了棲地破碎化，是否造成周邊地區土壤重金屬含量偏高？同時彰雲亦為畜牧業大縣，大型的養殖戶多集中於河川下游與沿海地區，目前畜牧產生的豬糞尿廢水多數直接排入排水道，很快的進入海岸地區，對於海岸環境是否造成影響？為瞭解土壤重金屬累積現況，本研究利用兩年的時間進行重複採樣，分析彰雲海岸重金屬累積的濃度。

依據環境部（原環境保護署）公告重金屬濃度分析有原子吸收光譜法（atomic absorption）、感應耦合電漿法（inductively coupled plasma）及 X- 射線螢光法（X-ray fluorescence，XRF）三大類（環境部 2006；環境部 2012a；環境部 2012b），對於大多數重金屬元素，傳統之原子吸收光譜法（atomic absorption spectroscopy, AAS），因為可精確定量，已被廣泛應用於環境監測（Welz and Sperling 1999；Popescu *et al.* 2009；童等 2000；陸等 2001；于及林 2001），也包括生物體內元素含量檢驗（黃

2001； 劉 2002；Strezov and Nonova 2005），更應用於漁業或農業上（莊等 1994；于及林 2000a；于及林 2000b），然而原子吸收光譜法受限於單一元素定量，大批樣品分析時之效率較低（陸 2001）。感應耦合電漿法可同時測得樣本中多種元素，但在進行測定前樣本需經酸消化處理，還會造成環境污染。XRF 係利用 X-射線螢光光譜儀發射之初級 X- 射線（primary X-ray）作為激發源（primary source）照射樣本，樣本吸收 X- 射線的能量而激發，產生次級 X- 射線（secondaryX-ray），放出樣本所含元素的螢光光譜，經由分光晶體分光後，分析各不同波長的強度，即可得知樣本中組成元素的種類與含量（Jenkins 1999）。X- 射線螢光法具有快速、非接觸、非破壞性及多元素分析等特點，逐漸廣為應用，相關原理、操作、應用，及其與實驗室重金屬分析進行比較，國內外有相當多文獻可以參考（Muchori 1984；Shefsky 1997；Jenkins 1999；Dos Anjos *et al.* 2000；Sitko *et al.* 2004；Kilbride*et al.* 2006；劉 2012； 楊 等 2012；Weindorf *et al.* 2012；彰化縣政府 2016），類似的研究除有應用於城市垃圾、有機化合物處理監測（Dos Anjos *et al.* 2000），亦應用於測定高污染土壤（Sitko *et al.* 2004），以及追蹤農業或陸域土壤的污染監測（楊等 2012；Ravisankar *et al.* 2015；Liang*et al.*2018；Tighe *et al.* 2018），或污染湖岸和流入湖泊的溪流沉積物重金屬濃度（Makundi 2001；彰化縣政府 2016；劉 2018a）等較高濃度的檢測，也可應用非高濃度的農業環境質量評估，海域或湖泊等沈積物的監測（Muchori 1984；Battiston *et al.* 1993；Makundi 2001；Manceau *et al.* 2002；Weindorf *et al.* 2012； 劉 2012； 劉 2014a； 劉 2014b； 劉 2015；Chandramohan *et al.* 2016b；Gandhi 2017； 劉 2017a； 劉 2017b；Liang *et al.*2018； 劉 2018b；劉 2019），甚至對於生物中微量元素的變化亦可偵測（Tomassini *et al.* 1976；Sauter *et al.* 1979； 劉 1999；Liang *et al.* 2018），例如運用在褐藻天然濃度變化，測量受污染較嚴重的

頂部和底部之間，以及不同海藻樣本和採樣季節之間可能的微量元素變化（Sauter *et al.* 1979）。此外，比較北極的地衣與在污染區周邊地區濃度，計算與冶煉廠距離（Tomassini *et al.*1976），證實 XRF 比傳統分析技術更快，表現出更好的靈敏度和再現性，樣品在分析中也沒有被破壞，亦提供了與傳統實驗室分析相當的重金屬水平的質量結果。本研究依據中華民國 95 年 1 月 18 日環署檢字第 0950006426 號公告之標準（環境部 2006）以型號 XL3t 700 之 X- 射線螢光光譜儀檢測樣本中重金屬濃度，國內外應用於測定沿海沉積物之主要和微量元素分佈與本研究的調查對象最為相關（Muchori 1984；Battiston *et al.* 1993；葉等 2011；劉 2012；劉 2014a；劉 2014b；劉 2015；彰化縣政府 2016；Ravisankar *et al.* 2015; Chandramohan *et al.* 2016a；Chandramohan *et al.* 2016b；劉 2017a；Gandhi 2017；劉 2018a；劉 2018b；劉 2019）。

本研究之儀器曾分別於曾文溪口、大肚溪口兩試驗區，利用 XRF 進行快速篩檢結果，再以王水消化法及原子吸收光譜法檢測部分樣本，證實在環境部所訂之土壤重金屬含量分級標準中，有六種元素於不同分析方式中呈現相符合的趨勢（劉 2012；彰化縣政府 2016）。筆者亦已運用此光譜儀於臺灣多處海岸進行檢測，檢測結果其相關研究有宜蘭（劉 2018c）、彰化縣大肚溪口、臺南市曾文溪口（劉 2012；劉及陳 2020）、新竹（劉 2015；劉 2018a）、苗栗（劉 2017b）、臺中（劉 2021）等海岸溼地底泥，以及北海岸（劉 2014b；劉 2017b）、桃園（劉 2014a；劉 2014b；劉 2017a）、臺灣東南部之生物礁海岸（劉 2019）等地調查，推論可能之污染來源。其中宜蘭海岸在五十二甲濕地，鉛、鋅明顯偏高（劉 2018c）。西北觀音新屋藻礁海岸觀音藻礁之銅、鋅、鉻、砷、鍶、鈦、鋯含量偏高，確實有外來污染為觀音人工蛇籠護岸堤內填土方（劉 2014a；劉 2014b），桃園富林、老街以傳統工業為主，受觀音、大園工業區排水影響，鋅、鎳、銅、錳、鐵、砷、鉛、

鉬數值極端的高，桃園藻礁海岸污染情形嚴重（劉 2017a）。在新竹海岸分析紅樹林清除前後土壤中重金屬變化，確認鉛、鋅、銅、鐵、錳等元素濃度於移除紅樹林後有極顯著的降低（劉 2015）。新竹新豐鳳鼻海岸之銅、鋅、鉛、錫、鎳、鐵、錳、砷、鉬、鎘、銀的數值極端偏高，污染源為集塵灰（劉 2017a）。麗水海岸臺灣旱招潮（*Xeruca formosensis*）棲地的南邊 2020 年有光電工程進行，有填土，比較 2 年數據，螃蟹樣本之鈦、鋯、鐵含量異常增高（劉 2021）。臺東杉原及白石牛海岸鉻、鎳偏高，鉛、錳、砷、汞在小野柳呈現多個離群高值，砷、鉛、錳在郡界、小野柳有較高的數值（劉 2019）。根據上述多年數據顯示，不同棲地類型有顯著差異，但除了部分有施工的採樣站外，兩個不同的年度整體無顯著差異。

本研究於彰化縣、雲林縣海岸透過固定採樣站調查水質、水文、土壤重金屬等環境樣本蒐集與分析，藉由調查土壤重金屬對應畜牧業廢水或光電設施相關性，釐清海岸受到污染的來源，瞭解污染程度及分析其影響，並整合過往調查資料，進行棲地評估。檢測結果除參考環境部公告之底泥指標、土壤污染物監測、管制標準砷、鎘、鉻、汞、鎳、鉛、鋅及銅的法定標準，對於尚未明列於行政院環境部的排放標準法規中的多種重金，將交互對照不同地區之海岸，推論污染程度，試圖進一步追蹤，作為未來污染物的來源之參考，提供後續經營管理之參考，至於是否影響生物多樣性或底棲性動物體內重金屬含量，則於另文討論。

材料與方法

據多年數據顯示，重金屬濃度於不同棲地類型或受排水影響，會有顯著差異，因此水文、水質、土壤質地等檢測皆與重金屬樣本之採樣區同步進行。

（一）微棲地之水文、水質、土壤質地及重金屬測定，採樣作業均以行政院環境部公告之採樣法作業。

1. 水文、水質測定：每個固定採樣站現場以德國 WTW 196T 水質測定儀測

量水溫（water temperature, WT）、導電度（electrical conductivity, EC）、溶氧量（dissolved oxygen, DO）、氫離子濃度指數（hydrogen ion concentration, pH）。可以測量海水的水質儀器笨重且檢測程序繁瑣，根據經驗 pH 值、鹽度對於底棲動物群聚影響較為明顯，為了解簡易型的水質檢測筆與精密的水質檢測儀器測量值的差異，特別在每個固定採樣站現場同步以日本 Horiba 多參數水質檢測筆（Compact Water Quality Meter）LAQUAtwin 水質計進行簡易的 pH 值、鹽度、NO_3 現場檢測，數值可作為未來若需採用簡易測量方式時的參考，檢驗數據在表格中以 pH 值（簡易）及鹽度（簡易）呈現。若數值具有參考價值，未來可考慮採用輕便型的多參數水質檢測筆進行。

2. 土壤測定：採樣作業均以行政院環境部公告之採樣法作業。

（1）土壤質地：土壤粒徑分析（particle size distribution analysis）以比重計法（hydrometer method）分析土壤粒徑計算砂粒（sand, 2–0.05mm）、坋粒（silt, 0.05–0.002mm）與粘粒（clay, <0.002mm）之含量百分比，由質地三角圖（textural triangle chart）劃分質地等級（textural class）。

（2）土壤重金屬：依行政院環境部公告之土壤和底泥中元素濃度快速篩選法，利用 X- 射線螢光光譜儀進行 32 種土壤重金屬。本研究採用美國 Thermo NITON 手持式 XRF 分析儀 XL3t Series，採樣作業均以行政院環境部公告之採樣法作業（環境部 2006；環境部 2012a），執行品保、品管。樣本經充分乾燥，放置在樣本承裝器中，以塑膠膜遮蓋後再行分析檢測。每樣本以 X- 射線螢光光譜儀進行，每次檢驗前執行儀器校正，以確認其準確性。檢測元素分別為鉬 Mo、鋯 Zr、鍶 Sr、鈾 U、銣 Rb、釷 Th、鉛 Pb、硒 Se、砷 As、汞 Hg、鋅 Zn、鎢 W、銅 Cu、鎳 Ni、鈷 Co、鐵 Fe、錳 Mn、鉻 Cr、釩 V、鈦 Ti、鈧 Sc、鈣 Ca、鉀 K、硫 S、鋇 Ba、銫 Cs、碲 Te、銻 Sb、錫 Sn、鎘 Cd、銀 Ag、鈀 Pd 等 32 種重金屬，每樣點有 3 次的重覆取樣。

（二）水文、水質、土壤質地及重金屬資料分析

原始資料經整理後以敘述統計（descriptive statistics）呈現，依照採樣站分別列出各元素的最大值，並檢驗不同土層以及不同年度之間差異，檢驗方式以調整多重比較 p 值（bonferroni 法）之 T 檢定，顯著水準 95%，分析結果選定特定元素，繪製盒形圖，討論重金屬濃度在空間分布現象，本研究之運算及繪圖以 SPSS（Statistical Product and Service Solutions）程式來進行。

結果與討論

（一）採樣站描述及座標

本研究於彰雲海岸濕地設置 28 固定採樣站（sampling station）（附錄 1、附錄 2），採樣工作於 2022–2023 年進行，採樣時間選擇退潮時段。研究地點現況概述、28 個固定採樣站之編號、名稱及座標分別描述。環境因子現場測量採樣站之水文、水質，棲地土壤樣本粒徑分析及土壤樣本 32 種重金屬檢測檢驗分析。

彰化臺中以大肚溪為界，臺中火力發電廠、彰濱工業區的突堤效應，形成大肚溪南岸大面積沙泥灘地及沙質灘地以短指和尚蟹（*Mictyris brevidactylus*）與乳白南方招潮（*Austruca lactea*）為主。河岸與海岸各設置採樣站，並以 GPS 測得 TWD97 系統之座標，採樣站 A1 大肚溪南岸（198468 2676260）位於臺 61 線下方、採樣站 A2 大肚溪口南岸（196207 2676036）位於全興工業區外，伸港溪底排水外海。另於大肚溪口北岸龍井及麗水增設對照，採樣站簡稱北。

伸港地區原本有大面積臺灣旱招潮棲地，因為垃圾掩埋場造成族群幾乎滅絕，目前在各界人士多方努力族群漸漸恢復，設置採樣站 B 伸港（194895 2673746），位於臺 61 線西側之寮仔地溝排水。

彰濱工業區慶安水道外有一片廣闊的潮間帶水域，目前正設置為光電區，高潮線附近有紅樹林分布，採樣站 C 線西（191607 2669217）位於彰濱工業區線西光電區隔紅樹林分布區之外

圍堤防。

彰濱工業區南段吉安水道，鄰近垃圾場，沙質灘地以短指和尚蟹與乳白南方招潮為主，設置採樣站 D 吉安（188815 2662377）位於鹿安橋下。

福寶、漢寶有大面積畜牧養殖場，舊濁水溪又稱東螺溪，採樣站 E 舊濁水溪口（188314 2661316）位於吉安水道、員林大排、舊濁水溪等 3 水系的匯流口，採樣站 F 福寶海堤水門外（187010 2660674）位於福寶濕地，泥灘地表層呈黃色黏土層，小積水處呈白色的混濁水，且空氣惡臭，其溶氧度偏低，採樣站G漢寶溪口（185495 2659558）位於漢寶濕地。採樣站 H 八洲排水道口（198104 2676759）亦位於福寶濕地，以乳白南方招潮主。

採樣站 I 蚵路（181785 2657004）位於漢寶外海，可由蚵路往外海 2.5 km 處，沙質灘地，蚵路附近被放置大量的建築廢棄物，棲息地多石塊和牡蠣殼等，形成類似礫岩海岸，底棲物種有土夸大額蟹 (*Metopograpsus thukuhar*)、絨毛近方蟹 (*Hemigrapsus penicillatus*)，中低潮線沙質灘地有遠海梭子蟹（*Portunus pelagicus*）、勝利黎明蟹 (*Matuta victor*)、寬身大眼蟹 (*Macrophthalmus abbreviatus*) 等。

王功、永興海埔地設置採樣站 J1 王功（180373 2651801）位於漁港王者之弓橋外，採樣站 J2 後港（180245 2651690）位於後港溪口南岸，採樣站 K 永興（178339 2648631）位於永興海堤南側，二林溪口北岸。

採樣站 L 芳苑（179496 2647798）位於西華宮外，土壤質地為粘質壤土或砂質黏壤土，高潮線附近有大面積紅樹林分布，目前新設架高步道，步道兩旁紅樹林有清除。

大城鄉及芳苑鄉亦有大面積畜牧養殖場，但規模都比較小，所以直接排放的問題比福寶漢寶更為嚴重，採樣站 M 三豐（177861 2644335）位於新街海堤水門外，空氣惡臭，採樣站 N 魚寮（176540 2641552）位於魚寮溪口南岸，這一段海堤內側閒置魚溫或邊際土地，原本有大量的過境水鳥棲息，已經在 2023 年設置為光電區。

採樣站 O 大城（174281 2639057）位於濁水溪口北岸、採樣站 P 麥寮

（171338 2636390）位於濁水溪口南岸，濁水溪口早期沒有臺灣旱招潮，現在卻成為臺灣旱招潮分佈面積最大、密度最高的區域。

新興、台西海埔地設置採樣站 Q 新虎尾（167738 2628694）位於新虎尾溪口北岸之沙質灘地，採樣站 R 臺西（165151 2626150）位於臺西海園北側，為臺灣旱招潮分佈區，採樣站 S 舊虎尾（165907 2621777）位於舊虎尾溪口南岸。

採樣站 T 四湖（163597 2619822）位於四湖工作站內之水門，工作站內大面積苗圃，與外海連同的水系。採樣站 U 三條崙（162646 2617932）位於海水浴場舊址，採樣站 V 萡子寮（161634 2615452）位於萡子寮北側沙丘內側，採樣站 W 金湖（161438 2608485）位於金湖碼頭北側。

較為內陸的滯洪池濕地有採樣站 X 成龍濕地（163896 2606694）位於臺 61 線西側，採樣站 Y 湖口濕地（164720 2604798）位於楦梧滯洪池。採樣站 Z 北港溪口（162385 2603637）位於雲林和嘉義的交界，牛挑灣溪口南岸，北港溪口北岸，下湖口安檢所南側。

（二）水質檢測

調查時間主要選擇退潮，可檢視匯入水質的狀況（附錄 3），綜觀分區表，採樣站間差異大，年度之間的差異相對不顯著（附錄 4、附錄 6）。

1. 水溫

統計 2022–2023 年彰雲海岸 28 個採樣站 174 個水質樣點及大肚溪口北岸 1 個採樣站 3 個水質樣點，共計測量 177 個水質資料，調查季節跨春夏秋冬 4 季，水溫介於 16.0–38.8°C，平均 27.94°C（附錄 3）。

2. pH 值

正常情形 pH 值與溫度及溶氧量有相關性，然兩年所測得的數據，差異已經大於正常相關性。pH 值介於 6.87–9.67，pH 值平均 7.96（SD = 0.39, n = 177）（附錄 3）。

採樣站 M（三豐）的 pH 值 2 年平均為 7.03（SD = 0.14）（附錄 4），測得最低 6.87 值（附錄 5）為新街海

堤水門外，此採樣站會直接受海水潮汐影響，然此站的數值遠低於平均海水 pH 值，且 2 年都是最低，2 年平均各為 6.94、7.12（附錄 6），有異常偏低，此測站的溶氧值也是偏低。

採樣站 L（芳苑）pH 值 2 年平均為 8.7（SD = 0.57）（附錄 4），最高 9.67（附錄 5），2 年平均各為 8.74、8.64（附錄 6），有異常偏高。此採樣站為排水匯入潮間帶，略受潮汐影響，鹽度僅海水平均鹽度的二分之一，應該不會有如此高的 pH 值，推測有異常排水匯入。

採樣站 P（麥寮）2022 年測得最高值，pH 值達 8.94（附錄 5），平均值 8.39（附錄 6）高於海水平均值，2023 年的數值較為正常，平均值 8.21（附錄 6），此採樣站異常現象與魚塭廢水排入有關。

3. 鹽度及導電度

鹽度介於 0.5–65.9 psu，平均 21.49 psu（SD = 12.19, n = 177），導電度 1.09–90.9 ms/cm 平均 36.34 ms/cm（SD = 17.60, n = 177）（附錄 3），整體而言變化很大。採樣站 B（伸港）不同月分皆測得較為偏低的鹽度，最低為 0.5 psu，2022 年平均 1.13 psu，2023 年 6.63 psu（附錄 6）。採樣站 M（三豐）於 10 月及 11 月測得較為偏低的鹽度，2022 年平均 4.40 psu，2023 年平均 1.5 psu，最低為 0.8 psu，導電度 1.8 ms/cm（附錄 6），呈現幾乎淡水的狀況。採樣站 Y 湖口濕地 2022 年測得鹽度 46.2 psu，導電度 67.1 ms/cm，2023 年測 65.90 psu，導電度 90.9 ms/cm 顯著高於平均海水鹽度，此採樣站不受潮汐影響，冬春季鹽份呈過飽和。

4. 溶氧

溶氧百分率 (Dissolved oxygen saturation) 平均為 79.06%（SD = 40.68, n = 172）（附錄 3），有 5 個樣點資料，因為超過 200% 的數值，因此無法呈現。例如 2022 年最高值採樣站 Y（湖口），溶氧值為 11.42 mg/l，溶氧百分率 198.7%（附錄 5），2023 年也測溶氧量 16 mg/l，溶氧百分率無法呈現。本採樣站之不同採樣點差異極大，最低溶氧值為 0.023 mg/l，溶氧百分率僅有 0.4%。同樣有溶氧過飽和的情形發

生在採樣站 C、K、W，近年都有藻華的現象。採樣站 F（福寶）最低溶氧值，2022 年為 0.018 mg/l，溶氧百分率僅有 0.3%，2023 年更低，0.01 mg/l，溶氧百分率僅有 0.2%。採樣站 M（三豐）皆測得偏低的溶氧值，2022 年為 0.03–0.08 mg/l，溶氧百分率僅有 0.4–1.1%，2023 年更低為 0.01–0.051 mg/l，溶氧百分率僅有 0.1–1.0%（附錄 6），此 2 採樣站皆與畜牧產生的糞尿廢水排入有關。採樣站 U（三條崙）平均溶氧值 6.79 mg/l 差異小（SD = 0.5, n = 6）（附錄 4、附錄 5），為平均海水數值。

5. 硝酸鹽 (NO_3^-)

硝酸鹽數值以大肚溪口南岸、線西工業區光電區、吉安水道、舊濁水溪口、王功漁港、後港溪口、芳苑數值偏高（附錄 6）。

綜合檢視彰雲海岸各採樣站水質差異大，由於調查時間多為退潮，僅採樣站 I、U、V 有較為穩定海水的平均鹽度及 pH 值，採樣站 A2、B 的平均鹽度及 pH 值較低，溶氧值尚在平均值，但採樣站 F、H、M 之鹽度、pH 值及溶氧值皆偏低，畜牧糞尿廢水確實有影響。藻類明顯的採樣站通常會有溶氧過飽和的數值，伴隨著高 pH 值，例如採樣站 I、Y，採樣站 Y 的鹽度冬春季過高，全年的變化很大，採樣站 L 雖然有非常高的 pH 值，但是溶氧卻異常低，也屬於異常的採樣站。簡易型的 pH 值和鹽度測量結果，雖在極端值時不敏感，然整體趨勢是符合由精密儀器所測量的結果。

（三）土壤粒徑檢驗分析

土壤粒徑進行 28 個採樣站及大肚溪口北岸 1 個對照採樣站，每 1 次採樣有上下兩層不同的樣點，分別標示為表層土、底層土，每個樣點進行土壤粒徑分析，若採樣站因棲地類型不同，則增設樣區，2022 年採樣站 L 因底層土石塊太多，無法往下挖，另增設 1 個樣區，每年有 30 樣區，2 年共分析 121 樣本，121 筆資料進入分析（表 1、附錄 7、附錄 8、附錄 9）。統計 121 筆樣點資料，砂粒 46–95% 平均為 73.69%（SD = 13.81, n = 121），砏粒 0–32% 平均為 14.06%（SD

= 9.05, n = 121），粘粒 4–27% 平均為 12.25%（SD = 5.50, n = 121）（附錄 7），採樣的土壤多數歸類為砂質土、壤質砂土、砂質壤土，有少部分為壤土。

土壤粒徑最大的為採樣站 J1（王功）、U（三條崙）、採樣站 V（箔子寮）、採樣站 W（金湖），上層砂粒比例等於或略大於下層，為海岸典型砂質灘地。

採樣站 A1 大肚溪口南岸、採樣站 C 位於線西工業區光電區北側、採樣站 K 永興海堤南側二林溪口北岸，上層砂粒比例顯著低於下層，且 2 年間無顯著差異（附錄 8、附錄 9），顯示棲地逐漸變泥。採樣站 I 漢寶外海蚵路 2 年間土壤粒徑有顯著差異，底層砏粒及黏粒比表層高。採樣站 N（魚寮）下層為石礫層無法下挖，常見秀麗長方蟹 (*Metaplax elegans*)。採樣站 L（芳苑）紅樹林底層粒徑砂粒比例顯著低（附錄 8），以弧邊管招潮蟹（*Tubuca arcuata*）為優勢。採樣站 O（大城）、採樣站 P（麥寮）為壤土，屬臺灣旱招潮棲地。採樣站 A2（大肚溪）、採樣站 H（八洲）、採樣站 I（王功）、採樣站 Z（北港溪）介於砂質土、壤質砂土至砂質壤土間，以乳白南方招潮為主要優勢。採樣站 D（吉安）、採樣站 E（舊濁水）為砂質黏壤土，以萬歲大眼蟹 (*Macrophthalmus banzai*) 主要優勢。舊濁水溪口的年度差異較為顯著，2 年間的土壤粒徑砂粒比例顯著增加（附錄 9、附錄 10）。採樣站 X（湖口）底層的砂粒比較少，砏粒顯著比表層高很多（附錄 7、附錄 8），以臺灣厚蟹 (*Helice formosensis*) 為主要優勢。

（四）土壤重金屬分析

土壤重金屬統計彰雲海岸 28 個採樣站及大肚溪口北岸 1 個對照採樣站，每個採樣站有上下兩層 2 個樣區的資料，2022 年採樣站 H（八洲）、採樣站 L（芳苑）、採樣站 Q（新虎尾）棲地類型差異增設樣點，期中分析後發現採樣站 C（線西）、採樣站 D（吉安）、採樣站 W（金湖）有異常數據，進行再次採樣 3 個，計 73 樣點，2023 年計 58 樣點，共計 369 樣點資料。

每一個土壤樣點各有三次重複，共計 396 筆資料進入分析（附錄 11）。

1.Cu

統計 396 筆樣點資料，Cu 的平均 22.35 mg/kg（SD = 17.84, n = 396）（附錄 11），採樣站 C、D、E、F、L、M、S 數值偏高（附錄 12），最高值 88.55 mg/kg 為採樣站 C（線西）工業區光電區，因 2022 年平均 32.75 mg/kg，底層土未檢出，故表層土顯著高於底層土，經二次採樣，仍是底層土未檢出，表層土顯著高於底土，2023 年平均 56.22 mg/kg，未達顯著差異的原因是底表層土的差異更大（圖 7），表、底層土平均分別為 58.91 mg/kg、22.23mg/kg 有顯著差異（附錄 15），確認為近期造成的污染，原因推論為在潮間帶設置光電板工程擾動所致。依據環境部公告之底泥指標 Cu 上限值 157.0 mg/kg、下限值 50.0mg/kg，線西表層土已高於下限值，需增加檢測頻率值。

採樣站 D（吉安）底層土 Cu 最高值 78.69 mg/kg（附錄 13），底、表層土平均分別為 42.62 mg/kg、51.58 mg/kg，年度間及土層間的差異皆不顯著（附錄 15、附錄 16），屬於長期累積。同採樣站 D 之 Hg 亦高於其他採樣站，2 年平均達 6.21 mg/kg，為各採樣站之冠（附錄 12）。本採樣站為吉安水道位於鹿安橋下鄰近垃圾場，表、底層土皆已高於下限值，需增加檢測頻率值。

採樣站 E（舊濁水）2022 年底層土壤中 Cu 的最高值 80.98 mg/kg（附錄 14），底層土已高於下限值，需增加檢測頻率值。舊濁水溪又稱東螺溪，沿岸多有大型的養殖戶，因部分畜牧廢水直接排入，本採樣站 2 年平均值達 50.86 mg/kg，為各採樣站之冠（附錄 12），底、表層土平均分別為 59.21 mg/kg、42.51 mg/kg 土層間無顯著差異（附錄 15），顯示為長期累積，且同採樣站 E 之 Zn、Cr、S 等 2 年平均值亦高於其他採樣站，確實有污染。然 2022 年、2023 年平均分別為 66.64 mg/kg、35.08 mg/kg 年度間有顯著差異（附錄 16），根據土壤粒徑檢測結果，舊濁水溪口之土壤粒徑有顯著改變，砂粒增加，比較 2 年有多種重金

屬有顯著下降，但也有可能是畜牧污水改善的結果。

比較臺灣其他處海岸，西北觀音新屋藻礁海岸觀音藻礁有外來污染為觀音人工蛇籠護岸堤因破堤，因堤內所回填的廢棄物被溶出，近岸處 Cu 的數值全高於下限值，接近上限值（劉 2014a；劉 2014b），桃園富林、老街受觀音、大園工業區排水影響，Cu 數值極端偏高，最大值高達 1249.8 mg/kg（劉 2017a）。新竹新豐鳳鼻海岸集塵灰 Cu 的數值極端的高，最大值高達 4355.2 mg/kg（劉 2017a），遠高於上限值，上述地點多數重金屬也都超標，為確認污染區，鳳鼻海岸資料發表後，相關單位於 2018 年已進行污染整治。除上述 2 區，臺灣其他處海岸僅宜蘭五十二甲濕地最大值為 94.27 mg/kg（劉 2018c）、臺東三仙台海岸最大值 130.8 mg/kg（劉 2019）及臺中松柏港最大值 122 mg/kg（劉 2021）高於下限值。

2.Zn

Zn 的平均 331.69 mg/kg（SD = 49.39, n = 396）（附錄 11），採樣站 E（舊濁水）2 年平均達 233.59 mg/kg，為各採樣站之冠（附錄 12），底、表層土平均分別為 267.13 mg/kg、200.05 mg/kg 無顯著差異（附錄 15），2022 年、2023 年平均分別為 299.12 mg/kg、168.06 mg/kg 有顯著差異（附錄 16），依據環境部公告之底泥指標 Zn 的上限值 384 mg/kg、下限值 140 mg/kg，已高於下限值，需增加檢測頻率值。

本採樣站 2023 年檢測結果 Cu 及 Zn 都有顯著的下降（附錄 15），表層土檢驗的數值也有降低，推論畜牧排水經過積極處理，有效減緩海岸 Cu 及 Zn 累積的狀況。於 2022 年、2023 年平均值除了 Cu、Zn 都顯著下降外，還有 Mo、Rb、Th、As、Fe、Cr 都有顯著下降。

比較臺灣其他處海岸，除桃園富林、老街、新竹新豐鳳鼻海岸外，宜蘭海岸在五十二甲濕地，Zn 明顯的偏高，最大值達 601.70 mg/kg（劉 2018c），臺中松柏港底層土 Zn 高達 1587 mg/kg，平均 955.99 mg/kg（劉 2021）皆高於上限值。

3.Hg

同採樣站E（舊濁水）底層土Hg高達23.7 mg/kg（附錄13、附錄14），依據環境部公告之底泥指標Hg上限值0.87 mg/kg、下限值0.23 mg/kg，已高於上限值，疑為長期廢水排放造成的污染，應啟動風險評估。

由於Hg易揮發，在檢測前處理乾燥時，很容易就降低含量，往年檢測多數樣本為微量或未檢出，多年檢測資料僅新竹新豐鳳鼻海岸受集塵灰污染的309.73 mg/kg極端偏高值（劉2017a），西北藻礁海岸最高在新屋海岸53.6 mg/kg（劉2017a），復興漁港52.0 mg/kg，觀音藻礁蛇籠護岸堤破堤處28 mg/kg（劉2014b），客雅水資源回收中心外圍14.5 mg/kg（劉2015），汞在生物礁樣本明顯高於沙粒，因此舊濁水數值屬異常。

4.S

同採樣站E（舊濁水）之S於2年平均值達2975 mg/kg，為各採樣站之冠（附錄12），年度間及土層間的差異皆不顯著（附錄15、附錄16），屬於長期累積。

S的平均值1133.16 mg/kg（SD = 810.24, n = 396）（附錄11），最高值3738.9 mg/kg（附錄13）為採樣站F（福寶）表層土，本採樣站底、表層土平均分別為3017 mg/kg、2901 mg/kg無顯著差異（附錄15），2022年、2023年平均分別為3241 mg/kg、2677 mg/kg有顯著差異（附錄16）。

本採樣站測得最低溶氧值，2022年為0.018 mg/l，溶氧百分率僅有0.3%，2023年更低，0.01 mg/l，溶氧百分率僅有0.2%。本採樣站因常年排放畜牧廢水，海岸泥灘地表層累積厚厚的糞便，氧化還原層不到1cm，底質硫化的情形非常嚴重，是海岸潮間帶底棲蟹類數量最少的採樣站，只能在堤腳礫石間尋獲少許。

S的平均值採樣站F、E很高外，採樣站M（三豐）也偏高，2年平均達2198 mg/kg，底、表層土平均分別為2207 mg/kg、2189 mg/kg，2022年、2023年平均分別為2214 mg/kg、2182 mg/kg，土層間、年度間皆無顯著差異（附錄15、附錄16），屬於長期累積。

本採樣站亦排放惡臭的畜牧廢水，從

大排經新街海堤之水門排放到海裡的水流，在衛星圖上可視，常年呈現黑色水體，海岸泥灘地表層底棲蟹類的洞口極少，氧化還原層薄，底質硫化的情形亦頗嚴重，超泥濘的灘地，幾乎無法行走。週邊的漁民若要下海作業，必須藉助大滑板，趴在滑板上面滑出潮間帶，此海岸潮間帶底棲蟹類數量少，本採樣站只能勉強採集到弧邊管招潮蟹。

5.Fe

同採樣站 M（三豐）還有 Fe、Co、Sr、Rb、V、Sc、Ca、K 等多種元素年平均值為各採樣站之冠（附錄 12），Fe 的值 2 年平均達 33697 mg/kg，為各採樣站之冠（附錄 12），底、表層土平均分別為 34160 mg/kg、33235 mg/kg，2022 年、2023 年平均分別為 32706 mg/kg、4689 mg/kg，土層間、年度間皆無顯著差異（附錄 15、附錄 16），屬於長期累積。Fe 連續在採樣站 L（芳苑）、M（三豐）、N（魚寮）、O（大城）、P（麥寮）、Q（新虎尾）、S（舊虎尾）的數值都偏高（附錄 12）。

6.Zr

Zr 的平均值 299.34 mg/kg（SD = 140.53, n = 396）（附錄 11），最高值 1248 mg/kg（附錄 11、附錄 13、附錄 14）為採樣站 W（金湖），本採樣站因為 2022 年發現異常，已重複採樣多次。除此站外，採樣站 J1（王功）、J2（後港）及 K（永興）的數值也顯著偏高（附錄 12）。2022 年採樣站 J1 表層土高達 1057.75 mg/kg（附錄 13、附錄 14），土層間、年度間皆無顯著差異（附錄 15、附錄 16），未達顯著差異的原因是底表層土、年度間的差異更大，顯示為偶發狀況，例如港口疏濬機具。採樣站 J2 的 Zr 值 2 年平均達 684.9 mg/kg，為各採樣站之冠（附錄 12），底、表層土平均分別為 674.6 mg/kg、695.2 mg/kg 無顯著差異（附錄 15），屬於長期累積，2022 年、2023 年平均分別為 570.1 mg/kg、799.7 mg/kg 有顯著差異（附錄 16），有增加趨勢。

7.Pb

Pb 的平均值 22.23 mg/kg（SD = 7.96, n = 396）（附錄 11），採樣站 L

（芳苑）2 年平均達 31.65 mg/kg，為各採樣站之冠（附錄 12），同採樣站水質測得超高 pH 值，應追蹤來源。Pb 的最高值 74.14 mg/kg 為採樣站 X（成龍），底、表層土平均分別為 17.99 mg/kg、39.54 mg/kg 無顯著差異（附錄 15），屬於長期累積，2022 年、2023 年平均分別為 10.70 mg/kg、46.83 mg/kg 有顯著差異（附錄 16），有增加趨勢。依據環境部公告之底泥指標 Pb 上限值 161 mg/kg、下限值 48.0 mg/kg，未高於下限值，此採樣站 X 為滯洪池，潮汐的影響不大，如此高的 Pb 值，應追蹤來源，2018 年在宜蘭 52 甲濕地有類似的情形，也是測到非常高的 Pb 值，最大值高達 407.6 mg/kg（劉 2018c）。整體而言雖然這兩處濕地所採集的樣本 Pb 值偏高，若與桃園工業污染海岸樣區及新竹新豐海岸比，並無較高，但若與西海岸之一般樣區相比，仍是較高。

8.As

As 的平均 9.30 mg/kg（SD = 3.66, n = 396）（附錄 11），採樣站 S 舊虎尾溪口 2 年平均 14.91 mg/kg 為各採樣站之冠（附錄 12），最高值為採樣站 A2（大肚溪口南岸）22.97 mg/kg（附錄 13、附錄 14）。依據環境部公告之底泥指標 As 上限值 33.0 mg/kg、下限值 11.0 mg/kg，大肚溪口南岸 2023 年採得之數值高於下限值，需增加檢測頻率。

9.Mn

Mn 的平均 320.0 mg/kg（SD = 139.6, n = 396）（附錄 11），採樣站 W（金湖）2 年平均 529.9 mg/kg 為各採樣站之冠（附錄 12），最高值為採樣站 T 四湖工作站水門 1003.1 mg/kg（附錄 13、附錄 14）。

10.Cr

Cr 的平均值 27.70 mg/kg（SD = 17.28, n = 396）（附錄 11），最高值 119.35 mg/kg 出現在採樣站 W（金湖）（附錄 13、附錄 14），依據環境部公告之底泥指標 Cr 上限值 233.0 mg/kg、下限值 76.0 mg/kg，金湖採得之數值高於下限值，需增加檢測頻率。同一個採樣站中，除 Cr 高於下限值外，Mo 14.76 mg/kg、Zr 1248 mg/kg、Th 34.30 mg/kg、As 21.73 mg/

kg、Ti 6075.4 mg/kg 數值都是最高（附錄 13、附錄 14），As 21.73 mg/kg、Hg 18.12 mg/kg 皆為次高，Hg 已高於底泥指標上限值 0.87 mg/kg，As 已高於底泥指標下限值 11.0 mg/kg，金湖採樣站為簡易碼頭，多種重金屬數值為彰雲海岸各樣本之冠，確認有不明污染源。

比較臺灣其他海岸，筆者曾於 2016–2017 年調查東海岸，在臺東杉原美麗灣測得最大值 611.4 mg/kg，平均值 142.11 mg/kg（n = 30）（劉 2019），大部分樣本都超過環境部的土壤污染監測標準 175。在臺灣西北部藻礁海岸平均值 24.19 mg/kg（n = 525）（劉 2017a），最大值 350.59 mg/kg 採自觀音工業區外側富林溪口採樣站。金湖採樣站高於新竹（不含集塵灰或爐石採樣資料）（劉 2015；劉 2018a）及苗栗海岸（劉 2018b）。

11.Ti

Ti 的平均值 3337.75 mg/kg（SD = 714.98, n = 396）（附錄 11），最高值 6075 mg/kg 出現在採樣站 W（金湖）（附錄 13、附錄 14），2 年平均 4192 mg/kg 在採樣站 N（魚寮），底、表層土平均分別為 4269 mg/kg、4154 mg/kg 無顯著差異（附錄 15），屬於長期累積，2022 年、2023 年平均分別為 3914 mg/kg、4331 mg/kg 有顯著差異（附錄 16），有增加趨勢。

12.Co

Co 的平均值 60.88 mg/kg（SD = 53.59, n = 396）（附錄 11），最高 286.61 mg/kg 又出現在採樣站 M（三豐），土層間、年度間皆無顯著差異（附錄 15、附錄 16），屬於長期累積。

13.Sc

Sc 的平均值 5.22 mg/kg（SD = 5.82, n = 396）（附錄 11），最高 31.17 mg/kg 又出現在同採樣站 M（三豐），且 2 年平均 19.19 mg/kg 為各採樣站之冠（附錄 12），土層間、年度間皆無顯著差異（附錄 15、附錄 16），屬於長期累積。

14.V

V 的平均值 42.42 mg/kg（SD = 18.96, n = 396）（附錄 11），最高 111.35 mg/kg 又出現在同採樣站 M（三豐），且 2 年平均 68.20 mg/kg 為各

採樣站之冠（附錄 12），土層間、年度間皆無顯著差異（附錄 15、附錄 16），屬於長期累積。

15.Ni

Ni 的平均值 2.33 mg/kg，最高值 94.50 mg/kg，為採樣站 A1（大肚溪口南岸）位於臺 61 線下方，採樣這 2 年正進行施工。依據環境部公告之底泥指標 Ni 上限值 80.0 mg/kg、下限值 24.0 mg/kg，已高於底泥指標上限值，應啟動風險評估。採樣站 B（伸港）位於寮仔地溝排水，於這 2 年平均值 47.16 mg/kg，為各採樣站之冠（附錄 12），然土層間、年度間皆無顯著差異（附錄 15、附錄 16），應屬於長期累積，大肚溪口南岸及伸港寮仔地溝皆受全興工業區排水，應增加檢測頻率。

筆者曾於 1998 年及 1999 年在大肚溪口南岸樣點檢驗重金屬，以王水消化全量（NIEA S321.62C）及 0.1N 的 HCl 萃取量（NIEA S320.60T）兩種方法進行，取樣點較靠近全興工業區排水，兩年分別測得全量為 580.2mg/kg、347mg/kg，萃取量為 254.3mg/kg、152mg/kg（劉等 1998；劉等 1999；劉等 2000；劉 2001；劉 2002）。再對照彰化縣政府於 2016 年委託東海大學熱帶生態學與生物多樣性中心執行大肚溪口野生動物保護區土壤底泥環境調查計畫，也強調位於伸港排水與全興排水外圍樣點之 Ni 值超標，測值為 94.75mg/kg，以王水消化法檢測 Ni 濃度 140.9mg/kg（彰化縣政府 2016），同時比對 2013–2014 年執行營建署城鄉發展分署委託同一團隊在全彰化海岸進行底泥重金屬調查 Ni 也有超標現象（內政部營建署城鄉發展分署 2015）。

比較臺灣其他海岸，筆者曾於 2016–2017 年調查東海岸，在臺東杉原美麗灣測最大值 354.9 mg/kg，平均值 132.66 mg/kg（n = 30），大部分樣本都超過環境部的土壤污染監測標準 130 mg/kg（劉 2019）。杉原北邊的白石牛海岸的 Ni 最大值 140.21 平均值 67.52 mg/kg（n=24），也是偏高。Ni 在臺灣西北部藻礁海岸平均值 31.1 mg/kg（n = 525）（劉 2017a），最大值 456.1 mg/kg 亦採自觀音工業

區外側富林溪口採樣站，為生物礁底質，在苗栗海岸最大值 50 mg/kg，平均值 10.20 mg/kg（n = 255）（劉 2018b）。

16.Cd

Cd 的平均值 7.27 mg/kg，最高值出現在採樣站 U 三條崙海水浴場，為 19.37 mg/kg，在採樣站 I（漢寶）延伸往外海約 2 km 之蚵路，2 年平均值 9.87 mg/kg，為各採樣站之冠（附錄 12），土層間、年度間皆無顯著差異（附錄 15、附錄 16），屬於長期累積。依據環境部公告之底泥指標 Cd 上限值 2.49 mg/kg、下限值 0.65 mg/kg，皆已高於底泥指標上限值，應啟動風險評估。

結論

本研究為臺灣海岸潮間帶重金屬調查系列之一，透過 XRF 進行大範圍的快篩，能夠快速的找到重金屬污染源，甚至在有些覺得應該沒有污染的地方，卻檢測出嚴重的污染，例如桃園觀音藻礁、新竹新豐鳳鼻海岸、臺東杉原美麗灣等。

針對環境部公告之底泥指標、土壤污染物監測、管制標準的砷、鎘、鉻、汞、鎳、鉛、鋅及銅，透過與傳統實驗室重金屬檢驗，以及長期的經驗，快篩對於 Hg 及 Cd 的結果與實驗室的差異較大，現場整合分析也比較難歸納污染脈絡，其餘元素大概可以分成傳統工業污染、畜牧廢水、以有毒廢棄物作為填方、碼頭或建築施工等幾大來源，通常有汙染的地方，就會有好幾種元素同時都是偏高的。本研究透過兩個年份還有不同深度的土層的比較，去推論污染的時間點。

本研究綜合分析兩年的採樣數據，採樣站之間的差異很大，年度的差異較為不顯著，顯示許多採樣站的污染是長期累積。彰雲海岸近年來臨海地區及潮間帶新增不少光電設施，其中以線西海岸規模最大，調查確認線西採樣站 Cu 之表層土壤顯著高於底層土壤，且兩年結果一致，此現象在其他採樣站罕見，底、表層土顯著差異除有施工外，僅松柏港，比較 2 年數據，Zn、Cu、Cr、Pb、Ni 元素皆為底層土壤數值高於表層，可以確認

松柏港在早期就已經遭受汙染，之後覆蓋在表層因為是砂質壤土，海岸漂沙的移動性較高，所以數值較低。線西採樣站剛好相反，因為設置光電板，水流變緩，兩年間土壤粒徑顯著變小，棲地已明顯的泥化，加上光電設施可能有些元素釋出，所以才會連續 2 年 Cu 表層土壤顯著高於底層土壤。

彰化縣與雲林縣多為平原地形，溪水流動平緩，海岸潮間帶的波浪小，無論溪流和海岸對於污染物的自淨能力低，大型的畜牧養殖戶多集中於河川下游與沿海地區，畜牧產生的豬糞尿廢水有些會排入排水道，進入海岸地區，長年來對於海岸生態環境造成極大，依據本研究結果確實有異常。有畜牧廢水排入的採樣站，例如彰化福寶海堤水門、新街海堤的三豐採樣站，其氨氮偏高及溶氧度偏低，且土壤重金屬如 Cu、Zn、Fe、S、Co、Sr、Rb、V、Sc 等含量偏高，這些採樣站因為土壤硫化，底棲動物的種類及數量都很少，甚至會完全找不到。此外，養豬廢水排放至河道，撲鼻的臭味，對海岸濕地生態旅遊意願產生負面的影響。雖然彰化及雲林縣政府皆已提出相關政策來輔導畜牧業者轉型資源化經濟，然目前尚未達標，因此效益有限。同時因為畜牧廢水排入海中，會使潮間帶的底泥變得非常的泥濘，甚至連行走都沒有辦法，漁民必須要藉著大滑板才可以出去收漁獲，且漁獲種類及數量也受到影響，也影響週邊居民靠海謀生的機會。年度的差異以舊濁水溪口較為顯著，土壤粒徑改變，砂粒比例顯著增加，目前檢測有多種重金屬有顯著下降，也有可能是畜牧污水改善的結果，持續進行海岸環境生態監測實屬必要。

彰雲海岸 2 年調查採樣數據，多數受畜牧廢水影響的採樣站水中 pH 值偏低，平均值低於正常海水 pH 值，長期不利海洋生物存活。但彰化芳苑 pH 值卻偏高，高於海水正常平均值，有異常，同採樣站 Cu、Pb 也偏高，需追溯排水源頭。

本研究執行因同步進行生態調查，所選擇的環境採樣站多為生態尚可的位置，因此與往年曾經調查的點位不盡相同，對照其他團隊的採樣結

果，雖然這些取樣點非同一位置，但可看出大肚溪口南岸受全興工業區的排水長期影響。整體而言，彰雲海岸重金屬的濃度較苗栗、臺中、臺南等地高。

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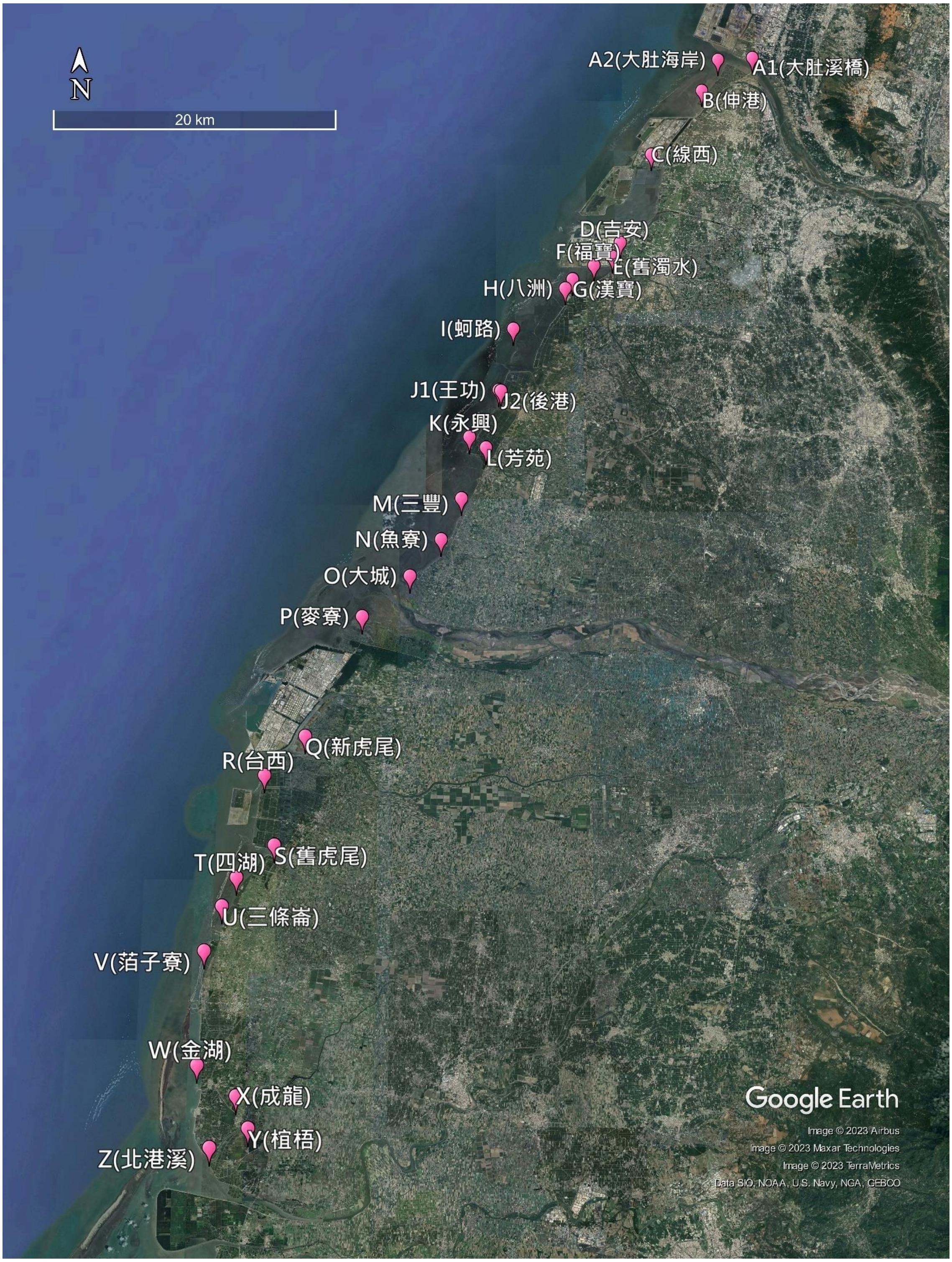
表 1 2022–2023 年間各樣站的採樣點數
Table1 Number of sampling points at each sampling station, 2022–2023

Sampling station	Sampling points		
	Water quality (2022/2023)	Soil particle size (2022/2023)	Heavy metal (2022/2023)
A1	3/3	2/2	6/6
A2	4/3	2/2	12/9
B	3/3	2/2	6/6
C	3/3	4/2	12/6
D	3/3	4/2	12/6
E	3/3	2/2	6/6
F	3/3	2/2	6/6
G	3/3	2/2	6/6
H	3/3	2/2	9/6
I	3/3	2/2	6/6
J1	3/3	2/2	6/6
J2	3/3	2/2	6/6
K	3/3	2/2	6/6
L	3/3	3/2	9/6
M	3/3	2/2	6/6
N	3/3	1/2	3/6
O	3/3	2/2	6/6
P	4/3	2/2	6/6
Q	4/3	4/2	12/6
R	3/3	2/2	6/6
S	3/3	2/2	6/6
T	3/3	2/2	6/6
U	3/3	2/2	6/6
V	3/3	2/2	6/6
W	3/3	3/2	18/6
X	3/3	2/2	6/6
Y	4/5	2/2	6/6
Z	3/3	2/2	6/6
north	2/1	0/2	12/6
	90/87	63/58	219/177
total	177	121	396

附錄 1 彰雲海岸 28 個採樣站位置圖，2022–2023 年。
Appendix 1 Twenty-eight sampling stations in Chang-Yun coastal wetlands of Taiwan, 2022–2023.



附錄 2 彰雲海岸 28 個採樣站編號位置描述及座標 (TWD97)，2022–2023 年
Appendix 2 Descriptions and coordinates (TWD97) of the 28 sampling stations in Changhua and Yunlin coastal wetlands

Sampling station	Name of sampling station	Chinese name of sampling station	Description of sampling station	Coordinate (TWD97)
A1	Dadu Bridge	大肚溪橋	大肚溪口南河岸台 61 線下方	(198468 2676260)
A2	Dadu Coast	大肚海岸	大肚溪口南海岸	(196207 2676036)
B	Shenggang	伸港	伸港寮仔地溝排水位於台 61 線西側	(194895 2673746)
C	Xianxi	線西	線西工業區光電區	(191607 2669217)
D	Ji'an	吉安	吉安水道位於鹿安橋下鄰近垃圾場	(188815 2662377)
E	Old Zhuoshui	舊濁水	舊濁水溪口(東螺溪口)	(188314 2661316)
F	Fubao	福寶	福寶海堤水門外	(187010 2660674)
G	Hanbao	漢寶	漢寶溪口	(185495 2659558)
H	Bazhou	八洲	八洲排水道口	(198104 2676759)
I	Oyster Road	蚵路	蚵路外海	(181785 2657004)
J1	Wang Gong	王功	王功漁港位於王者之弓橋外	(180373 2651801)
J2	Hougang	後港	後港溪口	(180245 2651690)
K	Yongxing	永興	永興海堤南側二林溪口北岸	(178339 2648631)
L	Fang Yuan	芳苑	芳苑西華宮外	(179496 2647798)
M	Sanfeng	三豐	三豐新街海堤水門外	(177861 2644335)
N	Yuliao	魚寮	魚寮溪口南岸	(176540 2641552)
O	Dacheng	大城	大城濁水溪口北岸	(174281 2639057)
P	Mailiao	麥寮	麥寮濁水溪口南岸	(171338 2636390)
Q	New Huwei	新虎尾	新虎尾溪口	(167738 2628694)
R	Taixi	台西	台西海園北側	(165151 2626150)
S	Old Huwei	舊虎尾	舊虎尾溪口	(165907 2621777)
T	Sihu	四湖	四湖工作站水門	(162646 2617932)
U	Santiaolun	三條崙	三條崙海水浴場舊址	(161634 2615452)
V	Bazi Liao	萡子寮	萡子寮北側沙丘內側	(161438 2608485)
W	Jinhua	金湖	金湖碼頭北側	(163896 2606694)
X	Chenglong	成龍	成龍濕地	(164720 2604798)
Y	Xufu	椬梧	湖口濕地之椬梧滯洪池	(162385 2603637)
Z	Beigang River	北港溪	北港溪口北岸(下湖口安檢所南側)	(163597 2619822)

附錄 3 彰雲海岸及大肚溪北岸水質樣點檢測資料敘述統計表，2022–2023 年
Appendix 3 Statistics of water quality data along Changhua and Yunlin coastal wetlands and north bank of Dadu Estuary, 2022–2023

	N	Minimum	Maximum	Mean	SD
water temperature ℃	177	16.00	38.80	27.94	4.40
pH	177	6.87	9.67	7.96	.39
salinity psu	177	.50	65.90	23.68	12.19
electrical conductivity ms/cm	177	1.09	90.90	36.34	17.60
dissolved oxygen saturation %	172	.10	198.70	79.06	40.68
dissolved oxygen mg/l	176	.01	19.38	5.63	3.13
NO_3 mg/l	164	30	1200	553.26	242.89
pH(LAQUA twin)	130	6.9	9.5	7.68	.38
salinity(LAQUA twin)	160	.7	50.7	20.34	9.95

附錄 4 彰雲海岸 28 個採樣站及大肚溪北岸 1 個採樣站之水質樣點檢測平均值，2022–2023 年

Appendix 4 Average of water quality across 28 sampling stations along Changhua and Yunlin coastal wetlands and 1 sampling station at the north bank of Dadu Estuary, 2022–2023

	Water temperature ℃			pH			Salinity psu			Electrical conductivity ms/cm			Dissolved oxygen saturation %			Dissolved oxygen mg/l			NO_3 mg/l			pH (LAQUA twin)			Salinity (LAQUA twin)		
	Mean	**SD**	N	Mean	**SD**	N	Mean	**SD**	N	Mean	**SD**	N	Mean	**SD**	N	Mean	**SD**	N	Mean	**SD**	N	Mean	**SD**	N	Mean	**SD**	N
A1	30.47	4.12	6	7.68	.18	6	22.12	5.88	6	34.88	8.12	6	87.93	11.04	6	5.84	.68	6	653	210	6	7.4	.3	6	21.5	4.0	6
A2	27.49	3.93	7	7.73	.22	7	5.03	5.25	7	8.70	8.36	7	70.86	26.14	7	5.41	2.06	7	213	139	7	7.6	.3	7	5.4	4.7	7
B	23.18	4.26	6	7.83	.26	6	4.18	7.14	6	7.16	11.39	6	72.15	35.59	6	6.15	3.10	6	131	112	6	7.6	.4	6	3.9	5.4	6
C	26.95	5.44	6	8.18	.41	6	19.77	9.03	6	31.26	13.58	6	97.72	39.18	6	8.99	5.57	6	530	263	6	7.7	.3	6	16.8	7.8	6
D	27.93	6.53	6	7.82	.17	6	25.80	6.85	6	40.02	10.20	6	72.95	17.67	6	5.10	1.66	6	588	122	6	7.4	.2	6	21.8	5.3	6
E	27.77	8.78	6	8.07	.14	6	29.15	4.67	6	44.92	6.43	6	91.25	23.87	6	6.23	1.71	6	635	162	6	7.7	.3	6	23.9	3.4	6
F	27.08	6.47	6	7.69	.22	6	17.68	8.27	6	28.22	11.94	6	34.37	39.43	6	2.26	2.52	6	455	175	6	7.5	.3	6	15.5	6.8	6
G	28.87	3.66	6	7.78	.26	6	7.23	2.99	6	12.51	4.76	6	66.53	28.20	6	4.97	2.17	6	260	86	6	7.6	.1	6	6.7	2.3	6
H	31.60	2.00	6	7.73	.14	6	18.98	2.69	6	30.28	3.88	6	26.85	26.28	6	1.82	1.77	6	525	70	6	7.6	.2	6	16.5	2.4	6
I	31.97	2.52	6	8.33	.26	6	33.47	.94	6	50.53	1.26	6	107.18	23.72	6	6.96	2.17	6	752	58	6	7.9	.5	6	28.1	1.7	6
J1	26.17	1.72	6	8.10	.20	6	30.90	1.99	6	47.40	2.69	6	98.23	9.29	6	6.68	.72	6	830	164	6	7.8	.2	6	26.1	1.0	6
J2	26.38	1.71	6	7.80	.29	6	25.38	7.05	6	39.38	10.33	6	57.98	51.84	6	4.02	3.55	6	696	144	6	7.5	.2	6	22.5	6.2	6
K	25.55	3.73	6	7.93	.40	6	15.12	12.51	6	24.08	18.61	6	55.04	29.74	6	5.73	4.70	6	325	193	6	7.9	.8	6	11.0	10.7	6
L	28.07	1.50	6	8.69	.57	6	16.68	10.20	6	26.62	15.29	6	55.02	45.24	6	3.83	3.11	6	495	331	6	8.3	1.1	6	13.6	8.4	6
M	26.17	3.43	6	7.03	.14	6	2.95	4.17	6	5.27	6.83	6	1.57	2.35	6	.13	.19	6	74	66	6	7.3	.3	6	7.5	10.8	6
N	28.68	2.55	6	7.90	.23	6	20.65	6.29	6	32.51	9.06	6	66.53	22.67	6	4.62	1.67	6	543	229	6	7.6	.2	6	17.1	5.5	6
O	28.25	4.31	6	8.13	.18	6	23.18	10.37	6	36.09	15.43	6	116.65	28.65	6	7.93	1.61	6	624	227	6	7.8	.2	6	20.3	8.9	6
P	29.39	2.01	7	8.31	.38	7	25.53	4.28	7	39.74	6.02	7	105.00	24.09	7	6.95	1.55	7	706	148	7	8.0	.4	7	22.6	3.7	7
Q	26.96	4.15	7	7.92	.19	7	23.04	11.26	7	35.86	16.23	7	76.37	27.70	7	5.19	1.60	7	600	360	7	7.7	.3	7	19.3	11.5	7
R	28.95	3.41	6	7.82	.11	6	29.55	1.88	6	45.37	2.61	6	95.13	29.32	6	6.19	1.65	6	632	103	6	7.5	.2	6	26.4	4.3	6
S	25.93	3.43	6	7.84	.29	6	19.43	10.03	6	30.78	14.61	6	71.83	42.58	6	5.07	2.85	6	460	178	6	7.6	.3	6	18.8	8.9	6
T	29.97	3.43	6	7.88	.28	6	30.27	2.55	6	46.27	3.66	6	84.57	38.15	6	5.43	2.46	6	802	130	6	7.5	.5	6	26.2	1.3	6
U	29.70	2.75	6	8.12	.13	6	33.18	1.30	6	50.32	1.83	6	106.92	5.60	6	6.79	.50	6	668	99	6	7.7	.3	6	27.1	1.2	6
V	29.50	3.05	6	8.02	.17	6	33.05	1.44	6	49.93	2.15	6	95.98	13.48	6	6.13	.95	6	678	133	6	7.6	.2	6	27.3	2.0	6
W	27.38	4.36	6	8.01	.09	6	30.77	3.41	6	46.35	5.21	6	92.33	13.05	6	6.19	.97	6	643	72	6	7.8	.2	6	26.4	2.6	6
X	27.94	5.36	7	8.07	.42	7	30.97	3.49	7	47.41	4.87	7	79.97	60.59	7	6.79	5.34	7	591	140	7	8.1	.4	7	26.1	3.7	7
Y	27.91	6.79	8	8.30	.46	8	50.05	10.00	8	71.96	12.52	8	108.77	87.04	8	8.03	5.93	8	779	124	8	8.0	.5	8	41.3	7.1	8
Z	26.95	4.04	6	8.13	.14	6	30.18	5.83	6	41.33	12.52	6	107.92	13.73	6	7.31	.67	6	533	135	6	7.6	.3	6	24.1	6.9	6
North	26.43	8.12	3	7.87	.36	3	26.90	5.54	3	41.70	7.28	3	92.43	25.84	3	6.37	.99	3	573	102	3	7.6	.2	3	20.4	7.3	3

Note: measured using the LAQUA twin water quality tester.

附錄 5 彰雲海岸於 28 個採樣站及大肚溪北岸 1 個採樣站之水質樣點檢測最大值及最小值，2022－2023 年

Appendix 5 Maximum and minimum values of water quality across 28 sampling stations along Changhua and Yunlin coastal wetlands and 1 sampling station at north bank of Dadu Estuary, 2022–2023

	Water temperature ℃		pH		Salinity psu		Electrical conductivity Ms/cm		Dissolved oxygen saturation %		Dissolved oxygen mg/l		NO_3mg/l		pH (LAQUA twin)		Salinity (LAQUA twin)	
	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum
A1	34.20	23.50	7.94	7.44	29.00	13.20	44.30	22.50	101.40	73.30	6.63	4.88	950	380	7.7	7.0	25.9	15.6
A2	33.70	23.50	8.02	7.46	16.80	2.00	27.40	3.79	99.10	34.50	8.10	2.56	480	88	8.0	7.2	15.9	2.8
B	29.50	17.20	8.10	7.52	18.70	.50	30.30	1.09	122.60	25.20	10.18	1.90	330	30	8.2	7.3	14.8	.7
C	34.50	21.90	8.70	7.48	27.30	3.60	42.70	6.65	125.20	31.50	19.38	2.44	870	150	8.0	7.3	23.5	3.7
D	33.80	18.00	8.04	7.64	31.70	12.90	49.10	20.70	91.70	45.50	7.22	2.90	750	430	7.7	7.2	28.7	12.5
E	37.00	16.00	8.23	7.86	35.90	24.10	53.80	37.80	121.70	52.40	7.71	3.00	820	400	8.0	7.2	28.5	20.2
F	33.30	18.20	8.05	7.53	32.70	10.50	49.70	17.06	93.70	.20	6.03	.01	760	270	7.9	7.2	27.8	9.4
G	32.80	22.40	8.07	7.46	11.50	3.80	19.14	6.80	101.60	31.10	7.12	2.32	350	120	7.8	7.5	10.1	3.2
H	34.50	29.60	7.94	7.60	22.30	16.30	35.10	26.50	65.60	2.30	4.56	.15	650	460	7.9	7.4	19.5	13.7
I	35.70	29.40	8.76	8.05	34.90	32.50	52.40	49.40	128.90	62.90	10.33	3.62	820	690	8.3	7.2	30.1	25.1
J1	29.30	24.60	8.48	7.90	32.80	27.50	49.90	42.80	112.00	86.60	7.74	5.84	1000	660	8.1	7.6	27.1	25.0
J2	28.80	23.70	8.15	7.47	32.60	13.20	49.60	21.20	120.60	.70	8.25	.05	950	590	7.8	7.1	28.4	13.2
K	31.10	19.70	8.59	7.53	32.10	2.20	49.10	4.14	97.70	24.60	14.62	1.90	580	120	8.5	7.3	26.5	1.9
L	30.60	26.70	9.67	8.01	29.80	4.00	46.00	7.21	123.40	6.50	8.52	.45	960	180	9.5	7.2	21.9	4.2
M	31.10	20.40	7.25	6.87	11.40	.80	19.10	1.67	6.30	.10	.51	.01	190	32	7.6	7.0	26.0	1.0
N	32.50	25.60	8.28	7.56	26.30	10.20	40.10	17.26	101.30	46.30	6.91	3.13	930	330	7.8	7.4	23.9	9.1
O	33.20	20.40	8.28	7.79	31.90	4.10	48.60	7.41	155.30	91.40	10.25	6.09	870	380	8.0	7.4	26.5	4.6
P	33.10	26.90	8.94	7.70	32.40	21.50	49.40	33.90	133.10	59.10	8.47	4.03	930	560	8.5	7.4	28.1	19.4
Q	31.90	21.60	8.13	7.59	33.20	7.40	50.20	12.90	105.50	31.60	6.99	2.47	1200	230	8.0	7.4	28.6	4.9
R	33.50	24.50	8.01	7.71	31.00	25.90	47.60	40.40	139.30	49.60	8.47	3.46	830	560	7.8	7.2	33.3	20.1
S	29.60	20.40	8.21	7.41	33.40	6.00	50.50	10.80	120.70	13.10	7.80	1.07	750	200	8.0	7.3	27.1	5.8
T	33.40	25.60	8.13	7.49	33.40	27.70	50.80	42.70	130.50	30.70	8.02	1.93	990	630	7.9	6.9	28.2	24.7
U	34.10	26.80	8.25	7.88	34.70	31.20	52.40	47.40	116.80	101.50	7.72	6.29	830	560	8.0	7.4	28.8	25.6
V	33.20	24.80	8.16	7.74	34.40	30.90	51.80	46.60	106.20	70.40	7.16	4.56	910	520	7.9	7.3	29.0	23.9
W	34.30	21.50	8.12	7.92	33.30	24.20	50.80	37.60	105.50	75.80	7.10	4.94	730	510	8.0	7.6	29.5	22.4
X	37.20	21.60	8.56	7.63	35.00	24.50	53.30	38.70	168.40	5.20	15.27	.35	750	390	8.6	7.5	29.6	19.9
Y	38.80	20.80	8.87	7.66	65.90	36.30	90.90	53.90	198.70	.40	16.00	.02	960	650	8.8	7.6	50.7	30.5
Z	32.40	20.50	8.34	8.00	33.80	18.50	51.00	21.60	129.30	89.70	8.18	6.15	700	350	7.9	7.2	31.9	14.5
North	35.80	21.50	8.24	7.53	33.30	23.70	50.10	37.40	119.10	67.50	6.98	5.23	690	500	7.8	7.4	28.6	14.7

附錄 6 彰雲海岸於 28 個採樣站及大肚溪北岸 1 個採樣站之水質樣點檢測平均值之年度差異，2022–2023 年

Appendix 6 Average of water quality from annual differences across 28 sampling stations along Changhua and Yunlin coastal wetlands and 1 sampling station at north bank of Dadu Estuary, 2022–2023

		Water temperature ℃	pH	Salinity psu	Electrical conductivity ms/cm	Dissolved oxygen saturation %	Dissolved oxygen mg/l	NO_3 mg/l	pH (LAQUA twin)	Salinity (LAQUA twin)
A1	2022	28.93	7.73	17.63	28.67	82.67	5.75	710	7.2	18.0
	2023	32.00	7.62	26.60	41.10	93.20	5.92	597	7.5	24.9
A2	2022	25.83	7.64	6.40	10.90	57.65	4.50	262	7.4	6.9
	2023	29.70	7.84	3.20	5.76	88.47	6.63	147	7.9	3.5
B	2022	25.47	7.61	1.73	3.38	42.90	3.55	130	7.4	2.4
	2023	20.90	8.06	6.63	10.95	101.40	8.74	132	7.9	5.5
C	2022	27.27	7.92	13.03	21.28	83.20	6.05	533	7.5	12.8
	2023	26.63	8.43	26.50	41.23	119.50	11.94	525	7.9	22.8
D	2022	32.63	7.75	22.23	34.57	70.60	4.54	633	7.3	19.6
	2023	23.23	7.89	29.37	45.47	75.30	5.65	543	7.5	23.9
E	2022	28.20	8.04	25.27	39.47	94.33	6.41	653	7.7	21.7
	2023	27.33	8.09	33.03	50.37	88.17	6.06	617	7.7	26.2
F	2022	27.33	7.67	13.33	21.78	28.20	1.91	377	7.5	11.7
	2023	26.83	7.72	22.03	34.67	40.53	2.60	533	7.6	19.3
G	2022	27.77	8.01	6.30	10.94	90.83	6.90	227	7.6	5.5
	2023	29.97	7.54	8.17	14.08	42.23	3.03	293	7.6	7.9
H	2022	32.37	7.80	19.53	31.03	40.70	2.72	553	7.4	17.8
	2023	30.83	7.66	18.43	29.53	13.00	.92	497	7.7	15.2
I	2022	33.03	8.14	32.97	49.83	93.20	5.67	757	7.2	28.7
	2023	30.90	8.52	33.97	51.23	121.17	8.25	747	8.2	27.4
J1	2022	25.67	8.14	29.43	45.40	99.67	6.90	933	7.8	26.5
	2023	26.67	8.06	32.37	49.40	96.80	6.46	675	7.7	25.6
J2	2022	27.60	7.82	21.33	33.47	79.37	5.49	750	7.6	20.2
	2023	25.17	7.78	29.43	45.30	36.60	2.55	615	7.3	26.1
K	2022	27.07	7.83	16.80	26.70	60.40	4.33	420	-	17.0
	2023	24.03	8.03	13.43	21.47	47.00	7.12	230	7.9	5.0
L	2022	28.03	8.74	17.93	28.57	37.10	2.54	705	8.3	20.6
	2023	28.10	8.64	15.43	24.67	72.93	5.12	285	8.4	6.6
M	2022	28.13	6.94	4.40	7.60	.67	.05	86	7.0	3.5
	2023	24.20	7.12	1.50	2.94	2.47	.20	56	7.4	13.5
N	2022	27.77	8.04	24.17	37.57	64.87	4.46	627	7.6	19.5
	2023	29.60	7.76	17.13	27.45	68.20	4.77	460	7.6	14.7
O	2022	30.90	8.08	16.33	26.00	100.70	6.86	700	7.8	16.9
	2023	25.60	8.18	30.03	46.17	132.60	8.99	510	7.8	25.4
P	2022	30.08	8.39	22.38	35.30	103.23	6.84	793	8.0	20.1
	2023	28.47	8.21	29.73	45.67	107.37	7.09	575	8.0	26.4
Q	2022	25.20	7.92	21.90	34.43	69.55	4.90	643	7.4	17.8
	2023	29.30	7.92	24.57	37.77	85.47	5.59	557	7.7	20.3
R	2022	31.67	7.85	29.83	45.63	108.50	6.80	657	7.6	26.5
	2023	26.23	7.79	29.27	45.10	81.77	5.57	607	7.5	26.3
S	2022	25.80	7.65	14.97	24.27	41.13	2.93	380	7.3	17.5
	2023	26.07	8.03	23.90	37.30	102.53	7.20	540	7.6	20.0
T	2022	30.20	7.70	29.40	45.07	56.30	3.68	870	7.1	26.6
	2023	29.73	8.06	31.13	47.47	112.83	7.18	733	7.9	25.9
U	2022	31.00	8.05	32.90	49.87	104.60	6.52	687	7.5	27.0
	2023	28.40	8.20	33.47	50.77	109.23	7.05	650	7.9	27.2
V	2022	29.73	8.03	32.07	48.43	98.20	6.29	693	7.4	26.4
	2023	29.27	8.01	34.03	51.43	93.77	5.96	663	7.8	28.1
W	2022	28.33	7.94	28.57	42.53	90.13	6.02	603	7.7	24.7
	2023	26.43	8.09	32.97	50.17	94.53	6.36	683	7.9	27.6
X	2022	26.60	7.74	30.45	46.75	47.53	3.11	570	7.5	25.2
	2023	29.73	8.51	31.67	48.30	144.85	11.69	620	8.3	27.0
Y	2022	32.00	8.21	45.17	65.83	125.50	7.26	925	-	38.7
	2023	25.46	8.36	52.98	75.64	92.03	8.61	720	8.0	42.3
Z	2022	27.83	8.17	27.00	41.70	104.13	7.03	483	-	20.5
	2023	26.07	8.09	33.37	40.97	111.70	7.59	583	7.6	26.5
North	2022	21.75	7.69	23.70	37.50	79.10	6.07	515	7.5	16.3
	2023	35.80	8.24	33.30	50.10	119.10	6.98	690	7.8	28.6

附錄 7 彰雲海岸土壤粒徑 28 個採樣站及大肚溪北岸 1 個採樣站之分區表，2022–2023 年

Appendix 7 Statistics of soil particle size data at 28 sampling stations along the Changhua and Yunlin coastal wetlands and 1 sampling station at north bank of Dadu Estuary, 2022–2023

	Sand					Silt					Clay				
	Maximum	Minimum	Median	Mean	SD	Maximum	Minimum	Median	Mean	SD	Maximum	Minimum	Median	Mean	SD
A1	60	56	60	58.75	1.89	29	24	27	26.75	2.06	17	12	15	14.50	2.38
A2	92	71	81	81.25	9.18	17	2	10	9.75	6.60	12	6	9	9.00	2.58
B	75	59	70	68.25	7.63	22	13	17	17.00	4.24	19	11	15	14.75	3.50
C	90	77	84	83.67	5.72	12	4	8	7.83	3.43	12	6	9	8.50	2.51
D	74	63	70	69.67	4.13	21	12	17	16.17	3.31	16	13	14	14.17	1.47
E	84	54	66	67.50	13.63	31	7	22	20.50	11.09	15	9	12	12.00	2.58
F	91	62	69	72.75	13.02	25	1	18	15.25	10.78	14	8	13	12.00	2.71
G	93	79	82	83.75	6.40	12	2	10	8.25	4.35	10	5	9	8.00	2.16
H	82	67	77	75.75	6.50	20	9	14	14.25	4.57	13	8	10	10.00	2.16
I	93	60	89	82.75	15.63	24	1	4	8.25	10.87	16	6	7	9.00	4.76
J1	92	76	85	84.50	7.72	14	2	7	7.25	5.74	10	5	9	8.25	2.36
J2	76	62	72	70.50	5.97	20	14	16	16.25	2.63	18	10	13	13.25	3.40
K	86	73	81	80.25	5.91	17	5	10	10.50	5.20	10	8	10	9.25	0.96
L	56	46	56	53.00	4.47	27	18	23	22.80	3.27	27	20	26	24.20	3.03
M	60	50	52	53.50	4.73	32	18	26	25.50	6.24	23	18	22	21.00	2.16
N	61	53	53	55.67	4.62	30	20	27	25.67	5.13	20	17	19	18.67	1.53
O	57	50	54	53.75	2.87	32	26	29	28.75	3.20	24	12	17	17.50	5.51
P	62	59	60	60.25	1.26	26	21	23	23.25	2.22	18	14	17	16.50	1.73
Q	92	59	74	74.17	13.79	21	3	14	12.50	7.12	23	5	12	13.33	7.03
R	81	76	79	78.75	2.22	15	10	12	12.00	2.16	10	9	9	9.25	0.50
S	55	50	53	52.75	2.22	30	21	26	25.75	3.69	24	18	22	21.50	3.00
T	86	85	86	85.50	0.58	7	4	5	5.00	1.41	10	8	10	9.50	1.00
U	93	73	92	87.50	9.71	18	2	3	6.50	7.68	9	4	6	6.00	2.16
V	94	89	91	91.25	2.06	3	1	2	2.00	0.82	8	5	7	6.75	1.26
W	95	94	94	94.20	0.45	1	0	1	0.80	0.45	6	4	5	5.00	0.71
X	85	82	84	83.50	1.73	8	5	7	6.75	1.26	11	8	10	9.75	1.26
Y	82	62	64	68.00	9.38	23	9	20	17.75	6.18	18	9	15	14.25	4.11
Z	84	76	82	80.75	3.95	13	7	10	9.75	3.20	11	9	9	9.50	1.00
North	85	78	82	81.50	4.95	12	7	10	9.50	3.54	10	8	9	9.00	1.41

附錄 8 彰雲海岸土壤粒徑 28 個採樣站及大肚溪北岸 1 個採樣站之上下土層統計表，2022–2023 年

Appendix 8 Statistics of soil particle size data from upper and lower soil layers at 28 sampling stations along the Changhua and Yunlin coastal wetlands and 1 sampling station at north bank of Dadu Estuary, 2022–2023

	Sand								Clay								Silt							
	Lower soil layer				Upper soil layer				Lower soil layer				Upper soil layer				Lower soil layer				Upper soil layer			
	Maximum	Minimum	Mean	SD	Maximum	Minimum	Mean	SD	Maximum	Minimum	Mean	SD	Maximum	Minimum	Mean	SD	Maximum	Minimum	Mean	SD	Maximum	Minimum	Mean	SD
A1	60	60	60	0	59	56	58	2	16	13	15	2	17	12	15	4	27	24	26	2	29	27	28	1
A2	92	85	89	5	77	71	74	4	8	6	7	1	12	10	11	1	7	2	5	4	17	13	15	3
B	74	65	70	6	75	59	67	11	16	13	15	2	19	11	15	6	19	13	16	4	22	14	18	6
C	90	87	89	2	81	77	79	2	7	6	6	1	12	10	11	1	7	4	5	2	12	9	11	2
D	74	69	72	3	70	63	67	4	14	13	13	1	16	13	15	2	18	12	14	3	21	16	18	3
E	73	54	64	13	84	59	72	18	15	11	13	3	13	9	11	3	31	16	24	11	28	7	18	15
F	73	65	69	6	91	62	77	21	14	13	14	1	13	8	11	4	22	13	18	6	25	1	13	17
G	93	83	88	7	80	79	80	1	8	5	7	2	10	9	10	1	9	2	6	5	12	10	11	1
H	82	67	75	11	79	75	77	3	13	9	11	3	10	8	9	1	20	9	15	8	15	13	14	1
I	93	60	77	23	93	85	89	6	16	6	11	7	8	6	7	1	24	1	13	16	7	1	4	4
J1	90	80	85	7	92	76	84	11	10	8	9	1	10	5	8	4	10	2	6	6	14	3	9	8
J2	72	62	67	7	76	72	74	3	18	13	16	4	12	10	11	1	20	15	18	4	16	14	15	1
K	86	84	85	1	78	73	76	4	9	8	9	1	10	10	10	0	8	5	7	2	17	12	15	4
L	56	46	51	7	56	51	54	3	27	22	25	4	26	20	24	3	27	22	25	4	24	18	22	3
M	54	50	52	3	60	50	55	7	23	18	21	4	22	21	22	1	32	23	28	6	29	18	24	8
N	53	53	53	.	61	53	57	6	20	20	20	.	19	17	18	1	27	27	27	.	30	20	25	7
O	57	50	54	5	54	54	54	0	24	12	18	8	20	14	17	4	31	26	29	4	32	26	29	4
P	60	59	60	1	62	60	61	1	18	17	18	1	17	14	16	2	24	22	23	1	26	21	24	4
Q	92	59	79	18	76	59	69	9	23	5	12	10	20	10	15	5	18	3	9	8	21	14	16	4
R	78	76	77	1	81	80	81	1	10	9	10	1	9	9	9	0	15	12	14	2	11	10	11	1
S	54	50	52	3	55	52	54	2	24	20	22	3	24	18	21	4	26	26	26	0	30	21	26	6
T	86	85	86	1	86	85	86	1	10	8	9	1	10	10	10	0	7	4	6	2	5	4	5	1
U	91	73	82	13	93	93	93	0	9	6	8	2	5	4	5	1	18	3	11	11	3	2	3	1
V	91	89	90	1	94	91	93	2	8	7	8	1	7	5	6	1	3	2	3	1	2	1	2	1
W	94	94	94	0	95	94	94	1	5	5	5	0	6	4	5	1	1	1	1	0	1	0	1	1
X	85	82	84	2	85	82	84	2	11	8	10	2	10	10	10	0	7	7	7	0	8	5	7	2
Y	64	64	64	0	82	62	72	14	18	13	16	4	17	9	13	6	23	18	21	4	21	9	15	8
Z	84	76	80	6	84	79	82	4	11	9	10	1	9	9	9	0	13	7	10	4	12	7	10	4
North	78	78	78	.	85	85	85	.	10	10	10	.	8	8	8	.	12	12	12	.	7	7	7	.

附錄 9 彰雲海岸土壤粒徑 28 個採樣站及大肚溪北岸 1 個採樣站之年度差異統計表，2022–2023 年
Appendix 9 Statistics of soil particle size data from annual differences across 28 sampling stations along the Changhua and Yunlin coastal wetlands and 1 sampling station at north bank of Dadu Estuary, 2022–2023

	Sand								Clay								Silt							
	2022				2023				2022				2023				2022				2023			
	Maximum	Minimum	Mean	SD	Maximum	Minimum	Mean	SD	Maximum	Minimum	Mean	SD	Maximum	Minimum	Mean	SD	Maximum	Minimum	Mean	SD	Maximum	Minimum	Mean	SD
A1	60	59	60	1	60	56	58	3	13	12	13	1	17	16	17	1	29	27	28	1	27	24	26	2
A2	85	77	81	6	92	71	82	15	10	8	9	1	12	6	9	4	13	7	10	4	17	2	10	11
B	65	59	62	4	75	74	75	1	19	16	18	2	13	11	12	1	22	19	21	2	14	13	14	1
C	90	77	84	6	87	78	83	6	12	6	9	3	10	6	8	3	11	4	7	4	12	7	10	4
D	74	63	70	5	69	68	69	1	16	13	14	1	16	13	15	2	21	12	16	4	18	16	17	1
E	59	54	57	4	84	73	79	8	15	13	14	1	11	9	10	1	31	28	30	2	16	7	12	6
F	65	62	64	2	91	73	82	13	13	13	13	0	14	8	11	4	25	22	24	2	13	1	7	8
G	83	80	82	2	93	79	86	10	10	8	9	1	9	5	7	3	10	9	10	1	12	2	7	7
H	79	67	73	8	82	75	79	5	13	8	11	4	10	9	10	1	20	13	17	5	15	9	12	4
I	85	60	73	18	93	93	93	0	16	8	12	6	6	6	6	0	24	7	16	12	1	1	1	0
J1	92	90	91	1	80	76	78	3	8	5	7	2	10	10	10	0	3	2	3	1	14	10	12	3
J2	72	62	67	7	76	72	74	3	18	12	15	4	13	10	12	2	20	16	18	3	15	14	15	1
K	86	78	82	6	84	73	79	8	10	9	10	1	10	8	9	1	12	5	9	5	17	8	13	6
L	56	46	51	5	56	56	56	0	27	26	26	1	22	20	21	1	27	18	23	5	24	22	23	1
M	60	54	57	4	50	50	50	0	23	22	23	1	21	18	20	2	23	18	21	4	32	29	31	2
N	61	61	61	.	53	53	53	0	19	19	19	.	20	17	19	2	20	20	20	.	30	27	29	2
O	54	50	52	3	57	54	56	2	24	20	22	3	14	12	13	1	26	26	26	0	32	31	32	1
P	62	60	61	1	60	59	60	1	18	17	18	1	17	14	16	2	22	21	22	1	26	24	25	1
Q	87	59	69	13	92	76	84	11	23	8	16	7	10	5	8	4	21	5	15	7	14	3	9	8
R	80	78	79	1	81	76	79	4	10	9	10	1	9	9	9	0	12	11	12	1	15	10	13	4
S	55	50	53	4	54	52	53	1	24	24	24	0	20	18	19	1	26	21	24	4	30	26	28	3
T	86	85	86	1	86	85	86	1	10	10	10	0	10	8	9	1	5	4	5	1	7	4	6	2
U	93	91	92	1	93	73	83	14	6	5	6	1	9	4	7	4	3	2	3	1	18	3	11	11
V	91	89	90	1	94	91	93	2	8	7	8	1	7	5	6	1	3	2	3	1	2	1	2	1
W	94	94	94	0	95	94	95	1	6	5	5	1	5	4	5	1	1	0	1	1	1	1	1	0
X	82	82	82	0	85	85	85	0	11	10	11	1	10	8	9	1	8	7	8	1	7	5	6	1
Y	82	64	73	13	64	62	63	1	13	9	11	3	18	17	18	1	23	9	16	10	21	18	20	2
Z	84	84	84	0	79	76	78	2	9	9	9	0	11	9	10	1	7	7	7	0	13	12	13	1
North	.	.	.	.	85	78	82	5	.	.	.	.	10	8	9	1	.	.	.	.	12	7	10	4

附錄 10 彰雲海岸土壤粒徑 28 個採樣站及大肚溪北岸 1 個採樣站之年度差異及上下土層平均值統計表，2022–2023 年

Appendix 10 Statistics of soil particle size data from upper and lower soil layers and annual differences across 28 sampling stations along the Changhua and Yunlin coastal wetlands and 1 sampling station at north bank of Dadu Estuary, 2022–2023

	Sand				Silt				Clay			
Year	2022		2023		2022		2023		2022		2023	
Layer	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper
A1	60	59	60	56	27	29	24	27	13	12	16	17
A2	85	77	92	71	7	13	2	17	8	10	6	12
B	65	59	74	75	19	22	13	14	16	19	13	11
C	90	79	87	78	4	10	7	12	7	11	6	10
D	74	67	69	68	13	19	18	16	14	15	13	16
E	54	59	73	84	31	28	16	7	15	13	11	9
F	65	62	73	91	22	25	13	1	13	13	14	8
G	83	80	93	79	9	10	2	12	8	10	5	9
H	67	79	82	75	20	13	9	15	13	8	9	10
I	60	85	93	93	24	7	1	1	16	8	6	6
J1	90	92	80	76	2	3	10	14	8	5	10	10
J2	62	72	72	76	20	16	15	14	18	12	13	10
K	86	78	84	73	5	12	8	17	9	10	8	10
L	46	54	56	56	27	21	22	24	27	26	22	20
M	54	60	50	50	23	18	32	29	23	22	18	21
N	.	61	53	53	.	20	27	30	.	19	20	17
O	50	54	57	54	26	26	31	32	24	20	12	14
P	60	62	59	60	22	21	24	26	18	17	17	14
Q	73	66	92	76	12	18	3	14	16	17	5	10
R	78	80	76	81	12	11	15	10	10	9	9	9
S	50	55	54	52	26	21	26	30	24	24	20	18
T	86	85	85	86	4	5	7	4	10	10	8	10
U	91	93	73	93	3	2	18	3	6	5	9	4
V	89	91	91	94	3	2	2	1	8	7	7	5
W	94	94	94	95	1	1	1	1	5	6	5	4
X	82	82	85	85	7	8	7	5	11	10	8	10
Y	64	82	64	62	23	9	18	21	13	9	18	17
Z	84	84	76	79	7	7	13	12	9	9	11	9
North	.	.	78	85	.	.	12	7	.	.	10	8

附錄 11 彰雲海岸 28 個採樣站及大肚溪北岸 1 個採樣站 32 種土壤重金屬含量最大值及平均值，2022–2023 年

Appendix 11 Maximum and average values (mg/kg) of 32 heavy metals along the Changhua and Yunlin coastal wetlands and 1 sampling station at north bank of Dadu Estuary, 2022–2023

	N	Maximum	Mean	SD
Mo	396	14.76	1.55	1.90
Zr	396	1248.0	299.34	140.53
Sr	396	151.63	91.34	19.17
U	396	13.32	1.17	2.21
Rb	396	140.21	86.64	20.49
Th	396	34.30	14.83	4.01
Pb	396	74.14	22.23	7.96
Se	396	2.54	.09	.32
As	396	22.97	9.30	3.66
Hg	396	23.70	3.70	4.53
Zn	396	331.69	107.10	49.39
W	396	76.65	13.26	15.33
Cu	396	88.55	22.38	17.81
Ni	396	94.50	23.33	18.84
Co	396	286.61	60.88	53.59
Fe	396	37349	23093.90	5792.09
Mn	396	1003.1	320.00	139.60
Cr	396	119.35	27.70	17.28
V	396	111.35	42.42	18.96
Ti	396	6075	3337.75	714.98
Sc	396	31.17	5.22	5.82
Ca	396	21402	7436.76	3185.71
K	396	24352	16179.80	3423.80
S	396	3739	1133.16	810.24
Ba	396	554.79	428.35	42.28
Cs	396	118.39	78.82	16.67
Te	396	225.29	133.97	34.37
Sb	396	76.59	34.90	10.96
Sn	396	67.57	41.21	10.23
Cd	396	19.37	7.27	3.52
Ag	396	10.85	2.76	2.26
Pd	396	15.28	2.78	2.84

附錄 12 彰雲海岸 28 個採樣站及大肚溪北岸 1 個採樣站之土壤重金屬分區平均值，2022–2023 年
Appendix 12 Average values (mg/kg) of heavy metals from 28 sampling stations along the Changhua and Yunlin coastal wetlands and 1 sampling station at north bank of Dadu Estuary, 2022–2023

	Mo	Zr	Sr	U	Rb	Th	Pb	Se	As	Hg	Zn	W	Cu	Ni	Co	Fe	Mn	Cr	V	Ti	Sc	Ca	K	S	Ba	Cs	Te	Sb	Sn	Cd	Ag	Pd
A1	0.3	290.5	87.5	0.50	96.5	15.6	28.2	0.05	9.4	4.0	107.2	25.5	30.1	40.5	87.7	24398.5	355.4	15.3	45.3	3896.4	2.4	4746.7	18332.4	556.0	445.2	71.0	109.0	24.8	43.2	4.4	1.4	1.5
A2	0.8	301.3	65.9	1.23	73.7	12.1	19.7	0.03	8.3	2.5	113.9	17.3	25.4	35.0	35.3	18233.9	253.3	18.7	28.7	2684.2	2.1	4253.3	14722.1	1186.8	434.0	86.1	146.2	38.7	47.4	7.6	2.2	2.2
B	0.3	303.5	77.4	1.75	89.6	15.1	24.1	0.24	10.1	3.6	117.0	24.9	28.4	47.2	39.5	21864.4	319.7	37.7	46.3	3466.1	3.2	3883.1	17394.6	457.5	430.6	75.6	127.9	33.9	41.2	7.1	2.0	1.8
C	0.9	306.3	61.4	0.67	74.5	12.1	17.5	0.15	7.9	3.7	118.4	10.5	40.6	32.0	30.7	16992.1	244.2	25.4	37.2	2780.9	1.9	3658.1	15162.1	685.3	446.9	89.0	161.4	41.5	50.3	8.3	4.2	3.4
D	1.1	218.7	92.7	1.03	95.5	14.9	28.6	0.09	9.3	6.2	183.8	11.2	47.1	34.4	45.6	25006.3	337.5	40.5	47.4	3639.4	4.5	7119.4	18746.3	1310.5	430.1	74.0	126.7	32.6	40.7	6.7	2.9	1.5
E	1.6	206.0	104.1	0.53	107.4	15.9	27.0	0.15	9.1	5.5	233.6	18.0	50.9	35.0	61.9	27910.8	268.7	44.4	57.0	3725.5	5.6	6138.3	18999.0	2975.5	401.3	59.7	99.3	24.6	35.0	5.4	1.9	2.0
F	2.1	264.4	102.8	0.11	102.8	14.8	26.0	0.24	7.3	3.1	175.6	11.8	35.9	28.6	77.4	26799.9	285.0	39.9	54.3	3704.5	5.8	6449.4	18697.7	2959.2	430.3	71.4	121.2	29.8	38.6	5.3	2.2	2.3
G	1.0	225.0	104.4	1.95	88.1	14.0	19.3	0.18	7.9	3.8	96.0	13.4	10.8	23.2	63.6	23226.9	403.2	18.9	43.6	3287.7	7.2	10391.0	16633.1	535.9	482.2	89.7	148.3	38.2	47.6	9.0	2.1	2.8
H	1.1	313.6	100.7	2.34	90.3	14.4	21.1	0.04	8.1	3.8	143.7	15.6	19.8	22.7	69.2	22087.4	262.2	29.0	35.2	3361.7	6.8	8116.6	16611.9	1920.0	417.0	72.5	123.1	30.0	37.9	6.3	2.5	1.7
I	0.8	208.8	91.1	1.78	80.3	12.6	17.6	0.00	6.5	2.9	76.4	11.0	5.1	17.5	34.7	21339.5	306.1	17.4	41.0	2958.2	5.0	8767.0	14834.5	685.7	466.1	94.3	158.3	41.9	47.7	9.9	3.2	2.9
J1	2.9	492.5	71.1	0.31	70.4	12.3	16.4	0.12	9.3	2.8	65.9	5.8	12.9	16.9	65.5	17903.6	218.1	14.5	38.0	2722.5	2.5	7089.9	14100.5	1035.3	433.5	91.0	156.3	43.1	49.6	8.1	4.3	2.8
J2	3.0	684.9	90.5	2.01	90.9	17.3	22.0	0.00	10.1	2.1	98.7	14.6	20.1	21.3	55.6	24279.8	281.5	30.6	44.1	3799.9	6.0	7353.4	17554.6	1010.8	440.4	79.4	137.5	35.7	40.4	7.8	2.3	2.9
K	1.2	535.5	79.7	1.90	72.1	14.6	18.8	0.02	8.5	3.7	72.3	14.8	15.4	19.7	50.4	19450.6	238.3	20.6	37.4	3204.3	5.7	8091.3	15023.7	1139.0	422.6	84.5	144.1	36.6	41.7	6.9	2.5	2.9
L	2.1	217.5	118.3	0.94	117.6	19.6	31.7	0.20	10.4	3.2	136.8	13.7	37.9	25.9	74.8	31720.8	390.6	40.1	56.6	4012.2	7.5	8113.3	19513.3	1290.7	378.5	54.7	93.5	21.6	25.0	5.6	2.4	2.2
M	1.8	201.8	124.2	0.78	126.9	18.7	30.4	0.16	10.6	5.1	162.0	18.7	36.8	20.4	109.4	33697.4	477.5	38.9	68.2	4159.9	19.2	13849.0	21183.9	2197.8	430.4	61.9	102.2	26.7	32.2	6.9	1.9	5.3
N	1.9	266.7	116.1	0.02	117.3	18.2	27.9	0.00	12.0	4.6	116.1	11.6	23.7	36.6	90.4	31604.8	412.7	31.6	61.1	4192.2	6.0	9444.9	20698.4	1816.4	404.3	58.8	89.4	24.3	28.2	5.1	1.6	2.7
O	1.8	276.8	118.8	1.32	104.7	15.6	25.6	0.25	12.0	5.4	99.2	12.2	21.2	19.6	102.8	29555.7	483.3	31.3	56.9	3873.0	11.9	10519.7	17383.6	555.1	406.9	63.9	113.2	28.3	32.7	7.0	2.1	2.9
P	1.9	259.5	109.0	0.23	101.3	17.9	24.0	0.03	12.0	3.4	91.2	10.1	19.1	21.1	85.9	27603.5	503.6	32.6	47.5	3904.5	9.3	9199.8	18268.6	447.4	426.1	69.4	115.1	29.2	33.1	5.6	2.4	1.3
Q	1.4	234.5	94.1	2.18	87.6	14.7	21.9	0.00	8.2	2.8	92.7	10.6	13.0	21.8	61.0	23704.9	296.6	30.3	45.0	3329.3	6.0	8137.9	16226.3	923.4	437.4	85.1	151.7	40.6	42.3	8.6	3.7	3.5
R	1.8	283.6	84.5	1.30	71.7	11.4	15.3	0.06	11.7	2.4	65.5	13.9	7.2	14.2	31.9	18911.4	250.3	23.9	32.7	3043.4	3.2	6607.0	14453.0	1104.4	430.9	87.5	155.7	41.2	43.3	9.2	3.4	3.0
S	3.6	248.1	110.2	0.27	117.2	18.7	30.0	0.12	14.9	4.1	160.0	14.3	33.9	11.3	103.8	33336.7	397.2	36.4	53.4	4148.2	6.5	7182.1	19792.5	1515.7	393.4	58.4	96.5	28.1	31.2	6.7	2.6	2.9
T	0.8	202.9	83.9	1.29	76.5	13.5	15.4	0.02	6.2	2.3	72.4	9.3	9.0	12.4	59.3	19893.8	395.1	15.3	29.6	2914.6	1.7	6783.3	14149.3	878.6	465.9	91.6	159.4	41.2	47.7	9.2	3.0	2.8
U	0.8	223.2	79.2	0.02	66.5	11.0	14.0	0.12	8.0	5.8	57.6	10.1	4.3	11.4	53.6	17071.0	205.8	17.5	30.5	2616.2	2.3	8064.2	12638.0	721.1	456.9	96.4	171.2	46.7	49.3	9.3	4.8	4.6
V	2.1	339.1	83.2	0.95	60.1	13.7	17.8	0.08	11.2	2.8	58.3	8.6	7.4	12.4	49.8	19896.6	298.9	17.0	34.1	2916.2	5.6	11403.9	11147.0	578.4	431.0	95.3	165.3	44.8	48.7	8.4	4.2	3.5
W	2.6	399.2	92.1	1.58	58.4	16.8	17.2	0.01	11.7	4.1	72.2	13.9	8.8	15.5	58.4	22152.5	529.9	31.1	34.5	3044.9	6.2	10533.6	11160.6	521.7	432.0	91.8	138.9	37.0	50.2	6.7	2.0	4.4
X	1.9	270.6	92.3	0.16	65.4	12.8	28.8	0.22	7.2	2.8	55.2	10.6	24.6	16.8	26.5	15860.4	214.2	17.5	29.0	2735.7	3.5	8412.7	13688.5	1632.1	405.6	80.6	139.0	39.1	39.8	8.2	3.1	2.9
Y	1.0	260.9	95.3	1.14	88.0	15.5	20.2	0.05	9.3	5.2	83.9	9.4	17.2	29.6	69.0	23470.5	163.9	28.9	48.7	3557.8	3.3	4478.6	16333.7	956.0	409.3	71.6	125.7	33.8	34.2	6.3	2.9	2.6
Z	1.1	291.5	77.7	2.49	67.6	11.7	16.2	0.12	6.8	4.0	64.9	9.3	9.5	19.8	26.0	17366.7	209.9	18.7	30.0	2996.9	2.6	5739.7	14896.4	1301.5	430.8	83.3	144.4	36.0	43.8	7.2	2.5	2.0
North	1.6	320.2	76.5	1.77	90.1	15.6	25.9	0.02	7.0	2.4	98.4	12.9	24.0	12.2	81.7	21685.1	225.4	31.5	38.7	3160.8	1.9	4005.5	16307.7	851.0	402.1	76.6	133.3	34.4	37.2	7.6	3.3	2.4

附錄 13 彰雲海岸 28 個採樣站及大肚溪北岸 1 個採樣站之土壤重金屬上下土層最大值，2022–2023

Appendix 13 Maximum values (mg/kg) of heavy metals from 28 sampling stations categorized by upper and lower soil layers along the Changhua and Yunlin coastal wetlands and 1 sampling station at north bank of Dadu Estuary, 2022–2023

	Mo		Zr		Sr		U		Rb		Th		Pb		Se		As		Hg		Zn		W		Cu		Ni		Co		Fe	
	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper
A1	1.96	.59	317.1	305.7	89.67	93.29	.00	4.02	103.82	102.86	17.37	19.81	34.56	30.97	.00	.63	11.63	14.18	9.89	9.70	122.34	130.20	64.16	35.53	38.87	42.35	58.32	**94.50**	174.93	144.95	26024	26845
A2	4.67	4.53	387.6	513.1	72.12	85.21	8.92	3.85	74.10	92.09	16.01	17.78	19.84	28.56	.65	.00	8.32	**22.97**	6.19	14.39	138.36	158.16	40.97	52.66	37.28	54.40	54.22	68.93	72.64	85.93	16418	26091
B	.84	1.11	333.3	340.0	84.04	90.62	.00	8.51	97.68	100.34	17.08	20.08	30.21	30.51	2.04	.89	12.06	12.32	13.23	8.59	121.18	140.51	33.77	**76.65**	37.37	47.48	63.07	69.72	89.67	41.30	24001	25932
C	2.52	3.21	485.9	349.9	63.31	73.26	5.52	3.20	74.80	89.66	14.98	17.03	21.56	26.92	.77	1.75	9.58	11.66	9.70	14.20	155.39	184.77	46.25	26.64	50.50	**88.55**	67.95	54.75	102.52	103.85	16903	20293
D	2.92	6.22	238.1	245.7	106.94	124.44	4.46	8.73	102.51	105.68	15.40	22.62	33.28	39.97	.62	.40	11.90	14.45	12.51	14.91	216.50	229.24	19.50	46.02	78.69	68.73	63.23	68.59	104.38	161.45	27721	29478
E	3.69	6.77	213.2	227.1	121.11	107.82	3.06	.39	131.63	126.29	23.17	22.59	31.98	33.80	.89	.23	15.76	14.48	**23.70**	11.09	**331.69**	293.82	49.97	46.09	80.98	68.76	66.68	42.50	150.69	121.67	32685	32833
F	5.03	3.88	291.9	385.6	111.99	110.05	.00	1.26	115.32	111.01	20.49	19.13	35.64	29.24	.84	1.44	11.56	12.08	10.68	8.57	213.58	238.35	38.31	9.56	63.18	53.44	55.33	53.88	177.03	66.16	30636	28086
G	.51	3.39	250.8	289.1	110.04	108.72	7.61	3.90	89.69	99.16	16.89	17.61	21.67	25.70	.74	1.12	12.62	11.78	6.38	11.62	104.68	111.86	41.43	36.90	13.07	34.89	59.67	44.73	136.58	127.06	26525	24455
H	.53	4.13	375.5	335.1	115.60	108.58	5.65	9.94	94.59	99.06	17.41	19.38	24.51	24.89	.56	.00	11.71	17.06	15.54	7.97	144.08	188.96	42.22	40.78	38.19	35.81	64.16	61.33	147.26	130.46	25191	23654
I	.51	3.86	250.8	234.7	110.04	108.72	7.61	3.90	86.39	93.29	15.23	16.46	21.67	25.70	.00	.00	12.19	9.69	7.09	11.46	96.09	92.89	30.82	29.54	13.07	8.92	43.89	35.81	66.63	79.21	22440	24423
J1	3.46	7.87	546.6	1057.8	90.61	93.88	.02	1.99	80.05	85.89	12.80	18.23	20.41	22.99	1.36	.13	14.02	10.35	7.37	6.41	92.43	93.21	30.27	19.75	17.74	47.63	20.79	39.23	106.47	78.52	21287	22049
J2	5.66	5.49	781.8	905.9	104.96	90.53	9.17	6.90	99.54	88.31	22.16	20.70	31.88	23.53	.00	.00	15.05	12.98	4.75	13.25	110.14	105.36	40.09	29.88	42.41	34.60	42.11	32.02	164.67	105.45	27879	23973
K	4.27	2.28	532.2	723.9	105.49	90.05	5.03	5.28	77.38	85.74	17.18	18.90	22.58	22.44	.28	.00	10.54	10.78	9.98	3.32	90.44	86.83	24.25	41.55	21.61	26.42	29.60	44.83	71.37	188.48	20661	20661
L	4.70	4.16	222.7	241.1	**151.63**	124.13	3.12	7.48	138.88	125.26	28.76	27.61	38.72	39.35	.00	2.18	12.36	15.48	8.64	14.38	165.06	159.54	25.89	43.53	50.73	57.43	47.62	47.81	161.69	142.61	36881	34387
M	4.06	4.74	204.7	242.4	131.35	129.30	4.83	1.38	**140.21**	137.26	22.72	22.65	32.02	36.21	1.79	.18	15.52	10.78	14.25	20.52	190.69	202.46	58.00	48.26	49.35	43.91	51.12	36.21	132.84	**286.61**	35570	35601
N	3.54	3.58	275.9	304.5	124.98	120.99	.00	.22	124.49	119.54	23.33	19.78	30.48	31.15	.00	.00	13.23	16.94	10.06	10.26	141.02	130.06	28.22	24.03	34.20	40.51	53.57	47.88	154.42	138.53	32912	32079
O	8.75	4.12	371.2	338.7	127.94	131.42	9.99	2.86	128.61	120.37	21.20	19.41	29.15	36.92	.22	1.57	16.05	18.84	16.35	19.90	125.16	105.74	38.40	29.69	36.15	41.33	22.49	53.51	225.18	159.95	35867	32851
P	4.42	3.44	269.4	295.7	119.25	111.61	2.75	.00	112.52	102.88	21.25	19.78	32.50	28.66	.00	.33	14.79	17.55	15.39	5.34	104.46	105.20	12.95	39.38	20.83	35.96	47.21	49.13	112.24	174.25	30344	28508
Q	3.42	6.30	298.9	276.7	142.74	116.58	8.42	**13.32**	113.26	117.23	20.96	19.77	31.85	41.06	.00	.00	10.56	13.87	12.25	8.22	129.38	169.75	29.24	44.61	26.45	38.49	39.32	50.66	128.39	133.87	31027	33800
R	2.96	4.05	340.0	290.2	108.33	82.18	6.68	6.30	81.90	73.94	12.98	13.51	22.21	17.88	.42	.00	17.78	11.25	9.18	8.19	73.97	72.29	13.66	41.15	17.12	15.22	30.71	32.11	90.52	23.05	21828	18950
S	6.00	8.31	254.1	276.1	117.62	117.49	.65	2.60	125.52	118.42	23.65	21.25	32.90	34.71	.81	.00	19.52	17.38	11.72	9.89	191.47	164.22	34.96	43.30	58.17	36.93	17.79	18.43	210.86	185.51	**37349**	35741
T	2.90	3.82	252.1	220.0	99.73	87.18	5.03	3.75	85.06	78.68	16.79	15.95	19.68	18.72	.28	.00	9.71	10.48	2.71	7.23	75.48	89.91	37.92	11.93	13.84	13.77	20.65	37.10	120.77	85.36	22710	21503
U	1.80	3.43	254.5	308.5	89.76	85.04	.00	.15	72.35	69.34	12.87	12.98	17.19	17.24	1.35	.13	10.04	13.38	13.36	14.40	69.63	61.04	34.17	30.29	10.79	7.58	42.01	33.59	78.96	108.28	18877	18678
V	2.69	4.23	554.6	469.0	91.09	87.95	.99	5.46	67.12	66.83	19.72	15.91	24.60	22.25	.94	.00	14.86	16.44	9.31	7.68	67.20	76.44	5.19	37.95	16.82	17.45	25.63	30.22	204.06	95.00	21644	21484
W	**14.76**	5.66	**1248.0**	821.4	114.37	109.48	4.51	5.46	62.72	69.69	**34.30**	23.75	23.74	27.99	.00	.26	**21.73**	14.87	14.21	18.12	106.85	89.58	52.61	37.76	22.31	9.89	36.41	44.24	197.52	157.49	34486	32384
X	3.42	3.47	289.1	327.7	87.74	122.85	.00	1.90	66.92	70.75	16.37	18.90	26.55	**74.14**	**2.54**	.00	10.61	8.52	12.99	1.24	57.33	69.45	52.10	16.12	23.45	72.36	29.83	46.13	69.91	106.56	16296	17428
Y	2.13	3.76	315.1	292.9	106.00	106.05	4.53	2.44	93.45	103.81	18.76	21.53	29.58	26.73	.61	.00	14.12	11.04	10.65	5.06	90.11	111.99	7.90	39.63	27.75	33.97	67.28	44.44	121.64	167.55	25374	27057
Z	5.48	.97	341.3	313.4	88.99	83.68	2.94	8.94	79.05	70.81	15.47	15.34	21.35	20.07	.01	1.43	9.77	11.79	9.07	11.13	85.39	67.99	15.87	50.41	25.54	11.27	67.67	34.06	72.83	64.41	21061	18551
North	5.26	3.90	408.3	408.1	93.35	94.14	8.78	1.80	119.13	108.88	20.57	17.61	37.44	31.35	.41	.00	11.17	9.45	10.35	9.37	140.56	134.68	52.64	45.54	30.19	43.83	19.86	57.01	208.18	189.55	30058	27601

	Mn		Cr		V		Ti		Sc		Ca		K		S		Ba		Cs		Te		Sb		Sn		Cd		Ag		Pd	
	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper
A1	371.0	437.2	20.90	34.68	54.05	79.38	4157	4345	7.37	10.02	4619	5760	20297	20283	762	810	474.55	505.96	87.53	89.45	136.45	131.97	41.36	37.72	48.43	56.08	6.67	7.69	3.44	3.87	7.37	2.10
A2	173.1	779.4	31.49	58.00	44.01	52.56	2852	3747	4.29	11.56	4451	6707	15042	19948	2517	1387	461.28	535.52	104.83	116.90	170.03	212.57	49.88	59.64	54.42	63.30	10.67	18.50	6.57	9.07	8.78	12.01
B	358.4	432.5	54.67	55.87	54.68	82.40	3908	4175	6.59	6.53	4767	5177	19815	19575	691	984	488.48	442.31	108.37	85.45	213.72	155.16	47.51	37.47	50.24	45.86	14.90	9.13	6.42	4.50	4.84	4.73
C	318.4	438.2	36.06	51.87	46.18	58.11	2872	3639	6.93	6.53	3837	4883	16798	18699	1439	1115	500.71	496.95	107.28	97.72	204.15	191.94	50.36	56.19	61.47	59.46	17.96	10.55	6.90	5.72	10.28	8.58
D	340.6	504.6	48.97	58.52	88.74	55.76	3967	4314	11.82	10.87	9666	11496	20888	21631	2176	2184	521.29	453.78	109.52	81.13	204.21	136.88	**76.59**	34.38	56.17	42.87	15.81	8.46	10.16	4.54	4.36	7.06
E	378.4	301.5	77.71	62.76	92.37	89.61	4460	4188	13.19	9.71	10565	4551	22398	21899	3331	3170	480.33	458.96	79.18	84.09	115.22	163.16	30.43	38.85	49.73	55.53	9.34	10.59	2.69	4.13	4.05	6.97
F	383.6	362.1	66.45	60.06	73.36	89.32	4299	4080	9.62	12.31	8911	7331	21589	19657	3363	**3739**	515.60	535.83	84.77	109.09	145.59	175.29	44.65	43.09	48.81	59.21	8.84	15.24	6.15	4.88	6.33	10.26
G	546.8	481.7	24.76	39.79	61.66	67.84	3527	3664	14.80	17.09	13709	14240	18365	19219	882	842	542.13	477.24	105.20	94.79	181.85	176.66	51.45	47.70	64.16	48.08	13.81	13.14	4.19	5.44	7.27	4.83
H	356.8	290.6	63.36	42.88	58.65	55.04	3728	3624	20.47	12.40	9199	9516	18442	17883	2656	2284	485.43	426.32	89.39	88.17	157.06	160.91	43.43	37.10	48.08	43.59	11.08	9.40	4.10	4.48	7.54	3.18
I	323.9	456.0	24.76	39.79	61.66	67.84	3223	3270	14.80	12.36	13709	14240	16506	16708	982	1029	485.67	**554.79**	105.36	110.54	202.33	194.50	54.47	51.35	62.04	**67.57**	13.81	13.14	6.90	6.80	5.59	4.83
J1	311.8	304.1	22.77	27.39	59.47	85.82	3976	3464	13.92	4.43	9647	10100	18073	18055	1930	1792	492.22	460.93	98.16	105.91	201.86	193.12	50.59	52.72	57.85	57.33	11.58	14.57	8.48	3.97	7.21	7.43
J2	359.1	328.6	40.77	49.48	62.54	55.06	4167	3927	11.06	11.07	8239	7707	19228	18887	1805	879	463.77	479.71	84.91	91.82	145.33	172.94	46.59	58.91	45.94	45.32	12.45	14.71	4.60	5.60	8.03	7.35
K	306.3	339.8	29.05	39.10	50.25	76.82	3341	3677	20.23	10.89	16837	9423	16128	17144	2358	1851	454.65	454.17	110.60	97.98	201.53	155.04	60.48	47.00	58.30	47.07	10.31	11.36	8.55	4.65	6.44	10.04
L	483.6	475.7	46.75	47.62	93.97	66.61	4689	4471	16.67	16.25	13554	10329	23860	21042	2474	2104	454.21	429.58	72.76	74.34	109.49	134.52	30.47	36.43	31.70	41.30	6.78	11.96	5.37	5.96	4.71	8.31
M	605.6	495.7	59.39	75.06	**111.35**	101.86	4568	4745	25.20	**31.17**	15342	**21402**	**24352**	23927	2646	2539	467.07	497.11	81.47	78.50	163.27	131.10	49.56	35.76	53.27	40.02	12.58	12.68	2.71	4.88	**15.28**	8.49
N	502.7	445.2	37.14	54.69	82.33	77.25	4314	4595	9.99	14.14	9914	10120	22125	21894	2285	2315	401.06	445.29	54.85	77.09	106.40	118.19	36.22	27.71	25.88	40.35	6.60	9.89	.46	7.96	5.07	4.20
O	694.7	471.3	54.34	45.00	84.54	68.68	4415	4172	22.84	19.04	13586	13368	21829	20002	807	844	436.34	430.89	75.62	66.53	136.33	134.16	47.15	37.97	41.69	35.24	11.76	10.75	8.04	2.00	10.07	4.88
P	526.7	648.6	48.31	43.19	62.24	63.74	4190	4216	11.47	24.79	10322	10550	19637	20776	815	665	475.22	446.25	85.88	74.21	160.41	145.79	46.06	39.72	40.34	42.56	12.52	9.96	4.92	5.37	9.08	2.46
Q	399.7	393.3	42.33	55.11	71.65	70.02	4249	4417	18.63	18.83	17038	9120	21434	20272	1982	2305	491.45	490.75	107.99	103.13	205.62	197.75	54.02	57.75	59.72	48.33	14.79	11.87	5.63	7.01	8.81	8.45
R	348.7	263.4	46.86	30.25	42.59	47.92	3787	3349	8.78	9.26	12460	7826	18759	15641	1731	1917	536.81	437.05	**118.39**	92.52	**225.29**	184.14	60.84	48.48	58.37	49.62	15.57	13.09	7.28	7.60	8.13	8.19
S	423.8	507.7	44.62	46.37	68.09	77.56	4513	4553	16.83	14.52	7521	8412	22520	22159	2509	1565	429.40	459.09	72.83	78.16	134.24	121.99	33.38	39.95	34.61	37.17	9.12	10.78	4.46	4.28	8.08	7.33
T	**1003.1**	378.4	26.04	21.31	49.10	35.47	3374	3253	10.73	3.73	11225	9291	15813	16224	1093	1834	499.02	518.73	101.36	110.53	176.74	203.74	48.80	59.20	55.97	56.45	11.15	18.91	8.35	7.02	4.13	5.91
U	272.5	244.8	31.93	28.01	55.02	56.37	3343	2742	5.74	5.36	9878	8247	14941	12969	1428	1138	486.60	505.02	105.50	106.74	206.57	210.63	63.97	55.02	60.02	56.06	**19.37**	11.47	8.15	7.65	9.88	7.39
V	458.2	433.4	57.28	31.24	60.63	45.76	5247	3573	14.35	13.66	14322	16198	12938	12649	892	670	491.10	436.04	102.32	114.36	202.07	183.19	68.01	48.08	62.02	48.45	12.36	10.64	**10.85**	6.01	6.92	8.00
W	820.4	609.7	110.97	**119.35**	63.76	50.72	**6075**	3599	15.87	16.11	15969	15833	13133	12815	1504	909	488.80	480.96	101.84	107.94	187.82	198.73	50.63	49.71	56.61	61.30	11.54	11.95	7.76	5.96	10.63	7.58
X	286.1	258.4	41.00	30.89	44.53	44.87	3063	3108	5.82	14.66	8714	11285	15789	15257	2624	2712	450.87	425.62	92.35	81.94	170.93	156.95	48.95	43.27	46.26	48.26	9.21	11.74	5.17	6.42	10.23	7.54
Y	221.4	188.3	41.57	42.65	53.88	76.17	3946	4085	9.54	4.32	7029	3744	17731	20103	1960	1911	423.81	450.02	78.58	88.27	165.54	161.71	43.15	43.66	38.88	43.08	8.93	9.55	6.00	5.14	5.23	7.13
Z	293.0	265.9	24.58	36.01	58.73	38.47	3735	3313	9.35	9.86	7010	7007	19498	15623	1958	1420	477.13	463.03	96.21	88.93	158.40	163.64	41.23	52.12	49.87	55.58	9.93	10.83	4.37	6.78	3.38	4.49
North	460.7	457.0	44.87	51.55	75.13	70.01	4149	3991	6.53	7.05	4355	5728	20430	19283	2775	796	425.93	470.17	84.06	102.72	148.44	204.35	46.24	50.81	44.50	52.89	11.01	12.34	3.95	7.00	6.02	8.30

附錄 14 彰雲海岸 28 個採樣站及大肚溪北岸 1 個採樣站之土壤重金屬不同年度差異最大值，2022–2023

Appendix 14 Maximum and average values (mg/kg) of heavy metals categorized from annual differences across 28 sampling stations along the Changhua and Yunlin coastal wetlands and 1 sampling station at north bank of Dadu Estuary, 2022–2023

	Mo		Zr		Sr		U		Rb		Th		Pb		Se		As		Hg		Zn		W		Cu		Ni		Co		Fe	
	2022	2023	2022	2023	2022	2023	2022	2023	2022	2023	2022	2023	2022	2023	2022	2023	2022	2023	2022	2023	2022	2023	2022	2023	2022	2023	2022	2023	2022	2023	2022	2023
A1	.76	1.96	305.7	317.1	93.15	93.29	4.02	2.03	99.45	103.82	19.68	19.81	34.56	30.97	.00	.63	14.18	11.63	7.42	9.89	112.46	130.20	52.13	64.16	42.35	37.23	58.32	**94.50**	165.38	174.93	25272	26845
A2	4.67	.00	513.1	362.9	85.21	78.10	8.92	3.85	85.28	92.09	17.78	17.24	24.67	28.56	.65	.00	11.08	**22.97**	7.55	14.39	158.16	154.25	52.66	27.77	50.76	54.40	68.93	65.65	85.93	56.55	20665	26091
B	1.11	.84	292.4	340.0	90.62	75.43	8.51	.00	100.34	86.60	20.08	16.39	30.51	26.74	2.04	.89	12.15	12.32	8.59	13.23	140.51	114.23	52.22	**76.65**	47.48	35.82	55.01	69.72	72.64	89.67	25932	20689
C	3.21	.00	485.9	321.4	73.26	69.13	5.52	3.20	89.66	83.93	17.03	16.56	24.04	26.92	1.75	.77	11.66	10.17	14.20	8.74	178.53	184.77	26.64	46.25	88.55	76.51	55.09	67.95	103.85	102.52	20293	19356
D	6.22	2.92	245.7	227.2	99.12	124.44	8.73	4.46	103.81	105.68	20.88	22.62	39.97	38.39	.62	.57	14.45	14.27	12.51	14.91	229.24	216.50	46.02	24.72	68.73	78.69	63.23	68.59	107.97	161.45	29478	27913
E	6.77	1.62	210.7	227.1	121.11	119.43	.39	3.06	131.63	102.47	23.17	14.65	33.80	29.55	.89	.59	15.76	10.35	**23.70**	8.63	**331.69**	225.14	46.09	49.97	80.98	58.61	66.68	65.58	150.69	105.18	32833	28604
F	5.03	.29	385.6	291.9	105.37	111.99	1.26	.00	115.32	108.19	19.13	20.49	34.55	35.64	1.44	.00	12.08	8.47	4.95	10.68	238.35	177.17	16.97	38.31	63.18	44.21	39.69	55.33	177.03	138.96	30636	28791
G	3.28	3.39	250.8	289.1	110.04	108.51	7.61	3.55	93.29	99.16	16.46	17.61	25.70	22.73	.00	1.12	5.70	12.62	11.46	11.62	96.09	111.86	30.82	41.43	13.07	34.89	27.21	59.67	76.07	136.58	24423	26525
H	4.13	.64	317.9	375.5	115.60	100.61	4.27	9.94	99.06	93.72	19.38	16.06	24.89	24.79	.00	.56	17.06	11.71	15.54	7.32	188.96	154.08	40.78	42.22	38.19	33.83	49.90	64.16	147.26	107.62	25191	23809
I	3.28	3.86	250.8	234.7	110.04	82.55	7.61	3.35	93.29	79.98	16.46	13.82	25.70	17.28	.00	.00	5.70	12.19	11.46	7.09	96.09	71.47	30.82	29.54	13.07	8.79	27.21	43.89	76.07	79.21	24423	22341
J1	7.87	3.76	1057.8	546.6	56.51	93.88	.00	1.99	63.33	85.89	14.48	18.23	16.82	22.99	1.36	.13	14.02	13.05	7.37	4.42	55.81	93.21	30.27	19.75	17.74	47.63	39.23	29.77	98.84	106.47	17112	22049
J2	5.49	5.66	634.5	905.9	104.96	92.52	9.17	6.90	99.54	98.21	21.11	22.16	23.00	31.88	.00	.00	15.05	12.98	4.75	13.25	110.14	109.10	24.63	40.09	39.10	42.41	39.03	42.11	105.91	164.67	27879	26023
K	1.63	4.27	723.9	524.1	83.99	105.49	5.28	.00	74.68	85.74	16.15	18.90	18.51	22.58	.28	.00	10.54	10.78	9.55	9.98	68.87	90.44	39.16	41.55	26.06	26.42	25.49	44.83	60.55	188.48	19881	20661
L	4.70	2.54	234.3	241.1	117.90	**151.63**	2.49	7.48	138.88	118.36	27.61	28.76	39.35	33.75	.67	2.18	15.48	14.57	9.35	14.38	165.06	160.98	43.53	25.89	46.26	57.43	47.81	47.62	161.69	131.43	36881	32804
M	4.74	.77	242.4	220.6	131.35	128.65	4.83	2.65	128.21	**140.21**	22.72	22.65	32.02	36.21	1.79	.18	14.12	15.52	14.25	20.52	202.46	161.34	58.00	48.26	43.91	49.35	51.12	39.85	132.84	**286.61**	35105	35601
N	3.23	3.58	263.3	304.5	114.15	124.98	.22	.00	119.54	124.49	16.86	23.33	31.15	30.48	.00	.00	16.94	13.36	10.26	10.06	109.76	141.02	20.70	28.22	29.79	40.51	40.32	53.57	76.17	154.42	32079	32912
O	8.75	3.17	228.4	371.2	131.42	127.94	2.94	9.99	128.61	98.57	21.20	18.71	36.92	26.05	.00	1.57	18.84	15.07	16.35	19.90	125.16	103.85	38.40	24.04	41.33	36.15	26.75	53.51	225.18	164.30	35867	27612
P	4.42	3.15	269.4	295.7	119.25	110.73	.00	2.75	112.52	107.50	20.93	21.25	32.50	28.66	.33	.00	13.81	17.55	8.44	15.39	99.22	105.20	12.84	39.38	35.96	23.09	47.21	49.13	174.25	104.45	30344	28508
Q	6.30	.94	298.9	276.7	142.74	87.97	8.42	**13.32**	117.23	83.92	20.96	16.70	41.06	24.08	.00	.00	13.87	11.98	12.25	7.86	169.75	92.59	44.61	28.64	38.49	14.33	50.66	48.72	133.87	128.39	33800	23352
R	4.05	3.49	309.6	340.0	85.04	108.33	6.68	6.30	73.94	81.90	13.51	12.98	22.21	17.88	.42	.00	17.78	14.75	9.18	8.19	73.97	72.29	23.05	41.15	14.55	17.12	15.86	32.11	90.52	89.47	19139	21828
S	6.00	8.31	254.1	276.1	117.49	117.62	.65	2.60	125.52	125.35	21.37	23.65	34.71	33.12	.60	.81	19.52	18.75	9.89	11.72	181.84	191.47	39.90	43.30	45.42	58.17	17.79	18.43	210.86	185.51	35741	37349
T	1.63	3.82	208.2	252.1	99.73	87.18	5.03	2.20	85.06	80.93	16.79	15.18	19.68	19.10	.00	.28	10.48	10.17	3.56	7.23	76.53	89.91	37.52	37.92	13.13	13.84	37.10	20.65	48.70	120.77	22710	21503
U	3.43	1.80	308.5	254.5	79.88	89.76	.15	.03	71.39	72.35	12.98	12.87	17.24	16.09	1.35	.13	10.46	13.38	13.36	14.40	63.63	69.63	25.62	34.17	10.79	7.58	19.61	42.01	108.28	87.85	18678	18877
V	4.23	2.89	469.0	554.6	87.95	91.09	.36	5.46	67.12	64.88	15.85	19.72	22.25	24.60	.01	.94	16.44	13.44	9.31	4.86	76.44	61.38	37.95	30.45	14.66	17.45	8.85	30.22	95.00	204.06	21454	21644
W	**14.76**	6.77	**1248.0**	647.3	114.37	109.48	5.46	2.34	68.93	69.69	**34.30**	20.90	27.99	19.40	.26	.00	21.73	16.42	18.12	8.32	106.85	89.58	52.61	28.03	21.61	22.31	44.24	36.41	157.49	197.52	34486	26374
X	3.42	3.47	295.4	327.7	92.74	122.85	.00	1.90	70.75	66.56	18.90	16.30	14.70	**74.14**	.00	**2.54**	8.37	10.61	6.00	12.99	66.39	69.45	16.12	52.10	13.80	72.36	46.13	29.83	106.56	69.91	17428	16296
Y	2.39	3.76	261.5	315.1	98.43	106.05	3.92	4.53	93.45	103.81	18.76	21.53	29.58	26.73	.00	.61	12.13	14.12	10.65	8.85	86.30	111.99	39.63	22.14	21.76	33.97	38.07	67.28	122.89	167.55	25374	27057
Z	5.48	.04	313.4	341.3	83.06	88.99	3.97	8.94	66.38	79.05	12.94	15.47	15.86	21.35	.04	1.43	9.13	11.79	11.13	8.98	66.92	85.39	20.03	50.41	25.54	25.13	34.06	67.67	64.41	72.83	16759	21061
North	5.26	3.90	391.5	408.3	94.14	70.01	8.78	2.78	119.13	82.25	20.57	20.10	37.44	25.23	.00	.41	11.17	9.09	10.35	2.56	140.56	83.35	52.64	30.43	43.83	33.73	57.01	35.95	208.18	127.07	30058	17584

	Mn		Cr		V		Ti		Sc		Ca		K		S		Ba		Cs		Te		Sb		Sn		Cd		Ag		Pd	
	2022	2023	2022	2023	2022	2023	2022	2023	2022	2023	2022	2023	2022	2023	2022	2023	2022	2023	2022	2023	2022	2023	2022	2023	2022	2023	2022	2023	2022	2023	2022	2023
A1	402.3	437.2	21.47	34.68	79.38	72.51	4233	4345	7.37	10.02	5760	5369	20062	20297	804	810	463.69	505.96	74.54	89.45	131.97	136.45	37.72	41.36	56.08	53.50	6.67	7.69	3.87	3.44	3.16	7.37
A2	355.7	779.4	58.00	48.45	52.56	43.66	3747	3664	11.56	5.48	6707	4253	18443	19948	2517	1387	468.73	535.52	104.83	116.90	170.03	212.57	49.88	59.64	53.59	63.30	10.72	18.50	6.57	9.07	8.78	12.01
B	432.5	350.1	50.62	55.87	82.40	54.68	4175	3829	6.59	5.66	5177	3196	19815	18369	620	984	435.98	488.48	80.75	108.37	155.16	213.72	36.58	47.51	43.11	50.24	8.56	14.90	4.50	6.42	4.73	4.84
C	438.2	318.4	51.87	44.20	58.11	51.18	3536	3639	6.93	1.77	4883	3943	18369	18699	828	1439	496.95	500.71	98.81	107.28	204.15	192.97	56.19	53.83	59.05	61.47	17.96	12.84	6.90	6.16	8.58	10.28
D	504.6	400.8	58.52	49.49	62.59	88.74	4266	4314	11.82	10.87	8062	11496	21631	21332	1835	2184	521.29	471.32	109.52	74.85	204.21	137.28	**76.59**	36.68	56.17	50.28	15.81	9.20	10.16	5.87	7.06	4.36
E	378.4	362.9	77.71	51.75	92.37	90.93	4381	4460	9.71	13.19	7191	10565	22398	21367	3206	3331	393.36	480.33	49.52	84.09	81.59	163.16	25.73	38.85	30.39	55.53	6.60	10.59	4.13	2.69	4.52	6.97
F	362.1	383.6	66.45	59.28	89.32	73.36	4160	4299	9.62	12.31	8544	8911	20837	21589	**3739**	3196	419.65	535.83	69.10	109.09	145.59	175.29	44.65	43.09	39.35	59.21	6.58	15.24	6.15	4.88	2.37	10.26
G	456.0	546.8	39.79	22.39	67.84	55.60	3270	3664	14.80	17.09	14240	12056	16708	19219	882	842	485.67	542.13	96.37	105.20	176.66	181.85	47.76	51.45	48.08	64.16	13.81	13.31	5.44	3.68	5.24	7.27
H	356.8	333.9	63.36	30.42	58.65	44.12	3624	3728	15.91	20.47	9516	8478	17372	18442	2405	2656	445.98	485.43	88.17	89.39	160.91	137.45	43.43	35.17	48.08	44.50	11.08	9.85	4.48	4.10	7.54	3.53
I	456.0	322.2	39.79	13.93	67.84	40.16	3270	3197	14.80	12.36	14240	8645	16708	15917	882	1029	485.67	**554.79**	96.37	110.54	176.66	202.33	47.76	54.47	**48.08**	67.57	13.81	12.58	5.44	6.90	5.24	5.59
J1	252.1	311.8	18.55	27.39	44.01	85.82	2381	3976	13.92	4.43	7305	10100	12725	18073	826	1930	443.22	492.22	105.91	98.16	193.12	201.86	52.72	44.21	57.33	57.85	14.57	11.58	8.12	8.48	7.43	7.21
J2	359.1	328.6	44.59	49.48	62.54	55.96	4152	4167	11.06	11.07	8239	7707	19106	19228	1597	1805	460.27	479.71	91.82	90.61	172.94	143.59	58.91	34.91	45.94	45.75	14.71	7.26	5.60	2.61	8.03	7.35
K	279.3	339.8	34.05	39.10	76.82	50.36	3624	3677	6.20	20.23	7777	16837	15844	17144	804	2358	454.65	454.17	110.60	86.78	201.53	151.31	60.48	43.72	58.30	47.07	10.31	11.36	8.55	5.39	10.04	6.44
L	475.7	483.6	47.62	45.60	90.42	93.97	4575	4689	9.68	16.67	8823	13554	22689	23860	1485	2474	403.89	454.21	69.86	74.34	121.78	134.52	30.84	36.43	34.31	41.30	10.08	11.96	5.13	5.96	7.18	8.31
M	552.4	605.6	75.06	59.39	101.86	**111.35**	4409	4745	**31.17**	25.20	**21402**	11998	23216	**24352**	2646	2391	467.07	497.11	81.47	78.50	163.27	131.10	49.56	28.35	53.27	40.02	12.58	12.68	4.22	4.88	**15.28**	6.13
N	445.2	502.7	54.69	37.14	62.29	82.33	4109	4595	14.14	13.74	10013	10120	21215	22125	1380	2315	445.29	442.03	77.09	65.34	118.19	106.87	27.71	36.22	34.10	40.35	9.89	6.60	7.96	4.78	4.20	5.07
O	694.7	463.9	54.34	45.00	84.54	63.36	4415	4160	17.00	22.84	9271	13586	21829	18330	844	814	436.34	433.95	70.09	75.62	134.16	136.33	47.15	37.97	34.05	41.69	11.76	6.65	8.04	3.39	10.07	5.42
P	513.1	648.6	48.31	45.53	62.24	63.74	4190	4216	11.66	24.79	10322	10550	19475	20776	815	537	446.25	475.22	72.91	85.88	125.10	160.41	39.72	46.06	39.65	42.56	9.96	12.52	5.37	4.92	2.21	9.08
Q	399.7	393.3	55.11	34.62	71.65	62.83	4417	3797	18.83	7.33	17038	7747	21434	17563	2305	559	482.01	491.45	103.13	107.99	190.69	205.62	54.10	57.75	47.76	59.72	11.87	14.79	7.01	5.18	8.45	8.81
R	348.7	335.8	30.25	46.86	47.92	42.59	3349	3787	9.26	8.78	7826	12460	15641	18759	1321	1917	417.52	536.81	92.52	**118.39**	184.14	225.29	48.48	60.84	49.62	58.37	12.38	15.57	7.60	6.02	8.19	8.13
S	507.7	456.7	44.62	46.37	73.75	77.56	4553	4446	14.52	16.83	8412	7516	22178	22520	1921	2509	429.40	459.09	72.83	78.16	123.70	134.24	33.38	39.95	34.39	37.17	10.78	9.12	4.46	4.06	8.08	2.38
T	**1003.1**	378.4	26.04	23.72	35.47	49.10	3331	3374	10.73	2.92	11225	9291	16224	15140	917	1834	499.02	518.73	101.36	110.53	171.33	203.74	48.16	59.20	53.04	56.45	10.04	18.91	8.35	7.02	5.91	4.02
U	272.5	238.2	28.01	31.93	56.37	55.02	2742	3343	5.74	5.36	9871	9878	13513	14941	552	1428	464.62	505.02	105.78	106.74	206.57	210.63	63.97	55.02	60.02	56.06	**19.37**	9.26	8.15	7.65	9.88	8.48
V	319.6	458.2	21.39	57.28	60.63	37.33	3069	5247	14.35	8.73	13629	16198	12649	12938	822	892	436.04	491.10	114.36	101.11	202.07	178.15	68.01	52.43	58.98	62.02	12.36	10.64	**10.85**	6.01	6.92	8.00
W	820.4	609.7	**119.35**	46.89	63.76	49.83	**6075**	4775	15.87	16.11	15833	15969	13133	12612	778	1504	488.80	480.96	107.94	102.87	198.73	162.46	50.63	45.05	59.58	61.30	11.95	10.20	7.76	5.96	10.63	6.10
X	258.4	286.1	41.00	18.19	44.87	44.53	2878	3108	14.66	4.07	8071	11285	14992	15789	1206	2712	444.59	450.87	92.35	90.13	170.93	160.11	46.25	48.95	48.26	46.26	11.74	10.94	6.42	5.17	10.23	7.54
Y	215.7	221.4	41.57	42.65	53.11	76.17	3800	4085	8.37	9.54	4500	7029	16898	20103	563	1960	450.02	441.76	88.27	78.58	161.71	165.54	43.66	43.15	39.90	43.08	9.55	9.53	6.00	4.71	4.49	7.13
Z	250.0	293.0	36.01	24.58	37.76	58.73	2821	3735	9.86	9.35	7007	7010	15173	19498	1857	1958	448.47	477.13	96.21	87.59	158.40	163.64	41.23	52.12	55.58	48.33	9.93	10.83	5.34	6.78	3.53	4.49
North	460.7	198.5	51.55	37.45	75.13	56.72	4149	3095	7.05	4.85	5728	3560	20430	16106	2775	853	470.17	425.93	102.72	89.92	204.35	173.00	50.81	46.24	52.89	44.50	12.34	11.37	7.00	6.51	8.30	6.88

附錄 15 彰雲海岸 28 個採樣站及大肚溪北岸 1 個採樣站之土壤重金屬上下土層平均值（a, b 粗體字表示差異顯著），2022–2023 年

Appendix 15 Average values (mg/kg) of heavy metals categorized from upper and lower soil layers and years across 28 sampling stations along the Changhua and Yunlin coastal wetlands and 1 sampling station at north bank of Dadu Estuary (a, b bold indicates significant difference), 2022–2023

		Mo	Zr	Sr	U	Rb	Th	Pb	Se	As	Hg	Zn	W	Cu	Ni	Co	Fe	Mn	Cr	V	Ti	Sc	Ca	K	S	Ba	Cs	Te	Sb	Sn	Cd	Ag	Pd
A1	Lower	.51a	**300.7a**	85.44a	.00a	95.35a	14.31a	29.44a	.00a	9.00a	3.83a	102.82a	27.85a	28.29a	34.42a	111.89a	23499a	**320.8a**	11.45a	39.28a	3801a	2.22a	**4247a**	17717a	618a	425.83a	67.96a	104.36a	23.59a	**37.30a**	4.71a	1.36a	2.11a
	Upper	.10a	**280.3b**	89.54a	1.01a	97.71a	16.84a	27.01a	.11a	9.90a	4.10a	111.55a	23.17a	31.96a	46.57a	63.48a	25298a	**390.0b**	19.21a	51.24a	3992a	2.65a	**5247b**	18948a	494a	464.66a	74.01a	113.62a	26.00a	**49.15b**	4.19a	1.51a	.88a
A2	Lower	.83a	261.7a	**59.00a**	1.94a	**66.91a**	10.68a	**16.60a**	.07a	**5.62a**	1.84a	106.54a	13.22a	18.84a	**25.37a**	31.38a	**15144a**	**132.2a**	11.15a	25.95a	2408a	1.23a	3970a	13677a	**1579a**	433.39a	88.91a	153.63a	40.78a	47.42a	6.35a	2.63a	2.31a
	Upper	.73a	331.1a	**71.07b**	.69a	**78.74b**	13.20a	**21.94b**	.00a	**10.32b**	2.97a	119.42a	20.39a	30.30a	**42.25b**	38.15a	**20551b**	**344.1b**	24.40a	30.80a	2891a	2.74a	4466a	15506a	**892b**	434.44a	84.00a	140.61a	37.15a	47.36a	8.59a	1.94a	2.21a
B	Lower	.37a	300.7a	76.02a	.00a	87.95a	14.69a	23.96a	.34a	9.58a	4.77a	111.49a	17.71a	22.60a	41.07a	**64.73a**	21142a	289.1a	37.69a	43.29a	3351a	2.50a	3756a	17011a	414a	434.87a	78.56a	136.20a	32.13a	41.16a	8.44a	2.78a	1.87a
	Upper	.26a	306.3a	78.73a	3.50a	91.20a	15.59a	24.16a	.15a	10.55a	2.40a	122.52a	32.00a	34.28a	53.25a	**14.25b**	22587a	350.3a	37.70a	49.38a	3581a	3.92a	4010a	17779a	501a	426.40a	72.64a	119.68a	35.59a	41.15a	5.83a	1.30a	1.82a
C	Lower	.67a	313.2a	**55.92a**	.99a	**67.44a**	**10.62a**	**14.95a**	.09a	**6.17a**	2.81a	**83.15a**	12.00a	**22.23a**	32.42a	31.11a	**14819a**	**166.7a**	**19.51a**	32.07a	**2364a**	1.78a	**3158a**	**13703a**	839a	438.78a	89.97a	161.65a	41.27a	50.56a	8.92a	4.74a	2.96a
	Upper	1.21a	299.5a	**66.85b**	.36a	**81.63b**	**13.61b**	**20.01b**	.20a	**9.71b**	4.63a	**153.56b**	9.05a	**58.91b**	31.64a	30.34a	**19165b**	**321.6b**	**31.26b**	42.27a	**3198b**	2.07a	**4158b**	**16621b**	531a	454.93a	88.10a	161.24a	41.67a	50.11a	7.58a	3.66a	3.88a
D	Lower	.73a	212.6a	**85.29a**	.98a	92.46a	**12.91a**	**26.21a**	.13a	8.44a	4.77a	**165.30a**	4.73a	42.62a	30.90a	43.88a	**23712a**	**298.7a**	36.73a	**55.59a**	3545a	3.80a	6802a	18695a	1321a	**446.39a**	**79.77a**	**143.80a**	**39.05a**	**44.71a**	7.85a	3.92a	1.55a
	Upper	1.48a	224.9a	**100.19b**	1.08a	98.61a	**16.84b**	**31.02b**	.04a	10.24a	7.66a	**202.38b**	17.73a	51.58a	37.82a	47.25a	**26300b**	**376.3b**	44.22a	**39.11b**	3733a	5.18a	7437a	18798a	1300a	**413.85b**	**68.25b**	**109.67b**	**26.10b**	**36.63b**	5.53a	1.91a	1.36a
E	Lower	.95a	209.9a	**114.15a**	1.00a	112.57a	16.92a	29.90a	.25a	**12.07a**	6.35a	267.13a	23.77a	59.21a	44.73a	58.01a	29607a	**331.8a**	53.31a	66.35a	3986a	**8.39a**	**8009a**	20202a	3035a	411.79a	57.25a	89.15a	22.51a	32.75a	5.42a	1.94a	1.57a
	Upper	2.34a	202.0a	**94.01b**	.07a	102.29a	14.93a	24.08a	.05a	**6.11b**	4.74a	200.05a	12.16a	42.51a	25.27a	65.89a	26215a	**205.5b**	35.46a	47.55a	3465a	**2.77b**	**4268b**	17796a	2916a	390.87a	62.14a	109.50a	26.72a	37.21a	5.46a	1.89a	2.34a
F	Lower	2.34a	238.1a	103.77a	.00a	108.28a	15.83a	**30.13a**	.23a	7.47a	2.61a	189.91a	**20.20a**	39.73a	25.79a	**112.64a**	**29080a**	311.8a	51.39a	60.95a	**4053a**	4.52a	**7269a**	**20320a**	3017a	440.27a	71.09a	123.48a	31.51a	37.34a	4.41a	1.90a	2.07a
	Upper	1.80a	290.6a	101.92a	.21a	97.24a	13.78a	**21.78b**	.24a	7.08a	3.62a	161.34a	**3.45b**	32.13a	31.43a	**42.13b**	**24520b**	258.2a	28.50a	47.63a	**3356b**	6.99a	**5630b**	**17075b**	2901a	420.32a	71.73a	119.00a	28.17a	39.81a	6.29a	2.46a	2.47a
G	Lower	**.09a**	215.6a	102.60a	2.65a	85.54a	14.09a	**17.04a**	.12a	8.21a	2.01a	93.35a	14.15a	7.22a	26.00a	48.12a	23386a	364.9a	17.17a	40.76a	3263a	8.29a	10217a	16232a	626a	498.94a	95.66a	157.13a	39.85a	50.28a	9.10a	2.31a	2.88a
	Upper	**2.01b**	234.3a	106.14a	1.24a	90.62a	13.84a	**21.49b**	.24a	7.67a	5.53a	98.70a	12.61a	14.31a	20.47a	79.16a	23068a	441.5a	20.70a	46.48a	3312a	6.19a	10565a	17034a	446a	465.51a	83.65a	139.42a	36.47a	44.99a	8.87a	1.96a	2.77a
H	Lower	.15a	**332.2a**	104.50a	2.32a	90.43a	14.79a	19.45a	.09a	8.71a	4.34a	132.39a	20.43a	21.82a	36.40a	74.79a	**23442a**	**301.1a**	32.37a	**42.95a**	3466a	7.76a	8507a	17029a	**2333a**	**448.37a**	**79.79a**	130.29a	33.96a	41.66a	6.64a	2.88a	2.85a
	Upper	1.66a	**301.3b**	98.13a	2.35a	90.13a	14.06a	22.28a	.00a	7.73a	3.43a	151.27a	12.43a	18.45a	13.49a	65.51a	**21184b**	**236.3b**	26.81a	**30.07b**	3292a	6.15a	7856a	16334a	**1645b**	**396.04b**	**67.61b**	118.29a	27.37a	35.46a	6.11a	2.26a	.96a
I	Lower	.09a	212.3a	88.02a	2.75a	78.17a	13.67a	17.41a	0.001	6.40a	2.83a	74.69a	8.54a	5.88a	18.79a	28.29a	20437a	**248.5a**	17.77a	41.33a	2888a	5.80a	8722a	14391a	773a	455.00a	93.49a	150.42a	39.93a	43.75a	8.98a	2.88a	2.25a
	Upper	1.56a	205.2a	94.09a	.81a	82.37a	11.54a	17.72a	0.001	6.51a	3.05a	78.06a	13.43a	4.40a	16.26a	41.20a	22242a	**363.6b**	17.08a	40.76a	3028a	4.13a	8812a	15278a	598a	477.25a	95.13a	166.24a	43.93a	51.66a	10.75a	3.45a	3.59a
J1	Lower	**1.34a**	398.4a	69.35a	.00a	68.90a	10.97a	15.46a	.23a	11.10a	3.22a	68.36a	7.67a	7.62a	10.35a	**83.27a**	17445a	218.7a	12.44a	35.03a	2739a	3.30a	7269a	14012a	1187a	440.93a	93.59a	162.81a	42.56a	50.58a	9.23a	**6.41a**	2.95a
	Upper	**4.37b**	586.7a	72.76a	.62a	71.95a	13.56a	17.31a	.02a	7.48a	2.46a	63.51a	3.89a	18.13a	23.46a	**47.80b**	18362a	217.6a	16.59a	40.94a	2706a	1.76a	6911a	14189a	884a	426.13a	88.41a	149.82a	43.65a	48.64a	6.89a	**2.14b**	2.69a
J2	Lower	3.66a	674.6a	**95.60a**	1.53a	**96.86a**	18.43a	**24.59a**	0.001	11.06a	1.72a	**105.50a**	17.57a	**28.12a**	24.60a	67.41a	**26448a**	297.0a	30.52a	47.69a	**4055a**	5.85a	7695a	**18644a**	**1511a**	445.64a	77.61a	132.83a	32.11a	41.94a	6.96a	2.84a	3.04a
	Upper	2.42a	695.2a	**85.42b**	2.49a	**85.01b**	16.23a	**19.34b**	0.001	9.24a	2.39a	**91.81b**	11.71a	**12.13b**	18.07a	43.88a	**22112b**	266.1a	30.71a	40.54a	**3544b**	6.14a	7012a	**16465b**	**511b**	435.10a	81.29a	142.16a	39.27a	38.83a	8.62a	1.70a	2.85a
K	Lower	1.26a	473.6a	75.61a	1.61a	68.16a	13.21a	19.02a	.05a	8.32a	**6.26a**	70.40a	8.04a	13.62a	17.31a	30.77a	18897a	221.1a	19.37a	29.13a	**2966a**	7.37a	8325a	14314a	1202a	417.74a	85.20a	154.23a	37.16a	43.47a	6.25a	3.42a	3.13a
	Upper	1.20a	597.5a	83.71a	2.19a	76.09a	16.00a	18.65a	.00a	8.72a	**1.17b**	74.13a	21.58a	17.19a	22.18a	70.08a	20004a	255.6a	21.83a	45.69a	**3443b**	3.97a	7857a	15733a	1076a	427.54a	83.84a	134.01a	35.96a	40.00a	7.47a	1.54a	2.71a
L	Lower	2.53a	210.0a	120.55a	.52a	122.89a	20.27a	34.06a	.00a	8.55a	2.50a	**147.80a**	10.09a	39.82a	26.86a	97.26a	33235a	**344.3a**	36.46a	**69.50a**	4201a	8.51a	7988a	**21081a**	1238a	383.26a	51.10a	86.65a	18.74a	20.43a	4.39a	2.23a	2.03a
	Upper	1.79a	222.4a	116.81a	1.22a	113.99a	19.16a	30.05a	.33a	11.65a	3.65a	**129.39b**	16.16a	36.59a	25.19a	59.83a	30711a	**421.5b**	42.61a	**47.97b**	3887a	6.85a	8197a	**18468b**	1326a	375.34a	57.18a	98.03a	23.57a	28.07a	6.39a	2.52a	2.39a
M	Lower	1.91a	192.0a	126.49a	1.25a	128.90a	17.79a	30.37a	.30a	**13.28a**	6.05a	154.98a	17.93a	40.53a	19.85a	85.47a	34160a	**518.8a**	35.04a	69.58a	4168a	19.61a	12455a	21691a	2207a	425.77a	59.73a	94.62a	25.56a	31.02a	6.64a	**.79a**	6.01a
	Upper	1.60a	211.7a	121.99a	.32a	124.88a	19.57a	30.38a	.03a	**7.84b**	4.12a	169.11a	19.54a	33.12a	20.91a	133.34a	33235a	**436.3b**	42.76a	66.82a	4152a	18.78a	15243a	20677a	2189a	435.01a	64.06a	109.80a	27.83a	33.32a	7.20a	**2.96b**	4.57a
N	Lower	2.26a	271.3a	120.74a	.00a	**122.13a**	**20.73a**	27.79a	0.001	11.80a	5.99a	125.88a	9.85a	25.93a	43.78a	105.90a	**32517a**	437.0a	29.80a	70.99a	4269a	3.87a	9819a	21494a	2052a	383.43a	**48.37a**	75.44a	21.27a	24.21a	5.08a	.23a	3.48a
	Upper	1.79a	264.4a	113.78a	.04a	**114.88b**	**16.95b**	27.90a	0.001	12.10a	3.97a	111.15a	12.45a	22.51a	32.95a	82.63a	**31149b**	400.5a	32.56a	56.12a	4154a	7.04a	9258a	20301a	1698a	414.80a	**63.94b**	96.33a	25.75a	30.23a	5.07a	2.32a	2.33a
O	Lower	2.27a	282.8a	115.28a	2.15a	103.18a	16.83a	25.85a	.04a	12.20a	4.78a	101.43a	14.81a	22.86a	12.70a	130.62a	29706a	529.5a	30.85a	61.29a	3750a	14.81a	10361a	16915a	498a	414.44a	65.95a	122.19a	32.35a	33.64a	7.21a	2.92a	**4.90a**
	Upper	1.38a	270.8a	122.37a	.48a	106.22a	14.33a	25.39a	.46a	11.86a	6.07a	97.07a	9.58a	19.47a	26.53a	75.06a	29405a	437.1a	31.76a	52.42a	3996a	9.08a	10678a	17852a	612a	399.38a	61.87a	104.15a	24.29a	31.80a	6.78a	1.37a	**.93b**
P	Lower	1.95a	**243.5a**	110.51a	.46a	**105.88a**	18.81a	24.34a	.00a	11.89a	5.54a	94.46a	5.24a	15.99a	19.06a	61.12a	**28725a**	493.3a	37.71a	48.46a	4011a	7.86a	9020a	18724a	530a	423.03a	68.76a	114.11a	30.75a	32.69a	6.36a	1.75a	1.91a
	Upper	1.92a	**275.5b**	107.52a	.00a	**96.74b**	17.00a	23.72a	.06a	12.17a	1.17a	87.99a	14.97a	22.28a	23.13a	110.61a	**26482b**	513.9a	27.53a	46.63a	3798a	10.74a	9380a	17813a	365a	429.20a	70.12a	116.03a	27.68a	33.61a	4.80a	3.12a	.78a
Q	Lower	1.23a	234.9a	98.16a	1.94a	88.20a	15.45a	21.11a	0.001	7.41a	2.85a	85.64a	9.99a	14.05a	16.01a	62.43a	23761a	301.9a	31.31a	47.87a	3440a	5.39a	9329a	17138a	862a	453.15a	89.58a	158.35a	40.77a	44.82a	9.36a	3.58a	4.33a
	Upper	1.48a	234.2a	90.03a	2.41a	86.96a	13.99a	22.74a	0.001	8.91a	2.84a	99.76a	11.20a	11.86a	27.57a	59.53a	23649a	291.4a	29.31a	42.21a	3218a	6.54a	6947a	15315a	984a	421.73a	80.67a	145.01a	40.38a	39.86a	7.88a	3.73a	2.60a
R	Lower	1.77a	**310.6a**	**91.79a**	1.13a	74.63a	10.98a	14.75a	.13a	12.93a	2.13a	66.73a	**5.46a**	8.76a	13.84a	**58.58a**	**20107a**	**283.6a**	29.23a	33.95a	3148a	3.11a	7755a	15198a	1108a	449.22a	91.17a	159.99a	41.86a	43.15a	10.25a	3.88a	3.01a
	Upper	1.78a	**256.6b**	**77.13b**	1.46a	68.72a	11.72a	15.84a	.00a	10.38a	2.61a	64.35a	**22.25b**	5.56a	14.62a	**5.14b**	**17716b**	**217.0b**	18.64a	31.38a	2939a	3.27a	5459a	13707a	1101a	412.62a	83.86a	151.37a	40.63a	43.39a	8.20a	2.92a	2.91a
S	Lower	3.73a	**237.0a**	107.18a	.11a	**123.47a**	19.05a	29.08a	.24a	15.42a	4.82a	**175.76a**	7.84a	38.21a	12.98a	108.51a	34211a	371.9a	38.41a	51.81a	4197a	7.53a	6912a	20656a	**1928a**	395.53a	59.23a	101.97a	31.21a	30.88a	6.24a	2.86a	4.12a
	Upper	3.45a	**259.1b**	113.13a	.43a	**110.84b**	18.45a	30.83a	.00a	14.40a	3.46a	**144.15b**	20.79a	29.63a	9.58a	99.00a	32463a	422.5a	34.32a	54.92a	4099a	5.43a	7452a	18929a	**1104b**	391.26a	57.58a	91.11a	25.07a	31.53a	7.25a	2.29a	1.60a
T	Lower	.48a	208.9a	88.64a	1.32a	78.94a	13.11a	15.54a	.05a	5.80a	**.92a**	71.04a	16.58a	9.73a	13.00a	63.67a	20060a	559.8a	17.49a	35.50a	3073a	2.30a	7350a	14627a	842a	477.36a	92.71a	161.08a	40.22a	48.79a	8.21a	2.80a	2.50a
	Upper	1.20a	196.9a	79.12a	1.25a	74.04a	13.82a	15.28a	.00a	6.60a	**3.61b**	73.85a	1.99a	8.32a	11.88a	54.86a	19727a	230.4a	13.07a	23.62a	2756a	1.11a	6216a	13671a	915a	454.47a	90.58a	157.78a	42.08a	46.71a	10.18a	3.16a	3.14a
U	Lower	.82a	206.9a	81.09a	.00a	**68.74a**	11.14a	15.04a	.23a	7.51a	7.39a	59.42a	6.54a	5.02a	13.17a	46.42a	17582a	223.2a	19.87a	34.59a	2797a	3.05a	8594a	13278a	781a	454.33a	94.22a	168.70a	45.43a	46.52a	9.57a	5.27a	5.99a
	Upper	.74a	239.4a	77.24a	.03a	**64.23b**	10.89a	12.91a	.02a	8.41a	4.20a	55.70a	13.68a	3.58a	9.63a	60.69a	16560a	188.3a	15.09a	26.42a	2436a	1.46a	7534a	11998a	661a	459.42a	98.66a	173.61a	48.06a	52.16a	9.11a	4.24a	3.17a
V	Lower	1.43a	336.8a	83.04a	.27a	62.25a	14.09a	16.59a	.16a	11.45a	3.29a	59.23a	1.04a	6.99a	9.30a	65.07a	19105a	294.3a	22.17a	33.67a	3074a	5.74a	10085a	11559a	659a	442.67a	96.49a	168.75a	**52.04a**	**53.85a**	9.26a	4.84a	4.05a
	Upper	2.75a	341.5a	83.46a	1.63a	57.97a	13.21a	18.98a	.00a	11.01a	2.27a	57.30a	16.23a	7.80a	15.59a	34.53a	20688a	303.5a	11.80a	34.58a	2758a	5.53a	12723a	10735a	497a	419.24a	94.18a	161.84a	**37.48b**	**43.51b**	7.45a	3.65a	3.05a
W	Lower	3.60a	506.9a	91.46a	1.43a	56.59a	19.26a	17.89a	.00a	12.74a	2.48a	71.58a	17.41a	**11.22a**	10.83a	60.39a	23575a	557.7a	39.31a	35.51a	3397a	6.12a	10995a	10962a	**652a**	420.32a	90.27a	140.25a	37.20a	50.87a	6.43a	1.66a	4.19a
	Upper	1.59a	291.4a	92.79a	1.72a	60.25a	14.40a	16.46a	.02a	10.67a	5.78a	72.83a	10.34a	**6.40b**	20.12a	56.33a	20730a	502.1a	22.91a	33.52a	2692a	6.37a	10072a	11359a	**392b**	443.77a	93.40a	137.64a	36.88a	49.62a	6.90a	2.35a	4.55a
X	Lower	1.69a	259.7a	**84.80a**	.00a	65.12a	13.15a	17.99a	.44a	7.45a	**5.26a**	51.67a	15.15a	12.72a	15.06a	27.50a	15688a	209.2a	18.56a	33.16a	2790a	1.21a	7722a	14095a	1734a	424.69a	84.89a	145.39a	41.91a	41.06a	8.10a	3.61a	3.61a
	Upper	2.04a	281.5a	**99.86b**	.32a	65.62a	12.39a	39.54a	.00a	6.98a	**.37b**	58.80a	5.97a	36.52a	18.64a	25.48a	16033a	219.2a	16.54a	24.94a	2681a	5.75a	9104a	13282a	1530a	**386.53b**	76.23a	132.65a	36.29a	38.48a	8.25a	2.59a	2.28a
Y	Lower	.36a	279.0a	100.08a	1.87a	88.79a	15.31a	20.13a	.10a	10.78a	**8.22a**	85.24a	3.93a	18.38a	37.46a	51.28a	24213a	**197.5a**	27.11a	45.64a	3693a	**5.67a**	**5619a**	16511a	892a	401.08a	67.27a	120.46a	31.26a	32.11a	5.25a	2.21a	2.74a
	Upper	1.55a	242.8a	90.51a	.41a	87.26a	15.66a	20.29a	.00a	7.77a	**2.10b**	82.62a	14.92a	15.94a	21.70a	86.80a	22728a	**130.3b**	30.60a	51.76a	3422a	**.87b**	**3338b**	16156a	1020a	417.55a	75.94a	130.96a	36.31a	36.26a	7.39a	3.66a	2.44a
Z	Lower	1.95a	287.4a	77.55a	.90a	69.61a	11.85a	17.60a	.00a	7.71a	4.16a	66.64a	2.65a	13.06a	20.81a	35.93a	17960a	198.8a	15.81a	33.21a	3086a	2.19a	5238a	15562a	**1715a**	441.31a	83.69a	145.50a	34.32a	44.08a	6.40a	1.40a	1.72a
	Upper	.16a	295.5a	77.79a	4.08a	65.53a	11.48a	14.78a	.25a	5.96a	3.75a	63.23a	16.00a	5.87a	18.82a	16.15a	16773a	221.1a	21.64a	26.82a	2908a	2.94a	6242a	14231a	**888b**	420.29a	82.86a	143.32a	37.63a	43.43a	7.98a	3.69a	2.26a
North	Lower	1.73a	308.2a	77.77a	**3.17a**	97.81a	16.93a	28.16a	.05a	7.64a	2.06a	102.77a	17.42a	**16.66a**	7.45a	86.44a	22801a	209.4a	33.41a	40.45a	3403a	2.10a	**3544a**	17392a	**1290a**	389.30a	**67.84a**	118.55a	31.27a	34.12a	6.95a	**2.28a**	2.05a
	Upper	1.48a	332.2a	75.29a	**.38b**	82.47a	14.28a	23.72a	.00a	6.38a	2.67a	94.10a	8.45a	**31.32b**	16.91a	76.98a	20569a	241.4a	29.50a	36.86a	2918a	1.78a	**4467b**	15224a	**412b**	414.81a	**85.30b**	148.07a	37.51a	40.32a	8.18a	**4.27b**	2.73a

Note: Values in the same column of subtable with different subscript are significantly different at $p < .05$ in the two-sided test of equality for column means. Tests assume equal variances.

1. This category is not used for comparisons because there are no other valid categories to be compared with.

2. Tests are adjusted for all pairwise comparisons within a column of each innermost subtable using the Bonferroni correction.

3. Pairwise comparisons are not performed for some subtables because of numerical problems.

附錄 16 彰雲海岸 28 個採樣站及大肚溪北岸 1 個採樣站之土壤重金屬年度差異平均值（a, b 粗體字表示顯著差異），2022–2023 年

Appendix 16 Average values (mg/kg) of heavy metals categorized from upper and lower soil layers and years across 28 sampling stations along the Changhua and Yunlin coastal wetlands and 1 sampling station at north bank of Dadu Estuary (a, b bold indicates significant difference), 2022–2023

		Mo	Zr	Sr	U	Rb	Th	Pb	Se	As	Hg	Zn	W	Cu	Ni	Co	Fe	Mn	Cr	V	Ti	Sc	Ca	K	S	Ba	Cs	Te	Sb	Sn	Cd	Ag	Pd
A1	2022	.23a	294.1a	87.85a	.67a	**92.88a**	14.94a	28.82a	.00a	9.29a	2.58a	**98.99a**	28.46a	30.86a	39.52a	85.56a	**23155a**	330.0a	10.76a	50.74a	3767a	2.22a	4749a	17811a	540a	**424.47a**	66.03a	100.62a	20.64a	40.09a	4.42a	1.57a	1.28a
	2023	.38a	286.9a	87.14a	.34a	**100.19b**	16.21a	27.64a	.11a	9.61a	5.35a	**115.38b**	22.56a	29.39a	41.46a	89.81a	**25642b**	380.8a	19.90a	39.79a	4025a	2.65a	4744a	18854a	572a	**466.01b**	75.94a	117.36a	28.95a	46.36a	4.47a	1.30a	1.71a
A2	2022	1.35a	**358.2a**	67.59a	1.60a	70.68a	12.02a	19.06a	.05a	6.85a	2.04a	115.10a	20.24a	25.09a	35.06a	40.41a	**16631a**	189.0a	22.51a	32.55a	2769a	2.88a	**4735a**	14510a	1268a	**417.74a**	83.38a	141.76a	37.27a	**44.17a**	7.48a	2.43a	1.83a
	2023	.00a	**225.5b**	63.63a	.73a	77.66a	12.25a	20.44a	.00a	10.25a	3.08a	112.29a	13.43a	25.80a	34.95a	28.37a	**20371b**	339.0a	13.67a	23.63a	2570a	1.04a	**3611b**	15004a	1078a	**455.65b**	89.73a	152.10a	40.62a	**51.68b**	7.84a	1.98a	2.81a
B	2022	.22a	**286.1a**	**83.97a**	3.50a	**96.10a**	**16.73a**	25.79a	.34a	10.60a	2.73a	**127.72a**	21.05a	33.44a	**35.92a**	32.30a	**23974a**	**362.2a**	35.26a	**59.29a**	3779a	3.88a	**4808a**	18503a	372a	**414.28a**	**66.76a**	116.40a	**29.64a**	**36.21a**	**5.01a**	1.98a	.91a
	2023	.40a	**320.9b**	**70.78b**	.00a	**83.05b**	**13.55b**	22.33a	.15a	9.53a	4.44a	**106.28b**	28.66a	23.43a	**58.40b**	46.69a	**19754b**	**277.2b**	40.13a	**33.37b**	3153a	2.55a	**2958b**	16286a	543a	**446.99b**	**84.44b**	139.48a	**38.08b**	**46.10b**	**9.26b**	2.10a	2.78a
C	2022	**1.41a**	315.3a	60.66a	.53a	74.07a	12.52a	**15.99a**	.15a	8.19a	3.88a	**101.28a**	6.60a	32.75a	**25.64a**	25.10a	16893a	232.9a	24.25a	37.86a	2717a	2.74a	3852a	15048a	**505a**	439.94a	88.55a	161.75a	42.54a	48.64a	8.84a	4.68a	2.95a
	2023	**.00b**	288.3a	62.83a	.95a	75.46a	11.31a	**20.46b**	.13a	7.44a	3.41a	**152.51b**	18.36a	56.22a	**44.81b**	41.98a	17191a	266.6a	27.65a	35.79a	2909a	.30a	3271a	15391a	**1045b**	460.68a	90.01a	160.83a	39.31a	53.72a	7.09a	3.24a	4.37a
D	2022	.93a	217.5a	**85.38a**	1.17a	**93.10a**	14.79a	27.34a	.09a	8.75a	5.29a	**172.07a**	13.20a	43.00a	31.05a	32.58a	24219a	337.9a	**45.26a**	49.41a	3552a	4.20a	**6037a**	18280a	**934a**	433.73a	**78.23a**	131.72a	35.16a	40.70a	7.39a	3.48a	1.26a
	2023	1.45a	221.3a	**107.45b**	.74a	**100.41b**	15.06a	31.16a	.09a	10.53a	8.05a	**207.38b**	7.30a	55.30a	40.97a	71.54a	26582a	336.7a	**30.92b**	43.23a	3814a	5.06a	**9284b**	19678a	**2063b**	422.91a	**65.57b**	116.78a	27.40a	40.61a	5.28a	1.78a	1.84a
E	2033	**2.82a**	207.1a	109.38a	.07a	**123.65a**	**19.16a**	29.89a	.19a	**11.85a**	8.43a	**299.12a**	17.80a	**66.64a**	31.83a	85.71a	**31827a**	282.1a	**60.79a**	54.50a	3932a	5.62a	5463a	20167a	2836a	**349.24a**	**41.37a**	**72.76a**	**17.48a**	**25.56a**	4.55a	2.40a	.94a
	2023	**.47b**	204.8a	98.77a	1.00a	**91.21b**	**12.69b**	24.09a	.11a	**6.33b**	2.66a	**168.06b**	18.13a	**35.08b**	38.18a	38.19a	**23995b**	255.2a	**27.98b**	59.41a	3519a	5.54a	6813a	17832a	3114a	**453.42b**	**78.03b**	**125.89b**	**31.74b**	**44.40b**	6.33a	1.43a	2.97a
F	2022	**4.08a**	303.2a	101.96a	.21a	**110.11a**	15.96a	28.90a	.47a	**9.62a**	1.84a	**215.53a**	5.18a	**44.53a**	20.26a	87.18a	**28754a**	312.3a	**59.24a**	60.16a	3831a	6.40a	6537a	19150a	**3241a**	**367.19a**	**54.16a**	**98.54a**	24.39a	**29.37a**	3.71a	1.90a	.97a
	2023	**.06b**	225.5a	103.73a	.00a	**95.41b**	13.65a	23.00a	.00a	**4.93b**	4.38a	**135.72b**	18.47a	**27.33b**	36.96a	67.58a	**24846b**	257.7a	**20.65b**	48.41a	3578a	5.12a	6362a	18246a	**2677b**	**493.40b**	**88.66b**	**143.94b**	35.28a	**47.77b**	6.99a	2.47a	3.57a
G	2022	1.00a	222.6a	103.97a	2.71a	85.59a	13.26a	20.43a	.00a	**4.97a**	2.88a	**88.54a**	10.02a	6.22a	14.62a	**24.40a**	**22273a**	**340.2a**	**26.21a**	49.25a	**3115a**	6.29a	11328a	**15422a**	565a	465.29a	92.68a	152.99a	40.47a	43.90a	**11.67a**	2.66a	3.09a
	2023	1.10a	227.4a	104.76a	1.19a	90.57a	14.67a	18.11a	.36a	**10.91b**	4.66a	**103.50b**	16.74a	15.31a	31.86a	**102.88b**	**24180b**	**466.1b**	**11.67b**	37.99a	**3460b**	8.20a	9454a	**17844b**	507a	499.16a	86.63a	143.56a	35.85a	51.36a	**6.29b**	1.61a	2.56a
H	2022	1.63a	**299.0a**	103.25a	1.39a	90.55a	14.97a	21.63a	.00a	7.79a	4.53a	144.90a	12.72a	18.72a	**12.76a**	74.92a	22265a	260.8a	**37.48a**	37.23a	3336a	6.25a	8420a	16359a	**1705a**	405.47a	74.02a	132.45a	**33.08a**	38.67a	6.98a	2.77a	1.92a
	2023	.20a	**335.5b**	96.82a	3.76a	89.80a	13.43a	20.42a	.09a	8.62a	2.69a	141.95a	20.00a	21.41a	**37.50b**	60.67a	21822a	264.3a	**16.36b**	32.22a	3401a	7.61a	7661a	16992a	**2243b**	434.23a	70.16a	109.06a	**25.40b**	36.85a	5.33a	2.12a	1.42a
I	2022	1.00a	222.6a	**103.97a**	2.71a	**85.59a**	13.26a	**20.43a**	0.001	**4.97a**	2.88a	**88.54a**	10.02a	6.22a	14.62a	24.40a	22273a	340.2a	**26.21a**	**49.25a**	**3115a**	6.29a	**11328a**	15422a	565a	465.29a	92.68a	152.99a	40.47a	43.90a	11.67a	2.66a	3.09a
	2023	.64a	195.0a	**78.14b**	.85a	**74.96b**	11.95a	**14.70b**	0.001	**7.93b**	3.00a	**64.20b**	11.96a	4.06a	20.44a	45.09a	20406a	271.9a	**8.64b**	**32.84b**	**2801b**	3.65a	**6206b**	14247a	806a	466.96a	95.94a	163.67a	43.38a	51.51a	8.07a	3.67a	2.76a
J1	2022	4.24a	509.3a	**53.32a**	.00a	**59.22a**	11.06a	**13.60a**	.23a	8.77a	3.68a	**48.46a**	5.58a	7.37a	12.85a	57.88a	**14911a**	**186.6a**	**9.73a**	27.33a	**2067a**	3.34a	**5094a**	**11382a**	**486a**	**415.32a**	90.80a	157.45a	45.63a	48.46a	9.15a	4.25a	4.01a
	2023	1.46a	475.7a	**88.78b**	.62a	**81.62b**	13.48a	**19.17b**	.02a	9.81a	2.00a	**83.41b**	5.98a	18.38a	20.96a	73.18a	**20896b**	**249.6b**	**19.30b**	48.64a	**3378b**	1.72a	**9086b**	**16819b**	**1585b**	**451.75b**	91.20a	155.18a	40.57a	50.76a	6.97a	4.30a	1.63a
J2	2022	3.71a	**570.1a**	92.35a	1.53a	90.20a	16.92a	19.98a	0.001	10.30a	1.62a	95.57a	10.02a	17.52a	20.37a	48.13a	24219a	278.4a	33.03a	38.98a	3714a	7.45a	7410a	16660a	1008a	428.79a	81.24a	145.31a	40.72a	39.39a	**10.55a**	**3.34a**	3.56a
	2023	2.37a	**799.7b**	88.67a	2.49a	91.66a	17.74a	23.95a	0.001	10.00a	2.49a	101.75a	19.26a	22.72a	22.29a	63.16a	24341a	284.7a	28.20a	49.25a	3886a	4.54a	7296a	18450a	1013a	451.96a	77.66a	129.69a	30.67a	41.38a	**5.03b**	**1.19b**	2.34a
K	2022	**.51a**	**608.5a**	**71.50a**	**3.80a**	**66.74a**	**12.65a**	**16.92a**	.05a	9.07a	3.67a	**61.77a**	12.21a	11.87a	11.71a	17.87a	18668a	203.8a	23.01a	43.75a	2990a	2.54a	**6202a**	14020a	**556a**	430.20a	90.74a	160.21a	**42.49a**	44.71a	7.45a	2.41a	3.45a
	2023	**1.94b**	**462.6b**	**87.83b**	**.00b**	**77.51b**	**16.56b**	**20.75b**	.00a	7.97a	3.76a	**82.76b**	17.40a	18.94a	27.78a	**82.98b**	**20233b**	**272.8b**	18.19a	31.07a	3419a	8.79a	**9981b**	16027a	**1722b**	415.07a	78.30a	128.03a	**30.63b**	38.76a	6.27a	2.55a	2.39a
L	2022	**2.78a**	**211.0a**	**111.80a**	.28a	**123.95a**	19.39a	**33.87a**	.09a	10.15a	1.88a	137.72a	14.15a	**32.98a**	21.54a	**103.03a**	**32990a**	368.9a	**43.04a**	55.46a	3956a	**4.41a**	**6299a**	19438a	**874a**	**354.35a**	**48.88a**	88.27a	18.18a	21.40a	5.78a	1.93a	1.91a
	2023	**1.05b**	**227.1b**	**128.07b**	1.93a	**107.96b**	19.92a	**28.33b**	.36a	10.80a	5.15a	135.31a	13.10a	**45.24b**	32.33a	**32.46b**	**29817b**	423.3a	**35.82b**	58.27a	4097a	**12.18b**	**10835b**	19626a	**1916b**	**414.74b**	**63.55b**	101.29a	26.82a	30.42a	5.31a	3.12a	2.76a
M	2022	**3.36a**	202.5a	126.02a	1.12a	**120.75a**	18.49a	29.40a	.30a	10.72a	4.94a	**176.16a**	14.33a	35.56a	23.22a	66.04a	32706a	491.0a	44.15a	59.48a	3869a	21.20a	**16649a**	19899a	2214a	414.89a	66.79a	116.13a	**33.16a**	35.00a	8.53a	1.40a	7.14a
	2023	**.14b**	201.1a	122.46a	.44a	**133.04b**	18.87a	31.36a	.03a	10.40a	5.23a	**147.93b**	23.14a	38.09a	17.54a	152.77a	34689a	464.1a	33.65a	76.92a	4451a	17.19a	**11049b**	22469a	2182a	445.89a	57.01a	88.29a	**20.24b**	29.33a	5.31a	2.35a	3.44a
N	2022	2.26a	**233.2a**	**110.57a**	.07a	114.03a	16.21a	28.98a	0.001	13.21a	5.87a	**101.42a**	10.38a	20.76a	**19.90a**	72.21a	31027a	421.6a	39.61a	51.62a	**3914a**	6.01a	9112a	19698a	**1248a**	410.01a	66.39a	96.75a	26.90a	27.67a	7.22a	3.04a	3.31a
	2023	1.79a	**283.5b**	**118.87b**	.00a	118.93a	19.20a	27.30a	0.001	11.39a	4.03a	**123.38b**	12.18a	25.09a	**44.89b**	99.48a	31894a	408.2a	27.65a	65.81a	**4331b**	5.97a	9611a	21198a	**2101b**	401.51a	54.93a	85.67a	22.93a	28.50a	4.00a	.91a	2.42a
O	2022	3.13a	**212.2a**	117.79a	.49a	**118.51a**	16.16a	28.09a	.00a	14.15a	2.73a	**108.66a**	19.69a	23.99a	**9.64a**	135.41a	**32869a**	**548.5a**	36.11a	61.72a	3883a	9.63a	**8517a**	18602a	565a	412.58a	60.95a	110.74a	30.45a	30.46a	**9.54a**	2.28a	3.66a
	2023	.53a	**341.4b**	119.86a	2.14a	**90.89b**	15.00a	23.15a	.50a	9.91a	8.12a	**89.83b**	4.70a	18.34a	**29.59b**	70.27a	**26242b**	**418.1b**	26.51a	51.99a	3863a	14.26a	**12523b**	16165a	545a	401.25a	66.87a	115.61a	26.20a	34.98a	**4.46b**	2.01a	2.17a
P	2022	**2.88a**	**242.0a**	111.51a	.00a	102.16a	17.63a	25.38a	.06a	11.26a	3.17a	88.80a	4.53a	20.55a	13.34a	113.03a	27814a	**442.4a**	34.04a	44.03a	3769a	8.52a	9160a	17450a	**571a**	409.98a	66.23a	101.78a	29.19a	29.83a	6.23a	2.37a	.68a
	2023	**.99b**	**276.9b**	106.52a	.46a	100.46a	18.18a	22.68a	.00a	12.80a	3.55a	93.65a	15.69a	17.72a	28.85a	58.71a	27393a	**564.8b**	31.20a	51.06a	4040a	10.08a	9239a	19088a	**324b**	442.25a	72.66a	128.36a	29.24a	36.47a	4.93a	2.50a	2.01a
Q	2022	**1.90a**	233.1a	99.92a	1.04a	93.25a	15.65a	24.21a	0.001	7.78a	3.34a	104.75a	10.36a	16.15a	19.00a	75.22a	25361a	303.0a	**35.24a**	47.81a	3387a	7.66a	8804a	16517a	**1173a**	**419.73a**	**79.07a**	**137.20a**	38.13a	**38.77a**	7.83a	3.64a	3.15a
	2023	**.27b**	237.5a	82.45a	4.45a	76.25a	12.86a	17.36a	0.001	8.93a	1.86a	68.61a	11.06a	6.58a	27.38a	32.48a	20392a	283.9a	**20.45b**	39.49a	3214a	2.59a	6806a	15645a	**424b**	**472.86b**	**97.23b**	**180.64b**	45.46a	**49.48b**	10.20a	3.69a	4.10a
R	2022	1.98a	266.0a	80.91a	1.47a	70.56a	11.39a	15.47a	.13a	12.81a	2.97a	63.27a	9.25a	6.47a	**8.13a**	31.55a	18870a	248.0a	23.75a	32.21a	2893a	4.49a	5638a	13910a	856a	**399.14a**	81.46a	151.21a	39.68a	38.14a	9.34a	4.01a	3.53a
	2023	1.58a	301.2a	88.02a	1.12a	72.80a	11.32a	15.12a	.00a	10.50a	1.76a	67.81a	18.46a	7.85a	**20.33b**	32.17a	18952a	252.6a	24.12a	33.12a	3193a	1.90a	7576a	14996a	1353a	**462.70b**	93.57a	160.15a	42.81a	48.39a	9.11a	2.78a	2.38a
S	2022	4.35a	**237.6a**	109.22a	.11a	117.79a	18.13a	29.16a	.10a	14.80a	2.72a	159.67a	13.85a	32.54a	11.11a	104.56a	33742a	403.2a	36.72a	58.59a	4095a	6.56a	7408a	19682a	1335a	387.16a	55.24a	92.20a	26.44a	29.92a	7.55a	2.70a	**4.70a**
	2023	2.84a	**258.6b**	111.09a	.43a	116.53a	19.36a	30.75a	.14a	15.02a	5.56a	160.24a	14.79a	35.31a	11.45a	102.95a	32932a	391.2a	36.00a	48.14a	4201a	6.41a	6956a	19903a	1697a	399.63a	61.57a	100.87a	29.83a	32.49a	5.94a	2.45a	**1.03b**
T	2022	.48a	195.9a	85.62a	2.21a	77.30a	**14.63a**	15.60a	.00a	6.85a	1.57a	70.62a	8.62a	7.78a	13.16a	**24.08a**	20758a	528.2a	13.44a	30.06a	3086a	2.48a	7425a	15125a	**531a**	457.27a	**84.89a**	**141.85a**	37.18a	48.92a	7.24a	2.65a	3.73a
	2023	1.21a	209.9a	82.14a	.37a	75.68a	**12.30b**	15.22a	.05a	5.54a	2.96a	74.28a	9.95a	10.27a	11.72a	**94.45b**	19029a	262.0a	17.11a	29.06a	2743a	.93a	6142a	13174a	**1226b**	474.56a	**98.40b**	**177.00b**	45.13a	46.58a	11.16a	3.32a	1.91a
U	2022	1.26a	203.6a	**75.66a**	.03a	65.57a	10.77a	14.86a	.23a	8.58a	6.14a	55.23a	5.65a	4.65a	3.46a	**73.72a**	17181a	224.7a	17.69a	37.63a	2443a	2.21a	7590a	12007a	**386a**	447.19a	98.82a	174.33a	50.41a	49.64a	**11.66a**	**6.22a**	4.12a
	2023	.30a	242.7a	**82.67b**	.01a	67.39a	11.26a	13.09a	.02a	7.33a	5.46a	59.89a	14.58a	3.95a	19.34a	**33.40b**	16961a	186.9a	17.27a	23.39a	2789a	2.30a	8538a	13269a	**1056b**	466.56a	94.06a	167.98a	43.08a	49.05a	**7.02b**	**3.29b**	5.04a
V	2022	2.65a	297.2a	82.37a	.10a	61.90a	12.76a	16.32a	.00a	11.48a	4.03a	59.67a	7.19a	4.84a	**3.16a**	33.55a	**18622a**	**247.2a**	14.39a	37.34a	2638a	8.25a	10079a	11019a	**453a**	419.64a	98.31a	**182.89a**	47.86a	46.92a	9.32a	4.22a	4.80a
	2023	1.53a	381.0a	84.12a	1.80a	58.71a	14.54a	19.26a	.16a	10.98a	1.53a	56.87a	10.08a	9.94a	**21.73b**	66.05a	**21171b**	**350.6b**	19.58a	30.92a	3195a	3.02a	12729a	11275a	**704b**	442.26a	92.36a	**147.70b**	41.65a	50.44a	7.40a	4.26a	2.30a
W	2022	2.45a	392.5a	90.45a	1.86a	57.93a	16.19a	16.92a	.01a	11.46a	4.54a	70.90a	14.41a	8.22a	16.99a	46.15a	22114a	520.9a	34.53a	35.34a	2988a	6.73a	10258a	11262a	**402a**	432.82a	92.67a	146.07a	37.53a	50.45a	7.02a	1.92a	4.64a
	2023	3.02a	419.0a	97.13a	.74a	59.88a	18.76a	17.95a	.00a	12.45a	2.90a	76.14a	12.28a	10.59a	10.93a	94.99a	22267a	557.0a	20.85a	32.06a	3217a	4.80a	11360a	10856a	**880b**	429.71a	89.32a	117.57a	35.55a	49.60a	5.60a	2.26a	3.55a
X	2022	1.89a	284.1a	87.55a	.00a	65.93a	13.14a	**10.70a**	.00a	6.44a	1.63a	53.81a	8.87a	**6.38a**	13.58a	31.60a	16101a	197.2a	**28.09a**	32.98a	2700a	**6.28a**	**7533a**	13378a	**959a**	400.36a	80.55a	143.00a	37.53a	39.77a	8.18a	2.60a	2.85a
	2023	1.84a	257.2a	97.11a	.32a	64.80a	12.40a	**46.83b**	.44a	7.98a	4.00a	56.67a	12.25a	**42.86b**	20.11a	21.38a	15620a	231.2a	**7.00b**	25.12a	2771a	**.68b**	**9292b**	13999a	**2305b**	410.86a	80.58a	135.03a	40.68a	39.77a	8.17a	3.60a	3.04a
Y	2022	1.02a	**229.6a**	**89.88a**	1.12a	83.07a	**13.41a**	20.34a	.00a	8.03a	5.33a	**76.85a**	12.45a	**11.86a**	20.08a	50.76a	22790a	166.2a	32.65a	42.67a	3375a	1.90a	3745a	15515a	**314a**	407.92a	71.97a	124.71a	33.03a	31.44a	5.79a	3.21a	1.58a
	2023	.89a	**292.1b**	**100.72b**	1.16a	92.98a	**17.56b**	20.07a	.10a	10.52a	4.99a	**91.01b**	6.40a	**22.47b**	39.08a	87.32a	24151a	161.6a	25.05a	54.73a	3740a	6.64a	5212a	17152a	**1598b**	410.71a	71.24a	126.71a	34.54a	36.93a	6.85a	2.66a	3.60a
Z	2022	**2.11a**	271.2a	73.14a	**.68a**	**63.83a**	**9.62a**	**14.25a**	.01a	6.06a	4.12a	60.08a	5.85a	6.98a	15.72a	26.06a	**15774a**	**170.0a**	19.34a	30.48a	**2649a**	3.35a	**5053a**	13738a	1133a	**411.38a**	83.38a	145.00a	36.03a	44.16a	6.38a	2.46a	1.64a
	2023	**.01b**	**311.8b**	**82.19b**	**4.31b**	**71.31b**	**13.71b**	**18.13b**	.24a	7.61a	3.80a	69.78a	12.79a	11.95a	23.91a	26.02a	**18960b**	**249.9b**	18.12a	29.56a	**3345b**	1.78a	**6427b**	16055a	1470a	**450.23b**	83.16a	143.83a	35.92a	43.35a	8.00a	2.64a	2.35a
North	2022	1.62a	**294.9a**	**82.72a**	2.42a	**97.24a**	15.77a	**28.10a**	.00a	7.22a	3.20a	**109.92a**	15.74a	25.57a	11.06a	86.11a	**24182a**	264.2a	**36.24a**	40.02a	3355a	2.19a	**4360a**	**17222a**	980a	399.58a	72.27a	124.91a	32.43a	35.40a	6.89a	2.79a	2.36a
	2023	1.58a	**370.8b**	**64.14b**	.48a	**75.95b**	15.27a	**21.62b**	.07a	6.59a	.71a	**75.46b**	7.32a	20.84a	14.43a	72.92a	**16690b**	148.0a	**21.87b**	35.92a	2773a	1.44a	**3298b**	**14479b**	592a	407.01a	85.19a	150.10a	38.32a	40.86a	8.92a	4.24a	2.46a

Note: Values in the same column of subtable with different subscript are significantly different at $p < .05$ in the two-sided test of equality for column means. Tests assume equal variances.

1. This category is not used for comparisons because there are no other valid categories to be compared with.
2. Tests are adjusted for all pairwise comparisons within a column of each innermost subtable using the Bonferroni correction.
3. Pairwise comparisons are not performed for some subtables because of numerical problems.

Applying the plant conservation priority index to assess the habitat of 36 cemeteries in Miaoli

應用植物保育優先指數於苗栗 36 處公墓生育地評估

Tien-Shui Chen[1], Po-Jung Chen[1], Chih-Chiang Wang[2] and Ming-Ya Shen[1,3,*]

陳添水 [1] 陳柏蓉 [1] 王志強 [2] 沈明雅 [1,3,*]

[1]Taiwan Biodiversity Research Institute, Nantou, Taiwan

[2]Department of Forestry, National Pingtung University of Science and Technology, Pingtung, Taiwan

[3]Graduate Institute of Bioresources, National Pingtung University of Science and Technology, Pingtung, Taiwan

[1] 農業部生物多樣性研究所 552005 南投縣集集鎮民生東路 1 號

[2] 國立屏東科技大學森林系 921301 屏東縣內埔鄉學府路 1 號

[3] 國立屏東科技大學生物資源博士班 921301 屏東縣內埔鄉學府路 1 號

[*]Corresponding author: yea@tbri.gov.tw

[*] 通訊作者：yea@tbri.gov.tw

Abstract

Human activities or development leading to habitat loss and fragmentation are major threats to biodiversity. However, certain specifically low-intensity land uses, such as cemeteries and military control zones, grow into biodiversity hotspots and even habitats for rare plant communities. In this study, we utilized plant survey data from cemeteries in the Miaoli region to establish Conservation Priority Index (CPI) parameters based on species information, including species richness, native species, endemic species, and threatened species. We evaluated and classified 36 cemeteries in urgent need of attention and sensitive areas. The CPI in Tongsiao Township Cemetery No.14 was ranked the highest priority, followed by Miaoli City Cemetery No.2 and Tongsiao Township Cemetery No.5. The conservation priority was classified into four levels: Class A (7 sites), Class B (9 sites), Class C (11 sites), and Class D (9 sites). Sites in Class A areas were greater than 2 hectares, with surrounding land use mostly consisting of large areas of broadleaf forests or grasslands and unused lands, providing rich potential seed bank environments. After screening and assessment, this study suggests prioritizing sensitive areas for protection and aims to provide relevant management agencies with references for avoiding land development, conserving threatened plants, and facilitating restoration efforts.

Key words: Cemetery, Plant Conservation Priority, Assessment

摘要

人類活動或開發造成棲地喪失與破碎化為生物多樣性之主要威脅，然而某些特殊低度開發土地利用如墓地與軍事管制區成為生物多樣性熱區，甚至為稀有植

物植群之生育地。本研究使用苗栗地區公墓植物普查資料嘗試以物種資訊，以物種數、原生種數、特有種數及受脅物種數等參數，建立保育優先指數（Conservation Priority Index, CPI），將亟需關注與敏感區域之 36 處公墓進行評估與分級。保育優先指數以通霄鎮第十四公墓為最高，其次為苗栗市第二公墓與通霄鎮第五公墓。保育優先分級為 A 級（7 處）、B 級（9 處）、C 級（11 處）及 D 級（9 處），列為 A 級者面積皆大於 2ha，周邊土地利用類別多佔有較大之闊葉林、草生地與未使用地，提供豐富潛在種子庫環境。本研究經過篩選與評估分級，建議優先保護之敏感區域，希冀提供相關管理單位對於土地開發迴避、受脅植物保育及復育參考。

關鍵詞：公墓、保育優先指數、評估

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Introduction

Human activities or development leading to habitat loss and fragmentation are major threats to biodiversity worldwide, and their negative impacts on the environment are considered one of the most important issues in conservation (Wilcox and Murphy 1985; Sih *et al.* 2000; Fahrig 2003). In certain cultural contexts, such as cemeteries and military control zones, low-intensity land uses may create biodiversity hotspots and even habitats for rare plant communities. For example, in the southern Ukrainian steppe, the transformation of land into agricultural fields resulted in the preservation of kurgan burial mounds, which provided shelter for steppe plants and became biodiversity hotspots (Dembicz *et al.* 2016; Moysiyenko *et al.* 2014).

In the Threatened Plant Important Habitat Layer published by the Taiwan Endemic Species Research Institute, Council of Agriculture (now the Taiwan Biodiversity Research Institute, Ministry of Agriculture) in 2020, many cemeteries in Miaoli County were located within important habitat areas. These cemeteries are often situated close to residential areas and surrounded by farmland, orchards, livestock farms, residential areas, or artificial structures, making them susceptible to human activities. Moreover, some of these cemeteries encounter pressure from land development, resulting in habitat loss (Chang *et al.* 2021). Similar situations exist in the Himalayan region, where systematic species survey data based on habitat types, elevation, population size, and threat category are used to establish a Conservation Priority Index (CPI) for assessing plant diversity and prioritizing conservation efforts (Rana *et al.* 2020; Rana and Samant 2010).

The unique tradition of tomb-sweeping by the public around the time of Qingming Festival not only involves regular disturbances, such as clearing weeds and burning offerings, but also effectively inhibits the expansion of aggressive and invasive plant species. This allows native plant species within the cemetery to have sufficient space for growth. As a result, many cemeteries can maintain similar environmental conditions for decades or even centuries, preserving the gene pool and sustaining the lifeblood of rare plants. However, in recent years, cemeteries have gradually been prohibited from new burials and encouraged to transform into public parks. Against this backdrop of development pressure, once cemetery lands are developed or repurposed, rare plants would face the risk of losing their habitats. Therefore, the preservation of the habitats of rare plants within cemeteries has become more urgent. This study aims to establish a CPI based on species information from plant surveys in cemeteries of Miaoli County. Cemeteries were evaluated and classified into those that require urgent attention and sensitive areas. The results will provide relevant management agencies with references for policy-making and management planning.

Materials and Methods

1. Data cleaning

A plant survey and positioning were conducted in the cemeteries of Miaoli County from 2017 to 2020. The plant data were collected by trained citizen scientists who photographed and uploaded the information to the "Taiwan Biodiversity Network (TBN)," developed by the Taiwan Biodiversity Research Institute, Ministry of Agriculture (Shen *et al.*, 2025). Cemeteries were selected through random sampling, and local residents were consulted to identify suitable sites with high plant diversity and rarity. Larger or more diverse cemeteries were prioritized for investigation. We employed line transects along accessible paths to record plant species as comprehensively as possible. Scientific names were verified using the TBN, and phenological observations were recorded for each species.

Plant data and coordinates were processed using ArcGIS Pro software to generate plant distribution maps and conduct analyses. The area of cemetery land was surveyed based on the Land Use Investigation data produced by the Ministry of the National Land Surveying and Mapping Center, Ministry of the Interior. Records lacking species-level identification or located beyond 5 meters from the cemetery boundary, as well as cemeteries with insufficient data, were excluded from the analysis. A total of 36 cemeteries were included in the assessment of conservation priority (Fig. 1).

2. Calculation of Conservation Priority Index (CPI)

The calculation of CPI was primarily based on the method used by Rana *et al.* (2020), with the selection of four parameters: species richness, native species, endemic species, and threatened species. With a total of 500 species identified after data cleaning, the species richness represented the richness of each cemetery. The native species was used to assess the species composition of cemetery habitats. Endemic species and threatened species were further evaluated to determine the rarity of species and the need to conserve their habitats. These parameters were then converted into a CPI for each cemetery habitat. The scores were converted according to the following steps:

(1) Each parameter for each cemetery was converted into a percentage based on the total species richness, total native species, total endemic species, and total threatened species.

(2) The percentage values were converted into scores based on ranges, with scores given in five categories: 2, 4, 6, 8, and 10. The scoring criteria are shown in Table 1 for species richness, native species, endemic species, and threatened species.

(3) The CPI was calculated as the sum of scores for species richness, native species, endemic species, and threatened

species.

(4) Based on the total score, the conservation priority was classified into four levels: A, B, C, and D.

3. Land use around the cemetery

To further understand the relationship among CPI, grading, cemetery habitat, and surrounding land use, the land use categories and proportions within a 300-meter radius around the cemetery center were extracted. The Land Use Investigation Layer was indirectly obtained through the Council of Agriculture from the maintenance data updated by the National Land Surveying and Mapping Center of the Ministry of the Interior from 2020 to 2021. The relationship between environment and species was examined based on the proportion of land use areas.

Results and Discussion

1. Species composition

After data cleaning, a total of 2,511 records were obtained from the plant survey conducted in cemeteries of Miaoli County from 2017 to 2020. There are 500 species from 109 families recorded in 36 cemeteries. The family with the highest species richness is Poaceae with 90 species, followed by Fabaceae with 59 species, Asteraceae with 51 species, and Cyperaceae with 27 species. Together, these four families constitute 45% of the total species recorded. Among them, there are 378 native species belonging to 94 families, accounting for 75.6% of the total species. Poaceae is also the most dominant family among native species, with 68 species, followed by Fabaceae with 44 species, Cyperaceae with 27 species, and Asteraceae with 24 species. There are 18 species from 14 families identified as endemic, four of which are threatened. These include three endangered species (EN): *Taraxacum formosanum*, *Vitis thunbergii* var. *taiwaniana*, and *Bupleurum kaoi*, and one vulnerable species (VU): *Styrax matsumurae*. Additionally, one species is listed as near threatened (NT): *Erianthus formosanus*, and one species is listed as data deficient (DD): *Digitaria magna*. The remaining species are categorized as least concern (LC). Among the threatened species, there are 30 species from 18 families, including six species listed as critically endangered (CR), 14 species classified as endangered (EN), and 10 species classified as vulnerable (VU).

2. Conservation priority assessment

CPI of each cemetery is determined by converting various parameters into scores for species richness, native species, endemic species, and threatened species. The resulting CPI is then ranked from highest to lowest. The following seven cemeteries are classified as A-level, with CPI ranging from 26 to 40. The scores for each parameter are detailed in Table 2.

In the A-level classification, Tongsiao Township Cemetery No.14 achieves a perfect score of 10 in all four parameters, totaling 40. It ranks the highest among all 36 surveyed cemeteries in terms of species richness, native species, endemic species, and threatened species. Following closely are Miaoli City Cemetery No.2 and Tongsiao Township Cemetery No.5, both with a total score of 36. Miaoli City Cemetery No.2 has a score of 6 for endemic species, while the other three parameters have scores of 10. Tongsiao Township Cemetery No.5 has scores of 8 for species richness and native species, with the other two parameters scoring 10. Ranked next are Xihu Township Cemetery No.1 and Tongsiao Township Cemetery No.24, both with a total score of 34. In these cemeteries, the score for endemic species is 10, while the scores for the other three parameters are 8. Finally, Tongsiao Township Cemetery No.6 and Tongsiao Township Cemetery No.8 have a total score of 26. Tongsiao Township Cemetery No.6 has a score of 8 for threatened species, while the rest have scores of 6. Tongsiao Township Cemetery No.8 has a score of 8 for native species, while the rest have scores of 6.

In the B-level classification, there are 9 cemeteries with index scores ranging from 16 to 20. Among them, Cemetery No.7 in Yuanli Township has 6 threatened species, making it the highest score of 8 for threatened species among B-level cemeteries. The scores for the other parameters vary between 2 and 6 for each cemetery.

In the C-level classification, there are 11 cemeteries with index scores ranging from 10 to 14. Among them, Shilin Cemetery in Tai'an Township has 4 endemic species, earning it the highest of 8 for endemic species C-level cemeteries.

In the D-level classification, there are 9 cemeteries with an index score of 8. All parameters for these cemeteries received the lowest score of 2. The score range of endemic species is from 0 to 1, and the score of threatened species ranges from 0 to 2 for each cemetery.

3. The relationship between conservation priority and land use

Matching the CPI and classification with the surrounding land use categories for the 36 cemeteries, the categories and proportions of the largest land use area around each cemetery are listed in Table 3. If the largest area around a cemetery is with sea (040600) or reservoir (040201), the next largest area will also be listed. Among the 7 cemeteries classified as A grade, all have areas greater than 2 hectares. In terms of surrounding land use categories besides the predominant broadleaf forests (020200), most areas also include grasslands (090200) and unused land (090501), and all of them are potential environments with a rich seed bank. Taking the highest-scoring cemetery, Tongsiao Township No.14 Cemetery, with a total score of 40 as an example, the category with the widest area of land use is broadleaf forest at 22%. Sporadic unused lands and rivers (040101) and ditches (040104) are found around the broadleaf forests, providing diverse habitat conditions and potential seed bank environments. For Miaoli City No.2 Cemetery, besides the 25% of unused land without or partial exposure, there are also areas surrounded by broadleaf forests and mixed forests of bamboo and broadleaved mixed forest (020402). The surrounding area of Xihu Township No.1 Cemetery is predominantly covered by large areas of broadleaf forests, contributing to a robust seed bank.

Cemeteries classified as B to D grades vary in size, ranging from the smallest at 0.48 hectares to the largest at 18.24 hectares. Their surrounding areas also include higher land use categories, and are highly disturbed by human activities, such as paddy fields (010101), dry farms (010102), fruit trees (010103), young woodlands (020600), or bamboo groves (020300) with lower biodiversity. Taking Longtan Township No.8 Cemetery as an example of D grade, its location is close to the sea, with 34% of the surrounding area being sea surface, followed by 14% of young woodlands (020600) with significant human disturbance. Although this cemetery has a large area, the surrounding environment providing a source of seed bank is limited, leading to a relatively lower assessment grade for this location.

For the smallest area with grade C cemetery, Shilin Cemetery in Tai'an Township, it is surrounded mostly by fruit trees and bamboo groves, with a small portion of broadleaf forests. This cemetery has recorded endemic species, resulting in a higher score in the endemic species category.

Rare and threatened plants may have historically lost their habitats, making cemetery environments inadvertently become their sanctuaries, thus unintentionally creating hotspots for threatened plant species. Furthermore, each cemetery varies in size and surrounding environment, leading to differences in the soil seed bank that they can provide. Even in the surrounding environments near broadleaf forests, the areas can also supply a variety of seeds, depending on the species composition and density of the forest. Cemeteries adjacent to agricultural land, such as paddy fields, dry farms, and fruit trees, are susceptible to the effects of agricultural practices, such as the use and drift of herbicides and pesticides by farmers. Additionally, human disturbances, such as burning during grave sweeping seasons, become important factors influencing the succession of cemetery vegetation.

Conclusion

This study established a CPI based on four parameters: species richness, native species, endemic species, and threatened species, and 36 cemeteries in Miaoli County were evaluated and classified according to this index, with the Tongsiao Township Cemetery No.14 ranked highest, followed by the Miaoli City Cemetery No.2 and Tongsiao Township Cemetery No.5. The conservation priority was classified into four levels: A, B, C, and D, with 7, 9, 11, and 9 cemeteries respectively. Those classified as level A have a significant presence of broadleaf forests or grasslands and unused land in their surrounding land use categories, providing a rich potential seed bank environment.

Apart from artificial structures, such as tombstones and roads, most cemetery environments consist of open grassland areas. With the tradition of grave sweeping annually, there are few human activities and disturbances in normal, regular days, making cemeteries habitats for threatened plants. However, with the increasing demand for land development and changes in burial customs, maintaining sensitive plant ecological environments, such as forests, grasslands, and unused land around burial sites, has become an urgent issue. Through plant survey data obtained from surveys, screened and evaluated to classify priority protection areas, our study provides information relevant to management units for avoiding land development, conserving threatened plants, and promoting habitat restoration.

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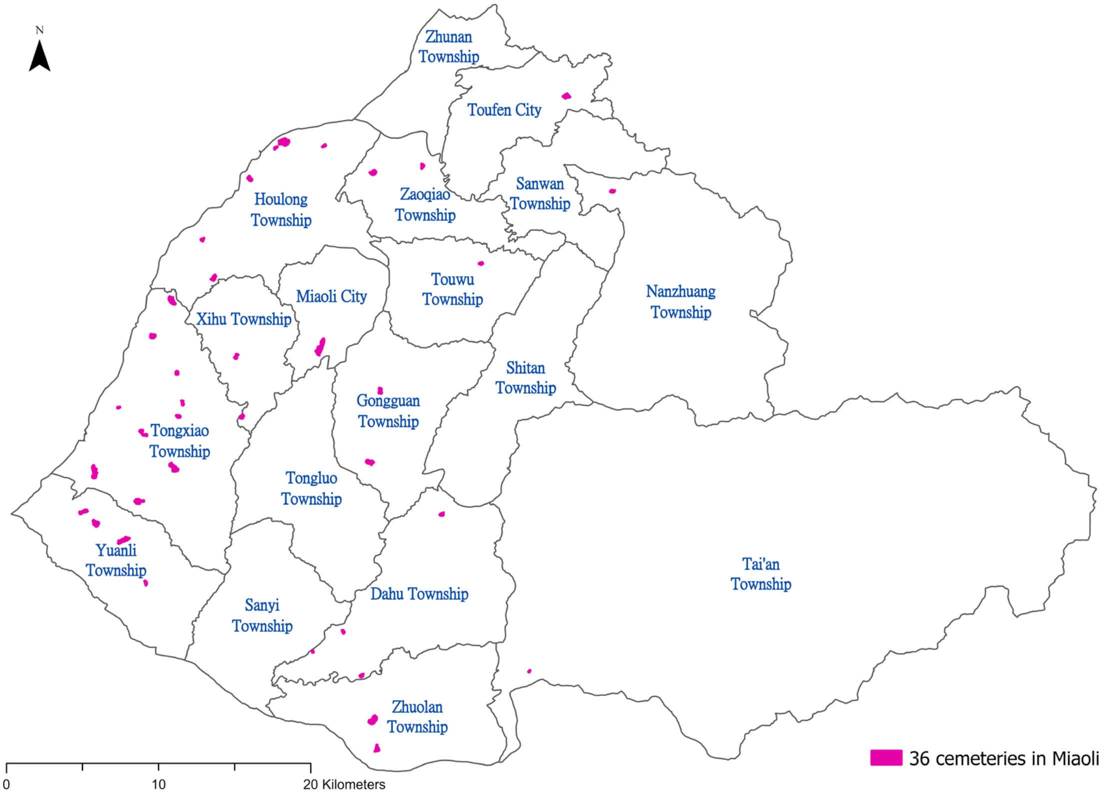

Fig. 1 A distribution map of the 36 cemeteries in Miaoli County used for assessment.
圖 1 苗栗縣 36 處評估公墓分布圖。

Table 1 Assessment parameters and scoring criteria for the conservation priority index
表 1 保育優先指數評估參數與評分標準

Scoring	Species richness (%)	Native species (%)	Endemic species (%)	Threatened species (%)
Range	0–28	0–29	0–37	0–29
10	>25	>25	>25	>25
8	20–25	20–25	20–25	20–25
6	15–20	15–20	15–20	15–20
4	10–15	10–15	10–15	10–15
2	<10	<10	<10	<10

Table 2 Conservation priority index scores for cemeteries in Miaoli
表 2 苗栗公墓的植物保育優先指數評分

Locations of the cemeteries	Speciesrichness	Species richness (%)	Species richness score	Native species	Native species (%)	Native species score	Endemic species	Endemic species (%)	Endemic species score	Threatened species	Threatened species (%)	Threatened species score	Conservation priority index	Conservation priority level
Tongluo Township Cemetery No.14	147	29.4	10	115	30.4	10	5	27.8	10	9	30.0	10	40	A
Miaoli City Cemetery No.2	138	27.6	10	105	27.8	10	3	16.7	6	9	30.0	10	36	A
Tongluo Township Cemetery No.5	110	22.0	8	91	24.1	8	5	27.8	10	8	26.7	10	36	A
Xihu Township Cemetery No.1	105	21.0	8	88	23.3	8	5	27.8	10	7	23.3	8	34	A
Tongluo Township Cemetery No.24	114	22.8	8	91	24.1	8	7	38.9	10	6	20.0	8	34	A
Tongluo Township Cemetery No.6	89	17.8	6	67	17.7	6	3	16.7	6	6	20.0	8	26	A
Tongluo Township Cemetery No.8	96	19.2	6	78	20.6	8	3	16.7	6	5	16.7	6	26	A
Yuanli Township Cemetery No.7	74	14.8	4	58	15.3	6	0	0.0	2	6	20.0	8	20	B
Yuanli Township Cemetery No.6	85	17.0	6	69	18.3	6	1	5.6	2	5	16.7	6	20	B
Nanzhuang Township Cemetery No.3	78	15.6	4	63	16.7	6	3	16.7	6	3	10.0	4	20	B
Tongluo Township Cemetery No.9	81	16.2	6	62	16.4	6	3	16.7	6	2	6.7	2	20	B
Houlong Township Cemetery No.21	88	17.6	6	71	18.8	6	2	11.1	4	2	6.7	2	18	B
Zaoqiao Township Cemetery No.7	75	15.0	4	62	16.4	6	3	16.7	6	1	3.3	2	18	B
Houlong Township Cemetery No.23	69	13.8	4	53	14.0	4	0	0.0	2	5	16.7	6	16	B
Zhuolan Township Cemetery No.1	58	11.6	4	44	11.6	4	2	11.1	4	4	13.3	4	16	B
Tongluo Township Cemetery No.19	66	13.2	4	54	14.3	4	3	16.7	6	2	6.7	2	16	B
Houlong Township Dasha Village Cemetery No.7	46	9.2	2	33	8.7	2	3	16.7	6	3	10.0	4	14	C
Tongluo Township Cemetery No.3	63	12.6	4	49	13.0	4	2	11.1	4	1	3.3	2	14	C
Tongluo Township Cemetery No.18	52	10.4	4	40	10.6	4	2	11.1	4	1	3.3	2	14	C
Tai'an Township Shilin Cemetery	34	6.8	2	27	7.1	2	4	22.2	8	0	0.0	2	14	C
Toufen City Liudongli Douhuanping Cemetery	53	10.6	4	35	9.3	2	3	16.7	6	0	0.0	2	14	C
Xihu Township Cemetery No.2	65	13.0	4	45	11.9	4	2	11.1	4	0	0.0	2	14	C
Dahuxiang Township Cemetery No.9	35	7.0	2	30	7.9	2	3	16.7	6	1	3.3	2	12	C
Zaoqiao Township Cemetery No.5	69	13.8	4	45	11.9	4	1	5.6	2	1	3.3	2	12	C
Yuanli Township Cemetery No.5	27	5.4	2	21	5.6	2	0	0.0	2	3	10.0	4	10	C
Yuanli Township Cemetery No.10	32	6.4	2	29	7.7	2	2	11.1	4	2	6.7	2	10	C
Dahuxiang Township Cemetery No.12	35	7.0	2	28	7.4	2	2	11.1	4	1	3.3	2	10	C
Houlong Township Cemetery No.10	50	10.0	2	31	8.2	2	1	5.6	2	2	6.7	2	8	D
Dahuxiang Township Cemetery No.1	27	5.4	2	25	6.6	2	1	5.6	2	1	3.3	2	8	D
Dahuxiang Township Cemetery No.10	22	4.4	2	17	4.5	2	1	5.6	2	1	3.3	2	8	D
Houlong Township Cemetery No.8	36	7.2	2	24	6.3	2	0	0.0	2	1	3.3	2	8	D
Touwu Township Cemetery No.11	22	4.4	2	20	5.3	2	0	0.0	2	1	3.3	2	8	D
Gongguan Township Cemetery No.11	32	6.4	2	26	6.9	2	1	5.6	2	0	0.0	2	8	D
Gongguan Township Cemetery No.9	26	5.2	2	19	5.0	2	1	5.6	2	0	0.0	2	8	D
Zhuolan Township Cemetery No.2	30	6.0	2	22	5.8	2	0	0.0	2	0	0.0	2	8	D
Tongluo Township Cemetery No.29	21	4.2	2	17	4.5	2	0	0.0	2	0	0.0	2	8	D

Table 3 Conservation priority of Miaoli cemeteries and surrounding land use categories with the largest area

表 3 苗栗公墓植物保育優先性與周遭土地利用類別面積最大者

Locations of the cemeteries	Area (ha)	Species richness score	Native species score	Endemic species score	Threatened species score	Conservation priority index	Conservation priority rank	Max land use area code	Max land use category	Max land use category percentage
Tongluo Township Cemetery No.14	8.92	10	10	10	10	40	A	020200	Broadleaf forest	22%
Miaoli City Cemetery No.2	16.20	10	10	6	10	36	A	090501	Unused land	25%
Tongluo Township Cemetery No.5	10.88	8	8	10	10	36	A	020200	Broadleaf forest	23%
Xihu Township Cemetery No.1	3.80	8	8	10	8	34	A	020200	Broadleaf forest	58%
Tongluo Township Cemetery No.24	5.84	8	8	10	8	34	A	090200	Grassland	48%
Tongluo Township Cemetery No.6	12.44	6	6	6	8	26	A	090501	Unused land	33%
Tongluo Township Cemetery No.8	2.92	6	8	6	6	26	A	020200	Broadleaf forest	26%
Yuanli Township Cemetery No.7	9.36	4	6	2	8	20	B	020200	Broadleaf forest	33%
Yuanli Township Cemetery No.6	8.36	6	6	2	6	20	B	010101	Paddy field	42%
Nanzhuang Township Cemetery No.3	2.72	4	6	6	4	20	B	020200	Broadleaf forest	22%
Tongluo Township Cemetery No.9	9.80	6	6	6	2	20	B	090200	Grassland	25%
Houlong Township Cemetery No.21	3.68	6	6	4	2	18	B	090501	Unused land	45%
Zaoqiao Township Cemetery No.7	4.64	4	6	6	2	18	B	020200	Broadleaf forest	41%
Houlong Township Cemetery No.23	1.84	4	4	2	6	16	B	090200	Grassland	47%
Zhuolan Township Cemetery No.1	13.56	4	4	4	4	16	B	010103	Fruit tree	37%
Tongluo Township Cemetery No.19	2.72	4	4	6	2	16	B	020200	Broadleaf forest	47%
Houlong Township Dasha Village Cemetery No.7	1.56	2	2	6	4	14	C	010102	Dry farm	45%
Tongluo Township Cemetery No.3	4.84	4	4	4	2	14	C	010102	Dry farm	18%
Tongluo Township Cemetery No.18	2.04	4	4	4	2	14	C	020200	Broadleaf forest	21%
Tai'an Township Shilin Cemetery	0.48	2	2	8	2	14	C	010103	Fruit tree	30%
Toufen City Liudongli Douhuanping Cemetery	5.76	4	2	6	2	14	C	020200	Broadleaf forest	40%
Xihu Township Cemetery No.2	2.56	4	4	4	2	14	C	020200	Broadleaf forest	25%
Dahuxiang Township Cemetery No.9	1.72	2	2	6	2	12	C	020200	Broadleaf forest	47%
Zaoqiao Township Cemetery No.5	2.84	4	4	2	2	12	C	020200	Broadleaf forest	53%
Yuanli Township Cemetery No.5	5.24	2	2	2	4	10	C	010101	Paddy field	20%
Yuanli Township Cemetery No.10	1.72	2	2	4	2	10	C	010102	Dry farm	51%
Dahuxiang Township Cemetery No.12	0.72	2	2	4	2	10	C	020200	Broadleaf forest	35%
Houlong Township Cemetery No.10	4.04	2	2	2	2	8	D	010102	Dry farm	20%
Dahuxiang Township Cemetery No.1	2.80	2	2	2	2	8	D	020300	Bamboo grove	44%
Dahuxiang Township Cemetery No.10	2.52	2	2	2	2	8	D	020200	Broadleaf forest	26%
Houlong Township Cemetery No.8	18.24	2	2	2	2	8	D	040600	Sea	34%
								020600	Young woodland	14%
Touwu Township Cemetery No.11	2.00	2	2	2	2	8	D	040201	Reservoir	38%
								020200	Broadleaf forest	37%
Gongguan Township Cemetery No.11	4.48	2	2	2	2	8	D	020200	Broadleaf forest	25%
Gongguan Township Cemetery No.9	5.68	2	2	2	2	8	D	020300	Bamboo grove	24%
Zhuolan Township Cemetery No.2	4.80	2	2	2	2	8	D	010103	Fruit tree	46%
Tongluo Township Cemetery No.29	0.60	2	2	2	2	8	D	090501	Unused land	33%

Appendix 1 A plant survey list of 36 cemeteries in Miaoli County
附錄 1 苗栗 36 處公墓植物調查名錄

Family	Scientific Name	Rank	Native/Exotic	*Red List of Taiwan
Acanthaceae	*Dicliptera chinensis* (L.) Juss.	species	Native	LC
Acanthaceae	*Justicia procumbens* L.	species	Native	LC
Actinidiaceae	*Actinidia rufa* (Siebold & Zucc.) Planch. ex Miq.	species	Native	LC
Adoxaceae	*Sambucus chinensis* Lindl.	species	Native	LC
Adoxaceae	*Viburnum luzonicum* Rolfe	species	Native	LC
Aizoaceae	*Tetragonia tetragonoides* (Pall.) Kuntze	species	Native	LC
Altingiaceae	*Liquidambar formosana* Hance	species	Native	LC
Amaranthaceae	*Amaranthus viridis* L.	species	Naturalized	Not Applicable
Amaranthaceae	*Celosia argentea* L.	species	Native	LC
Amaranthaceae	*Chenopodium acuminatum* Willd. subsp. *virgatum* (Thunb.) Kitam.	subspecies	Native	LC
Amaranthaceae	*Chenopodium ambrosioides* L.	species	Naturalized	Not Applicable
Amaranthaceae	*Chenopodium serotinum* L.	species	Native	LC
Amaranthaceae	*Gomphrena celosioides* Mart.	species	Naturalized	Not Applicable
Amaryllidaceae	*Allium macrostemon* Bunge	species	Native	DD
Anacardiaceae	*Pistacia chinensis* Bunge	species	Native	LC
Anacardiaceae	*Rhus javanica* L. var. *roxburghiana* (DC.) Rehder & E.H.Wils.	subspecies	Native	LC
Apiaceae	*Bupleurum kaoi* T.S.Liu, C.Y.Chao & T.I.Chuang #	species	Native	EN
Apiaceae	*Centella asiatica* (L.) Urb.	species	Native	LC
Apocynaceae	*Cynanchum atratum* Bunge	species	Native	EN
Apocynaceae	*Dregea volubilis* (L.f.) Benth.	species	Native	LC
Apocynaceae	*Gymnema sylvestre* (Retz.) Schultes	species	Native	LC
Apocynaceae	*Trachelospermum jasminoides* (Lindl.) Lemaire	species	Native	LC
Apocynaceae	*Tylophora ovata* (Lindl.) Hook. ex Steud.	species	Native	LC
Aquifoliaceae	*Ilex asprella* (Hook. & Arn.) Champ.	species	Native	LC
Araceae	*Amorphophallus kiusianus* (Makino) Makino	species	Native	LC
Araceae	*Arisaema heterophyllum* Blume	species	Native	LC
Araliaceae	*Aralia decaisneana* Hance	species	Native	LC
Araliaceae	*Eleutherococcus trifoliatus* (L.) S.Y.Hu	species	Native	LC
Araliaceae	*Hydrocotyle batrachium* Hance	species	Native	LC
Araliaceae	*Schefflera octophylla* (Lour.) Harms	species	Native	LC
Araliaceae	*Tetrapanax papyriferus* (Hook.) K.Koch	species	Native	LC
Arecaceae	*Arenga tremula* (Blanco) Becc.	species	Native	LC
Arecaceae	*Phoenix hanceana* Naudin	species	Native	LC
Aristolochiaceae	*Aristolochia heterophylla* Hemsl. #	species	Native	LC
Asparagaceae	*Asparagus cochinchinensis* (Lour.) Merr.	species	Native	LC
Asparagaceae	*Liriope minor* (Makino) Makino var. *angustissima* (Ohwi) S.S.Ying #	subspecies	Native	LC
Asphodelaceae	*Dianella ensifolia* (L.) DC.	species	Native	LC
Asteraceae	*Ageratum conyzoides* L.	species	Naturalized	Not Applicable
Asteraceae	*Ageratum houstonianum* Mill.	species	Naturalized	Not Applicable
Asteraceae	*Ambrosia artemisiifolia* L.	species	Naturalized	Not Applicable

Asteraceae	*Ambrosia psilostachya* DC.	species	Naturalized	Not Applicable
Asteraceae	*Artemisia capillaris* Thunb.	species	Native	LC
Asteraceae	*Artemisia indica* Willd.	species	Native	LC
Asteraceae	*Artemisia japonica* Thunb.	species	Native	LC
Asteraceae	*Artemisia lancea* Van.	species	Native	LC
Asteraceae	*Aster shimadae* (Kitam.) Nemoto	species	Native	VU
Asteraceae	*Aster subulatus* (Michx.) hort. ex Michx.	species	Naturalized	Not Applicable
Asteraceae	*Bidens pilosa* L. var. *radiata* (Sch.Bip.) Sherff	subspecies	Naturalized	Not Applicable
Asteraceae	*Blumea hieracifolia* (D.Don) DC.	species	Native	LC
Asteraceae	*Blumea lacera* (Burm.f.) DC.	species	Native	LC
Asteraceae	*Chromolaena odorata* (L.) R.M.King & H.Rob.	species	Naturalized	Not Applicable
Asteraceae	*Cirsium japonicum* DC. var. *australe* Kitam.	subspecies	Native	LC
Asteraceae	*Cirsium lineare* (Thunb.) Sch.Bip.	species	Native	EN
Asteraceae	*Conyza bonariensis* (L.) Cronq.	species	Naturalized	Not Applicable
Asteraceae	*Conyza sumatrensis* (Retz.) Walker	species	Naturalized	Not Applicable
Asteraceae	*Crassocephalum crepidioides* (Benth.) S.Moore	species	Naturalized	Not Applicable
Asteraceae	*Dendranthema lavandulifolium* (Fisch. ex Trautv.) Y.Ling & C.Shih var. *tomentellum* (Hand.-Mazz.) Y.Ling & C.Shih	subspecies	Native	EN
Asteraceae	*Eclipta prostrata* (L.) L.	species	Native	LC
Asteraceae	*Elephantopus mollis* Kunth	species	Naturalized	Not Applicable
Asteraceae	*Emilia fosbergii* Nicolson	species	Naturalized	Not Applicable
Asteraceae	*Emilia sonchifolia* (L.) DC. var. *javanica* (Burm.f.) Mattfeld	subspecies	Native	LC
Asteraceae	*Eupatorium formosanum* Hayata #	species	Native	LC
Asteraceae	*Eupatorium lindleyanum* DC.	species	Native	VU
Asteraceae	*Gaillardia pulchella* Foug.	species	Naturalized	Not Applicable
Asteraceae	*Galinsoga quadriradiata* Ruiz & Pav.	species	Naturalized	Not Applicable
Asteraceae	*Gnaphalium calviceps* Fernald	species	Naturalized	Not Applicable
Asteraceae	*Gnaphalium purpureum* L.	species	Naturalized	Not Applicable
Asteraceae	*Ixeridium laevigatum* (Blume) J.H.Pak & Kawano	species	Native	LC
Asteraceae	*Ixeris chinensis* (Thunb.) Nakai	species	Native	LC
Asteraceae	*Mikania micrantha* Kunth	species	Naturalized	Not Applicable
Asteraceae	*Pluchea sagittalis* (Lam.) Cabera	species	Naturalized	Not Applicable
Asteraceae	*Praxelis clematidea* (Griseb.) R.M.King & H.Rob.	species	Naturalized	Not Applicable
Asteraceae	*Pterocypsela formosana* (Maxim.) C.Shih	species	Native	LC
Asteraceae	*Pterocypsela indica* (L.) C.Shih	species	Native	LC
Asteraceae	*Sigesbeckia orientalis* L.	species	Naturalized	Not Applicable
Asteraceae	*Solidago virgaurea* L. var. *leiocarpa* (Benth.) A.Gray	subspecies	Native	LC
Asteraceae	*Soliva anthemifolia* (Juss.) R.Br. ex Less.	species	Naturalized	Not Applicable
Asteraceae	*Sonchus asper* (L.) Hill	species	Naturalized	Not Applicable
Asteraceae	*Sonchus oleraceus* L.	species	Naturalized	Not Applicable
Asteraceae	*Taraxacum formosanum* Kitam. #	species	Native	EN
Asteraceae	*Tithonia diversifolia* (Hemsl.) A.Gray	species	Naturalized	Not Applicable
Asteraceae	*Tridax procumbens* L.	species	Naturalized	Not Applicable
Asteraceae	*Vernonia cinerea* (L.) Less. var. *cinerea*	species	Native	LC
Asteraceae	*Vernonia cinerea* (L.) Less. var. *parviflora* (Reinw.) DC.	subspecies	Native	LC
Asteraceae	*Wedelia prostrata* (Hook. & Arn.) Hemsl. var. *prostrata*	species	Native	LC

Asteraceae	*Wedelia prostrata* (Hook. & Arn.) Hemsl. var. *robusta* Makino	subspecies	Native	LC
Asteraceae	*Wedelia trilobata* (L.) Hitchc.	species	Naturalized	Not Applicable
Asteraceae	*Xanthium strumarium* L.	species	Naturalized	Not Applicable
Basellaceae	*Anredera cordifolia* (Ten.) Steenis	species	Naturalized	Not Applicable
Basellaceae	*Basella alba* L.	species	Naturalized	Not Applicable
Blechnaceae	*Blechnopsis orientalis* (L.) C.Presl	species	Native	LC
Blechnaceae	*Woodwardia prolifera* Hook. & Arn.	species	Native	LC
Boraginaceae	*Bothriospermum zeylanicum* (J.Jacq.) Druce	species	Native	LC
Brassicaceae	*Coronopus didymus* (L.) Sm.	species	Naturalized	Not Applicable
Brassicaceae	*Lepidium bonariense* L.	species	Naturalized	Not Applicable
Brassicaceae	*Lepidium virginicum* L.	species	Naturalized	Not Applicable
Cactaceae	*Cereus repandus* (L.) Mill.	species	Naturalized	Not Applicable
Cactaceae	*Opuntia dillenii* (Ker) Haw.	species	Naturalized	Not Applicable
Campanulaceae	*Wahlenbergia marginata* (Thunb.) A.DC.	species	Native	LC
Cannabaceae	*Aphananthe aspera* (Thunb.) Planch.	species	Native	LC
Cannabaceae	*Celtis formosana* Hayata #	species	Native	LC
Cannabaceae	*Celtis sinensis* Pers.	species	Native	LC
Cannabaceae	*Humulus scandens* (Lour.) Merr.	species	Native	LC
Cannabaceae	*Trema orientalis* (L.) Blume	species	Native	LC
Cannaceae	*Canna indica* L.	species	Naturalized	Not Applicable
Caprifoliaceae	*Lonicera japonica* Thunb.	species	Native	LC
Caryophyllaceae	*Dianthus superbus* L. var. *longicalycinus* (Maxim.) F.N.Williams	subspecies	Native	LC
Caryophyllaceae	*Drymaria cordata* (L.) Willd. ex Schult.	species	Naturalized	Not Applicable
Caryophyllaceae	*Silene fortunei* Vis.	species	Native	LC
Caryophyllaceae	*Stellaria aquatica* (L.) Scop.	species	Native	LC
Celastraceae	*Celastrus kusanoi* Hayata	species	Native	LC
Cleomaceae	*Cleome rutidosperma* DC.	species	Naturalized	Not Applicable
Commelinaceae	*Commelina auriculata* Blume	species	Native	LC
Commelinaceae	*Murdannia loriformis* (Hassk.) R.S.Rao & Kammathy	species	Native	LC
Convolvulaceae	*Cuscuta campestris* Yunck.	species	Native	DD
Convolvulaceae	*Ipomoea biflora* (L.) Persoon	species	Native	LC
Convolvulaceae	*Ipomoea cairica* (L.) Sweet	species	Naturalized	Not Applicable
Convolvulaceae	*Ipomoea eriocarpa* R.Br.	species	Naturalized	Not Applicable
Convolvulaceae	*Ipomoea indica* (Burm.f.) Merr.	species	Naturalized	Not Applicable
Convolvulaceae	*Ipomoea obscura* (L.) Ker Gawl.	species	Native	LC
Convolvulaceae	*Ipomoea pes-caprae* (L.) R.Br. subsp. *brasiliensis* (L.) Ooststr.	subspecies	Native	LC
Convolvulaceae	*Ipomoea triloba* L.	species	Naturalized	Not Applicable
Convolvulaceae	*Merremia quinata* (R.Br.) Ooststr.	species	Native	DD
Cordiaceae	*Cordia dichotoma* G.Forst.	species	Naturalized	Not Applicable
Crassulaceae	*Bryophyllum pinnatum* (Lam.) Kurz	species	Naturalized	Not Applicable
Cucurbitaceae	*Melothria pendula* L.	species	Naturalized	Not Applicable
Cucurbitaceae	*Momordica charantia* L.	species	Naturalized	Not Applicable
Cucurbitaceae	*Solena amplexicaulis* (Lam.) Gandhi	species	Native	LC
Cucurbitaceae	*Trichosanthes cucumeroides* (Ser.) Maxim. ex Franch. & Sav.	species	Native	LC
Cyperaceae	*Bulbostylis barbata* (Rottb.) C.B.Clarke	species	Native	LC
Cyperaceae	*Carex breviculmis* R.Br.	species	Native	LC

Cyperaceae	*Cyperus brevifolius* (Rottb.) Endl. ex Hassk.	species	Native	LC
Cyperaceae	*Cyperus compressus* L.	species	Native	LC
Cyperaceae	*Cyperus cyperinus* (Retz.) Valck.Sur.	species	Native	LC
Cyperaceae	*Cyperus difformis* L.	species	Native	LC
Cyperaceae	*Cyperus distans* L.f.	species	Native	LC
Cyperaceae	*Cyperus haspan* L.	species	Native	LC
Cyperaceae	*Cyperus iria* L.	species	Native	LC
Cyperaceae	*Cyperus nutans* Vahl subsp. *subprolixus* (Kük.) T.Koyama	subspecies	Native	LC
Cyperaceae	*Cyperus odoratus* L.	species	Native	LC
Cyperaceae	*Cyperus pilosus* Vahl	species	Native	LC
Cyperaceae	*Cyperus polystachyos* Rottb.	species	Native	LC
Cyperaceae	*Cyperus pumilus* L.	species	Native	LC
Cyperaceae	*Cyperus rotundus* L.	species	Native	LC
Cyperaceae	*Cyperus tenuiculmis* Boeckeler	species	Native	LC
Cyperaceae	*Cyperus tuberosus* Rottb.	species	Native	LC
Cyperaceae	*Fimbristylis dichotoma* (L.) Vahl	species	Native	LC
Cyperaceae	*Fimbristylis eragrostise* (Nees & Meyen ex Nees) Hanc	species	Native	VU
Cyperaceae	*Fimbristylis ovata* (Burm.f.) J.Kern	species	Native	LC
Cyperaceae	*Fimbristylis tomentosa* Vahl	species	Native	LC
Cyperaceae	*Fuirena ciliaris* (L.) Roxb.	species	Native	NT
Cyperaceae	*Fuirena umbellata* Rottb.	species	Native	LC
Cyperaceae	*Mariscus sumatrensis* (Retz.) J.Raynal	species	Native	LC
Cyperaceae	*Scirpus ternatanus* Reinw. ex Miq.	species	Native	LC
Cyperaceae	*Scleria levis* Retz.	species	Native	LC
Cyperaceae	*Scleria radula* Hance	species	Native	LC
Dennstaedtiaceae	*Microlepia strigosa* (Thunb.) C.Presl	species	Native	LC
Dennstaedtiaceae	*Pteridium latiusculum* (Desv.) Hieron. ex R.E.Fr. subsp. *latiusculum*	species	Native	LC
Dennstaedtiaceae	*Pteridium latiusculum* (Desv.) Hieron. ex R.E.Fr. subsp. *japonicum* (Nakai) Fraser-Jenk.	subspecies	Native	LC
Dioscoreaceae	*Dioscorea doryphora* Hance	species	Native	LC
Dioscoreaceae	*Dioscorea japonica* Thunb.	species	Native	LC
Droseraceae	*Drosera indica* L.	species	Native	EN
Ebenaceae	*Diospyros eriantha* Champ. ex Benth.	species	Native	LC
Ehretiaceae	*Ehretia acuminata* R.Br.	species	Native	LC
Ehretiaceae	*Ehretia dicksonii* Hance	species	Native	LC
Elaeagnaceae	*Elaeagnus oldhamii* Maxim.	species	Native	DD
Equisetaceae	*Equisetum ramosissimum* Desf.	species	Native	LC
Euphorbiaceae	*Acalypha australis* L.	species	Native	LC
Euphorbiaceae	*Euphorbia cyathophora* Murray	species	Naturalized	Not Applicable
Euphorbiaceae	*Euphorbia maculata* L. L.	species	Naturalized	Not Applicable
Euphorbiaceae	*Euphorbia heterophylla* L.	species	Naturalized	Not Applicable
Euphorbiaceae	*Euphorbia hirta* L.	species	Naturalized	Not Applicable
Euphorbiaceae	*Euphorbia prostrata* Aiton	species	Native	LC
Euphorbiaceae	*Euphorbia serpens* Kunth	species	Naturalized	Not Applicable
Euphorbiaceae	*Mallotus japonicus* (Thunb.) Müll.Arg.	species	Native	LC
Euphorbiaceae	*Mallotus paniculatus* (Lam.) Müll.Arg.	species	Native	LC

Euphorbiaceae	*Mallotus repandus* (Willd.) Müll.Arg.	species	Native	LC
Euphorbiaceae	*Ricinus communis* L.	species	Naturalized	Not Applicable
Euphorbiaceae	*Triadica cochinchinensis* Lour.	species	Native	LC
Euphorbiaceae	*Triadica sebifera* (L.) Small	species	Naturalized	Not Applicable
Fabaceae	*Abrus precatorius* L.	species	Native	LC
Fabaceae	*Acacia confusa* Merr.	species	Native	LC
Fabaceae	*Albizia kalkora* Prain	species	Native	DD
Fabaceae	*Albizia procera* (Roxb.) Benth.	species	Native	LC
Fabaceae	*Alysicarpus ovalifolius* (Schum.) J.Léonard	species	Naturalized	Not Applicable
Fabaceae	*Alysicarpus vaginalis* (L.) DC.	species	Native	LC
Fabaceae	*Archidendron lucidum* (Benth.) I.Nielsen	species	Native	LC
Fabaceae	*Cajanus scarabaeoides* (L.) Thouars	species	Native	LC
Fabaceae	*Callerya reticulata* (Benth.) Schot	species	Native	LC
Fabaceae	*Canavalia rosea* (Sw.) DC.	species	Native	LC
Fabaceae	*Chamaecrista nictitans* (L.) Moench subsp. *patellaria* (DC. ex Collad.) H.S.Irwin & Barneby var. *glabrata* (Vogel) H.S.Irwin & Barneby	subspecies	Naturalized	Not Applicable
Fabaceae	*Chamaecrista nomame* (Siebold) H.Ohashi	species	Native	DD
Fabaceae	*Codariocalyx motorius* (Houtt.) H.Ohashi	species	Native	LC
Fabaceae	*Crotalaria albida* Heyne ex Roth	species	Native	LC
Fabaceae	*Crotalaria micans* Link	species	Naturalized	Not Applicable
Fabaceae	*Crotalaria sessiliflora* L.	species	Native	LC
Fabaceae	*Crotalaria zanzibarica* Benth.	species	Naturalized	Not Applicable
Fabaceae	*Dendrolobium trianglare* (Retz.) Schindl.	species	Native	LC
Fabaceae	*Desmodium heterocarpon* (L.) DC. var. *heterocarpon*	subspecies	Native	LC
Fabaceae	*Desmodium heterocarpon* (L.) DC. var. *strigosum* Meeuwen	subspecies	Native	LC
Fabaceae	*Desmodium heterophyllum* (Willd.) DC.	species	Native	LC
Fabaceae	*Desmodium microphyllum* (Thunb.) DC.	species	Native	LC
Fabaceae	*Desmodium tortuosum* (SW.) DC.	species	Naturalized	Not Applicable
Fabaceae	*Desmodium triflorum* (L.) DC.	species	Native	LC
Fabaceae	*Dunbaria rotundifolia* (Lour.) Merr.	species	Native	NT
Fabaceae	*Flemingia macrophylla* (Willd.) Kuntze ex Prain var. *philippinensis* (Merr. & RoFée) H.Ohashi	subspecies	Native	LC
Fabaceae	*Galactia tashiroi* Maxim.	species	Native	LC
Fabaceae	*Indigofera hirsut* L.	species	Native	LC
Fabaceae	*Indigofera spicata* Forssk.	species	Native	LC
Fabaceae	*Indigofera suffruticosa* Mill.	species	Native	LC
Fabaceae	*Lespedeza cuneata* (Dum-Cours.) G.Don.	species	Native	LC
Fabaceae	*Lespedeza daurica* (Laxm.) Schindl.	species	Native	CR
Fabaceae	*Lespedeza thunbergii* (DC.) Nakai subsp. *formosa* (Vogel) H.Ohashi	subspecies	Native	LC
Fabaceae	*Leucaena leucocephala* (Lam.) de Wit	species	Naturalized	Not Applicable
Fabaceae	*Macroptilium atropurpureus* (DC.) Urb.	species	Naturalized	Not Applicable
Fabaceae	*Medicago lupulina* L.	species	Naturalized	Not Applicable
Fabaceae	*Melilotus indicus* (L.) All.	species	Naturalized	Not Applicable
Fabaceae	*Millettia pachycarpa* Benth.	species	Native	LC
Fabaceae	*Mimosa diplotricha* C.Wright ex Sauvalle	species	Naturalized	Not Applicable
Fabaceae	*Mimosa pudica* L.	species	Naturalized	Not Applicable

Fabaceae	*Mucuna macrocarpa* Wall.	species	Native	LC
Fabaceae	*Neonotonia wightii* (Wight & Arn.) Lackey	species	Naturalized	Not Applicable
Fabaceae	*Phyllodium pulchellum* (L.) Desv.	species	Native	LC
Fabaceae	*Pueraria lobata* (Willd.) Ohwi subsp. *thomsonii* (Benth.) H.Ohashi & Tateishi	subspecies	Naturalized	Not Applicable
Fabaceae	*Pueraria montana* (Lour.) Merr.	species	Native	LC
Fabaceae	*Pueraria phaseoloides* (Roxb.) Benth.	species	Naturalized	Not Applicable
Fabaceae	*Pycnospora lutescens* (Poir.) Schindl.	species	Native	LC
Fabaceae	*Rhynchosia minima* (L.) DC.	species	Native	LC
Fabaceae	*Rhynchosia rothii* Benth. ex Aitch.	species	Native	LC
Fabaceae	*Rhynchosia volubilis* Lour.	species	Native	LC
Fabaceae	*Sesbania cannabiana* (Retz.) Poir	species	Naturalized	Not Applicable
Fabaceae	*Smithia sensitiva* Aiton	species	Native	LC
Fabaceae	*Tadehagi triquetrum* (L.) H.Ohashi subsp. *pseudotriquetrum* (DC.) H.Ohashi	subspecies	Native	LC
Fabaceae	*Uraria crinita* (L.) Desv. ex DC.	species	Native	LC
Fabaceae	*Uraria lagopodioides* (L.) Desv. ex DC.	species	Native	LC
Fabaceae	*Vigna hosei* (Craib) Backer	species	Native	LC
Fabaceae	*Vigna radiata* (L.) Wilczek var. *sublobata* (Roxb.) Verdc.	subspecies	Native	LC
Fabaceae	*Vigna reflexopilosa* Hayata	species	Native	LC
Fabaceae	*Zornia cantoniensis* Mohlenbr.	species	Native	LC
Geraniaceae	*Geranium carolinianum* L.	species	Naturalized	Not Applicable
Gleicheniaceae	*Dicranopteris linearis* (Burm.f.) Underw.	species	Native	LC
Hypericaceae	*Hypericum japonicum* Thunb.	species	Native	LC
Hypoxidaceae	*Curculigo orchioides* Gaertn.	species	Native	LC
Hypoxidaceae	*Hypoxis aurea* Lour.	species	Native	LC
Iridaceae	*Iris domestica* (L.) Goldblatt & Mabb.	species	Native	LC
Lamiaceae	*Anisomeles indica* (L.) Kuntze	species	Native	LC
Lamiaceae	*Callicarpa formosana* Rolfe	species	Native	LC
Lamiaceae	*Clerodendrum cyrtophyllum* Turcz.	species	Native	LC
Lamiaceae	*Clerodendrum inerme* (L.) Gaertn.	species	Native	LC
Lamiaceae	*Leucas chinensis* (Retz.) R.Br.	species	Native	LC
Lamiaceae	*Scutellaria indica* L.	species	Native	LC
Lamiaceae	*Vitex negundo* L.	species	Native	LC
Lamiaceae	*Vitex rotundifolia* L.f.	species	Native	LC
Lamiaceae	*Vitex trifolia* L.	species	Native	VU
Lauraceae	*Cassytha filiformis* L.	species	Native	LC
Lauraceae	*Cinnamomum burmannii* (Nees & T.Nees) Blume	species	Naturalized	Not Applicable
Lauraceae	*Cinnamomum camphora* (L.) J.Presl	species	Native	LC
Lauraceae	*Lindera glauca* (Siebold & Zucc.) Blume	species	Native	LC
Lauraceae	*Litsea hypophaea* Hayata #	species	Native	LC
Lauraceae	*Machilus zuihoensis* Hayata #	species	Native	LC
Liliaceae	*Lilium formosanum* Wallace #	species	Native	LC
Linderniaceae	*Bonnaya antipoda* (L.) Druce	species	Native	LC
Linderniaceae	*Torenia crustacea* (L.) Cham. & Schltdl.	species	Native	LC
Lindsaeaceae	*Odontosoria chinensis* (L.) J.Sm.	species	Native	LC

Loganiaceae	*Mitrasacme pygmaea* R.Br.	species	Native	LC
Lygodiaceae	*Lygodium japonicum* (Thunb.) Sw.	species	Native	LC
Lythraceae	*Lagerstroemia subcostata* Koehne	species	Native	LC
Malpighiaceae	*Hiptage benghalensis* (L.) Kurz.	species	Native	LC
Malvaceae	*Corchorus aestuans* L.	species	Native	LC
Malvaceae	*Grewia piscatorum* Hance	species	Native	LC
Malvaceae	*Grewia rhombifolia* Kaneh. & Sasaki #	species	Native	LC
Malvaceae	*Helicteres augustifolia* L.	species	Native	LC
Malvaceae	*Hibiscus tiliaceus* L.	species	Native	LC
Malvaceae	*Malvastrum coromandelianum* (L.) Garcke	species	Naturalized	Not Applicable
Malvaceae	*Melochia corchorifolia* L.	species	Native	LC
Malvaceae	*Sida cordifolia* L.	species	Native	LC
Malvaceae	*Sida rhombifolia* L. subsp. *Rhombifolia*	subspecies	Native	LC
Malvaceae	*Sida spinosa* L.	species	Naturalized	Not Applicable
Malvaceae	*Triumfetta bartramia* L.	species	Native	LC
Malvaceae	*Urena lobata* L.	species	Native	LC
Malvaceae	*Waltheria americana* L.	species	Native	LC
Melastomataceae	*Melastoma candidum* D.Don	species	Native	LC
Meliaceae	*Melia azedarach* L.	species	Native	LC
Menispermaceae	*Cocculus orbiculatus* (L.) DC.	species	Native	LC
Menispermaceae	*Stephania japonica* (Thunb.) Miers var. *hispidula* Yamam.	subspecies	Native	LC
Menispermaceae	*Stephania japonica* (Thunb.) Miers var. *japonica*	subspecies	Native	LC
Molluginaceae	*Mollugo stricta* L.	species	Native	LC
Molluginaceae	*Mollugo verticillata* L.	species	Naturalized	Not Applicable
Moraceae	*Broussonetia monoica* Hance	species	Native	LC
Moraceae	*Broussonetia papyrifera* (L.) L'Hér. ex Vent.	species	Native	LC
Moraceae	*Ficus erecta* Thunb. var. *beecheyana* (Hook. & Arn.) King	subspecies	Native	LC
Moraceae	*Ficus superba* (Miq.) Miq. var. *japonica* Miq.	subspecies	Native	LC
Moraceae	*Malaisia scandens* (Lour.) Planch.	species	Native	LC
Moraceae	*Morus australis* Poir.	species	Native	LC
Myrtaceae	*Syzygium formosanum* (Hayata) Mori #	species	Native	LC
Onagraceae	*Ludwigia epilobioides* Maxim.	species	Native	LC
Onagraceae	*Ludwigia hyssopifolia* (G.Don) Exell	species	Native	LC
Onagraceae	*Ludwigia octovalvis* (Jacq.) P.H.Raven	species	Native	LC
Onagraceae	*Oenothera laciniata* Hill	species	Naturalized	Not Applicable
Orchidaceae	*Geodorum densiflorum* (Lam.) Schltr.	species	Native	LC
Orchidaceae	*Spiranthes sinensis* (Pers.) Ames	species	Native	LC
Orobanchaceae	*Centranthera cochinchinensis* (Lour.) Merr.	species	Native	NT
Orobanchaceae	*Siphonostegia chinensis* Benth.	species	Native	EN
Oxalidaceae	*Oxalis corniculata* L.	species	Native	LC
Oxalidaceae	*Oxalis corymbosa* DC.	species	Naturalized	Not Applicable
Pandanaceae	*Pandanus odoratissimus* L.f.	species	Native	LC
Papaveraceae	*Corydalis tashiroi* Makino	species	Native	LC
Passifloraceae	*Passiflora suberosa* L.	species	Naturalized	Not Applicable
Phyllanthaceae	*Bischofia javanica* Blume	species	Native	LC
Phyllanthaceae	*Breynia officinalis* Hemsl. var. *accrescens* (Hayata) M.J.Deng & J.C.Wang	subspecies	Native	LC

Phyllanthaceae	*Breynia officinalis* Hemsl. var. *officinalis*	subspecies	Native	LC
Phyllanthaceae	*Bridelia tomentosa* Blume	species	Native	LC
Phyllanthaceae	*Flueggea suffruticosa* (Pall.) Baill.	species	Native	LC
Phyllanthaceae	*Flueggea virosa* (Roxb. ex Willd.) Voigt	species	Native	LC
Phyllanthaceae	*Glochidion philippicum* (Cavan.) C.B.Rob.	species	Native	LC
Phyllanthaceae	*Glochidion puberum* (L.) Hutch.	species	Native	VU
Phyllanthaceae	*Glochidion rubrum* Blume	species	Native	LC
Phyllanthaceae	*Glochidion zeylanicum* (Gaertn.) A.Juss. var. *lanceolatum* (Hayata) M.J.Deng & J.C.Wang	subspecies	Native	LC
Phyllanthaceae	*Glochidion zeylanicum* (Gaertn.) A.Juss. var. *tomentosum* Trimem	subspecies	Native	LC
Phyllanthaceae	*Phyllanthus debilis* Klen ex Willd.	species	Naturalized	Not Applicable
Phyllanthaceae	*Phyllanthus ussuriensis* Rupr. & Maxim.	species	Native	LC
Phytolaccaceae	*Phytolacca americana* L.	species	Naturalized	Not Applicable
Pittosporaceae	*Pittosporum tobira* W.T.Aiton	species	Native	LC
Plantaginaceae	*Scoparia dulcis* L.	species	Naturalized	Not Applicable
Plantaginaceae	*Veronica peregrina* L.	species	Naturalized	Not Applicable
Poaceae	*Alloteropsis semialata* (R.Br.) Hitchc.	species	Native	EN
Poaceae	*Apluda mutica* L.	species	Native	LC
Poaceae	*Aristida chinensis* Munro	species	Native	CR
Poaceae	*Arthraxon hispidus* (Thunb.) Makino	species	Native	LC
Poaceae	*Arundinella setosa* Trin.	species	Native	LC
Poaceae	*Bothriochloa glabra* (Roxb.) A.Camus	species	Native	LC
Poaceae	*Bothriochloa intermedia* (R.Br.) A.Camus	species	Native	LC
Poaceae	*Bothriochloa ischaemum* (L.) Keng	species	Native	LC
Poaceae	*Brachiaria mutica* (Forssk.) Stapf	species	Naturalized	Not Applicable
Poaceae	*Brachiaria subquadripara* (Trin.) Hitchc.	species	Native	LC
Poaceae	*Brachiaria villosa* (Lam.) A.Camus	species	Native	LC
Poaceae	*Capillipedium parviflorum* (R.Br.) Stapf var. *parviflorum*	species	Native	LC
Poaceae	*Capillipedium parviflorum* (R.Br.) Stapf var. *spicigerum* (Benth.) C.C.Hsu	subspecies	Native	LC
Poaceae	*Cenchrus echinatus* L.	species	Naturalized	Not Applicable
Poaceae	*Chloris barbata* Sw.	species	Native	LC
Poaceae	*Chloris divaricata* R.Br. var. *cynodontoides* (Balansa) Lazarides	subspecies	Naturalized	Not Applicable
Poaceae	*Chloris gayana* Kunth	species	Naturalized	Not Applicable
Poaceae	*Chrysopogon aciculatus* (Retz.) Trin.	species	Native	LC
Poaceae	*Cymbopogon tortilis* (J.Presl) A.Camus	species	Native	LC
Poaceae	*Cynodon dactylon* (L.) Pers.	species	Native	LC
Poaceae	*Cynodon nlemfuensis* Vanderyst	species	Naturalized	Not Applicable
Poaceae	*Dactyloctenium aegyptium* (L.) P.Beauv.	species	Native	LC
Poaceae	*Dichanthium annulatum* (Forssk.) Stapf	species	Naturalized	Not Applicable
Poaceae	*Digitaria ciliaris* (Retz.) Koeler	species	Native	LC
Poaceae	*Digitaria henryi* Rendle	species	Native	LC
Poaceae	*Digitaria heterantha* (Hook.f.) Merr.	species	Native	EN
Poaceae	*Digitaria leptalea* Ohwi	species	Native	LC
Poaceae	*Digitaria magna* (Honda) Tsuyama #	species	Native	DD
Poaceae	*Digitaria radicosa* (J.Presl) Miq. var. *hirsuta* (Ohwi) C.C.Hsu	subspecies	Native	LC
Poaceae	*Digitaria sanguinalis* (L.) Scop.	species	Naturalized	Not Applicable

Poaceae	*Digitaria setigera* Roem. & Schult.	species	Native	LC
Poaceae	*Digitaria violascens* Link	species	Native	LC
Poaceae	*Echinochloa colona* (L.) Link	species	Native	LC
Poaceae	*Echinochloa crus-galli* (L.) P.Beauv.	species	Native	LC
Poaceae	*Eleusine indica* (L.) Gaertn.	species	Native	LC
Poaceae	*Eragrostis amabilis* (L.) Wight & Arn. ex Nees	species	Native	LC
Poaceae	*Eragrostis atrovirens* (Desv.) Trin. ex Steud.	species	Native	LC
Poaceae	*Eragrostis brownii* (Kunth) Nees.	species	Native	LC
Poaceae	*Eragrostis nevinii* Hance	species	Native	CR
Poaceae	*Eragrostis nutans* (Retz.) Nees ex Steud.	species	Native	DD
Poaceae	*Eragrostis pilosa* (L.) P.Beauv.	species	Native	LC
Poaceae	*Eragrostis pilosissima* Link.	species	Native	CR
Poaceae	*Eragrostis tenuifolia* (A.Rich.) Hochst. ex Steud.	species	Naturalized	Not Applicable
Poaceae	*Eremochloa ophiuroides* (Munro) Hack.	species	Native	LC
Poaceae	*Erianthus formosanus* Stapf #	species	Native	NT
Poaceae	*Eriochloa procera* (Retz.) C.E.Hubb.	species	Native	LC
Poaceae	*Eriochloa villosa* (Thunb.) Kunth	species	Native	EN
Poaceae	*Eulalia quadrinervis* (Hack.) Kuntze	species	Native	CR
Poaceae	*Hackelochloa granularis* (L.) Kuntze	species	Native	LC
Poaceae	*Hemarthria compressa* (L.f.) R.Br.	species	Native	LC
Poaceae	*Heteropogon contortus* (L.) P.Beauv. ex Roem. & Schult.	species	Naturalized	Not Applicable
Poaceae	*Imperata cylindrica* (L.) P.Beauv. var. *major* (Nees) C.E.Hubb. ex C.E.Hubb. & Vaughan	subspecies	Native	LC
Poaceae	*Isachne globosa* (Thunb.) Kuntze	species	Native	LC
Poaceae	*Ischaemum barbatum* Retz. var. *gibbum* (Trin.) Ohwi	subspecies	Native	LC
Poaceae	*Ischaemum indicum* (Houtt.) Merr.	species	Native	LC
Poaceae	*Leersia hexandra* Sw.	species	Native	LC
Poaceae	*Miscanthus floridulus* (Labill.) Warb. ex Schum. & Laut.	species	Native	LC
Poaceae	*Miscanthus sinensis* Andersson	species	Native	LC
Poaceae	*Narenga porphyrocoma* (Hance) Bor	species	Native	NT
Poaceae	*Panicum bisulcatum* Thunb.	species	Native	LC
Poaceae	*Panicum curviflorum* Hornem. var. *suishaense* (Hayata) Veldkamp	subspecies	Native	CR
Poaceae	*Panicum maximum* Jacq.	species	Naturalized	Not Applicable
Poaceae	*Panicum repens* L.	species	Native	LC
Poaceae	*Paspalum commersonii* Lam.	species	Native	LC
Poaceae	*Paspalum dilatatum* Poir.	species	Naturalized	Not Applicable
Poaceae	*Paspalum notatum* Flugg	species	Naturalized	Not Applicable
Poaceae	*Paspalum orbiculare* G.Forst.	species	Native	LC
Poaceae	*Paspalum paniculatum* L.	species	Naturalized	Not Applicable
Poaceae	*Paspalum scrobiculatum* L.	species	Native	LC
Poaceae	*Paspalum urvillei* Steud.	species	Naturalized	Not Applicable
Poaceae	*Pennisetum polystachion* (L.) Schult.	species	Naturalized	Not Applicable
Poaceae	*Pennisetum purpureum* Schumach.	species	Naturalized	Not Applicable
Poaceae	*Pennisetum setaceum* (Forssk.) Chiov.	species	Naturalized	Not Applicable
Poaceae	*Poa annua* L.	species	Native	LC
Poaceae	*Rhynchelytrum repens* (Willd.) C.E.Hubb.	species	Naturalized	Not Applicable

Poaceae	*Rottboellia exaltata* L.f.	species	Native	LC
Poaceae	*Saccharum spontaneum* L.	species	Native	LC
Poaceae	*Sacciolepis indica* (L.) Chase	species	Native	LC
Poaceae	*Setaria palmifolia* (J.Koenig.) Stapf	species	Native	LC
Poaceae	*Setaria parviflora* (Poir.) Kerguelen	species	Naturalized	Not Applicable
Poaceae	*Setaria sphacelata* (Schumach.) Stapf & C.E.Hubb. ex Moss	species	Naturalized	Not Applicable
Poaceae	*Setaria verticillata* (L.) P.Beauv.	species	Naturalized	Not Applicable
Poaceae	*Sorghum halepense* (L.) Pers.	species	Naturalized	Not Applicable
Poaceae	*Sorghum nitidum* (Vahl) Pers. f. *nitidum*	species	Native	LC
Poaceae	*Sorghum nitidum* (Vahl) Pers. f. *aristatum* C.E.Hubb.	subspecies	Native	Not Applicable
Poaceae	*Spinifex littoreus* (Burm.f.) Merr.	species	Native	LC
Poaceae	*Sporobolus indicus* (L.) R.Br. var. *flaccidus* (R.Br.) Veldkamp	subspecies	Native	DD
Poaceae	*Sporobolus indicus* (L.) R.Br. var. *major* (Buse) Baaijens	subspecies	Native	LC
Poaceae	*Thaumastochloa cochinchinensis* (Lour.) C.E.Hubb.	species	Native	LC
Poaceae	*Zoysia sinica* Hance	species	Native	LC
Polygalaceae	*Polygala chinensis* L.	species	Native	VU
Polygalaceae	*Polygala japonica* Houtt.	species	Native	LC
Polygonaceae	*Fallopia multiflora* (Thunb.) Haraldson #	species	Native	LC
Polygonaceae	*Persicaria chinensis* (L.) H.Gross	species	Native	LC
Polygonaceae	*Persicaria lapathifolia* (L.) Delarbre	species	Native	LC
Polygonaceae	*Persicaria perfoliata* (L.) H.Gross	species	Naturalized	Not Applicable
Polygonaceae	*Persicaria senticosa* (Meisn.) H.Gross ex Nakai	species	Native	LC
Polygonaceae	*Polygonum plebeium* R.Br.	species	Naturalized	Not Applicable
Polygonaceae	*Rumex acetosa* L.	species	Native	LC
Polygonaceae	*Rumex crispus* L. var. *japonicus* (Houtt.) Makino	subspecies	Naturalized	Not Applicable
Portulacaceae	*Portulaca pilosa* L.	subspecies	Native	LC
Primulaceae	*Anagallis arvensis* L.	species	Native	LC
Primulaceae	*Ardisia virens* Kurz	species	Native	LC
Primulaceae	*Lysimachia fortunei* Maxim.	species	Native	LC
Primulaceae	*Lysimachia remota* Petitm.	species	Native	LC
Primulaceae	*Maesa perlaria* (Lour.) Merr. var. *formosana* (Mez) Yuen P.Yang	subspecies	Native	LC
Pteridaceae	*Onychium japonicum* (Thunb.) Kunze	species	Native	LC
Pteridaceae	*Pityrogramma calomelanos* (L.) Link	species	Naturalized	Not Applicable
Pteridaceae	*Pteris ensiformis* Burm.	species	Native	LC
Pteridaceae	*Pteris semipinnata* L.	species	Native	LC
Pteridaceae	*Pteris vittata* L.	species	Native	LC
Ranunculaceae	*Clematis chinensis* Osbeck var. *tatushanensis* T.Y.A.Yang	subspecies	Native	NT
Ranunculaceae	*Clematis grata* Wall.	species	Native	LC
Rhamnaceae	*Berchemia lineata* (L.) DC.	species	Native	LC
Rhamnaceae	*Paliurus ramosissimus* (Lour.) Poir.	species	Native	EN
Rosaceae	*Duchesnea chrysantha* (Zoll. & Mor.) Miq.	species	Native	LC
Rosaceae	*Potentilla discolor* Bunge	species	Native	NT
Rosaceae	*Prunus japonica* Thunb.	species	Naturalized	Not Applicable
Rosaceae	*Prunus pogonostyla* Maxim.	species	Native	VU
Rosaceae	*Rosa bracteata* Wendl.	subspecies	Native	VU
Rosaceae	*Rubus alnifoliolatus* H.Lév.	species	Native	LC

Rosaceae	*Rubus croceacanthus* H.Lév. var. *croceacanthus*	subspecies	Native	LC
Rosaceae	*Rubus hui* Diels	species	Native	LC
Rosaceae	*Rubus parvifolius* L.	subspecies	Native	LC
Rosaceae	*Rubus trianthus* Focke	species	Native	LC
Rubiaceae	*Galium spurium* L. var. *echinospermum* (Wallr.) Hayek	subspecies	Native	LC
Rubiaceae	*Hedyotis corymbosa* (L.) Lam.	species	Native	LC
Rubiaceae	*Hedyotis tenelliflora* Blume	species	Native	LC
Rubiaceae	*Mitracarpus hirtus* (L.) DC.	species	Naturalized	Not Applicable
Rubiaceae	*Paederia foetida* L.	species	Native	LC
Rubiaceae	*Richardia scabra* L.	species	Naturalized	Not Applicable
Rubiaceae	*Rubia akane* Nakai	subspecies	Native	LC
Rubiaceae	*Spermacoce articularis* L.f.	species	Naturalized	Not Applicable
Rubiaceae	*Spermacoce latifolia* Aubl.	species	Naturalized	Not Applicable
Rubiaceae	*Spermacoce mauritiana* Gideon	species	Naturalized	Not Applicable
Rutaceae	*Murraya exotica* L.	species	Native	LC
Rutaceae	*Zanthoxylum nitidum* (Roxb.) DC.	species	Native	LC
Rutaceae	*Zanthoxylum simulans* Hance	species	Native	EN
Salicaceae	*Salix warburgii* Seemen #	species	Native	LC
Salicaceae	*Scolopia oldhamii* Hance	species	Native	LC
Santalaceae	*Thesium chinense* Turcz.	species	Native	VU
Sapindaceae	*Cardiospermum halicacabum* L.	species	Naturalized	Not Applicable
Schisandraceae	*Kadsura japonica* (L.) Dunal	species	Native	LC
Scrophulariaceae	*Buddleja asiatica* Lour.	species	Native	LC
Scrophulariaceae	*Myoporum bontioides* (Siebold & Zucc.) A.Gray	species	Native	EN
Smilacaceae	*Smilax china* L.	species	Native	LC
Solanaceae	*Physalis angulata* L.	species	Naturalized	Not Applicable
Solanaceae	*Solanum americanum* Mill.	species	Naturalized	Not Applicable
Solanaceae	*Solanum erianthum* D.Don	species	Naturalized	Not Applicable
Styracaceae	*Styrax matsumurae* Perkins #	species	Native	VU
Symplocaceae	*Symplocos chinensis* (Lour.) Druce	species	Native	LC
Talinaceae	*Talinum paniculatum* (Jacq.) Gaertn.	species	Naturalized	Not Applicable
Thelypteridaceae	*Ampelopteris prolifera* (Retz.) Copel.	species	Native	LC
Thelypteridaceae	*Cyclosorus acuminatus* (Houtt.) Nakai ex H.Ito	species	Native	LC
Thelypteridaceae	*Cyclosorus parasiticus* (L.) Farw.	species	Native	LC
Thymelaeaceae	*Wikstroemia indica* (L.) C.A.Mey.	species	Native	LC
Typhaceae	*Typha orientalis* C.Presl	species	Native	LC
Ulmaceae	*Ulmus parvifolia* Jacq.	species	Native	NT
Ulmaceae	*Zelkova serrata* (Thunb.) Makino	species	Native	LC
Urticaceae	*Boehmeria densiflora* Hook. & Arn.	species	Native	LC
Urticaceae	*Boehmeria nivea* (L.) Gaudich. var. *nivea*	subspecies	Naturalized	Not Applicable
Urticaceae	*Boehmeria nivea* (L.) Gaudich. var. *tenacissima* (Gaudich.) Miq.	subspecies	Native	LC
Urticaceae	*Gonostegia hirta* (Blume) Miq.	species	Native	LC
Urticaceae	*Pouzolzia zeylanica* (L.) Benn.	species	Native	LC
Verbenaceae	*Duranta erecta* L.	species	Naturalized	Not Applicable
Verbenaceae	*Lantana camara* L.	species	Naturalized	Not Applicable

Violaceae	*Viola inconspicua* Blume subsp. *nagasakiensis* (W.Becker) J.C.Wang & T.C.Huang	subspecies	Native	LC
Violaceae	*Viola confusa* Champ. ex Benth.	species	Native	LC
Vitaceae	*Ampelopsis brevipedunculata* (Maxim.) Trautv. var. *ciliata* (Nakai) F.Y.Lu	subspecies	Native	LC
Vitaceae	*Ampelopsis brevipedunculata* (Maxim.) Trautv. var. *hancei* (Planch.) Rehder	subspecies	Native	LC
Vitaceae	*Cayratia japonica* (Thunb.) Gagnep.	species	Native	LC
Vitaceae	*Tetrastigma formosanum* (Hemsl.) Gagnep. #	species	Native	LC
Vitaceae	*Vitis thunbergii* Siebold & Zucc. var. *taiwaniana* F.Y.Lu #	subspecies	Native	EN
Zingiberaceae	*Alpinia zerumbet* (Pers.) B.L.Burtt & R.M.Sm.	species	Native	LC
Zygophyllaceae	*Tribulus terrestris* L.	species	Native	LC

#: Endemism.

* Red List of Taiwan: CR, Critically Endangered; EN, Endangered; VU, Vulnerable; NT, Near Threatened; LC, Least Concern; DD, Data Deficient.

Sentinel-2 光譜與紋理特徵對土地覆蓋分類效能的改進

Enhancing land cover classification using spectral and texture features from Sentinel-2 data

黃靜宜

Jing-Yi Huang

農業部生物多樣性研究所 552005 南投縣集集鎮民生東路 1 號

Taiwan Biodiversity Research Institute, Nantou, Taiwan

通訊作者：lily@tbri.gov.tw

Corresponding author: lily@tbri.gov.tw

摘要

即時並有效地掌握土地覆蓋資訊，對於地景規劃或自然資源管理至關重要。遙測影像分類技術作為當代獲取該資訊的主要手段，如何提升其分類效能，仍是遙測研究持續關注的課題之一。本研究以大肚臺地為例，首先，透過 Sentinel-2（S2）原始波段的組合，生成可突顯地物光譜特徵的光譜指標，同時基於灰階共生矩陣，擷取可反映空間排列特徵的紋理指標，再分別令其與原始波段整合，作為隨機森林分類演算法的輸入資料集，對 7 種土地覆蓋類型進行分類，最後，評估並比較不同特徵組合的分類效果。研究結果顯示，儘管 S2 原始波段在地覆分類中具相當潛力，但用於辨別高異質性混淆植被或高變異性草本植被時，其效果仍顯不足。無論添加光譜或紋理特徵，均有助整體分類效能的提升，且兩類特徵

對特定類別準確度的提升具互補性，合併添加可獲得最佳分類效果，總體準確度與Kappa係數，分別可達90.56%、0.88，相較於僅使用原始波段，約可提升3.35%、0.04，並在 McNemar 檢定下，達差異顯著水準（$p \leq 0.001$），各類別 F1 分數亦能獲不同程度的改善（0.64–11.06%）。綜合上述結果，本研究建議在選擇土地覆蓋分類輸入資料集時，除常見的光譜特徵外，亦可考慮額外添加紋理特徵，以最大程度提高分類準確度。

關鍵詞：灰階共生矩陣、植生指標、隨機森林、遙感探測、土地覆蓋分類

Abstract

Timely and effective acquisition of land cover information is crucial for landscape planning and natural resource management. Remote sensing image classification is a primary method for acquiring land cover information, and enhancing the performance of classification still remains a key research topic to focus on. In our study, spectral features were generated from the combinations of Sentinel-2 (S2) original bands in Dadu Terrace area to highlight the spectral characteristics of land cover types. Simultaneously, texture features reflecting spatial arrangement patterns were extracted using the gray-level co-occurrence matrix. These features were then combined with the original bands to form input datasets for the random forest classification algorithm, which was used to classify seven land cover types. Finally, the classification performance of different feature combinations was evaluated and compared. The results indicate that although the S2 original bands display considerable potential in land cover classification, they are still insufficient for distinguishing heterogeneous mixed vegetation or highly variable herbaceous vegetation. Incorporating either commonly used spectral features or texture features improved overall classification performance and also enhanced classification accuracy from their complementary effects on the specific categories. Using the combination of spectral and texture features achieved the best results with an overall accuracy of 90.56% and a Kappa coefficient of 0.88, representing improvements of 3.35% and 0.04, respectively, over the use of original bands alone, and these improvements were statistically significant ($p \leq 0.001$), confirmed by the McNemar test. Additionally, the F1-scores across all categories also showed enhancement, ranging from 0.64 to 11.06%. In summary, this study recommends to use combination of texture features and spectral features to maximize classification accuracy when selecting input datasets for land cover classification.

Keywords: gray-level co-occurrence matrix, vegetation indices, random forest, remote sensing, land cover classification

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緒言

土地覆蓋（land cover）資訊不僅為陸地表面元素的組成和分布提供描述，還反映了人類對這些元素的使用目的或影響（Foody 2002）。即時且有效地掌握地覆資訊，對於地景規劃或自然資源管理至關重要，相較於傳統地面調查與航照判識，衛星遙測數據具備穩定性、可重複觀測、覆蓋範圍廣和成本低等優勢，儼然成為當代土地覆蓋分類的主要材料來源。通常，遙測數據在地覆分類上的應用，係基於地物對特定波段反射特徵的差異來進行（Lu and Weng 2007），其過程通常透過一組已標記且具代表性的訓練資料集，使用統計或機器學習演算法，探索各類別光譜特徵，並將影像的像元從原始資料轉換為具意義的分類資訊。分類準確性取決於訓練資料集的代表性（Kavzoglu 2009），以及目標類別在光譜特徵空間中的分離度（Gambarova *et al.* 2010）。時至今日，免費開放獲取的多光譜影像，如 Sentinel-2（S2）或 Landsat，已成為地覆測繪或監測應用的首選材料（Phiri *et al.* 2020），然而，在實務應用中，面對高度複雜的異質性地景時，經常囿於地景中生態複雜性、物候多樣性，以及光譜混淆等因素的影響（Jozdani *et al.* 2019; Wei *et al.* 2023），導致部分目標類別分類效果不彰。儘管新一代高光譜影像提供了更寬的光譜範圍，以及更高的光譜解析力，有助類別分離度的提高，然礙於成本昂貴與獲取不易等特性，未能廣泛應用。因此，持續在多光譜影像的基礎上，探尋有效的方法，精進分類性能，仍是當前遙測研究的重要課題（Macintyre *et al.* 2020）。

添加輔助資料集（ancillary datasets）是提升多光譜影像分類性能常見的策略之一。輔助資料可由影像初始觀測數據直接進行特徵擷取或衍生計算，生成一組可豐富或突顯特定地表特徵的新訊息，以此作為分類用的補充解釋特徵，通常有助於提升分類準確度（Lv *et al.* 2014），植生與紋理指標即為常見的輔助資料（Kavzoglu and Bilucan 2023）類型之一。遙測影像所提供的光譜資訊，

是光學感測器以像元為單位，接收並記錄地表不同地物對電磁波譜的反射率，而兩個或多個波段的光譜反射率經過數學算術組合後，可為突顯特定地物特徵的光譜指標，相較於單一波段，更有利於強調地物間的差異（Brendel *et al.* 2019），惟常見植生指標（vegetation indices, VIs）仍存在飽和效應（saturation effect）、混合像元（mixed pixel），以及類別間光譜過於相似等不確定性（Huete *et al.* 1997; Rodriguez-Galiano and Chica-Olmo 2012），導致分類混淆的情形難以避免，此時紋理（texture）特徵有機會彌補此類缺失。與光譜特徵不同的是，紋理特徵非關注單個像元，而是強調影像局部區域色調強度的空間排列與變化（Hall-Beyer 2017），紋理特徵的擷取方法多樣，其中灰階共生矩陣（gray-level co-occurrence matrix, GLCM）最為常見，概念上是圖像中所有像元灰階值組合出現頻率的度量，最初用於圖像分類（Haralick *et al.* 1973），現今於地覆分類研究上多有應用，該類特徵有助降低因光譜相似性所產生的類別混淆，使分類準確度獲得有效提升（Kabir *et al.* 2010; Hall-Beyer 2017）。

大肚臺地為林業及自然保育署國土生態綠網計畫指認關注區域之一，現已規劃為大肚臺地淺山保育軸帶，相關單位刻正積極推動區內植被復育、入侵種移除、生態廊道串連與棲地營造等工作，足見其生態保育價值。然而，近代都市擴張、農業使用，以及頻繁的野火干擾等因素，致其地覆變化快速而明顯（張及章 2004；邱等 2012；嚴 2012），至今由入侵植物大黍（*Panicum maximum*）所引發的野火干擾，仍持續且規律在發生，對生態復育工作構成嚴峻挑戰。由於土地覆蓋與野火風險息息相關，除直接供給燃料來源外，亦影響野火的發生與蔓延（Nunes *et al.* 2005; Pereira *et al.* 2014），故精準掌握土地覆蓋資訊，對於燃料管理與野火風險評估甚為重要。有鑑於此，本研究以大肚臺地為試驗區，首先自 S2 影像擷取植被與紋理等兩類特徵，並將其與 S2 原始波段進行整合，以隨機森林（random forest, RF）演算法，執行土地覆蓋分類，評估並比較不同特徵組合下的分類效能，研究目的在於一、評估 S2 對測繪研究區土地覆蓋的可行性；二、確立有助提升分類性能的特徵組合與重要變項，期研究成果可作為未來土地覆蓋監測與管理之參考資訊。

材料與方法

1、研究區概述

大肚臺地東臨臺中盆地，西接清水平原，北起大甲溪南岸，南至大肚溪北岸，為一南北長約 20 km、東西寬約 5–7 km 的長形臺地，面積約 140 km^2（圖 1）。臺地頂部平坦開闊，平均海拔約 180 m，海拔 310 m 的大肚山為其最高點。由於地形因素，土壤多為紅黏土，並含有大量礫石，保水性差，農業活動以旱作為主。根據鄰近之大雅（中科園區）氣象站 2018–2022 年的統計資料顯示，該區年均溫約 23°C，年降水量約 1,488 mm，具明顯乾濕季，乾季（10 至翌年 2 月）與濕季（3 至 9 月）月平均降雨量，

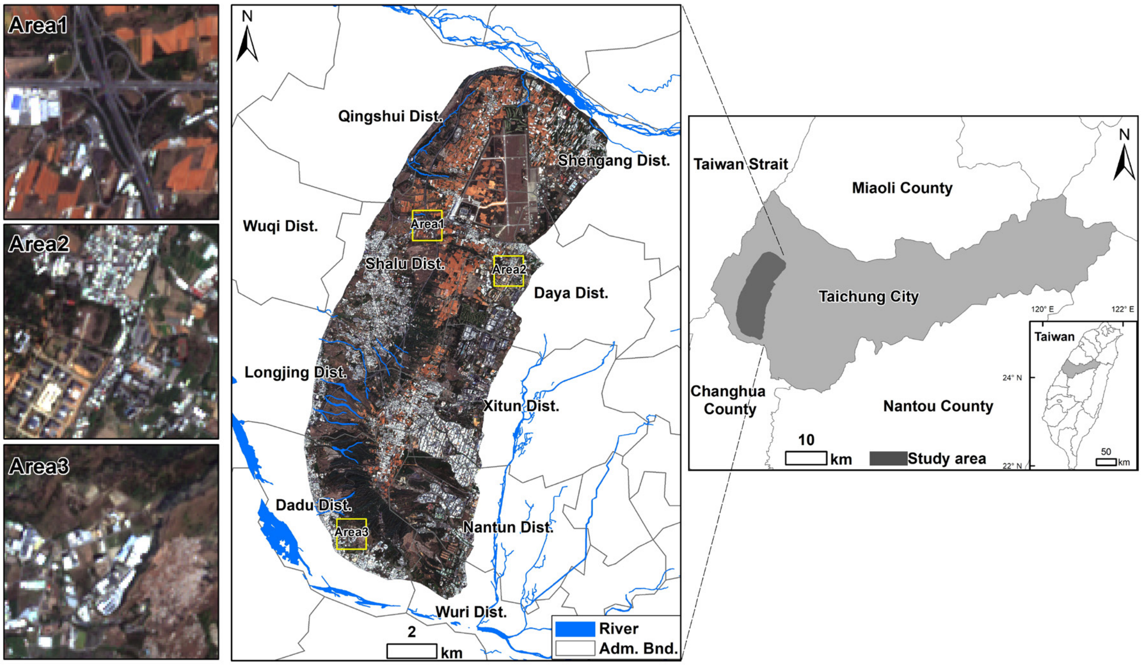

圖 1 研究區地理位置。
Fig. 1 Geographical location of the study area.

分別為 26 mm、194 mm。由於人為開發與野火干擾，目前植被組成以相思樹（*Acacia confusa*）、大黍最為優勢（Lin *et al.* 2022），受乾季強烈東北季風與降水稀缺的影響，隨之大量凋萎乾枯的大黍植物體，遂成為野火重要燃料源（Ho *et al.* 2016；張及章 2004；林等 2005），所導致的火草循環，亦促使森林植被逐漸退化為疏林或草生地，且難以被恢復或逆轉（Lin *et al.* 2022；邱等 2012）。

2、研究方法

(1) 遙測資料與前處理

考量研究區野火主要燃料源（大黍）對水分逆境敏感，其植物體於乾季呈現乾枯狀態（Ho *et al.* 2016），此物候特性有助於覆蓋類別的分類，故選擇乾季影像作為分析材料。所使用之 Sentinel-2B 影像自哥白尼數據空間生態系統（https://dataspace.copernicus.eu/）下載，篩選無雲或低雲覆率之清晰影像，選定的影像屬 Level-2A 處理等級的產品，即所提供之地表反射率已完成正射、大氣與地形校正（Gascon *et al.* 2017），拍攝日期為 2024 年 2 月 14 日（圖 1）。Sentinel-2 為歐洲太空總署（European Space Agency, ESA）發射之衛星，掃描寬度廣達 290 km，光譜資訊涵蓋可見光、近紅外、紅邊（red-edge, 680–780 nm）及短紅外光範圍（443–2,190 nm），具備 3 種空間解析力，共 13 個波段，其中除 B1、B9 與 B10 等 3 個波段為 60 m，主要供大氣校正使用，本研究不予納入分析外，其餘 B2 至 B4、B8（10 m），以及 B5、B6、B7、B8A 與 B11、B12（20 m）等 10 個波段影像波段均用於後續分類使用（表 1），同時透過 ESA 專為 Sentinel 系列影像所開發的免費軟體 SNAP（Sentinel Application Platform），以最近相鄰法（nearest neighbor）進行像元重取樣，將前述 10 個波段影像之空間解析力統一為 10 m。此方法不僅簡單快速，且能完全保留原始像元訊息（Parker *et al.* 1983），有利確保數據的完整性與分析的一致性。

(2) 特徵擷取

所使用的特徵數據包含基於光譜

表 1 本研究所使用 Sentinel-2 多光譜影像波段參數
Table 1 The parameters of the Sentinel-2 spectral bands used in this study

Spectral bands	Central wavelength (nm)	Spatial resolution (m)
Blue (B2)	490	10
Green (B3)	560	10
Red (B4)	665	10
Vegetation Red Edge 1 (B5)	705	20
Vegetation Red Edge 2 (B6)	740	20
Vegetation Red Edge 3 (B7)	783	20
Near InfraRed (B8)	842	20
Narrow Near InfraRed (B8A)	865	20
Short Wave InfraRed (B11)	1610	20
Short Wave InfraRed (B12)	2190	20

所推導之植生指標，以及 GLCM 紋理指標兩類，均於 SNAP 9.0 平台進行運算。植生指標為兩個或兩個以上的波段的數學組合，演算容易且具穩健性，常應用於植被監測與生物物理參數的反演，對產製土地覆蓋圖資而言，具明確指示作用（Mansourmoghad *et al.* 2022），其中常態化差異植生指標（normalized difference vegetation index, NDVI）與植被生物量密切相關（Ricotta *et al.* 1999），應用最屬廣泛；土壤調整植生指標（soil adjusted vegetation index, SAVI）與增揚植生指標（enhanced vegetation index, EVI）則是納入土壤調整因子或大氣阻力因子，降低土壤背景或大氣條件對植被訊號的干擾，同時提升植被偵測的敏感度，兩者皆為常見的植生指標（Huete *et al.*2014）；紅邊對偵測植被葉綠素含量靈敏（Horler *et al.* 1983），亦為 S2 影像提供的光譜優勢，有助土地利用分類（Pradhan *et al.* 2021），故同步計算常態化差異紅邊指標（normalized difference red edge index, NDRE）；再者，考量研究區在乾季存在大量乾枯或老化生物量，併同計算植物老化反射指標（plant senescence reflectance index, PSRI）、

乾枯燃料指標（dead fuel index, DFI）與常態化差異水分指標（normalized difference water index, NDWI）等指標（Cao *et al*. 2010; Gao 1996; Merzlyak *et al*. 1999），用以反應植被水勢或乾燥植被的覆蓋狀態；此外，研究區在乾季適值休耕期，存在大面積裸露表土，使用裸土指標（bare soil index, BSI）可有效突顯其特徵（Abida *et al*. 2022），上述 8 項根據不同波段光譜反射率所衍生的植生指標計有 8 項，其演算公式如表 2。

除植生指標外，紋理特徵亦有助於提升分類準確度（Hall-Beyer 2017; Iqbal *et al*. 2021），尤其在區分光譜反應特徵相似，但空間排列型態不同的植被類型時，效果尤為顯著（Kupidura 2019）。首先，將 S2 的 10 個原始波段導入 SNAP 9.0 平台的紋理分析模組，基於 Haralick *et al*.（1973）所提出的 GLCM 進行紋理特徵的擷取。所有參數是參考過去文獻（Mohammadpour *et al*. 2022; Tavares *et al*. 2019）進行設定，過程採用概率量化器，量化級別設為 32，視窗大小為 5 × 5，像元位移量為 1，在所有方向上，建構 GLCM $P(i,j \mid d,\theta)$，即計算影像中灰階級 i（參考像元）與

表 **2** 本研究使用之植生指標

Table 2 Vegetation indices used in this study

Index	Abbreviation	Formula and S2 bands used	Reference
Normalized difference vegetation index	NDVI	$\frac{B_8 - B_4}{B_8 + B_4}$	Rouse *et al*.(1974)
Soil adjusted vegetation index	SAVI	$\frac{B_8 - B_4}{B_8 + B_4 + 0.5} \times 1.5$	Huete (1988)
Enhanced vegetation index	EVI	$\frac{B_8 - B_4}{B_8 + (6 \times B_4) - (7.5 \times B_2) + 1} \times 2.5$	Huete *et al*. (1997)
Normalized difference red edge index	NDRE	$\frac{B_7 - B_6}{B_7 + B_6}$	Peng and Gitelson (2012); Munyati (2022)
Plant senescence reflectance index	PSRI	$\frac{B_4 - B_2}{B_6}$	Merzlyak *et al*. (1999)
Dead fuel index	DFI	$100 \times \left(\frac{1 - B_{12}}{B_{11}}\right) \times \frac{B_4}{B_8}$	Cao *et al*. (2010)
Normalized difference water index	NDWI	$\frac{B_{8a} - B_{11}}{B_{8a} + B_{11}}$	Gao (1996); Munyati (2022)
Bare soil index	BSI	$\frac{(B_{11} + B_4) - (B_8 + B_2)}{(B_{11} + B_4) + (B_8 + B_2)}$	Diek *et al*. (2017)

灰階級 j（鄰近像元）出現於特定空間關係下（d, θ）的聯合機率，其中 d 為距離，θ 為方向（Humeau-Heurtier 2019），所計算特徵指標包含對比（contrast, CON）、相異性（dissimilarity, DIS）、同質性（homogeneity, HOM）、熵（entropy, ENT）、角二階距（angular second moment, ASM）、均值（mean, MEAN）、變異數（variance, VAR）、相關性（correlation, COR）等 8 種，其中 CON、DIS、HOM 等 3 項屬對比性類群（contrast group），主要透過灰階對（i 與 j）間灰階差，進行權重縮放，可作為圖像均勻度的量測；ASM 與 ENT 則屬規律性類群（orderliness group），權重的賦予取決於參考像元與某特定鄰近像元共同出現頻率（即 $P_{i,j}$），用以評估圖像規則性或複雜性；MEAN、VAR、COR 計算方式與常見描述性統計相似，惟仍須根據 $P_{i,j}$ 進行加權，可用來表現圖像灰階分布的平均值與離散情形，以及參考像元與某特定鄰近像元的間的線性關係，有助理解圖像本身的基本紋理特徵，3 者可歸屬於描述性統計類群（descriptive statistics group）。以 10 個原始波段演算上述 8 項紋理指標（表 3，Hall-Beyer 2000），共獲得 80 張紋理特徵影像。接續將所有紋理特徵影像以主成分分析（principal components analysis, PCA）進行降維，並依前人研究建議（Liu *et al.* 2018），選定新成分影像的數量以累積解釋變異量至少達 85% 為標準，最終保留前 8 張主成分影像，其累積解釋變異量達 86.71%（附錄 1），可供為後續土地覆蓋分類輸入變項使用。

(3) 參考資料集

基於乾季野火風險控管的目的，本研究將土地覆蓋類別區分為植被與非植被兩類 7 種（表 4、圖 2）。植被包含木本植被、草本植被、乾燥植被、乾燥植被混生木本植被、乾燥植被混生草本植被等 5 種，在此，本研究假設所有植被型皆可作為潛在燃料來源，尤其在低植被含水量的乾燥條件下，不僅存在更高的可燃料性，亦能促使野火蔓延（張及章 2004; Kang *et al.* 2022）；非植被則涵蓋人為不

表 3 本研究使用之 GLCM 紋理指標
Table 3 GLCM texture indices used in this study

Group	Index	Abbreviation	Formula	Reference
Contrast	Contrast	CON	$\sum_{i,j=0}^{N-1} P_{i,j}\,(i-j)^2$	Hall-Beyer (2000)
	Dissimilarity	DIS	$\sum_{i,j=0}^{N-1} P_{i,j}\,\lvert i-j\rvert$	
	Homogeneity	HOM	$\sum_{i,j=0}^{N-1} \frac{P_{i,j}}{1+(i-j)^2}$	
Orderliness	Angular Second Moment	ASM	$\sum_{i,j=0}^{N-1} {P_{i,j}}^2$	
	Entropy	ENT	$\sum_{i,j=0}^{N-1} P_{i,j}\left(-lnP_{i,j}\right)$	
Descriptive statistics	GLCM Mean	MEAN	$\sum_{i,j=0}^{N-1} i\left(P_{i.j}\right)$	
	GLCM Variance	VAR	$\sum_{i,j=0}^{N-1} P_{i,j}\,(i-\mu_i)^2$	
	GLCM Correlation	COR	$\sum_{i,j=0}^{N-1} P_{i,j}\left[\frac{(i-\mu_i)(j-\mu_j)}{\sqrt{({\sigma_i}^2)({\sigma_j}^2)}}\right]$	

$P_{i,j}$ is the probability of values *i* and *j* occurring in adjacent pixels in the original image within the window defining the neighborhood. Both *i* and *j* are the labels of the columns and rows, respectively, of the GLCM. In the GLCM COR equation, μ is the mean and σ the standard deviation, both as defined by the formula for GLCM MEAN and GLCM VAR in the table.

透水層與裸土等 2 種，相對不具備燃料源潛力。於研究區範圍內，隨機選取 2,790 個地面參考資料，以 Google Earth 高解析度影像，作為地真參考資料，盡可能選擇與分類材料拍攝日期相近之高解析力影像，透過視覺判釋，並輔以現地勘查，逐一標記每樣點土地覆蓋類別。

(4) 土地覆蓋分類

以 10 個原始波段輸入變項作為對照組，並分別添加 8 個植生指標、8 個紋理特徵影像，以及涵蓋所有 26 個特徵圖層的 4 種變項組合，採 RF 演算法進行地覆分類。RF 建構在決策樹（decision tree）的基礎上，它透過 bagging 隨機產生大量訓練子集，生成大量的決策樹，對未被選擇的袋外樣本（out-of-bag, OOB）進行預測，基於分類問題，其最後結果是經由每棵決策樹採投票取得共識所獲得（Breiman 2001）。鑑於 RF 演算法是一種集成大量決策樹的分類器，不僅可在相對小的數據量上，求解高度非線性的問題，亦可同時處理大量的輸入特徵，相較於其他演算法，其分類效能佳，近代廣泛應用於生態學、土地利用與覆蓋分類等研究領域（Gislason *et al.* 2006; Cutler *et al.* 2007）。本研究使用 R 軟體套件 ”randomForest”（Breiman *et al.* 2018），其中每個節點可隨機選取用以分裂之候選特徵數（mtry），以及建構決策樹的棵數（ntree）等兩參數，參考過去研究（Immitzer *et al.* 2016; Sothe *et al.*

表 4 土地覆蓋類別與樣本數
Table 4 Land-cover classification scheme and sample size

Land cover type	Abbreviation	Description	Samples
Woody vegetation	WV	Woody vegetation (tree or shrub cover) (> 75%), interspersed with other cover types	642
Herbaceous vegetation	HV	Covered by herbaceous vegetation, including pineapple, ginger, banana, sweet potato, rice, artificial turf, or fallow land (> 75%), interspersed with other cover types	210
Dry vegetation	DV	Covered by vegetation lacking greenery, such as dead, aging, or post-harvest crop residues.	383
Mosaic dry vegetation / woody vegetation	MDW	Predominantly dry vegetation (> 50%) with interspersed tree or shrub cover (< 50%)	300
Mosaic dry vegetation / herbaceous vegetation	MDH	Predominantly dry vegetation (> 50%) with interspersed live, green herbaceous cover (< 50%)	151
Impervious surface	IS	Various artificial surfaces, such as buildings, roads, and graveyards	866
Bare soil	BS	Winter fallow fields or landslide sites characterized by exposed soil surfaces	238

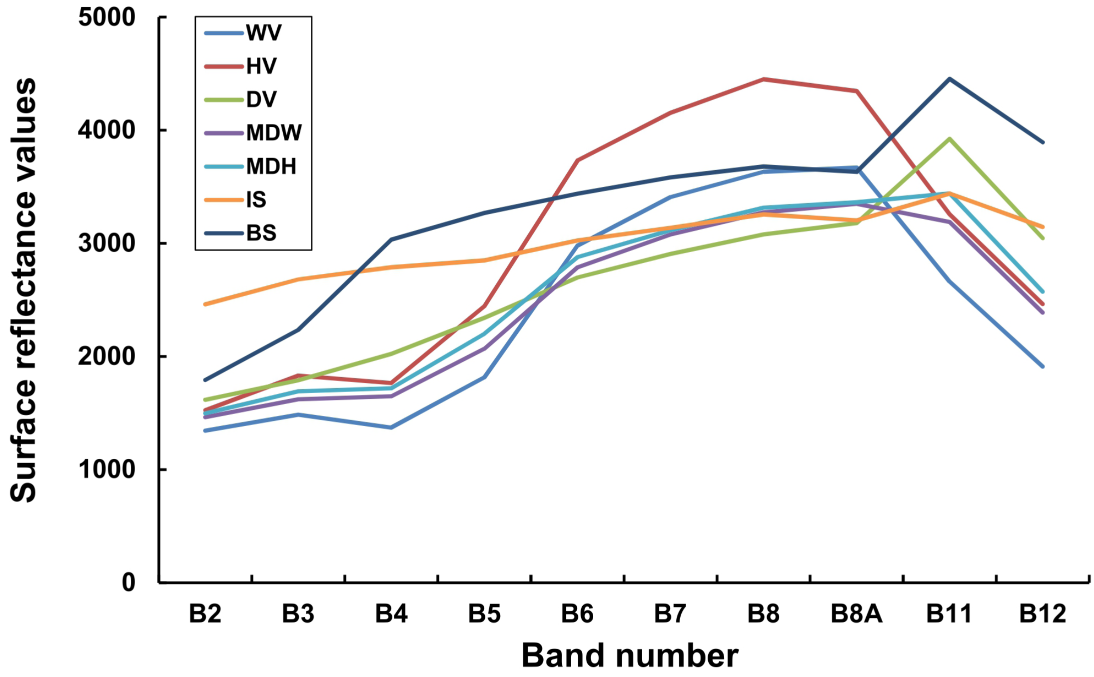

圖 2 不同土地覆蓋類別的光譜反射曲線，數據來自於 Sentinel-2 衛星影像 Level-2A 產品 12-bit 輻射解析力原始波段之地表反射率值。

Fig. 2 Spectral reflectance curve of different land cover types, derived from Sentinel-2 Level-2A product with the surface reflectance values of 12-bit radiometric resolution.

2017）建議，採預設值設定，即 mtry 為輸入特徵數量的平方根、ntree 為 500。此外，RF 分類過程中，以 Gini 指數（Gini index）平均降低量，評估該特徵的重要性，當該指數降低量愈多，表示該特徵對分離類別的貢獻愈大。使用分層隨機取樣，先抽取 70% 地面參考資料（n = 1,953），作為訓練集（training set），用以訓練分類模型，剩餘的 30% 資料（n = 837），則保留作為測試集（test set），用於後續分類模型的準確性評估。

(5) 準確度評估與差異性檢定

使用混淆矩陣（confusion matrices）計算總體準確度（overall accuracy, OA）和 Kappa 係數兩種常見指標，用以衡量整體分類效能，OA 表示圖面上隨機選擇位置，被正確分類的機率，OA 達 80% 可視為高準確度（Teluguntla2018）；Kappa 係數則為

分類結果與真實參考資料的一致性，範圍為 0（無一致性）至 1（完全一致），Kappa 值大於 0.8 可謂高一致性（Landis and Koch 1977）。另外，生產者準確度（producer's accuracy, PA）、使用者準確度（user's accuracy, UA），以及兩者的調和平均數（harmonic mean）F1 分數（F1-score），可用以評估各類別的分類效能，其值愈高，代表分類性能愈佳（Sokolova and Lapalme 2009）。

參考 De Leeuw（2006）建議，採用 McNemar test 進行差異性檢定，用以瞭解原始波段在添加不同特徵數據後，對改變其分類效能的顯著程度，該檢定是基於卡方檢定（χ^2）檢定統計量，由添加特徵數據前後的兩種分類誤差矩陣計算得出，其演算公式如下：

其中 f_{12} 表示原始波段輸入法（方法 1）分類錯誤，但添加特徵數據輸入法（方法 2）分類正確的樣本數；f_{21} 則表示方法 1 分類正確，但方法 2 分類錯誤的樣本數。

結果

在不同特徵組合下作為分類模型輸入集下，其分類後之 OA 與 Kappa 係數，以及添加光譜或紋理輔助特徵前、後準確度之差異性檢定結果（圖 3、表 5）顯示，單以原始波段作為 RF 分類輸入時，其 OA 為 87.22%、Kappa 為 0.84，整體準確度已達良好標準，然相較於其他添加輔助資料的處理而言，分類效果相對較弱。分別添加光譜特徵或紋理特徵後，其分類結果之 OA、Kappa 均可獲得提升，並達顯著差異（$p \leq 0.05$）。將原始波段、光譜特徵與紋理特徵全數作為輸入時，可獲得最佳分類效果，並達差異極顯著水準（$p \leq 0.001$），其 OA 與 Kappa，分別達到 90.56%、0.88，相較於無添加輔助特徵前，約可提升 3.35%、0.04。總結來說，S2 原始波段對研究區土地覆蓋類別分類已具相當潛力，無論添加光譜或紋理特徵，均有助於分類準確度的提升，兩類特徵合併使用，可獲得最佳的效果。

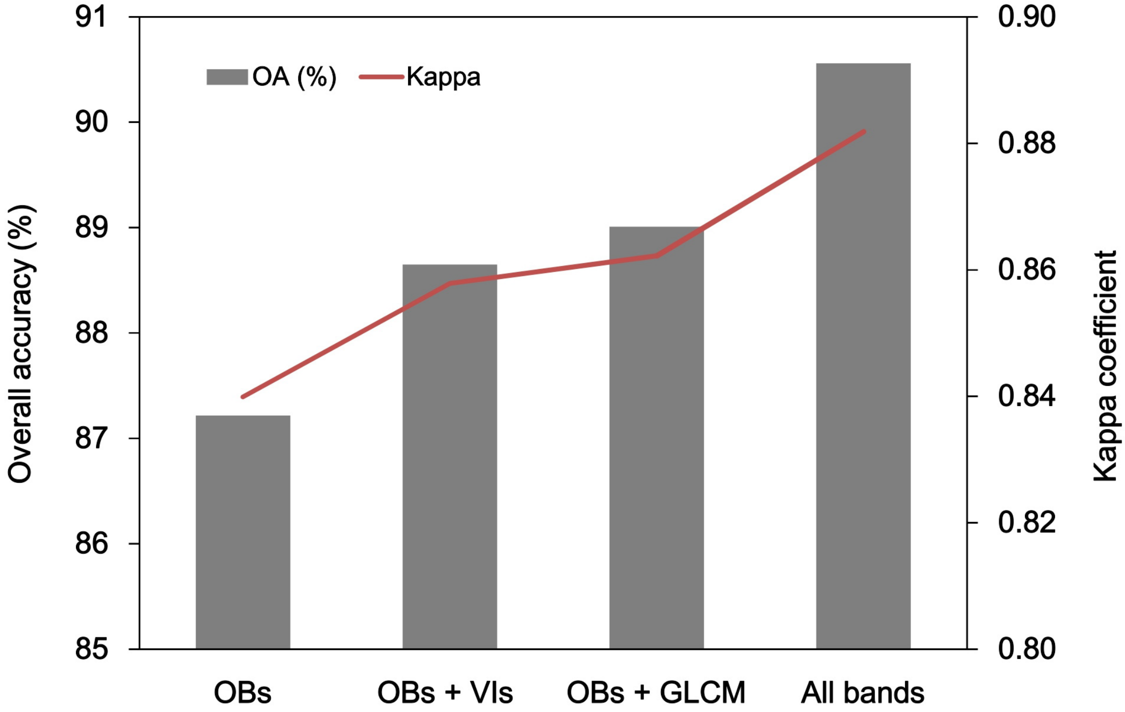

圖 3 不同特徵輸入組合下隨機森林分類結果的總體準確度與 kappa 係數。
Fig. 3 Comparisons of overall accuracy and Kappa coefficient derived from RF in different feature sets.

表 5 添加不同類別特徵前後之 McNemar’s 差異性檢定
Table 5 McNemar’s test for comparing the differences between OBs and additional features

Input dataset	f_{11}	f_{12}	f_{21}	f_{22}	Total	Chi-square (χ^2)	*P* value
OBs vs. OBs + VIs	86	21	9	721	837	4.033	0.045
OBs vs. OBs + GLCMs	78	29	14	716	837	4.558	0.033
OBs vs. All bands	73	34	6	724	837	18.225	<0.001

f_{11} denotes the number of cases with wrong classifications in both maps: classifier 1 (original bands, OBs) and classifier 2 (inclusion of feature, IoF).

f_{12} represents the number of cases that are wrongly classified by OBs but correctly classified by IoF.

f_{21} indicates the number of cases that are correctly classified by OBs but wrongly classified by IoF.

f_{22} denotes the number of cases with correct classifications in both the OBs and IOF maps.

在不同特徵的輸入組合下，其Gini指數平均降低量排序結果如圖4所示。圖4顯示在無添加特徵的情況下，以可見光（B2、B3、B4）波段最屬重要，短紅外光波段（B11、B12）次之（圖4a），且不論額外添加光譜或紋理特徵，抑或合併使用，B2（B）、B4（R）波段皆是RF分類過程相對重要的特徵變項。以額外添加光譜特徵來看，NDVI、SAVI與PSRI等3項特徵，對增強類別分離度較為有效（圖4b）；而紋理特徵部分，則以PC3貢獻度最高，其次為PC1，其餘成分相重要性相對較低（圖4c）；在所有特徵皆作為輸入的情況下，亦有類似的結果，整體而言光譜特徵的重要性優於紋理特徵（圖4d）。總結來看，可見光範圍波段，尤其是B2與B4波段是執行研究區土地覆蓋分類不可或缺的輸入變項，在額外特徵的添加上，可優先選擇突顯綠色植被的NDVI、SAVI，以及可突顯乾燥或老化植被的PSRI等光譜特徵，若需進一步添加紋理特徵，則可嘗試搭配COR特徵，即PC3的主要負荷變項（附錄1），儘管紋理特徵在輔助資料的添加處理中的表現多敬陪末座，然紋理特徵的添加，對提升分類準確度而言，仍具顯著效果。

不同特徵輸入組合下，各類別分類準確度與混淆矩陣結果，如表6–9所示。當僅使用S2原始波段作為輸入時（表6），WV與IS兩類型最容易判別，所有類別準確度指標均達90%以上，而MDH、HV、MDW等3類則效果較差，F1分數均未達80。具體而言，MDH與HV的PA稍低，有較多測試樣本被錯誤歸類，MDH錯誤歸類多集中於MDW，HV則是分散在各類別中。同樣的，MDW也有相對多的樣本，被錯誤歸類為MDH，導致MDH具有較低的UA，顯示該3類別的混淆是造成分類誤差的主要原因。在添加光譜特徵的處理下，上述3類別，僅有MDH可獲得較顯著的改善，另可發現DV、IS、BS等高同質性類型，亦在此處理中獲得進一步的提升。添加紋理特徵後，幾乎可提升所有類別之分離度，尤其HV、MDW、MDH等3高異質類別，格

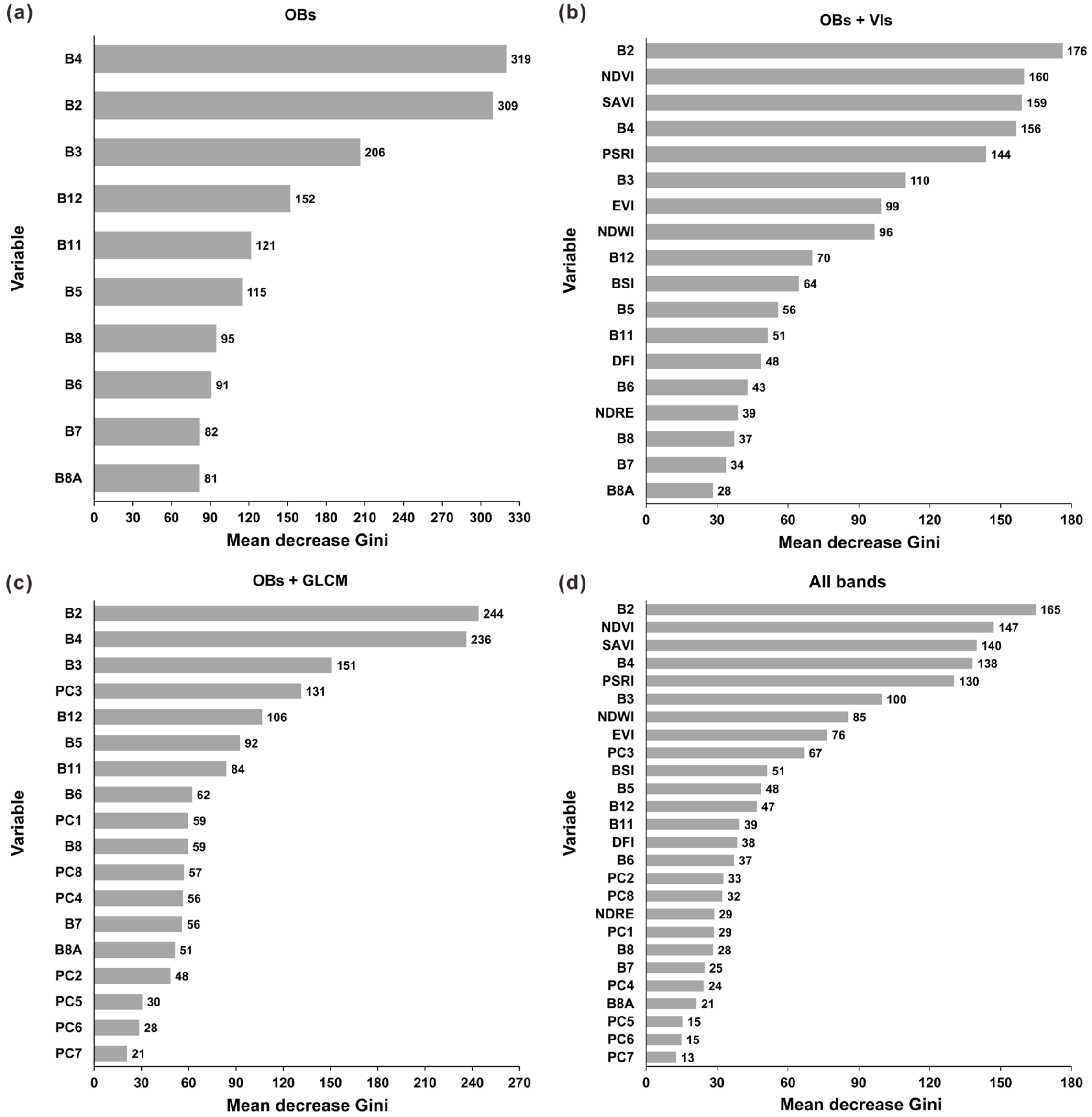

圖 4 不同特徵輸入組合下 Gini 平均降低量。（a）原始波段；（b）原始波段添加 VIs 光譜特徵；（c）原始波段添加 GLCM 紋理特徵；（d）所有特徵變項。

Fig. 4 The decreased mean of Gini in different feature sets. (a) OBs; (b) OBs + VIs; (c) OBs + GLCM, and (d) all bands.

外受惠於紋理特徵的添加。將原始波段、光譜特徵與紋理特徵全數作為輸入時，各類別 F1 分數皆可獲得不同程度的改善（0.64–11.06%）。在全區尺度下，不同特徵組合的分類結果在空間分布型態上呈現高度一致（附錄 2），各地表覆蓋類型的面積分配亦大致相近（圖 5），前三大組成類別為 IS（34.47–36.34%）、WV（21.64–22.33%）、DV（14.56–15.51%）。然而，進一步針對異質性較高的三個區域進行放大檢視（圖 6）後，仍可觀察到不同特徵組合對局部細節的影響，特別是在植被與非植被鑲嵌而成的破碎化地景下，添加特徵有助改善椒鹽效應（salt and pepper effect），其中考量鄰域像元空間關係的紋理特徵效果略佳，不僅提升空間連續性，亦降低細碎雜訊。S2 原始波段雖對於研究區土地覆蓋分類已展現出潛力，但在高異質性或高變異性植被類別上，其準確度仍顯不足，無論添加光譜或紋理特徵，均有助於分類準確度的提升，且兩類特徵對不同特定類別準確度的提升具互補性，合併使用可獲得最佳的效果。

表 6 使用原始波段作為輸入之分類結果混淆矩陣
Table 6 Confusion matrix of the classification results with original bands

Land cover type		Classified data (OBs classifier)							
		WV	HV	DV	MDW	MDH	IS	BS	Row total
Reference data	WV	185	3	2	2	0	1	0	193
	HV	7	44	1	3	2	6	0	63
	DV	1	2	105	3	2	1	1	115
	MDW	8	2	1	72	4	3	0	90
	MDH	1	4	4	15	20	1	0	45
	IS	0	0	8	1	0	246	5	260
	BS	0	0	1	0	0	12	58	71
	Column total	202	55	122	96	28	270	64	837
PA (%)		95.85	69.84	91.30	80.00	44.44	94.62	81.69	
UA (%)		91.58	80.00	86.07	75.00	71.43	91.11	90.63	
F1 score		93.67	74.58	88.61	77.42	54.79	92.83	85.93	

表 7 使用原始波段添加光譜特徵作為輸入之分類結果混淆矩陣

Table 7 Confusion matrix of the classification results with OBs and additional spectral features

	Land cover type	Classified data (OBs + VIs classifier)							
		WV	HV	DV	MDW	MDH	IS	BS	Row total
Reference data	WV	184	3	2	4	0	0	0	193
	HV	7	42	1	2	5	6	0	63
	DV	0	1	109	2	1	1	1	115
	MDW	10	3	1	68	5	3	0	90
	MDH	1	3	3	12	26	0	0	45
	IS	0	0	4	0	0	253	3	260
	BS	0	0	0	1	0	10	60	71
	Column total	202	52	120	89	37	273	64	837
	PA (%)	95.34	66.67	94.78	75.56	57.78	97.31	84.51	
	UA (%)	91.09	80.77	90.83	76.4	70.27	92.67	93.75	
	F1 score	93.16	73.04	92.77	75.98	63.41	94.93	88.89	

表 8 使用原始波段添加 GLCM 紋理特徵作為輸入之分類結果混淆矩陣

Table 8 Confusion matrix of the classification results with OBs and additional GLCM texture features

	Land cover type	Classified data (OBs + GLCM classifier)							
		WV	HV	DV	MDW	MDH	IS	BS	Row total
Reference data	WV	184	3	2	3	0	1	0	193
	HV	5	46	1	4	1	6	0	63
	DV	2	1	105	1	4	1	1	115
	MDW	8	4	1	76	0	1	0	90
	MDH	1	4	5	10	24	1	0	45
	IS	0	0	5	0	0	253	2	260
	BS	0	0	0	0	1	13	57	71
	Column total	200	58	119	94	30	276	60	837
	PA (%)	95.34	73.02	91.30	84.44	53.33	97.31	80.28	
	UA (%)	92.00	79.31	88.24	80.85	80.00	91.67	95.00	
	F1 score	93.64	76.03	89.74	82.61	64.00	94.40	87.02	

表 9 使用所有特徵數據作為輸入之分類結果混淆矩陣
Table 9 Confusion matrix of the classification results using all bands

Land cover type		Classified data (All bands classifier)							
		WV	HV	DV	MDW	MDH	IS	BS	Row total
Reference data	WV	186	3	2	2	0	0	0	193
	HV	5	44	1	2	5	6	0	63
	DV	0	1	110	2	1	0	1	115
	MDW	5	3	0	76	3	3	0	90
	MDH	2	3	3	10	27	0	0	45
	IS	0	0	2	0	0	255	3	260
	BS	0	0	0	0	1	10	60	71
	Column total	198	54	118	92	37	274	64	837
PA (%)		96.37	69.84	95.65	84.44	60.00	98.08	84.51	
UA (%)		93.94	81.48	93.22	82.61	72.97	93.07	93.75	
F1 score		95.14	75.21	94.42	83.52	65.85	95.51	88.89	

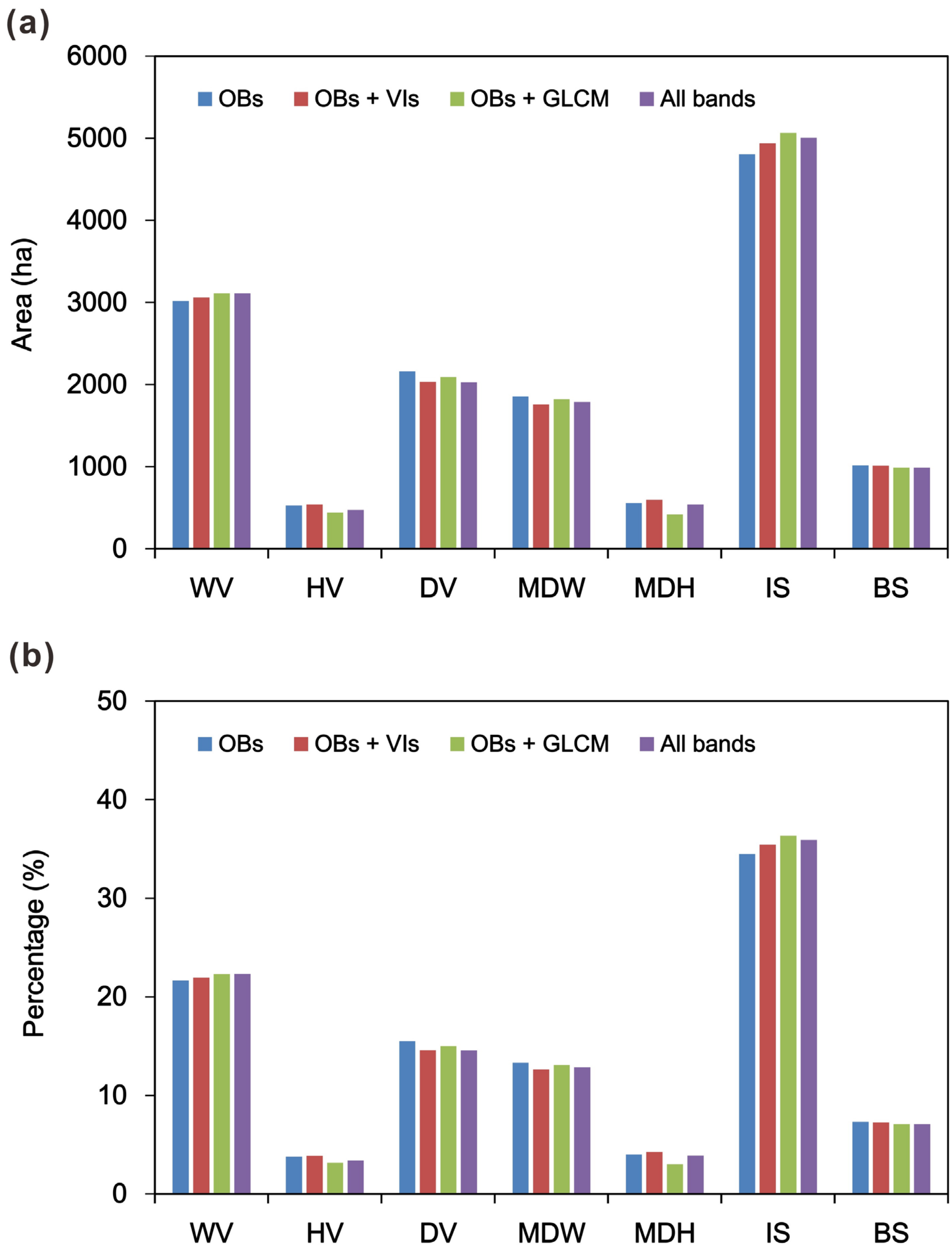

圖 5 不同特徵組合下土地覆蓋分類結果的比較。（a）面積；（b）於研究區域的占比。

Fig. 5 Comparison of land cover classifications using different feature sets in terms of (a) total area and (b) percentage of the entire study area.

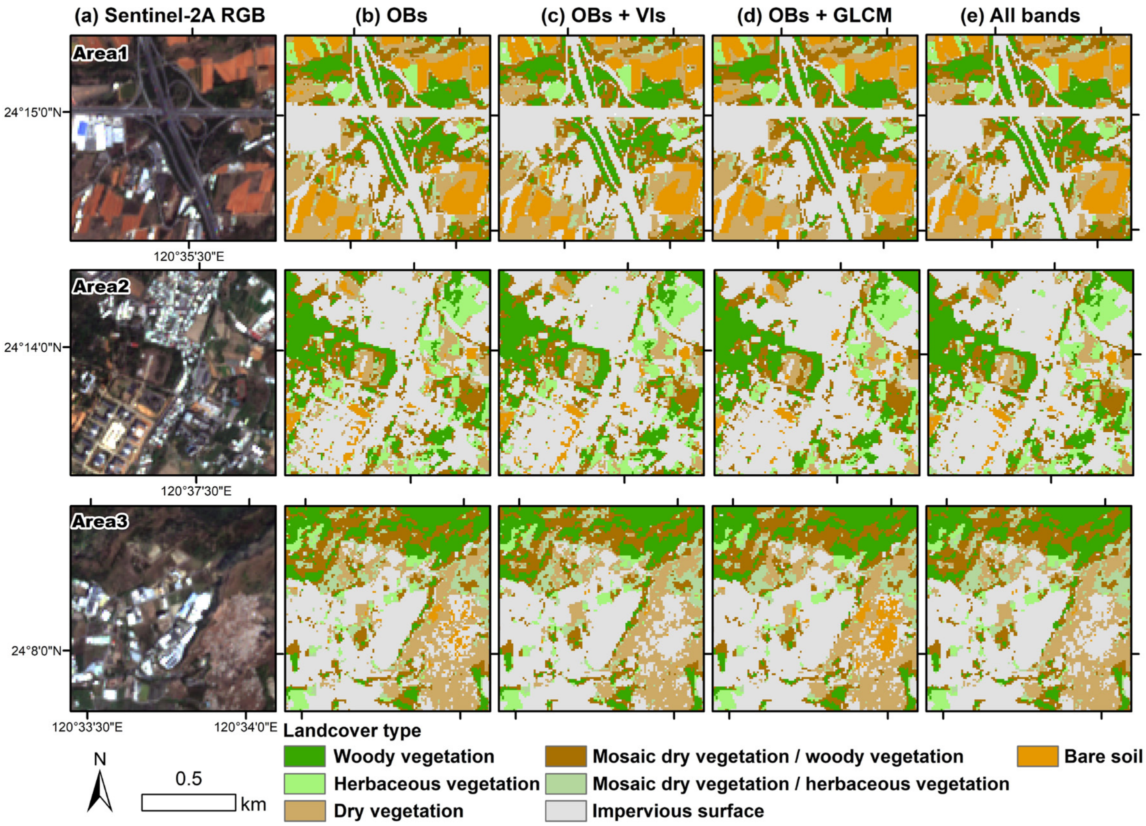

圖 6 不同特徵組合下三個複雜區域土地覆蓋分類結果的放大檢視。（a）Sentinel-2 RGB 影像；（b）原始波段；（c）原始波段添加 VIs 光譜特徵；（d）原始波段添加 GLCM 紋理特徵；（e）所有特徵變項。

Fig.6 Detailed classification results of different feature sets in three complex areas. (a) RGB Sentinel-2 image, (b) OBs, (c) OBs + Vis, (d) OBs + GLCM, and (e) all bands.

討論

在不額外添加輔助資料的情況下，以 S2 原始波段作為輸入，已能達到良好的分類效果，其分類潛力可在過去研究獲得證實（Saini and Ghosh 2018b; Macintyre *et al.* 2020），分類層級甚至可達樹種或作物別（Persson *et al.* 2018; Saini and Ghosh 2018a）。然而，本研究中的 MDW、MDH、HV 等類別，原始波段並未能將其有效分離，檢視其光譜反射特徵（圖 2），推論其原因在於這些類別本質上屬於高異質性的混淆型植被，或類別內存在高變異性的農作植被。具體而言，MDW 與 MDH 具有相似的光譜特徵，而 HV 類別內組成多樣且生長階段差異大，易與其他類別間發生光譜特徵重疊，致使分類結果產生混淆（Rodriguez-Galiano and Chica-Olmo 2012）。又地景中存在高比例的不透水層或土壤背景，也可能削弱植被對光譜的反應（Huete 1988; Skougaard *et al.* 2015）。此外，歸納分類效果較差類別之空間特徵為一、區塊細小而破碎，與其他類別高度交錯鑲嵌；二、多分布在人為與自然地景的過渡或邊緣區域，此種空間特徵，或許基於中解析力影像進行分類，本質上就較為困難。上述因素皆可能導致這 3 種類型在特徵空間中難以有效分離，即便添加能突顯地覆差異的植生指標，其分離度仍無法達到理想狀態。此種情況下，紋理特徵似乎有助於提升其分離度，此可歸因於紋理特徵在於提供同譜異物的空間資訊，反映了與周邊鄰近像元的關聯性，與光譜特徵僅基於像元光譜反射率的組合有所不同。Ma *et al.*（2021）的研究結果也提到，添加光譜特徵可進一步區分木本與非木本植被，但對於相近植被型別的辨別仍有困難。相對地，添加紋理特徵可捕捉因灰階空間關聯所引起的局部差異，進而有助增強植被型別間的分離度，足見兩類特徵對不同類別的分離度各具貢獻，具有互補性，亦有文獻（Wikantika *et al.* 2004; Chairet *et al.* 2019）指出，兩類特徵的結合將為分類結果提供最佳準確度，這種多源數據產生的協同效應（synergistic effects），有助於建構更穩健且可靠的

分類模型（Bazzo *et al.* 2024）。此外，本研究是以 DV 作為關鍵的潛在燃料源的假設下，將其視為優先關注的主要類別，而 MDW、MDH 作為 DV 與其他地覆的混淆植被，不可否認地存在某種程度的潛在風險，建議未來在應用分類結果時，進一步輔以高解析度影像或現地勘查，進行分類結果的編修，提升分類圖資的應用價值。

B2、B4、NDVI、SAVI、PSRI 為大肚臺地地覆分類最重要的波段或光譜特徵。Immitzer *et al.*（2016）同樣發現 B2、B4 兩道可見光波段為樹種分類研究中最佳預測變項，而最廣為人知的 NDVI，已在多項複雜地覆分類研究中（Jin *et al.* 2018; Somayajula *et al.* 2020）確認以其作為分類變項的可行性與重要性。一般而言，自然或半自然地景為涵蓋植被與土壤背景的混合像元，不論植被密度如何，植被光譜即難以避免受到土壤亮度的干擾（Huete *et al.* 1985），本研究所使用的 S2 影像取自乾季，多數旱作地處於土壤裸露的休耕狀態，SAVI 針對土壤條件進行調整（Huete 1988），可能對區內土壤背景的影響提供了有效的改進。值得注意的是，紅邊作為 S2 的優勢波段，並在森林植被或作物類別的分類研究中表現突出（Immitzer *et al.* 2016; Persson *et al.* 2018; Wakulińska *et al.* 2020），但在本研究結果中，除 PSRI 指標涉及 RE1 外，其餘重要相對較低，推測與本研究僅就單期的乾季影像進行分類有關，而紅邊可能更適用於多時序的植被物候監測（Persson *et al.* 2018; Zhang *et al.* 2020; Yu *et al.* 2022）。在紋理特徵方面，PC1 與可見光的 ENT 與 DIS 特徵高度相關，主要反映局部區域的邊緣紋理資訊，該成分雖解釋最多的總變異量，但其涵蓋資訊可能更多是反映地景整體的紋理結構，而非特定地覆類別的區分特徵。相對的，PC3 主要與紅邊和近紅外光波段的 COR 特徵相關，反映局部區域中灰度值的線性關係或相似程度，這種內部紋理特徵對於區分光譜相似，但空間結構不同的類別（如 MDW 與 MDH）可能別具意義，此與 Kupidura（2019）與 Mohammadpour *et al.*（2022）的研究結果

一致，Hall-Beyer（2017）檢測紋理指標在不同地景與尺度下的關連性的研究中亦指出，當需考慮邊緣特徵的情況下，COR 可作為 MEAN 的替代指標，用以進行基本紋理的度量，同時強調該指標對區塊（patch）內部特徵的解釋有關，有助於區別不同的目標類別。最後，由 Gini 平均降低量顯示（圖 4），紋理特徵雖非 RF 分類過程的重要變項，然其特徵納入與否，確實可對分類性能構成影響，這些單獨來看預測能力稍弱的紋理特徵，可能透過與其他特徵的協同作用發揮其影響力，進而獲得較佳的分類效果，只是目前尚難由 RF 的變項重要性評估，來解釋或確認此種效應（Chen and Ishwaran 2012; Bazzo*et al.* 2024）。

儘管許多研究（Adeli *et al.* 2022; Mohammadpour *et al.* 2022）強調了紋理特徵對於改進地覆分類效能的重要性，但亦有研究（Hurskainen *et al.* 2019）持相反意見，指出紋理特徵在某些情境下無法顯著提升分類性能，甚至認為紋理特徵判別地覆類別的能力不如光譜特徵（Lu *et al.* 2014）。這種分歧可能源於感測器來源、地景特徵的差異，以及測量尺度和輸入特徵組合等複雜因素，使得對於最佳分類特徵的確認，極具挑戰且不具通用性（Lu *et al.* 2014）。考慮到 GLCM 在捕捉多尺度紋理資訊方面的能力有限（De Siqueira *et al.* 2013），或許藉由多尺度（視窗大小）紋理特徵的比較，可獲得最佳分析尺度。然而，這一過程通常耗時費力，本研究在紋理特徵的運算上，僅先參考過去同樣使用 S2 作為材料的研究，進行空間參數設定，並未進行最佳尺度測試，這對掌握不同尺度下紋理特徵對分類性能影響，可能存在一定程度的侷限，未來的研究可考慮納入更廣泛的輔助資料集，並進行多尺度分析，以更深入探討紋理特徵在地覆分類的應用潛力和適用性。

最後，由於本研究所用的材料、年代、分類目的、方法及目標類別均存在差異，無法與其他同為大肚臺地土地利用或覆蓋的相關研究逕行比較。儘管如此，本研究基於衛星影像的尺度，在類別層級上尋求提升分類

準確度的策略，除對分類輔助資料的添加提供建議外，也為該地更新了有效的地覆資訊。事實上，大肚臺地多數野火與大黍物候習性及人為因素有關（莊及曾 2021），藉由精準的地覆資訊，強化對關鍵地覆類型的關注，應有助於野火風險控管，特別是不透水層與乾燥植被之間的空間關係，這些荒地與都市交界區（Wildland-Urban Interface），往往是野火問題最顯著的地方（Radeloff *et al.* 2018; Guo *et al.* 2024）。同時，理解高易燃性地覆類型的空間分布，有助推敲野火蔓延的潛在途徑（Gray and Dickson 2016; Buchholtz *et al.* 2023），以利未來燃料管理優先性與防火線佈局的規劃。

結論

本研究以 S2 原始波段作為地覆分類模型的的基礎輸入變項，並嘗試額外添加光譜與紋理輔助特徵，以 RF 進行大肚臺地土地覆蓋分類，以評估與比較不同特徵組合在提升分類準確度方面的效能。根據研究結果，提出以下結論：一、就總體準確度來看，單獨使用 S2 原始波段作為分類輸入已可獲得良好的分類效果，但相比添加輔助特徵的結果，其效能較差；二、高異質性類別是大肚臺地土地覆蓋分類中的主要誤差來源。光譜特徵在辨識高同質性類別時表現較佳；而在提升高異質性類別的分離度方面，紋理特徵則更具關鍵作用。總結而言，光譜與紋理特徵各自對不同類型的土地覆蓋具顯著貢獻，且彼此具有互補性。整合光譜與紋理特徵作為分類輔助特徵，可達到最佳分類效果。最後，本研究建議，當分類區域屬於高異質性地景，且光譜數據未能達到分類需求時，除了使用常見的光譜特徵外，應考慮額外添加紋理特徵作為輔助，以進一步提升分類準確度。

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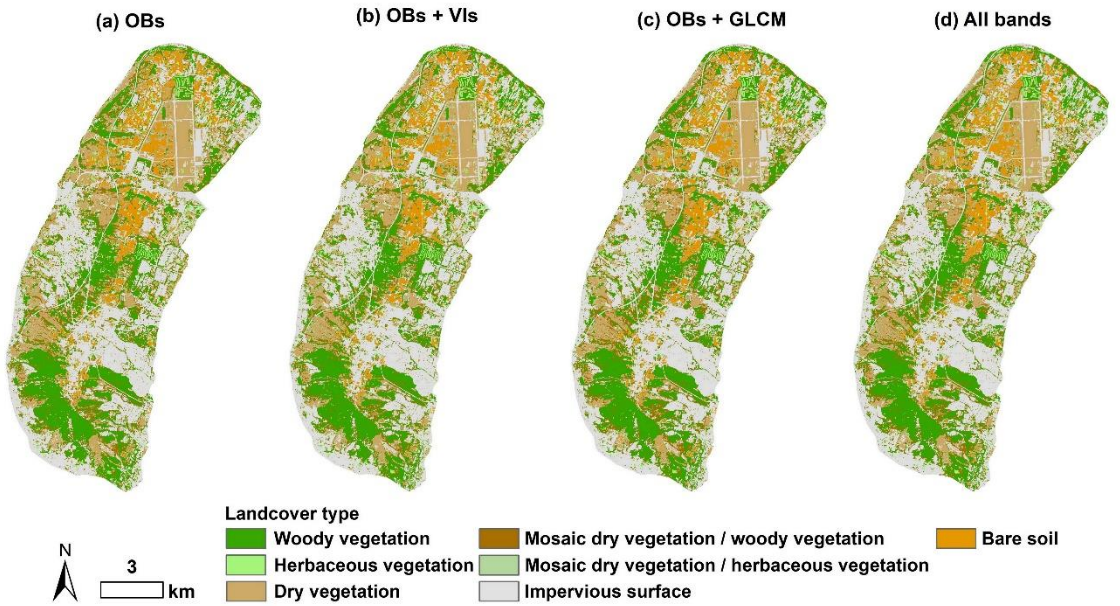
附錄 1 主成分分析前 8 個主要成分及其主要貢獻變項
Appendix 1 Eight principal components and their key contributing variables identified by PCA

PC Layers	Variance (%)	Cumulative % of total variance (%)	Input variables	Factor loadings
			B4_ENT	0.157
PC1	33.460	33.460	B4_DIS	0.151
			B3_ENT	0.150
			B3_DIS	0.094
PC2	18.708	52.168	B3_CON	0.091
			B2 _DIS	0.089
			B8A_COR	0.177
PC3	11.343	63.511	B8_COR	0.173
			B7_COR	0.169
			B4_COR	0.210
PC4	7.694	71.204	B5_COR	0.189
			B2_COR	0.187
			B8A_VAR	0.185
PC5	7.227	78.431	B8_VAR	0.177
			B7_VAR	0.173
			B3_COR	0.227
PC6	3.312	81.743	B4_COR	0.201
			B2_COR	0.198
			B11_HOM	0.211
PC7	3.032	84.775	B12_HOM	0.203
			B11_ASM	0.184
			B11_ENT	0.274
PC8	1.932	86.707	B2_VAR	0.199
			B12_ENT	0.181

附錄 2 不同特徵組合下研究區域的土地覆蓋分類結果。（a）原始波段；（b）原始波段添加 VIs 光譜特徵；（c）原始波段添加 GLCM 紋理特徵；（d）所有特徵變項。

Appendix 2 The result of Land cover classification in the study area using different feature sets. (a) OBs, (b) OBs + VIs, (c) OBs + GLCM, and (d) all bands.



大洋性海豚親緣地理研究現況與展望：以真瓶鼻海豚為例

An overview and perspective on the phylogeographic studies of oceanic delphinids: a case analysis for common bottlenose dolphin (*Tursiops truncatus*)

陳瑩 [*] 古靖 林家榆

Ing Chen*, Jing Ku and Chia-Yu Lin

國立臺灣師範大學地理學系 106308 臺北市和平東路一段 162 號

Department of Geography, National Taiwan Normal University, Taipei Taiwan

* 通訊作者：ingchen@ntnu.edu.tw

*Corresponding author:ingchen@ntnu.edu.tw

摘要

海豚科（Delphinidae）包含 38 個物種，為現生海洋哺乳動物中多樣性最高的類群。現生所有的大洋性海豚（oceanic delphinids），均為海豚科的物種。由於大洋性海豚分布範圍廣、又多以遠洋海域為主要棲地，因此除了少數明星物種如虎鯨（*Orcinus orca*）、真瓶鼻海豚（*Tursiops truncatus*）外，觀察資料或採集樣本均不完整。本研究短報以資料相對齊全的真瓶鼻海豚為例，回顧其親緣地理

學和基因體學的最新研究進展，著重其分類系統之動態變化。過去的分類標準僅認可兩個瓶鼻海豚屬（*Tursiops* sp.）物種，即真瓶鼻海豚與印太洋瓶鼻海豚（*T. aduncus*），而最新研究確認第三個物種，即坦氏瓶鼻海豚（*T. erebennus*）。同時，真瓶鼻海豚內部可再細分出四個在地理上具有特殊性的亞種或生態型。透過討論多樣化的親緣關係和族群結構，本研究提供瓶鼻海豚保育的基礎知識，並探討全球氣候變遷下，真瓶鼻海豚乃至於小型鯨豚未來可能面臨的全球性和在地性族群發展趨勢與挑戰。

關鍵詞：海洋哺乳動物、模式生物、生態保育、研究回顧

The family Delphinidae, containing 38 species, is the most diverse group among extant marine mammals. All living oceanic dolphins belong to this family. Due to their extensive distribution and primary habitats in offshore waters, observation data or sample collections from oceanic dolphins are mostly patchy, with the exception of a few relatively well-studied species, such as the killer whale (*Orcinus orca*) and common bottlenose dolphin (*Tursiops truncatus*). This mini review focuses on the common bottlenose dolphin, a species with relatively comprehensive data, to study recent advancements in its phylogeography and genomics, particularly emphasizing the dynamic changes in its classification. Traditionally, only two species within the genus *Tursiops* were recognized: the common bottlenose dolphin and the Indo-Pacific bottlenose dolphin (*T. aduncus*). However, recent studies have confirmed a third species, the Tamanend's bottlenose dolphin (*T. erebennus*). Additionally, four geographically distinctive subspecies or ecotypes have been identified within the common bottlenose dolphin. Through discussing the diverse phylogenetic relationships and population structures, this study not only provides foundational knowledge for bottlenose dolphin conservation, but also explores the potential global and local population trends and challenges for the common bottlenose dolphin and other small cetaceans under global climate change.

Key words: marine mammal, model organism, conservation, research review

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緒言

海洋哺乳動物泛指所有依賴海洋環境生存的半水生或完全水生的哺乳動物，包含鰭足下目（Infraorder Pinnipedia）、海牛目（Sirenia）、鯨下目（Infraorder Cetacea）、海獺（*Enhydra lutris*）、秘魯水獺（*Lontra felina*）、北極熊（*Ursus maritimus*）等 137 個物種（Committee on Taxonomy 2023）。除了海牛目的物種全為植食性動物外，海洋哺乳動物均為肉食性動物，於所在的生態系中普遍扮演著高級掠食者（top predator），或是關鍵物種（keystone species）的角色（Harwood 2001）。關鍵物種具有穩定當地生態系食物鏈、調節生物量等重要生態功能（Valls *et al.* 2015），也因此經常被視為監測公共衛生，如環境中重金屬、有機毒物、塑膠微粒（microplastics）等等污染物質含量的哨兵物種（sentinel species）（Chen *et al.* 2017b; Zantis *et al.* 2021; Williams *et al.* 2023）。另一方面，海洋哺乳動物通常同時是具有魅力、普遍受到大眾歡迎的中大型動物，所以在生態保育經營策略中，海洋哺乳動物也經常被定位為「吸引大眾重視生物多樣性保護」的旗艦物種（flagship species）（Zacharias and Roff 2001; Ritter 2022）。無論是由科

學理性或是社會心理層面出發，海洋哺乳動物的研究和保育，均具有一定程度的重要性。

在海洋哺乳動物中，鯨下目擁有最高的物種多樣性（共計 94 個物種，其中 1 種可能已滅絕），而在鯨下目當中又以海豚科（Delphinidae）包含最多的物種（總計 38 個物種；Committee on Taxonomy 2023）。 海豚科的物種多為大洋性（oceanic）的中小型海豚，牠們具有極佳自主活動力，主要出沒於大洋海域，對陸地的依賴程度低，再加上過去研究人員對廣闊海洋進行大範圍深入調查的技術瓶頸或預算限制，導致人們對大洋型海豚的生態學知識和保育評估的把握，相對於陸生哺乳動物，有著相當大的差距（Harwood 2001; Kaschner *et al.* 2012）。臺灣東部海岸坡度陡降，緊鄰全球最大水體太平洋，終年有暖流黑潮流經，因此即使在近岸區域，仍然經常可見真瓶鼻海豚（*Tursiops truncatus*）、花紋海豚（*Grampus griseus*）、飛旋海豚（*Stenella longirostris*）等大洋型海豚物種出沒（Yang *et al.* 1999; Tseng *et al.* 2011）。由於與大洋型海豚相關的科學和生態資訊相對欠乏，以及牠們「很常見」的刻板印象，導致牠們在國際間保育行動中的順位普遍不高，而可能使環境經營者忽略了這些物種的族群量波動趨勢，也可能有導致在地族群局部滅絕的風險（Ashe *et al.* 2021）。

真瓶鼻海豚廣泛分佈於世界各大洋熱帶及溫帶水域（圖 1），是一種常見的大洋型海豚。相對於其他大洋型海豚，在野外觀察研究真瓶鼻海豚相對容易，因為牠們也經常出現在淺水、沿海水域。此外，真瓶鼻海豚具有高度認知能力（Marino 2004）以及複雜的社會結構（Shane *et al.* 1986），因而成為研究鯨豚行為與認知的理想選擇（Hanke and Erdsack 2015）。在圈養條件下，瓶鼻海豚屬物種也是相對容易飼養和訓練的鯨豚種類（Wells and Scott 2018），牠們能在可控的環境中透過人為訓練，執行各種任務，包含娛樂展演、軍事行動、或科學研究（但是有爭議性，

見 Corkeron 2018 的討論）。綜合這些外在生態和內在生物學特色，使得真瓶鼻海豚成為鯨豚研究的模式生物（model organism），也是目前科學研究最為透徹的鯨豚物種：粗略估算，在目前已發表、以鯨豚（cetacean*）為題材的科學文獻當中，大約每 4–5 篇就有 1 篇與真瓶鼻海豚有關（圖 2）。

有鑑於真瓶鼻海豚在鯨豚中的代表性，本研究短報將透過回顧全球真瓶鼻海豚相關的研究進展及資源現況，就未來趨勢及潛在保育議題進行討論。由於有關真瓶鼻海豚的基礎生物學和生態學整合性資訊，包括分布範圍、生態學、生活史、行為生理、人類活動影響等等，在近年出版的海洋哺乳動物百科全書第三版（Encyclopedia of Marine Mammals. Third Edition）、以及國際自然保護聯盟紅皮書（IUCN Red List），皆有專文提供詳盡的描述（Wells and Scott 2018; Wells *et al.* 2019），過去亦有學術專書可供參考（Caldwell and Caldwell 1972; Leatherwood and Reeves 1990; Reynolds III *et al.* 2000），因此本短報將聚焦於先前回顧型文獻較少報導的新興研究領域，特別是親緣地理（phylogeography）及基因體學（genomics）方面之研究進展；同時介紹近年內一些在傳統生物學範疇中突破性的研究發現，最後在文末嘗試就未來趨勢以及潛在的全球性或在地性保育議題，進行初步討論。

分類與親緣地理

瓶鼻海豚廣泛分布於全球溫帶及熱帶、大洋及近岸海域，而各地的瓶鼻海豚在外形和骨骼形態上具有明顯差異性，因此在早期依賴傳統頭骨形態特徵的分類學中，瓶鼻海豚曾經一度多達超過 20 個獨立物種（Wells and Scott 2018）。即使 Rice (1998) 透過檢視當時可取得的全球瓶鼻海豚傳統形態學及分子遺傳學資料，定調瓶鼻海豚屬（Genus *Tursiops*）內僅有印太洋瓶鼻海豚（*T. aduncus*）和真瓶鼻海豚（*T. truncatus*）兩個物種，但事實上瓶鼻海豚屬內物種的分類地位，截至今日仍尚未完全明

朗。海洋哺乳動物學會分類委員會（Committee on Taxonomy, Society for Marine Mammalogy; 以下簡稱分類委員會）做為全球海洋哺乳動物分類標準的權威機構，目前認可瓶鼻海豚屬物種有三種，分別為印太洋瓶鼻海豚、真瓶鼻海豚以及坦氏瓶鼻海豚（*T. erebennus*）；其中真瓶鼻海豚之內又再細分四個亞種，詳見後述（Committee on Taxonomy 2023）。

Möller *et al.* (2008) 及 Charlton-Robb *et al.* (2011) 主張棲息於澳洲南部和東南部沿岸水域的瓶鼻海豚，在頭骨形態、粒線體 DNA 細胞色素 b（cytochrome b）及控制區（control region）、及微衛星基因座（microsatellite loci）多型性上，和澳洲其他海域採集到的印太洋瓶鼻海豚以及真瓶鼻海豚樣本間，有明顯的分化現象，因此主張這些海豚應視為獨立的物種，稱為布魯安海豚（Burrunan dolphin, *T. australis*）。然而分類委員會在近年駁回這項主張，除了是考量 Charlton-Robb *et al.* (2011) 中形態學和分子遺傳學的比較基準僅包含澳洲海域的瓶鼻海豚、且樣本數量少等原因之外，後續有納入兩種瓶鼻海豚模式標本的形態學研究（Jedensjö *et al.* 2020），以及涵蓋更廣域瓶鼻海豚樣本的單核苷酸多型性（single nucleotide polymorphism, SNP）分子遺傳學研究（Moura *et al.* 2020; Pratt *et al.* 2023），顯示南澳的布魯安海豚在形態學上並沒有明顯特殊性，且在親緣關係上更可能是一個屬於印太洋瓶鼻海豚的支系（Committee on Taxonomy 2023）。

另一方面，早在 90 年代就有初步的形態學、生態學、及分子遺傳資料指出，生息於北美大陸東岸、即西北大西洋海域的瓶鼻海豚，具有近岸、離岸的族群分化現象（Mead and Potter 1995; Hoelzel *et al.* 1998）。但是因為瓶鼻海豚為全球廣泛分布的物種，長久以來一直缺乏與其他海域個體比較形態或分子遺傳資料，以資確認西北大西洋沿岸型瓶鼻海豚的特殊性。直到近年，學者利用全粒線體基因體（mitogenome）、限制酶位點標定定序（restriction site-associated DNA sequencing, RADseq）及細胞核全基因體等定序資料，分析北大西洋兩岸、印度洋、地中海及黑海等地的瓶鼻海豚屬物種之親緣遺傳關係，發現分布於西北大西洋近岸地區的瓶鼻海豚，應是上述真瓶鼻海豚支系演化中最早獨立出來的支系（Moura *et al.* 2013, 2020; Louis *et al.* 2021）。在形態上，西北大西洋近岸型的瓶鼻海豚具有頭骨較小（頭骨基長 condylobasal length 426–510 mm；離岸型真瓶鼻海豚的測量值為 466–550 mm），脊椎骨數目較少（總數為 59–61；離岸型真瓶鼻海豚脊椎骨數目為 62–65）、頭骨形狀特化等形態特色，明顯與其他已知的瓶鼻海豚不同（Costa *et al.* 2022）。因此 Costa *et al.* (2022) 主張生息於北美大陸東岸、即西北大西洋沿岸淺海域的瓶鼻海豚族群，應視為獨立種群，採用 1865 年美國動物學家 E. D. Cope 之命名 *T. erebennus*，建議以模式標本採集地原住民部落國家（Nanticoke Lenni-Lenape Tribal Nation）的傳奇領袖坦慕尼（Chief Tamanend, 'The Affable'）之名為俗名，稱之為坦氏瓶鼻海豚（Tamanend's bottlenose dolphin）。分類委員會亦已於 2023 年認可坦氏瓶鼻海豚為第三個瓶鼻海豚屬物種。

目前分類委員會認可四個真瓶鼻海豚亞種，分別是真瓶鼻海豚指名亞種（common bottlenose dolphin, *T. t. truncatus*）、黑海瓶鼻海豚（Black Sea bottlenose dolphin, *T. t. ponticus*）、拉氏瓶鼻海豚（Lahille's bottlenose dolphin, *T. t. gephyreus*）、以及東熱帶太平洋瓶鼻海豚（Eastern Tropical Pacific bottlenose dolphin, *T. t. nuuanu*）（Committee on Taxonomy 2023）。四個亞種中，以黑海瓶鼻海豚分布範圍最為侷限，其分布範圍僅限於黑海海域（圖 1）。成年黑海瓶鼻海豚的體長及頭骨測量形質（除了頭骨寬度沒有顯著差異外），皆明顯較生活於地中海及北大西洋東岸的真瓶鼻海豚短（Viaud-Martinez *et al.* 2008）。在分子遺傳證據上，黑海瓶鼻海豚的微衛星基因座多型性和粒線體 DNA 控制區序列單套型（haplotype）分布，異於歐洲其他海

域的真瓶鼻海豚族群，且多樣性明顯偏低（Natoli *et al.* 2003, 2005; Viaud-Martinez *et al.* 2008）。利用全粒線體基因體序列重建之親緣譜系研究顯示，黑海瓶鼻海豚的母系血緣並非單系群（Moura *et al.* 2013）；但後續利用超過 26,000 個 SNP 點位重建的瓶鼻海豚親緣譜系顯示，黑海瓶鼻海豚自成一獨立支系，源自於地中海的族群（Moura *et al.* 2020）。除此之外，黑海內嚴重的水質污染、頻繁的交通運輸、以及漁業衝突問題，將黑海瓶鼻海豚族群提升為亞種，有助於推展相關保育行動（Viaud-Martinez *et al.* 2008; Birkun 2012）。

拉氏瓶鼻海豚主要分布範圍為南美洲東岸，從巴西南岸至阿根廷中部沿岸，主要棲地為河口、潟湖等的淺水區域（圖 1）。相較於真瓶鼻海豚和印太洋瓶鼻海豚，拉氏瓶鼻海豚具有體形較大（體全長 366 cm）、脊椎數目較少（總數為 57–59）、頭骨較大（頭骨基長 533–609 mm）等明顯形態特色差異性（Costa *et al.* 2016; Wickert *et al.* 2016; Hohl *et al.* 2020）。拉氏瓶鼻海豚的頭骨形態數據資料，在主成分分析（principal component analysis, PCA）中，亦明顯異於其他新興的真瓶鼻海豚亞種或族群（Costa *et al.* 2022）。因此也有學者主張拉氏瓶鼻海豚應視為獨立物種（Wickert *et al.* 2016; Hohl *et al.* 2020）。另一方面，偵測微衛星基因座和粒線體 DNA 控制區序列多樣性的分子遺傳研究顯示，雖然近岸的拉氏瓶鼻海豚和離岸的真瓶鼻海豚之間，有顯著的族群基因分化現象，但在代表近岸和離岸的海豚族群樣本中，均有少數雜交的個體，顯示兩者之間可能仍然有基因交流（Fruet *et al.* 2017）。在利用粒線體 DNA 控制區單套型序列建立的瓶鼻海豚遺傳譜系樹中，拉氏瓶鼻海豚的母系血緣亦非單系群（Costa *et al.* 2022）。然而蒐羅南半球各地瓶鼻海豚屬物種的 SNP 點位資料，又支持拉氏瓶鼻海豚和離岸真瓶鼻海豚之間有明顯譜系分化現象，唯其支系長度較短，顯見拉氏瓶鼻海豚的演化歷史尚淺（Pratt *et al.* 2023）。

除了真瓶鼻海豚指名亞種外，前

述的真瓶鼻海豚新種或亞種（即黑海瓶鼻海豚、拉氏瓶鼻海豚、以及坦氏瓶鼻海豚），皆為具有地理分布範圍相當侷限，又或棲息於近岸海域之族群生態特色。而最近被提出討論的東熱帶太平洋瓶鼻海豚，則是棲息於遠洋離岸環境，分布邊界尚無法確認的種群（Costa *et al.* 2023）。

透過查驗採集自美國加州及墨西哥西岸，擱淺或漁業混獲致死瓶鼻海豚的外型、頭骨形態、以及其他生態特色，Walker (1981) 歸納出北美大陸西岸海域的瓶鼻海豚，依照地理區位，應該有 1) 南加州與墨西哥近岸型、2) 北方溫帶離岸型、以及 3) 東熱帶太平洋離岸型等三種生態型。三個生態型之間的頭骨形態具有差異但不甚明顯，最大的差別在於牙齒的大小，以及近岸型的海豚寄生蟲感染情況明顯較少。後續檢驗微衛星基因座和粒線體 DNA 控制區序列多樣性的分子族群遺傳研究更進一步指出，Walker 分類之南加州與墨西哥近岸型以及北方溫帶離岸型之中，應可再各自細分出近岸及離岸的獨自族群（Segura *et al.* 2006; Lowther-Thieleking *et al.* 2015）。為了確認北美及中美洲西岸的瓶鼻海豚到底有多少種，Costa *et al.* (2022, 2023) 比較了分別代表加州近岸、加州灣內、東熱帶太平洋、西北太平洋（日本）的真瓶鼻海豚，以及拉氏瓶鼻海豚、坦氏瓶鼻海豚、和印太洋瓶鼻海豚的頭骨形質測量資料。結果發現，東熱帶太平洋族群的頭骨與印太洋瓶鼻海豚的頭骨較為相似，明顯較其他真瓶鼻海豚生態型小，所以東熱帶太平洋瓶鼻海豚應視為不同的亞種。而採集自加州近岸或離岸，以及加州灣內近岸或離岸海域的真瓶鼻海豚樣本，在頭骨形態上則沒有明顯差異。目前尚無分子遺傳證據以資確認東熱帶太平洋瓶鼻海豚在瓶鼻海豚屬內的親緣地位。

族群遺傳及基因體學

關於真瓶鼻海豚極易在小尺度空間環境下形成獨立生態型的現象，Louis *et al.* (2021) 分析了採集自英國、愛爾蘭、美國東岸和西岸等各地離岸和近岸海域族群、總共 57 隻真

瓶鼻海豚的全基因體序列資料。結果發現，這些海域形成近岸族群的現象，應各為獨立的平行演化（parallel evolution）事件。研究中篩檢出 7,165 個可能與適應近岸棲地有關的 SNP 點位，並透過最近共祖時間分析（Time to Most Recent Common Ancestor, TMRCA），推論「適應近岸棲地的能力」應屬真瓶鼻海豚之祖徵之一，與前人研究推論相符（Moura *et al.* 2013, 2020）。該研究更進一步偵測到近岸族群的演化進程，可能與行為及生態適應相關的 45 個基因的天擇有關。舉例而言，與認知、學習、記憶有關的基因 reelin (RELN) 和 adenosine deaminase RNA specific B2 (inactive) (ADARB2)，以及和脂肪儲存及代謝有關的基因 acylglycerol kinase (AGK)、lipin 2 (LPIN2) 和 klotho beta (KLB) 等，這些基因在不同的近岸族群中，同樣出現受到選汰的訊號，顯示其功能有一定程度之重要性。相似的研究結果也見於 Pratt *et al.* (2023) ，該研究蒐羅並分析南半球海域包含真瓶鼻海豚、拉氏瓶鼻海豚、印太洋瓶鼻海豚以及布魯安海豚等總計 353 隻海豚、18,060 個 SNP 點位的基因體資料，發現近岸型的海豚（拉氏瓶鼻海豚、印太洋瓶鼻海豚和布魯安海豚）在與心血管循環（如 protein kinase AMP-activated non-catalytic subunit gamma 2 ‘PRKAG2’、ryanodine receptor 2 ‘RYR2’）、脂質形成及能量產製（如 3-oxoacid CoA-transferase 1 ‘OXCT1’、glypican 3 ‘GPC3’、PR/SET domain 16 ‘PRDM16’）、肌肉骨骼系統（如 phosphoinositide-3-kinase regulatory subunit 1 ‘PIK3R1’、glypican 3 ‘GPC3’）、以及腦神經系統發育等（如 potassium voltage-gated channel subfamily H member 5 ‘KCNH5’、zinc finger protein 345 ‘ZNF345’、NK2 homeobox 2 ‘NKX2-2’、shroom family member 4 ‘SHROOM4’）相關功能性基因，多有受到天擇而呈現平行演化的現象。Cammen *et al.* (2015) 透過比較墨西哥灣內於 1992–2006 年間死於有害藻華（harmful algal blooms）事件與倖存的近岸瓶鼻海豚族群之間的基因體差異，找到數個可能與當地

瓶鼻海豚族群抵禦藻華毒性有關的基因點位，其中包括與調控免疫力有關的主要組織相容性複合體（Major Histocompatibility Complex; MHC）基因片段。

截至 2024 年底，於開放基因組資料庫 NCBI Genome Assembly database (https://ncbi.nlm.nih.gov/genome) 及 DNAzoo (https://dnazoo.org/assemblies) 上可取得的完整真瓶鼻海豚基因組序列（genome assembly），總共有 7 組，其中包括兩組染色體層級的高品質參考基因組（reference genome）（GCF_011762595.1, GCF_001922835.1）。透過比對包含真瓶鼻海豚在內的海洋及陸生哺乳動物物種的基因組序列，Foote *et al.* (2015) 揭露多個與適應水生環境有關的基因，在海洋哺乳動物類群中都有受到明顯的天擇選汰現象，為海洋哺乳動物的趨同演化（convergent evolution）提供了有力的基因證據。Kliesmete *et al.* (2023) 透過比對包括真瓶鼻海豚在內的 30 種哺乳動物 TMF1 regulated nuclear protein 1 (TRNP1) 基因的調控和編碼序列變異，歸納出哺乳動物大腦大小和皮質褶皺程度，與該基因的活化程度有正向相關性。Linguiti *et al.* (2021) 亦利用全基因組序列資料，建立真瓶鼻海豚 T cell receptor beta (TRB) 基因序列及蛋白質結構，確認真瓶鼻海豚的 TRB 基因組結構與其他偶蹄動物相似：由 T cell receptor beta diversity (TRBD)、T cell receptor beta joining (TRBJ) 以及 T cell receptor beta constant (TRBC) 等三個基因片段組成的 D-J-C cluster，以三個重複以內的頻率排列於 TRB 基因的 3’ 端。但真瓶鼻海豚的 TRB 基因之獨特性在於其長度僅 276Kb，相較於駱駝（*Camelus dromedarius*）、野豬（*Sus Scrofa*）、山羊（*Capra hircus*）等偶蹄動物（302Kb–558Kb）以及人類（*Homo sapiens*）（620Kb）為短，推測是因為真瓶鼻海豚基因體內片段重複（duplication）較少且發生過片段丟失（deletion），造成其 T cell receptor beta variables (TRBV) 基因組數目較少。

氣候變遷的影響

由於真瓶鼻海豚主要棲息於全球大陸棚及大洋中溫帶至熱帶水域，多數研究將其歸類為暖水性物種（warmer water-limited species），認為氣候持續暖化的情境有利真瓶鼻海豚生息，並預期其整體分布範圍將隨著氣候變遷逐漸向高緯度極區水域擴展，或通過拓殖（colonization）增加棲地面積（MacLeod 2009; van Weelden *et al*. 2021）。Principe *et al*. (2023) 調查坦氏瓶鼻海豚在美國南卡羅來納州查爾斯頓河口系統（Charleston Estuarine System, South Carolina）出現地點與水溫及鹽度間的關聯性，發現高鹽度和高水溫是顯著的海豚出現預測因子：在高鹽度的河川水域全年皆可發現坦氏瓶鼻海豚，而在低鹽度地區的水域，若是在水溫較高的時期，也偶爾會發現海豚。這項發現意味著在全球氣候變遷的趨勢下，瓶鼻海豚除了向高緯度地區移動外，也有向河流環境擴張的可能性。另一方面，Sousa *et al*. (2021) 認為馬卡羅尼西亞海域（Macaronesia）的真瓶鼻海豚群體的脆弱性，與該海域的平均海水溫度、酸度及溶氧量最為相關；而這些因素在氣候變遷下正在急劇變化，可能會對孤立族群的存續，帶來挑戰。

全球氣候變遷引發異常降雨及極地冰山融化，大量淡水注入海洋，導致海水鹽度降低，瓶鼻海豚個體及族群健康，可能因而受到影響。以美國路易斯安那州近岸族群的瓶鼻海豚為例，牠們經常使用鹽度高於 11 ppt 的區域，偶爾會在鹽度約為 8 ppt 的區域短暫停留，但會避免進入鹽度低於 5 ppt 的水域（Hornsby *et al.* 2017）。長時間暴露於低鹽度的水環境，可能導致海豚個體皮膚潰瘍、免疫力降低，進而影響生存率（McClain *et al.* 2020）。Fazioli 與 Mintzer (2020) 發現 2017 年颶風哈維（Hurricane Harvey）帶來的大量降雨，使美國德州加爾維斯頓灣（Galveston Bay）的真瓶鼻海豚在四個月內皮膚病變發生率顯著上升；且這些海豚為了避開低鹽度水域，普遍轉移至鹽度較高的深水區域，而在鹽度較低的水域中，96% 的個體身

上出現至少一處皮膚病變，其中 65% 的個體其病變程度相對嚴重。

此外，在氣候變遷情境下，食餌數量及分布勢必隨之改變，同樣可能影響海豚分布範圍，甚至成為生存挑戰（Perry *et al.* 2005）。直布羅陀海峽（Strait of Gibraltar）的長期鯨豚監測紀錄發現，身形削瘦（emaciation）的情況普遍好發於真瓶鼻海豚，且在特定年份特別嚴重，推測可能與年間食餌豐欠變化有關（Hanninger *et al.* 2023）。Zepeda-Borja *et al.* (2022) 發現墨西哥加州灣東南岸的真瓶鼻海豚相對數量及群體大小，與聖嬰現象（El Niño-Southern Oscillation）的發生具有相關性：反聖嬰年（La Niña）時觀測到的海豚數量多且群體大，可能與該時期沿岸食餌量大增有關。

討論與未來展望

由上述研究回顧可見，真瓶鼻海豚的族群結構複雜，但可以大致歸納成兩點結論：1) 真瓶鼻海豚在天擇選汰生理適應機制下，分化形成沿岸型與大洋型兩大類群；2) 沿岸型族群因各地沿岸環境差異、地理距離導致的族群隔離、小族群中大量基因漂變（genetic drift）、以及族群內社會親和性（social affinity）等內在與外在因素，容易形成地區性特化族群、生態型或亞種。然而目前的研究成果並未包含所有地理族群，且過去使用不同分子標記（molecular marker）取得之研究資料，難以整合進行統合分析（meta-analysis），所以尚無法全面了解真瓶鼻海豚的親緣地理全貌。先前分析微衛星基因座多型性和粒線體 DNA 控制區序列單套型多樣性的研究顯示，臺灣海域的真瓶鼻海豚可能也有近岸和離岸族群分化現象（Chen *et al.* 2017a），但是受限於傳統分子標記的解釋力有限，以及近岸海域樣本數目偏少，此一現象是否為真仍有待確認。隨著次世代基因定序（next-generation sequencing）技術普及，應用於野外生物族群監測變得更廣泛，配合資料開放政策及公民科學潮流興起，預期未來仍有機會發現新的真瓶鼻海豚族群或亞種，並藉由更精緻的基因體資料，能夠更精確估算各族群

間的基因流（gene flow），深入解析各族群的基因特徵、生理適應、或行為特化機制。

此外，真瓶鼻海豚為暖水性物種，過去多認為熱帶區域較不受冰河循環影響（參見 Cane 1998），因此已發表的分子生態研究，多直接採用現今氣候條件作為分析參數。然而隨科技進步，今日已有更精確的氣候及地質資料描繪熱帶海域的古氣候與海岸環境動態（Cane 1998; Voris 2000; Chiang 2009）。未來的親緣地理研究應納入更精準的古氣候與古海岸地形資料進行分析為宜。

同理，僅依賴現生真瓶鼻海豚棲地現況，包括水溫、鹽度、地形地貌等非生物環境因子，來推估物種在氣候變遷情境下的適應性並擬定保育策略，具有誤判風險。文獻回顧顯示，氣候變遷可能促使真瓶鼻海豚利用低鹽度棲地，或是造成其食餌分布變遷，進而影響個體健康。然而，氣候變遷對野生生物族群整體分布範圍變動的影響，如造成新棲地的生態平衡擾動（Alexander *et al.* 2015）、引入外來病原的可能性（VanWormer *et al.* 2019）、或局部區域族群滅絕的風險（Beever *et al.* 2011）等，迄今尚無針對真瓶鼻海豚，乃至於其他大洋性海豚物種的完整分析。

現今針對鯨豚族群的長期監測，包含本次文獻回顧中多數研究的資料來源，仍以蒐集擱淺或活組織採樣標本、目視調查、被動聲學偵測等傳統方法為主。然而近年在無人機（unmanned aerial vehicle, UAV）和環境 DNA（environmental DNA, eDNA）應用於海洋生物族群監測方面，已有顯著的技術突破（Suarez-Bregua *et al.* 2022; Álvarez-González *et al.* 2023）。預期在不久的將來，這些新興技術將為包含鯨豚在內的海洋生物及生態監測，帶來更細緻的科學資料，並提供新的觀點和思維。

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度新進教師專題研究計畫補助）資助執行。初步內容於 2023 年 1 月 17 日於臺灣東海大學舉辦之 2023 動物行為暨生態研討會海洋保育工作坊口頭發表。作者感謝審稿人及編輯提供之寶貴意見。

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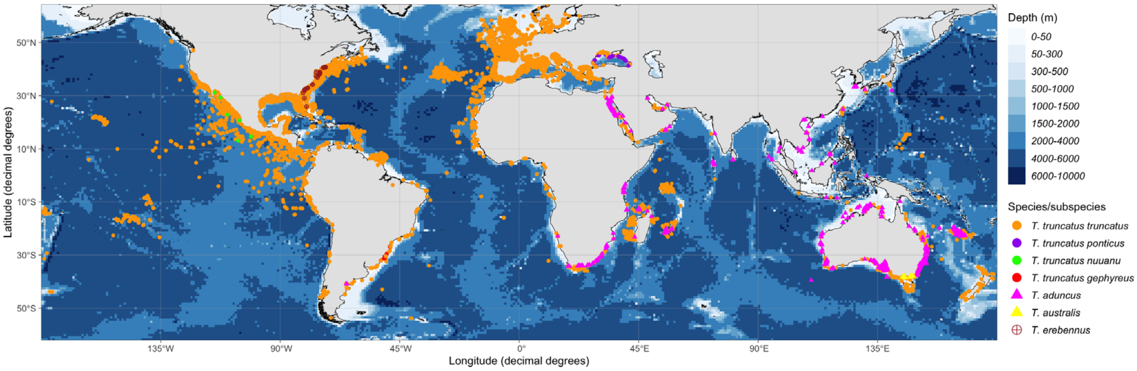

圖 1 全球生物多樣性資訊機構（Global Biodiversity Information Facility, GBIF）登載之瓶鼻海豚屬（genus *Tursiops*） 物種出現位置（GBIF.org 2023, 2024）。由於瓶鼻海豚的系統分類在 1998 年前相當混亂，因此除了東熱帶太平洋瓶鼻海豚（*T. t. nuuanu*）以外，本圖僅採用具有觀察年份紀錄，且為 2000 年以後之觀察紀錄之點位資料。東熱帶太平洋瓶鼻海豚出現紀錄皆為推測位置，來源為美國自然史博物館（Smithsonian National Museum of Natural History）館藏歷史文件（1971 年）及墨西哥國家生物多樣知識與利用委員會（La Comisión Nacional para el Conocimiento y Uso de la Biodiversidad; CONABIO）未知年份紀錄。布魯安海豚（*T. australis*）雖非海洋哺乳動物學會正式認可之瓶鼻海豚物種（Committee on Taxonomy 2023），本研究仍獨立圖示標示，以利讀者判讀。

Fig. 1 Occurrence records of species in the genus *Tursiops* as registered by the Global Biodiversity Information Facility (GBIF.org 2023, 2024). Due to unresolved taxonomy in this genus prior to 1998, only post-2000 occurrence records with recorded observation dates are included, with the exception of records for the Eastern Tropical Pacific bottlenose dolphin (*T. t. nuuanu*). Occurrence records for the Eastern Tropical Pacific bottlenose dolphin are based on inferred locations, sourced from historical documents at the Smithsonian National Museum of Natural History (1971) and undated records from Mexico's National Commission for Knowledge and Use of Biodiversity (CONABIO). Although the Burrunan dolphin (*T. australis*) is not recognized by the Committee on Taxonomy of the Society for Marine Mammalogy, its records are highlighted with different color codes for reader comprehension and recognition.

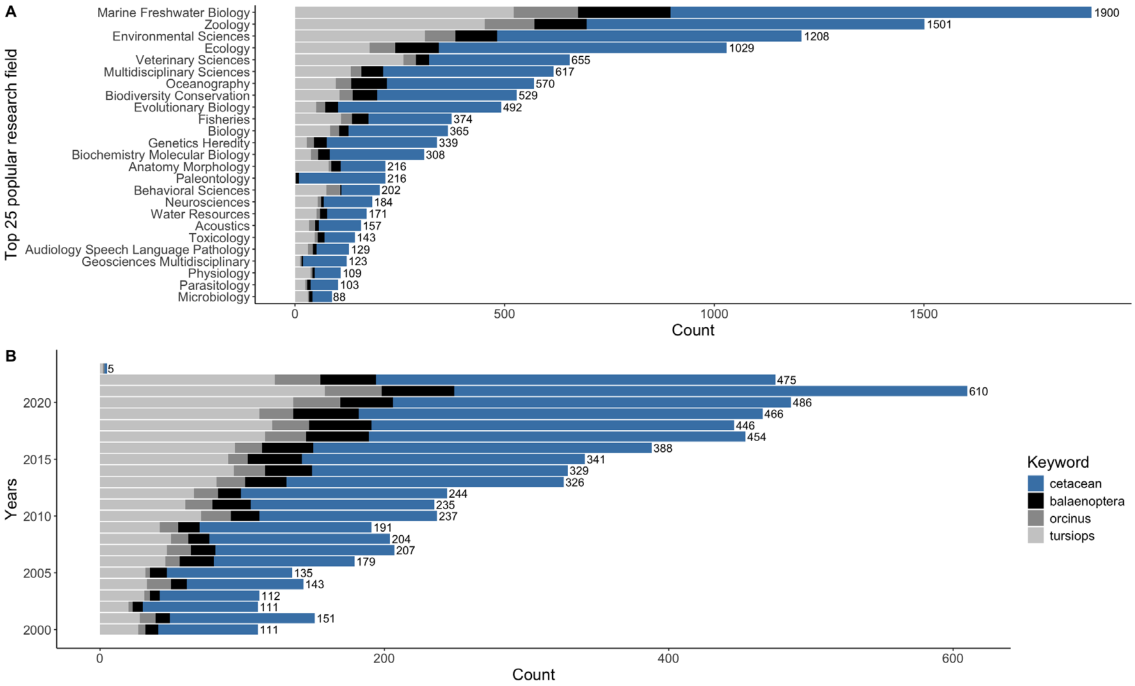

圖 2 科學論文線上資料庫「Web of Science」的引用文獻索引「Science Citation Index Expanded (SCI-Expanded)」中，收錄以「鯨豚」為主題的論文統計資料（統計截至 2023 年 1 月 10 日）。使用「TS=cetacean*」搜尋資料庫中歸類以鯨豚為題材的文獻，總共 7,447 筆；為呈現不同類群間研究文獻數量上的差異，亦使用「TS=cetacean* AND balaenoptera」搜尋與鬚鯨有關的文獻，總共 657 筆，比例約 8.8%；使用「TS=cetacean* AND orcinus」搜尋與虎鯨有關的文獻，總共 440 筆，比例約 5.9%。由於本研究焦點物種瓶鼻海豚（*Tursiops truncatus*）已知在部分文獻中會以 *Tursiops* sp. 表示，且本研究欲排除討論瓶鼻海豚的近源種印太洋瓶鼻海豚（*Tursiops aduncus*），所以統計以瓶鼻海豚為題材的文獻方式採用搜尋「TS=cetacean* AND tursiops」的文獻總筆數，再扣除「TS=cetacean* AND tursiops AND aduncus NOT truncatus」的方式計算，總共取得 1795 筆，比例約 24.1%。上圖 A 為統計文獻數目最多的 25 個研究領域中各類群的文獻數目，下圖 B 為統計 2000–2023 年各類群的文獻數目。圖中藍色長條及黑色數字表示以鯨豚（cetacean*）為主題的文獻數目，淺灰色長條代表瓶鼻海豚（*Tursiops*）、灰色代表虎鯨（*Orcinus*）、鐵灰色代表鬚鯨屬（*Balaenoptera*）的文獻數目統計。

Fig. 2 Statistics of cetacean-related publications indexed in the Science Citation Index Expanded (SCI-Expanded), Web of Science database (as of January 10, 2023). Using the search term “TS = cetacean*,” a total of 7,447 publications related to cetaceans were retrieved. To show the disparity in publication volume across different cetacean groups, additional searches were conducted as follow. The “TS = cetacean* AND balaenoptera” yielded 657 publications related to mysticetes, representing approximately 8.8%, and “TS = cetacean* AND orcinus” yielded 440 publications related to killer whales, representing about 5.9%. The focal species of this study was the common bottlenose dolphin (*Tursiops truncatus*), sometimes labelled as *Tursiops* sp. in certain publications. In order to exclude the closely related Indo-Pacific bottlenose dolphin (*Tursiops aduncus*) in this study, publications related to the common bottlenose dolphin were calculated by subtracting results for “TS = cetacean* AND tursiops AND aduncus NOT truncatus” from “TS = cetacean* AND tursiops”, resulting in a total of 1,795 publications (~24.1%). The top panel (A) shows the number of publications for each group across the 25 most represented research fields, while the bottom panel (B) illustrates the annual number of publications for each group from 2000 to 2023. In the figure, blue bars and black numbers represent the number of publications focused on cetaceans (cetacean*), while light gray bars on bottlenose dolphins (*Tursiops*), gray bars on killer whales (*Orcinus*), and dark gray bars on *Balaenoptera* species.

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

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