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Mapping of Taiwan's wetland distribution using the 2020–2021 land use investigation data

以 2020–2021 國土利用現況調查成果資料繪製臺灣濕地分布圖

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Abstract

In order to promote the conservation of wetlands in Taiwan, the Wetland Conservation Act came into effect on February 2, 2015. However, basic information, such as the types, areas, and distribution of wetlands in Taiwan, were still incomplete. In this study, the data from the Land Use Investigation maintained by the National Land Surveying and Mapping Center, Ministry of the Interior for the years 2020 to 2021 were used, along with relevant remote sensing imagery and integrated image platforms. The Land Use Investigation data, consisting of 93 categories, were matched with the 42 wetland classification types defined by the Ramsar Convention, and those wetland types were extracted by using Geographic Information System (GIS) software for mapping and analysis to understand the spatial distribution of wetlands in Taiwan. The study identified 24 Ramsar wetland categories, including 9 marine/coastal wetland categories, 5 inland wetland categories, and 9 artificial wetland categories, with a total area of 462,000 hectares. This information could serve as a foundational dataset for wetland-related research and provide wetland management authorities with references and applications in decision-making, planning, and operational management.

Key words: wetland, Ramsar Convention, Geographic Information System (GIS)

摘要

臺灣為推動濕地生態之保育，濕地保育法業於 2015 年 2 月 2 日開始施行，惟有關臺灣濕地之類型、面積及分布等基礎資訊仍不完整。本研究以內政部 2020–2021 年更新維護之國土利用現況調查成果資料為材料，配合相關遙測影像資料與介接影像平台，將國土利用調查資料 93 類與拉姆薩公約之濕地分類類型 42 類按其定義進行配對，並以地理資訊系統軟體萃取濕地類型，完成製圖與分析，以瞭

解臺灣濕地之空間分布。研究篩選出拉姆薩濕地類型計有 24 類，包括海洋／海岸濕地 9 類、內陸濕地 5 類及人為濕地 9 類，面積合計 46.2 萬 ha，此資訊可提供濕地相關研究基礎資料，以及濕地管理單位在決策、規劃及經營管理之參考與應用。

關鍵詞：濕地、拉姆薩公約、地理資訊系統

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Introduction

Wetlands are one of the Earth's most productive ecosystems, providing unique and abundant habitats that nurture rich biodiversity and biomass. They were also recognized as crucial repositories of plant genetic materials (Ramsar Convention Secretariat 2006). Wetlands offer diverse ecological functions and services, such as water supply, water quality improvement, recreation, and habitat support. On average, the annual value of wetlands was estimated to exceed $2,800 per hectare (Brander *et al.* 2006). According to the Millennium Ecosystem Assessment, global wetlands disappeared more rapidly than other ecosystems (Agardy and Alder 2005). Therefore, it was important to record that information on the distribution and status of wetlands. With significant advancements in the spatial resolution and availability of Earth observation data, these technologies can be widely applied to wetland monitoring and mapping (Fitoka and Keramitsoglou 2008). The global coverage of inland and coastal wetlands exceeds 12.1 million square kilometers, nearly the size of Greenland. Of this total, 54% were permanently submerged, and 46% experienced seasonal flooding (Gardner *et al.* 2018). The largest areas of wetlands were in Asia which covers 32% of the global area, followed by North America (27%), Latin America and the Caribbean region (16%) (Davidson *et al.* 2018). However, natural wetlands gradually disappeared, and wetland-dependent species, such as fish, water birds, and turtles, seriously declined. Approximately one-fourth of these species face the threat of extinction, particularly in tropical regions (Gardner *et al.* 2018).

Due to the lack of clear boundaries between wetlands and aquatic or terrestrial areas, various academic fields focus on different aspects of wetland research, and the recognition of wetlands varies among different countries or regions. According to the first article of the Ramsar Convention, which defines wetlands, "wetlands are areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres" (Ramsar Convention Secretariat 1971). This definition was the broadest and most widely accepted internationally. Taiwan, in its Wetland Conservation Act announced on July 3, 2013, largely adopted the definition of wetlands from the Ramsar Convention. The Convention categorizes wetlands into three major types: Marine/Coastal Wetlands, Inland Wetlands, and Human-Made Wetlands. Each of these major types was further subdivided into 12, 20, and 10 categories, respectively, totaling 42 wetland types (Ramsar Convention Secretariat 2013).

To promote the conservation of wetland ecosystems, the Ministry of the Interior in Taiwan designated 75 national important wetlands in 2007. In 2010, the Executive Yuan approved the "National

Important Wetland Conservation Plan (Years 100–105)" as a blueprint for promoting wetland conservation and restoration. Furthermore, on July 3, 2013, the Wetland Conservation Act was announced, and on February 2, 2015, it was implemented on World Wetlands Day. In total, 83 national important wetlands were identified, including 2 international-level important wetlands, 40 national-level important wetlands, and 41 temporarily designated local-level important wetlands, covering a total area of approximately 47,600 hectares. Among the 41 locally designated important wetlands, a reassessment had been conducted, with 23 locations completed and ongoing assessments (Urban and Rural Development Branch, Construction and Planning Agency, Ministry of the Interior, 2019). However, existing research projects tended to focus on aspects, such as wetland survey and maintenance, ecological restoration, environmental education, and related measures under the Wetland Conservation Act. Essential and important issues, such as wetland types, their respective areas, and distribution in Taiwan have not been thoroughly addressed. This study primarily adopts the method used by Chen (2017) for producing wetland distribution maps based on the Ramsar Convention wetland classification. The Land Use Investigation maintained by the National Land Surveying and Mapping Center, Ministry of the Interior for the years 2020–2021 was used, along with relevant remote sensing imagery, followed by employing the Geographic Information System (GIS) tools to extract wetland types. The study aimed to create wetland maps and conduct spatial analysis to understand the spatial distribution of wetlands in Taiwan, which could address the aforementioned issues and provide wetland management agencies with references and applications for decision-making, planning, and operational management.

Materials and methods

1. **Study area**

The definition of wetlands in Article 4 of the Wetland Conservation Act in Taiwan was as follows: "refers to natural or artificial areas, permanent or temporary, stationary or flowing, with fresh, salt, or brackish water, including marshes, lagoons, peatlands, intertidal zones, and water areas, including areas of marine water the depth of which at low tide does not exceed six meters". This definition was nearly consistent with the definition in the Ramsar Convention. The wetlands obtained in this study were based on the wetland types defined by the Ramsar Convention. Due to the lack of complete depth data for the surrounding sea areas of outlying islands, the research scope was limited to Taiwan's main island and its surrounding sea areas within 6 meters.

2. **Materials**

The primary data used in this study was the Land Use Investigation layer. This numerical 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 in the years 2020 to 2021. The land use classification system was divided into three levels: the first level includes 9 major classes, the second level was further subdivided into 48 subclasses, and the third level was then further detailed into 93 categories, as detailed in Appendix 1 (National Land Surveying and Mapping Center, Ministry of the Interior 2010). The depth data for the surrounding sea areas were provided by the Department of Land Administration of Ministry of the Interior. These included the completed basic sea area maps and depth survey data for 5m and 10m water depth lines, from which the 6m water depth line was interpolated using an interpolation method. Upon consulting with the National Land Surveying and Mapping Center of the Ministry of the Interior regarding the most recently completed basic sea area maps and depth survey data, it was confirmed that this data was managed and supplied by the Department of Land Administration of Ministry of the Interior. The 6m water depth lines were edited and produced using ArcGIS Pro.

3. **Wetland extraction**

The Ramsar Convention categorizes wetland types into three main groups: Marine/Coastal Wetlands, Inland Wetlands, and Artificial Wetlands. Each of these groups was further subdivided into 12, 20, and 10 types, respectively, resulting in a total of 42 wetland types, as detailed in Appendix 2 (Ramsar Convention Secretariat 2013). We matched the wetland classification types of Land Use Investigation with the Ramsar Convention accorded to their definitions of wetland types. This matching process involved incorporating relevant reference layers and imagery, including obtaining the coastal area boundary layer from the National Land Management Agency, accessing the National Land Surveying and Mapping Center's Land Surveying Map Network Map Service System, utilizing nationwide aerial photography and Formosat-2 satellite through the Aerial Survey and Remote Sensing Branch's Taiwan Aerial Photography and Formosat-2 Image Supply Platform, and using data from Google Maps and Google Earth Pro. These sources were used to filter and identify land use categories that meet the definition of wetlands.

4. **Image processing**

The land use categories containing wetlands, identified through the matching and filtering process, were merged and mapped using GIS software, specifically ESRI ArcGIS Pro.

Results and discussion

We matched and extracted the wetland types based on the definitions of the 93 land use categories in the Land Use Investigation with the 42 wetland classification types of the Ramsar Convention. The goal was to identify and extract wetland types. The results show that out of the 93 land use categories, 24 matched the wetland types defined by the Ramsar Convention. The extracted data encompassed a total of 1,147,875 records with a cumulative area of 2,300,004 hectares. The matching and extraction results were detailed in Table 1. Among the identified wetland types, 13 land use categories, including paddy fields, aquaculture, rivers, dredging rivers, canals, drainage ditches, reservoirs, lakes, other reservoirs, canal sandbar beach place, sea, wetlands and beaches, conformed to the wetland classification types defined by the Ramsar Convention. Additionally, 11 land use categories, such as broadleaf forests, government agencies, elementary schools, middle schools, colleges and universities, other cultural facilities, park green square, the salt industry and related facilities, grassland, reef rock, and the place of partial areas have not been used, including some sections qualified as wetlands.

Due to differences in the classification types between the Land Use Investigation and Ramsar Convention wetland classification, the corresponding relationship was not a simple one-to-one mapping. Instead, it was often involved with one-to-many or many-to-one relationships. In one-to-many relationships, for example, some aquacultures were corresponded to Ramsar wetland types 1 (aquaculture ponds) and J (coastal saline lagoons) because they were located in lagoons. Rivers were subdivided to correspondence to Ramsar wetland types F (estuarine waters), mangroves (I), streams (M, N), and irrigation or drainage channels (3, 9). In many-to-one relationships, for instance, paddy fields, some government agencies, and elementary schools collectively correspond to Ramsar wetland type 3 (paddy fields). Dredging rivers, canals, drainage ditch, middle schools, and the park green square jointly correspond to Ramsar wetland type 9 (canals, drainage channels, and ditches).

Some land use categories posed challenges in classification, such as the rivers category needing differentiation into estuaries, permanent, or seasonal rivers. The drainage ditches category could not be distinguished from irrigation channels or drainage channels in some cases. The spring wetlands category may have small or elongated channels that may be difficult to mark, especially when located under forests. Some mangrove categories were often classified as either natural or artificial broad-leaved pure forests. Other categories, such as those belonging to schools, parks, military lands, etc., require further extraction to identify pools. The handling of these issues has been discussed by Chen (2017), and other related problems were outlined below.

The land use classification of Land Use Investigation classifies rice crops as "rice fields” category in the third-level classification for the years 2006–2015. Other paddy crops, including water bamboo shoots, calla taro, water weeds, lotus, water lily, water lotus, water chestnut, Dajia rush, triangular rush (saline grass), and cattail plants, were classified as "dry farm." In the classification for the years 2016–2019, paddy fields were further divided into rice fields and other paddy fields categories. However, in the classification of Land Use Investigation for the years 2020–2021, rice fields with other paddy fields were merged into a general category of “paddy fields". Upon verification, it was found that some of the other wet fields were planted aquatic crops in rotation with rice. Approximately half of the entries in the land classification in the year 2008 were erroneously categorized as either "rice field " or " dry farm".

The data on reservoir categories comply with the Ramsar Convention's wetland classification types for reservoir storage areas (with an area exceeding 8 hectares), consisting of 43 polygons. There are also 43 polygons with areas below 8 hectares. However, some polygons in this category, when referenced against images, were found to be segmented by roads or bridges, resulting in blocks smaller than 8 hectares. Upon closer inspection by enlarging the images, it was discovered that if these segments were connected to existing reservoirs, they were considered part of the same polygon and were still classified as Type 6 (permanent freshwater lakes). Additionally, during image comparison, it was observed that reservoirs may appear segmented due to different wet and dry seasons. Therefore, a detailed examination through image enlargement was necessary to confirm whether these segments represent areas of the same reservoir.

The lake category includes some parts of water named lakes that were not naturally formed. If their proximity to agriculture and roads suggests artificial origins, they were classified as artificial lakes. The classification principles for cases where these lakes are intersected by roads or bridges are as follows:

If the segmentation exceeds 8 hectares, they were categorized as Type 6 (water storage area).

If the segmentation was less than 8 hectares, they were categorized as Type 2 (pond).

For natural lakes that were intersected by roads or bridges:

If the segmentation exceeds 8 hectares, they were categorized as Type O (permanent freshwater lake).

If the segmentation is less than 8

hectares, they were categorized as (Tp, Ts) (permanent freshwater marsh and pond, seasonal freshwater swamp and pond).

The wetland category layer primarily consists of nationally important wetlands, such as the Chenglong Important Wetland, and wetland parks like the Jhongdu Wetland Park. Some areas designated as wetland parks had undergone land use transformation, becoming aquaculture ponds or salt pans. Depending on their water body size, they were classified as Convention wetland type 6 (water storage areas) or 2 (ponds). Alternatively, based on their environmental characteristics, they may be categorized as H (intertidal marshes) or I (intertidal forested wetlands), such as intertidal marshes or intertidal mangrove swamps.

Regarding the beach category, certain blocks appear to be intertidal mudflats when viewed on the layer, located near the coastline and adjacent to mountains. However, a 3D inspection revealed them to be exposed mountain slopes with steep gradients. They remain unaffected during high tide, and rainwater or seawater does not easily accumulate in these areas. As a result, they were classified as non-wetlands. In cases where intertidal mudflats had mangrove distribution, they were extracted as Convention wetland type I (intertidal forested wetlands).

For the broadleaf forest category, the focus was on extracting habitats where mangroves have been grown. These habitats were often located along the coast and around aquaculture ponds near the sea. Some tree species, such as *Casuarina equisetifolia* used in windbreak forests, may grow in mixed stands with mangroves. Certain windbreak tree species, like the *Hibiscus tiliaceus*, could resemble mangroves when they were farther away. It was crucial to identify their growth environment, leaf width, leaf shape, and root location to confirm the accuracy of tree species identification.

In the reservoir category, some constructed wetlands were originally paddy fields or ponds. After conversion into constructed wetlands, they primarily served as sewage treatment areas. When these areas were inspected, their functionality as constructed wetlands was considered, and they are classified as Convention wetland type 8 (Wastewater treatment areas).

In the reef crag category, it was observed during layer inspection that some areas classified as rocky shore were actually exposed land in inland mountainous regions. These areas were then classified as non-wetlands.

For the grassland category, some layers showed the presence of mangroves along ditches and drainage channels near the estuary. In such cases, the extraction process identifies them as Convention wetland type I (intertidal forested wetlands).

The areas and proportions of various wetland types extracted according to wetland classification are summarized in Table 2, and the distribution of wetlands in Taiwan is illustrated in Figure 1. The total area of 24 wetland types was 462,079.00 hectares. Among the three major wetland categories as following:

Marine/Coastal Wetlands had a total area of 112,419.64 hectares, constituting 24.33% of the total wetland area. This category includes nine types, such as shallow marine waters, coral reefs, rocky marine shores, sand bars or sand dune, estuarine waters, intertidal mud or sand, intertidal marshes, intertidal forested wetlands, and coastal saline lagoons. Shallow marine waters, with an area of 74,717.24 hectares (16.17%), are the largest subtype.

Inland Wetlands covered a total area of 99,457.70 hectares, accounting for 21.52% of the total wetland area. This category includes aquaculture ponds, ponds (usually less than 8 hectares), rice fields, irrigation channels or drainage ditches, salt fields, reservoir areas, excavation areas, wastewater treatment areas (artificial wetlands), canals, drainage channels, and ditches. Rivers in inland areas, totaling 97,513.34 hectares (21.10%), were the largest subtype.

Human-made Wetlands, the largest in terms of area among the three categories, had a total area of 250,201.66 hectares, representing 54.15% of the total wetland area. This category includes aquaculture ponds, ponds, paddy fields, irrigation channels or drainage channels, salt pans, water storage areas, excavations, wastewater treatment areas and canals. Among them, paddy fields, covering 168,433.51 hectares (36.45%), were widely distributed in the plains of Taiwan and represent the largest subtype among wetland categories.

Conclusion

In this study, we utilized the Land Use Investigation data that have been maintained by the National Land Surveying and Mapping Center, Ministry of the Interior in Taiwan for the years 2020–2021. The wetland types were matched with the classifications defined by the Ramsar Convention. The ground spatial resolution of aerial imagery for wetland inspection was less than 50 cm, an improvement over the previous use of color-fused satellite imagery with a resolution of 2 meters, enhancing wetland identification capabilities. However, distinguishing between permanent and seasonal streams, especially for many narrow and elongated streams exhibiting intermittent patterns during the dry season, still remains challenging due to the often subterranean flow.

Additionally, the lack of differentiation between irrigation and drainage channels in the data results in shared channels for industrial and agricultural purposes. Therefore, distinguishing between irrigation channels and drainage channels in human-made wetlands using imagery remains challenging.

GIS software was employed to extract wetland types and produce a wetland distribution layer. We identified 24 Ramsar wetland types, including 9 marine/coastal wetland types, 5 inland wetland types, and 9 artificial wetland types. The total area was 462,079 hectares. This information serves as fundamental data for wetland-related research, providing wetland management units with reference data for decision-making, planning, and operational management. It could also be used for subsequent research applications, such as wetland assessment, net-zero loss policies, biomass, carbon emission inventories, ecological service calculations, and studies on various wetland types.

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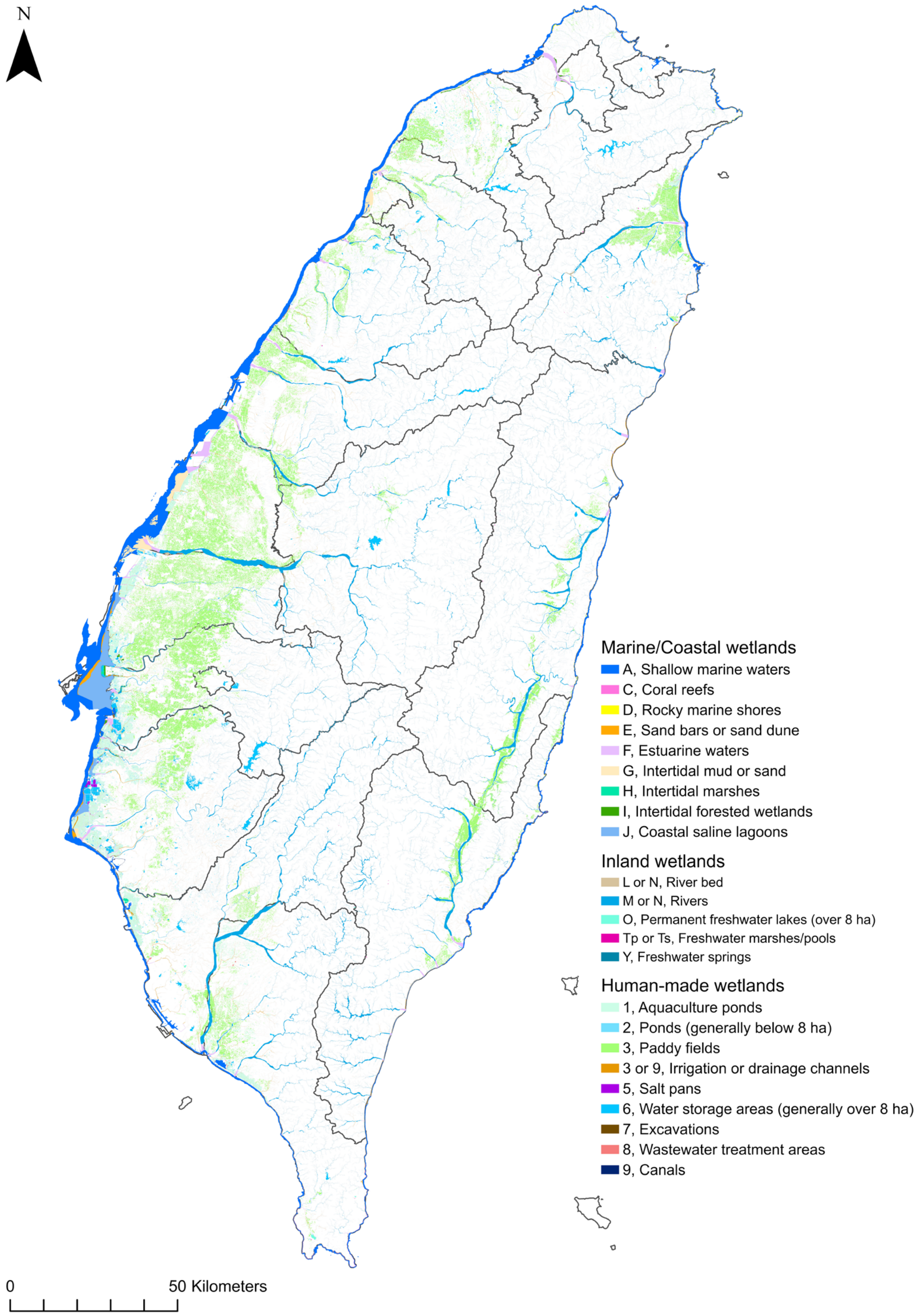

圖 1 臺灣濕地分布圖。

Fig. 1 Map showing wetland distribution in Taiwan. (English codes or numbers correspond to the code of the Ramsar wetland classification system)

Table 1 Land Use Investigation Data matched with the wetland types specified in the Ramsar Convention
表 1 國土利用現況調查成果資料與拉姆薩公約之濕地類型配對表

L_C3*	Lcode_C3**	Ramsar_code***
Paddy field	010101	3
Aquaculture	010200	1,J
River	040101	F, I, (M, N), (3, 9)
Dredging River	040102	9, not wetland
Canal	040103	9
Drainage ditch	040104	(3, 9), 9, F, I, J, Y, (M, N)
Reservoir	040201	6, not wetland
Lake	040202	O, (Tp, Ts), 2, 6, Y, not wetland
Other reservoirs	040203	A, O, (Tp, Ts), Y, 2, 6, 7, 8
Canal sandbar beach place	040300	G, I, (L, N)
Sea	040600	A, J
Wetland	090100	E, F, G, H, I, (L, N), 1, 2, 6, 8, (3, 9), not wetland
Beach	090301	D, E, F, G, I, (L, N), (M, N), not wetland
Broadleaf forest	020200	part of H, I
Governmental agency	060100	part of F, J, (M, N), 1, 2, 3, (3, 9)
Elementary school	060202	part of 2, 3, (3, 9)
Middle school	060203	part of 2, 9, (3, 9)
Universities, colleges and institutes	060204	part of 1, 2, 6, (3, 9)
Other cultural facilities	070103	part of 2, Y
Park green square	070200	part of 2, 3, 6, 8, 9, (3, 9), A, D, I, (M, N), O, Y
Salt industry and related facility	080300	part of 1, 2, 5, 6, (3, 9), H, I
Grassland	090200	part of I, (M, N), 2
Reef crag	090303	part of C, D, E, G, (L, N)
the place has not been used	090501	part of 2, (3, 9), F, I

*L_C3: Landuse_Class3; **Lcode_C3: Landuse code_Class3; ***Ramsar_code: Ramsar Convention's wetland classification codes

*第三級土地類別：國土利用現況調查成果資料第三級土地利用類別；**第三級土地利用類別代碼；***拉姆薩公約濕地分類代碼

Table 2 Wetland types and areas in Taiwan
表 2 臺灣濕地類型與面積

Ramsar code	Wetland types	Area (hectare)	Area (%)
Marine/Coastal wetlands		112,419.64	24.33
A	Shallow marine waters (海岸淺水域)	74,717.24	16.17
C	Coral reefs (珊瑚礁)	348.97	0.08
D	Rocky marine shores (岩礁)	547.75	0.12
E	Sand bars or sand dune (沙洲或沙丘)	2,981.50	0.65
F	Estuarine waters (河口)	10,459.40	2.26
G	Intertidal mud or sand (潮間帶泥灘或沙灘)	8,527.32	1.85
H	Intertidal marshes (潮間帶草澤)	432.87	0.09
I	Intertidal forested wetlands (潮間帶林澤)	1,131.25	0.24
J	Coastal saline lagoons (海岸鹹水潟湖)	13,273.33	2.87
Inland wetlands		99,457.70	21.52
L, N	River bed (河床)	1,551.13	0.34
M, N	Rivers (溪流)	97,513.34	21.10
O	Permanent freshwater lakes (over 8 ha) (永久性淡水湖泊)	254.53	0.06
Tp, Ts	Freshwater marshes/pools (淡水沼澤與池塘)	122.35	0.03
Y	Freshwater springs (淡水湧泉)	16.35	0.00
Human-made wetlands		250,201.66	54.15
1	Aquaculture ponds (養殖池)	38,894.11	8.42
2	Ponds (generally below 8 ha) (池塘)	10,550.84	2.28
3	Paddy fields (水田)	168,433.51	36.45
3, 9	Irrigation or drainage channels (灌溉渠道或排水道)	18,188.43	3.94
5	Salt pans (鹽田)	463.63	0.10
6	Water storage areas (generally over 8 ha) (蓄水區)	13,418.38	2.90
7	Excavations (開鑿區)	0.07	0.00
8	Wastewater treatment areas (廢水處理區)	204.85	0.04
9	Canals (運河)	47.84	0.01
Total		462,079.00	100.00

Appendix 1 The classification system used in the Land Use Investigation Data of Taiwan for the years 2020-2021

附表 1 臺灣 2020-2021 年國土利用現況調查成果土地使用分類系統

Code 1	Class 1	Code 2	Class 2	Code 3	Class 3
01	Agriculture	0101	Farm crops	010101	Paddy field
				010102	Dry farm
				010103	Fruit tree
		0102	Aquaculture	010200	Aquaculture
		0103	Poultry	010301	Livestock
				010302	Pasture
		0104	Agriculture related facilities	010401	Agricultural production facilities
				010402	Agricultural production, marketing and processing facilities
02	Forestry	0201	Conifer forest	020100	Conifer forest
		0202	Broadleaf forest	020200	Broadleaf forest
		0203	Bamboo grove	020000	Bamboo grove
		0204	Confusion forest	020401	Conifer and broad-leaf confusion forest
				020402	Bamboo and broad-leaf confusion forest
				020403	Bamboo and Conifer confusion forest
				020404	Bamboo, conifer and broad-leaf confusion forest
		0205	Shrubland	020500	Shrubland
		0206	Young woodland	020600	Young woodland
		0207	Other forest-use land	020700	Other forest-use land
03	Transportation	0301	Airport	030100	Airport
		0302	Railroad and related facility	030201	Common railroad
				030202	Railroad related facility
		0303	High-speed railroad and related facility	030301	Common railroad
				030302	High-speed railroad-related facility
		0304	Mass rapid transit and related facility	030401	Mass rapid transit
				030402	Mass rapid transit-related facility
		0305	Path and related facility	030501	National highway
				030502	Provincial road
				030503	Expressway
				030504	Common path
				030505	Path related facility
		0306	Harbor	030601	Commercial harbor

				030602	Fishing port
				030603	Special-purpose port
				030604	Other port related facility
04	Water Conservancy	0401	River course	040101	River
				040102	Dredging River
				040103	Canal
				040104	Drainage ditch
		0402	Reservoir	040201	Reservoir
				040202	Lake
				040203	Other reservoirs
		0403	Canal sandbar beach place	040300	Canal sandbar beach place
		0404	Water conservation structure	040401	Embankment
				040402	Water Gate
				040403	Pumping station
				040404	Reservoir barrage
				040405	Underground takes the water well
				040406	Other water conservancy facility
		0405	Flood prevention path	040500	Flood prevention path
		0406	Sea level	040600	Sea
05	Built-up Land	0501	Trade	050101	Retail sales wholesale
				050102	Service industry
		0502	Pure housing	050200	Pure housing
		0503	Mixed-use housing	050301	The concurrently industry uses the housing
				050302	The concurrently trade uses the housing
				050303	Concurrently others use housing
		0504	Manufacturing industry	050400	Manufacturing industry
		0505	Stores in a storehouse	050500	Stores in a storehouse
		0506	Religion	050600	Religion
		0507	Funeral and burial facility	050700	Funeral and burial facility
		0508	Other built-up Land	050801	Constructs
				050802	Other
06	Public Land	0601	Governmental agency	060100	Governmental agency

		0602	School	060201	Preschool
				060202	Elementary school
				060203	Middle school
				060204	Universities, colleges and institutes
				060205	Special school
		0603	Medical health care	060300	Medical health care
		0604	Social welfare facility	060400	Social welfare facility
		0605	Public utility	060501	Meteorology
				060502	Electric power
				060503	Gas
				060504	Running water
				060505	Gas station
		0606	Environmental protection facility	060600	Environmental protection facility
07	Recreation and Leisure	0701	Cultural facilities	070101	Decretory cultural facilities
				070102	General cultural facilities
				070103	Other cultural facilities
		0702	Park green square	070200	Park green square
		0703	Leisure facility	070301	Amusement place
				070302	Sports place
08	Minerals	0801	Mining industry and related facility	080100	Mining industry and related facility
		0802	Earthstone and related facility	080200	Earthstone and related facility
		0803	Salt industry and related facility	080300	Salt industry and related facility
09	Miscellaneous Land	0901	Wetland	090100	Wetland
		0902	Grassland	090200	Grassland
		0903	Bare land	090301	Beach
				090302	Landslide
				090303	Reef crag
		0904	Builds the surplus cubic meter of earth and stone	090400	Builds the surplus cubic meter of earth and stone
		0905	Exposed open area	090501	Has not used the place
				090502	In artificial change land

Data sorted out and modified from the Land Use Investigation of Taiwan National Land Surveying and Mapping Center, M.O.I. (https://www.nlsc.gov.tw/cl.aspx?n=13705)

Appendix 2 Ramsar wetland classification system
附表 2 拉姆薩公約濕地類型分類系統

Wetland Code/Description
Marine/Coastal Wetlands
A -- Permanent shallow marine waters in most cases less than six metres deep at low tide; includes sea bays and straits.
B -- Marine subtidal aquatic beds; includes kelp beds, sea-grass beds and tropical marine meadows.
C -- Coral reefs.
D -- Rocky marine shores; includes rocky offshore islands and sea cliffs.
E -- Sand, shingle or pebble shores; includes sand bars, spits and sandy islets; includes dune systems and humid dune slacks.
F -- Estuarine waters; permanent water of estuaries and estuarine systems of deltas.
G -- Intertidal mud, sand or salt flats.
H -- Intertidal marshes; includes salt marshes, salt meadows, salting and raised salt marshes; includes tidal brackish and freshwater marshes.
I -- Intertidal forested wetlands; includes mangrove swamps, nipah swamps and tidal freshwater swamp forests.
J -- Coastal brackish/saline lagoons; brackish to saline lagoons with at least one relatively narrow connection to the sea.
K -- Coastal freshwater lagoons; includes freshwater delta lagoons.
Zk(a) – Karst and other subterranean hydrological systems, marine/coastal.
Inland Wetlands
L -- Permanent inland deltas.
M -- Permanent rivers/streams/creeks; includes waterfalls.
N -- Seasonal/intermittent/irregular rivers/streams/creeks.
O -- Permanent freshwater lakes (over 8 ha); includes large oxbow lakes.
P -- Seasonal/intermittent freshwater lakes (over 8 ha); includes floodplain lakes.
Q -- Permanent saline/brackish/alkaline lakes.
R -- Seasonal/intermittent saline/brackish/alkaline lakes and flats.
Sp -- Permanent saline/brackish/alkaline marshes/pools.
Ss -- Seasonal/intermittent saline/brackish/alkaline marshes/pools.
Tp -- Permanent freshwater marshes/pools; ponds (below 8 ha), marshes and swamps on inorganic soils; with emergent vegetation water-logged for at least most of the growing season.
Ts -- Seasonal/intermittent freshwater marshes/pools on inorganic soils; includes sloughs, potholes, seasonally flooded meadows and sedge marshes.
U -- Non-forested peatlands; includes shrub or open bogs, swamps and fens.

Va -- Alpine wetlands; includes alpine meadows and temporary waters from snowmelt.
Vt -- Tundra wetlands; includes tundra pools and temporary waters from snowmelt.
W -- Shrub-dominated wetlands; shrub swamps, shrub-dominated freshwater marshes, shrub carr, alder thicket on inorganic soils.
Xf -- Freshwater, tree-dominated wetlands; includes freshwater swamp forests, seasonally flooded forests and wooded swamps on inorganic soils.
Xp -- Forested peatlands; peat-swamp forests.
Y -- Freshwater springs; oases.
Zg -- Geothermal wetlands.
Zk(b) – Karst and other subterranean hydrological systems, inland

Human-made wetlands

1 -- Aquaculture (e.g., fish/shrimp) ponds.
2 -- Ponds; includes farm ponds, stock ponds, small tanks; (generally below 8 ha).
3 -- Irrigated land; includes irrigation channels and rice fields.
4 -- Seasonally flooded agricultural land (including intensively managed or grazed wet meadow or pasture).
5 -- Salt exploitation sites; salt pans, saline etc.
6 -- Water storage areas; reservoirs/barrages/dams/impoundments (generally over 8 ha).
7 -- Excavations; gravel/brick/clay pits; borrow pits, mining pools.
8 -- Wastewater treatment areas; sewage farms, settling ponds, oxidation basins, etc.
9 -- Canals and drainage channels, ditches.
Zk(c) – Karst and other subterranean hydrological systems, human-made.

Data Source: https://www.ramsar.org/

Orostachys japonica (Maxim.) A. Berger (Crassulaceae), a newly recorded genus and species from the Matsu Islands

馬祖產新紀錄屬及新紀錄種：晚紅瓦松

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Abstract

In this paper, we report a newly recorded species, *Orostachys japonica* (Maxim.) A. Berger (Crassulaceae) from the Matsu Islands. It is also an unrecorded genus of Matsu. This species is distributed in Russia, China, South Korea, and Japan. It has been recorded in Anhui, Heilongjiang, Jiangsu, Shandong, and Zhejiang provinces in China. Although the Matsu Islands are closely adjacent to China, it has not been recorded there. In this report, we provide descriptions, line drawings, and colored photographs captured from the natural habitat for helping with identification.

Key words: *Orostachys japonica*, Crassulaceae, Matsu

摘要

本文報導馬祖地區景天科（Crassulaceae）新紀錄瓦松屬（*Orostachys* Fischer）的新紀錄種植物－晚紅瓦松（*Orostachys japonica* (Maxim.) A. Berger）。本種分布於俄羅斯、中國、韓國及日本，在中國安徽、黑龍江、江蘇、山東及浙江有記錄。馬祖地區鄰近中國，但未曾紀錄過此種。本研究提供晚紅瓦松的形態特徵描述、線繪圖及彩色照片等資料，並提供其分布、生育環境及分類學注釋以供鑑定參考。

關鍵詞：晚紅瓦松、景天科、馬祖

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Introduction

The Matsu Islands mainly consist of five islands: Dongyin, Peigan, Nangan, Dongju, and Xiju, and numerous small islets. They are located approximately 211 km west of Keelung, Taiwan, and approximately 16 km east of Fujian, China. The fauna and flora composition of the Matsu Islands is similar to that of China (Ota and Lin 1997). The vascular plants within the Matsu flora comprise 677 species (including intra-specific taxa) in 472 genera and 131 families that have been reported (Huang 2002; Kuo 2004; Tzeng *et al.* 2012; Tzeng *et al.* 2014). In recent years, many newly recorded and naturalized plants have been documented in Matsu (Jung 2017). The family Crassulaceae DC., belonging to the order Rosales, includes succulent herbaceous plants (The Angiosperm Phylogeny Group 2016). Approximately 1,400 species in 35 genera have been reported (Christenhusz and Byng 2016), and they are mainly distributed throughout the Northern Hemisphere. According to Kuo (2004), two genera of Crassulaceae, i.e., *Bryophyllum* and *Sedum,* are recognized in the Matsu Islands. These include one naturalized *Bryophyllum* species (i.e., *B. pinnatum* (Lam.) Kurz), and three native *Sedum* species (i.e., *S. formosanum* N.E. Brown, *S. lineare* Thunb., and *S. drymarioides* Hance) (Kuo 2004; Tzeng *et al.* 2012). Moreover, a recent report indicated that *S. lineare* in the Matsu islands was misidentified and has been published as a new species, *S. matsuense* (Lu and Wang 2023). From a botanical exploration in the Matsu islands, we found an *Orostachys* species that has occurred in Gordon Island, and the distribution range of *Orostachys s*pecies includes the Matzu Islands. However, this species has never been recorded in the Matzu Islands. In the present study, we recognized the presence of this unrecorded genus and species in the Matzu Islands, and provided the morphological description, line drawing, photographs, and distribution map to facilitate the identifications.

Systematic treatment

Orostachys is a newly recorded genus for the Flora of Matzu islands.

Orostachys Fisher, Mém. Soc. Imp. Naturalistes Moscou. 2: 270. 1809. 瓦松屬

A biennial monocarpic herb, roots fibrous, rhizome absent. Leaves alternate of first year arranged in solitary dense rosette, basal, linear to ovate, often with dull purple dots; apex usually cuspidate or obtuse, cartilaginous appendage to rarely softly obtuse or acuminate. Flowering stem solitary, arising the center of rosette in two years; stem leaves alternate. Inflorescence terminal, a dense raceme or thyrse, narrowly pyramidal to cylindric, many flowered thyrsoids, bracteate; flowers bisexual, subsessile or pedicellate, 5-merous; sepals usually shorter than petals; petals subconnate at base, white, pink, or red, lanceolate; stamens 2 × as many as petals, 2 whorled. Nectar scales small. Carpels erect, free, stipitate, ovules many. Stigma slender. Follicles erect, beaked at apex, many-seeded.

About 13 species in preliminary East-Asian distribution and like origin (Ohba 1978; Ohba 2003): China, Japan, Kazakhstan, Korea, Mongolia, and Russia (Thiede and Eggli 2007); eight species in China (Fu and Ohba 2001). No records from Taiwan.

Orostachys japonica (Maxim.) A. Berger, Nat. Pflanzenfam., ed. 2 [Engler&Prantl] 18a: 464 (1930). 晚紅瓦松

Cotyledon japonica Maxim., Bull. Acad. Imp. Sci. Saint-Pétersbourg xxx. (1883) 122.

Rosette leaves linear or narrowly oblong, 0.8–1.4 cm long, 0.4–0.5 cm broad, short; appendage white, suborbicular, not cartilaginous, centrally spinose. Stem leaves linear, lanceolate,

lanceolate to ovate, 1.9–2.8 cm long, 0.2–0.7 cm broad, apex narrowly acuminate spinose. Flowering plant 12–18 cm. Inflorescence racemose or basally branched and conical, dense, 8–10 cm long, 2–4 cm in diam; bracts lanceolate to ovate, apex acuminate; pedicels ca. 3 mm long. Sepals greenish, narrowly oblong, 4–5 mm long, 1–2 mm broad, glabrous. Petals white, narrowly oblong to oblong, 5–7 mm long, 1.2–1.3 mm broad, base connate for ca. 1 mm, apex acuminate. Stamens 10–12, 5–7 mm long, shorter than or equaling petals; anthers purple. Nectar scales subquadr angular, apex subemarginate. Follicles oblong, 6 mm long, apical beak slender. Seeds numerous, ovoid, minute.

Specimens examined: Lienchiang County (Matzu Islands), Beigan Township, Gordon, alt. 0–5 m, 15 Jan. 2022, *W.Y. Wang 2970* (TAIF) [TAI551714]

Distribution: The native range of this species is in Southeast Asia. China (i.e., provinces of Anhui, Heilongjiang, Jiangsu, Shandong, Zhejiang), Korea (Fu and Ohba 2001; Chang *et al.* 2014), Japan (Thiede and Eggli 2007) and Russia (Fu and Ohba 2001). It is a biennial plant that primarily grows in the temperate biome.

Habitat and Ecology: This population was found in the Gordon Island, Matsu Islands, and grew on rocks on seaside slopes at an elevation of 5 m (Fig. 3). Accompanying plants include *Peucedanum japonicum* Thunb., *Lysimachiamauritiana* Lam., *Euonymus japonicas* Thunb., *Dianthus superbus* L. var. *longicalycinus* (Maxim.) Will., and *Pittosporum tobira* (Thunb.) W.T. Aiton.

Phenology: Flowering occurs from August to September, with fruiting starting from September to October.

IUCN Red list category: In Russia, Japan, Korea, and China, *Orostachys japonica* inhabits rocks on slopes, house roofs, and mossy tree trunks (Fu and Ohba 2001). *Orostachys japonica* is currently known only from one locality (Gordon) in the Matzu Islands, with an area of occupancy of less than 2 km^2. The estimated population size ranges from 200 to 400 individuals. According to the IUCN Red List categories criteria, we assessed *O. japonica* as Nationally Critically Endangered (CR) in the Matzu Islands [B1a+C1+D1+D2] (IUCN 2024). However, *O. japonica* was only found in Gordon and was under military protection. Besides, it is widely distributed in China, Japan, and Korea, and possibly was migrated from these neighboring areas. Therefore, we reconsider that the assessment of this species in Matzu Island should be downgraded from CR to Vulnerable (VU) based on the ICUN Red List category (IUCN 2024).

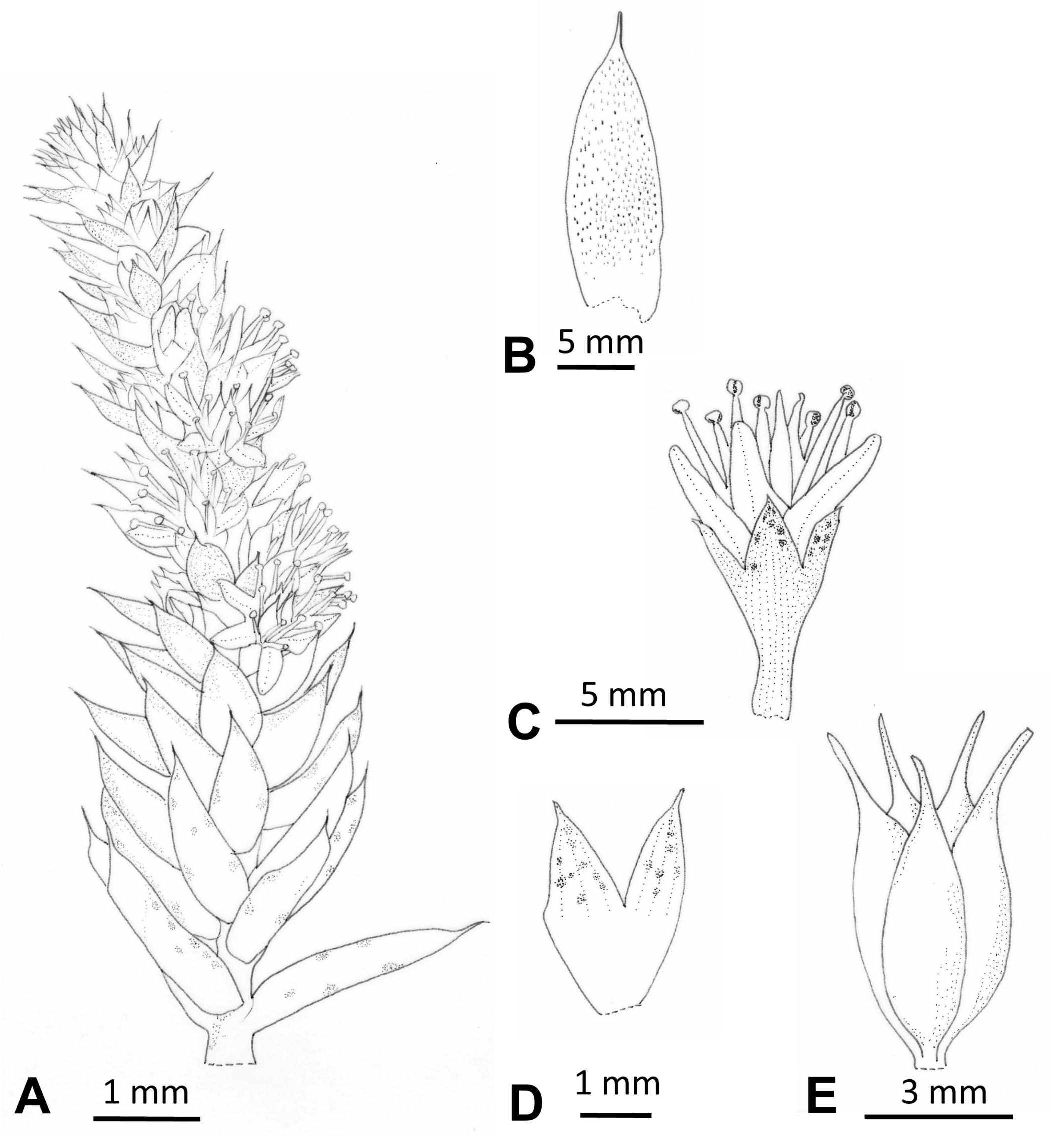

Fig. 1 Illustration of *Orostachys japonica* (Maxim.) A. Berger, A. Flowering plant; B. Leaf; C. Flower; D. Calyx; E. Fruit. (Illustrated by C.K. Yang, from *W.Y. Wang 2970*)

圖 1 晚紅瓦松（*Orostachys japonica* (Maxim.) A. Berger）。A. 開花植株；B. 葉；C. 花；D. 花萼；E. 果實。

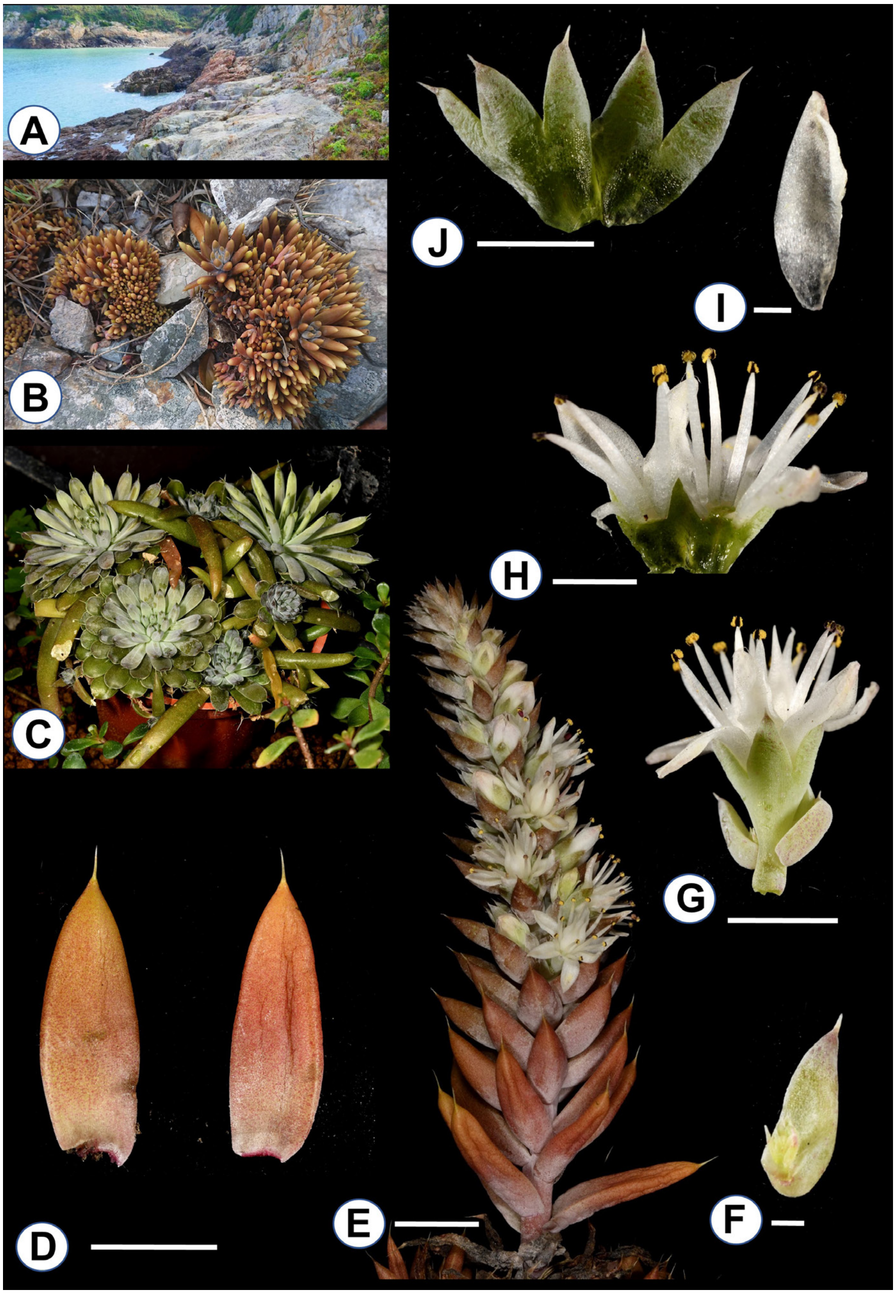

Fig. 2 Habitat and morphology of *Orostachys japonica* (Maxim.) A. Berger, A. Habitat; B. Habit (individual mature on rock); C. Individual cultivation; D. Stem leaves; E. Flowering plant; F. bract; G. A lateral view of flower; H. Calyx, petals and stamens; I. Petal; J. Calyx. Scale bars: D, G = 6 mm; E = 1 cm; F, I = 1 mm; H, J = 4 mm. (photos were taken by W.Y. Wang)

圖 2晚紅瓦松（*Orostachys japonica* (Maxim.) A. Berger）。A. 生育地；B. 植株（岩石上的成熟個體）；C. 栽培的個體；D. 莖生葉；E. 開花植株；F. 苞片；G. 花側面；H. 花萼、花瓣及雄蕊；I. 花瓣；J. 花萼。

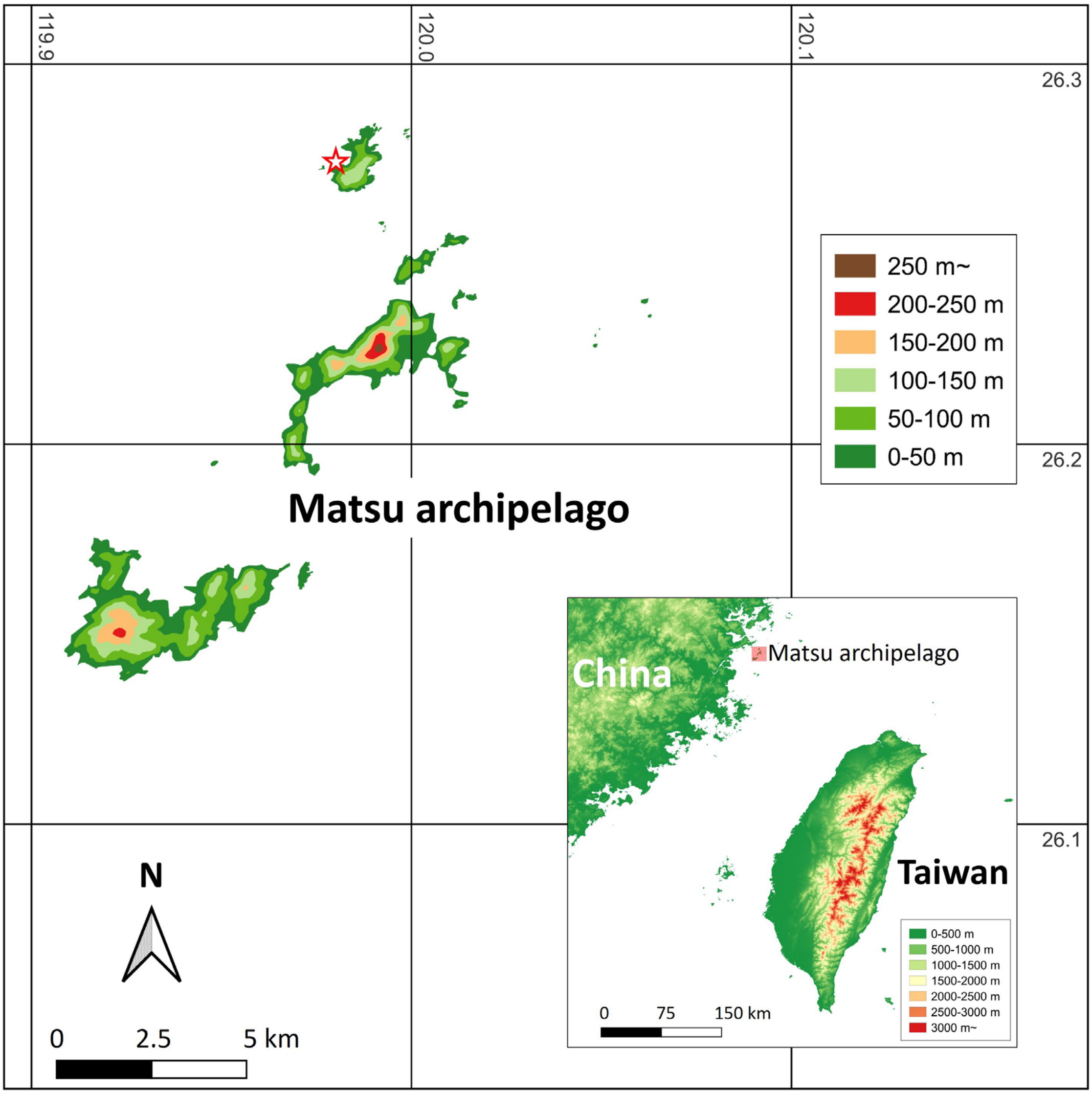

Fig. 3 Distribution of *Orostachys japonica* (Maxim.) A. Berger, (Star) in the Matsu islands.
圖 3 晚紅瓦松（*Orostachys japonica* (Maxim.) A. Berger）在馬祖的分布圖。

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以卷積神經網路從 Sentinel-2 資料測繪外來種植物之入侵分佈

Mapping distribution of invasive alien plant species from Sentinel-2 data using convolutional neural networks

呂明倫

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摘要

具入侵性的外來種植物擴散能力強，不僅會威脅生物多樣性，也對農業造成巨大的經濟損失，銀合歡 (*Leucaena leucocephala* (Lam.) de Wit) 是世界百大外來入侵物種之一，現已嚴重威脅到臺灣恆春半島的生態系。遙測影像可觀測大範圍的地表資訊，具潛力進行銀合歡入侵分佈的測繪工作，本研究以恆春半島為研究區，整合 Sentinel 2 影像資料與卷積神經網路 (convolutional neural network, CNN)，建立可預測銀合歡覆蓋率的深度學習模型，進而測繪銀合歡的入侵程度並估算分佈面積。研究結果顯示，運用 CNN 所建立的 IPNet 模型在準確度指標上 (R^2 約為 0.78)，比其他經過測試的深度學習模型表現更好。依據覆蓋率高低分為 5 種入侵

程度，推估屬銀合歡入侵嚴重的面積計有 4,442 ha，占全區約 11%。總結而言，本研究所開發的 IPNet 模型是一種低成本、高效率的測繪方法，並且為銀合歡的入侵問題，提供了明確的空間分佈資訊。

關鍵詞：生物多樣性、銀合歡、遙測、恆春半島、深度學習

Abstract

Invasive alien plant species have a strong spreading ability, which not only threatens biodiversity but also causes substantial economic losses in agriculture. *Leucaena leucocephala* (Lam.) de Wit is one of the top 100 alien invasive species in the world, and they have been seriously threatening the ecosystem of the Hengchun Peninsula. Remote sensing imagery can provide a wide range of surface information with a potential for mapping the distribution of *L. leucocephala* invasion. This study focused on the Hengchun Peninsula, integrating Sentinel-2 data with a convolutional neural network (CNN) to develop a deep learning model capable of predicting the cover fraction, mapping the degree of invasion, and estimating the distribution of *L. leucocephala*. The results indicate that the proposed IPNet model using CNN was significantly better than the other tested deep learning models in terms of the accuracy metrics ($R^2 \fallingdotseq 0.78$). The invasion was categorized into five degrees based on the cover fractions, with severe invasion estimated to cover an area of 4,442 hectares, accounting for approximately 11% of the entire region. In conclusion, the IPNet model developed in this study is a low-cost with high-efficiency mapping method that provides clear spatial distribution information on *L. leucocephala* invasion.

Key words: biodiversity, *Leucaena leucocephala*, remote sensing, Hengchun Peninsula,

deep learning

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緒言

具入侵性的外來種植物 (invasive alien plant species, IAPS) 擴散能力強，所帶來的影響往往是負面的，不僅會威脅生物多樣性，也對農業造成巨大的經濟損失 (Marbuah *et al.* 2014; Diagne *et al.* 2021)。有效地掌握 IAPS 的空間分佈資訊，對於防治作業的成功與否至關重要 (Sofaer *et al.* 2018; Bradley *et al.* 2019)，過去的作法是依賴人工實地調查，然而，這種方式經常受制經費及勞動力的短缺，無法獲取完整的資訊，故有必要尋找另一種高效又準確的替代方案。

遙測影像富含豐富的光譜反射資訊，可觀測大面積及多時段的地貌，遙測產品的種類繁多，如無人機、雷達、光達及光學衛星等影像，其中，光學衛星的普及性高，常見的 Sentinel 2 或 Landsat 等系列衛星，被認為是有效掌握 IAPS 分佈的重要資料之一 (Bradley 2014; Thamaga and Dube 2018; Vaz *et al.* 2018)，此外，這兩種衛星都有提供免費的影像供應平台，可透過網路下載取得。目前機器學習為分析遙測影像資料的主要方法，也是測繪地景要素常用的技術，在眾多的機器學習演算法中，人工神經網路 (artificial neural network, ANN) 仿人腦功能的運作，利用大量的神經元聯結進行演算，組成一個高度複雜且互聯的多層次網路，並以梯度下降法 (gradient descent) 搜索最佳模型，演算過程中，神經元的資訊可透過一個或多個隱藏層，從輸入層向前傳播到輸出層，預測結果再利用反向傳播更新權重，可有效應用於衛星影像的資料分析 (Kanellopoulos and Wilkinson

2010)。

拜人工智能快速發展所賜，ANN 可產生更深的隱藏層，故深度學習應運而生，其中，專司影像處理的卷積神經網路 (convolutional neural network, CNN) 不若 ANN 沒有考慮到影像上的空間特徵，即所有像元都做為獨立向量來處理，CNN 則明確地關注影像的空間脈絡，並透過參數共享概念，自動提取像元的光譜和局部紋理特徵，也克服了 ANN 常見的過度擬合問題，可精確地辨識各種植被、作物及土地利用類型 (Sharma *et al.* 2017; Kussul *et al.* 2017; Kattenborn *et al.* 2021; Rodríguez-Garlito *et al.* 2023)。CNN 可執行的任務，大致可分為分類與迴歸兩種，由於自然界中的植被景緻，大多會呈現出漸層式的變化，尤其是 IAPS 入侵原生棲地後，常導致影像產生混合像元，因此，連續性的覆蓋率資訊更適合描述植被生態議題，此外，就經營管理面而言，量化 IAPS 的覆蓋率，有利於判定不同的入侵程度，以及決定防治的優先性 (Vilà *et al.* 2011; Kattenborn *et al.* 2020; Preston *et al.* 2023)，由此可知，藉由 CNN 迴歸模型測繪 IAPS 覆蓋率，可為防治作業提供更豐富的參考資訊。

源自於中美洲一帶之銀合歡 (*Leucaena leucocephala* (Lam.) de Wit)，是世界百大外來入侵物種之一，因其入侵性強，又具排他性，儼然威脅到臺灣的生物多樣性，最嚴重的地區為全臺最南端的恆春半島 (Lu *et al.* 2013)，該區四處可見到大片的銀合歡純林或與原生樹種共生的混淆林。近年由農業部林業及自然保育署大力主導，建構跨機關合作平臺，共同針對銀合歡入侵問題進行大規模的防治作業，有鑑於此，建構 CNN 迴歸模型來測繪恆春半島的銀合歡入侵分佈，為本研究的主要目標，目前國內外似乎尚未有相關的研究報告。基於以上目標，本研究的工作項目包含：一、藉由光學衛星影像資料建立可預測銀合歡覆蓋率的 CNN 模型；二、比較不同神經網路架構的模型性能；三、測繪銀合歡的入侵程度並估算分佈面積。

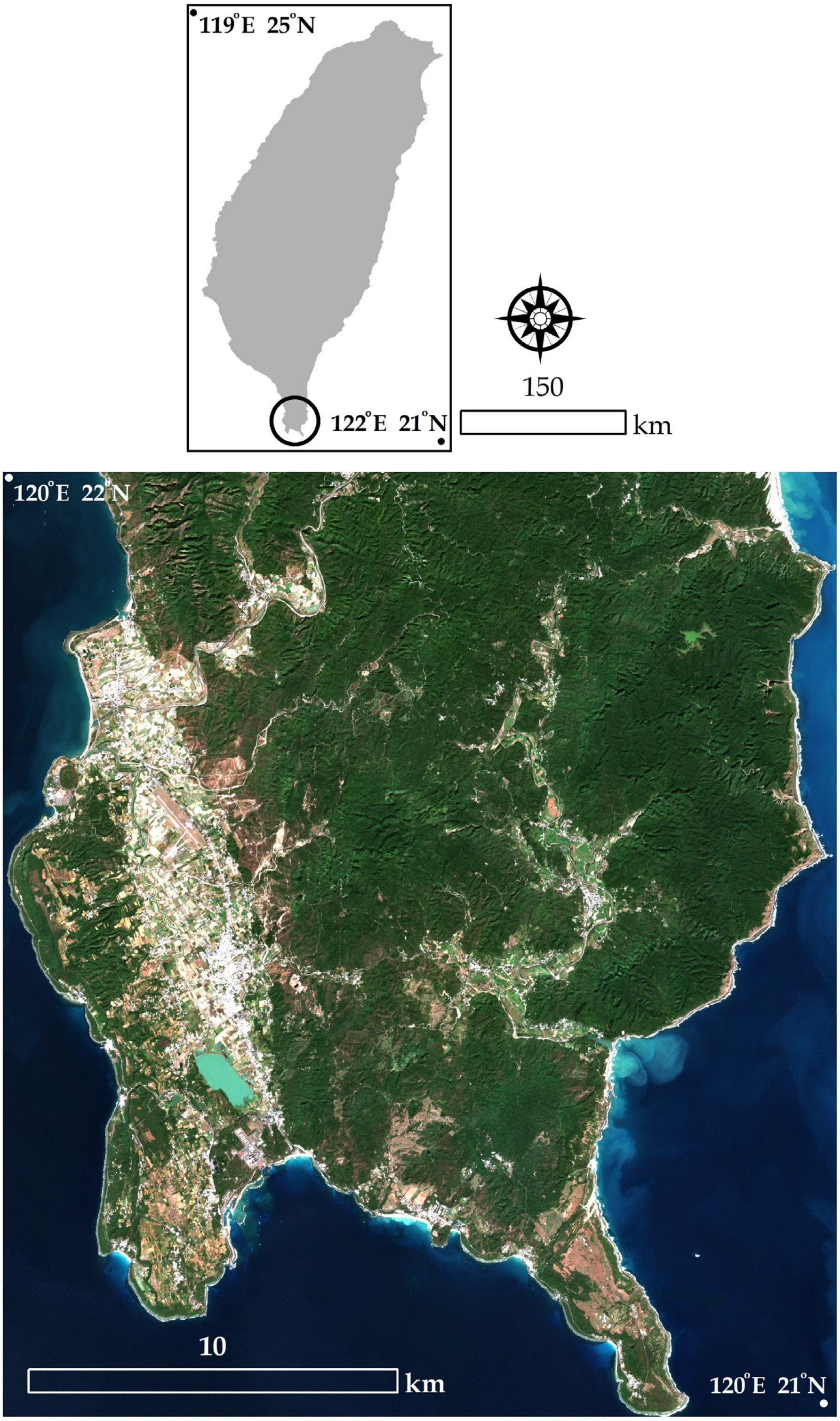

圖 1 研究區位置圖 (背景為 Sentinel 2 的 RGB 影像)。
Fig. 1 Location of the study area (background shows the RGB imagery of Sentinel 2).

材料與方法

一、研究區概述

研究區位於恆春半島，範圍及地理位置如圖 1 所示，地形以低山與丘陵台地為主，最高峰里龍山海拔高度為 1,062 m。據中央氣象局恆春測候站氣象資料可知，本區年溫差不大，1 月最冷，平均氣溫為 20.5℃；7 月最熱，平均氣溫為 28.3℃。年降雨量在 2,000–3,500 mm 之間，分布於 5 至 10 月，11 月起因受東北季風影響，平均降雨量逐漸下降 (100 mm 以下)，至翌年 4 月氣候較為乾燥，因此，本研究區域內 (尤其西半部)，可明顯區分乾、濕兩種季節，屬熱帶季風型氣候。根據呂等 (2008) 的研究，乾季時的銀合歡葉子會大量枯落，留下深褐色的成熟莢果，其所表現出的光譜特徵，有利於與其他優勢植群做區別。

二、研究方法

(一) 蒐集衛星影像及地面資料

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、紅邊及短紅外光範圍，共切割成 13 個波段影像，具備 3 種空間解析力，其中第 2、3、4 和 8 等 4 個波段的為 10 m，第 5、6、7、8A、11 和 12 等 6 個波段為 20 m，第 1、9 和 10 等 3 個波段為 60 m。研究區的 Sentinel 2 影像從 browser.dataspace.copernicus.eu 下載，篩選少雲層覆蓋且清晰的影像，選定的影像屬 Level-2A 處理等級的產品，即地表反射率經過大氣校正，拍攝日期為 2020 年 3 月 1 日 (圖 1)。由於 60 m 的波段影像，主要功能為雲霧過濾與大氣相關的應用，故本研究僅用到第 2 到 8、8A、11 和 12 等 10 個波段影像，透過 ESA 專為處理 Sentinel 影像資料所開發的免費軟體：Sentinel Application Platform (eo4society.esa.int/resources/snap)，以最近相鄰法 (nearest neighbor) 進行 10 m 空間解析力的像元重取樣，再將每一像元值進行標準化，重新調整到 0–1 的範圍，有助於降低數據間的歧異性 (Sola and Sevilla 1997)。

使用 5 × 5 像元大小為一區塊，

將 Sentinel 2 影像分割成 50 × 50 m 的網格圖，另一方面，參考國土利用現況調查成果圖 (maps.nlsc.gov.tw/S09SOA)，以森林、農地、建地與裸地等 4 類主要土地覆蓋型做為分層，逢機抽取 250 個，共計 1,000 個區塊做為樣本，再依各分層劃分 60% 做為訓練集，20% 為模型擬合過程中的驗證集，剩下 20% 用於評估模型性能的測試集。以 Google Earth 影像做為地真參考，選擇趨近 Sentinel 2 影像的拍攝日期，每一樣本進行地面踏勘及人工判釋銀合歡範圍工作，並計算及標註覆蓋率。

(二) 卷積神經網路

CNN 的神經元是按照影像的高度及寬度來排列，並使用一系列的卷積和激活函數從影像中提取特徵 (如線條、邊緣、形狀和紋理等)，本研究從典型的 VGG (Simonyan and Zisserman 2014) 與 Xception 架構 (Chollet 2017) 獲得啟發，發展出的 CNN 架構簡稱為 IPNet (圖 2)，該架構計有 4 個卷積層，前兩層各由 64 個濾波器所組成，後兩層增加到 128 個，濾波器大小均為 3 × 3 個像元，卷積的運算過程中，每一個卷積層的輸出做為下一個卷積層的輸入，且各層之間都導入批次標準化 (batch normalization)、ReLU 激活函數與 dropout 率 (0.1) 步驟，最後一個卷積層結束後進入一個全域最大池化層，再由最終的全連接層附加 Linear 激活函數進行輸出，輸出層的結果為銀合歡覆蓋率。至於輸入層的資料維度為 4D 張量 (tensor)，包含樣本數、影像行、列及通道，其中，樣本數共有 600 個 (另有 200 個為驗證集)，影像的行與列為 5 × 5 個像元，通道則為 10(10 個波段)。運算過程中，所有卷積運行的步幅設為 1，並用 0 填充確保輸出的大小與輸入相同，另由於本架構屬小區塊樣本的學習，故沒有使用池化層來簡化特徵。

IPNet 架構的演算尚需設置多種超參數，包括期數 (epoch)、批次大小 (batch size)、學習率 (learning rate)、優化器 (optimizer)、損失函數 (loss function) 等。本研究經反覆測試，設定期數為 100，批次大小為 32，學習率方面，設定 0.001 為初始

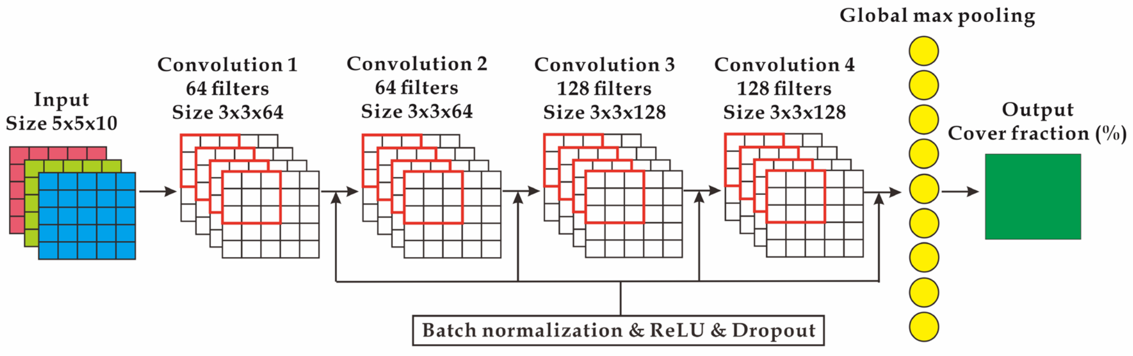

圖 2 本研究提出的卷積神經網路架構。
Fig. 2 Architecture of the proposed convolutional neural network.

值，搭配 Adam 優化器的梯度下降演算，根據驗證集的損失值變化自動調整 (最小設定 1e–10)，損失函數使用適用於迴歸任務的均方誤差 (mean squared error)。關於開發 CNN 架構的軟體和硬體環境，利用 R 語言介面的 TensorFlow 和 Keras 套件進行演算與測試，硬體方面仰賴工作站：Intel(R) Xeon(R) Silver 4208 CPU 及圖形處理器：NVIDIA RTX A6000。

（三） **模型性能比較**

模型開發完畢後，依據 20% 的測試集 (200 個區塊樣本) 與預測結果進行性能評估，計算平均絕對誤差 (mean absolute error, MAE)、均方根誤差 (root mean square error, RMSE)、平均絕對百分比誤差 (mean absolute percentage error, MAPE) 與決定係數 (R^2)。除本研究開發的 IPNet 架構外，另建立無卷積運算過程的深度神經網路 (deep neural network, DNN) 和 Sharma *et al.* (2017) 同樣基於衛星影像所開發的深度 CNN(Deep CNN, DCNN) 架構，用於比較不同深度學習模型的性能差異。DNN 是由 4 個隱藏層所構成，第 1 層產生 128 個神經元，第 2 層起神經元數量以兩倍遞減，至第 4 層剩 16 個，每一層輸出後都導入批次標準化、ReLU 激活函數與 dropout 率步驟；DCNN 架構則有 5 個卷積層，濾波器大小為 3×3 個像素元，每層的數量從 8 到 128 以兩倍遞增，

外加 1 個由 3,200 個神經元所組成的全連接層，各層都搭配 ReLU 激活函數輸出。這兩種深度學習架構的輸入、輸出層及超參數都比照 IPNet。

結果

IPNet 的訓練過程中，訓練集的初始損失值為 2,296，之後便開始逐漸遞減，至第 40 個 epoch 以後達到收斂的效果，最低損失值為 225。從驗證集來看，初始損失值為 3,646，第 40 個 epoch 以前皆有明顯的波動，但仍呈現下降趨勢，從第 53 個 epoch 開始收斂，損失值均不超過 350，最低為 343(圖 3)。總體來看，兩種資料集的最終表現相當，顯示不存在過度擬合，因此，本研究依據驗證集的最低損失值做為最終預測模型。

表 1 列出 IPNet 與其他兩種深度學習模型的性能，總體而言，本研究建構的 IPNet 模型優於其他兩種模型，在評估誤差方面的指

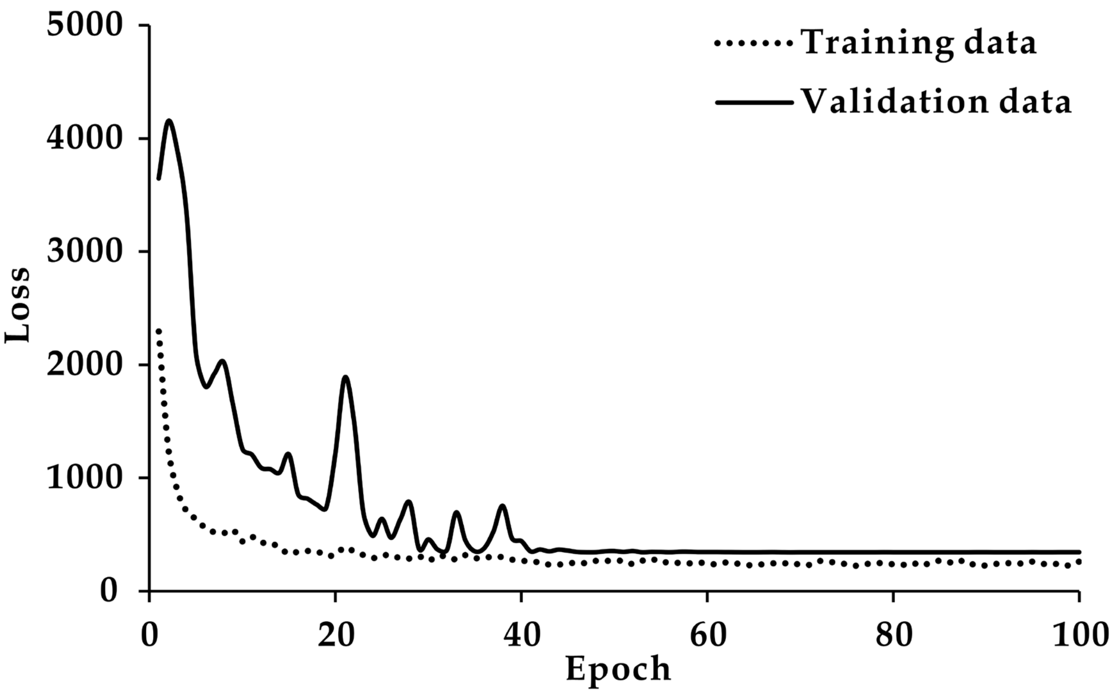

圖 3 IPNet 架構的損失曲線。
Fig. 3 Loss curves of IPNet architecture.

表 1 比較 3 種深度學習模型之統計準確度指標
Table 1 Comparisons of statistical accuracy metrics among three deep learning models

Metrics	IPNet	DCNN	DNN
Mean absolute error	12.56	14.23	34.97
Root mean square error	16.47	18.41	43.56
Mean absolute percentage error (%)	62.91	75.66	71.87
Coefficient of determination (R^2)	0.78	0.72	0.66

標，MAE(12.56)、RMSE(16.47) 及 MAPE(62.91) 都達最低，評估預測與觀察值相關性的 R^2 則最高 (0.78)。相較於其他兩種模型，DCNN 的表現次之，所有的指標都指出，DNN 的表現相對較不理想，由此顯示，有經過卷積運算的 CNN 架構更勝於 DNN。

運用深度學習預測銀合歡覆蓋率的結果如圖 4，為清楚比較不同演算法間的差異，使用自然間斷法將覆蓋率分為 5 級，做為銀合歡入侵程度的觀察指標，該法是依據分組後的組內最小變異數來決定，可在 ArcGIS 軟體執行。圖中顯示 3 種演算法的預測結果，空間分佈型態相去不遠，入侵程度較高的地區都偏重於西半部，惟 IPNet 與 DCNN 預測的面積明顯大於 DNN，由此顯示，性能相對較低的 DNN 模型，低估了銀合歡的入侵範圍。從面積來看，次高及高入侵度以上屬銀合歡入侵嚴重的地區，IPNet 模型推估有 4,442 ha，占全區約 11%，DCNN 為 3,678 ha (9%)，DNN 僅 有 1,968 ha (5%)。

討論

近年來已有大量的深度學習模型被開發出來，透過深層的 CNN 自動萃取空間特徵，不僅減少了人工的操作，並證實提升了辨識 IAPS 的準確度 (Kattenborn*et al.* 2021)，然而，這些研究報告中，很大占比都是藉助無人航空載具 (unmanned aerial vehicle) 的超高影像解析力資料，其雖具辨識物種細部特徵的優勢，但可探測範圍狹小則為一大限制，目前將深度學習

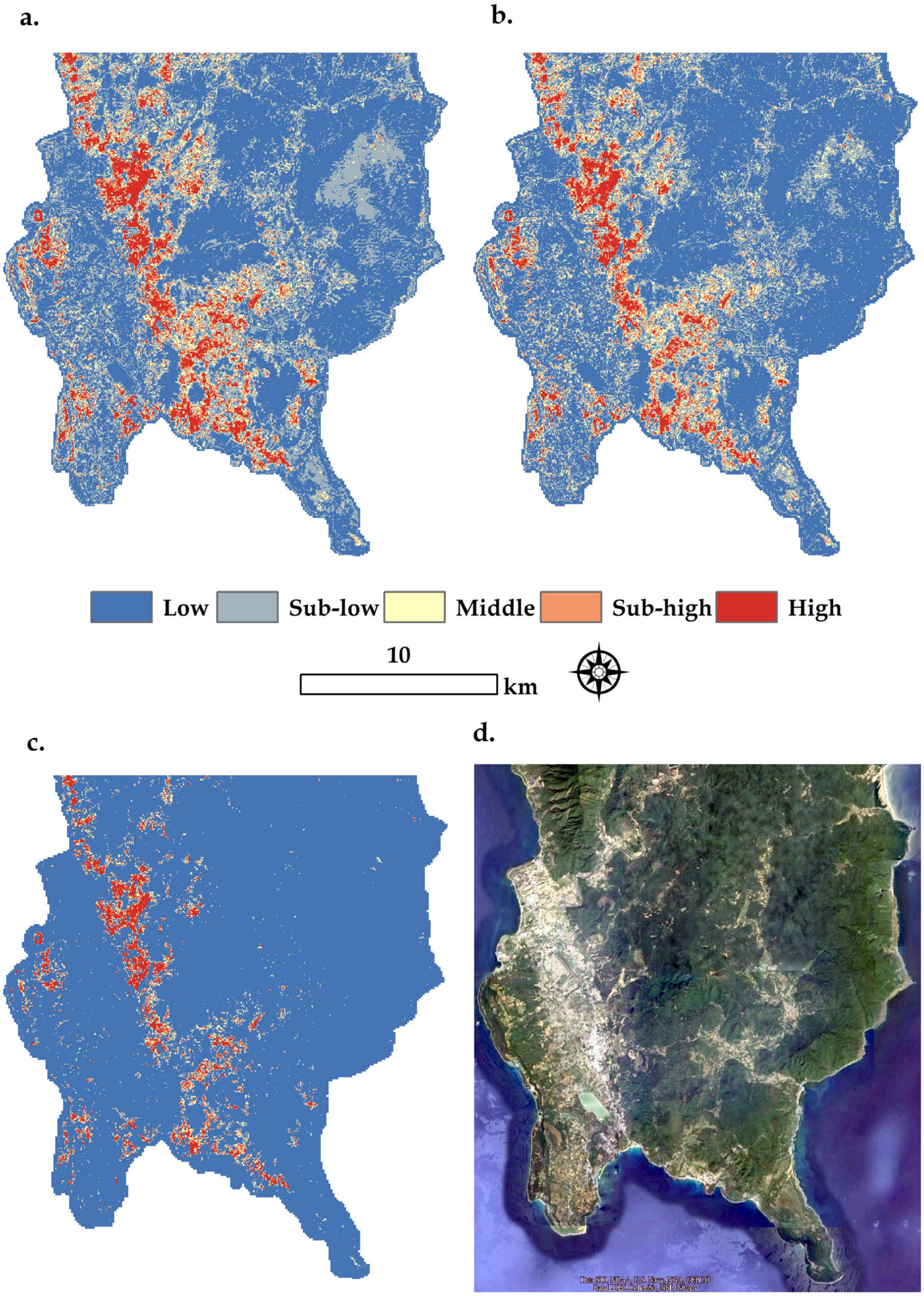

圖 4 使用不同演算法測繪出銀合歡的入侵程度 (根據自然間斷分為 5 級)，(a) IPNet、(b) DCNN、(c) DNN 及 (d) 地真資料，源自 Google Earth。

Fig. 4 Invasiveness of *Leucaena leucocephala* mapped from different algorithms: (a) IPNet, (b) DCNN, (c) DNN, and (d) real ground data adopted from Google Earth. Five levels of the invasiveness are used based on natural breaks.

表 2 根據 3 種不同演算法將銀合歡入侵程度劃分成 5 級的面積
Table 2 Areas of invasiveness for *Leucaena leucocephala* divided into five levels according to three different algorithms

Level	IPNet		DCNN		DNN	
	Area (ha)	%	Area (ha)	%	Area (ha)	%
High	2340	6.05	1680	4.34	1117	2.89
Sub-high	2102	5.43	1998	5.16	851	2.20
Middle	2879	7.44	2987	7.72	757	1.96
Sub-low	10459	27.03	9250	23.91	793	2.05
Low	20914	54.05	22778	58.87	35176	90.91

應用於大範圍 IAPS 測繪的研究案例並不多。過往的研究已證實，恆春半島的 IAPS：銀合歡，可從衛星影像上偵測重要特徵，主要方法是透過各種特徵工程，即在建模之前找尋該物種獨特的光譜反應或影像紋理做為變項，再進一步建構傳統的統計模型進行測繪 (鍾及呂 2006; Tsai and Chou 2006; Tsai *et al.* 2007)。時至今日，應用於測繪銀合歡入侵的深度學習模型仍有待開發，因此，本研究有別以往，在大尺度衛星影像的基礎上，發展可精進銀合歡辨識能力的 CNN 模型。

根據本研究的觀察，銀合歡因受氣候的影響，可從乾季的衛星影像上發現其相對獨特的光譜反應，並與其他周邊的原生植被產生差異，故有機會測繪其入侵分佈。本研究所發展出的 IPNet 模型證實了 CNN 演算法與 Sentinel 2 影像結合，可實踐大面積測繪銀合歡的入侵分佈，儘管模型訓練初期，驗證集的損失明顯高於訓練集，最大的可能是，因使用的訓練集樣本較大，故可提供更穩定的梯度更新，反觀，驗證集樣本小，造成初期的損失波動會更大，但隨著進入中期，學習到的特徵更多，損失逐漸收斂，代表模型已經有效地掌握資料特徵。相較於其他兩種深度學習模型，IPNet 性能表現更佳，如與 Sharma *et al.* (2017) 所開發的 DCNN 相比，兩種模型的深度相當，最大差別在於 IPNet 於各卷積層的輸出都導入了批次標準化與 dropout 步驟，這兩種

常見的處理技術，不僅可加速訓練過程，也能穩定模型，減少過度擬合的問題 (Srivastava *et al.* 2014; Ioffe and Szegedy 2015)，對性能的提升有一定的幫助。至於 DNN 的架構，因沒有經過卷積層的空間演算過程，限制了提取重要特徵的能力，導致最終模型的性能表現最差，相比另外兩個 CNN 模型，預測結果明顯低估高覆蓋率及高估低覆蓋率的範圍，參考過往利用衛星影像預測植被覆蓋率的相關研究，也有發現類似的現象 (Nill *et al.* 2022; Viana-Soto *et al.* 2022)，主因應是無法有效提取混淆植被的過渡特徵。綜合以上結果顯示，CNN 在影像辨識方面確實有其優勢。

如何在有限的資源下，進行既有全面性又有系統性的 IAPS 移除或防範措施，實為一項重大挑戰，因此，提供優先處理已被入侵地區的空間分佈及未來潛在的入侵風險資訊，將有利於資源集中投入最具成本效益的防治工作 (Papeş *et al.* 2011)。本研究建立的 IPNet 迴歸模型，主要功能是預測銀合歡的覆蓋率，做為入侵程度判定的指標，依據預測結果分成 5 種入侵程度的原則下，未來可針對各個分級制訂不同的控制策略，高入侵度無庸置疑為優先控制區，次高入侵度則為其衛星族群，這些區域應依照程度大小施予不同強度的移除工作，中入侵度範圍可視為潛在風險區或做為緩衝區，透過長期監控掌握族群的動態，以預防新生的族群入侵。

結論

本研究基於免費的 Sentinel 2 影像與 CNN 開發 IPNet 模型，為銀合歡的入侵問題，提供了明確的空間分佈資訊，就經營管理面而言，是一種低成本、高效又準確的測繪方法，所產製的入侵分佈圖，也可做為防治工作的基本參考圖。然而，為了精益求精，對於 IPNet 模型的性能表現，本研究認為應有改進的空間，主因是恆春半島的銀合歡，在不同的季節會有物候反應 (呂等 2008)，僅依靠空間維度可能會忽略掉因物候產生改變的光譜反射特徵，因此，藉由可涵蓋時間維度的 CNN 架構，如 3 維 CNN 或具

循環傳遞特性的卷積長短期記憶網路 (convolutional long short-term memory) 等演算法，分析多時段的 Sentinel 2 資料，有機會捕捉完整的時序變化特徵，是提升預測準確度的潛力方案，因此，本研究未來會在 IPNet 的架構上，持續做更多的延伸測試。

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臺灣新紀錄卷柏科植物—白毛卷柏

Selaginella albociliata P.S. Wang, a newly recorded species of Selaginellaceae from Taiwan

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摘要

本文報導一臺灣新紀錄之卷柏科卷柏屬植物 — 白毛卷柏 (*Selaginella albociliata* P. S. Wang)。內文記述該新紀錄種之形態特徵、地理分布範圍、棲地特性及分類註記等資訊，並提供其照片及臺產卷柏屬植物之檢索表為參。

關鍵詞：新紀錄種、卷柏科、卷柏屬、白毛卷柏、臺灣

Abstract

This paper reports a new record of a Selaginellaceae species in Taiwan, *Selaginella albociliata* P. S. Wang. The text describes the morphological characteristics, geographical distribution, habitat preferences, and taxonomic notes of this newly recorded species. Additionally, photographs and a key to the *Selaginella* species in Taiwan are provided for reference.

Key words: New record species, Selaginellaceae, *Selaginella*, *Selaginella albociliata*, Taiwan

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緒言

卷柏科 (Selaginellaceae) 植物為常綠或夏綠型的中小型草本植物，生態習性以土生或石生為主，鮮有著生者；在分類系統方面，隸屬於維管束植物 (Tracheophyta) 下的石松門 (Lycopodiophyta) 石松綱 (Lycopodiopsida) 卷柏目 (Selaginellales)，並與石松科 (Lycopodiaceae) 及水韭科 (Isoetaceae) 合稱為石松類植物 (lycophytes)。石松類植物和蕨類植物 (monilophytes；又稱鏈束植物)，是維管束植物中唯二以孢子為繁殖主體的類群。

卷柏科植物有別於其它石松類植物之最大辨識特徵，在於其植物體中、末段分枝之正面 (或可稱上表面) 通常具 4 行小葉 (microphylls；特指石松類植物的葉片，葉形小，僅具 1 條主脈，無葉隙)，且孢子有大、小之分。根據 1975 年臺灣植物誌第一卷的記載，臺灣原產的卷柏科植物計 14 種 (DeVol 1975)，外加後來報導的歸化種翠雲草 (又名藍地柏；*Selaginella uncinata* (Desv. ex Poir.) Spring) (DeVol and Kuo 1979)，共計 15 種。然而，隨著時序的推進，新物種的發現是必然的；依據 TPG (2019) 及其後續持續更新的資料，臺產的卷柏科植物已增加為 19 種 (TPG 2019)。

本文作者群在花蓮縣玉里鎮赤柯山區進行植物資源調查時，發現一種近似於 2009 年報導之臺灣新紀錄種琉球卷柏 (*Selaginella lutchuensis* Koidz.) 的植物 (Chang *et al.* 2009)，主要區別點在於其小葉邊緣，特別是中葉，具有細長的白色緣毛，明顯異於琉球卷柏。在檢視鄰近區域的卷柏科分類之相關文獻 (Alston 1935, Wang 1990, Chang *et al.* 2012, Tan 2013, Zhang *et al.* 2013, Ebihara 2016, Shalimov *et al.* 2019) 及標本 (HAST, PE, TAI, TAIF, TNM) 後，確認赤柯山所採集到的卷柏屬物種，為臺灣新紀錄種 — 白毛卷柏 (*Selaginella albociliata* P.S. Wang) (圖 1)。本文除了根據文獻、標本及野外調查資訊，報導該種之命名、形態特徵、分布範圍、生態特性等背景資料，也依據「國際自然與自然資源保育聯盟」(International Union for Conservation of Nature and Natural

Resources) 之紅色名錄類別及評估標準 (IUCN Standards and Petitions Committee 2024)，提出該種之瀕危等級建議。此外，本文也提供其彩色照片，以及含括臺灣地區所有卷柏屬植物之修正檢索表，供學界參考。

分類處理

卷柏科 SELAGINELLACEAE

Selaginella albociliata P.S. Wang, J. Arnold Arbor. 71(2): 269. 1990. 白毛卷柏 (圖 1)

模式資訊 (typus)：*P.S. Wang 77981*, 20 May 1988,CHINA, Guizhou, Libo County, on limestone surface along the Wujia River, alt. 530 m; holotype: HGAS. *P.S. Wang 76801*, CHINA, Guizhou, Libo County, on wet rock surface in forest, alt. 660 m; paratype: CDBI, HGAS, PE(PE 00405375! & PE00405377!).

形態特徵 (morphology)：

常綠草本，多岩生，常見平鋪匍伏於岩石或附近之土坡上。植物 5–12 cm 長；主莖匍匐狀，圓柱體形，連同營養葉 (小葉) 之寬幅約 3 mm，常分支，並於不定距離處發根，多與其餘個體植株群集成綠色團墊。營養葉呈二形；腹葉於莖體腹面處完整可見 (側葉；於植株背面處無法見得葉基)，為卵狀橢圓形至卵狀披針形，1.5–2 mm × 0.6–1.2 mm，兩側幾乎對稱，基部圓形，頂端 (末端) 鈍尖或細尖，邊緣則有白邊 (軟骨質邊)，且長緣毛多數，緣毛長 0.05–0.1 mm；背葉於莖體背面完整可見 (中葉；於植株腹面處幾乎不可見或僅得見其葉尖處)，呈圓形至卵圓形，形體明顯小於腹葉，0.4–1.5 mm × 0.4–0.8 mm，與上下相鄰之背葉略有間隔 (間生)，彼此鮮少接觸，葉基圓形，葉頂端則常驟尖 (具長尾尖)，偶見鈍尖，葉緣有白邊，且長緣毛多數，緣毛長 0.05–0.1 mm。孢子囊穗位於莖體頂端，通常單一，結構緊密，6–12 mm × 2–2.5 mm，具背腹性。孢子葉亦二形，其背、腹葉之生長與營養葉相較呈轉置 (倒置) 狀態，葉緣亦具白邊；背葉較大，橢圓狀披針形，2–2.5 mm × 0.6–0.8 mm，葉緣毛短，長約 0.05 mm，然偶

見長毛 (可達 0.1 mm)，葉頂端漸尖；腹葉者較小，橢圓狀卵形，1.8–2 mm × 0.6–0.8 mm，葉片中央明顯具隆線，葉緣具長毛。孢子囊二形，大、小孢子囊生於孢子葉葉腋內的短梗上；小孢子橘紅色，大孢子灰白色。

Evergreen herb, predominantly epilithic, sprawling prostrate on rocks or nearby soil slopes. Plants 5–12 cm long; main stems creeping, terete, ca. 3 mm broad including vegetative leaves (microphylls, lycophylls), often branched, usually forming mats, rooting (bearing rhizophores) at intervals throughout. Vegetative leaves dimorphous; ventral leaves (lateral leaves) ovate-oblong to ovate-lanceolate, 1.5–2 mm × 0.6–1.2 mm, almost symmetrical, round at base, acute or apiculate at apex, margin white (cartilaginous) and with numerous long cilia, cilia 0.05–0.1 mm long; dorsal leaves (median leaves) round to ovate, apparently smaller than ventral ones, 0.4–1.5 mm × 0.4–0.8 mm, not approximate, round at base, cuspidate or sometimes acute at apex, margin white and with numerous long cilia, cilia 0.05–0.1 mm long. Strobili 6–12 mm × 2–2.5 mm, dorsiventral, compact, terminal, usually solitary. Sporophylls dimorphic, resupinate, white-margined; dorsal (upper) sporophylls oblong-lanceolate, 2–2.5 mm × 0.6–0.8 mm, margin usually short ciliolate, cilia ca. 0.05 mm long. but long hairs (up to 0.1 mm) are occasionally present, apex acuminate; ventral (lower) sporophylls oblong-ovate, 1.8–2 mm × 0.6–0.8 mm, apparently carinate, margin long ciliolate. Sporangia heterosporous; microsporangia and megasporangia occurring on short stalks in the axils of ligulate sporophylls; microspores tangerine, megaspores grayish white.

分布範圍：中國大陸 (廣西、貴州) 及臺灣 (花蓮)。

Distribution: Mainland China (Guangxi, Guizhou), and Taiwan (Hualien).

棲地環境：在臺灣，主要生長於

林緣近溪流處之石灰質岩塊或鄰近土坡上，海拔約 600–800 m。

Habitat: In Taiwan, the species primarily grow on calcareous rocks or nearby soil slopes near streams at the forest edge, at elevations of approximately 600–800 m.

引證標本 (specimen cited): TAIWAN. Hualien County, Yuli Township, Chike Mountain (or Jinzhen Mountain), alt. 800 m, *P.F. Lu31816*, 1 Mar. 2019, TAIF.

保育等級評估：有關本種在臺灣的分布情形，目前僅知花蓮縣境內一處分布地，且於該區域內只有數個亞族群。考量花東縱谷兩側山脈範圍仍有許多地方鮮為人至，本種之真實分布狀況及族群數量仍然不明，因此本文作者群依據 IUCN Standards and Petitions Committee (2024) 的評估標準，建議本種之紅色名錄類別為「資料缺乏 (DD)」。

Conservation status: Currently, only one distribution site is known in Taiwan, with a small number of subpopulations in that area. However, the actual population size remains uncertain due to considering the region (East Longitudinal Valley), and many areas are rarely visited by people. Therefore, we recommend the category of Data Deficient (DD) is appropriate for *Selaginella albociliata* (IUCN 2024).

分類註記：白毛卷柏之外觀形態及棲地偏好與琉球卷柏十分類似，若非仔細觀察細部特徵，很難區辨。目前琉球卷柏在臺灣的分布地點，以東部及東南部 (含離島) 之近海淺山為主，概有花蓮縣豐濱鄉及臺東縣成功鎮、長濱鄉、蘭嶼鄉等境內 6 個地點，合理推測未來會有更多的族群被發現。本種與琉球卷柏的小葉葉緣，其實都可發現長 0.05–0.1 mm 之長毛，區別在於本種出現頻度高，尤其是營養葉之背葉，其長毛明顯且穩定呈現；反觀琉球卷柏，其長毛係偶爾出現，且數量稀少。以 Chang *et al.* 2012 所載之檢索表為基礎，新修訂之臺灣產卷柏屬植物物種檢索表刊載如後。

Taxonomic note: The morphology

and habitat preference of *Selaginella albociliata* are very similar to those of *S. lutchuensis*, so it is difficult to distinguish them without careful observation of the detailed features. Currently, the distribution of *S. lutchuensis* in Taiwan is primarily in the low coastal mountains of the eastern and southeastern regions (including offshore islands), with six known locations in Fengbin Township of Hualien County, Chenggong Township, Changbin Township, and Lanyu Township of Taitung County. It is reasonable to speculate that more populations will be discovered in the future. Both *S. albociliata* and *S. lutchuensis* have long hairs measuring 0.05–0.1 mm on the margins of their microphylls. However, the frequency of these long hairs is higher in *S. albociliata*, particularly on vegetative dorsal leaves, where they are prominent and consistently present. In contrast, *S. lutchuensis* exhibits these long hairs only occasionally and in sparse numbers.

Based on the key reported by Chang *et al*. in 2012, the newly emended key to the species of *Selaginella* in Taiwan is provided as follows.

臺灣產卷柏屬植物物種檢索表 (Key to species of *Selaginella* in Taiwan)：

1. Stems and roots entangled forming treelike trunk..***S. tamariscina* 萬年松**

1. Stems creeping, prostrate, ascending, or caulescent…................................ 2

2. Stems caulescent; trophophylls on the basal part of erect stems monomorphic...................................3

2. Stems creeping, prostrate, ascending, or caulescent; trophophylls dimorphic, or subdimorphic on the basal part of erect stems if plants caulescent …....................................5

3. Trophophylls peltately attached on the basal part of erect stems …...........................***S. stauntoniana* 擬密葉卷柏**

3. Trophophylls basally attached on the

basal part of erect stems …...............4

4. Leaves on main stems approximate; main stems circular in cross-section; dorsal trophophylls with two longitudinal grooves, and usually acuminate at apex; both dorsal and ventral trophophylls not white-margined ....***S. involvens*** 密葉卷柏

4. Leaves on main stems distant; main stems with distinct keels in cross-section; dorsal trophophylls with only one longitudinal groove, and usually long-tailed at apex; both dorsal and ventral trophophylls white-margined …............***S. moellendorffii*** 異葉卷柏

5. Stems caulescent or nearly so (with short prostrate basal portion) …........6

5. Stems creeping, prostrate, or ascending, but not caulescent...........7

6. Margins of all trophophylls loosely serrulate; strobili complanate ....***S. labordei*** 玉山卷柏

6. Margins of all trophophylls entire; strobili tetragonal …........................... .... ***S. delicatula*** 全緣卷柏

7. Sporophylls laxly arranged, hence forming unobvious strobili…............8

7. Sporophylls compactly arranged, hence forming distinct strobili …......9

8. Margins of both trophophylls and sporophylls loosely serrulate............ ....***S. nipponica*** 日本卷柏

8. Margins of both trophophylls and sporophylls loosely laciniate ……. ....***S. helvetica* subsp. *pseudonipponica*** 擬日本卷柏

9. Strobili tetragonal, sporophylls monomorphic …..............................10

9. Strobili complanate, sporophylls dimorphic.......................................14

10. Stems always creeping....................11

10. Stems creeping at basal to middle portions, but ascending at middle to distal portion.................................12

11. Margins of both trophophylls and sporophylls distinctly white cartilaginous, usually iridescent, entire, but sometimes very minutely serrulate at apex ....***S. uncinata*** 翠雲草

11. Margins of both trophophylls and sporophylls not cartilaginous, not iridescent, usually loosely serrulate, sometimes entire……………………..
..................***S. remotifolia*** 疏葉卷柏

12. Margins of trophophylls minutely serrulate at apical half part, but fimbriate at basal half part; strobili loosely tetragonal ………………
........................***S. repanda*** 高雄卷柏

12. Margins of trophophylls loosely and minutely serrulate; strobili strictly tetragonal 13

13. Upper surface of ventral trophophylls smooth ………...............***S. doederleinii* subsp. *doederleinii*** 生根卷柏

13. Upper surface of ventral trophophylls muricate …………………***S. doederleinii* subsp. *trachyphylla*** 粗葉卷柏

14. Apices of dorsal trophophylls rounded to acuminate....................15

14. Apices of dorsal trophophylls apparently aristate to caudate........18

15. Apices of dorsal trophophylls rounded to obtuse, occasionally acute; margins of all trophophylls minutely serrulate ………………
…………………***S. devolii*** 棣氏卷柏

15. Apices of dorsal trophophylls apparently acuminate to attenuate…
....16

16. Margins of both trophophylls and sporophylls loosely laciniate at basal half part and often with few cilia; dorsal trophophylls without white cartilaginous margin ……………
…………………***S. ciliaris*** 緣毛卷柏

16. Margins of both trophophylls and sporophylls subentire to minutely serrulate, but never laciniate and without cilia 17

17. Stems 4.5–9.0 mm wide (including leaves); axillary trophophylls ovate to narrowly triangular at creeping branches……..................................
................***S. boninensis*** 小笠原卷柏

17. Stems 3.5–6.5 mm wide (including leaves); axillary trophophylls lanceolate to broadly lanceolate at creeping branches……………………..

..................*S. heterostachys* 姬卷柏

18. Plants mostly ascending; apex of ventral trophophylls obtuse to acute; margins of both ventral trophophylls and sporophylls without cilia ....*S. aristata* 膜葉卷柏
18. Plants usually creeping and repeatedly branching, and hence forming a dense mat; margins of both ventral trophophylls and sporophylls usually with cilia........19
19. Dorsal trophophylls denticulate at margin, occasionally bearing 1–2 long cilia at basal part ....*S. lutchuensis* 琉球卷柏
19. Dorsal trophophylls apparently ciliolate at margin ....*S. albociliata* 白毛卷柏

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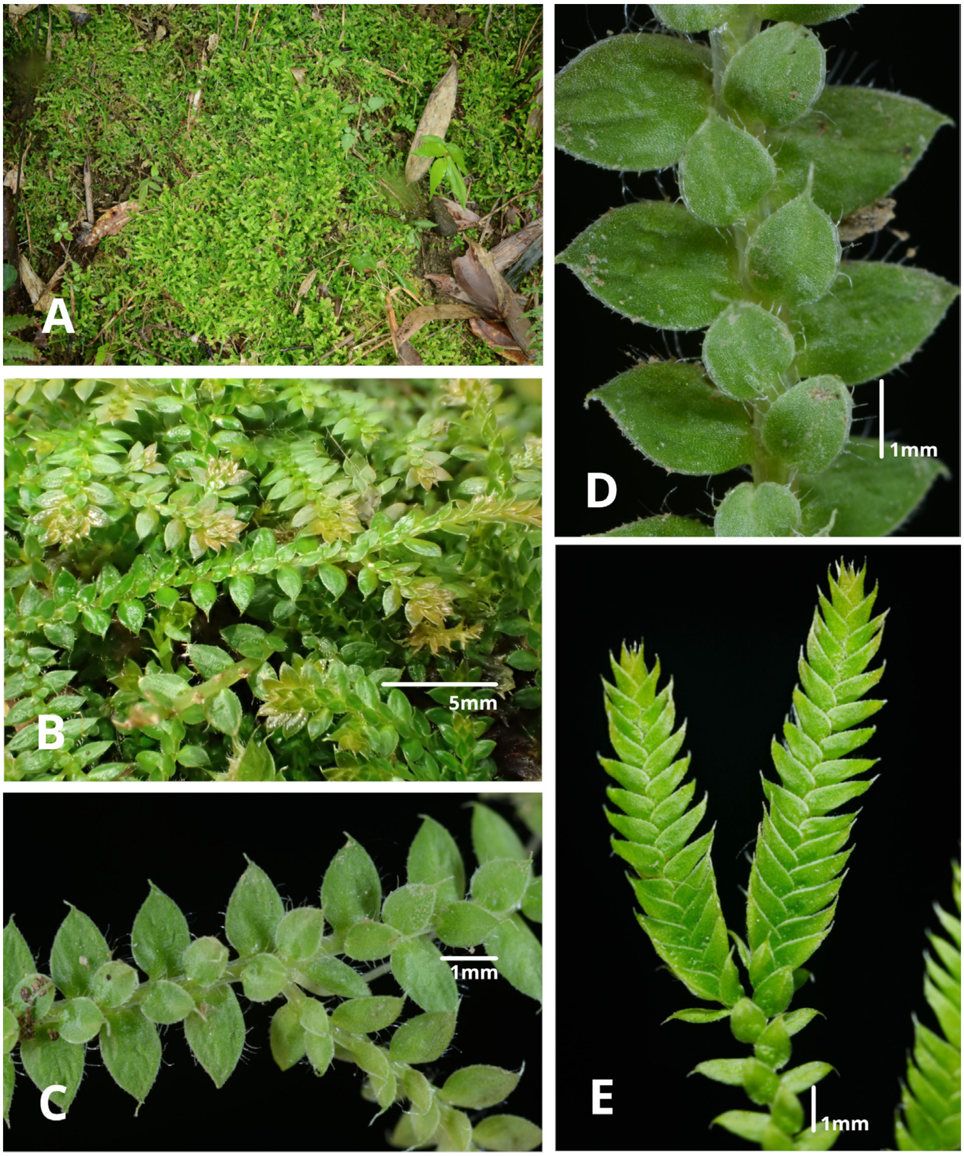

圖 1 白毛卷柏之生育地及外部形態。A. 生育地及棲生於上之白毛卷柏族群。B. 植株近照，莖體常分叉。C 及 D. 植株上表面 (背面) 近照；側葉較大，自莖部下表面 (腹面) 橫生而出；中葉較小，生自莖部之上表面，其葉片頂端驟出之尾尖及葉緣之長毛相當明顯。E. 孢子囊穗；側葉在營養莖及孢子囊穗之主軸上的生長位置明顯不同，轉置現象清楚可見。

Fig. 1 Habitat and external morphology of *Selaginella albociliata*. A. Habitat and population of *S. albociliata* thriving on it. B. Close-up of the plant, showing frequently branching stems. C & D. Close-up of the dorsal surface of the plant; the larger lateral leaves (ventral leaves) extend horizontally from the ventral side of the stem, while the smaller median leaves (dorsal leaves) arise from the dorsal side. The abruptly pointed tips of the median leaves and the prominent long hairs on the leaf margins are clearly visible. E. Strobili (cones); the growth position of the lateral leaves on the vegetative stem and the main axis of the strobili are completely opposite, with the phenomenon of resupination clearly visible.

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3. Cover page should contain title of manuscript, author name(s), author's (s') affiliation(s), corresponding author's name, telephone number, fax number and e-mail address, and a short running title.
4. Title should be less than 30 words. Capitalize the first letter of each word except articles, conjunctions and prepositions.
5. Author's name should be first name first followed by surname. For multiple authors, use a comma to separate the names but the last two names by "and."
6. Running title should be less than 50 letters including spaces.
7. Abstract must be a single paragraph not exceeding 500 words.
8. Key words should be no more than 5 words.

III. Manuscript Format:

1. Manuscript must be typed using standard software (Microsoft Word) with top, bottom, left and right. Mark page numbers on the bottom.
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For journals:

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

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

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

For books and symposiums:

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

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

For website:

POWO. 2023. Plants of the World Online. Facilitated by the Royal Botanic Gardens, Kew. Published on the Internet. Retrieved on 29 September 2023 from http://www.plantsoftheworldonline.org/

8. Table should be typed on a separate sheet and be headed by a title of dual languages (Chinese and English). It consists of only horizontal lines and typed with English terms (if possible) and Arabic numerals. If foot notes are required, mark with superscripts 1, 2, *, #, etc.
9. Figure should be drawn with black ink on a separate white tracing paper with a figure legend of the dual languages below. Computer graph made from laser printer is acceptable.
10. Photograph should be a glossy black and white shot with sufficient resolution to be clearly legible after reduction. When multiple photos are employed, the author should arrange them in plates. Micrographs should include bars indicating scales of magnification. Photos should be pasted on white A4 paper loosely with the figure legend below.

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