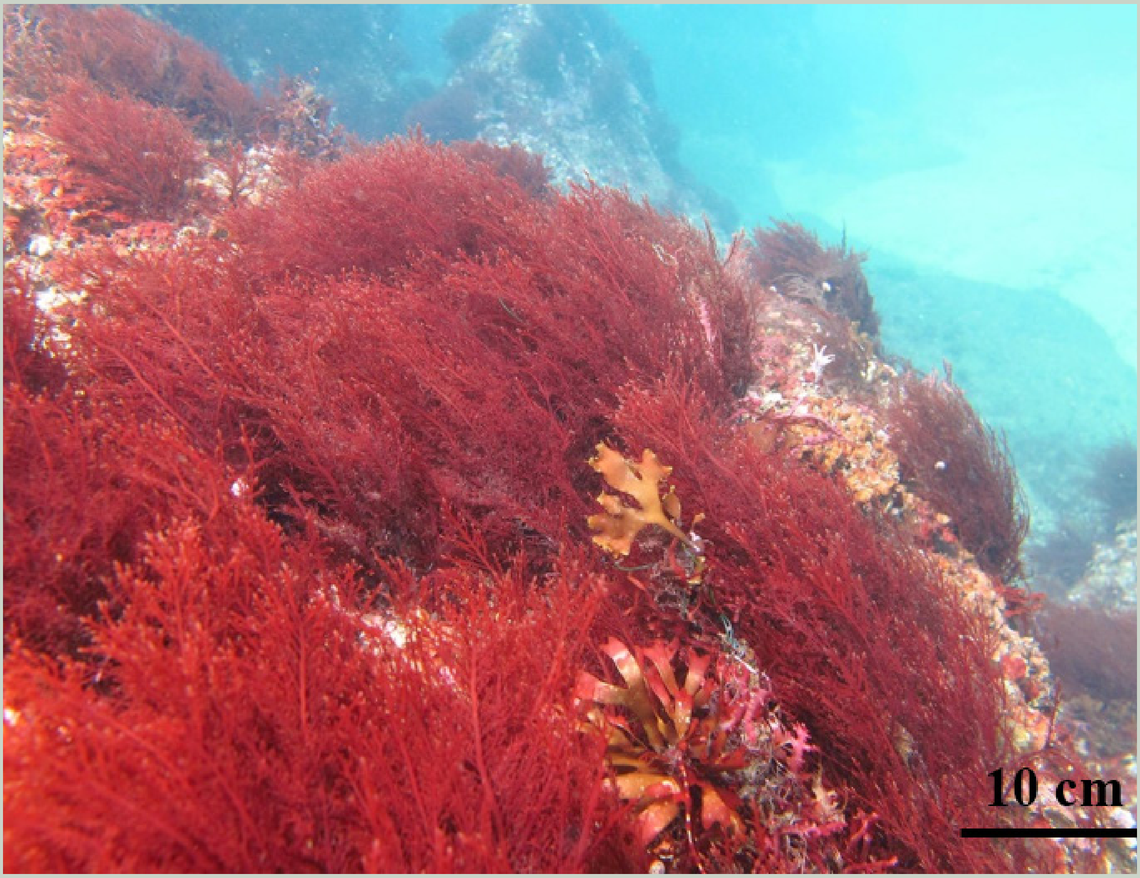
台灣生物多樣性研究

Taiwan Journal of Biodiversity

第 24 卷第一期
Vol.24 ,No.1
中華民國 111 年 1 月
Jan 2022



目　錄

contents

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（原為《特有生物研究》半年刊，
2010 年元月起更名，並以季刊發行）

發行人 / 楊嘉棟
總編輯 / 薛美莉

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出版編輯 / 王經文
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住址 / 南投縣集集鎮 55244 民生東路 1 號
電話 /049-2761331 轉 616
網址 /http://www.tesri.gov.tw
美編 / 黃淑芬
出版日期 / 中華民國 111 年 1 月
創刊日期 / 中華民國 88 年元月
出版登記 / 局版台誌第 10207 號

Taiwan Journal of Biodiversity

(Continuation of former journal of
“Endemic Species Research”, 1999-2009)

Publisher/Jia-Dong Yang
Editor-in-chief/Mei-Li Hsueh

English Editors/Hen-Biau King,
Publishing Editors/Ching Wen Wang
Published by Endemic Species Research Institute
1 Min-Sheng E. Road, Jiji, Nantou 55244,
Taiwan, R.O.C.
Tel: 886-49-2761331 ext. 616
http://tesri.tesri.gov.tw

Published Date: October 2021

GPN: 2009900002
ISSN: 2076-6971

模擬氣候變遷影響台灣常見花蜂之分佈範圍

Modeling effects of climate change on common pollen bees' range in Taiwan

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摘 要

野生花蜂在食物鏈中常扮演著重要的能量推動角色，所提供的授粉服務，能幫助植物繁衍與作物生產，是建構陸域生態系完整性與維持人類社會發展的核心物種。氣候變遷被認定是威脅花蜂族群減少的原因之一，本研究以台灣本島 10 種常見花蜂為目標，運用物種點位資料與集成式生態棲位建模，研究結果顯示，所建構的預測模型具備良好的性能，進一步推估代表濃度途徑 (representative concentration pathway, RCP) 情境下，物種適宜棲地之時空動態，研究發現，高排碳的情境 (RCP 8.5)，將導致花蜂的適宜棲地發生明顯改變，有 6 種花蜂呈現減少，4 種具擴張趨勢，位於高緯度及高海拔的物種皆有適宜棲地縮減的可能，反觀，適於低緯度及低海拔區域的耐熱物種會增加。因此，未來有關因應氣候變遷的保育策略，建議考量這兩種不同的環境做分區規劃。

關鍵詞：授粉、生態棲位建模、適宜棲地、時空動態、保育

Abstract

Wild pollen bees often play an important energy-promoting role in the food chain. The pollination services they provide can help plant reproduction and crop production. They are the keystone species that contribute to the integrity of the terrestrial ecosystem and maintain the development of human society. Climate change is identified as one of the reasons that threaten the reduction of pollen bee populations. In this study, an ecological niche model was "assembled" for 10 common pollen bee species in Taiwan based on species occurrence records. The results showed that our model has good performance, and further estimated the spatiotemporal dynamics of suitable habitats under the representative concentration pathway (RCP). The study found that the high carbon emission situation scenario (RCP 8.5) may cause significant changes to suitable habitats of pollen bees. Among them, six species showed a decrease in population and four species had a trend of expansion. Species located at high latitudes and altitudes may experience possible loss of suitable habitat, while heat-resistant species that prefer low latitudes and altitude areas may increase in population. Therefore, we recommend to consider these two different environments for zone planning in future conservation strategies in response to climate change.

Key words: pollination, ecological niche modeling, suitable habitat, spatiotemporal dynamics, conservation

緒言

自 19 世紀以來世界人口數持續攀升，同一時期，人類過度依賴石化燃料並破壞生態環境，使二氧化碳等溫室氣體在大氣中的濃度大幅提高，全球的平均溫也隨之上揚，政府間氣候變遷專門委員會 (The Intergovernmental Panel on Climate Change; IPCC) 預測，與 1986~2005 年相比，到 21 世紀末 (2081~2100 年)，全球平均溫度最低會升高 0.3°C，最高將升高到 4.8°C (IPCC 2013)。暖化會對生物多樣性會造成重大影響，由於氣候與生物之分佈及生存密切相關，情況持續惡化將可能導致某些物種消失 (Schloss *et al*. 2012, Randall and Woesik 2015)。

花蜂 (pollen bees) 因以植物的花粉及花蜜為糧食，故會頻繁的訪花，間接幫助作物或植物授粉，是自然界中最重要的授粉昆蟲之一，在食物鏈中常扮演著重要的能量推動角色，所提供的授粉服務，對植物繁衍起相當關鍵的傳遞作用 (Potts *et al*. 2016, Pufal *et al*. 2017)。就人類社會而言，野生花蜂參與了全球約 1/3 農作物的授粉工作 (Kremen *et al*. 2007, Klatt *et al*. 2014)，在授粉效率的表現上比會釀蜜的蜜蜂 (honeybees) 更加優越 (Garibaldi *et al*. 2013)，因此，維持其物種多樣性不僅可確食物的供應 (Winfree *et al*. 2018)，亦可穩定地方的經濟收入 (Giannini *et al*. 2017)，由此顯示，野生蜂是建構陸域生態系完整性與維持人類社會發展的核心物種。

近代全球蜂類數量大幅減少，成因雖眾說紛紜，惟氣候變遷被認定是 21 世紀的主要威脅之一 (Kerr *et al*. 2015, Papanikolaou *et al*. 2016, Aguirre-Gutiérrez *et al*. 2017)，因環境或物候的改變，會迫使野生花蜂須另尋其他適合的生存棲地。Nemésio *et al*. (2016) 就指出，暖化使巴西大西洋森林的平均氣溫升高，北方的特有蘭花蜂 (orchid bee) 可能會因此向南遷移，但因森林砍伐形成的地景破碎化會阻斷蜂群的路徑；同樣在巴西，Giannini *et al*. (2020) 針對亞馬遜森林東部 5 科 216 種花蜂，評估暖化對分佈的影響，發現 95% 的物種，適宜棲地面積將會縮減；在東亞地區，Naeem *et al*.

(2019) 評估 29 種特有熊蜂 (bumblebee) 對未來氣候變遷的分佈影響，並發現超過一半的物種呈現面積縮小狀態；Gonzalez *et al*. (2021) 則指出，哥倫比亞 9 種常見能幫助作物授粉的無螯蜂 (stingless bee) 中，有 7 種氣候適宜區顯著減少，從而影響到當地農村的經濟。

生態棲位建模 (ecological niche modeling, ENM) 是根據目標物種存在的環境條件，預測適宜的棲地範圍，其整合物種出現所在的背景資料 (環境因子)，經過演算獲取未知點的分佈可能性。國內外將 ENM 應用於氣候變遷對物種分佈影響的研究方興未艾，因所建構之模型再搭配氣候變遷情境，有助預測出未來的時空動態資訊，這其中也包含許多花蜂的研究 (呂等 2019, Marchioro *et al*. 2020, Giannini *et al*. 2020, Gonzalez *et al*. 2021)。 為提升 ENM 的準確性和可靠性，集成式生態棲位建模 (‘ensemble’ ecological niche modeling, EENM) 受到廣泛的應用，其利用不同的演算法建構多模型，並將各模型預測結果結合為一，以達到共識的效果 (Araújo and New 2007)，常見的演算法如廣義相加模型 (generalized additive model, GAM) 與多變量適應迴歸 (multivariate adaptive regression splines, MARS) 屬非線性迴歸之統計模型；增強迴歸樹 (boosted regression tree, BRT)、隨機森林 (random forest, RF)、最大熵 (maximum entropy, MaxEnt) 與支援向量機 (support vector machine, SVM) 等屬機器學習演算法，近年這些方法常被用於 EENM，做為推估物種適宜棲地的工具 (Naimi and Araújo 2016, Hao *et al*. 2019)，也有被應用於蜂類的研究 (Elias *et al*. 2017, Giannini *et al*. 2020, Lu *et al*. 2021)。

目前台灣預測氣候變遷對花蜂影響的研究仍屬少數，本研究便採用生物調查資料與 EENM 為基礎，模擬 10 種常見花蜂的適宜棲地，進一步配合近期發展的氣候變遷情境，預測時空動態，研究成果期能有助推動生物多樣性保育和永續利用工作。

材料與方法

一、研究區概述

臺灣位於歐亞大陸與太平洋的交界處，西隔臺灣海峽與中國大陸相望 (圖 1a)，土地面積約 36,000 km^2，為世界第 38 大島嶼，島內多為山地與丘陵，地形起伏變化大，平均海拔高約 660 m，最高山為玉山，標高 3,952 m，平原主要分佈於西部沿海 (圖 1b)，人口約 2,300 萬人，大多數集中於西部平原的都會區。氣候方面，因北回歸線貫穿，以北為亞熱帶季風氣候，以南則為熱帶季風氣候，另由於高山林

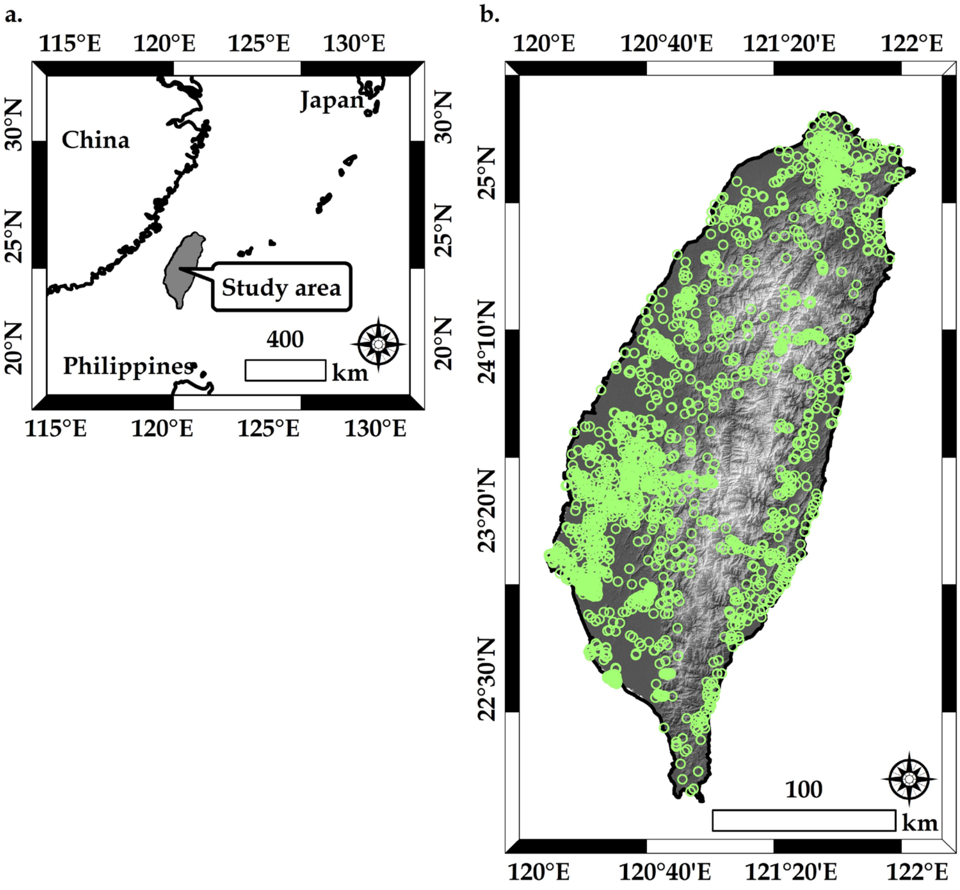

圖 **1.** (a) 研究區地理位置圖；(b) 物種出現點位 (綠色標記) 及數值高程模型 (digital elevation model)，顏色愈亮，表示海拔愈高。

Fig. 1. (a) Geographical location of the study area; (b) Species occurrence records (green circle) and digital elevation model, where darker colors indicate higher elevations.

立，隨著海拔的落差，構成熱帶、亞熱帶、溫帶及寒帶等複雜的氣候類型。

二、研究方法

(一) 物種資料

蒐集了無墊蜂 (*Amegilla*)、蜜蜂 (*Apis*)、熊蜂 (*Bombus*) 與木蜂 (*Xylocopa*) 等 4 屬共 10 種常見的花蜂出現點位 (圖 1b)，來源包括林務局生態調查資料庫系統 (ecollect.forest.gov.tw)，該批資料整合台灣近 20 年的全國生物調查成果；其次，整理林業試驗所昆蟲標本館之標本採集紀錄；此外，也納入 Global Biodiversity Information Facility 的資料，其中的 iNaturalist 數據僅使用研究等級。所有數據的座標僅保留 3 位小數以上，像元的空間解析力設定為 1×1 km，並排除網格內重複記錄點位，可減少空間自相關及地理取樣偏差的影響，整理後計有 1465 筆資料 (表 1)。

(二) 環境資料

針對現時的氣候資料，從 WorldClim 資料庫收集了 19 個生物氣候變項 (Hijmans *et al*. 2005)；地形方面，從內政部取得數值高程模型 (digital elevation model)，進一步利用 ArcGIS

表 **1.** 物種的調查紀錄筆數，符合 1×1 km 的空間解析力

Table 1. Occurrence records of the study species and were georeferenced to the spatial resolution of the 1×1 km.

Species	Chinese name	Record
Amegilla calceifera	鞋斑無墊蜂	27
Amegilla urens	螯無墊蜂	22
Apis mellifera	西方蜜蜂	976
Bombus bicoloratus	雙色熊蜂	73
Bombus flavescens	黃色熊蜂	63
Bombus formosellus	信義熊蜂	33
Bombus trifasciatus	威氏熊蜂	45
Xylocopa collaris	白領帶木蜂紹德亞種	84
Xylocopa rufipes	紅胸木蜂	42
Xylocopa tranquebarorum	銅翼背木蜂	100

10.6 軟體製作坡度與坡向；另由 Socioeconomic Data and Applications Center 獲得人類影響指數 (human influence index)，所有圖層的空間解析力重取樣為 1×1 km，總計有 23 個預測變項供建構模型。為克服變項在統計上的多重共線性問題，以 R (3.6.3 版本) 的 usdm 軟件包 (Naimi *et al*. 2014) 計算變異數膨脹因子 (variance inflation factor, VIF)，僅保留 VIF<5 的預測變項，該標準下，篩選出 8 個變項建構模型 (表 2)。

對於未來的模型，本研究假設氣候因子會隨著氣候變遷情境發生變化，其餘的變項則保持恆定，因此，選擇了 3 種碳排放情境，即 Intergovernmental Panel on Climate Change 第 5 次評估報告所發布之代表濃度途徑 (representative concentration pathway, RCP)，RCP 2.6、4.5 和 8.5 各表示輻射驅動力 (radiative forcing) 於 1750~2100 年間增加了 2.6、4.5 及 8.5 Wm^{-2}，平均溫度的預期變化範圍各為 0.3~1.7 °C、1.1~2.6 °C 與 2.6~4.8 °C，分別代表輕度、中度和重度等暖化情境 (IPCC 2013)。可從 WorldClim 各別獲得 2070 年 (2061~2080 年的平均值) 3 種情境下，藉由統計降尺度產生 1×1 km 解析力的生物氣候變項，選擇適用於預測台灣氣候的全球氣候模式 (global climate model, GCM)，包括 CESM1-CAM5、CSIRO-Mk3-6-0、

表 **2.** 模擬花蜂分佈的預測變量

Table 2. Predictor variable to model the distribution of pollen bees.

Variable	Source
Temperature seasonality	WorldClim dataset
Maximum temperature of the warmest month	
Annual precipitation	
Precipitation seasonality (coefficient of variation)	
Precipitation of warmest quarter	
Slope	Ministry of the Interior
Aspect	
Human influence index	SDAC

SDAC=Socioeconomic Data and Applications Center

GISS-E2-R 與 MIROC5 (Lin and Tung 2017)，使用這 4 個 GCM 生產的未來生物氣候，各別為每個物種建模，並取平均獲得棲地適宜性，可消彌 GCM 間的不確定性 (Araujo and New 2007)。

(三) 生態棲位建模

藉由 R 平台的 sdm 軟件包 (Naimi and Araújo 2016) 執行 EENM，預測各種花蜂的適宜棲地，使用的演算法包括了 GAM、MARS、BRT、RF、MaxEnt 與 SVM 等 6 種，由於所有演算法都需要背景點位 (偽無出現點)，因此，每一物種在研究區內生逢機產生 10000 個點位。將各物種出現的點位逢機選取 70% 做為訓練資料集，剩餘 30% 做為測試資料集，每種演算法使用 bootstrap 抽樣法來評估模型性能，進行 10 次的重複運算，10 種花蜂 ×6 種演算法 ×10 次重複，總共建構 600 個模型。

準確度評估依接受者操作特徵 (receiver operating characteristic) 所產生之曲線面積 (area under the curve, AUC)，以及真實技能統計值 (true skill statistics, TSS) 評估模型的性能，其中 AUC 值域介於 0.5~1，當值愈高代表模式預測出來的準確性愈佳，TSS 則落於 +1 至 -1，接近 1 表示模型幾乎完美，反之亦然 (Allouche *et al*. 2006)，當 AUC 與 TSS 分別高於 0.8 及 0.6 以上即為良好的標準 (Swets 1988, Ben Rais Lasram *et al*. 2010)。模型的集成方法是留 TSS>0.6 之模型，再基於 TSS 做加權平均，產生各物種的集成概率圖，概率愈大者，愈有可能是其適宜的棲地，故可表示棲地適宜性。

各物種的適宜棲地範圍，參考靈敏度 (sensitivity) 和特異性 (specificity) 相加後的最大值，取該值對應的概率做為閾值，並轉換為二位元 (binary) 的適宜 (1) 和非適宜 (0) 棲地圖。現時與 2070 年代 3 種氣候變遷情境下，10 種蜂種各別可產生 4 種適宜棲地面積，以現時為基期，可獲得現時至未來之面積增減率，即 (未來 - 現時)/ 現時 ×100。此外，將研究區各種蜂種之適宜棲地累加，可獲得物種數目分佈圖，僅保留物種數≧ 1 之網格，可獲取整

體花蜂適宜棲地範圍，並瞭解從現時至未來 (3 種氣候變遷情境) 之空間轉移與面積變化情形。

結果

利用 6 種演算法各別獲得 10 種花蜂的預測模型，藉由測試資料集計算出來的平均 AUC 與 TSS 如表 3，除 *A. mellifera* 僅有 RF 較佳外，多數物種在各演算法下的擬合結果皆表現良好，又以 RF 的表現最佳，由於每種花蜂都有模型達到性能良好的標準，為獲得高準確的預測結果，後續僅保留 292 個高性能的模型 (TSS>0.6) 進行集成運算。

使用 EENM 模擬各花蜂的適宜棲地，結果發現，無墊蜂、蜜蜂與木蜂等 3 屬多分佈於平地至低海拔山區，除 *A. mellifera* 外，多數座落在北部地區，中南部較為零散，另熊蜂屬適宜棲地的海拔分佈較高，主要在中央高山帶 (圖 2)。以現時的適宜棲地面積為基礎，隨著氣候變遷的發展，發現大多數的花蜂會受到影響，10 種物種中，6 種花蜂的適宜棲地面積會縮減， 而 *A. calceifera*、*B. flavescens* 與 *B. formosellus* 等 3 種的面積消失 40% 以上，另外 3 種相對影響幅度較小；適宜棲地面積擴增者計有 4 種，*A. mellifera*、*B. bicoloratus* 與 *X. tranquebarorum* 在 RCP 8.5 的情境增加最明顯，均超過 100%，*X. collaris* 則較為穩定 (圖 3)。

從現時至 2070 年代，整體花蜂適宜棲地的範圍變化如圖 4 及圖 5，3 種氣候變遷情境下，空間分佈型態隨著暖化的現象提升，變動程度也愈劇烈 (圖 4)。面積經計算後可知，適宜棲地擴增的比縮減的現象明顯，RCP 2.6 與 RCP 4.5 情境下，適宜棲地增加面積分別為 4645 km^2 與 5283 km^2，RCP 8.5 情境更突增了 8228 km^2，另一方面，該情境減少的面積約 5856 km^2(圖 5)。就空間分佈而言 (圖 4)，適宜棲地擴增的範圍以低海拔地區為主，東、西兩側平原大多由 *A. mellifera* 所貢獻，南部的山區為 *B. bicoloratus*，尤其是 RCP 8.5 情境可看出明顯的趨勢；適宜棲地縮減則位於中至高海拔山區，該區物種則以熊蜂為主 (補

表 **3.** 廣義相加模型 (generalized additive model, GAM)、多變量適應迴歸 (multivariate adaptive regression splines, MARS)、增強迴歸樹 (boosted regression tree, BRT)、隨機森林 (random forest, RF)、最大熵 (maximum entropy, MaxEnt) 與支援向量機 (support vector machine, SVM) 所獲得之接受者操作特徵曲線面積及真實技能統計值

Table 3. Scores collected from the area under the receiver operating characteristic Curve (AUC) and true skill statistic (TSS) to boosted regression tree (BRT), generalized additive model (GAM), multivariate adaptive regression splines (MARS), maximum entropy (MaxEnt), random forest (RF), and support vector machine (SVM).

Species		BRT	GAM	MARS	MaxEnt	RF	SVM
A. calceifera	AUC	0.90	0.86	0.89	0.87	0.90	0.86
	TSS	0.71	0.71	0.72	0.68	0.75	0.70
A. urens	AUC	0.90	0.90	0.85	0.87	0.90	0.86
	TSS	0.74	0.73	0.68	0.72	0.74	0.66
A. mellifera	AUC	0.78	0.79	0.79	0.79	0.91	0.78
	TSS	0.41	0.43	0.43	0.44	0.68	0.44
B. bicoloratus	AUC	0.76	0.77	0.78	0.85	0.85	0.83
	TSS	0.49	0.46	0.60	0.62	0.64	0.62
B. flavescens	AUC	0.89	0.86	0.88	0.87	0.90	0.88
	TSS	0.67	0.63	0.66	0.68	0.70	0.66
B. formosellus	AUC	0.92	0.93	0.91	0.93	0.95	0.94
	TSS	0.78	0.80	0.76	0.78	0.84	0.83
B. trifasciatus	AUC	0.91	0.91	0.89	0.89	0.92	0.90
	TSS	0.72	0.75	0.72	0.72	0.73	0.69
X. collaris	AUC	0.87	0.85	0.86	0.86	0.92	0.86
	TSS	0.67	0.64	0.67	0.64	0.73	0.68
X. rufipes	AUC	0.92	0.91	0.90	0.91	0.95	0.92
	TSS	0.77	0.77	0.76	0.75	0.82	0.76
X. tranquebarorum	AUC	0.89	0.78	0.86	0.88	0.87	0.84
	TSS	0.67	0.47	0.62	0.64	0.67	0.65

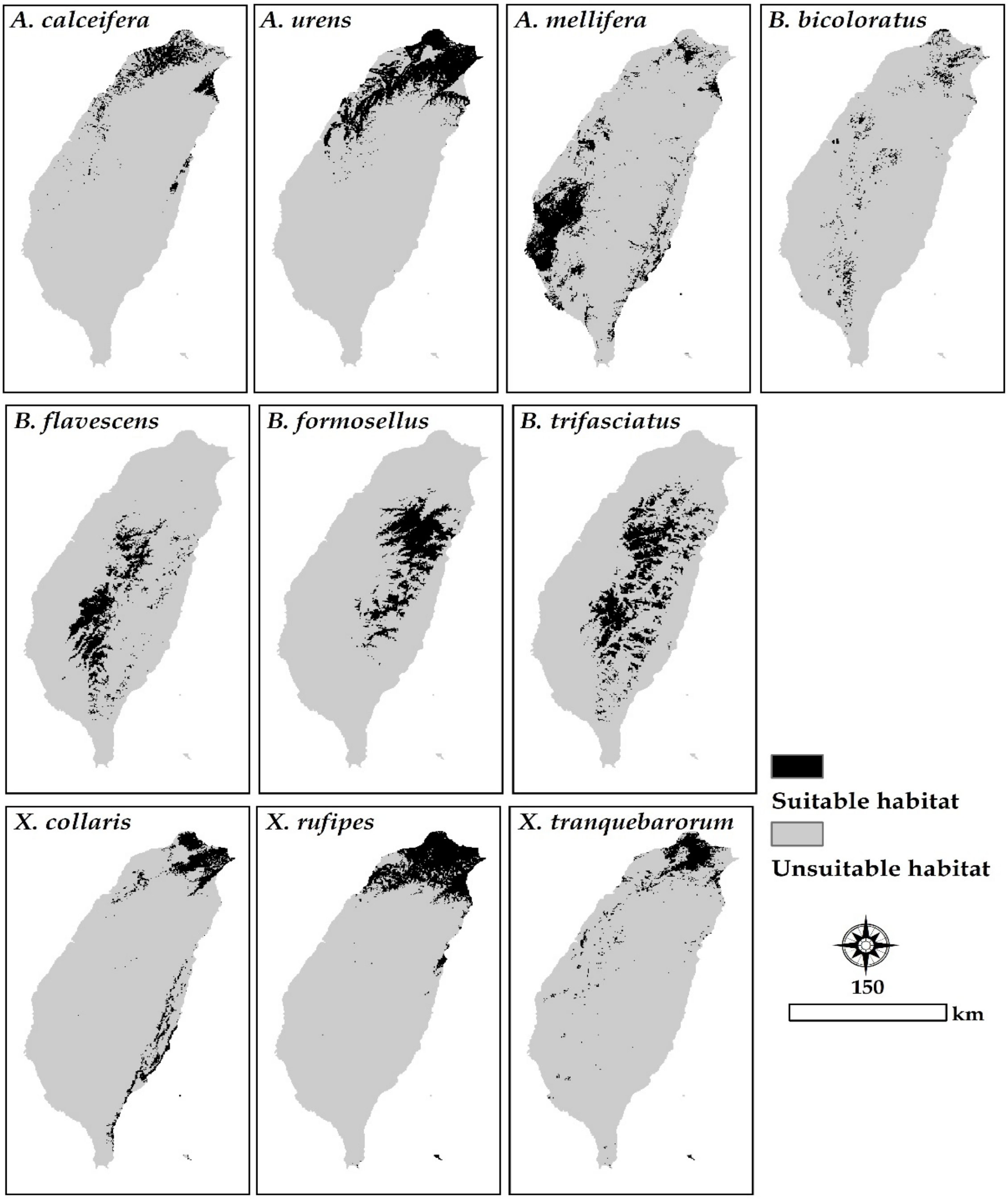

圖 **2.** 各花蜂物種現時的預測分佈範圍

Fig. 2. Predicted current distribution of pollen bee species.

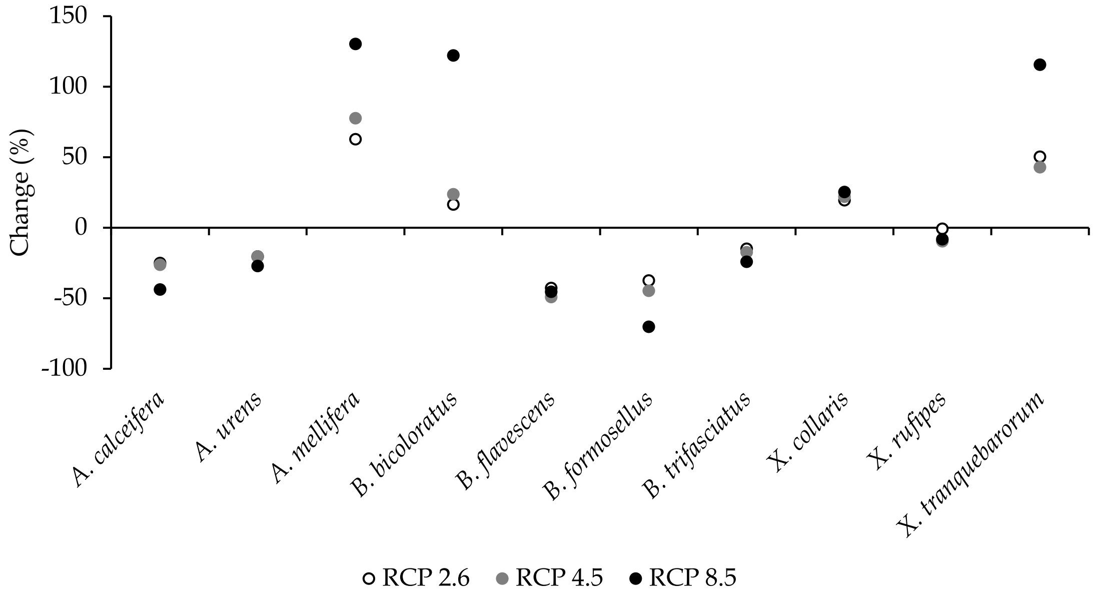

圖 **3.** 10 種蜂種在現時和未來 RCP 2.6、RCP 4.5 和 RCP 8.5 氣候變遷情境 (2070 年代) 的適宜棲地面積變化。

Fig. 3. Shifts in suitable habitat areas of 10 bee species in a RCP 2.6, RCP 4.5, and RCP 8.5 scenario of future climate change for the 2070s, respectively.

充圖 3)。

討 論

EENM 為預測氣候變遷對物種適宜棲地影響之利器，透過多模型的整合可提升預測的準確性 (Araújo and New 2007, Marmion *et al*. 2009)。本研究結果證實，該種方式的建模，對於花蜂的分佈預測也可獲得良好的效果，然而，集成建模的缺點，即在於需要歷經長時間的訓練過程，就單一的演算法而言，本研究發現 RF 的表現最理想 (表 3)，這與過去探討多種蜂類的研究結果一致 (Elias *et al*. 2017)，因此，欲提升運算效能，單獨使用 RF 建模是一種可考慮的選項。

蜂類本身對氣候的反應相當敏感，因此，氣候因子常被做為觀察生物習性的重要指標 (Dew et al. 2016, Shell and Rehan 2016)，本研究用於建構模型的變項也以氣候類為多數 (表 2)，因此，預測出來的花蜂適宜棲地，會明顯受到氣候特徵的影響。關

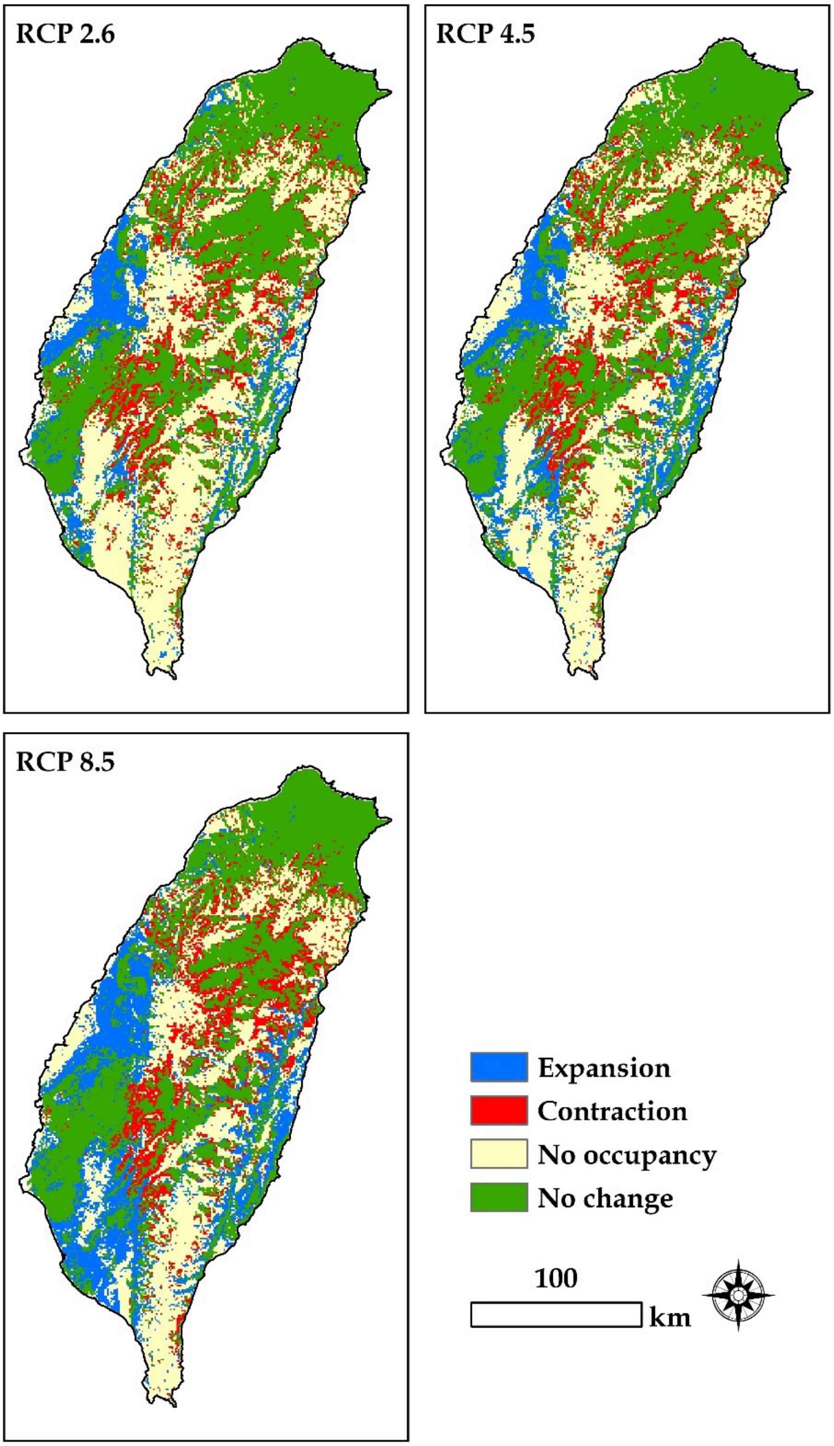

圖 **4.** 現時至 2070 年代間常見花蜂在不同氣候變遷情景下，適宜棲地之時空動態。

Fig. 4. Spatiotemporal dynamics of suitable habitat for the common pollen bee in different climate change scenarios from present to 2070s.

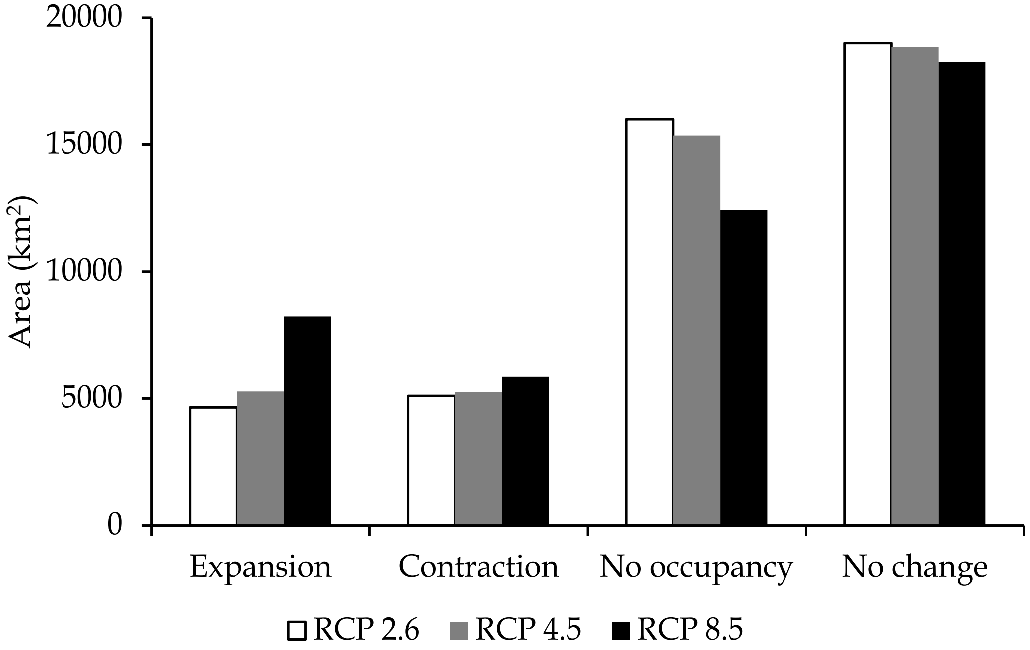

圖 **5.** 現時至 2070 年代間常見花蜂在不同氣候變遷情景之面積變化計算。

Fig. 5. Histogram of area changes of common pollen bees in different climate scenarios from the present to the 2070s.

於各花蜂分佈特性的文獻，國內除熊蜂屬外，其他類群較為缺乏，參考國外的研究可知，無墊蜂與木蜂屬是廣泛分布於低中海拔和溫度偏高的環境 (Karunaratne and Edirisinghe 2009)，但本研究的結果明顯集中於北部地區，中南部顯得非常零星，這與過往的研究有些落差，應有可能是物種本身的調查點位不均，造成預測結果有明顯的空間異質性。相較於廣泛分佈於低海拔的 *A. mellifera* (Ruttner *et al.* 1978)，適宜棲地主要在中南部，但其他各地也有存在一些小區塊的面積，較符合應有的認知，由此可知，目前國內可利用的資料庫中，無墊蜂與木蜂屬的調查點位仍有缺口有待補充。

熊蜂偏好於冷涼的氣候條件 Williams (1998)，本研究探討的 4 種熊蜂，*B. formosellus* 較侷限於高海拔，其餘為常見種且海拔分佈較廣，適宜棲地的

預測結果與過往的研究相去不遠，主要都分佈於山區 (宋等 2011)。

關於台灣的氣候變遷預測，前人的研究顯示，無論是過去及未來，所有 GCM 的預測結果顯示，台灣各地受全球暖化影響甚鉅，平均溫度都往升高的走向發展 (Hsu and Chen 2002, Lin *et al*. 2015; 2017)。在空間格局上，高山升溫的幅度會比平原地區明顯，緯度方面則是北部比南部地區明顯，這將對生態系和物種分佈產生重大影響 (Lin *et al*. 2015)。正如本研究以現有資料基礎所建構的模型，未來 RCP 8.5 氣候變暖的情境下，適宜棲地位於北部地區 (高緯度) 的物種，皆有縮減的可能，變化較明顯者為 *A. calceifera*，垂直梯度方面，則以 *B. flavescens* 與 *B. formosellus* 兩種高山熊蜂的減少幅度較大 (圖 3)。相反地，部分可調適暖化的花蜂面對氣候變遷卻能保持穩定發展，並擴張其族群勢力 (Giannini *et al*. 2013, Silva *et al*. 2015, 2017)，本研究的結果即發現，*A. mellifera*、*B. bicoloratus* 和 *X. tranquebarorum* 的適宜棲地都可能因暖化往低海拔及低緯度區域擴增。參考相關的研究中，呂等 (2019) 預測與 *A. mellifera* 親緣關係相當接近的 *Apis cerana*，同樣發現該蜂種的適宜棲地不減反增，這兩種物種本身皆有耐高溫的能力 (Li *et al*. 2019)。至於 *B. bicoloratus* 方面，其雖偏好冷涼氣候，惟宋等 (2011) 的調查指出，該種熊蜂於低海拔的分佈比其他種多，可能具有較佳的耐熱性，由此顯示，這些物種未來皆具備調適暖化的潛能。

集合 10 種花蜂的適宜棲地，觀察受氣候變遷驅動之時空動態，發現 RCP 8.5 情境會使整體適宜棲地擴增的現象大於縮減，範圍以平地及低海拔山區為主 (圖 4 及 5)，然而，僅由少數物種所貢獻，這樣的結果將不利於生物多樣性。另一方面，臺灣地狹人稠，低海拔環境藏有高度的干擾壓力，本研究僅基於氣候變遷情境的預測，縱使某些適應力強的物種會受惠，未來若受到人為干擾的影響，物種分佈的發展可能不如預期。以上多強調高碳排放情境的預測結果，相反，與低碳排放相比，花蜂受影響的程度相

對緩和，因此，要維持生物多樣性及族群的穩定發展，追根究底，應在於人類能否建構低排碳的經濟活動與生活模式。

結論

本研究首次提出了預測氣候變遷對臺灣常見花蜂的影響，主要結果發現，未來輕度與中度暖化的情境下，受影響的程度相對較小，但重度暖化的情境，將導致花蜂的適宜棲地發生明顯改變，位於高緯度及高海拔的物種皆有縮減的可能，反觀，適於低緯度及低海拔區域的耐熱物種會增加。因此，未來有關因應氣候變遷的保育策略，建議針對這兩種不同的環境做分區規劃，此外，控制碳的排放，盡可能讓人為活動符合輕度或中度暖化情境的發展，是讓物種分佈維持穩定的關鍵課題。

謝誌

本研究承行政院科技部專題研究計畫「MOST109-2628-M-329-001-MY2」之經費補助；林業試驗所陸聲山博士及嘉義大學植物醫學系宋一鑫副教授提供物種調查資訊供參考，特此致謝。

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鋸齒麒麟菜之世代判別與資源保護策略

Generation determination and resource protection methods of Eucheuma perplexum Doty.

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摘要

鋸齒麒麟菜 *Eucheuma perplexum* 為台灣本土料理涼拌蜈蚣菜的主要原料，因擁有充滿嚼勁的口感，深得大眾所愛。本研究使用核磁共振光譜法進行鋸齒麒麟菜之世代判定並於新北市瑞芳區深澳漁港海域實施兩項資源保護實驗。世代判定結果顯示，鋸齒麒麟菜配偶體及四分胞子體之藻體內鹿角菜膠皆為 *ι* 型，故需使用其他方式判定未成熟藻體之世代。而資源保護實驗結果顯示，單去除鋸齒麒麟菜群落周遭的競爭物種無法提升鋸齒麒麟菜之族群量，但於鋸齒麒麟菜生長高峰或攝食壓力高之時期予以保護，如設置保護籠等，可維持其正向的日成長量。本研究以累積鋸齒麒麟菜之生物學資訊及增加資源保護策略建議為目的，未來建議可投入資源以建立如鋸齒麒麟菜等高經濟藻種之養殖系統，並開發可迴避草食性生物之方法，以作為未來大型藻類養殖技術之基盤。

關鍵詞：鋸齒麒麟菜、鹿角菜膠、草食性生物、資源保護

Abstract

Eucheuma perplexum Doty is the main ingredient of a Taiwanese local dish “Liang Ban Wu Gong Cai” (cold centipede dish), and is loved by the locals for its chewy texture. In this research, the generation of *E. perplexum* is determined by using Nuclear Magnetic Resonance (NMR) spectroscopy. Two resource protection experiments were conducted in Shen-Ao Bay, Rui-Fang District, New Taipei City. The results from sex determination showed that both generations contain the same carrageenan, which is the iota type. It is necessary to use other methods to determine the sex of immature *E. perplexum*. The results of two protection experiments showed that although the removal of competing species around the communities of *E. perplexum* does not increase the population of *E. perplexum*, protecting them, e.g., in a cage during the high growth or high feeding pressure period can positively maintain their daily growth rate. The purpose of this research is to accumulate the biological information of *E. perplexum* and to find new strategies in resource conservation. It is recommended in the future to invest in exploring the establishment of a cultivation system for high-economic algae such as *E. perplexum*, and to develop methods to avoid herbivories, laying the foundation of the future seaweed cultivation technology.

Key words: *Eucheuma perplexum*, carrageenan, herbivory, resource protection

序言

鋸齒麒麟菜 *Eucheuma perplexum* Doty 屬於真紅藻綱 Florideophyceae、杉藻目 Gigartinales、紅翎菜科 Solieriaceae 之海藻，分布於溫帶至熱帶海域 (Yamada 1936)。其分類學上英文學名本稱作 *E. serra*，但依據 Dumilag 等 (2020) 針對本國基隆市八斗子海域之樣本的論述指出，臺灣與菲律賓海域之鋸齒麒麟菜正確英文學名為 *E. perplexum*，而原本的 *E. seera* 只分布於澳洲周圍海域。其外型為深紅色，擁有軟骨質的扁圓柱狀藻體，藻體直徑約 0.1-0.4 cm，呈現羽毛狀或不規則狀分枝，分枝前端呈突刺狀，整體呈現鋸齒般的外型，並分布於水深 3-5 m 處 (Yamada 1936, Chen *et al*. 2020)(圖 1)。此海藻經過川燙後冰鎮，搭配大蒜末、薑絲、芝麻、辣椒末及檸檬汁食用，為台灣本土料理「涼拌蜈蚣菜」的主要原料，在日本宮崎縣則被製成塊狀，醃製味增後當作傳統小吃 -Mukadenori Misoduke 食用 (Chen et al. 2020)。此種海藻除了食用以外，其藻體可萃取的高純度多聚糖 - 鹿角菜膠 (Carrageenan) 被廣泛應用在食品、工業及製藥的增稠劑及穩定劑，例如 : 冰淇淋、豆漿及牙膏等 (道本與五十嵐 1985; Lin *et al.* 2000, 2001)，為高經濟用途海藻，其販賣價格約為濕重量 1 公斤 900 新台幣左右 (Chen *et al*. 2020)。

此海藻為多年生海藻，夏季時遭受額帶刺尾魚 *Acanthurus dussumieri*

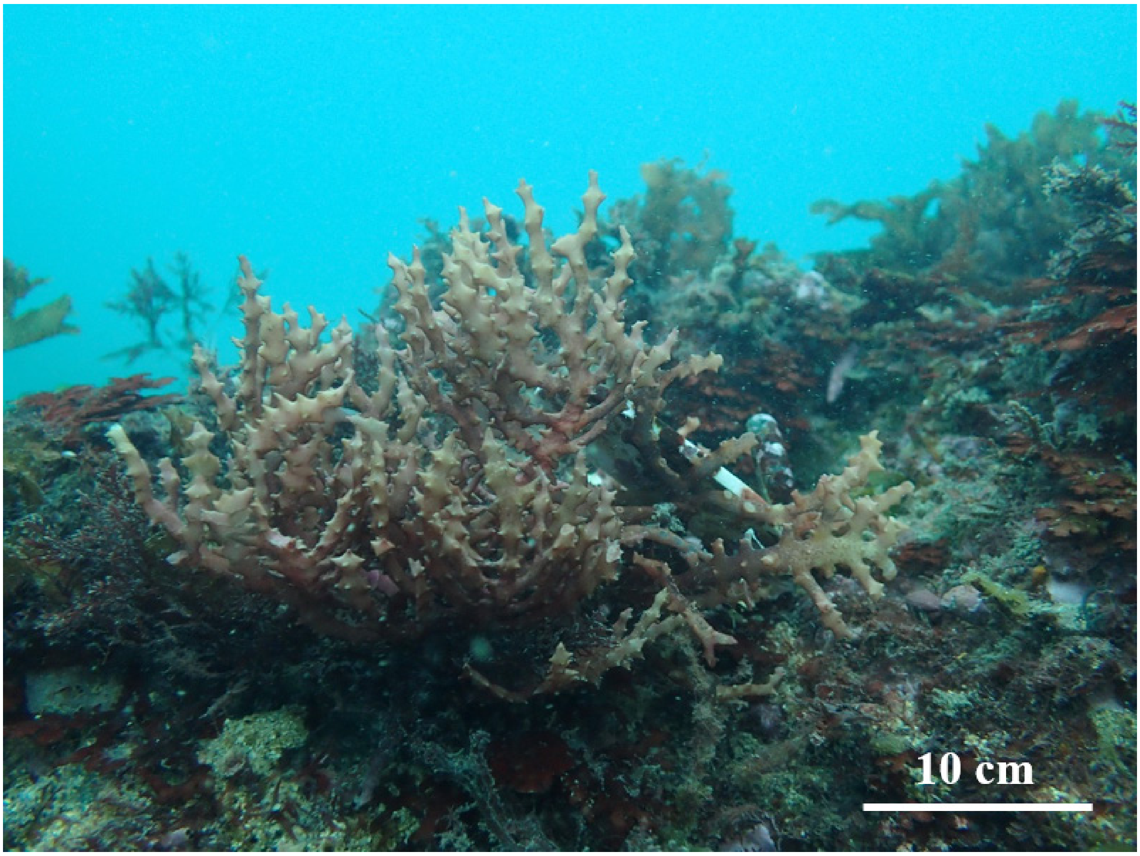


圖 1 生長在深澳漁港內的鋸齒麒麟菜：生長在深澳漁港水深 4 m 處之鋸齒麒麟菜個體。
Fig. 1. *Eucheuma perplexum* in Shen-Ao Bay: *E. perplexum* inhabiting at a depth of 4 m in Shen-Ao Bay.

等草食性生物 (Herbivory) 嚴重的啃食 (Browsing) 及仙菜科藻類寄生造成藻體損傷 (Chen *et al*. 2020)，導致資源量變動幅度極大。鋸齒麒麟菜之原料來源主要為販售店家等委託沿海地區漁民使用自由潛水進行潛水採集，日本九州地區因其採集方式與臺灣相同，資源量也未有詳細管理規範，以至於此高經濟藻種之資源量大幅減少，如今已難以採集 (大野等 2001)。此海藻在臺灣雖屬東北角海域排名第 6 之優勢藻種 (Lin *et al*. 2018)，但因與日本相同，並無相關規範管理資源量，其未來之資源量變化著實令人堪憂。

近年來，因鹿角菜膠的需求增加，麒麟菜屬 *Eucheuma* 的養殖市場逐漸擴大，現今最為普遍的養殖藻種為耳突麒麟菜 *Kappaphycus alvarezii*

(Doty) Doty ex Silva，乃因其鹿角菜膠品質與藻體生長率較高。而因麒麟菜屬之養殖方式皆採用無性繁殖 (Clone cultivation)，導致藻體喪失遺傳多樣性 (Hurtado and Cheney 2003)，造成環境適應力不佳、生長率下降、品質降低、*ice-ice* 病與寄生藻等問題頻繁發生 (Hurtado *et al*. 2012, 2015)。雖然有性生殖下的世代交替能提高藻體環境適應力，但因紅藻之未成熟個體的世代辨識十分困難，提升了有性養殖的難度。而鋸齒麒麟菜的未成熟藻體、成熟雄性藻體、四分胞子體皆屬無法使用肉眼判斷性別與世代之藻體(Chen *et al*. 2020)。如有明確方法能夠判別鋸齒麒麟菜之世代，能有效地了解海域內鋸齒麒麟菜之資源量，也能使臺灣朝向鹿角菜膠生產原料國的領域往前邁進一步，增加我國水產養殖的實力。

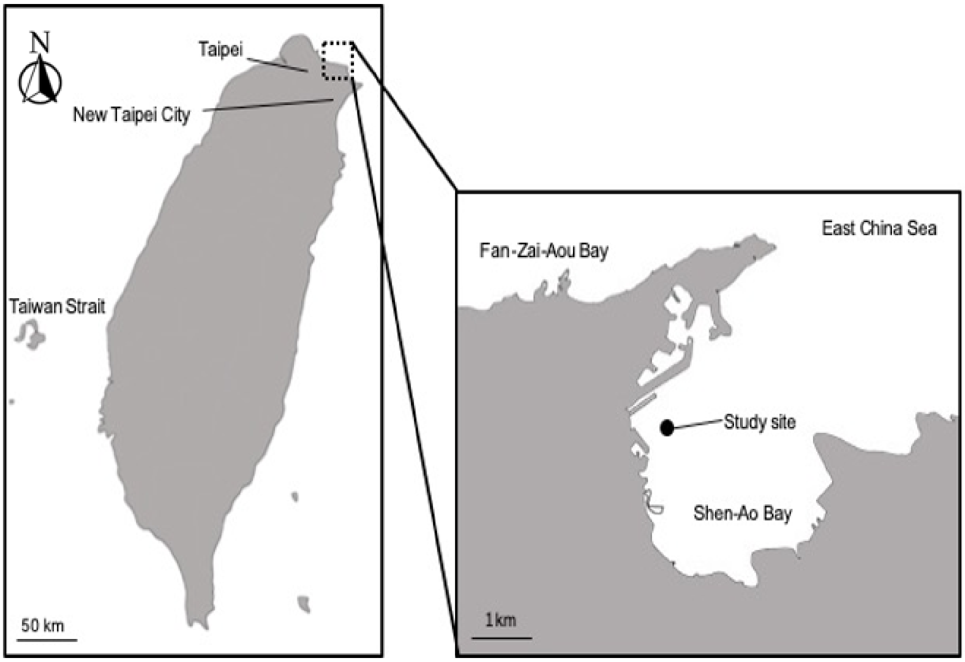
本論文將探討應用於紅翎菜科海藻中判定世代時使用的核磁共振光譜法 (Nuclear Magnetic Resonance spectroscopy，NMR) 是否能應用於鋸齒麒麟菜之世代判斷，並於新北市瑞芳區深澳漁港海域內進行鋸齒麒麟菜天然資源保護與群落擴增實驗以補充鋸齒麒麟菜生物學資訊及增加臺灣海域大型藻類資源保護經驗，期盼藉由本研究的結果能使我國大型藻類之資源保護及養殖技術基盤更加穩固。

材料與方法

一、調查地點

本研究之調查地點位於新北市瑞芳區深澳漁港 (25.127325, 121.820122) (圖 2)，屬台灣東北角海域。本調查海域全年受高溫、高能見度、低營養鹽的黑潮與低溫、高營養鹽、低能見度的中國沿岸流影響 (Jan *et al*. 2002)，擁有海洋生物多樣性高的環境。調查地點之海底底質為硬底質 (礁石) 與軟底質 (沙地) 混合，本研究於易於打樁及安裝不銹鋼籠等器材之礁石區 (4 m) 進行研究。

本研究調查地點之潮下帶海藻相主要為優美石花菜 *Gelifium elegans* Kützing(圖 3) 及鋸齒麒麟菜為優勢種並廣泛分布於 3~5 m 處，東青葉馬尾藻 *Sargassum ilicifolium* (Turner) C. Agardh 則分布於 3 m 以淺處。



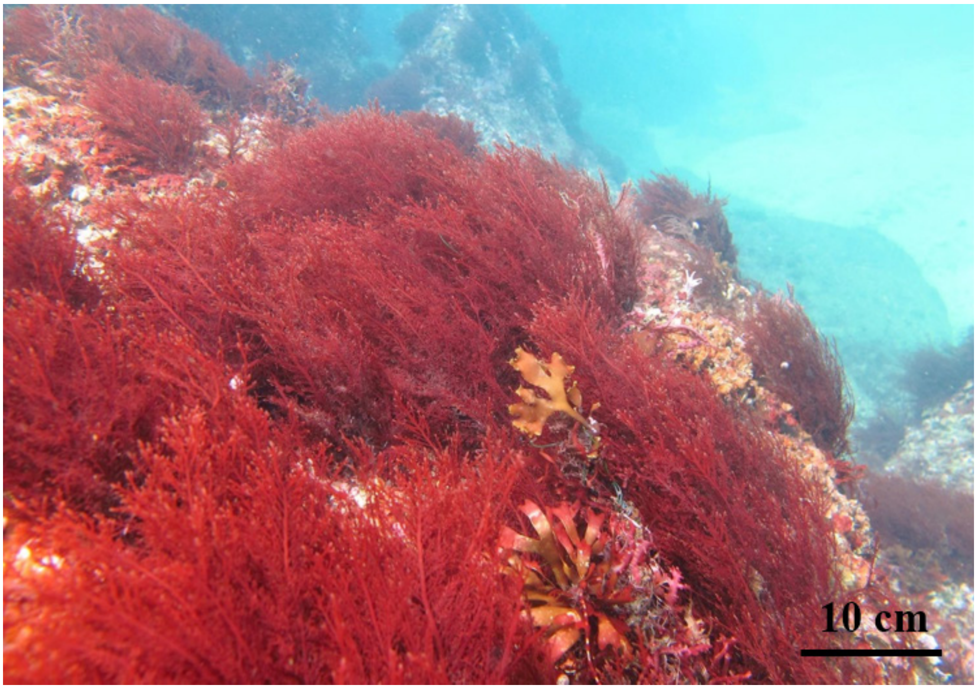


圖 2 本研究調查地點 : 本研究地點位於新北勢瑞芳區深澳漁港海域。

Fig. 2. Study site of this research: During our research, study site was located in Shen-Ao Bay, Rui-Fang District, New Taipei City.

圖 3 調查地點之優美石花菜群落 : 生長在本研究調查地點水深 4 m 處之優美石花菜群落。

Fig. 3. Communities of *Gelifium elegans* in study site: The communities of *G. elegans* inhabiting at a depth of 4 m in Shen-Ao Bay.

二、世代判定

無法由肉眼判斷世代之鋸齒麒麟菜成熟藻體，如雄性配偶體、四分胞子體，可藉由製作藻體切片後再使用顯微鏡觀察其生殖細胞等特徵判定性別及世代，而未成熟個體之世代目前尚無任何判定方式 (Chen *et al*. 2020)。早川 (2017) 指出鋸齒麒麟菜近緣種的線形軟刺藻 *Chondracanthus tenellus* (Harvey) Hommersand (杉藻目，杉藻科) 擁有因世代交替而產生不同類型鹿角菜膠的特性，並可藉由核磁共振光譜法判定其世代。本論文將利用此特性探討是否適用於鋸齒麒麟菜之世代判定。

鹿角菜膠類型分析之樣本為使用 2017 年 6 月 21 日於調查地點 (圖 2) 採集之冷凍藻體，經由藻體切片判斷性別及世代後，挑選成熟雌性配偶體 (單倍體，n) 及成熟四分胞子體 (雙倍體，2n) 各 1 藻體進行鹿角菜類型分析。

鹿角菜膠之萃取方式為，將藻體表面洗淨後，乾燥風乾，風乾後之藻體置入錐形瓶，並加入等於乾燥藻體約 33 倍之萃取液 (DW，1M NaOH)，將索氏提取器 (Soxhlet extractor) 安裝於錐形瓶後浸入 90˚ C 恆溫水浴槽中放置 3 小時。待鹿角菜膠液體提取完後，將其倒入玻璃過濾器過濾，將過濾後之過濾液加入約 3 倍量的 2- 丙醇 (99.9 %，7°C)，使其液體中之多糖體沉澱。隨後將其沉澱物移至培養皿中，放入 60°C 乾燥機中乾燥 2 日以上。2 日後取出培養皿並用研杵搗碎後加入重水 (deuterated water, D_2O) 使其濃度達到 2 % (v/v)，並使用設定至 80˚ C 之恆溫水浴槽加熱溶解 30 分鐘。加熱溶解後將樣本移入實驗燒杯中並使用超音波清洗機震動 15 分鐘，隨後再次使用 80˚ C 之恆溫水浴槽加熱溶解約 30 分鐘。將樣本取出 1 ml 至玻璃管中，並靜置於 80˚ C 恆溫裝置中，於玻璃管內加入微量的 2,2- 二甲基 -2- 矽戊烷 -5- 磺酸鈉 (Sodium 2,2-dimethyl-2-silapentane-5-sulfonate, DSS) 做為化學位移對照化合物，並用封口膜密封後可得測量樣本。

本研究之核磁共振光譜法 NMR 使用液態超導核磁共振儀 Bruker

AVANCE III 600 (Bruker)(樣本溫度 65° C，累加次數 64 次) 進行測量，將測量得之鋸齒麒麟菜之配偶體及四分胞子體光學頻譜與鹿角菜膠 κ 型與 ι 型樣本比較，並判定鋸齒麒麟菜之配偶體及四分胞子體之鹿角菜膠類型及世代判定的可行性。

1. 資源保護實驗

在本研究中資源保護實驗方法分為兩種方式進行，保護籠實驗是於 2019 年 5 月 14 日藉由水肺潛水 (SCUBA Diving) 將外觀無傷痕及附著物之野生鋸齒麒麟菜藻體採收上岸後，將分枝前端部切成一定大小 (約 1.6 ± 0.6 g)，並將每 5 個藻體固定於 1 條直徑約 0.5 mm 之養殖繩 (Cremona rope) 上，本實驗之樣本為 2 條養殖繩，共 10 藻體。將養殖繩用束帶固定於事前設置於水深 4 m 處之礁石海床上的不銹鋼方型籠 (20 x 20 x 20 cm，網目 5.5 mm)，籠

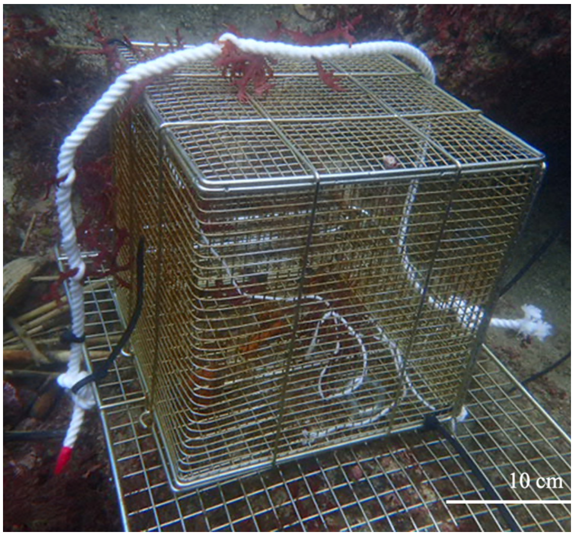


圖 4. 固定於海床之不銹鋼籠及養殖繩 : 本研究使用不鏽鋼籠保護海藻個體，並將海藻固定在繩子上。

Fig. 4. The cage with cremona ropes was deployed on the sea bottom at a depth of 4 m: In our research, we used a stainless cubic mesh cage to protect the thalli of *E. perplexum* which were inserted into cremona ropes.

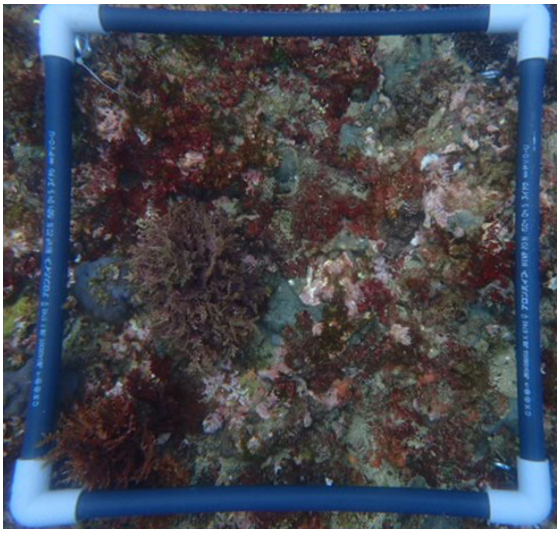


圖 5. 群落擴增實驗之對照區方框 : 本研究群落擴增實驗之對照區，PVC 水管為輔助識別方框範圍之工具。

Fig. 5. Control section of community expansion experiments: Control section in this research, we used PVC pipes to assist in identifying the sections range.

內外各固定 1 條養殖繩 (圖 4)。於實驗期間內每月一次將養殖繩取下並返回陸地測量藻體片之重量、殘存個體數並拍照記錄。測量完成後再將養殖繩固定回海中籠內及籠外。

第二種群落擴增實驗之方式為，在鋸齒麒麟菜成熟期間時 (2019 年 5 月 14 日)，於調查海域內海床上 (4 m)，使用鐵鎚、不銹鋼樁於海床上製成 50 x 50 cm 永久方框 (圖 5)，永久方框為 1 對照區與 3 競爭物種移除區 (下稱移除去)，共 4 區。移除區內將鋸齒麒麟菜以外之雜藻、固著性生物以刮刀刮除。並於 2019 年 5 月至 9 月內每月下水一次，調查方式為使用自製 50 x 50 cm PVC 水管輔助識別永久方框範圍，並拍攝方框內海藻群落擴增情形，並使用 Image J 計算鋸齒麒麟菜群落面積 (%) 變化。

結果

一、世代判定

鹿角菜膠標準品樣本 ι 型、κ 型、鋸齒麒麟菜配偶體及四分胞子體之 NMR 光譜分析結果如圖 6 所示，圖中 NMR 光譜峰之信號來源於鹿角菜膠分子的振動和轉動，而兩世代之藻體樣本皆於 1.6~1.8 ppm、1.85 ppm、4~4.6 ppm、5.15 ppm、5.8 ppm 處出現明顯光譜峰，並於 4.65 ppm 處出現最高峰，5.2~5.4 ppm 間出現連續兩光譜峰。兩世代之光譜峰與鹿角菜膠 κ 型與 ι 型樣本比較之結果指出鋸齒麒麟菜之兩世代皆為 ι 型鹿角菜膠。

二、資源保護實驗

資源保護實驗結果如圖 7 所示。保護籠之殘存個體數不論是籠內或籠外皆於 2019 年 6 月開始減少，籠外藻體於 8 月完全消失，9 月因米塔颱風影響導致籠子鬆脫、藻體流走而致實驗中止。藻體濕重量的結果指出，籠內外之藻體皆於 6 月呈現正成長，籠外藻體濕重量於 7 月開始下降並於藻體上觀察到啃食痕跡 (Bite mark)(圖 8)，籠內藻體則順利從 5 月 (1.6 ± 0.1 g, mean ± SD, n = 4) 成長至 8 月 (3.1 ± 0.4 g, mean ± SD, n = 2)，並觀察到二次附著器 (Secondary attachment disc) 生成及附著於養殖繩上 (圖 9)。

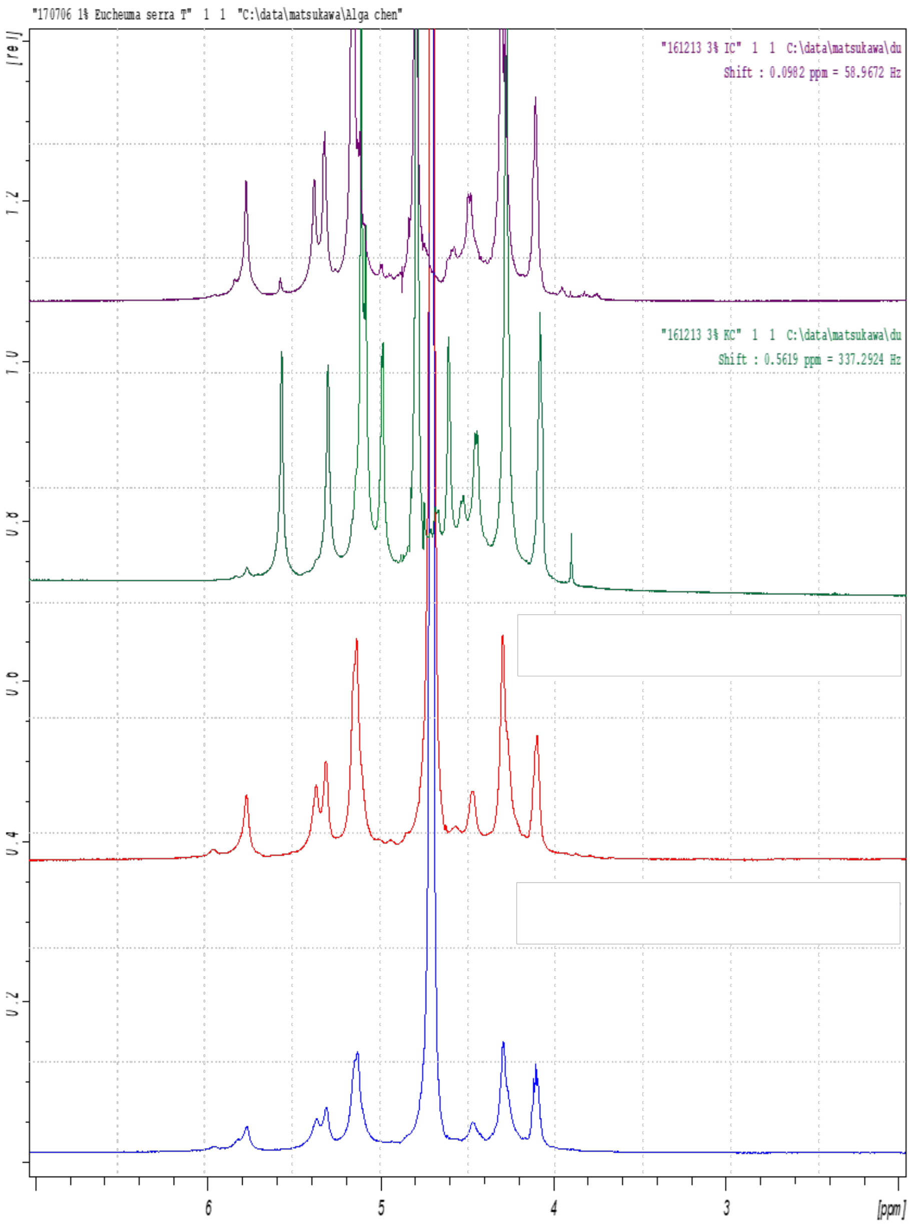


圖 6. 鹿角菜膠樣本 ι 型 (紫色)、κ 型 (綠色)、鋸齒麒麟菜配偶體 (紅色)、四分胞子體 (藍色) 之紫外線光譜峰比較：本研究使用 NMR 檢測鋸齒麒麟菜之兩世代鹿角菜膠類型與對照之鹿角菜膠樣本 ι 型、κ 型之比較，比較結果兩世代皆為 ι 型。

Fig.6. The comparison of ι type carrageenan sample (purple), κ type carrageenan sample (green), *Eucheuma perplexum* gametophyte (red), and tetrasporophyte (blue): we used NMR to analyze the type of carrageenan of 2 generations of *E. preplexum*, the results showed that both of the two generations are ι type.

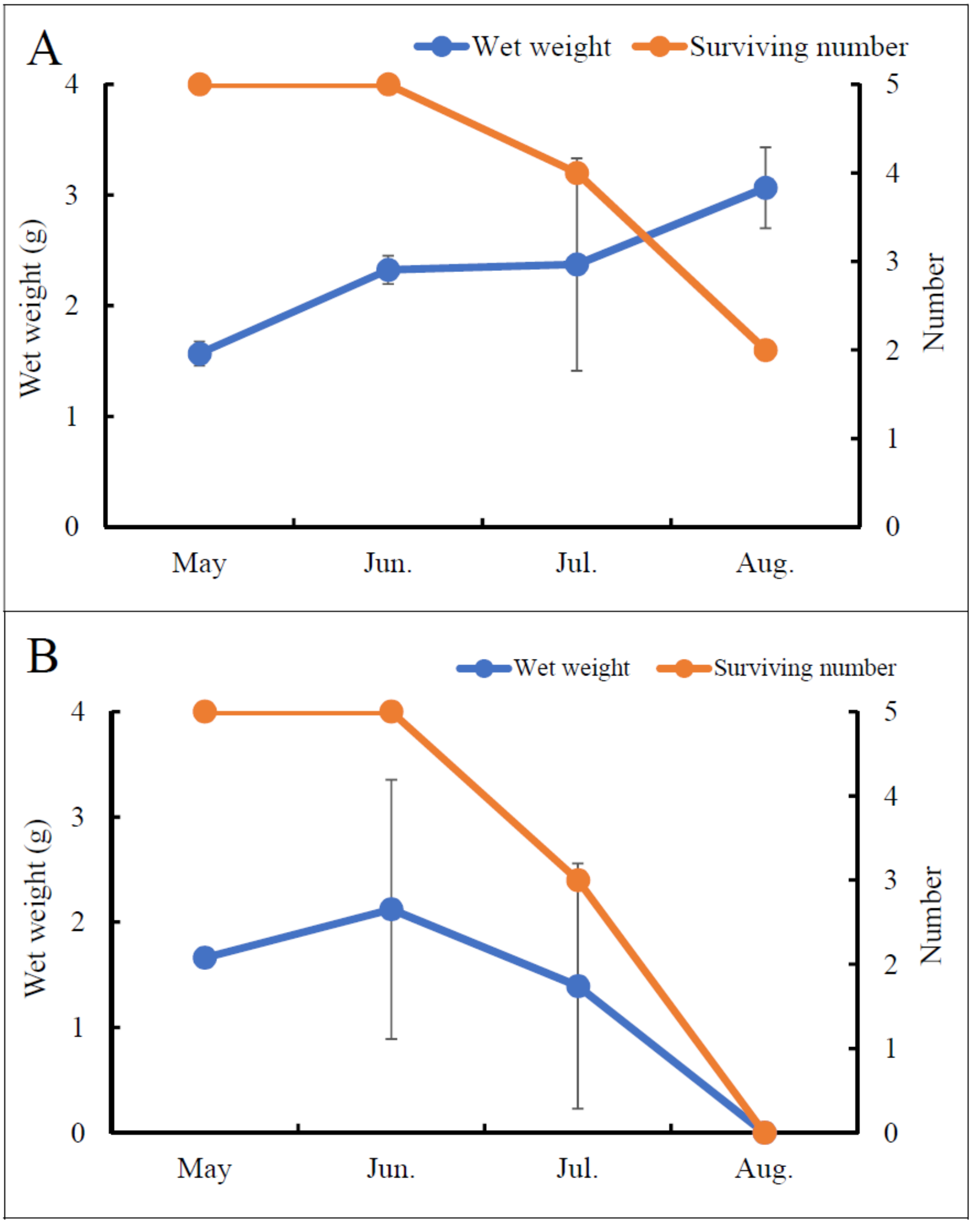
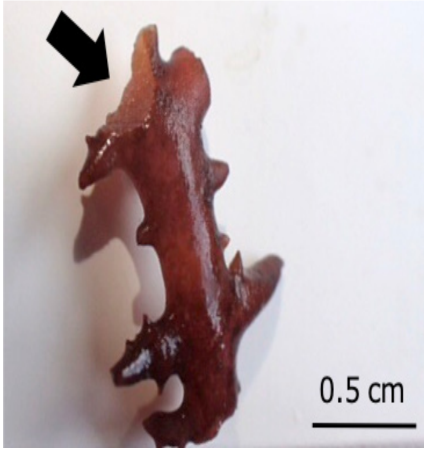


圖 7 籠內 (A) 外 (B) 之藻體濕重量與殘存藻體數的結果：籠內藻體之殘存藻體數多於籠外，濕重量也持續呈現正成長，直到籠子遭 9 月之颱風摧毀為止。

Fig. 7 The results of wet weight and surviving number of *Eucheuma perplexum* inside (A) and outside (B) the cage: the surviving number inside the cage was higher than outside, and wet weight also showed positive growth rates before the typhoon season in September.



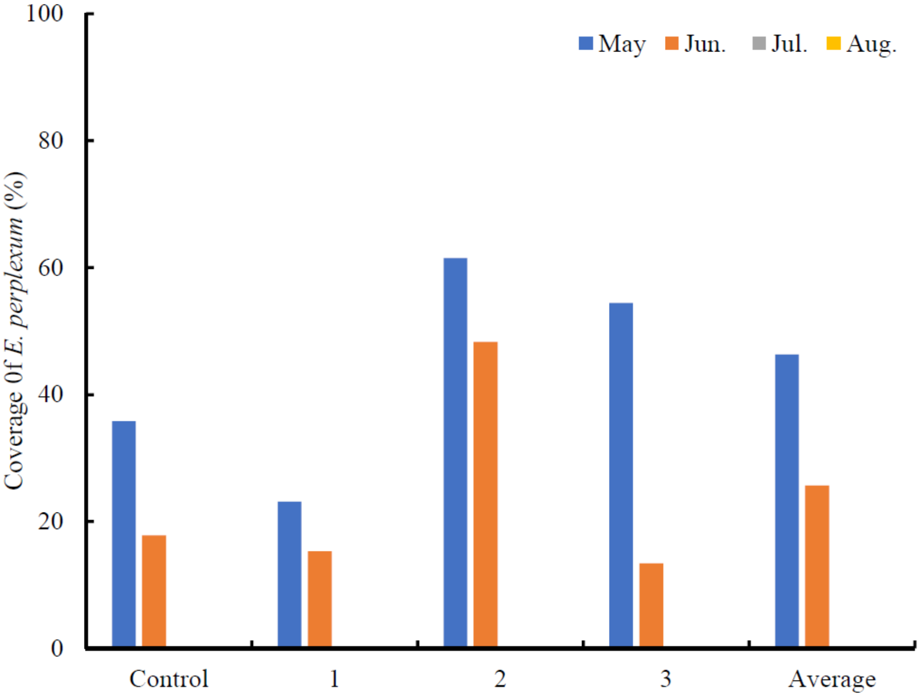


圖 8. 藻體上之啃食痕跡：籠外藻體可觀察到明顯草食性生物啃食痕跡。

Fig. 8. Bite marks on thallus: bite marks are visible on the thalli outside the cage.

圖 9. 鋸齒麒麟菜之二次附著器：籠內藻體生成二次附著器並附著於養殖繩上。

Fig. 9. Secondary attachment disc of *Eucheuma perplexum*: Thalli reattached on the cremona rope via secondary attachment disc (SAD) within the cage

圖 10. 競爭種移除實驗之鋸齒麒麟菜群落面積變化：共 4 區之鋸齒麒麟菜群落皆遭受嚴重啃食，導致群落全部消失。

Fig. 10. The coverage of *Eucheuma perplexum* in competing species removal experiments: including the control section, the communities of *E. perplexum* in all section were eaten by herbivores and as a result, the whole communities disappeared.

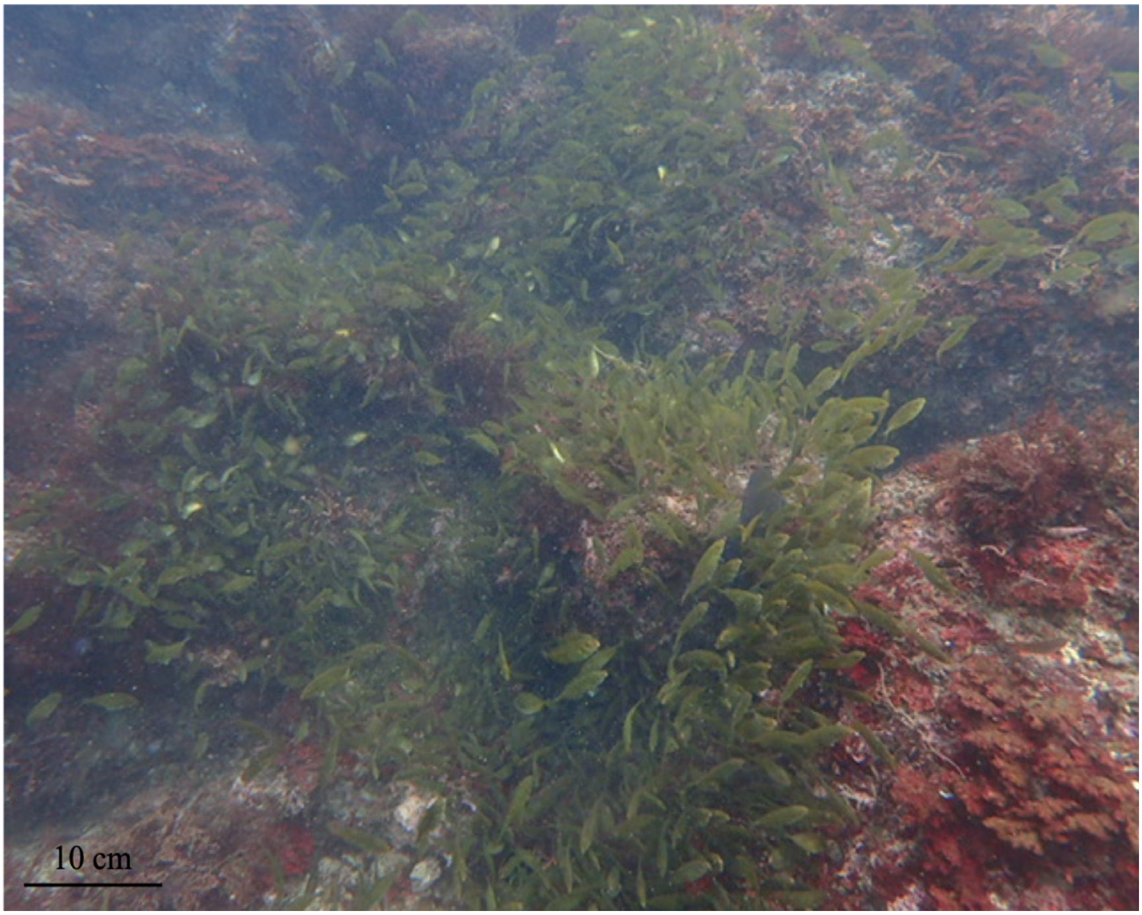


圖 11. 實驗期間出現於調查地點之刺藍子魚稚魚魚群 : 出現於調查地點之刺藍子魚雉魚魚群，數量驚人而且持續啃食礁石表面之大型海藻。

Fig. 11. The school of juvenile *Siganus spinus* swimming around the study site during experiments period: a school of juvenile *S. spinus* was found in the study site and was seen grazing on the surface of rocks.

群落擴增實驗結果如圖 10 所示。對照區之鋸齒麒麟菜分布面積從 5 月實驗開始時 (35.8%) 開始減少，6 月降至 17.8%，7 月時時則完全消失，9 月因米塔颱風的影響導致所有方框遭破壞，以致調查中止。移除區之結果也與對照區得到相似的結果。調查期間內皆可見草食性魚類 - 刺藍子魚 *Siganus spinus* 稚魚群於調查區附近活動並頻繁啄食礁石上之海藻 (圖 11)。

討論

NMR 核磁共振光譜法為用以化學位移校正、定量目標化合物之用，本研究成功使用 NMR 分析鋸齒麒麟菜之鹿角菜膠種類，根據分析結果得知兩世代皆為相同類型，故，鋸齒麒麟菜沒有世代交替產生不同鹿角菜膠類型之特徵，並與其他紅翎菜科 (van de Velde 2008)、杉藻科 (早川 2017) 海藻不同，無法使用此特性判定藻體世代。本研究分析出了臺灣東北角優勢海藻種 - 鋸齒麒麟菜之鹿角菜膠為富有彈性、柔軟且具保水性之 *ι* 型，未來可利用此資訊，將其投入適當之食品、工業產品加工，進而拓展其經濟價值。而因 NMR 法無法判定鋸齒麒麟菜之世代，肉眼無法判別未成熟藻體世代之課題仍舊存在，雖藻體成熟時可採用冷凍切片 (Frozen section) 判定生殖細胞等之特徵 (Chen *et al*. 2020)，但若是遇到冬季 (未成熟個體多) 或樣本數多時，依然會損耗大量的人力和時間成本，本研究在此建議未來可朝遺傳因子領域開發，例如 DAPI 染色法或許是一個十分有潛力判別藻體為單倍體或雙倍體之方式。

本研究之資源保護實驗最後雖受颱風影響導致籠內藻體消失，但籠內旱體成長結果與籠外藻體、同調查地點之鋸齒麒麟菜生活史結果 (Chen *et al*. 2020) 相比得知，於高啃食率 (Feeding rate) 時予以適當的保護，可保護鋸齒麒麟菜之自然資源。另外，本研究首次觀察到鋸齒麒麟菜之二次附著器生成，二次附著器之生成除了鋸齒麒麟菜外，同為紅藻的 *Solieria filiformis* (Kützing) Gabrielson (Perrone and Cecere 1997)、*Chondracanthus chamissoi* (C.Agardh) Kützing (Bulboa *et al*. 2013) 與雞冠菜 *Meristotheca papulose* (Montagne) J.Agardh (Chen *et al*. 2019) 皆有二次附著器生成之報告。二次附著器為海藻脫落後再附著之重要利器 (Chen *et al*. 2019)，此外，也有關於將二次附著器特性運用於海藻種苗養殖實作研究 (Hernández-González 2007)，固本研究觀察之鋸齒麒麟菜二次附著器生成或許可應用於未來大型藻類養殖技術開發。

而群落擴增實驗中，移除競爭種

並沒有使鋸齒麒麟菜群落擴增，故無法確認其有效性。野田等 (2014) 指出，在南日本海域中，只有單一藻種形成之藻床，即便是草食性魚類喜好性較低之藻種，也會在夏季時期遭受持續性的啃食，導致藻床衰退、消失。本研究在實驗開始時即發現許多啃食痕跡出現在藻體上，再加上草食性魚類的刺藍子魚之稚魚成群結隊於附近頻繁活動，故可推測移除競爭物種導致草食性魚類之攝食壓力 (Browsing pressure) 集中，以致鋸齒麒麟菜群落消失。本研究因颱風影響導致移除後之觀察時間不足，今後須將觀察時間增加，進行更長期之觀察。

本文作者 (2020) 曾指出，本調查海域之潛在攝食者為額帶刺尾魚，但，2019 年夏季調查時並未觀察到從前隨處可見之額帶刺尾魚魚群。取而代之的是刺籃子魚之稚魚魚群。雖然過去時曾使用刺藍子魚成魚於鋸齒麒麟菜之攝食實驗中，但結果並未出現明顯的攝食率 (Chen *et al*. 2020)。根據日本水產庁 (2015) 的報告指出，褐藍子魚 *S. fuscescens* 稚魚主要食物來源並非為大型藻類，而為寄生於大型藻類表體之絲狀寄生藻。本調查地於夏季時期能觀察到許多絲狀仙菜科海藻寄生於鋸齒麒麟菜上，據此推測刺藍子魚稚魚有極高的可能啃食此類絲狀寄生藻 (Chen *et al*. 2020)，造成宿主鋸齒麒麟菜藻體受損、消失。無論是額帶刺尾魚或刺藍子魚皆較少在魚市場上流通，但仍能在傳統市場中見到刺藍子魚 (陳 2017)，我國也曾有過種苗放流之紀錄 (Chang *et al*. 2010)。故此，今後須加強台灣東北角海域草食性魚類，甚至是如海膽、螺類等草食性底棲動物之食性研究，包含喜好性實驗、攝食量研究等，以了解沿海地區大型藻類面臨的生存壓力。

近年來，全球暖化造成水溫上升及海洋熱波等現象，都直接導致草食性生物食慾增加 (水產庁漁港漁場整備部 2017)，未來草食性生物造成大型藻類資源減少將可能無法避免，本論文建議未來在資源保護及養殖技術發展時應設法建立有效的草食性生物隔絕系統，以因應氣候變遷影響，守護好大海中最重要的初級生產者們。

謝誌

本作者感謝人生中最重要的父親陳明偉、母親楊尹雅、黃至薇在學術發展上的支持與鼓勵，並感謝所有參與本論文討論的友人們給予修改意見，也特別感謝 Khoi Yong Ho 先生的英文校閱，讓本文更臻完善。

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小花薺寧（唇形科）：臺灣植物誌新增物種

Mosla cavaleriei (Lamiaceae), an addition to the flora of Taiwan

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Abstract

The occurrence of *Mosla cavalerirei* H. Lév., previously recorded in southern China and northern Vietnam, is confirmed in Taiwan. This species could be distinguished from other congeneric species by having obvious pilose stems and leaves, leaf margin finely serrate with 6–14 pairs of teeth, shallowly toothed upper calyx, relatively small (2.5–3.5 mm long) corollas, and loosely netted nutlets.

Key words: *Mosla cavalerirei*, Lamiaceae, Taiwan, taxonomy.

摘要

本文報導原紀錄於中國南部及越南北部的小花薺薴 *Mosla cavaleriei* H. Lév. (唇形科) 亦生長於台灣。此種可藉由莖葉明顯被柔毛，葉緣具 6 – 14 對細鋸齒，萼筒上唇淺裂，較小的花冠筒 (2.5 – 3.5 mm) 及小堅果表面疏網狀之特徵與同屬其它類群區辨。

關鍵詞：小花薺薴、唇形科、臺灣、分類學

Introduction

Mosla is a genus of Lamiaceae comprised of about 22 species distributed in East Asia, the Himalayas, and Southeastern Asia (Li and Hedge 1994; Huang et al. 1998). When revising *Mosla* specimens stored in TAIF, we noticed that several collections from various locations of Taiwan do not agree well with the three currently known taxa (Hsieh and Huang 1999). After a careful study of literature, fresh materials, and herbaria specimens, we are convinced that an additional native species, *M. cavaleriei* H. Lév., occurs in Taiwan. Background data of its morphology, distribution, ecology, and conservation status are provided.

Key to the *Mosla* species in Taiwan

1. All bracts leaf-like, ovate to circular-obovate, surpassing calyx; nutlets pitted..............................*M. chinensis*
- At least upper bracts ovate-lanceolate to needle-like, not surpassing calyx (lower bracts occasionally leaf-like and surpassing calyx); nutlets netted...2
2. Upper lip of calyx deeply toothed, teeth narrowly triangular; nutlets densely netted.....................*M. scabra*
- Upper lip of calyx shallowly toothed, teeth broadly triangular; nutlets loosely need...3
3. Stems sparsely villous; leaves sparsely pilose, finely serrate with 6–14 pairs of teeth; corolla 2.5–3.5 mm long....... .... *M. cavaleriei*

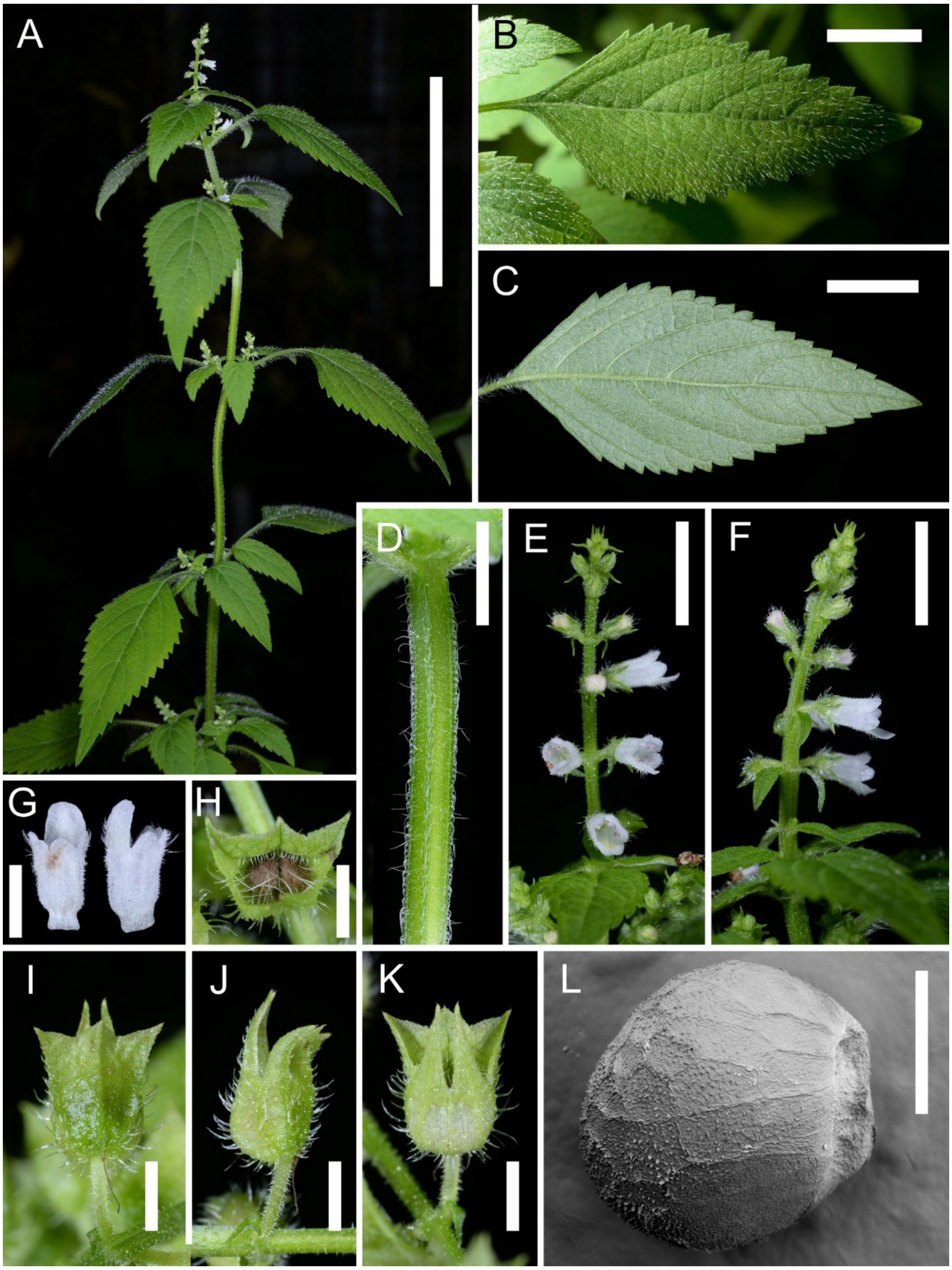

Fig. 1. Morphology of *Mosla cavaleriei* in Taiwan, from *Hsu 11021* (A–G), *Hsu 11078* (H–K) and *Hsu 4702* (L). A. Habit. B–C. Leaves; B, adaxial view; C, abaxial view. D. Stem. E–F. Inflorescence and flowers. G. Corollas, top view (left) and side view (right). H–K. Fruiting calyx; H, front view; I, top view; J, side view; K, bottom view. L. Nutlet. Scale bars: A = 5 cm; B–C = 1 cm; D–F = 5 mm; G–K = 2 mm; L = 0.5 mm.

- Stems glabrescent to sparsely pubescent; leaves glabrous or subglabrous, coarsely serrate with four to seven pairs of teeth; corolla 4–6 mm long..... .... *M. dianthera*

Taxonomic Treatment

Mosla cavaleriei H. Lév., Repert. Spec. Nov. Regni Veg. 9(211–213): 247–248. 1911.

≡*Orthodon cavaleriei* (H. Lév.) Kudô, Mem. Fac. Sci. Taihoku Imp. Univ. 2: 81. 1929.

Type: CHINA. Guizhou (Kouy-Tcheou): Pin-fa, 24 Sep 1902, *P. J. Cavalerie 530* (holotype: E-00417165 image!). 小花薺薴 Fig. 1.

Morphology: Herbs annual, 15–60(–100) cm tall. Stems branched, quadrangular, puberulent, and sparsely villous. Leaves opposite; petioles 1–2 cm long; leaf blades ovate, rhombic-ovate or ovate-lanceolate, (1.5–)2–4(–5) × 1–2.5 cm, papery, base rounded to broadly cuneate, margin finely serrate with six to 14 pairs of teeth, apex acute, adaxially sparsely pilose, abaxially pilose on veins, impressed glandular. Racemes 2.5–4.5 cm in flower, to 8 cm in fruit, finely pilose; bracts minute, ovate-lanceolate, slightly shorter to slightly longer than pedicels, sparsely pubescent and glandular. Pedicel ca. 1 mm. Calyx ca. 1.2 × 1.2 mm, dilated to 4–5 × ca. 3 mm in fruit, pilose outside; upper teeth minute, broadly triangular; lower teeth slightly longer, narrowly triangular. Corolla purplish or whitish, 2.5–3.5 mm long, pubescent outside, lower lip longer than upper lip. Nutlets gray-brown, subglobose, 1–1.5 mm in diam., loosely netted.

Distribution: Southern China, northern Vietnam, and Taiwan.

Ecology: Growing on humid, semi-open roadsides, forest margin and forest gaps at the elevations of 200–1900 m. Flowering and fruiting recorded from July to November.

Voucher specimens in Taiwan: New Taipei: Pinglin, 200–500 m, 8 Oct

1997, *Ho 647* (TAIF); Shihpai, 500 m, 24 Nov 2018, *Hsu 11078* (TAIF); Ssutu, 540 m, 24 Oct 2018, *Hsu 11021* (TAIF). Taoyuan: Lalashan Nature Preserve, 1550–1700 m, 25 Sep 1991, *Peng 14655* (HAST; TAIF). Hsinchu: Yuanyanhu, 1800–1900 m, 17 Sep 2000, *Chen et al. 3492* (TAIF). Yunlin: Shihbi, 21 Sep 2012, *Tsai et al. TSY478* (TAIF). Pingtung: Chinshuiying Anciant Trail, 1400–1500 m, 18 Sep 2011, *Hsu 4702* (TAIF). Ilan: Mt. Taiping, 23 Jul 1970, *Kao 7654* (PH, image; TAI); 100 Lindaw, 1320 m, 17 Sep 1996, *Wang & Lin 2202* (TAIF); Kulu Forest Trail, ca. 400 m, 7 Nov 2010, *Chen 1632* (TAIF); Songlohu, 1230 m, 20 July 2000, *Chen 7475* (TAIF); Sunglohu, 1300 m, 20 July 2000, *Chung 2715* (TAIF); *Chung 2716* (TAIF).

Additional specimens examined: CHINA. Sichuan: *Chenzhao 9769* (TAIF). VIETNAM. Ninh Binh: *Cuong et al. NMC 1222* (P, image).

Conservation status: Our herbaria and field surveys revealed that *Mosla cavaleriei* scattered among low- and mid-altitudinal mountainous regions throughout the main island of Taiwan, with several subpopulations located within protected areas, and no immediate or potential threats could be detected. Considering the fact that *M. cavaleriei* is naturally distributed in adjacent areas and has never been reported as a naturalized species, we consider it as a native species in Taiwan and evaluate it as Least Concern (LC) based on IUCN Red List Categories and Criteria (IUCN Standards and Petitions Committee 2019).

Taxonomic remarks: Morphologically, *Mosla cavaleriei* could be confused with *M. dianthera* as they share very similar calyx and nutlet morphology (Fig. 1H–L; also see Zhou et al. 1997; Hsieh and Huang 1999). However, as mentioned in the key, the former is readily distinguishable in having obvious pilose stems and leaves (Fig. 1A–D), fine serrate leaf margins (Fig. 1A–C), and much smaller corollas (Fig. 1E–G). Recent molecular data (Li et al. 2017) showed that these two species are genetically not closely allied.

Two taxa described from Japan, namely *Mosla hirta* (Hara) Hara [≡*Orthodon hirtus* Hara] and *M. dianthera* (Buch.-Ham. ex Roxb.) Maxim. var. *nana* (Hara) Ohwi [≡*O. grosseserratum* var. *nanum* Hara], are closely related to *M. cavaleriei*. Based on morphological descriptions (Hara 1936; 1938; 1955; Murata and Yamazaki 1993), we speculate that these two names are possibly later synonyms *M. cavaleriei*, and the treatment of Ying (2019) who synonymized them under *M. dianthera* is impractical. However, for now we hesitate to propose any formal taxonomic treatment as we have no access to their type materials. A critical review of Japanese materials might be necessary to eventually clarify their identities. Nevertheless, the plants once recognized as *M. hirta* or *M. dianthera* var. *nana* from Taiwan (Hara 1955; Huang and Cheng 1978) should be corresponded to *M. cavaleriei*.

Acknowledgements

We are grateful to the curators of E, HAST, P, TAI, and TAIF for herbaria and/or database access. We also thank Chien-Chih Chen and Ming-Yu Kuo for their kind assistance during field investigations.

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台灣生物多樣性研究 TW J. of Biodivers.24(1):47-56,2022

臺灣衛矛科深裂衛矛組的新紀錄種─百齒衛矛

Euonymus centidens H. Lév. (Celastraceae: sect. *Melanocarya*): a Newly Recorded Species in Taiwan

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Abstract

We report the first record of *Euonymus centidens* H. Lév. of the sect. *Melanocarya* (Celastraceae) in Taiwan. Three populations were found in mountainous areas at 500–600 m altitude in northern Taiwan, which thus represent the easternmost distribution of *E. centidens* in the world. The morphology of *E. centidens* is similar to that of a different species within the same genus, *E. tashiroi* Maxim. The most distinguishable characteristic between them is that the leaf margin is serrulate in *E. centidens* and is only slightly and obtusely serrate in *E. tashiroi*. A taxonomic description, color photographs, and line drawings of *E. centidens* are provided here to facilitate identification. It is needed to reveal further insights regarding the distribution and history of this Taiwan new record species.

Key words: Celastraceae, *Euonymus centidens*, newly recorded species, sect. *Melanocarya*, Taiwan

摘要

本文報導臺灣衛矛科深裂衛矛組 (sect. *Melanocarya*) 的新紀錄種—百齒衛矛 (*Euonymus centidens* H. Lév.)。此新紀錄種三個族群分布於臺灣北部海拔 300－600 m 山區，為本種於世界分布最東界。它的形態特徵近似於同屬之菱葉衛矛 (*E. tashiroi* Maxim.)，最大之差異為本種葉緣具細鋸齒，可明顯與菱葉衛矛之疏鋸齒區別。本文提供百齒衛矛的特徵描述、彩色照片和線繪圖以供鑑定參考。未來有必要探討此臺灣新紀錄種的分布和歷史。

關鍵詞：衛矛科、百齒衛矛、新紀錄種、深裂衛矛組、臺灣

Introduction

The genus *Euonymus* L. (Celastraceae) comprises approximately 130 species, of which about 115 species are distributed in Asia. This genus also occurs in Europe and North America, and ten species were reported in Taiwan (Lu and Yang 1993; Ma and Funston 2008). The Celastraceae can be divided into six sections, i.e., sect. *Echinococcus*, sect. *Euonymus*, sect. *Glyptopetalum*, sect. *Ilicifolia*, sect. *Kalonymus*, and sect. *Melanocarya* (Liu *et al.* 2021). Mostly native to East Asia, the eleven species of sect. *Melanocarya* are shrubs or small trees, which are mostly deciduous, and a few are evergreen. Leaves are opposite, flowers are 4-merous, petals are light yellow-green, capsules are 4-lobed, and seeds are covered by arils over half of the surface (Ma 2001; Liu *et al.* 2021). However, Zhang *et al*. (2012) suggested that the fleshy part of the Celastraceae seeds does not originate from the funiculus or the hilum, but from the exostomatic micropyle, thus the fleshy structure should not be referred to as “aril” but as “caruncula”. Therefore, we use the term caruncula to refer to the fleshy structure covering the Celastraceae seeds reported here.

Only one species of sect. *Melanocarya* was previously reported to occur in Taiwan, i.e., *Euonymus tashiroi* Maxim. However, recently, a different species of sect. *Melanocarya* was found in a low-altitude mountainous area in northern Taiwan. This species was thoroughly examined, and a literature search was conducted, after which we were able to confirm that this species was *Euonymus centidens* H. Lév. (Ma and Funston 2008), which was previously considered endemic to China. Thus, we here present the first record of this species in Taiwan, which therefore represents the easternmost distribution area of *E. centidens* in the world. A taxonomic description, color photographs, and line drawings of this species are provided here to facilitate identification.

Taxonomic treatment

Euonymus centidens H. Lév. Repert. Spec. Nov. Regni Veg. 13: 262. 1914.

百齒衛矛 (Fig. 1, 2)

Type: CHINA. Yunnan, Long-Ky, E. E. Maire *s.n.* (isotype E, photograph seen, Fig. 3).

Synonyms (Ma 2001):

E. euscaphioides F.H. Chen & M.C. Wang, Acta Phytotax. Sin. 3(2): 235, f. 2: 1-2. 1954. TYPE: CHINA. Jiangsi: Lushan, Wurushi, June 6, 1951, *M.C. Wang 710* (LBG, PE).

E. euscaphioides F.H. Chen & M.C. Wang var. *serrulata* F.H. Chen & M.C. Wang, Acta Phytotax. Sin. 3(2): 236. 1954. TYPE: CHINA. Jiangsi: Yifeng, Huanggangshan, Oct. 15, 1947, *Y.K. Hsiung 6397* (A, LBG).

E. streptoptera Merr., Sunyatsenia 1: 198. 1938. TYPE: CHINA. Kwangtung: Lokchong, May 14 and 17, 1929, *C.L. Tso 20487* (MO).

Morphological description: Evergreen shrub or small tree, branchlets and twigs 4-winged at the juvenile stage, converting to 4-angled at the woody stage. Leaves opposite, obovate to elliptic, 4.3–9.8 cm long, 3–4 cm wide, thick-papery to thin-leathery, base cuneate, margins serrulate, each side with approximately 30–50 teeth, apex acute to acuminate, both surfaces glabrous, lateral veins in 4–5 pairs, the apex of lateral veins curving inward and forming loops; petiole 2–3 mm or sessile; stipule triangular, ca. 1 mm long, persistent. Flowers axillary, solitary, 2-clustered, or in cymes, peduncle 1.7–2.4 cm long; calyx 4-lobed, each lobe 1.5 × 1 mm; petals 4, light-green to yellowish, suborbicular, 2–2.5 × 2.1–2.5 mm; disc ca. 1.5 mm in diameter; pedicel 3–5 mm long. Capsules ca. 1.5 cm in diameter, green at maturity, dehiscent into 4 lobes, sometimes only 2–3 lobes developed, each lobe ovoid, sepals persistent; seeds red, with orange caruncula.

Specimens examined: TAIWAN. New Taipei City: Pingxi District, Niaozui-

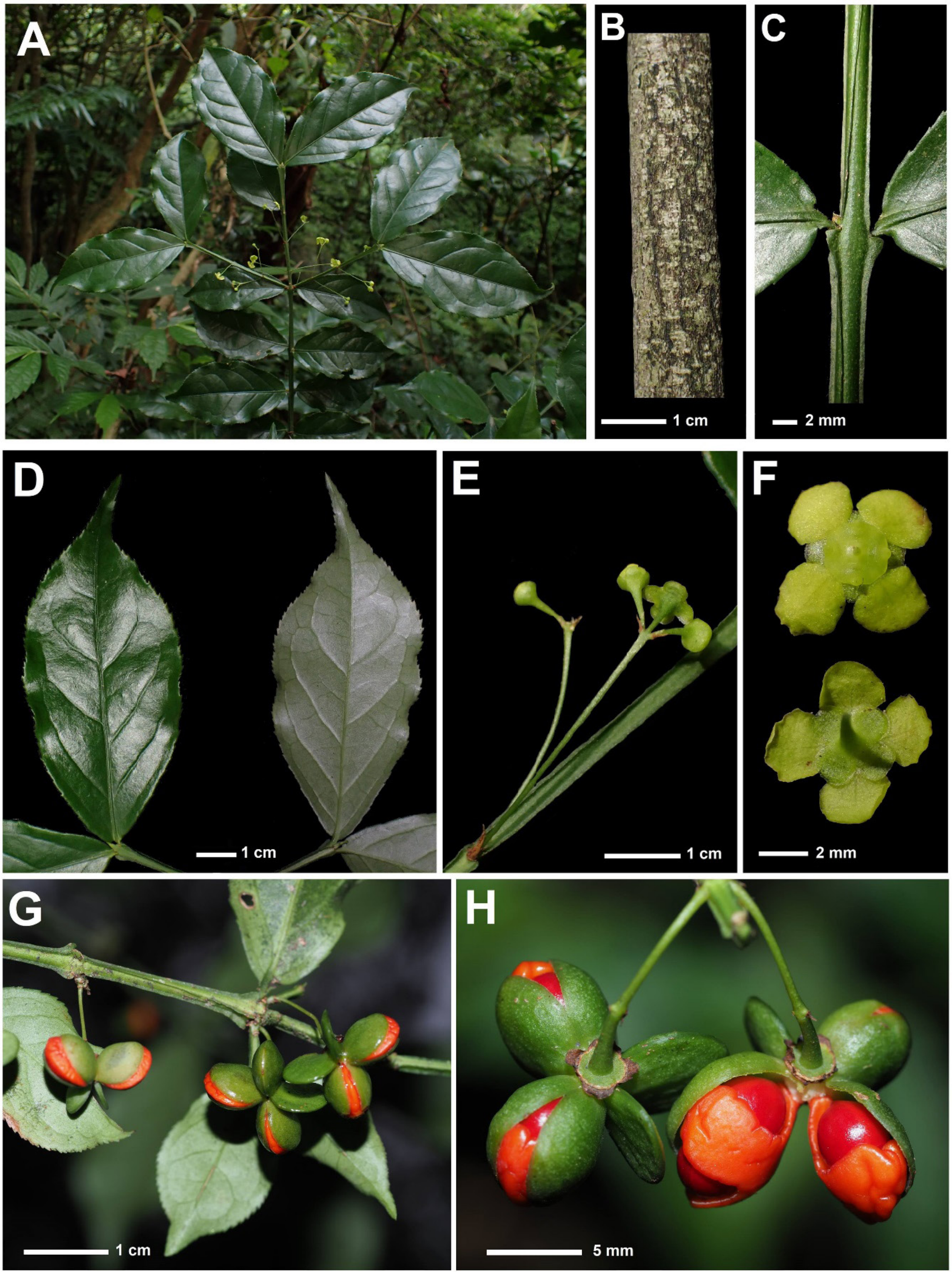

Fig. 1. *Euonymus centidens* H. Lév. A, habit; B, trunk; C, branchlet and twig 4-angled at the juvenile stages; D, leaves, adaxial (left) and abaxial (right) surface; E, cymes; F, flowers, adaxial (upper) and abaxial (lower) view; G, capsules dehiscent into 4 lobes at maturity; H, seeds red with orange-red caruncula. Photographed by Po-Hao Chen (A–F) and Juinn-Yih Huang (G–H).

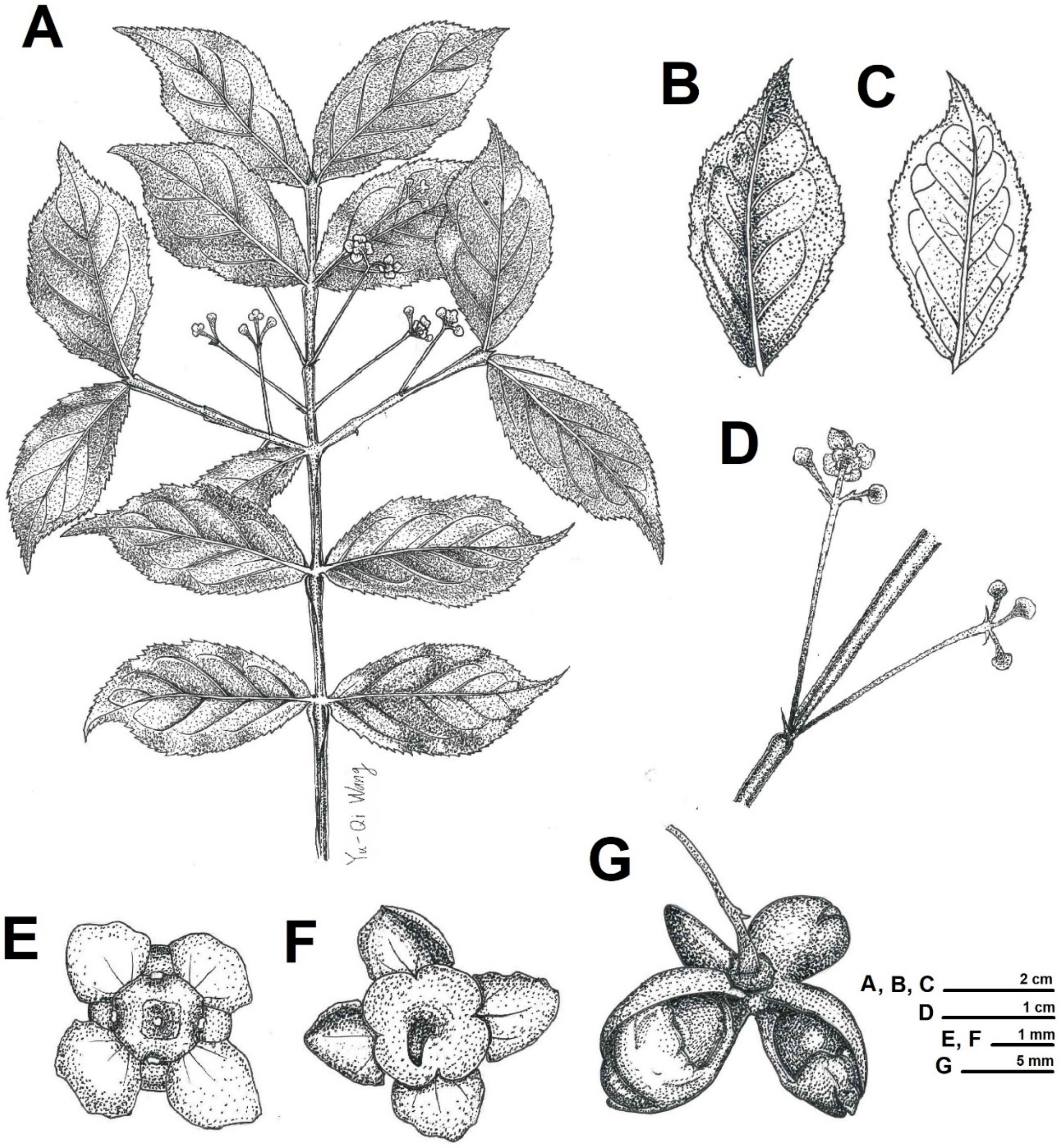

Fig. 2. Line drawings of *Euonymus centidens* H. Lév. A, flowering branch; B, leaf, adaxial view; C, leaf, abaxial view; D, inflorescence; E, flower, adaxial view F, flower, abaxial view; G, fruit. Drawing courtesy of Yu-Qi Wang.

Fig. 3. Isotype of *Euonymus centidens* H. Lév., E. E. Maire *s.n.* (Royal Botanic Garden, Edinburgh (E), E00275678, photograph).

Table 1. Characteristics of *Euonymus centidens* growing in China, *E. tashiroi*, and *E. centidens* growing in northern Taiwan

	E. centidens (Ma and Funston 2008)	*E. tashiroi* (Lu and Yang 1993)	*E. centidens* (this report)
Leaf length ×width (cm)	6–11 × 2.5–4.5	5–10 × 2–4.5	4.3–9.8 × 3–4
Leaf margin	crenulate, serrulate to serrate, or even ciliate	serrate or nearly entirely above the middle, and entire beneath the middle	serrulate
Pairs of lateral veins	5–7	ca. 5	4–5
Inflorescence	cymes single or clustered, axillary or terminal	flowers solitary or few clustered	flowers solitary, 2-clustered, or in cymes, axillary
Peduncle (cm)	2–3	1–5	1.7–2.4
Flower size in diameter (mm)	7–8	ca. 10	5.5–6.5
Petals shape	ovate	ovate	suborbicular
Caruncula color	bright red	bright red	orange-red

jianshan, May 7, 2021, *P.-H. Chen & A.-C. Chung 3253–3255* (TAIE); June 13, 2021, *P.-H. Chen & A.-C. Chung 3232–3234* (TAIE). Xiaozishan, August 2, 2021, *P.-H. Chen & A.-C. Chung 3296–3298* (TAIE).

Distribution: *Euonymus centidens* was previously recorded in China only, at altitude of approximately 250–1,400 m where it grows in woodlands and forests, and it is very common (Ma 2001). The populations in northern Taiwan grew next to forest hiking trails in a mountainous area at an altitude of approximately

300–600 m, thus representing the easternmost distribution of *E. centidens* in the world.

Habitat and ecology: mainly found in damp and shaded forest habitats, especially near rivers, mature *Euonymus centidens* individuals grow 2–3.5 m tall and show a stem diameter of up to 2 cm. Accompanying plants include *Ardisia sieboldii* Miq., *Arenga tremula* (Blanco) Becc., *Blastus cochinchinensis* Lour., *Elatostema lineolatum* Forst. var. *majus* Thwait., *Eurya chinensis* R. Br., *Ficus fistulosa* Reinw. & Blume, *Heptapleurum heptaphyllum* (L.) Y. F. Deng, *Lasianthus fordii* Hance, *Lasianthus wallichii* (Wight & Arn.) Wight, *Oreocnide pedunculata* (Shirai) Masam., *Saurauia tristyla* DC., *Tetrastigma hemsleyanum* Diels & Gilg, *Wendlandia formosana* Cowan, and *Zanthoxylum scandens* Blume. The flowering period is from May to June and fruiting occurs from June to November.

Discussion

According to the characteristics (Table 1) of *Euonymus tashiroi* and *E. centidens* (Table 1; Lu and Yang 1993; Ma and Funston 2008), and the *E. centidens* population found in northern Taiwan, the most distinguishing characteristic between *E. centidens* and *E. tashiroi* is the leaf margin, which is serrulate in *E. centidens* and serrate or nearly entire above the middle in *E. tashiroi*. However, *E. centidens* in China is deciduous, whereas the population in Taiwan is evergreen. This may be due to climatic differences such as the northeast monsoon in winter, which ameliorates the dry season and facilitates the evergreen habit of *E. centidens* in Taiwan. Further research it is needed to potentially reveal further insights regarding the distribution and history of this species in Taiwan.

IUCN Red list category: Nationally Endangered [D]

Euonymus centidens is currently known to occur in three locations in northern Taiwan, i.e., Xizhi District, Pingxi District, and Pinglin District. The respective estimated population sizes range from 30 to 50 individuals, with a national total of < 250 individuals. We thus categorized *E. centidens* as nationally endangered in Taiwan [D], according to the IUCN Red List Categories and Criteria (IUCN 2012; Editorial Committee of the Red List of Taiwan Plants 2017).

Acknowledgments

We are thankful to Jo-Ping Hsieh (謝若萍) and Fu-Xing Su (蘇福星) for providing collection information and photographs, and Yu-Qi Wang (王昱淇) for preparing the line drawings of *Euonymus centidens*.

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「台灣生物多樣性研究」稿約

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一、《台灣生物多樣性研究》爲行政院農業委員會特有生物研究保育中心出版之學術期刊，歡迎國內外學者發表有關生物多樣性或自然保育之學術論文與有關物種出現資料之資料論文，但以未曾在其他刊物發表之原創研究及資料爲限。

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2.中、日文書籍：徐國士。1980。台灣稀有及有絕滅危機之植物。台灣省教育廳。

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5.英文期刊：Pimm, S. L. and J. L. Gittleman. 1992. Biodiversity : Where is it ? Science 255: 940.

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.

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

8.英文彙編書籍：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, People’s Republic of China.

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

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

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Published by Endemic Species Research Institute,
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ISSN 2076697-1
9 772076 697002
GPN:2009900002