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2005-2008 年七家灣溪濱岸植群之生物多樣性研究

Biodiversity Investigation on Riparian Vegetations of Cijiawan Creek for the Years 2005-2008

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摘 要

七家灣溪是臺灣櫻花鉤吻鮭的重要棲地，為使其族群得以延續，保護森林溪流生態系乃是當務之急。而本研究為瞭解其濱岸植群之組成與結構變化，於 2005、2007-2008 年進行喬木、地被層植物之監測調查。研究結果得知 2005、2007-2008 年之物種組成並無太大變化，其群團分析的結果相似；皆可分為蓬草－臺灣紫珠型，栓皮櫟－化香樹型，臺灣二葉松－臺灣赤楊亞型，臺灣二葉松－栓皮櫟亞型，以及臺灣二葉松－臺灣赤楊－臺灣紫珠亞型等。此外，本研究以 2005、2007-2008 年之七家灣溪濱岸植群的植群調查資料，進行種豐富度指數分析比較，結果得知 2005 與 2007-2008 年間喬木層植物之多樣性無明顯變化；而以有勝溪測站之多樣性及均勻度最高，又觀魚台測站的多樣性較低，另高山溪測站較不均勻。另僅 2005 年乾季、2007 年濕季之地被層的 Shannon 均勻度指數具顯著差異，即濕季的物種組成較為均勻；而相同季節於不同年度間，其植群的種豐富度指數則無顯著差異，此等顯示二年度間之地被層植物的多樣性變動不大。是故在現今武陵地區相關經營單位管理之下，2005-2008 年七家灣溪濱岸植群多樣性維持穩定。

Abstract

Cijiawan Creek is the only stream of Taiwan where the Formosan landlocked salmon *Oncorhynchus masou formosanus* inhabits. To preserve this precious but endangered species, it is urgent to protect its stream habitat and riparian forest ecosystem. We investigated the overstory and understory vegetations of the riparian zone in 2005 and 2007-2008. The results showed that the species compositions resulted from the matrix cluster analysis were similar between 2005 and 2007-2008. They were dividable into two types and three subtypes: the *Tetrapanax papyriferus-Callicarpa formosana* type, the *Quercus variabilis-Platycarya strobilacea* type, the *Pinus taiwanensis-Alnus japonica* subtype, the *Pinus taiwanensis-Quercus variabilis* subtype, and the *Pinus taiwanensis-Alnus japonica-Callicarpa formosana* subtype. The results of the species abundance index analysis also showed that there was no significant difference in the species diversity of the overstory between 2005 and 2007. The diversity and evenness indices were the highest at Yousheng Creek Station, while the lowest diversity at the Fish-watching Platform Station and the lowest evenness at the Gaoshan Creek Station. There was significant difference in the evenness indices of the understory between the dry season in 2005 and the wet season in 2007, indicating the species composition was evener in the wet season. The species abundance indices of the understory were not significantly different in the same season among the different years. This meant that the diversities of the understories were fairly stable between the two years. Apparently, under the present management of the Wuling area authorities, the riparian vegetation diversity of Cijiawan Creek was fairly stable for the years 2005 to 2008.

關鍵詞：七家灣溪、濱岸植群、生物多樣性、種豐富度指數

Key words: Cijiawan Creek, riparian vegetation, biodiversity, species abundance indices

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緒言

臺灣櫻花鉤吻鮭(*Oncorhynchus masou formosanus* Jordan & Oshima)原廣泛分布大甲溪上游各支流，然受到人為間接、直接及自然因素的影響，現僅存於七家灣溪流域，故為使櫻

花鉤吻鮭族群得以延續，保護森林溪流生態系乃是當務之急。是故欲對溪流生態系進行最有效的經營與管理，必須建立起完善的生態系資料庫，而濱岸生態系(riparian ecosystem)之植群組成(composition)與結構(structure)，係為研究生態系動態的重要參數之一。濱岸生態系為

陸、水域生態系相互作用的交界，經常受到干擾而有不同植物群落組合，具有明顯的邊緣效應(edge effect)，其邊界不易確定。而濱岸帶(riparian zone)的寬度及濱岸植群(riparian vegetation)對溪流之影響強度，視溪流、地貌改變、相鄰的森林有關，並隨著河道改變及水位升降有所關聯(Gregory *et al.* 1991)。

濱岸植群特指生長於濱岸帶之植群，其具有三項主要特徵：一為因位處於河道兩側，一般呈現狹長型；再者，由相鄰的生態系向溪流傳送的物質和能量，必然經過濱岸帶，因此，濱岸生態系為典型的開放性系統；三是由於位處陸域與水域的交界帶，常為高地與溪流之間的橋樑(陳1996)。在定期的洪氾(flood)干擾下，濱岸植群多由具有忍受、抵抗干擾能力或為演替初期的植物所組成。而其物種之結構與分布，由地域性氣候、地質構造與過程、濱岸兩側生物和非生物過程等因素所共同影響，並與地形、地貌、土壤、水文、干擾、河流級序(stream order)等密切相關，進而影響濱岸植群的植物組成、結構，亦使濱岸植群呈現鑲嵌狀(mosaic)的分布(White and Greer 2006)。濱岸帶位於水陸交界，同時受到陸、水域環境的影響，造就濱岸植群的特殊性，不僅直接影響植群結構與組成，更間接影響生活在濱岸帶的其他生物與環境。是故本研究之目的即監測七家灣溪濱岸植群之物種與組成，並探究濱岸植群於2005年、2007-2008年及乾、濕季間的多樣性(diversity)變化。

材料與方法

一、研究地區

七家灣溪濱岸植群之研究範圍如圖1所示；係以七家灣溪為主軸，北起桃山瀑布，南至七家灣溪匯入大甲溪之交叉點，東側以羅葉尾山經武佐野群山之稜線為界，西側則以第一道山脊之主要分界，總面積約為2,092.27 ha。

二、研究方法

(一) 樣區設置與植群調查

本研究係植基於林(2002)執行「武陵地區生態系監測與模式建構規劃」，以及現仍執行中的「武陵地區長期生態監測暨生態模式建立」之整合計畫中的重要測站。故延續蔡等(2010)於2005年即在七家灣流域之桃山北溪(#1)、桃山西溪(#2)、觀魚台(#4)、繁殖場(#5)、高山溪(#8)及有勝溪(#9)等6處測站，分別設置永久樣區編號為1-12等12個10×25 m²的長形監測調查樣區(圖1)，其中2005年2月(乾季)調查喬木、地被層植物後，又於同年8月(濕季)調查地被層植物乙次。本研究再於2007年5-7月(濕季)及2008年2月(乾季)，完成喬木、地被層植物之複查。凡樣區內之樹木胸徑大於1 cm者，列入喬木層(overstory)，逐株予以量計胸高直徑(diameter at breast height, DBH)；其他胸高直徑小於1 cm之喬、灌木、草本、蕨類等皆列為地被層(understory)，並加以估計其覆蓋度(coverage)。

(二) 物種組成與植群型

原始調查資料之植物種類編碼建檔後，使用以CLIPPER程式語言所撰寫之程式(COMB.PRG, CLUSTER.EXE)，將各樣區原始調查資料轉換為資料庫格式，求得各種植物於各樣區之密度(density)、頻度(frequency)和優勢度(dominance)，再轉換為相對密度(relative density)、相對頻度(relative frequency)與相對優勢度(relative dominance)，三者加總而得之重要值指數(importance value index, IVI)，以瞭解各種植物於樣區中所占之重要性；而地被層植物之重要值指數係為相對頻度和相對覆蓋度(relative coverage)的總和。

矩陣群團分析法(matrix cluster analysis, MCA)係以各植物於各樣區中之重要值指數(IVI)為計算基礎；研究中採用 Motika *et al.* (1950)之相似性指數(index of similarity, IS)，首先計算兩兩樣區間之相似性指數，將相似性



圖 1. 七家灣溪濱岸植群監測研究區及樣區位置圖。

Fig. 1. The sampling stations and plots of riparian vegetations at Cijiawan Creek.

最高之二樣區合併為一合成樣區，再計算合併後之合成樣區與其他樣區間之相似性指數，如此依次合併，直至所有樣區合併至一合成樣區為止，各連結相似性指數繪製樹形圖(dendrogram)，以對植物群落加以分類。

(三) 種豐富度指數分析

原始調查資料之植物種類編碼建檔後，本研究依蔡等(2007)所使用之三種種豐富度指數(species abundance indices)；即 Shannon 訊息統計指數(H_{sw}, Shannon information statistics index)、Shannon 均勻度指數(E_{sw}, Shannon evenness index,)、Berger 豐富度指數(D_{BP}, Berger species abundance index)，將所得之監測調查資料加以分析，並透過SPSS for Windows(Advanced Statistics 15.0)統計軟體(SPSS Inc, 2006)，針對喬木、地被層植物之各類種豐富度指數的

分析結果；而因受資料為非常態分布(non-normal distribution)的限制下，故選擇無母數檢定(non-parametric test)—K獨立樣本(K independent samples)—Kruskal-Wallis 檢定(K-W test)，其中以 Monte Carlo 迭代演算 10,000 次求解其顯著性(雙尾)；再藉由非同質性假設(equal variance not assumed)的 Dunnett's T3 法比較其差異。

結果與討論

一、物種組成

將 2007-2008 年調查各測站之永久樣區中喬木層植物的重要值大於 30% 者，而地被層植物大於 10% 者選為優勢種；表 1-3 所列即各樣區之喬木、地被層的優勢種植物，茲分述如下：

表 1. 2007 年七家灣溪永久樣區喬木層優勢植物之重要值指數(%)

Table 1. Importance value indices (%) of the dominant species of overstory at the permanent sampling stations and plots along Cijiawan Creek, 2007

Species	Sampling stations and plots ^{1/}											
	#2		#5		#9		#8		#1		#4	
	1	2	3	4	5	6	7	8	9	10	11	12
<i>Gordonia axillaries</i>	0.0	0.0	0.0	0.0	2.6	31.7	0.0	0.0	0.0	0.0	0.0	0.0
<i>Rhododendron ellipticum</i>	0.0	0.0	0.0	0.0	12.7	30.8	0.0	0.0	0.0	0.0	0.0	0.0
<i>Quercus variabilis</i>	62.2	34.4	88.5	44.5	0.0	0.0	30.5	51.6	18.8	0.0	0.0	0.0
<i>Liquidambar formosana</i>	0.0	0.0	39.9	56.4	0.0	0.0	32.0	0.0	0.0	4.4	0.0	0.0
<i>Ulmus uyematsui</i>	3.0	9.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	32.9	0.0
<i>Callicarpa formosana</i>	4.3	8.1	0.0	0.0	33.7	24.4	1.1	0.0	71.7	0.0	0.0	0.0
<i>Pseudotsuga wilsoniana</i>	0.0	2.1	41.0	6.1	26.0	6.7	4.7	1.8	0.0	0.0	0.0	0.0
<i>Platycarya strobilacea</i>	0.0	0.0	4.7	47.3	0.0	0.0	77.9	83.9	0.0	0.0	0.0	0.0
<i>Vaccinium bracteatum</i>	25.4	17.9	25.3	38.2	0.0	0.0	49.4	119.9	0.0	0.0	0.0	0.0
<i>Clerodendrum trichotomum</i>	0.0	0.0	0.0	0.0	41.4	0.0	0.0	0.0	37.3	0.0	0.0	0.0
<i>Pinus taiwanensis</i>	95.3	137.0	0.0	16.4	42.5	36.9	19.5	0.0	8.8	44.1	57.6	191.3
<i>Alnus formosana</i>	10.1	0.0	0.0	0.0	75.9	14.9	27.6	9.2	27.8	177.3	202.5	108.7
<i>Tetrapanax papyriferus</i>	0.0	0.0	0.0	0.0	2.9	0.0	0.0	0.0	97.4	8.1	0.0	0.0

^{1/} Plots 1 and 2 were located at Taoshan West Stream Station (#2); Plots 3 and 4, at Salmon Breeding Center Station (#5); Plots 5 and 6, at Yousheng Creek Station (#9); Plots 7 and 8, at Gaoshan Creek Station (#8); Plots 9 and 10, at Taoshan North Stream Station (#1).; Plots 11 and 12, at Fish-watching Platform Station (#4); bold numbers, importance values > 30%, indicating the dominant plants.

表 2. 2007 年濕季七家灣溪永久樣區地被層優勢植物之重要值指數(%)

Table 2. Importance value indices (%) of the dominant species of understory at the permanent sampling stations and plots along Cijiawan Creek during the wet season, 2007

Species	Sampling stations and plots ^{1/}											
	#2		#5		#9		#8		#1		#4	
	1	2	3	4	5	6	7	8	9	10	11	12
<i>Miscanthus sinensis</i>	69.4	84.7	32.7	62.9	3.3	1.7	41.5	34.4	70.2	85.0	60.6	93.8
<i>Polygonum multiflorum</i>	0.0	0.6	0.0	0.0	0.9	0.7	1.5	1.6	5.6	15.2	15.5	21.5
<i>Artemisia indica</i>	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.7	0.0	4.5	14.5
<i>Clematis grata</i>	0.8	0.0	0.0	0.6	3.9	1.4	0.0	0.0	0.0	13.2	1.4	4.4
<i>Farfugium japonicum</i>	0.0	0.0	0.0	0.0	0.0	1.3	0.0	0.0	10.5	9.3	1.0	2.9
<i>Arundo formosana</i>	0.0	0.8	0.0	0.0	29.2	48.7	0.0	0.0	5.3	2.9	2.3	2.8
<i>Myrsine Africana</i>	5.4	8.4	10.4	3.0	0.0	0.0	0.7	6.5	0.0	0.9	0.0	1.4
<i>Pilea rotundinucula</i>	0.0	0.0	0.0	0.0	21.5	4.3	0.0	0.0	0.0	0.0	9.7	0.0
<i>Urtica thunbergiana</i>	0.0	0.0	0.0	0.0	10.6	2.7	0.6	0.0	14.2	7.8	4.1	0.0
<i>Tetragium umbellatum</i>	0.7	0.9	0.5	0.0	5.8	14.6	5.2	8.9	8.6	5.7	0.8	0.0
<i>Tetrapanax papyriferus</i>	0.0	0.0	0.0	0.0	2.4	5.5	0.0	0.0	10.1	4.5	0.7	0.0
<i>Oplismenus hirtellus</i>	0.0	0.0	0.0	0.0	0.0	0.0	7.3	14.7	0.0	0.0	0.7	0.0
<i>Woodwardia orientalis</i>	0.0	0.0	0.0	0.0	14.0	4.8	0.0	0.0	0.0	0.9	0.0	0.0
<i>Rhododendron noriakianum</i>	0.0	5.4	0.0	3.1	0.0	0.8	31.5	19.4	0.0	0.0	0.0	0.0
<i>Ophiopogon intermedius</i>	2.4	2.5	27.4	19.7	0.0	3.4	3.4	5.3	0.0	0.0	0.0	0.0
<i>Dryopteris atrata</i>	0.0	0.0	0.0	0.0	11.2	0.9	1.1	0.5	0.0	0.0	0.0	0.0

^{1/} Stations and plots denote to those in the footnote of Table 1; bold numbers, importance value >10%, indicating the dominant plants.

表 3. 2008 年乾季七家灣溪永久樣區地被層優勢植物之重要值指數(%)

Table 3. Importance value indices (%) of the dominant species of understory at the permanent sampling stations and plots along Cijiawan Creek during the dry season, 2008

Species	Sampling stations and plots ^{1/}											
	#2		#5		#9		#8		#1		#4	
	1	2	3	4	5	6	7	8	9	10	11	12 ^{2/}
<i>Miscanthus sinensis</i>	86.1	37.7	35.3	52.0	1.6	0.6	32.5	23.4	15.9	98.1	61.2	0.0
<i>Pilea rotundinucula</i>	0.0	0.0	0.0	0.0	11.0	4.5	0.0	0.0	0.0	0.0	27.8	0.0
<i>Polygonum multiflorum</i>	0.0	0.7	0.0	0.0	3.9	2.2	2.9	2.3	88.6	11.2	18.7	0.0
<i>Rubus parvialifolius</i>	0.0	1.4	0.0	2.8	0.0	0.0	1.2	0.6	1.7	10.1	11.1	0.0
<i>Urtica thunbergiana</i>	0.0	0.0	0.0	0.0	7.0	2.8	0.6	0.0	10.9	11.0	5.0	0.0
<i>Anisomeles indica</i>	5.0	49.3	2.1	0.0	0.6	0.0	4.1	2.3	0.0	0.0	3.1	0.0
<i>Arundo formosana</i>	0.0	4.2	0.0	0.0	32.8	33.1	0.0	0.0	9.4	3.9	1.1	0.0
<i>Rhododendron noriakianum</i>	0.0	0.0	0.0	0.0	0.0	0.0	23.1	0.0	1.6	0.0	1.0	0.0
<i>Woodwardia unigenmata</i>	1.8	0.0	0.0	0.0	26.2	18.5	0.6	0.0	0.0	0.0	1.0	0.0
<i>Tetragium umbellatum</i>	3.3	4.2	0.0	0.0	5.0	6.7	5.0	15.7	9.7	7.0	0.0	0.0
<i>Ophiopogon intermedius</i>	10.5	9.0	24.1	39.1	0.0	2.6	5.4	5.8	0.0	4.4	0.0	0.0
<i>Lepisorus pseudo-ussuriensis</i>	7.0	7.3	10.3	12.3	1.7	1.8	4.7	3.9	0.8	0.0	0.0	0.0
<i>Diplazium amamiana</i>	0.0	0.0	0.0	0.0	29.0	2.7	0.0	0.0	0.8	0.0	0.0	0.0
<i>Pseudotsuga wilsoniana</i>	2.0	0.0	11.4	2.5	0.0	0.0	3.2	5.2	0.0	0.0	0.0	0.0
<i>Myrsine Africana</i>	8.6	12.1	17.3	0.9	0.0	0.0	1.2	3.4	0.0	0.0	0.0	0.0
<i>Spiraea prunifolia</i>	0.0	0.0	21.9	2.9	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0
<i>Akebia longracemosa</i>	0.0	0.0	8.3	10.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Viburnum propinquum</i>	4.3	0.8	12.5	8.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

^{1/} Stations and plots denote to those in the footnote of Table 1; bold numbers, importance value >10% indicating the dominant plants.

^{2/} Plot 12 was destroyed in the rain season of 2007, and thus, its data were "0" for all species in the dry season of 2008.

(一) 桃山北溪測站(Station #1)

此測站之樣區 9、10 位於桃山北溪溪谷左岸之沖積扇。其喬木層優勢種植物為臺灣赤楊(*Alnus formosana*)、蓮草(*Tetrapanax papyriferus*)、臺灣紫珠(*Callicarpa formosana*)、臺灣二葉松(*Pinus taiwanensis*)，以及海州常山(*Clerodendrum trichotomum*)。而濕季時地被層優勢種植物如五節芒(*Miscanthus sinensis*)、臺灣何首烏(*Polygonum multiflorum*)、咬人貓(*Urtica thunbergiana*)、串鼻龍(*Clematis grata*)、臺灣山菊(*Farfugium japonicum*)及蓮草；又乾季時則以五節芒、臺灣何首烏、咬人貓，以及小椴葉懸鈎子(*Rubus parviaraliifolius*)為主。

(二) 桃山西溪測站(Station #2)

此測站之樣區 1、2 位於七家灣溪上游之支流—桃山西溪左岸的溪谷邊坡。其喬木層優勢種植物為臺灣二葉松、栓皮櫟(*Quercus variabilis*)。而濕季時地被層優勢種植物以五節芒為主；又乾季時則為五節芒、金劍草(*Anisomeles indica*)、小葉鐵仔(*Myrsine africana*)、間型沿階草(*Ophiopogon intermedius*)。

(三) 觀魚台測站(Station #4)

此測站之樣區 11、12 位於七家灣溪中段之溪谷沖積扇左岸，地勢平緩，植群極易受溪流洪氾影響；其中樣區 12 即因 2007 年雨季後樣區遭沖毀。喬木層優勢植物主要是臺灣赤楊、臺灣二葉松，次為阿里山榆(*Ulmus uyematsui*)。而濕季時地被層優勢種植物則以五節芒為主，其次是臺灣何首烏、艾(*Artemisia indica*)；另乾季時仍以五節芒為主，其次是圓果冷水麻(*Pilea rotundinucula*)、臺灣何首烏、小椴葉懸鈎子。

(四) 繁殖場測站(Station #5)

此測站之樣區 3、4 位於七家灣溪左岸。其喬木層優勢種植物如栓皮櫟、楓香(*Liquidambar formosana*)、化香樹(*Platycarya strobilacea*)、臺灣黃杉(*Pseudotsuga wilsoniana*)，以及米飯花(*Vaccinium bracteatum*)。而濕季時地被層優

勢種植物為五節芒、間型沿階草、小葉鐵仔；又乾季時則以五節芒、間型沿階草、擬烏蘇里瓦葦(*Lepisorus pseudo-ussuriensis*)、笑靨花(*Spiraea prunifolia*)、小葉鐵仔、臺灣黃杉、高山莢蒾(*Viburnum propinquum*)、五葉長穗木通(*Akebia longeracemosa*)等為主。

(五) 高山溪測站(Station #8)

此測站之樣區 7、8 位於七家灣溪支流—高山溪之右岸邊坡，其較不易受洪氾影響。喬木層優勢種植物諸如米飯花、化香樹、栓皮櫟、楓香。而濕季時地被層優勢種植物為五節芒、細葉杜鵑(*Rhododendron noriakianum*)，以及求米草(*Oplismenus hirtellus*)；又乾季時則以五節芒、細葉杜鵑、臺灣崖爬藤(*Tetrastigma umbellatum*)為主。

(六) 有勝溪測站(Station #9)

此測站之樣區 5、6 係位於武陵農場入口收費站旁之有勝溪下游右岸，由低河階延伸至中坡，地形由平緩至陡峭，兩岸腹地小；此測站為監測比較之對照測站。其喬木層優勢種植物為臺灣二葉松、臺灣赤楊、海州常山、臺灣紫珠、大頭茶(*Gordonia axillaris*)、西施花(*Rhododendron ellipticum*)。而濕季時地被層優勢植物主要以臺灣蘆竹(*Arundo formosana*)、圓果冷水麻、臺灣崖爬藤、東方狗脊蕨(*Woodwardia orientalis*)、紗櫛鱗毛蕨(*Dryopteris atrata*)、咬人貓為主；又乾季時則為臺灣蘆竹、頂芽狗脊蕨(*W. unigemmata*)、奄美雙蓋蕨(*Diplazium amamiana*)、圓果冷水麻。

此次複查濱岸植群之優勢種植物組成與蔡等(2010)之研究比較差異不大；即喬木層優勢植物多為陽性樹種，如臺灣二葉松、臺灣赤楊、栓皮櫟與化香樹等，而臺灣二葉松與臺灣赤楊是永久樣區中最為優勢的樹種。其中臺灣二葉松係武陵地區早期的主要造林樹種，迄今仍有大面積的臺灣二葉松林，因此，超過半數的樣區中以臺灣二葉松為其優勢種之一；另臺灣赤楊的生態幅度廣泛，為演替初期最早進入

裸地之樹種，常見七家灣溪沿岸受干擾之河谷開闊地、裸地及向陽地；又栓皮櫟為中海拔開闊地常見的陽性樹種，而 12 個永久樣區中，栓皮櫟僅於溪水干擾較少的樣區占有優勢，故洪氾可能會限制栓皮櫟之拓殖。王及邱(2004)指出自 1963-2003 年武陵地區共記錄林火 37 次。而呂(2004)論及火燒時高溫將臺灣二葉松毬果的樹脂溶化，使種子得以釋放，並於適當時機萌芽，形成苗木；另栓皮櫟則具有厚樹皮保護形成層，於火燒後快速萌蘖。此等顯示次數頻繁的林火，使對火燒具有抵抗或適應機制的臺灣二葉松與栓皮櫟成為區內的優勢樹種。

Hsieh *et al.* (1989)在德基水庫的植群研究中指出：臺灣赤楊為演替早期的先驅樹種，在干擾後得以快速建立形成優勢，而在干擾後 30-45 年，臺灣赤楊常發生更新困難之現象。然七家灣溪之洪氾干擾使濱岸植群維持在演替初期，而臺灣赤楊得以保持優勢。廖(1998)於臺灣赤楊之生態生理特性研究中提及：臺灣赤楊水分輸導能力高，且具根瘤能固定空氣中游离之氮素，並具有高光合速率，高葉片導度與廣溫性之特性，此等可能是臺灣赤楊在高光度，水分含量差異大的濱岸環境，具有優勢的關鍵。臺灣赤楊在武陵地區主要分布於溪谷沖積扇(郭 1995；徐 2006)，而許多研究亦指出在溪谷旁常有臺灣赤楊之分布(田等 2005；陳等 2007；陳等 2009；Hsieh *et al.* 1989；Yang *et al.* 2008)，顯示臺灣赤楊對濱岸環境具有極佳之適應性。

地被層優勢植物中最為優勢的植物為五節芒，除有勝溪測站之樣區外，五節芒於其他樣區的重要值都大於 30%。此外，吳(2006)於武陵地區進行之外來植物入侵及分布研究中指出：武陵地區最優勢的外來植物為大扁雀麥(*Bromus catharticus*)，其次為野茼蒿(*Conyza sumatrensis*)、白花三葉草(*Trifolium repens*)及大花咸豐草(*Bidens pilosa* var. *radiata*)。然無

論 2005 年首次調查，或後續之複查中，外來植物僅發現野茼蒿、加拿大蓬(*Conyza canadensis*)等，且於樣區內的數量稀少(甚至沒有)。其主要原因為吳(2006)係針對步道與道路兩旁的植群，其環境受人為干擾影響，與本研究所設置樣區之生育地環境或所受之干擾因子不同。因此，研究中樣區內外來種植物少，顯示目前外來種植物對濱岸植群不具入侵性，或入侵性尚未顯現，至於是否具有入侵情形，仍需持續觀察與研究方能確定。

二、植群型

研究中所繪之樹形圖(圖 2)，可依不同相似性指數之臨界值(threshold)劃分植物群落。研究中植群型依照合成樣區之優勢種予以命名，若同一林型中，優勢種有明顯差異，則再區分為亞型。若以相似性指數(IS) = 30%為臨界值，可將 2007 年之永久樣區的調查資料，劃分為 3 種主要植群型；即臺灣二葉松型(*Pinus taiwanensis* type)，蓮草—臺灣紫珠型(*Tetrapanax papyriferus-Callicarpa formosana* type)，以及栓皮櫟—化香樹型(*Quercus variabilis-Platycarya strobilacea* type)。又臺灣二葉松型依其內之優勢種組成之不同，可依相似度指數(IS) = 42%，再區分為臺灣二葉松—臺灣赤楊亞型(*Pinus taiwanensis-Alnus formosana* subtype)，臺灣二葉松—栓皮櫟亞型(*Pinus taiwanensis-Quercus variabilis* subtype)，以及臺灣二葉松—臺灣赤楊—臺灣紫珠亞型(*Pinus taiwanensis-Alnus formosana-Callicarpa formosana* subtype)，茲將各植群型之生育地環境與植物組成分述如下：

(一) 臺灣二葉松型

1. 臺灣二葉松—臺灣赤楊亞型

樣區 10、11、12 屬之；本型分布於桃山北溪、觀魚台等測站，樣區臨近溪水之第一河階，地形開闊平緩，易遭受洪水干擾。喬木層植物以臺灣赤楊、臺灣二葉松最為優勢；另地被層優勢植物則為五節芒、臺灣何首烏、串鼻龍等。

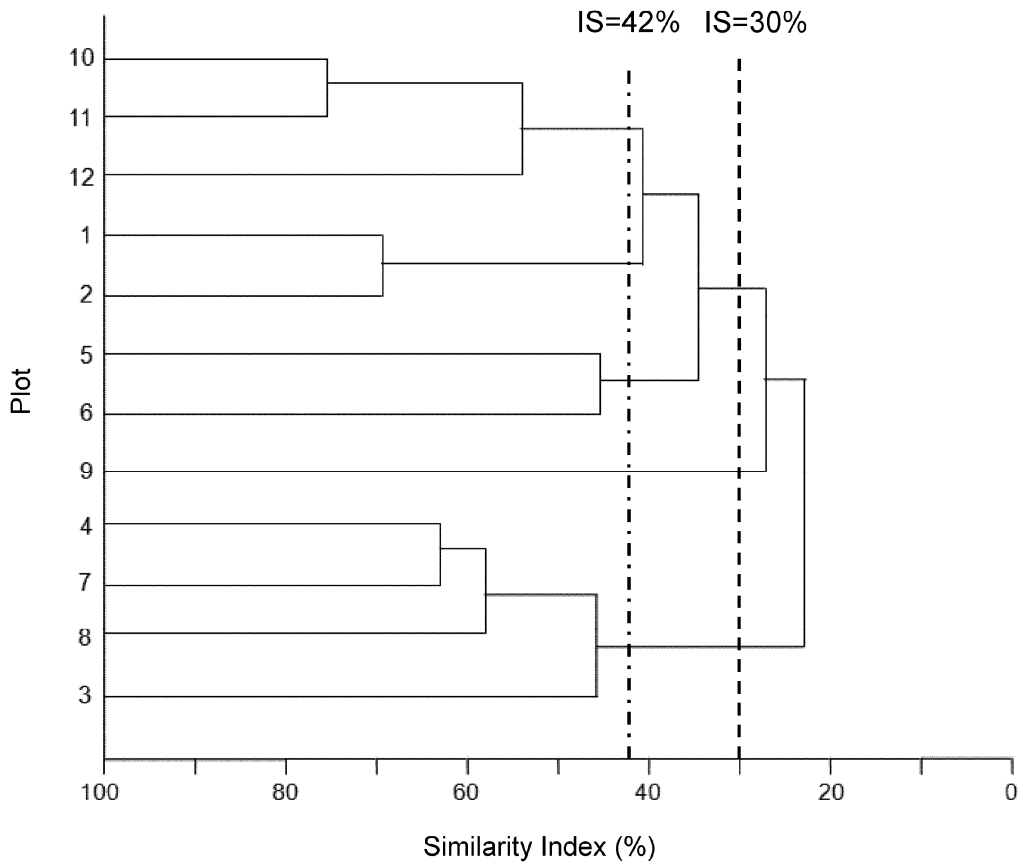


圖 2. 2007 年七家灣溪濱岸植群之永久樣區相似性樹形圖

Fig. 2. A dendrogram of riparian vegetatons at the permanent sampling plots along Cijiawan Creek, 2007.

2. 臺灣二葉松－栓皮櫟亞型

樣區 1、2 屬之；本型分布於桃山西溪測站，位於中坡地段而離溪水遠，較不易受洪氾干擾。其優勢樹種多為陽性樹種，諸如臺灣二葉松、栓皮櫟等；又地被層優勢植物主要如五節芒、高山破傘菊(*Syneilesis subglabrata*)。

3. 臺灣二葉松－臺灣赤楊－臺灣紫珠亞型

樣區 5、6 屬之；本型位於有勝溪測站。主要之喬木層優勢植物為臺灣二葉松、臺灣赤楊，除此二陽性樹種外，尚有大頭茶、海州常山、西施花、臺灣紫珠等；又此型之生育地環境較為潮濕，因此，五節芒並非此林型中地被層之優勢植物，取而代之的是喜好濕潤環境的臺灣蘆竹、圓

果冷水麻、臺灣崖爬藤、桫欏鱗毛蕨等。

(二) 蓮草－臺灣紫珠型

本型以樣區 9 為代表；分布於桃山北溪測站左岸一帶，地勢平坦，林地土壤層淺薄，多為堆積之砂質壤土。喬木層主要為中、小喬木，諸如蓮草、臺灣紫珠、海州常山；另地被層植物則以五節芒、咬人貓、山菊及蓮草為主。

(三) 栓皮櫟－化香樹型

樣區 3、4、7、8 屬之；本型分布於繁殖場、高山溪等測站。上層林冠為栓皮櫟、化香樹所構成，而次優勢樹種則是米飯花、楓香與臺灣黃杉等混生；又地被層則以五節芒、間型沿階草、細葉杜鵑、小葉鐵仔、五葉長穗木

通、求米草爲主。綜觀本型多位於中坡地段，亦常以栓皮櫟、臺灣二葉松混生爲主。

Harper and Macdonald (2001)指出濱岸植群隨著與溪流的距離增加呈現梯度變化，表現出明顯的邊緣效應。而 Nilsson and Svedmark (2002)將影響濱岸植群變化的主要因素分成三個層面；即水文、廊道(corridor)與地景(landscape)，並指出水文條件影響濱岸植群的主要因素，規律與穩定的洪氾有助於物種多樣性的維持與林分更新，亦能提高林分對環境干擾之敏感性(sensitivity)。本研究另將 2005 年之 12 個永久樣區資料進行群團分析，而此相似性樹

形圖(圖 3)與 2007 年複查的結果(圖 2)相似；唯一明顯之差異爲 2007 年的樣區資料中，繁殖場測站之樣區 4、高山溪測站之樣區 7 的相似度較高。而由重要值指數之結果比較研判；其主要原因爲樣區 7 的楓香略微增加，而使其植群之物種組成、豐富度等與樣區 4 較爲相似，因此，於歸群時先歸爲同群。是故依相似度臨界值 30%，將蔡等(2010)於 2005 年之樣區資料加以分群，則其植群歸群的結果與 2007 年相同，且樣區內的優勢植物組成變化不大，顯示喬木層的主要樹種組成及重要值，於此二年間無太大的差異。

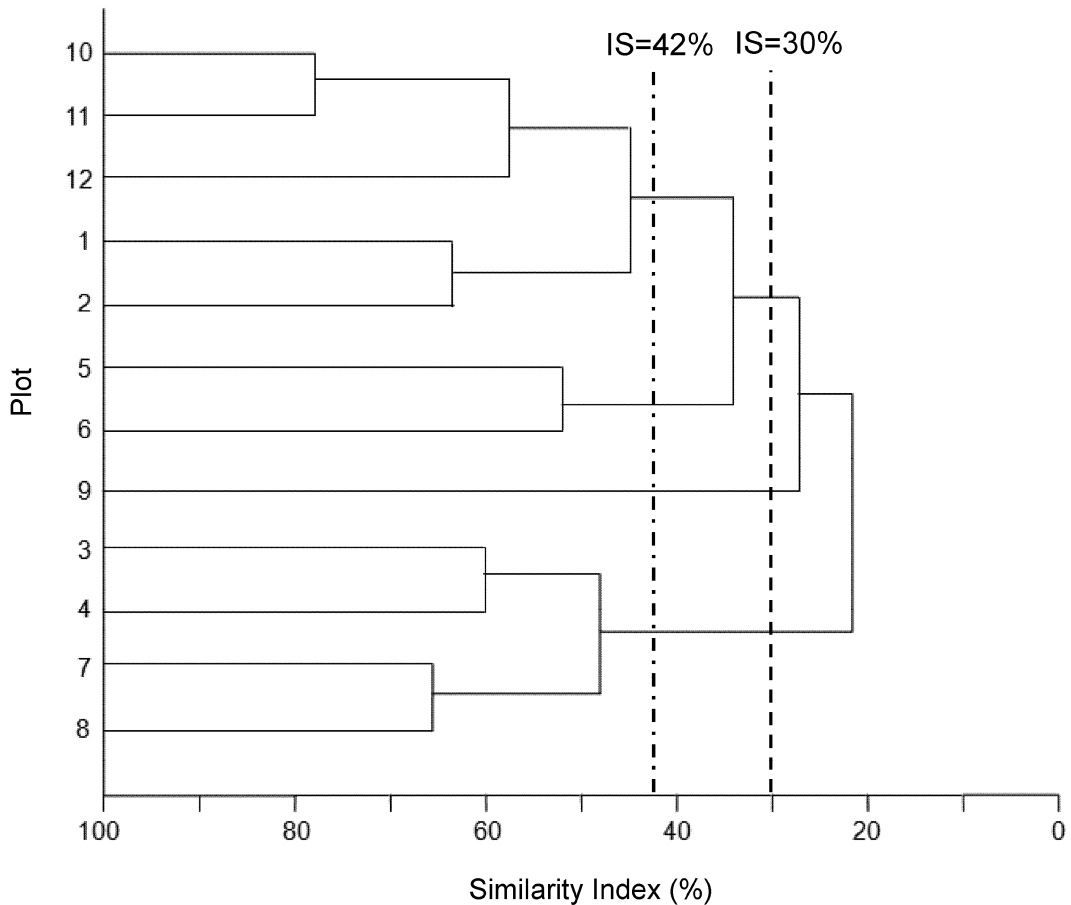


圖 3. 2005 年七家灣溪濱岸植群之永久樣區相似性樹狀圖

Fig. 3. A dendrogram of riparian vegetatons at the permanent plots along the Cijiawan Creek, 2005.

三、多樣性之探討

種間歧異度常以種豐富度(species richness)與種豐富度加以呈現，其中種豐富度僅以種數與總株數計算，而種豐富度則更深一層考量各物種間數量分配之情形。由表 4 之喬木層植物於 2005、2007 年之種豐富度指數的分析結果得知：各樣區的 Shannon 訊息統計指數(H_{sw})為 0.5-2.8，2005 年 Shannon 訊息統計指數最高者為有勝溪測站之樣區 6 (2.812)，而以觀魚台測站的樣區 12 最低(0.536)；又 2007 年亦以有勝溪測站之樣區 6 最高(2.716)，而觀魚台測站的樣區 12 最低(0.580)。另 Berger 豐富度指數(D_{BP})為 0.1-0.8，2005 年 Berger 豐富度指數最高者為觀魚台測站之樣區 12 (0.773)，而有勝溪測站的樣區 6 最低(0.134)；又 2007 年亦以觀魚台測站之樣區 12 最高(0.733)，而有勝溪測站的樣區 6 最低(0.140)。此外，Shannon 均勻度指數(E_{sw})為 0.6-0.9，2005 年 Shannon 均勻度指數以有勝溪測站的樣區 5 最高(0.903)，

而高山溪測站的樣區 8 最低(0.564)；又 2007 年亦以有勝溪測站的樣區 5 最高(0.887)，而高山溪測站的樣區 8 最低(0.552)。

為瞭解 2005 年乾、濕季，2007 年濕季及 2008 年乾季等 4 個時期地被層之多樣性變化，茲將各時期的種豐富度指數分析結果列於表 5 加以比較之；其中 2005 年 Shannon 訊息統計指數為 2.5-4.0，最高者是 2005 年濕季時有勝溪測站之樣區 6 (3.970)；而以 2005 年濕季的觀魚台測站之樣區 12 最低(2.514)。另 Berger 豐富度指數為 0.05-0.25，其中以 2005 年濕季的觀魚台測站之樣區 12 最高(0.209)，主要是樣區內之五節芒具有明顯優勢；而最低者為 2005 年濕季時高山溪測站之樣區 5 (0.076)，較無明顯的優勢種。又各樣區的 Shannon 均勻度指數為 0.8-0.9，最高者為 2005 年濕季時觀魚台測站之樣區 11 (0.905)，而以 2005 年乾季時繁殖場測站之樣區 3 最低(0.761)。此外，2007-2008 年各樣區的 Shannon 訊息統計指數

表 4. 2005、2007 年七家灣溪永久樣區喬木層植物之多樣性分析

Table 4. Results of the species diversity analysis of overstory at the permanent sampling stations and plots along Cijiawan Creek, 2005-2007

Samplin gstations	Sampling plots	2005					2007				
		Number of species	Number of individuals	H _{sw} ^{1/}	D _{BP} ^{2/}	E _{sw} ^{3/}	Number of species	Number of individuals	H _{sw} ^{1/}	D _{BP} ^{2/}	E _{sw} ^{3/}
#2	1	17	122	2.265	0.221	0.799	20	145	2.468	0.179	0.824
	2	19	101	2.371	0.297	0.805	20	113	2.479	0.274	0.827
#5	3	14	164	2.337	0.189	0.886	15	164	2.361	0.177	0.872
	4	15	135	2.303	0.178	0.850	16	136	2.341	0.176	0.844
#9	5	17	92	2.557	0.141	0.903	15	81	2.403	0.160	0.887
	6	25	187	2.812	0.134	0.874	23	157	2.716	0.140	0.866
#8	7	19	193	2.111	0.368	0.717	23	182	2.321	0.308	0.740
	8	13	230	1.447	0.522	0.564	14	234	1.456	0.521	0.552
#1	9	7	45	1.562	0.356	0.803	9	58	1.768	0.310	0.804
	10	6	70	1.333	0.471	0.744	8	60	1.533	0.483	0.737
#4	11	4	67	0.925	0.627	0.667	5	62	1.023	0.613	0.635
	12	2	44	0.536	0.773	0.773	2	45	0.580	0.733	0.837

^{1/} Shannon information statistic index

^{2/} Berger species abundance index

^{3/} Shannon evenness index

表 5. 2005-2008 年七家灣溪永久樣區地被層植物之多樣性分析
Table 5. Results of the species diversity analysis of understory at permanent sampling stations and plots along the Cijawan Creek, 2005-2008

Sampling stations	Sampling plots	Dry season 2005				Wet season 2005				Wet season 2007				Dry season 2008			
		H _{sw} ^{1/}	D _{BP} ^{2/}	E _{sw} ^{3/}	Number of species	H _{sw} ^{1/}	D _{BP} ^{2/}	E _{sw} ^{3/}	Number of species	H _{sw} ^{1/}	D _{BP} ^{2/}	E _{sw} ^{3/}	Number of species	H _{sw} ^{1/}	D _{BP} ^{2/}	E _{sw} ^{3/}	Number of species
#2	1	38	0.143	0.849	54	3.169	0.169	0.794	42	3.250	0.150	0.870	45	3.138	0.154	0.824	
	2	41		0.822	59	3.451	0.093	0.846	52	3.432	0.098	0.869	51	3.238	0.124	0.824	
#5	3	36	3.054	0.194	46	3.307	0.098	0.864	50	3.565	0.064	0.911	34	2.834	0.152	0.804	
	4	46	2.725	0.141	77	3.512	0.097	0.854	66	3.889	0.046	0.928	43	2.973	0.146	0.791	
#9	5	69	2.965	0.088	77	3.850	0.076	0.886	66	3.896	0.064	0.930	66	3.654	0.075	0.872	
	6	90	3.656	0.087	98	3.970	0.084	0.866	64	3.889	0.047	0.935	73	3.766	0.063	0.878	
#8	7	69	3.743	0.160	77	3.602	0.093	0.829	70	3.734	0.094	0.879	56	3.431	0.125	0.852	
	8	51	3.444	0.182	60	3.541	0.086	0.865	65	3.565	0.095	0.854	48	3.313	0.117	0.856	
#1	9 ^a	- ^a	- ^a	- ^a	46	3.028	0.186	0.791	41	3.122	0.110	0.841	36	2.753	0.194	0.768	
	10 ^b	- ^a	- ^a	- ^a	43	3.091	0.147	0.822	39	3.136	0.104	0.856	27	2.729	0.202	0.828	
#4	11 ^a	- ^a	- ^a	- ^a	46	3.465	0.086	0.905	46	3.299	0.162	0.862	34	2.812	0.224	0.797	
	12 ^a	- ^a	- ^a	- ^a	25	2.514	0.209	0.781	28	2.699	0.248	0.810	0 ^b	0.000 ^b	0.000 ^b	0.000 ^b	

^a The plot was not set up yet in the dry season in 2005, so there was no datum.

^b The plot was destroyed during the rain season in 2007, so data "0" for the dry season in 2008.

^{1/} Shannon information statistic index

^{2/} Berger species abundance index

^{3/} Shannon evenness index

為 2.7-3.9，其中最高者為 2007 年濕季時有勝溪測站之樣區 5 (3.896)；而以 2007 年濕季時觀魚台測站之樣區 12 最低(2.699)。另 Berger 豐富度指數為 0.05-0.25，其中以 2007 年濕季時觀魚台測站之樣區 12 最高(0.248)，即仍以五節芒為此區之優勢種；而最低者則為 2007 年濕季時繁殖場測站之樣區 4 (0.046)。又 Shannon 均勻度指數為 0.8-0.9，最高者為 2007 年濕季時有勝溪測站之樣區 6 (0.935)，而以 2008 年乾季時桃山北溪測站之樣區 9 最低(0.768)。

將二年度喬木層之種豐富度指數進行 Kruskal-Wallis 檢定的結果得知；2005、2007 年喬木層植物的種數(P=0.659)、總株數(P=0.963)、Shannon 訊息統計指數(P=0.557)、Berger 豐富度指數(P=0.763)、Shannon 均勻度指數(P=0.890)，顯示二年度間喬木層植物之多樣性沒有明顯變化。然若以個別樣區而言，可發現 2007 年時喬木層植物的晉級生長使其歧異度增加，而其各樣區喬木層植物之種數、總株數與 Shannon 訊息統計指數等多高於 2005 年；又 Berger 豐富度指數強調植群中之最優勢種，Berger 豐富度指數之下降，即代表優勢種占總量的比例減少，以及種數之增加，此與前述之 Shannon 訊息統計指數上升的結果相符。Yang *et al.* (2008)於楠梓仙溪上游植群研究中之優勢種為臺灣赤楊、臺灣紫珠、長葉木薑子與大葉溲疏的臺灣赤楊林型之 Shannon 訊息統計指數為 2.3。此與本研究位於中坡之臺灣二葉松—栓皮櫟亞型、臺灣二葉松—臺灣赤楊—臺灣紫珠亞型，以及栓皮櫟—化香樹型的 Shannon 訊息統計指數相近，而鄰近溪流灘地的臺灣二葉松—臺灣赤楊亞型、蓮草—臺灣紫珠型則較低。Lyon and Gross (2005)指出喬木層植物生命史長，不易在干擾強度大的溪流灘地建立族群，故具適應能力的樹種較易形成優勢，而喬木層植物之多樣性亦隨之降低。此結論與本研究結果相符，是故進一步推論臺灣二葉松

—臺灣赤楊亞型、蓮草—臺灣紫珠型等之植群型中，諸如臺灣赤楊、臺灣二葉松、蓮草、阿里山榆、臺灣紫珠等，亦較具有抵抗溪水干擾的能力。

2005、2007-2008 年之乾、濕季間地被層的種豐富度指數經 Kruskal-Wallis 檢定為種數(P=0.316)、Shannon 訊息統計指數(P=0.130)、Berger 豐富度指數(P=0.360)、Shannon 均勻度指數(P=0.004)，即 Shannon 均勻度指數具顯著性差異。而再經 Dunnett's T3 法進行事後檢定得知：僅 2005 乾季與 2007 年濕季有所差異(P=0.009)，即濕季的物種組成較為均勻。綜上得知於相同季節，各樣區地被層多樣性於不同年度無明顯變化。Jiang *et al.* (2002)於三峽地區的濱岸植群研究中提及濱岸植群受到擾動大，地被層植物多以一年生草本為主；而由於乾季時部分一年生草本植物死亡，致使物種種數、種豐富度指數下降。又趙(2003)於洪水頻率與河畔植生關係的研究中，其濱岸地被層植群則以多年生的禾本科植物為優勢種。本研究中多數樣區的地被層優勢物種為五節芒，若五節芒在樣區內大量增長，占據大部分資源，影響其他物種之生長空間，則使其物種豐富度較低(如樣區 9-12)；而有勝溪測站之樣區 6 的生育地環境潮濕，林下鬱閉，五節芒數量較少，使其他物種具有足夠的生長空間，故物種豐富度亦較高。

結論與建議

對濱岸植群而言，溪水的干擾具有一定程度的影響。七家灣溪濱岸植群除溪水氾濫影響外，水流的侵蝕作用導致邊坡陡峭，偶有崩塌的現象發生，故而環境較不穩定。然以其物種組成而言，2005、2007-2008 年的物種組成並無明顯變化，且歸群後之群團分析結果相似；皆可分為蓮草—臺灣紫珠型，栓皮櫟—化香樹型，臺灣二葉松—臺灣赤楊亞型，臺灣二葉松

一栓皮櫟亞型，以及臺灣二葉松—臺灣赤楊—臺灣紫珠亞型。

2005、2007 年間喬木層植物之多樣性沒有明顯變化，其中以有勝溪測站之歧異度及均勻度最高；又觀魚台測站的歧異度較低，而高山溪測站之均勻度較低。此外，2005 或 2007-2008 年之乾、濕季間地被層的種豐富度指數，僅 2005 乾季與 2007 年之濕季具顯著差異，即濕季的物種組成較為均勻；而相同季節於不同年度間，其植群多樣性則無顯著差異，即表示兩年度間之地被層植物的多樣性變動不大。綜上得知；在現今武陵地區相關經營單位管理之下，2005-2008 年七家灣溪濱岸植群多樣性維持穩定。又良好之濱岸植群覆蓋，可維持溪流溫度之恆定，有利於臺灣櫻花鉤吻鮭族群之生長及繁衍，而持續監測其濱岸植群之動態變化，亦有助於權責單位對其經營策略之擬定及執行方案績效的瞭解。

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引用文獻

- 王筱萱、邱祈榮。2004。武陵地區林火發生機制之分析。中華林學會 93 年度學術論文發表會論文集 pp.140-153。宜蘭縣。
- 田永柔、鄧書麟、呂福原、何坤益、張坤城。2005。嘉義縣低海拔地區崩塌地先驅植群之調查研究。中華林學季刊 38(1): 49-65。
- 吳姍樺。2006。雪霸國家公園外來植物入侵與分佈之調查。內政部營建署雪霸國家公園管理處。苗栗縣。
- 呂金誠。2004。武陵火燒後植被變化監測研究。內政部營建署雪霸國家公園管理處。苗栗縣。
- 林幸助。2002。武陵地區生態系監測與模式建構規劃。內政部營建署雪霸國家公園管理處。苗栗縣。
- 徐憲生。2006。七家灣溪濱岸植群監測與地景變遷。國立中興大學森林系碩士論文。臺中市。
- 郭城孟。1995。七家灣溪潛在植被之研究。雪霸國家公園管理處。苗栗縣。
- 陳吉泉。1996。河岸植被特徵及其生態系統和景觀中的作用。應用生態學報 7(4): 439-448。
- 陳志豪、陳明義、陳文民、陳恩倫。2009。合歡河流域植群分類與製圖。林業研究季刊 30(1): 1-15。
- 陳德仁、李金玲、許炳修、陳和田、薛燕璘、呂福原。2007。臺大實驗林沙里仙區楠櫛林帶之臺灣赤楊植群研究。中華林學季刊 40(2): 165-183。
- 廖天賜。1998。臺灣赤楊生理生態之基礎研究。國立中興大學植物學研究所博士論文。臺中市。
- 趙偉成。2003。洪水頻率與河畔植生關係之研究於臺灣南部地區。國立成功大學水利及海洋工程研究所碩士論文。臺南市。
- 蔡尚惠、林志銓、黃立彥、呂金誠、歐辰雄、吳聲海。2007。惠蓀林場紅檜人工林與闊葉樹次生林之種豐富度指數分析。中華林學季刊 40(3): 287-300。
- 蔡尚惠、徐憲生、呂金誠。2010。七家灣溪濱岸植群之組成與結構。林業研究季刊 32(1): 19-38。
- Gregory, S. V., F. J. Swanson and W. A. Mckee.

1991. An ecosystem perspective of riparian zones. *BioScience* 41(8): 540-551.
- Harper, K. A. and S. E. Macdonald. 2001. Structure and composition of riparian boreal forest: new methods for analyzing edge influence. *Ecology* 82(3): 649-659.
- Hsieh, C. F., T. H. Hsieh and S. M. Lin. 1989. Structure and succession of the warm-temperate rain forest at Techi Reservoir. *Journal of Taiwan Museum* 42: 77-89.
- Jiang, M. X., H. B. Deng and Q. H. Cai. 2002. Characteristics, classification and ordination of riparian plant communities in the Three-Gorges area. *Journal of Forestry Research* 13(2): 111-114.
- Lyon, J. and N. M. Gross. 2005. Patterns of plant diversity and plant-environmental relationships across three riparian corridors. *Forest Ecology Management* 204: 267-278.
- Motika, J., B. Dobrzanski and S. Zawadski. 1950. Wstepne badania nad lakami poludniowoschodniej Lubelszczyzny (Preliminary studies on meadows in the southeast of the province Lublin. Summary in English). *Annals of the University Marie Curie-Sklodowska, Section E* 5 (13): 367-447.
- Nilsson, C. and M. Svedmark. 2002. Basic principles and ecological consequences of changing water regimes: Riparian plant communities. *Environmental Management* 30(4): 468-480.
- SPSS Inc. 2006. SPSS 15.0 for Windows. SPSS Inc., USA.
- White, M. D. and K. A. Greer. 2006. The effects of watershed urbanization on the stream hydrology and riparian vegetation of Los Penasquitos Creek, California. *Landscape and Urban Planning* 74: 125-138.
- Yang, K. C., J. K. Lin, C. F. Hsieh, C. L. Huang, Y. M. Chang, L. H. Kuan, J. F. Su and S. T. Chiu. 2008. Vegetation pattern and woody species composition of a broad-leaved forest at the upstream basin of Nantzuhsienhsi in mid-southern Taiwan. *Taiwania* 53(4): 325-337.

小紅姬緣椿象之吸食提高其寄主植物倒地鈴種子發芽率

Enhancement Effect of the Feeding of *Leptocoris augur* on the Germination Rate of Its Host Plant *Cardiospermum halicacabum*

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摘 要

小紅姬緣椿象(*Leptocoris augur* Fabricius)具有特殊吸食口器，可突破倒地鈴(*Cardiospermum halicacabum* L.)的種子防衛。倒地鈴種子經小紅姬緣椿象吸食後，發芽率於 14~42 天間，可提高 3.2~6.0 倍(與對照組相比)。模擬野外小紅姬緣椿象的吸食實驗，含果莢種子餵養兩週後，種子發芽率於 28~42 天間，則可提高 2.6~9.0 倍。倒地鈴種子經吸食過後，發芽率提升的機制，類似對種皮的物理傷口，如縫衣針或指甲剪處理，透過種皮傷口增加種子的吸水量。種子被吸食過，不僅沒有死亡，且可促進發芽率。野外觀察近八成(78.2%)的種子只被刺吸一針或兩針，且刺吸的位置未傷及胚。小紅姬緣椿象與其寄主植物倒地鈴，顯現有互利共生的關係。

Abstract

Leptocoris augur Fabricius feeds on seeds of the heartseed vine (*Cardiospermum halicacabum* L.), using its unique mouthparts that are capable of piercing through the pod and seed coat. Germination rates of the seeds fed by *L. azrgus* were found to be 3.2 and 6.0 times higher than those of the unfed ones on

14 and 42 days after feeding, respectively. We also conducted a simulation experiment, in which heartseed vine seeds were fed by *L. argus* for two weeks. The germination rates of the seeds fed were 2.6 and 9.0 times higher than those of the unfed ones on 28 and 42 days after feeding, respectively. The underlying mechanism associated with the enhancement of the feeding on the germination were similar to that resulted from physical wounds by needle or nail clippers. The wounds improved water absorption of the seeds that in turn enhanced the germination rate. In our field observation, approximately eight out of ten (78.2 %) seeds were pierced once or twice by *L. argus*. The wounds did neither kill the seeds nor injure the embryos but enhanced the germination rate. Apparently, there is a mutualism relationship between *L. augur* and its host *C. halicacabum*.

關鍵詞：發芽率、互利共生、倒地鈴、小紅姬緣椿象、硬殼種子

Key words: germination rate, mutualism *Cardiospermum halicacabum*, *Leptocoris augur*, hardseed

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緒 言

有些植物具有「硬殼種子」(hard seeds)，或稱為「物理休眠的種子」(seeds with physical dormancy)；因有不透水種皮而必要經過物理性外傷，改善種皮的通透性，促進水分進入及氣體交換，才能發芽(陳等 2009; Baskin and Baskin 1998)。植食性昆蟲是硬種子發芽的潛在促進者(Karban and Lowenberg 1992; Takakura 2002)。吃食這些硬殼種子的昆蟲，與其寄主植物間，透過提升種子發芽率，而有互利共生的現象(Takakura 2002)。

植食性昆蟲可促使其寄主植物種子發芽率倍增。例如澳洲一種食種子椿象(*Oxycarenus luctuosus*)可讓草棉(*Gossypium sturtianum*)的發芽率增加 2~3 倍(Karban and Lowenberg 1992)。美國亞利桑那州棉花(*Gossypium thurberi*)被椿象(*Sphyracoris punctellus*)及象鼻蟲(*Anthonomus*

grandis)取食後，種子發芽率皆由 15% 增加至近 29% (Karban and Lowenberg 1992)。專食性昆蟲對其寄主植物種子發芽，更有不可或缺的關係(Takakura 2002)。

倒地鈴(*Cardiospermum halicacabum* L.)具有硬殼種皮，雖可防止昆蟲啃食，但造成其種子發芽率極低(呂及黃 2008)。小紅姬緣椿象(*Leptocoris augur* Fabricius)運用其特殊刺吸式口器，穿透種子外圍的氣囊和種皮，吸食倒地鈴種子(寄主植物)。雖然小紅姬緣椿象常見大量聚集吸食倒地鈴種子，但倒地鈴的分布在台灣中南部仍是相當普遍。自然界小紅姬緣椿象取食倒地鈴種子，並未造成倒地鈴族群減少。小紅姬緣椿象增加其寄主植物倒地鈴的發芽率，可能是個重要因素。

本研究採集的倒地鈴屬於蔓藤植物(又稱風船葛)，分類上屬於無患子目(Sapindales)、無患子科(Sapindaceae)、倒地鈴屬(*Cardiospermum*)，

原產地在南美洲，現在是台灣常見的野花(呂及黃 2008)。倒地鈴莖細長達數公尺，葉互生為二回三出或二回羽狀複葉，花腋生呈聚繖花序排列。種子位於蒴果中，蒴果膨脹充氣，果面呈三稜瓣，內有三個分室，每室內有一粒圓滑球形種子，未成熟時呈綠色具心臟形白斑，成熟時則轉為黑色具心臟形白斑(劉等 1998)。

小紅姬緣椿象在分類上屬於半翅目(Hemiptera)、姬緣椿象科(Rhopalidae)，身體背部呈橘紅色，具有刺吸式口器，是一種取食種子的椿象(Schaefer and Kotulski 2000)。但是若蟲口器長度要穿過果莢到達成熟種子很困難，因此若蟲大多取食有洞的種子(Newton 1984)。

本研究進行野外調查，了解倒地鈴與小紅姬緣椿象地理分布的關係，並微細觀察小紅姬緣椿象吸食倒地鈴種子的情況，以及於實驗室內驗證小紅姬緣椿象吸食是否提高倒地鈴種子發芽率，和其提升發芽率的可能機制(吸水性的關係)。

材料與方法

一、材料採集、飼養與分布相關調查

野生倒地鈴果莢採集自嘉義縣六腳鄉六嘉國中(23°30'6.03" N; 120°17'31.80")附近田圳邊。於 2009 年 4~7 月採集期間，隨機採集倒地鈴種子，以及同一地點的小紅姬緣椿象 5 齡若蟲及成蟲。本研究吸食影響的實驗都使用 5 齡若蟲，因為 5 齡若蟲吸食寄主種子的可能傷害，往往會比其他齡嚴重(Zink and Rosenheim 2005; Bommireddy *et al.* 2007)。飼養用的倒地鈴果莢(確定無椿象)採集自六嘉國中陽台上種植的倒地鈴。採集回來的若蟲，置入實驗室飼養箱(長 60 cm，寬 45 cm，高 45 cm)中，放入濕棉花(提供水分)，並按照若蟲數量，放入相同數量的倒地鈴種子飼養。

倒地鈴與小紅姬緣椿象兩者野外分布關係，調查範圍包括嘉義縣六腳鄉和太保市地

區，有出現倒地鈴的地點，記錄小紅姬緣椿象的分布情況。

二、小紅姬緣椿象吸食倒地鈴種子的觀察

倒地鈴的每顆種子上具有黑與白兩種顏色(圖 3A)，白色部分連接果莢呈心形。當種子未完全成熟時，白色部分是無法被吸食的，種子成熟後會掉落至果莢之中，小紅姬緣椿象成蟲及若蟲可由果莢上破洞進入吸食。為了瞭解種子被吸食是否因顏色不同或區域不同產生差異，我們在棲地調查時隨機收集 397 顆倒地鈴種子加以比較，並且進一步微細觀察白色區域和胚的構造關係。

三、小紅姬緣椿象吸食對種子(野外採集)發芽率之影響

選取野生倒地鈴外表飽滿充滿氣的果莢(確保未被吸食過)(圖 1A)，取出果莢內的種子餵食小紅姬緣椿象。所有種子都經過解剖顯微鏡檢查，確保完好，且未被吸食過，總計得到 323 顆種子。隨機取 18 顆種子與同地點採集的 23 隻小紅姬緣椿象 5 齡若蟲，同時放入飼養箱，持續餵養 14 天。飼養期間，每日中午檢查飼養箱內的種子，將有被吸食過的種子取出，並再放入未被吸食的種子，取代。飼養箱內於飼養期間種子數量都保持有 18 顆。持續飼養兩個星期，總計取出 54 顆被吸食過的種子(實驗組)。其餘有 269 顆未被吸食過的種子(對照組)。

四、模擬小紅姬緣椿象實際覓食情況

隨機選取實驗室陽台自行種植的倒地鈴果莢 50 個，果莢撕開，露出黑色種子，總計 140 顆種子，分成兩組，實驗組與對照組，各 70 顆未被取食過的種子。實驗組 70 顆種子全部放入飼養箱，內有 23 隻 5 齡若蟲，飼養 5 天後，再取出所有種子(70 顆)。對照組(70 顆)則未做任何處理。

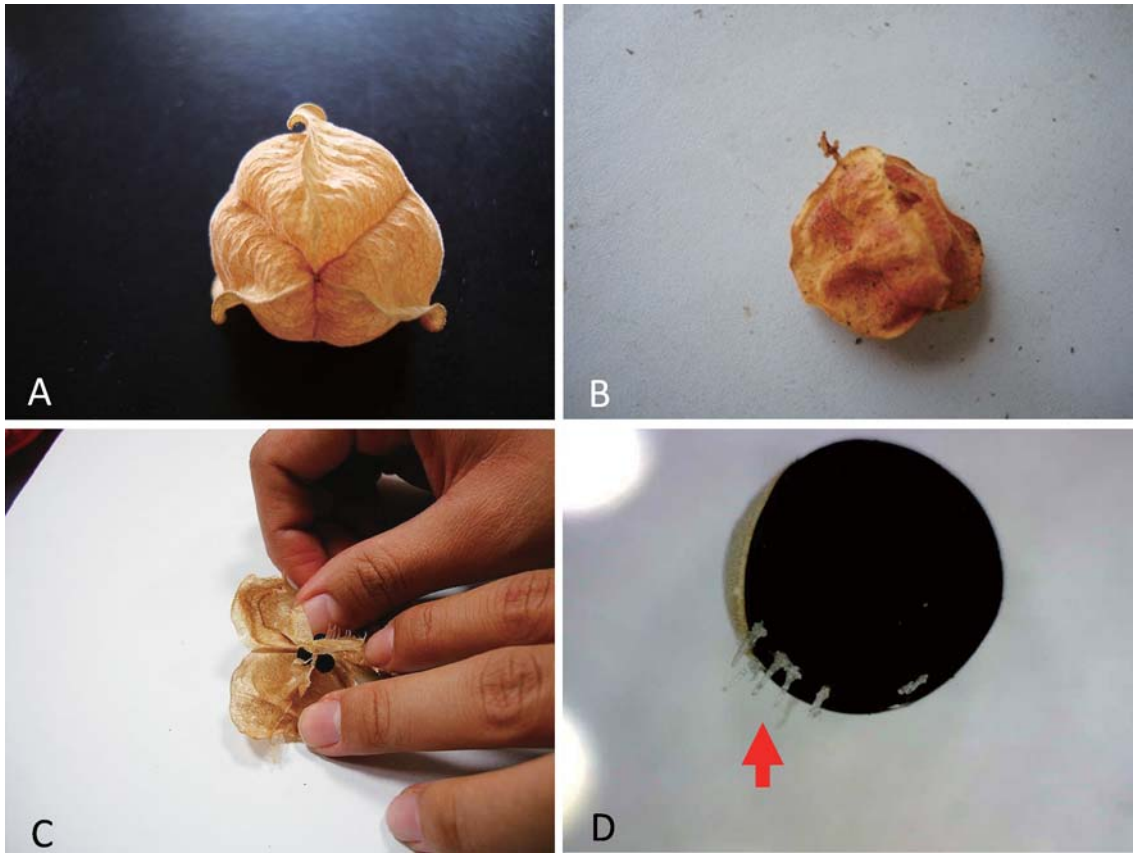


圖 1. 倒地鈴果莢中種子及吸食痕跡。A, 外表飽滿充滿氣的果莢；B, 被小紅姬緣椿象吸食的果莢；C, 撕開果莢內有種子；D, 椿象吸食種子遺留的痕跡。

Fig. 1. Pods and seeds of *Cardiospermum halicacabum* (A, a normal pod; B, a pod pierced by *Leptocoris augur*; C, seeds inside pod; D, cross section of a seed showing the piercing traces).

五、發芽率比較實驗

將實驗組和對照組的種子，分別進行發芽率的比較實驗。將種子浸泡於 25°C 自來水 24 小時。浸泡後，將實驗組和對照組的種子取出並分別播種於 70 格的穴盤中，穴格(45 x 45 x 45 mm)內盛泥炭苔、珍珠石、蛭石(2:1:1 體積比)之混合介質(呂及黃 2008)。放置於陽台能照到陽光的地方，每日澆水三次，於播種後第二星期起，每 14 天記錄種子發芽率，至第 42 日止(呂及黃 2008)。胚芽突破種皮即視為發芽。

六、種子發芽率提升的可能機制(吸水率)

野外採集，經過顯微鏡檢視，確認未被吸食過的倒地鈴種子，總計 720 顆。隨機取出 240 顆，分成 4 組(每組 60 顆)。每組分別做不同的處理(圖 2)，小紅姬緣椿象吸食、針刺破種皮、指甲剪夾裂種皮，以及不做任何處理(對照組)。這 4 組種子，同時分別浸泡於 25°C 自來水中，泡水時間總長 24 小時。每組都各以 5 個種子為一小組(每組各有 12 小組)，泡水前以微量天平一起秤重。泡水後，每隔 2 小時，各組都隨機取出一小組(5 顆種子)，表面

擦乾，再一起稱重。各小組稱種後再放入水中，持續 24 小時。各組都有 12 小組，各有 12 次稱重紀錄。每次記錄時的種子吸水率 = (泡水後種子平均重量 - 泡水前種子平均重量) ÷

泡水前種子平均重量(劉 2006)。持續泡水 24 小時後，各組都隨機選取 30 顆種子，進行發芽率比較實驗。

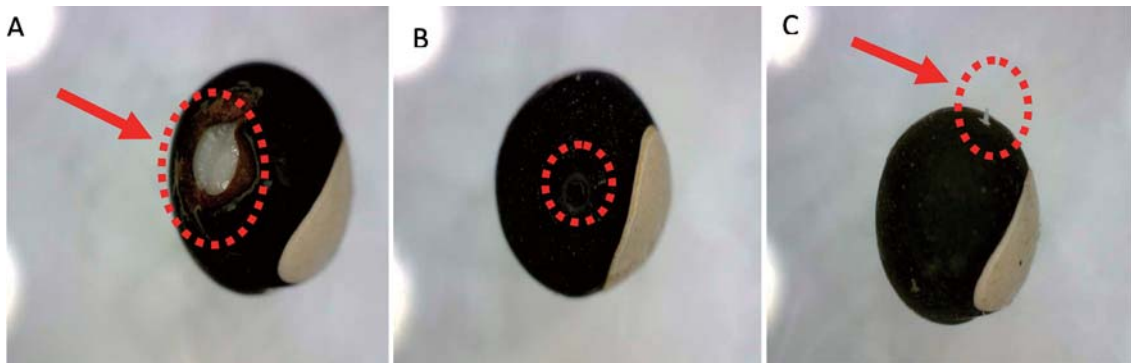


圖 2. 倒地鈴外種皮三種不同的處理。A, 以指甲剪剪去種皮；B, 利用縫衣針刺破種皮；C, 椿象吸食的处理。

Fig. 2. Three types of the wound treatments on the seeds of *Cardiospermum halicacabum* (A. cutting wound by nail clippers; B. puncture wound by needle; C. pierced by *Leptocoris augur*).

七、統計分析

發芽率實驗以卡方檢定(Chi-Square Test)進行獨立性檢定，來比較小紅姬緣椿象吸食與種子發芽是否具有關連性(Pagano and Gauvreau 2000)。種子發芽率提升的可能機制(吸水性)實驗，分為 12 個測量點，使用獨立樣本 T 檢定，檢定時先以 F 檢定比較母群體變異數是否相等，再判斷 T 檢定的結果，是否吸水性具有差異(Pagano and Gauvreau 2000)。本研究使用 SPSS 12 進行資料統計分析，並使用 Excel 2010 繪圖。

結 果

一、小紅姬緣椿象與寄主植物的分布相關性

野外調查於六腳鄉(20 處)和太保市(9 處)，總計 29 處的倒地鈴分布處，發現其中有 24 處有小紅姬緣椿象聚集。小紅姬緣椿象在六腳鄉

倒地鈴棲地出現率有 83%，在太保市出現率則有 100%。

二、小紅姬緣椿象吸食倒地鈴種子的觀察

小紅姬緣椿象吸食倒地鈴果莢後，除了果莢扁掉外，種子外皮會留下白色柱狀痕跡(圖 1D)，這個痕跡遇水則會消失。本研究棲地調查中隨機收集 397 顆倒地鈴種子，發現被吸食的有 102 顆，被吸食的種子中有 78.2% 被刺一至二處，刺的位置有 67.3% 在種子白色位置內(圖 3A)，比較刺的深度(圖 1D)及胚的位置(圖 3B)，小紅姬緣椿象的吸食並未傷其胚。

三、小紅姬緣椿象吸食對發芽率之影響

實驗組完整果莢(with intact pods)餵食兩星期間共有 54 顆種子被小紅姬緣椿象(23 隻)吸食。被吸食過的倒地鈴種子第 14、28、42 天發芽率依序為 1.9%、7.4% 和 22.2%，對照

組(未被吸食)依序為 0.4%、2.2%和 3.7% (表 1)。實驗組提升發芽率倍數(enhancement ratio)依序為 4.8 倍、3.2 倍和 6.0 倍(表 1)。以 Chi-

Square 進行獨立性檢定，計算第 42 天的卡方值為 $\chi^2 = 24.2 > 3.84$ ($\alpha = 0.05$ 自由度 = 1), $p < 0.001$ ，兩者差異顯著(表 1)。

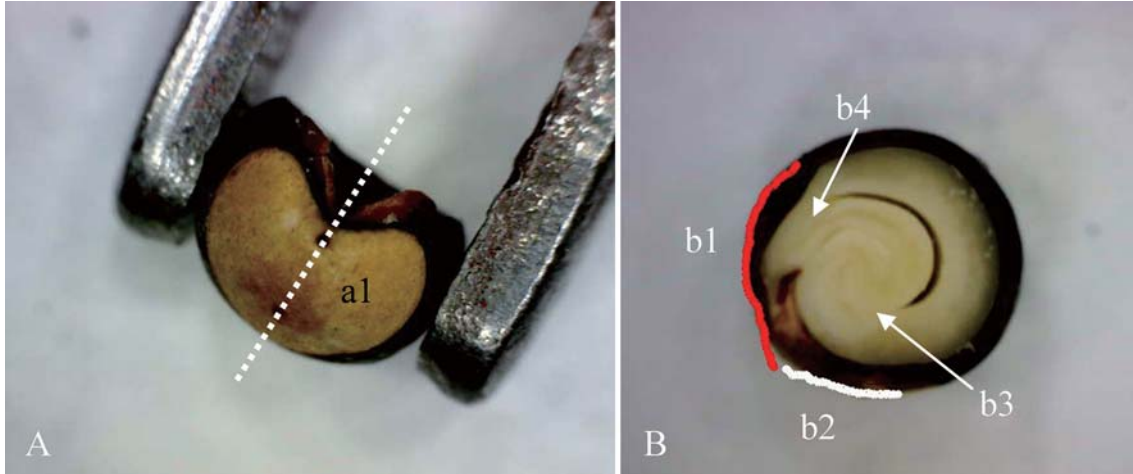


圖 3. 倒地鈴種子的側面(A)和種子的橫切面(B)。A. 白色虛線為 B 的切面；B，b1 處為胚根突破種皮位置，b2 為白色位置處(相對於 A 的 a1 處)，B3 為胚芽，B4 為胚根。

Fig. 3. Lateral view (A) and cross section (B) of the *Cardiospermum halicacabum* seed (A. white dotted line, cross section location; b1, area of the radicle penetrated the seed coat; b2, a1 area in Figure A; B3, germ; B4, radicle).

表 1. 小紅姬綠椿象吸食，對倒地鈴種子發芽率的影響。兩種不同處理，完整果莢(with intact pod)和撕開果莢(with torn pod)

Table 1. Effects of the feeding of *Leptocoris augur* on the germination rates of *Cardiospermum halicacabum* seeds with intact or torn pods

Treatments	N	Germination rate (%)			Chi-square value	P-value
		14 (day)	28 (day)	42 (day)		
With intact pods	54	1.9	7.4	22.2	24.2	< 0.001***
Control group	269	0.4	2.3	3.7		
Enhanced ratio		4.8	3.2	6.0		
With torn pods	70	--	38.6	52.9	16.2	< 0.001***
Control group	70	--	4.3	20.0		
Enhancement ratio		--	9.0	2.6		

四、模擬小紅姬綠椿象實際覓食情況

實驗組撕開果莢(with torn pods)的 70 顆種子連續飼養 5 天，有小紅姬綠椿象吸食過的種子第 28 日發芽率為 38.6%，第 42 日發芽率為 52.9%。對照組(未被吸食)的發芽率依序為 4.3% 和 20.0% (表 1)。實驗組提升發芽率倍數依序為 4.3 倍和 2.6 倍(表 1)。以 Chi-Square 進行獨立性檢定，計算第 42 天的卡方值為 $\chi^2 = 16.2 > 3.84$ ($\alpha = 0.05$ 自由度 = 1)， $p < 0.001$ ，兩者差異顯著(表 1)。

五、種子發芽率提升的可能機制(吸水率)

分別以人工處理種皮(指甲剪夾裂、針刺)及小紅姬綠椿象吸食處理種子，其吸水率於兩小時後，夾裂與針刺處理的種子吸水率上升至 10%，小紅姬綠椿象吸食至 9 小時後和上述兩

者相同。10 小時後人工處理種皮實驗組種子吸水量上升(圖 4)。泡水時間在第 12 小時以後，可見夾裂種子、針刺種子及小紅姬綠椿象吸食過的種子，吸水性增加(圖 4)。對照組吸水性增加很少(圖 4)。

進行小紅姬綠椿象吸食過的種子與對照組的吸水率平均數檢定，因為吸水率平均數 F 檢定之顯著性 $p < 0.001$ ， $t = -5.830$ 、自由度 = 11.032、 $p < 0.001$ ，兩個處理的吸水率平均數有明顯差異。相同的分析在縫衣針與指甲剪處理及縫衣針與椿象吸食處理的吸水率平均數檢定中，發現縫衣針與椿象吸食處理具有顯著差異($p < 0.05$ ，t 檢定)，但是縫衣針與指甲剪處理則未具有顯著差異($p = 0.514$ ，t 檢定)。因此可以將四條曲線依差異顯著與否方式分成 a、b、c 三個組群(圖 4)。

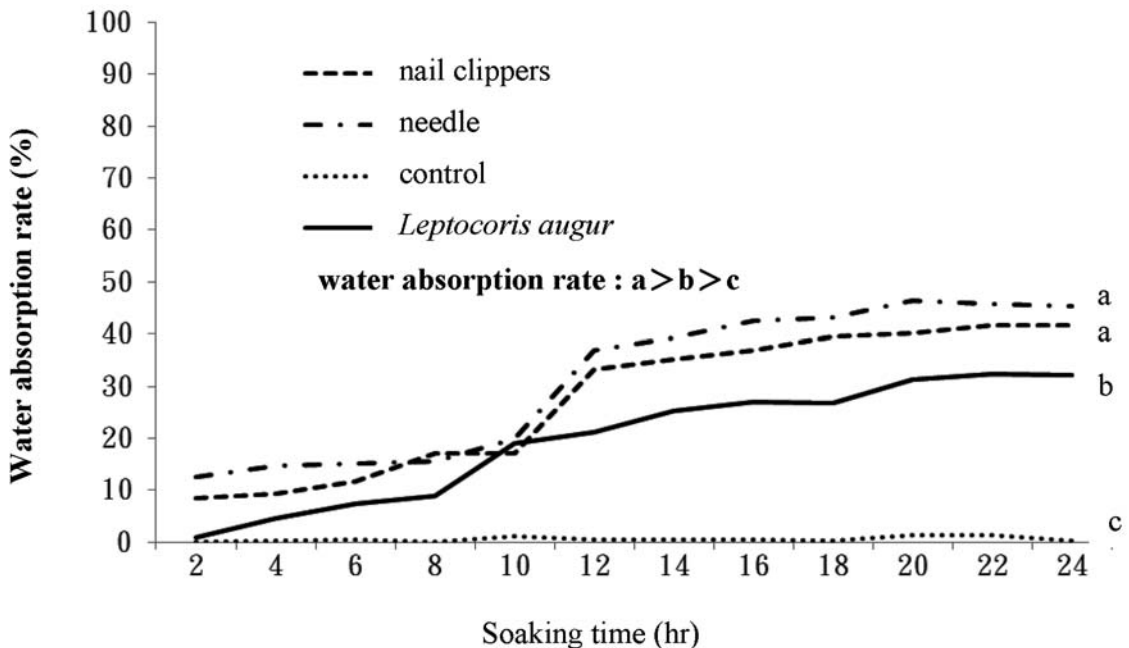


圖 4. 種皮不同處理對種子吸水性的影響。

Fig. 4. Average water absorption rates in relation to soaking periods for the *Cardiospermum halicacabum* seeds with wounds from different treatments.

於種子的吸水性測定實驗後，實驗組及對照組各 30 顆種子種植於穴盤中，種子發芽率如圖 5 所示。第 22 天時利用指甲剪及縫衣針處理的倒地鈴種子發芽率皆達到 73%，椿象吸食後的種子第 22 天時發芽率達到 30%，但對照組的發芽率只有 3%。

以卡方檢定進行小紅姬綠椿象吸食過的種子與對照組發芽率的獨立性檢定，計算第 22 天的卡方值為 $\chi^2 = 7.68 > 3.84$ ($\alpha = 0.05$ 自由

度 = 1)， $p < 0.01$ ，顯示二者差異顯著，即以撕開倒地鈴果莢餵食小紅姬綠椿象，種子經小紅姬綠椿象吸食後種子發芽率顯著增加。以相同方式檢驗縫衣針或指甲剪處理與椿象吸食的發芽率， $p < 0.001$ ，顯示二者差異顯著，種子經縫衣針或指甲剪處理與椿象吸食相比種子發芽率顯著增加。可以將第 22 天發芽率依差異顯著與否分成 a、b、c 三個組群(圖 5)。

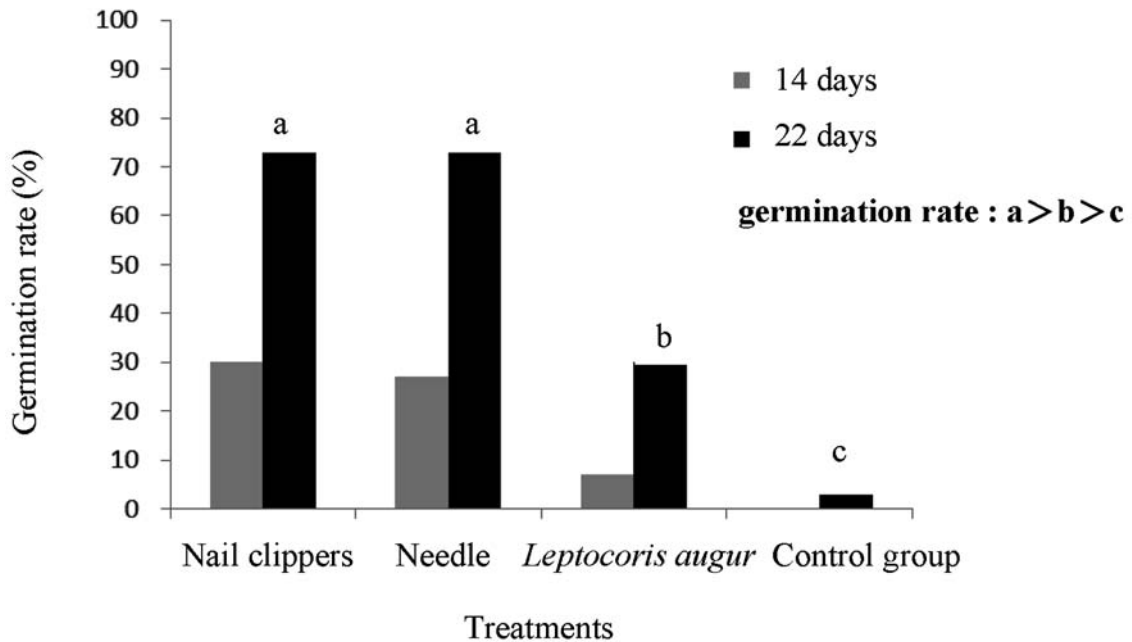


圖 5. 經不同處理後倒地鈴種子的發芽率。

Fig. 5. The germination rates of heartseed vine seeds with wounds from different treatments.

討 論

倒地鈴棲地出現小紅姬綠椿象聚集的機率很高，有八成以上(83%)。有些地區，如太保市，出現率更高達 100%。小紅姬綠椿象具有特殊吸食口器，可突破倒地鈴的種子防衛。吸食不同植物種子的椿象，會因不同植物種子防衛程度的不同，而演化出不同長度的口器(Carroll

et al. 1998)。小紅姬綠椿象的生活，明顯依賴倒地鈴棲地。

倒地鈴種子提供小紅姬綠椿象作為專一的食物來源，經過小紅姬綠椿象吸食後，倒地鈴的硬殼種子發芽率顯著增加。與對照組相比，完整果莢(whole pods)經小紅姬綠椿象吸食，確定有被吸食的種子，發芽率於 14~42 天間，可提高 3.2~6.0 倍(表 1)。如以撕開果莢(torn

Pods)的70顆種子連續飼養5天後，種子發芽率於14~42天間，則可提高2.6~9.0倍(表1)。這個結果與澳洲椿象吸食寄主植物草棉種子，促使發芽率提升2~3倍相似(Karban and Lowenberg 1992)。然而，小紅姬緣椿象可使其寄主植物倒地鈴種子發芽率的提升，似乎更顯著，最高可達9倍(表1)。

倒地鈴種子，受吸食過後，發芽率提升的機制，類似對種皮的物理傷口，以縫衣針或指甲剪處理亦得類似結果，透過種皮傷口增加種子的吸水量(圖4和表2)。隨著種子吸水量的增加，種子的發芽率提升(圖5)(Takakura 2002)。

專食性昆蟲的吸食，雖可破除種皮的物理休眠，但可能對種子造成致命傷害。寄主植物種子被食用，不僅未必可提升發芽率，更可能會因此受傷而無法發芽。有些研究指出可提升寄主植物發芽率的種子，其重量都是大於5g(Tomaz *et al.* 2007)。倘若是小於0.01g的種子，如含羞草(*Mimosa bimucronata*)的種子，其種子胚芽容易被植食性昆蟲損傷(Takakura 2002)。

倒地鈴雖然種子很小，平均重量每顆0.05g，但被小紅姬緣椿象吸食過後發芽率明顯提升。檢驗野外隨機採集的倒地鈴種子，發現有近八成(78.2%)的種子只被刺吸一針或兩針，且刺吸的位置對於胚的傷害不大。倒地鈴種子被吸食過後，可顯著促進發芽率，可能是目前已知最小種子之一(Takakura 2002)。

小紅姬緣椿象與其寄主植物倒地鈴，兩者顯現植物與植食昆蟲對抗(plant-herbivore antagonism)的互利共生關係。植物與植食昆蟲的共生關係有三種形式，植物與授粉昆蟲的互利共生(plant-pollinator mutualism)、植物與植食昆蟲對抗的互利共生(plant-herbivore antagonism)及過補償的演化現象(the evolution of overcompensation)(Järemo *et al.* 1999)。椿象與其寄主植物，兩者可能是經過武器競賽演化(evolutionary arms race)的結果(Carroll *et al.* 1998; Takakura

2002)。小紅姬緣椿象的口器突破倒地鈴種子的防衛，促進發芽率可能是附帶結果。

野外調查發現少數小紅姬緣椿象可能會出現在台灣欒樹棲地，與大量的另一種椿象，大紅姬緣椿象(*Leptocoris abdominalis*)混居。但是倒地鈴棲地卻只有小紅姬緣椿象聚集，沒有大紅姬緣椿象。初步調查發現這種現象和小紅姬緣椿象的口器長度顯著大於大紅姬緣椿象有關，倒地鈴果莢成熟時具有充氣莢膜，需較長的口器才能刺吸到種子。大紅姬緣椿象的口器可能不夠長，因此只能吸食成熟後會裂開果莢的種子(台灣欒樹)。美國的無患子椿象(soapberry bug, *Jadera haematoloma*)，因引入3種外來無患子科寄主植物，發現其可能於20~50年(40~150世代)間，就產生其口器長度因吸食不同果實而有適應性輻射演化(adaptive radiation)的現象(Carroll and Boyd 1992)。另一方面，台灣欒樹一年只結果一次，倒地鈴則是一年四季皆可形成種子。野外觀察發現大紅姬緣椿象以成蟲滯育的方式度過種子較少的時期，但無論是棲息於台灣欒樹上，或是於倒地鈴的小紅姬緣椿象都沒有發現成蟲滯育現象。大紅姬緣椿象與小紅姬緣椿象明顯有不同生活策略適應環境，以及其口器與不同寄主植物間的適應關係，值得進一步研究。

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引用文獻

- 呂廷森、黃俊凱。2008。倒地鈴種子發芽處理及盆栽化。臺灣園藝 54: 183-188。
- 陳衍伶、黃冠瑋、蔡智賢。2009。刻傷處理打破黃花刺梨種子休眠。華岡農科學報 23: 1-8。
- 劉守華。2006。不同類型玉米種子萌動吸水影響因素及其特點。瀋陽農業大學學報 37: 642-644。
- 劉和義、楊遠波、呂勝由、施炳霖。1998。臺灣維管束植物簡誌第三卷。行政院農業委員會。台北。
- Baskin, C. C. and J. M. Baskin. 1998. Seeds: ecology, biogeography, and evolution of dormancy and germination. Academic Press, San Diego.
- Bommireddy, P., B. Leonard and J. Temple. 2007. Influence of *Nezara viridula* feeding on cotton yield, fiber quality, and seed germination. Journal of Economic Entomology 100: 1560-1568.
- Carroll, S. P. and C. Boyd. 1992. Host race radiation in the soapberry bug: natural history with the history. Evolution 46: 1052-1069.
- Carroll, S. P., S. P. Klassen and H. Dingle. 1998. Rapidly evolving adaptations to host ecology and nutrition in the soapberry bug. Evolutionary Ecology 12: 955-968.
- Järemo, J., J. Tuomi, P. Nilsson and T. Lennartsson. 1999. Plant adaptations to herbivory: mutualistic versus antagonistic coevolution. Oikos 84: 313-320.
- Karban, R. and G. Lowenberg. 1992. Feeding by seed bugs and weevils enhances germination of wild *Gossypium* species. Oecologia 92: 196-200.
- Newton, P. 1984. A feeding association between a heteropteran bug and langurs. Journal of Bombay Natural History Society 81: 180-181.
- Pagano, M. and K. Gauvreau. 2000. Principles of biostatistics. Duxbury Thompson Learning, Australia.
- Schaefer, C. W. and J. Kotulski. 2000. Scentless plant bugs (Rhopalidae). pp. 309-319. In: C. W. Schaefer and A. R. Panizzi (eds.). Heteroptera of Economic Importance. Boca Raton, CRC Press. 828pp.
- Takakura, K. 2002. The specialist seed predator *Bruchidius dorsalis* (Coleoptera: Bruchidae) plays a crucial role in the seed germination of its host plant, *Gleditsia japonica* (Leguminosae). Functional Ecology 16: 252-257.
- Tomaz, C. A., D. Kestring and M. N. Rossi. 2007. Effects of the seed predator *Acanthoscelides schrankiae* on viability of its host plant *Mimosa bimucronata*. Biological Research 40: 281-290.
- Zink, A. G. and J. A. Rosenheim. 2005. Stage dependent feeding behavior by western tarnished plant bugs influences flower bud abscission in cotton. Entomologia Experimentalis et Applicata 117: 235-242.

Using Species Distribution Models to Assess the Rarity and Conservation Status of Taiwanese Birds

運用物種分布預測模式評估臺灣繁殖鳥類的稀有度及保育現狀

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Abstract

Taiwan's unique biodiversity is threatened by regional and global change. Therefore, there is an urgent need for improved monitoring and assessment of its flora and fauna. Here, we used a recently established database (1) to build distribution models of most of Taiwan's breeding birds, (2) to use these models to establish a measure of each species' coverage of the study area (called quartile rarity) and (3) to compare this new measure to two already established measures of species' status: namely, recorded rarity as scored by the Chinese Wild Bird Federation (2010) and Taiwanese conservation status as determined by the Council of Agriculture of Executive Yuan (2009). We found that there is a correlation between each species' coverage of the study area, recorded rarity and Taiwanese conservation status.

However, much variation remains unexplained. We focused on those species where there are discrepancies in status assessments between these three measures to be able to better assess the status of each bird species as well as to better monitor these species in the future. We also investigated the relationship of endemic status to the three species status measures: endemic status was not significantly related to the two measures of rarity, but had a significant association with conservation status. We recommend further studies exploring the wealth of biodiversity data now available on Taiwan's avifauna.

摘 要

由於臺灣的生物多樣性受到地區性與全球變遷的威脅，改善評估臺灣動植物現況的方式為當務之急。本文以近期建立的臺灣繁殖鳥類分布資料庫(1)建構臺灣繁殖鳥類的分布預測模式，(2)由模式預測結果建立新的評估標準「四分位數稀有度」，(3)比較「四分位數稀有度」與現存評估標準(包括由中華民國野鳥學會提供之「紀錄稀有度」與行政院農業委員會野生動物保育名錄之「保育等級」)。我們發現各鳥種在臺灣分布面積與紀錄稀有度、保育等級相關，然而三者間仍存在部分變異，因此進一步檢視在此三項標準間存在變異的鳥種。本研究並非意圖批評現存的標準，而是希望藉由檢視三項標準間的異同以評估物種狀態，並在未來提供更好的監測方式。此外，本文亦評估了特有狀態與前述三項標準的關係，但特有性與三者皆無顯著相關。我們建議未來可有更多研究善加利用已經建置且數量豐富的臺灣鳥類生物多樣性資料。

Key words: biodiversity, conservation priorities, GIS, sampling effort, endemism

關鍵詞：生物多樣性、保育優先性、地理資訊系統、調查努力量、特有性

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Introduction

The conservation of biodiversity has gained increasing attention from both the public and decision-makers because biodiversity is the basis for functioning ecosystems and the life-support system of the earth.

Ecosystem services have increasingly been

recognized as important to society both for the inherent value of the continuing existence of species and for their functional and economic value, such as to filter out pollution or to foster ecotourism (Millennium Ecosystem Assessment 2005). However, all levels of biodiversity have been rapidly eroding, despite repeated international and national pledges and efforts to halt the global,

regional and local decline of biodiversity (Butchart *et al.* 2010).

Taiwan is an important biodiversity hotspot of endemism for many taxa, including birds. Although Taiwan has a network of relatively well-protected areas, it also faces multiple challenges to its biodiversity due to unsustainable economic growth and its environmental consequences. Therefore, efforts to increase biodiversity monitoring and assessment of Taiwan's flora and fauna are urgently needed.

One of the most visible and well-documented taxa of Taiwan's fauna is its avifauna, with 589 bird species having been recorded in all of Taiwan, including its outlying islands (Chinese Wild Bird Federation 2011) of which 145 species are breeding birds from the island of Taiwan alone (Fang 2008). Recently, the first comprehensive avifauna of Taiwan was published (Severinghaus *et al.* 2010). Constant-effort monitoring schemes have also been set up, such as the Taiwan breeding bird survey (BBS Taiwan) (Lee *et al.* 2010), the monitoring avian productivity and survivorship in Taiwan (MAPS Taiwan) project which maintains constant effort mist-netting and banding sites (Lin and Chen 2011), and species-specific monitoring programs for the black-faced spoonbill *Platalea minor* (Yu 2010), Ryukyu scops-owl *Otus elegans* (Severinghaus 2007) and fairy pitta *Pitta nympha* (Lin 2011). As a consequence, more and more information is now available to assess the status of Taiwan's bird species pertaining to their rarity and threat of extinction (Council of Agriculture of Executive Yuan 2009; Chinese Wild Bird Federation 2010; Severinghaus *et al.* 2010).

With the growing availability of locational databases on Taiwanese birds, there is also a growing need to analyze this information. Previous

studies focused on species richness patterns in a specific local region (Hsu *et al.* 2004; Ko 2004; Peng 2008), Taiwan's mountains (Shiu and Lee 2003), or all of Taiwan (Lee *et al.* 2004). Species distribution models were used to study bird distributions only in a local region (Huang 2001; Koh *et al.* 2006a; Koh *et al.* 2006b) or of a single species or subfamily (Liao 1997; Ko *et al.* 2009a). Ho (2005) and Ding *et al.* (2006) selected avian biodiversity hotspots and studied bird species richness patterns in East Asia but did not focus on Taiwan. A hotspot analysis using Taiwan's birds was restricted to 14 out of the 17 endemic bird species (Ko *et al.* 2009b). We recently build distribution models for most of Taiwan's breeding birds to reassess the conservation status of Taiwanese birds and to calculate how well their distributions are covered by Taiwan's protected areas network (Wu *et al.*, In preparation). As rarity is one of the important categories for determining the conservation status of a species (Mace and Lande 1991), we use these distribution models to calculate a new measure of rarity (called quartile rarity) and compare it to two other already established measures used to assess the status of Taiwan's bird species.

Methods

Study area

The study area was the island of Taiwan that is situated at latitudes 21°54'N to 25°18'N and longitudes 120°27'E to 122°E with the maximum elevation of 3,952m. Its climate ranges from tropical in the south to subtropical in the north and alpine in the high mountains. The mean annual temperature is 18.0°C which decreases by -5.43°C/km in elevation (Su 1984). The average annual

precipitation is 2510 mm. The natural vegetation is almost exclusively forest, with great variation due to variable topography and human influences which have dramatically changed many of Taiwan's landscapes. We divided the study area into a total of 36,022 grid pixels, each in size of 1 km x 1 km.

Data collection and compilation

For this study, we selected the 145 bird species that are listed as breeding species on the island of Taiwan (Fang 2008). To determine the status of each species regarding its endemism, rarity, and global and Taiwanese conservation status, a variety of sources were consulted (Appendix 1). Distributional data for these bird species were derived from the following sources to build the first comprehensive distributional dataset of the breeding birds of Taiwan:

- (1) Data collected from 1993 to 2004 from each of Taiwan's counties collected by the Endemic Species Research Institute (ESRI) and local wild bird societies during a series of research projects. Data were collected along road segments of 2 to 3 km length that were covered during a 2-hour walk in the morning within 3 to 4 hours after sunrise and sampled once a season to once a month.
- (2) Data collected from 1999 to 2003 by the biological resources survey of Taiwan which was organized by the Spatial Ecology Lab of National Taiwan University (Koh *et al.* 2006a). Data were collected during 6 minutes point counts at a distance of 150 meters from each other along road segments of 1 to 2 km length (with 5 to 10 points as replications in each road segment) that were covered during a 3-hour walk after sunrise. Each segment was surveyed once.
- (3) Data collected by P.-F. Lee during the investigation of the current status of the Lanyang River system for the Water Resources Planning Institute which is part of the Ministry of Economic Affairs (MOEA). Data were collected by professional researchers once during each of the four seasons using the point count method. Seven sites were covered in 2002, and another seven in 2003. At each site, an observer walked along a river road and made 6 minute point counts at 200-meter intervals, and then, on the return walk, repeated each count. The counts were done once in the morning and once in the afternoon.
- (4) Data collected by P.-F. Lee and Chie-Jen Ko in Shei-Pa National Park, including the Kuanwu Recreation Area (Ko 2004), and the Xuejian Recreation Area. 47 sites in Shei-Pa and Kuanwu were censused three times during the 2003 breeding season, and 46 sites in Xuejian were censused three times during the 2004 breeding season.
- (5) Data collected in Taroko National Park by Peng (2008) using the point count method twice a month from April 2006 to March 2007 at 74 sites.
- (6) Data collected by Wen-Jay Chih, Chie-Jen Ko and Man-Yu Yang from the Szu-Tsao area for the Ecological Monitoring of Tainan Technology Industrial Park research project in 2008. Data were collected by making total counts of birds resting and feeding on a large number of salt pans and fish ponds.

For each record, the following information was entered by T.-Y. Wu into a database: (1) Latin binomial name; (2) number of individuals recorded if available, otherwise only presence recorded; (3) collection time (day, month and year); (4) ge-

ographical coordinates of collection localities; and (5) data sources.

We restricted records to those from the months of March to July, as this period corresponds to the main breeding season of most species. We excluded those species for which < 30 grid cells had been coded as present because distribution models usually do not perform well at low sample sizes (Stockwell and Peterson 2002; Wisz *et al.* 2008). Excluding those species with small sample sizes left us with 116 species (Appendix 1) with a total of 33,785 presence records within the 1 x 1 km grid and 2,455 grid cells containing one or more species.

Building distribution models

For each of the 116 selected species, we used its presence records to build a distribution model, which is a probabilistic map of the likelihood of the species' presence or absence within the study area. To build the models, 120 environmental data layers compiled by the Spatial Ecology Laboratory of National Taiwan University were used (for details, Lee *et al.* 1997) which were updated in 2008 by the same lab. These environmental data layers fell into 8 categories and covered the entire island of Taiwan with 36,022 1x1 km grid pixels, with all the layers overlaying perfectly.

We used a two-tailed *t-test* to test each of the selected environmental variables for significant association ($p < 0.05$) with the presence or absence of the species. Only significantly associated variables were retained. An Unweighted Pair Group Method with Arithmetic Mean (UPGMA) Tree in Ecological Niche Factor Analysis (ENFA) was run to avoid autocorrelation between the remaining variables. If two variables were correlated at a correlation coefficient > 0.9 , one of them was

randomly chosen and used for building the distribution model. The variables remaining after this selection were used to build the distribution models for each species.

The following five methods were used to build distribution models for each species: multiple discriminant analysis (Johnson and Wichern 1998), ecological niche factor analysis (Hirzel *et al.* 2002; Hirzel *et al.* 2004), genetic algorithm for rule-set production (Stockwell and Noble 1992; Stockwell 2005), logistic regression (Guisan and Zimmermann 2000; Austin 2002) and maximum-entropy (Phillips *et al.* 2006; Phillips *et al.* 2009). The three best performing models for each species based on their respective AUC (area under an ROC curve) scores (which is a generally accepted method of ranking model performance) were chosen. These three selected models were then summed up to derive one distribution model for each species (see Appendix 1 for the models selected for each species).

Finally, we deleted overpredicted areas for 11 of the 116 species by comparing our modelled distributions with published distribution maps (Severinghaus *et al.* 2010). Any region of Taiwan where the species had never been observed was converted into absence by using a variety of appropriate shape files (elevation, ecoregions, counties). These 'final maps' were used for all further analyses.

We categorized each species into one of four quartile categories whereby first, second, third and fourth quartile species correspond to the modeled distribution of the respective species covering 0-25%, 25-50%, 50-75% and 75-100% of all pixels of our study area, respectively (corresponding to almost 9,006 pixels or 9,006 km² per quartile). Appendix 1 gives the exact percentage

coverage for each species; note that none of the species fell exactly on the 25%, 50% and 75% dividing line. This categorical measure is called ‘quartile rarity’ from hereupon, in contrast with ‘recorded rarity’ which is a categorical measure established by the Chinese Wild Bird Federation (2010) where each species is categorized as rare (the respective bird species was recorded in < 20% of suitable habitats), uncommon (the respective bird species was recorded 20-70% of suitable habitats) or common (the respective bird species was recorded in > 70% of suitable habitats). Scores of recorded rarity were published by Severinghaus *et al.* (2010) and the Chinese Wild Bird Federation (2010), but the latter used more recent information (T.-S. Ding, personal communication 2011). Differences between these two assessments were minimal: the slaty-legged crane *Rallina eurizonoides* and the collared owlet *Glaucidium brodiei* were scored uncommon by the Chinese Wild Bird Federation (2010), but rare and common, respectively, by Severinghaus *et al.* (2010). As we did not model the slaty-legged crane due to its insufficient sample size (Appendix 1), the only difference relevant to our study is the different scores for the collared owlet. Therefore, we decided to use only the more recent assessment of recorded rarity (Chinese Wild Bird Federation 2010) for all 116 species.

The conservation status of each of Taiwan’s bird species was categorized by the Council of Agriculture of Executive Yuan (2009). The three measures of each species’ status, namely, quartile rarity, recorded rarity and conservation status, are given for each bird species in Appendix 1.

Results

Status of Taiwanese breeding birds

Appendix 1 lists the 145 known breeding bird species of Taiwan, but it does not include the > 30 invasive species which now regularly breed in Taiwan (Fang 2008; Chinese Wild Bird Federation 2010, 2011; Walther 2011). 17 species have full endemic status, 62 species are recognized endemic subspecies, and the remaining 66 species are not endemics. Only 7 out of the 145 species are listed as globally threatened: 5 as near-threatened, and the fairy pitta and Styan’s bulbul *Pycnonotus taiwanus* as vulnerable. However, more species are considered threatened within Taiwan: 5 are listed as endangered (Australasian grass-owl *Tyto longimembris*, black eagle *Ictinaetus malayensis*, mountain hawk-eagle *Nisaetus nipalensis*, black-naped oriole *Oriolus chinensis*, russet sparrow *Passer rutilans*), 33 as rare and valuable, and 11 as other conservation-dependent species, with the remaining 96 species not considered threatened within Taiwan. 26, 30 and 89 species were recorded as rare, uncommon and common, respectively. Considering quartile rarity, 22, 50, 35 and 9 species fell into the first, second, third and fourth quartile, respectively (note that the remaining 29 species were not modeled and therefore not categorized for ‘quartile rarity’).

Comparison among the species status measures

We used quartile rarity as one of the measures to reassess the conservation status of Taiwanese birds and to calculate how well their distributions are covered by Taiwan’s protected areas network (Wu *et al.*, In preparation). In this paper, we explored where there are inconsistencies between the three species status measures.

We first compared quartile rarity with recorded rarity, and then compared them with the birds' conservation status. Species recorded as rare fell only into the first or second quartile (Fig. 1) whereby the two bird species falling into the second quartile were the little forktail *Enicurus scouleri* and the yellow tit *Macholophus holsti*. Uncommon species fell only into the first, second and third quartile whereby the two species falling

into the first quartile were the cinnamon bittern *Ixobrychus cinnamomeus* and the crested myna *Acridotheres cristatellus* and the two species falling into the third quartile were the Taiwan partridge *Arborophila crudigularis* and the white-tailed robin *Cinclidium leucurum*. Common species fell into all four quartiles, with 16 species falling into the first quartile and 29 species falling into the second quartile.

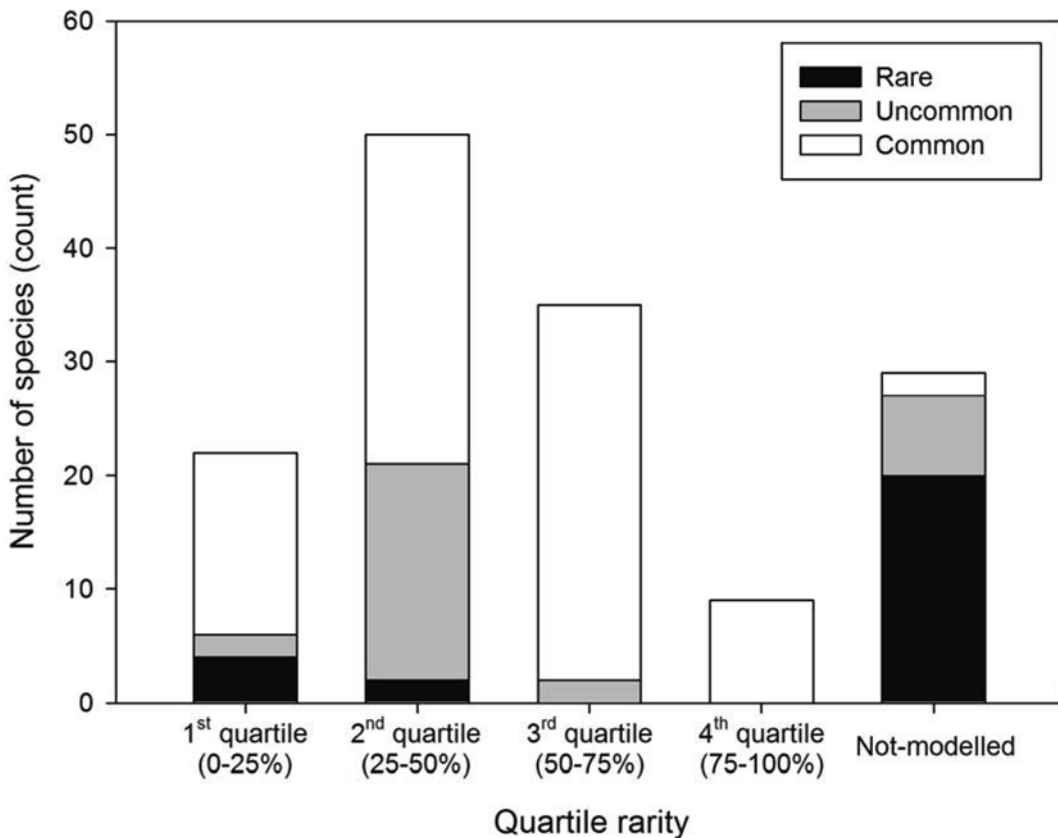


Fig. 1. Comparison of quartile rarity versus recorded rarity of 116 Taiwanese bird species (likelihood ratio chi-square, $G^2 = 28.59$, $n = 116$, $df = 6$, $p < 0.0001$). Quartiles 1-4 correspond to the percentage coverage of the study area by each species; 'Not-modelled' means the sample size was insufficient to model the species' distribution (Methods and Appendix 1).

Substituting categorical scores (rare = 1, uncommon = 2, common = 3) for recorded rarity and percent coverage of study area (Appendix 1) for quartile rarity, recorded rarity and percent coverage of study area were also significantly correlated, but with much unexplained variation remaining (Spearman-Rank test, $n = 116$, $Z = 4.57$, Rho corrected for ties = 0.28, $p < 0.0001$).

Comparing recorded rarity with Taiwanese conservation status (Fig. 2), we found that the distribution of conservation status categories were not distributed randomly amongst the three categories of recorded rarity. Endangered species only fell into the rare category, and rare and valuable species were least prevalent in the common category. However, other conservation-dependent species increased in prevalence from rare to common, as did the non-threatened species. Surprisingly, some rare and valuable species fell into the common category.

Comparing quartile rarity with Taiwanese conservation status (Fig. 3), we found that endangered species were found only in the first quartile, while other conservation-dependent species appeared in all quartiles except the fourth quartile. Rare and valuable species, meanwhile, appeared in all quartiles, but at a much higher percentage in the first and second quartile. The distribution of these categories was not significantly different from random.

Plotting the number of recorded pixels versus recorded rarity showed an overall positive relationship (Fig. 4 A), but it was also evident that many of the species recorded as uncommon or common were only recorded in relatively few pixels in our database. Plotting the number of predicted pixels versus recorded rarity showed a similar positive relationship (Fig. 4 B) but with

even more unexplained variation.

We finally compared endemic species status with the two categories of rarity and Taiwanese conservation status. Neither measure of rarity was significantly associated with endemic species status (Figs 5-6). All three categories of endemism were found within the three categories of recorded rarity (Fig. 5). For quartile rarity, however, there were no endemic species in the fourth quartile (Fig. 6). Endemism was not distributed randomly amongst the four categories of Taiwanese conservation status (Fig. 7). Endemic species were found in all categories except the endangered category, while endemic subspecies and non-endemic species were found in all four categories of threatened status.

Discussion

Recently, species distribution models have become an important tool in conservation biology because they usually allow a much better approximation of the true species distribution than the old-fashioned dot or range maps. These models have another advantage because they provide a more realistic estimate of the extent of occurrence, which is “the area contained within the shortest continuous imaginary boundary which can be drawn to encompass all the known, inferred or projected sites of present occurrence of a taxon” (IUCN Standards and Petitions Subcommittee 2010).

In this study, we estimated the extent of occurrence based on our distributional models for 116 species of Taiwanese breeding birds. As the models were based on a 1 x 1 km grid, the number of predicted pixels (Appendix 1) equals the number of square kilometers which equals the size of that

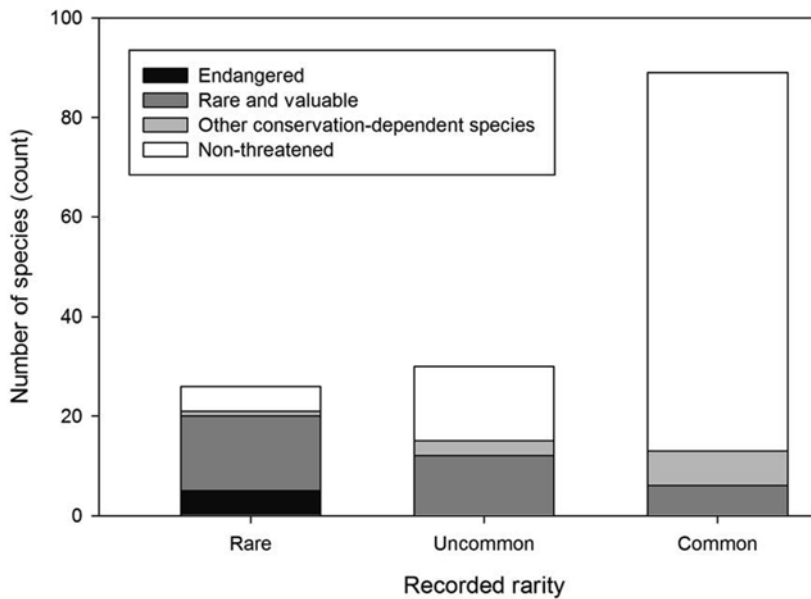


Fig. 2. Comparison of recorded rarity versus Taiwanese conservation status of 145 Taiwanese bird species (likelihood ratio chi-square $G^2 = 61.17$, $n = 145$, $df = 6$, $p < 0.0001$).

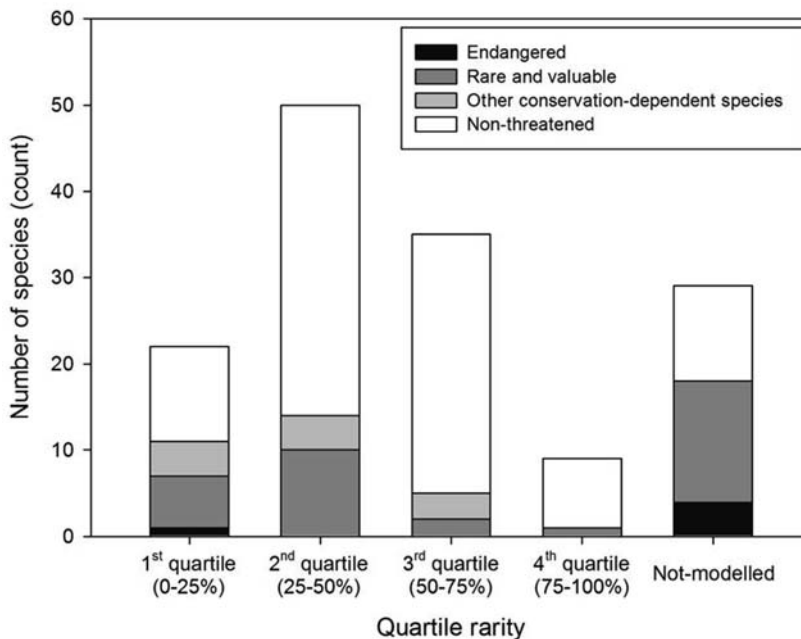


Fig. 3. Comparison of quartile rarity versus Taiwanese conservation status of 116 Taiwanese bird species (likelihood ratio chi-square $G^2 = 12.74$, $n = 116$, $df = 9$, $p = 0.17$). Quartiles 1-4 correspond to the percentage coverage of the study area by each species; 'Not-modelled' means the sample size was insufficient to model the species' distribution (Methods and Appendix 1).

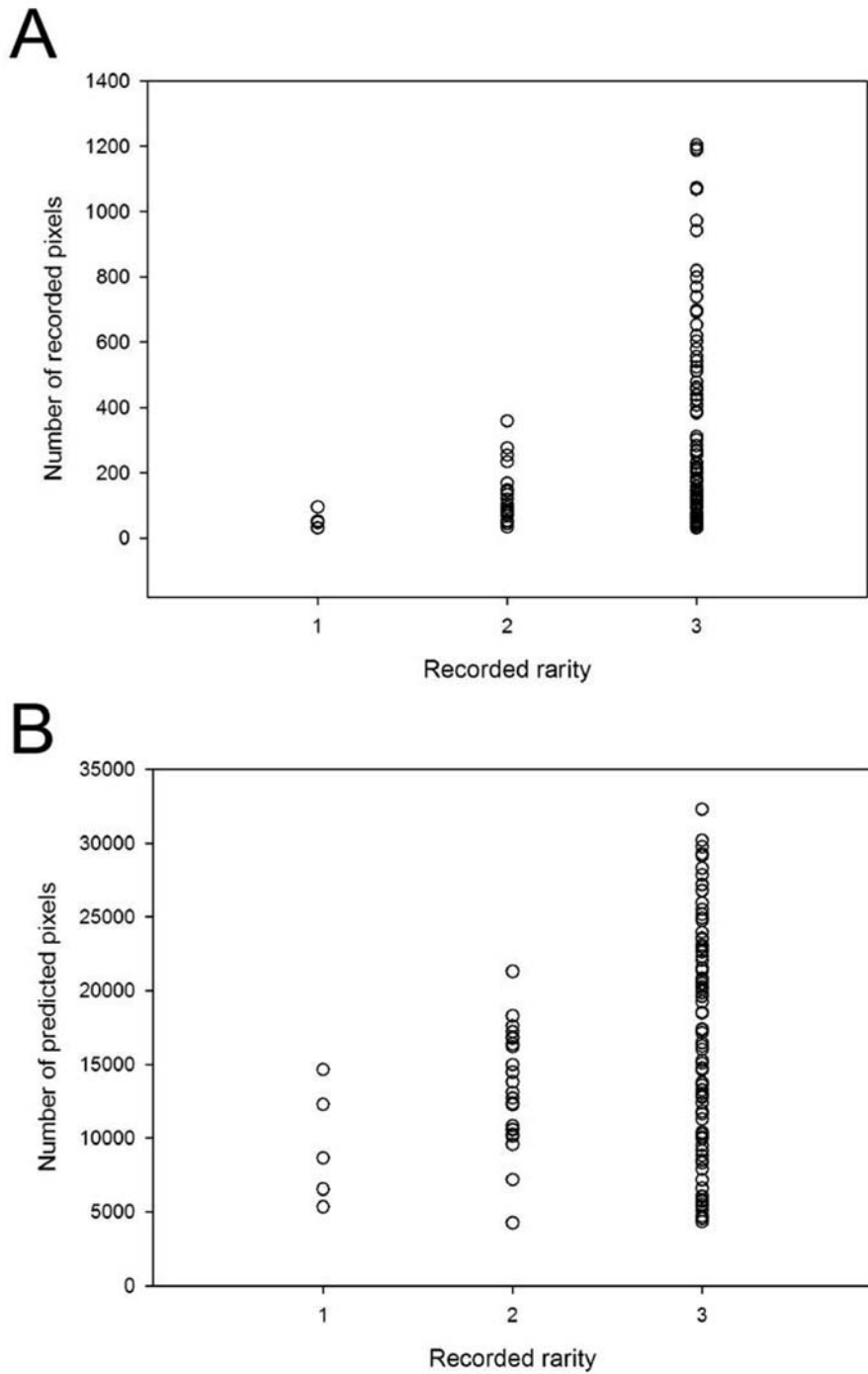


Fig. 4. Relationship between recorded rarity (rare = 1, uncommon = 2, common = 3) and: (A) the number of recorded pixels within our database (Spearman-Rank, $n = 116$, $Z = 8.77$, Rho corrected for ties = 0.70, $p < 0.0001$); (B) the number of predicted pixels within our database (Spearman-Rank, $n = 116$, $Z = 4.57$, Rho corrected for ties = 0.28, $p = 0.003$) of 116 Taiwanese bird species.

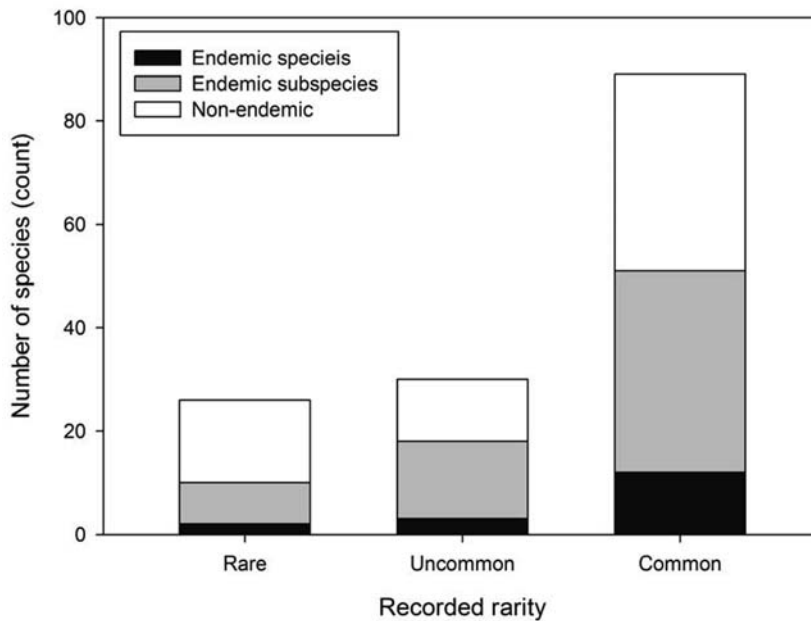


Fig. 5. Comparison of recorded rarity versus Taiwanese endemic status of 145 Taiwanese bird species (likelihood ratio chi-square $G^2 = 3.74$, $n = 145$, $df = 4$, $p = 0.44$).

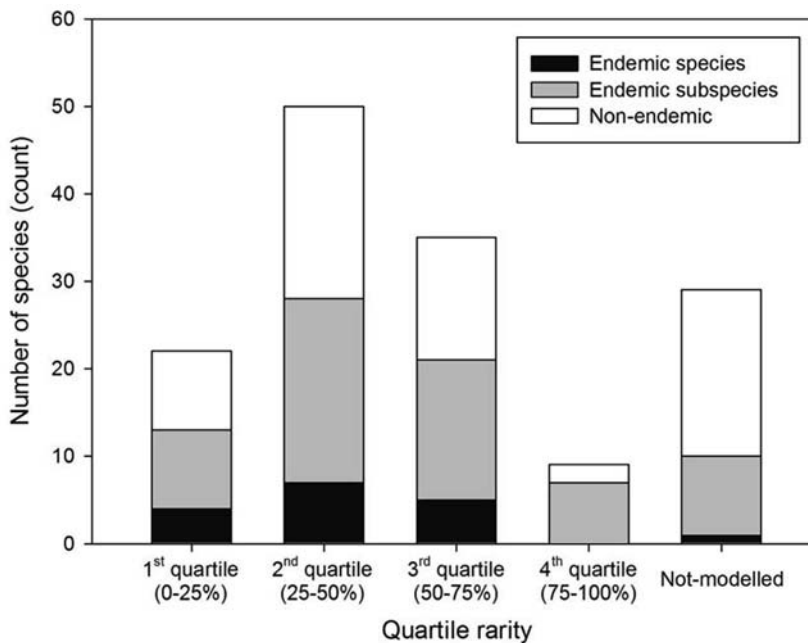


Fig. 6. Comparison of quartile rarity versus Taiwanese endemic status of 116 Taiwanese bird species (likelihood ratio chi-square $G^2 = 5.04$, $n = 116$, $df = 6$, $p = 0.54$). Quartiles 1-4 correspond to the percentage coverage of the study area by each species; 'Not-modelled' means the sample size was insufficient to model the species' distribution (Methods and Appendix 1).

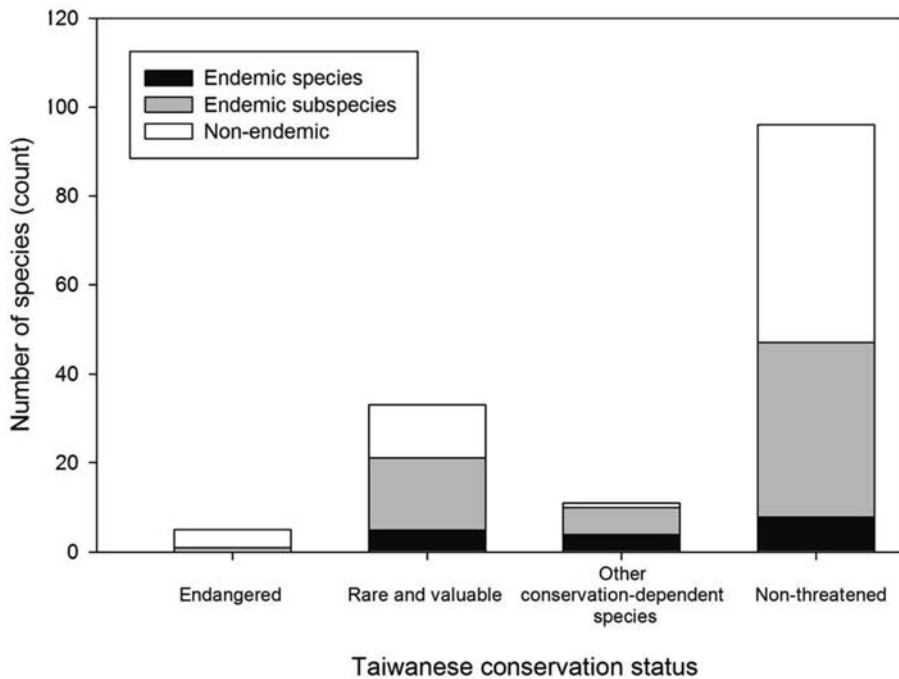


Fig. 7. Comparison of Taiwanese conservation status versus endemic species status of 145 Taiwanese bird species (likelihood ratio chi-square $G^2 = 14.16$, $df = 6$, $n = 145$, $p = 0.03$).

species' extent of occurrence. This continuous measure was transformed into a categorical measure called quartile rarity in order to compare it with two previously established measures, recorded rarity and Taiwanese conservation status. The reason for doing so is not to criticize these two already established measures, but rather to highlight where these measures agree and where they differ in assessing a species' status. Such comparisons should help us to better determine the status of each bird species as well as to better monitor these species in the future.

The general impression from our results is that the extent of occurrence (measured continuously as the number of predicted pixels and the percentage coverage of the study area or categorically as quartile rarity), recording frequency (measured

as both recorded rarity or recorded pixels) and Taiwanese conservation status are all correlated to some extent, but often which much variation left unexplained. As this overall result is to be expected, what we should focus on is the remaining unexplained variation.

For example, it should be worthwhile to look closer at species which are first-quartile species but which were recorded as common (Fig. 1) or as non-threatened (Fig. 3). In Wu *et al.* (In preparation), all those species were listed which are first quartile species as well as those species that are not well covered by protected areas in order to draw more attention to them.

Here, we want to draw attention to those 16 species (yellow bittern *Ixobrychus sinensis*, Malayan night-heron *Gorsachius melanolophus*,

ruddy-breasted crane *Porzana fusca*, greater painted-snipe *Rostratula benghalensis*, Oriental pratincole *Glareola maldivarum*, collared scops-owl *Otus lettia*, Eurasian magpie *Pica pica*, Eurasian nutcracker *Nucifraga caryocatactes*, coal tit *Periparus ater*, Styan's bulbul, Taiwan bush-warbler *Bradypterus alishanensis*, streak-throated fulvetta *Alcippe cinereiceps*, flamecrest *Regulus goodfellowi*, winter wren *Troglodytes troglodytes*, collared bush-robin *Tarsiger johnstoniae*, vinaceous rosefinch *Carpodacus vinaceus*) which are first quartile species but were recorded as common (Fig. 1). As the definition of common is "the respective bird species was recorded in > 70% of suitable habitats" (Appendix 1), we suggest that these suitable habitats may be relatively rare within the entire study area (i.e. mainland Taiwan) but relatively common within their respective ecoregions (e.g., high elevation species such as Eurasian nutcracker, coal tit, Taiwan bush-warbler, streak-throated fulvetta, flamecrest, winter wren, collared bush-robin and vinaceous rosefinch).

An alternative explanation is that some of our modeled distributions or underlying data sources are in need of improvement. For example, the Malayan night-heron and collared scops-owl are common in Taiwan's lowland areas within suitable habitats. However, the distribution model shows the Malayan night-heron to be common only in the central lowlands (Wu *et al.*, In preparation). Therefore, this species may be under-predicted by our distribution model because this species has recently become accustomed to human habitations. The Malayan night-heron was, until recently, only found in lowland forests where it was rare (Wang 1991) and secretive (Fang 2008). Recently, however, it has invaded all sorts of

urban parks, gardens and even small traffic islands in the middle of busy roads in Taipei (Lin *et al.* 2008; personal observations). As our database does not include such recent records, the Malayan night-heron's rapid expansion into human-dominated landscapes has not yet been included in our distribution maps.

A likely reason for underestimating the collared scops-owl's distribution could simply be that it is a nocturnal species, and since most of our data was collected during daylight, the collared scops-owl was most likely under-recorded. In Wu *et al.* (In preparation), we further suggest that the modeled distributions of four of the wetland species (specifically, yellow bittern, ruddy-breasted crane, greater painted-snipe, Oriental pratincole) may have been underestimated because of the lack of variables related to rivers or wetlands in our environmental data. Therefore, such variables should be added to the analysis, although additional locational data for these species are also needed.

The Eurasian magpie poses an interesting example of a species now common in urbanized areas, which was modeled to be mostly present in the urbanized areas of northwestern and southwestern Taiwan (Wu *et al.*, In preparation). Apparently, this species was originally only common in southern Taiwan (Swinhoe 1863) and later spread to the central-western and north-western regions where it is now common in urban areas, especially in park-like landscapes (Lin 1997). Meanwhile, its abundance apparently declined in the southern parts (Severinghaus *et al.* 2010; personal observations). Therefore, the Eurasian magpie can be considered common in its limited urban habitat, but rare within the entire study area. Likewise, the Styan's bulbul is very common in the eastern region of Taiwan, but is

also considered to be rare within all of Taiwan, possibly due to competition with the light-vented bulbul.

The usefulness of our distribution models is to throw up the question of whether the model's database, assumptions and methodology need to be improved, or whether other assessments of the species' status need to be reassessed (this study, Wu *et al.*, In preparation). This evaluation needs to be done on a species-by-species basis.

Of the 16 species mentioned above, six are categorized as threatened in Taiwan, but the other 10 species are considered non-threatened; given their restricted distributions, their status may also need to be reassessed. Furthermore, 10 of these species are endemic species or subspecies, further emphasizing their conservation value. On the other hand, the Taiwan partridge and the white-tailed robin were recorded as uncommon but are third quartile species (Fig. 1). As the definition of uncommon is "the respective bird species was recorded 20-70% of suitable habitats" (Appendix 1), we suggest that these suitable habitats are relatively widespread but that the species only infrequently occupies it or is recorded in it (Discussion below).

Similarly, there are five species (water rail *Rallus aquaticus*, watercock *Gallicrex cinerea*, small buttonquail *Turnix sylvaticus*, golden parrotbill *Paradoxornis verreauxi*, chestnut munia *Lonchura atricapilla*) which were recorded as rare but are considered non-threatened and 13 species (crested serpent-eagle *Spilornis cheela*, crested goshawk *Accipiter trivirgatus*, greater painted-snipe, Oriental pratincole, mountain scops-owl *Otus spilocephalus*, collared scops-owl, Formosan magpie *Urocissa caerulea*, green-backed tit *Parus monticolus*, coal tit, Styan's bulbul, Taiwan barwing *Actinodura morrisoniana*,

flamecrest, plumbeous redstart *Rhyacornis fuliginosa*) recorded as common but considered either rare and valuable or conservation-dependent species (Fig. 2).

Finally, there are 11 species (yellow bittern, cinnamon bittern, Malayan night-heron, ruddy-breasted crake, Eurasian Magpie, Eurasian nutcracker, Taiwan bush-warbler, streak-throated fulvetta, winter wren, collared bush-robin, vinaceous rosefinch) which are first quartile species but are considered non-threatened (Fig. 3). On the other hand, there are five third quartile species (Taiwan partridge, crested goshawk, mountain scops-owl, plumbeous redstart, white-tailed robin) and one fourth quartile species (crested serpent-eagle) which are considered threatened (Fig. 3). The reasons for their threatened status despite being widespread are various, although the particular reasons are not specified within the relevant document (Council of Agriculture of Executive Yuan 2009). Here, we briefly discuss these six species.

The Taiwan partridge is an endemic species, but little research has been done concerning the effects of hunting pressure or habitat loss (Severinghaus *et al.* 2010). Fang (2008) suggested the main pressure is habitat loss while tourism in forests and pesticides could also negatively influence this species. It may also be under-recorded because of its secretive behavior.

The crested goshawk is an endemic subspecies. Although it has adapted to human-influenced areas and has become the only diurnal raptor which can survive in urban areas in Taiwan (Severinghaus *et al.* 2010), the entire order Falconiformes is listed in the Appendix 2 of CITES (2011). Therefore, this species is listed as threatened in the COA schedule (Council of Agriculture of Executive Yuan 2009) but not listed in the IUCN

red list (International Union for Conservation of Nature and Natural Resources 2011).

The mountain scops-owl is also an endemic subspecies, is common in Taiwan and does not face severe threats (Severinghaus *et al.* 2010). The entire order Strigiformes is listed in the Appendix 2 of CITES (2011), but this species is not listed in the IUCN red list (International Union for Conservation of Nature and Natural Resources 2011).

The plumbeous redstart is also an endemic subspecies and is commonly found in suitable habitats (rivers of low to mid elevation areas), but faces high hunting pressure because of the cage bird trade which may be the reason why it is not found in all suitable habitats (Severinghaus *et al.* 2010).

The white-tailed robin is an endemic subspecies and faces no immediate threats to its population (Severinghaus *et al.* 2010).

The crested serpent-eagle lives in lowland forests and has even adapted to fragmented forests around urban areas (Severinghaus *et al.* 2010). This species is also listed in the Appendix 2 of CITES (2011) but not listed in the IUCN red list (International Union for Conservation of Nature and Natural Resources 2011).

These discrepancies in status assessments when using different criteria are to be expected. For example, widespread species may have low population densities, as may be the case for the Taiwan partridge and white-tailed robin. When assessing a species' status, we should include as many relevant categories as possible, which is why we recommended including quartile rarity and protected areas coverage into future assessments of the conservation status of Taiwanese birds (this study, Wu *et al.*, In preparation). However, these

comparisons also draw our attention to cases that do not seem to make much sense: for example, how can the crested serpent-eagle be a fourth-quartile species, be recorded as common within its suitable habitats which include fragmented forests near urban areas, but still considered to be a rare and valuable species? Such obvious discrepancies as the ones discussed above should alert us to reassess a species' status.

The assessments of each species' recorded rarity (Chinese Wild Bird Federation 2010) and conservation status (Council of Agriculture of Executive Yuan 2009) as detailed in Appendix 1 are based on expert opinions and scoring procedures detailed in the Council of Agriculture of Executive Yuan schedule (2008). This scoring procedure involves adding scores for five conservation-related categories, which are: population distribution, dominance in habitat, population trend, endemic status, and other threats (e.g., hunting, habitat loss). Here, we simply suggest that our new measures, percent coverage of study area, quartile rarity (both in Appendix 1) and percent coverage of protected areas (Wu *et al.*, In preparation) should be included in whatever scoring system is used to evaluate each species' conservation status in the future. Such an exercise would also prove very valuable for other taxa.

Our Fig. 4 highlights a further potential problem. Plotting the number of recorded and predicted pixels versus recorded rarity using categorical scores also shows that there remains considerable unexplained variation, especially among the common category (Fig. 4). Evidently, species recorded as common by the Chinese Wild Bird Federation (2010) range from being rarely to commonly recorded in our database and also had widely different extent of occurrences. Again,

this discrepancy justifies further investigation.

We also investigated the relationship of endemic status to these other three measures (Fig. 5-Fig. 7). As may be expected, endemic status is not obviously related to recorded rarity, quartile rarity or Taiwanese conservation status. However, it is important to point out those species which are endemic species or subspecies and also have low recorded and quartile rarity (of those species that were modeled, only ring-necked pheasant (*Phasianus colchicus*) and white-browed bush-robin (*Tarsiger indicus*) qualify; Wu *et al.*, In preparation).

One of the few drawbacks of modeling species distributions is that the rarest species, which are also often the most important for conservation efforts, cannot be reliably modeled because of insufficient sample size (Methods). For this reason, we were unable to model the distributions of 28 rare or cryptic species (Appendix 1). While some species are so localized that modeling is not necessary (e.g., the Australasian grass-owl only occurs in one severely restricted area in southern Taiwan, Severinghaus *et al.* 2010), other species are most likely under-recorded because they are cryptic (e.g., several of the wetland species) or nocturnal (e.g., several of the other owl species). For these species, special efforts must be made to increase the number of observations.

If sample sizes remain insufficient despite these efforts, there remain two possibilities to map these species: either simply map the occurrences without any modeling (e.g., using a dot map or a grid system) or, better, using expert-derived models in which the environmental preferences are not calculated statistically (as in the inductive models used in this study) but derived from expert knowledge (called deductive models, Corsi *et al.*

2000). The modeling of rare species is one of the frontiers of current research (for recent studies for birds, Guisan *et al.* 2006, Walther *et al.* 2007, Jiguet *et al.* 2010, Marini *et al.* 2010a, 2010b) which will help in modeling the distributions of Taiwan's rare and cryptic birds.

The ability provided by Geographic Information Systems to calculate each species' extent of occurrence and its coverage provided by the protected areas network (this study; Wu *et al.*, In preparation) are major improvements in assessing each species' conservation status as well as the overall performance of the protected areas network in maintaining the long-term survival of Taiwan's avifauna. These studies highlight the usefulness of large distributional databases and modern analytical methods such as species distribution modeling and Geographic Information Systems to help us with the monitoring and assessment of a large number of taxa.

Recent efforts by the Endemic Species Research Institute (ESRI) in collaboration with the Chinese Wild Bird Federation and the Institute of Ecology and Evolutionary Biology at National Taiwan University to expand citizen participation in the Taiwan Breeding Bird Survey (BBS Taiwan) (Lee *et al.* 2010) and the Monitoring Avian Productivity and Survivorship in Taiwan (MAPS Taiwan) project (Lin and Chen 2011) should be welcomed and supported as they supply the important baseline data for our assessment efforts within Taiwan, but should also be seen as important in the efforts to monitor biodiversity on a global scale (Walther *et al.* 2007; Scholes *et al.* 2008; Ash 2009)

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References

- Ash, N., Jürgens, N., Leadley, P., Alkemade, R., Araújo, M.B., Asner, G.P., Bachelet, D., Costello, M.J., Finlayson, M., Lavorel, S., Mace, G., Mooney, H.A., Parr, T., Scholes, R., Soberon, J., Turner, W., Prieur-Richard, A.-H., Larigauderie, A. and Walther, B.A. 2009. bioDISCOVERY: Assessing, monitoring and predicting biodiversity change. DIVERSITAS report No. 7. DIVERSITAS, Paris, France.
- Austin, M. P. 2002. Spatial prediction of species distribution: An interface between ecological theory and statistical modelling. *Ecological Modelling* 157: 101-118.
- BirdLife International. 2010. BirdLife Data Zone. <http://www.birdlife.org/datazone/species/index.html>
- Butchart, S. H. M., M. Walpole, B. Collen, A. van Strien, J. P. W. Scharlemann, R. E. A. Almond, J. E. M. Baillie, B. Bomhard, C. Brown, J. Bruno, K. E. Carpenter, G. M. Carr, J. Chanson, A. M. Chenery, J. Csirke, N. C. Davidson, F. Dentener, M. Foster, A. Galli, J. N. Galloway, P. Genovesi, R. D. Gregory, M. Hockings, V. Kapos, J. F. Lamarque, F. Leverington, J. Loh, M. A. McGeoch, L. McRae, A. Minasyan, M. H. Morcillo, T. E. Oldfield, D. Pauly, S. Quader, C. Revenga, J. R. Sauer, B. Skolnik, D. Spear, D. Stanwell-Smith, S. N. Stuart, A. Symes, M. Tierney, T. D. Tyrrell, J. C. Vie and R. Watson. 2010. Global biodiversity: Indicators of recent declines. *Science* 328: 1164-1168.
- Chinese Wild Bird Federation. 2010. The checklist of the birds of Taiwan. *Feather* 23: 66-95. (in Chinese)
- Chinese Wild Bird Federation. 2011. The checklist of the birds of Taiwan. *Feather* 24: 67-78. (in Chinese)
- CITES. 2011. CITES (the Convention on International Trade in Endangered Species of Wild Fauna and Flora). <http://www.cites.org/>
- Corsi, F., J. de Leeuw and A. Skidmore. 2000. Modelling species distribution with GIS. In Boitani, L. and T.K. Fuller, T.K. (editors). Pp. 389-434. *In: Research techniques in animal Ecology: Controversies and consequences*. Columbia University Press, New York, USA.
- Council of Agriculture of Executive Yuan. 2008. Directions for evaluating wildlife categories. *Nature Conservation Quarterly* 61: 72-75. (in Chinese)
- Council of Agriculture of Executive Yuan. 2009. Schedule of protected species. Council of Agriculture of Executive Yuan, R.O.C. (Taiwan) (in Chinese)
- Ding, T.-S., H.-W. Yuan, S. Geng, C.-N. Koh and P.-F. Lee. 2006. Macro-scale bird species richness patterns of the East Asian mainland and islands: Energy, area and isolation. *Journal of Biogeography* 33: 683-693.
- Fang, W.-H. 2008. The complete field guide of the birds of Taiwan. Owl Publishing House Co., LTD., Taipei, Taiwan. (in Chinese)
- Guisan, A. and N. E. Zimmermann. 2000. Predictive habitat distribution models in ecology. *Ecological Modelling* 135: 147-186.
- Guisan, A., O. Broennimann, R. Engler, M. Vust,

- N.G. Yoccoz, A. Lehmann, A. and N.E. Zimmermann. 2006. Using niche-based models to improve the sampling of rare species. *Conservation Biology* 20: 501-511.
- Hirzel, A. H., J. Hausser, D. Chessel and N. Perrin. 2002. Ecological-niche factor analysis: How to compute habitat-suitability maps without absence data? *Ecology* 83: 2027-2036.
- Hirzel, A. H., J. Hausser and N. Perrin. 2004. Biomapper 3.1. Laboratory for conservation Biology, Lausanne. <http://www.unil.ch/biomapper>
- Ho, L.-J. 2005. Selections and analyses of avian biodiversity hotspots in East Asia. School of Forestry and Resource Conservation. National Taiwan University, Taipei, Taiwan. (in Chinese)
- Hsu, F.-H., C.-T. Yao, S. R.-S. Lin, C.-C. Yang and S.-J. Lai. 2004. Avian species composition and distribution along elevation gradient in the Southern Taiwan. *Endemic Species Research* 6: 41-66. (in Chinese)
- Huang, P.-L. 2001. Distribution pattern of breeding birds in northern Taiwan. Institute of Zoology. National Taiwan University, Taipei. (in Chinese)
- International Union for Conservation of Nature and Natural Resources. 2011. The IUCN Red List of Threatened Species. <http://www.iucnredlist.org/>
- IUCN Standards and Petitions Subcommittee. 2010. Guidelines for using the IUCN Red List categories and criteria. Version 8.1. Prepared by the Standards and Petitions Subcommittee in March 2010. Downloadable from <http://intranet.iucn.org/webfiles/doc/SSC/RedList/RedListGuidelines.pdf>
- Jiguet, F., M. Barbet-Massin and P.-Y. Henry. 2010. Predicting potential distributions of two rare allopatric sister species, the globally threatened *Doliornis cotingas* in the Andes. *Journal of Field Ornithology* 81: 325-339.
- Johnson, R. A. and D. W. Wichern. 1998. Applied multivariate statistical analysis. 4th edition. Prentice-Hall International, Inc.
- Ko, C.-J. 2004. The relationship between avian community and forest landscapes in Guanwu, Taiwan. Institute of Ecology and Evolutionary Biology. National Taiwan University, Taipei. (in Chinese)
- Ko, C.-Y., P.-F. Lee, M.-L. Bai and R.-S. Lin. 2009a. A rule-based species predictive model for the vulnerable Fairy Pitta (*Pitta numpha*) in Taiwan. *Taiwania* 54: 28-36.
- Ko, C.-Y., R.-S. Lin, T.-S. Ding, C.-H. Hsieh and P.-F. Lee. 2009b. Identifying biodiversity hotspots by predictive models: A case study using Taiwan's endemic bird species. *Zoological Studies* 48: 418-431.
- Koh, C.-N., P.-F. Lee and R.-S. Lin. 2006a. Bird species richness patterns of northern Taiwan: Primary productivity, human population density, and habitat heterogeneity. *Diversity and Distributions* 12: 546-554.
- Koh, C.-N., P.-F. Lee and S.-H. Wu. 2006b. Does the distribution of breeding bird species richness in Taiwan follow the mid-domain effect? *Taiwania* 51: 108-116.
- Lee, P.-F., T.-S. Ding, F.-H. Hsu and S. Geng. 2004. Breeding bird species richness in Taiwan: Distribution on gradients of elevation, primary productivity and urbanization. *Journal of Biogeography* 31: 307-314.
- Lee, P.-F., C.-J. Ko, K.-W. Huang, W.-S. Gao, T.-Y. Wu, H.-S. Lin, W.-J. Chen, R.-S. Lin, M.-W. Fan, C.-F. Hsieh, W.-D. Yu. 2010. The Taiwan breeding bird survey 2009-2010. Endemic Species Research Institute, Nantou, Taiwan.

- Lee, P.-F., C.-Y. Liao, Y.-C. Lee, Y.-H. Pan, W.-H. Fu and H.-W. Chen. 1997. An ecological and environmental GIS database for Taiwan. Department of Zoology, National Taiwan University, Taipei, Taiwan. (in Chinese).
- Liao, C.-Y. 1997. The spatial distribution and predictive model of Timaliinae in Taiwan. Institute of Zoology, National Taiwan University, Taipei. (in Chinese)
- Lin, R.-S. 2011. Annual survey of the fairy pitta (*Pitta nympha*) population in Douliou hill areas-2010. Endemic Species Research Institute, Nantou, Taiwan. (in Chinese)
- Lin, R.-S. and J.-H. Chen. 2011. MAPS Taiwan manual 2011 protocol. Endemic Species Research Institute, Nantou, Taiwan. (in Chinese)
- Lin, W.-H. 1997. The history of the discovery of birds in Taiwan. Taiwan Interinds Publishing Inc., Taipei. (in Chinese)
- Lin, S.-H., C.-S. Chen, W.-H. Huang, C. Wang-Shih and K. K. Kuo. 2008. The dispersal of Malayan Night-Heron in Taipei. *Yuhina* 174: 2-3. (in Chinese)
- Mace, G. M. and R. Lande. 1991. Assessing extinction threats: Toward a reevaluation of IUCN threatened species categories. *Conservation Biology* 5: 148-157.
- Marini, M.A., M. Barbet-Massin, J. Martinez, N. P. Prestes and F. Jiguet. 2010a. Applying ecological niche modelling to plan conservation actions for the Red-spectacled Amazon (*Amazona pretrei*). *Biological Conservation* 143: 102-112.
- Marini, M.A., M. Barbet-Massin, L.E. Lopes and F. Jiguet. 2010b. Predicting the occurrence of rare Brazilian birds with species distribution models. *Journal of Ornithology* 151: 857-866.
- Millennium Ecosystem Assessment. 2005. Ecosystems and human well-being: Biodiversity synthesis. World Resources Institute, Washington, D.C., USA.
- Peng, C.-Y. 2008. Temporal and spatial variations of bird assemblage in the Taroko National Park. Institute of Ecology and Evolutionary Biology, National Taiwan University, Taipei. (in Chinese)
- Phillips, S. J., R. P. Anderson and R. E. Schapired. 2006. Maximum entropy modeling of species geographic distributions. *Ecological Modelling* 190: 231-259.
- Phillips, S. J., M. Dudik and R. E. Schapire. 2009. Maximum entropy species distribution modeling. <http://www.cs.princeton.edu/~schapire/maxent/>
- Scholes, R. J., G. M. Mace, W. Turner, G. N. Geller, N. Jürgens, A. Larigauderie, D. Muchoney, B. A. Walther and H. A. Mooney. 2008. Toward a global biodiversity observing system. *Science* 321: 1044-1045.
- Severinghaus, L. L. 2007. Cavity dynamics and breeding success of the Lanyu Scops Owl (*Otus elegans*). *Journal of Ornithology* 148: 407-416.
- Severinghaus, L. L., T.-S. Ding, W.-H. Fang, W.-H. Lin, M.-C. Tsai and C.-W. Yen. 2010. The avifauna of Taiwan. Forestry Bureau of Council of Agriculture of Executive Yuan, Taipei, Taiwan. (in Chinese)
- Shiu, H.-J. and P.-F. Lee. 2003. Seasonal variation in bird species richness along elevational gradients in Taiwan. *Acta Zoologica Taiwanica* 14: 1-21.
- Stockwell, D. 2005. DesktopGarp 1.1.6. San Diego Supercomputer Center. <http://www.nhm.ku.edu/desktopgarp/>
- Stockwell, D. R. B. and I. R. Noble. 1992. Induction

- of sets of rules from animal distribution data: A robust and informative method of data analysis. *Mathematics and Computers in Simulation* 33: 385-390.
- Stockwell, D. R. B. and A. T. Peterson. 2002. Effects of sample size on accuracy of species distribution models. *Ecological Modelling* 148: 1-13.
- Su, H.-J. 1984. Studies on the climate and vegetation types of the natural forests in Taiwan (I) Analysis of the variations in climate factors. *Quarterly Journal of Chinese Forestry* 17: 1-14.
- Swinhoe, R. 1863. The ornithology of Formosa, or Taiwan. *Ibis* 5: 377-435.
- Walther, B. A., A. Larigauderie, N. Ash, G. N. Geller, N. Jürgens and M. A. Lane. 2007. Toward a global biodiversity observation network. In GEO-Group on Earth Observations (editor). pp. 79-81. *In: The Full Picture*. Tudor Rose, Geneva, Switzerland.
- Walther, B.A., N. Schäffer, A. van Niekerk, W. Thuiller, C. Rahbek and S.L. Chown. 2007. Modelling the winter distribution of a rare and endangered migrant, the aquatic warbler *Acrocephalus paludicola*. *Ibis* 149: 701-714.
- Walther, B. A. 2011. First documented nesting of the red-whiskered bulbul *Pycnonotus jocosus* in Taiwan. *Taiwan Journal of Biodiversity* 13: 121-133.
- Wang, C.-H., S.-H. Wu, K.-Y. Huang, H.-Y. Yang, C.-H. Tsai, M.-C. Tsai and C.-L. Hsiao. 1991. *The field guide of the birds of Taiwan*. Yashen Press., Taipei, Taiwan. (in Chinese)
- Wisz, M. S., R. J. Hijmans, J. Li, A. T. Peterson, C. H. Graham and A. Guisan. 2008. Effects of sample size on the performance of species distribution models. *Diversity and Distributions* 14: 763-773.
- Wu, T.-Y., B.A. Walther, Y.-H. Chen, R.-S. Lin and P.-F. Lee. In preparation. Reassessment of the conservation status of Taiwanese birds: How distribution modeling can help species conservation.
- Yu, Y. T. 2010. International black-faced spoonbill census 2010. Black-faced Spoonbill Research Group, Hong Kong Bird Watching Society, Hong Kong.

Appendix 1. The percentage coverage of the study area, quartile rarity, recorded rarity and Taiwanese conservation status of the 145 species of Taiwanese breeding birds as listed in Fang *et al.* (2008). Latin and English names were taken from the Chinese Wild Bird Federation (2010) as well as their endemic species status; endemic = full endemic species status; name of subspecies' trinomial = recognized as endemic subspecies; all other species are listed as non-endemic. Global conservation status is given according to BirdLife International (2010): * = vulnerable; † = near-threatened; all other species are listed as least concern. The fourth column gives the number of 1 x 1 km grid pixels in which the respective species was recorded to be breeding ≥ 1 times during the months March to July. The fifth column gives the number of grid pixels in which the respective species was predicted to be present using our distribution models (Methods). Note that the White Wagtail was excluded a *priori* from distribution modeling because it was not possible to visually distinguish breeding individuals and wintering visitors, some of which extend their stay in Taiwan into the breeding season. The superscript letters indicate which three of the following five methods for building distribution models were chosen as the best performing models based on their AUC scores to derive at a final distribution model (Methods): multiple discriminant analysis (D), ecological niche factor analysis (E), genetic algorithm for rule-set production (G), logistic regression (L), and maximum-entropy (M). The sixth column gives the percentage coverage of the study area which is the number of predicted pixels (fifth column) divided by the total number of grid pixels of the study area (36,022) and multiplied by 100. The seventh column gives quartile rarity which was derived from the number in the sixth column (see Methods for details). The eighth column gives the recorded rarity scored by the Chinese Wild Bird Federation (2010) as follows: R = rare (the respective bird species was recorded in < 20% of suitable habitats), UC = uncommon (the respective bird species was recorded 20-70% of suitable habitats), C = common (the respective bird species was recorded in > 70% of suitable habitats). The ninth column gives the Taiwanese conservation status scored by the Council of Agriculture of Executive Yuan (2009) as follows: EN = endangered; RV = rare and valuable; CD = other conservation-dependent species; all other species are non-threatened.

Latin Name	Endemic species status	English Name	Number of grid pixels recorded	Number of grid pixels predicted	% coverage of study area	Quartile rarity	Recorded rarity	Taiwanese conservation status
<i>Coturnix chinensis</i>		blue-breasted quail	5	-	-	-	R	RV
<i>Arborophila crudigularis</i> †	endemic	Taiwan partridge	234	2127 ^{D,E,L}	59.07	3	UC	CD
<i>Bambusicola thoracicus</i>	<i>sonorivox</i>	Chinese bamboo-partridge	769	2830 ^{D,E,L}	78.57	4	C	-
<i>Lophura swinhoii</i> †	endemic	Swinhoe's Pheasant	43	13099 ^{G,L,M}	36.36	2	UC	RV
<i>Syrnaticus mikado</i> †	endemic	mikado pheasant	12	-	-	-	R	RV

Latin Name	Endemic species status	English Name	Number of grid pixels recorded	Number of grid pixels predicted	% coverage of study area	Quartile rarity	Recorded rarity	Taiwanese conservation status
<i>Phasianus colchicus</i>	<i>formosanus</i>	ring-necked pheasant	51	6534 ^{D,L,M}	18.14	1	R	RV
<i>Aix galericulata</i>		mandarin duck	19	-	-	-	UC	RV
<i>Tachybaptus ruficollis</i>		little grebe	96	9137 ^{D,E,L}	25.37	2	C	-
<i>Ixobrychus sinensis</i>		yellow bittern	48	5103 ^{D,L,M}	14.17	1	C	-
<i>Ixobrychus cinnamomeus</i>		cinnamon bittern	74	4229 ^{D,E,L}	11.74	1	UC	-
<i>Gorsachius melanolophus</i>		malayan night-heron	51	5686 ^{D,E,L}	15.78	1	C	-
<i>Nycticorax nycticorax</i>		black-crowned night-heron	255	13754 ^{D,E,L}	38.18	2	C	-
<i>Butorides striata</i>		striated heron	28	-	-	-	UC	-
<i>Bubulcus ibis</i>		cattle egret	383	16443 ^{D,E,L}	45.65	2	C	-
<i>Egretta garzetta</i>		little egret	602	20673 ^{D,E,L}	57.39	3	C	-
<i>Elanus caeruleus</i>		black-shouldered kite	1	-	-	-	R	RV
<i>Mitvus migrans</i>		black kite	27	-	-	-	R	RV
<i>Spilornis cheela</i>	<i>hoya</i>	crested serpent-eagle	555	27166 ^{D,E,L}	75.42	4	C	RV
<i>Accipiter trivirgatus</i>	<i>formosae</i>	crested goshawk	185	23554 ^{D,E,L}	65.39	3	C	RV
<i>Accipiter virgatus</i>	<i>fuscipectus</i>	besra	67	10082 ^{D,L,M}	27.99	2	UC	RV
<i>Ictinaetus malayensis</i>		black eagle	30	6516 ^{D,G,L}	18.09	1	R	EN
<i>Nisaetus nipalensis</i>		mountain hawk-eagle	14	-	-	-	R	EN
<i>Rallina eurizonoides</i>	<i>formosana</i>	slaty-legged crane	20	-	-	-	UC	-
<i>Gallirallus striatus</i>	<i>taiwanus</i>	slaty-breasted rail	10	-	-	-	UC	-
<i>Rallus aquaticus</i>		water rail	0	-	-	-	R	-

Latin Name	Endemic species status	English Name	Number of grid pixels recorded	Number of grid pixels predicted	% coverage of study area	Quartile rarity	Recorded rarity	Taiwanese conservation status
<i>Amaurornis phoenicurus</i>		white-breasted waterhen	197	13006 ^{D,G,L}	36.11	2	C	-
<i>Porzana fusca</i>		ruddy-breasted crane	34	5790 ^{D,E,L}	16.07	1	C	-
<i>Gallinix cinerea</i>		watercock	3	-	-	-	R	-
<i>Gallinula chloropus</i>		common moorhen	217	13734 ^{D,E,L}	38.13	2	C	-
<i>Turnix sylvaticus</i>		small buttonquail	1	-	-	-	R	-
<i>Turnix suscitator</i>	<i>rostratus</i>	barred buttonquail	71	11259 ^{D,G,L}	31.26	2	C	-
<i>Rostratula benghalensis</i>		greater painted-snipe	30	6571 ^{D,L,M}	18.24	1	C	RV
<i>Hydrophasianus chirurgus</i>		pheasant-tailed jacana	5	-	-	-	R	RV
<i>Glareola maldivarum</i>		oriental pratincole	60	5352 ^{E,L,M}	14.86	1	C	CD
<i>Columba pulchricollis</i>		ashy wood-pigeon	85	12249 ^{D,E,L}	34.00	2	UC	-
<i>Streptopelia orientalis</i>	<i>orii</i>	Oriental turtle-dove	122	21334 ^{D,L,M}	59.22	3	C	-
<i>Streptopelia tranquebarica</i>		red collared-dove	620	22015 ^{D,E,L}	61.12	3	C	-
<i>Streptopelia chinensis</i>		spotted dove	510	19241 ^{D,G,L}	53.41	3	C	-
<i>Chalcophaps indica</i>		emerald dove	102	12685 ^{D,L,M}	35.21	2	UC	-
<i>Treeron sieboldii</i>		white-bellied pigeon	142	16843 ^{D,G,L}	46.76	2	UC	-
<i>Cuculus sparverioides</i>		large hawk-cuckoo	185	15245 ^{D,G,L}	42.32	2	C	-
<i>Cuculus saturatus</i>		Himalayan cuckoo	477	27195 ^{D,E,L}	75.50	4	C	-
<i>Centropus bengalensis</i>		lesser coucal	302	15999 ^{D,G,L}	44.41	2	C	-
<i>Tyto longimembris</i>	<i>pithecopis</i>	Australasian grass-owl	3	-	-	-	R	EN
<i>Otus spilocephalus</i>	<i>hambroeki</i>	mountain scops-owl	178	19863 ^{D,E,G}	55.14	3	C	RV

Latin Name	Endemic species status	English Name	Number of grid pixels recorded	Number of grid pixels predicted	% coverage of study area	Quartile rarity	Recorded rarity	Taiwanese conservation status
<i>Otus leitia</i>	<i>glabripes</i>	collared scops-owl	68	7134 ^{D,G,L}	19.80	1	C	RV
<i>Ketupa flavipes</i>		tawny fish-owl	3	-	-	-	R	RV
<i>Strix leptogrammica</i>		brown wood-owl	7	-	-	-	R	RV
<i>Strix aluco</i>	<i>yamadae</i>	tawny owl	8	-	-	-	R	RV
<i>Glaucidium brodiei</i>	<i>pardalotum</i>	collared owl	119	16183 ^{D,E,L}	44.93	2	UC	RV
<i>Ninox japonica</i>		northern boobook	17	-	-	-	UC	RV
<i>Caprimulgus affinis</i>	<i>stictomus</i>	savanna nightjar	33	10047 ^{D,G,M}	27.89	2	C	-
<i>Apus pacificus</i>		fork-tailed swift	93	16364 ^{D,E,L}	45.43	2	UC	-
<i>Apus nipalensis</i>	<i>kuntzi</i>	house swift	541	29737 ^{D,E,L}	82.55	4	C	-
<i>Alcedo atthis</i>		common kingfisher	206	20466 ^{D,L,M}	56.82	3	C	-
<i>Megalaima nuchalis</i>	endemic	Taiwan barbet	1194	26744 ^{D,G,L}	74.24	3	C	-
<i>Dendrocopos canicapillus</i>		gray-capped woodpecker	213	22724 ^{D,E,L}	63.08	3	C	-
<i>Dendrocopos leucotos</i>	<i>insularis</i>	white-backed woodpecker	52	10537 ^{D,E,L}	29.25	2	UC	RV
<i>Picus canus</i>		gray-faced woodpecker	52	8621 ^{D,E,L}	23.93	1	R	RV
<i>Pitta nympha</i> *		fairy pitta	21	-	-	-	UC	RV
<i>Coracina macei</i>		large cuckoo-shrike	15	-	-	-	R	RV
<i>Pericrocotus solaris</i>		gray-chinned minivet	454	22924 ^{D,E,L}	63.64	3	C	-
<i>Lanius schach</i>		long-tailed shrike	144	9117 ^{D,G,L}	25.31	2	C	-
<i>Oriolus chinensis</i>		black-naped oriole	4	-	-	-	R	EN
<i>Oriolus traillii</i>	<i>ardens</i>	maroon oriole	86	14976 ^{D,L,M}	41.57	2	UC	RV

Latin Name	Endemic species status	English Name	Number of grid pixels recorded	Number of grid pixels predicted	% coverage of study area	Quartile rarity	Recorded rarity	Taiwanese conservation status
<i>Dicrurus macrocercus</i>	<i>harterti</i>	black drongo	523	19574 ^{D,G,L}	54.34	3	C	-
<i>Dicrurus aeneus</i>	<i>braunianus</i>	bronzed drongo	389	23935 ^{D,E,L}	66.45	3	C	-
<i>Hypothymis azurea</i>	<i>oberholseri</i>	black-naped monarch	739	22595 ^{D,G,L}	62.73	3	C	-
<i>Garrulus glandarius</i>	<i>taiwanus</i>	Eurasian jay	116	20246 ^{D,L,M}	56.20	3	C	-
<i>Urocissa caerulea</i>	endemic	Formosan magpie	103	12350 ^{D,L,M}	34.28	2	C	CD
<i>Dendrocitta formosae</i>	<i>formosae</i>	gray treepie	697	29269 ^{D,G,L}	81.25	4	C	-
<i>Pica pica</i>		Eurasian magpie	53	4319 ^{E,L,M}	11.99	1	C	-
<i>Nucifraga caryocatactes</i>	<i>owstoni</i>	Eurasian nutcracker	71	6010 ^{D,E,L}	16.68	1	C	-
<i>Corvus macrorhynchos</i>		large-billed crow	386	22705 ^{D,E,L}	63.03	3	C	-
<i>Parus monticolus</i>	<i>insperatus</i>	green-backed tit	283	13576 ^{D,E,L}	37.69	2	C	CD
<i>Macholophus holstii</i> ^s	endemic	yellow tit	95	12262 ^{D,E,L}	34.04	2	R	RV
<i>Periparus ater</i>	<i>pilosus</i>	coal tit	124	7862 ^{E,L,M}	21.83	1	C	CD
<i>Sittiparus varius</i>	<i>castaneiventris</i>	varied tit	50	10217 ^{D,L,M}	28.36	2	UC	RV
<i>Riparia paludicola</i>		plain martin	205	17320 ^{D,G,L}	48.08	2	C	-
<i>Hirundo rustica</i>		barn swallow	423	17377 ^{D,E,L}	48.24	2	C	-
<i>Hirundo tahitica</i>		Pacific swallow	653	21515 ^{D,G,L}	59.73	3	C	-
<i>Delichon dasypus</i>		Asian house-martin	84	13798 ^{D,E,L}	38.30	2	UC	-
<i>Cecropis striolata</i>		striated swallow	388	14720 ^{D,G,L}	40.86	2	C	-
<i>Aegithalos concinnus</i>		black-throated tit	207	16240 ^{D,L,M}	45.08	2	C	-
<i>Alauda gulgula</i>		Oriental skylark	177	10371 ^{D,E,L}	28.79	2	C	-

Latin Name	Endemic species status	English Name	Number of grid pixels recorded	Number of grid pixels predicted	% coverage of study area	Quartile rarity	Recorded rarity	Taiwanese conservation status
<i>Cisticola juncidis</i>		zitting cisticola	228	13247 ^{b,G,L}	36.77	2	C	-
<i>Cisticola exilis</i>	<i>volitans</i>	golden-headed cisticola	147	10810 ^{b,G,L}	30.01	2	UC	-
<i>Prinia crinigera</i>	<i>striata</i>	striated prinia	91	10234 ^{E,G,L}	28.41	2	C	-
<i>Prinia flaviventris</i>		yellow-bellied prinia	579	23446 ^{b,E,L}	65.09	3	C	-
<i>Prinia inornata</i>	<i>flavirostris</i>	plain prinia	693	25167 ^{E,G,L}	69.87	3	C	-
<i>Spizixos semitorques</i>	<i>cinereicapillus</i>	collared finchbill	438	23527 ^{b,E,L}	65.31	3	C	-
<i>Pycnonotus sinensis</i>	<i>formosae</i>	light-vented bulbul	1067	24897 ^{b,L,M}	69.12	3	C	-
<i>Pycnonotus taiwanus</i> *	endemic	styan's bulbul	269	5500 ^{d,G,M}	15.27	1	C	RV
<i>Hypsipetes leucocephalus</i>	<i>nigerrimus</i>	black bulbul	1187	30185 ^{b,G,L}	83.80	4	C	-
<i>Cettia fortipes</i>	<i>robustipes</i>	brownish-flanked bush-warbler	230	19635 ^{b,G,L}	54.51	3	C	-
<i>Cettia acanthizoides</i>	<i>concolor</i>	yellowish-bellied bush-warbler	126	11621 ^{d,L,M}	32.26	2	C	-
<i>Bradypterus alishanensis</i>	endemic	Taiwan bush-warbler	122	8474 ^{E,L,M}	23.52	1	C	-
<i>Abroscopus albogularis</i>		rufous-faced warbler	512	23076 ^{d,L,M}	64.06	3	C	-
<i>Pomatorhinus erythrocnemis</i>	<i>erythrocnemis</i>	spot-breasted scimitar-babbler	692	25945 ^{b,G,L}	72.03	3	C	-
<i>Pomatorhinus ruficollis</i>	<i>musicus</i>	streak-breasted scimitar-babbler	942	29139 ^{b,G,L}	80.89	4	C	-
<i>Prøeypga albiventer</i>	<i>formosana</i>	scaly-breasted wren-babbler	176	12839 ^{b,E,M}	35.64	2	C	-
<i>Stachyris ruficeps</i>	<i>praecognita</i>	rufous-capped babbler	1204	27835 ^{b,G,L}	77.27	4	C	-
<i>Garrulax albogularis</i>	<i>ruficeps</i>	white-throated laughingthrush	17	-	-	-	R	RV
<i>Garrulax poecilorhynchus</i>	<i>poecilorhynchus</i>	rusty laughingthrush	133	17199 ^{b,G,L}	47.75	2	UC	RV
<i>Garrulax taewanus</i> ^s	endemic	Taiwan hwamei	276	17604 ^{b,L,M}	48.87	2	UC	RV

Latin Name	Endemic species status	English Name	Number of grid pixels recorded	Number of grid pixels predicted	% coverage of study area	Quartile rarity	Recorded rarity	Taiwanese conservation status
<i>Garrulax morrisonianus</i>	endemic	white-whiskered laughingthrush	135	9938 ^{D,L,M}	27.59	2	C	-
<i>Lioicichla steerti</i>	endemic	Steere's liocichla	407	18459 ^{G,L,M}	51.24	3	C	-
<i>Actinodura morrisoniana</i>	endemic	Taiwan barwing	54	9478 ^{D,E,L}	26.31	2	C	CD
<i>Alcippe cinereiceps</i>	<i>formosana</i>	streak-throated fulvetta	101	8783 ^{E,L,M}	24.38	1	C	-
<i>Alcippe brunnea</i>	<i>brunnea</i>	dusky fulvetta	798	25504 ^{D,G,L}	70.80	3	C	-
<i>Alcippe morrisonia</i>	<i>morrisonia</i>	gray-cheeked fulvetta	1072	26777 ^{D,E,L}	74.34	3	C	-
<i>Heterophasia auricularis</i>	endemic	white-eared sibia	425	18530 ^{E,G,L}	51.44	3	C	-
<i>Yuhina brunneiceps</i>	endemic	Taiwan yuhina	438	17147 ^{E,G,L}	47.60	2	C	-
<i>Yuhina zantholeuca</i>		white-bellied yuhina	461	20088 ^{D,G,L}	55.77	3	C	-
<i>Paradoxornis webbianus</i>	<i>bulomachus</i>	vinous-throated parrotbill	158	15059 ^{D,G,M}	41.81	2	C	-
<i>Paradoxornis verreauxi</i>	<i>morrisonianus</i>	golden parrotbill	7	-	-	-	R	-
<i>Zosterops japonicus</i>		Japanese white-eye	972	32308 ^{D,E,L}	89.69	4	C	-
<i>Regulus goodfellowi</i>	endemic	flamecrest	77	6071 ^{E,G,M}	16.85	1	C	CD
<i>Troglodytes troglodytes</i>	<i>taivanus</i>	winter wren	43	4535 ^{D,G,L}	12.59	1	C	-
<i>Sitta europaea</i>		Eurasian nuthatch	121	11793 ^{D,G,L}	32.74	2	C	-
<i>Acridotheres cristatellus</i>	<i>formosanus</i>	crested myna	168	7143 ^{D,G,L}	19.83	1	UC	RV
<i>Myiophonus insularis</i>	endemic	Formosan whistling-thrush	311	20812 ^{D,G,L}	57.78	3	C	-
<i>Turdus poliocephalus</i>	<i>niveiceps</i>	island thrush	17	-	-	-	R	RV
<i>Brachypteryx montana</i>	<i>goodfellowi</i>	white-browed shortwing	171	12749 ^{D,L,M}	35.39	2	C	-
<i>Tarsiger indicus</i>	<i>formosanus</i>	white-browed bush-robin	47	5333 ^{D,E,L}	14.80	1	R	CD

Latin Name	Endemic species status	English Name	Number of grid pixels recorded	Number of grid pixels predicted	% coverage of study area	Quartile rarity	Recorded rarity	Taiwanese conservation status
<i>Tarsiger johnstoniae</i>	endemic	collared bush-robin	110	8289 ^{E,L,M}	23.01	1	C	-
<i>Rhyacornis fuliginosa</i>	<i>affinis</i>	plumbeous redstart	148	20714 ^{D,G,L}	57.50	3	C	CD
<i>Cinclidium leucurum</i>	<i>montium</i>	white-tailed robin	359	18274 ^{E,G,L}	50.73	3	UC	CD
<i>Enicurus scouleri</i>	<i>fortis</i>	little forktail	31	14639 ^{D,E,M}	40.64	2	R	RV
<i>Muscicapa ferruginea</i>		ferruginous flycatcher	83	10589 ^{D,G,L}	29.40	2	UC	-
<i>Ficedula hyperythra</i>	<i>innexa</i>	snowy-browed flycatcher	132	12833 ^{D,E,L}	35.63	2	C	-
<i>Niltava vivida</i>	<i>vivida</i>	vivid niltava	254	16738 ^{D,E,L}	46.47	2	UC	CD
<i>Cinclus pallasi</i>		brown dipper	43	14451 ^{D,G,L}	40.12	2	UC	-
<i>Dicaeum concolor</i>	<i>uchidai</i>	plain flowerpecker	26	-	-	-	UC	-
<i>Dicaeum ignipectum</i>	<i>formosum</i>	fire-breasted flowerpecker	134	14595 ^{E,G,L}	40.52	2	C	-
<i>Passer rutilans</i>		russet sparrow	9	-	-	-	R	EN
<i>Passer montanus</i>		Eurasian tree sparrow	819	21341 ^{D,G,L}	59.24	3	C	-
<i>Lonchura striata</i>		white-rumped munia	265	22299 ^{D,G,L}	61.90	3	C	-
<i>Lonchura punctulata</i>		nutmeg mannikin	388	24737 ^{D,G,L}	68.67	3	C	-
<i>Lonchura atricapilla</i>		chestnut munia	26	-	-	-	R	-
<i>Prunella collaris</i>	<i>fennelli</i>	alpine accentor	11	-	-	-	C	-
<i>Motacilla alba</i>		white wagtail	not used	-	-	-	C	-
<i>Carpodacus vinaceus</i>	<i>formosanus</i>	vinaceous rosefinch	39	4683 ^{D,E,L}	13.00	1	C	-
<i>Pyrhula nipalensis</i>	<i>uchidae</i>	brown bullfinch	79	12344 ^{E,L,M}	34.27	2	UC	-
<i>Pyrhula erythaca</i>	<i>owstoni</i>	gray-headed bullfinch	34	9544 ^{D,L,M}	26.49	2	UC	-

An *In Vitro* Test on Testosterone Production of Deer Leydig Cells

離體實驗研究鹿科動物萊氏細胞睪酮之生產

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Abstract

Testosterone production of Leydig cells (LC) purified from testes of the sambar deer (*Cervus unicolor swinhoei*), the sika deer (*Cervus nippon taiouanus*) and the Reeves' muntjac (*Muntiacus reevesi micrurus*) at the hard antler stage were examined *in vitro*. They were treated with various concentrations of human chorionic gonadotropin (hCG) and three steroidogenic precursors: namely, 25-OH-cholesterol, pregnenolone and androstenedione. The minimum effective concentrations for stimulating the LC testosterone productivity were determined at 0.5 IU/ml for hCG, 10³ nM for 25-OH-cholesterol, 10³ nM for pregnenolone, and

10^2 nM for androstenedione. All treatments resulted in detectable testosterone production after 3 days of the incubation for all three deer species tested. The results demonstrated that purified deer LC was a useful *in vitro* tool for further investigations on cervid physiology.

摘 要

本實驗純化台灣水鹿、台灣梅花鹿及台灣山羌硬角期萊氏細胞並檢測睪酮產量，將萊氏細胞處理人類絨毛膜性促素及三個前驅物，包含膽固醇、孕烯醇酮、雄脂烯二酮。在三種鹿科動物的實驗中，評估最小刺激睪酮產量的濃度依序人類絨毛膜性促素為 0.5 IU/ml、膽固醇為 10^3 nM、孕烯醇酮為 10^3 nM，以及雄脂烯二酮為 10^2 nM。實驗結果顯示培養三天即可刺激睪酮產量，藉由本研究之成果可提供鹿科動物離體實驗初步方法學之探討。

Key words: *Cervus nippon taiouanus*, *Cervus unicolor swinhoei*, *Muntiacus reevesi micrurus*, reproductive physiology, steroidogenesis, testosterone.

關鍵詞：台灣梅花鹿、台灣水鹿、台灣山羌、生殖生理、類固醇合成、睪酮

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Introduction

Testosterone is an important reproductive hormone produced mainly by testicular Leydig cells (LC) (Allen *et al.* 2006; Midzk *et al.* 2007). It is synthesized by a series of metabolic processes termed as “steroidogenesis” from cholesterol with stimulation of luteinizing hormone (LH) released from the anterior pituitary gland. The processes require enzymes to convert cholesterol into various forms of steroids to testosterone (Payne and Hales 2004).

Steroidogenesis starts by transferring cholesterol from the cytoplasmic pool into mitochondria. It

is facilitated by the steroidogenic acute regulatory protein (StAR protein) synthesized in the cytosol. Cholesterol in the cytoplasm is transferred into the mitochondrial inner membrane. This is the most rate-limiting step for the whole steroidogenesis where the cytochrome P450 side-chain cleavage (P450_{scc}) catalyzes the first side chain cleavage of cholesterol to yield pregnenolone. The pregnenolone is dehydrogenated to progesterone by 3β -hydroxysteroid dehydrogenase (3β -HSD), then converted to androstenedione by P450_{C17}, and finally reduced to testosterone by 17β -oxidoreductase.

For male cervids the testosterone level in the

blood fluctuates annually in accordance with seasonal changes in the testicular activity, creating the phenomenon of “annual re-puberty,” with an exception of the muntjacs (*Muntiacus* sp.) (Pei *et al.* 2009). Males become fertile and behaviorally active only during the period of high testosterone levels (Asher *et al.*, 1996; Bubenik *et al.* 1996; Blottner *et al.* 1996; Goeritz *et al.* 2003; Gómez *et al.* 2006; Li *et al.* 2001; Loudon and Curlewis 1988; Monfort *et al.* 1993; Rolf and Fischer 1996; Yamauchi *et al.* 1997). The level of testosterone also dictates the antler replacement cycle. Very low level in spring initiates hard antler casting and new growth of velvet antlers. The level rises in autumn for velvet shedding and antler hardening (Gómez *et al.*, 2006; Loudon and Curlewis 1988; Pei *et al.* 2009; Rolf and Fischer 1996; Scott *et al.* 1989; Yamauchi *et al.* 1997).

To have an in-depth understanding of the physiological mechanism of the “annual re-puberty” phenomenon is always a great interest to many scientists. In this study we developed and tested an *in vitro* technique for the first time to examine the mechanism of the steroidogenesis by purifying LC from testicles of three native deer species of Taiwan: the sambar deer, the sika deer, and the Reeves’ muntjac. The LC was incubated *in vitro* with each of hCG and three steroidogenic precursors, namely 25-OH-cholesterol (cholesterol), pregnenolone (Δ_5P) and androstenedione (Δ_4) to examine their effects on the testosterone production.

Materials and Methods

Fresh testicles of healthy adult male sambar deer, sika deer and Reeve’s muntjac with hard antlers were obtained from deer farms in the

central Taiwan in 2007 and 2008. The testicular interstitial cells were isolated with the collagenase dispersion method (Tsai *et al.* 2003). They were centrifuged at 4°C and 200 g for 10 min. The cell pellet volume was suspended in the incubation medium (1% bovine serum albumin in Medium 199, with 25 mM HEPES, 2.2 g/l NaHCO₃, 100 IU/ml penicillin-G, 50 µg/ml streptomycin sulfate, 2550 USP K U/l heparin, pH 7.4, and treated with 95% O₂ and 5% CO₂) to 5 ml, and then added gently to the upper layer of a continuous Percoll gradient. This continuous Percoll gradient was made of adding 9 parts of Percoll to 11 parts of 1.8 × concentrated incubation medium, and then, centrifuged at 4°C and 20,000 g for 60 min. The mixture of testicular interstitial cells was loaded onto the Percoll gradient and centrifuged at 4°C and 800 g for 20 min.

The LC layer was collected and diluted to 10 ml in the incubation medium and then centrifuged at 4°C and 200 g for 10 min. The LC concentration was set at 10⁵ cells/ml and viability over 85-95% in this study. They were determined with a hemocytometer and the trypan blue method (Tsai *et al.*, 2003). The LC culture followed the procedure described by Chen *et al.* (2002), in which purified LC was re-suspended in Medium 199 (pH= 7.4) with supplementation of 2.2 g/liter NaHCO₃, 2.4 g/liter HEPES, 0.1% BSA, 12.5 mg/liter gentamycin sulfate, and 0.5 mg/ml Bovine lipoprotein, and maintained at 34°C, 5% CO₂ and 95% O₂. The cultured LC was used in this study.

Two experiments were conducted to evaluate the ability of the testosterone production of the cultured LC. The first experiment measured the testosterone production of plain LC (10⁵ cells / ml) incubated for 3 days with different concentrations of hCG and three steroidogenic precursors. For

the second experiment, LC was treated with hCG and 3 steroidogenic precursors for 1, 2 and 3 days to measure the effectiveness of different time spans on the stimulation of daily testosterone production. The concentration of hCG and each of the precursors used in this experiment were determined by the first experiment.

Steroid hormone concentrations were measured with the enzyme immunoassay (EIA) (Yamauchi *et al.* 1999; Pereira *et al.* 2005); testosterone concentrations with IMMULITE 2000 assay (Siemens Medical Solutions Diagnostics Pte Ltd, 5210 Pacific Concourse Drive, Los Angeles, CA, USA) using a commercial kit (EIA L2KTW2, Simens Medical Solutions Diagnostics Pte Ltd). The Quality of Siemens Medical Solutions Diagnostics Pte Ltd was certified to ISO 13485: 2003, and the cross-reactivities of the antiserum were 100% testosterone, 2.0% 5 α -dihydrotestosterone, 0.5% 5 α -androstan-3 β , 17 β -diol, 0.6% androstenedione, 0% 5 α -androstan-3,17-dione, less than 1% cholesterol and pregnenolon. Assay sensitivity was 0.2 ng/ml, and the inter- and intra- assay coefficients of variation were 5.1 and 7.2%, respectively. The IMMULITE 2000 assay was an automatic two-site sandwich immunoassay with chemiluminescent detection (Owen and Roberts 2004).

All values were given as the means \pm SEM. Statistical significance between the mean values was assessed by Student's t-test with the significant level at $P < 0.05$.

Results

Experiment 1

The testosterone production by LC *in vitro* increased with the increase in concentrations of

hCG and three steroidogenic precursors for all 3 deer species studied. There was a sharp increase in the production when the concentrations reached the particular levels of 0.5 IU/ml for hCG, 10³ nM for 25-OH-cholesterol, 10³ nM for pregnenolone, and 10² nM for androstenedione. Although the production continued to increase when the concentrations were over these levels, they were considered as the minimum effective concentrations and used in Experiment 2 for the sensibility enhancement experiment to differentiate the effectiveness among the treatments. Results also showed that at the same concentration, androstenedione resulted in higher testosterone production than the other two precursors (Table 1).

Experiment 2

Productions of testosterone by LC in all treatments were low and showed no significant differences on the first 2 days of the incubation, but increased significantly on the 3rd day. The quantity of the testosterone produced on the 3rd-day was higher for the 25-OH-cholesterol treatment than that of the androstenedione treatment, indicating that there was a better stimulation of testosterone production by precursors at the later stage of the steroidogenic process (Table 2).

Discussion

Seasonal changes in testosterone production of male cervids have been known to be regulated by photoperiod through the hypothalamus-pituitary-gonad axis (Sempéré *et al.* 1992; Lincoln and Kay 1979; Kameyama *et al.* 2002). It has been showed that LH is required for the maintenance of LC-specific functions, and thus, it is the main physiological factor controlling the LC's production

Table 1. Comparison¹ of the average testosterone production (nM/3 days) of cultivated Leydig cells (LC; 10⁵ cells /ml) purified from hard-antlered male sambar deer, sika deer and muntjacs, and treated with various concentrations of human chorionic gonadotropin (hCG), 25-OH-cholesterol (cholesterol), pregnenolone, and androstenedione (sample size, 3 animals for each of the three species).

Treatments	Sambar deer		Sika deer		Muntjac	
	Average	SD	Average	SD	Average	SD
LC	0.76 ^a	0.10	0.97 ^a	0.13	0.90 ^a	0.10
LC+hCG 0.05 IU/ml	0.73 ^a	0.03	0.80 ^a	0.06	0.87 ^a	0.14
LC+hCG 0.50 IU/ml	1.46 ^b	0.10	1.53 ^b	0.14	2.11 ^b	0.07
LC+hCG 1.00 IU/ml	1.73 ^c	0.07	1.77 ^c	0.03	2.22 ^b	0.21
LC+hCG 2.00 IU/ml	2.29 ^d	0.21	2.11 ^d	0.14	3.54 ^c	0.10
LC	0.73 ^a	0.03	0.73 ^a	0.03	0.87 ^a	0.07
LC+Cholesterol 10 ² nM	0.83 ^a	0.14	0.76 ^a	0.10	0.94 ^a	0.10
LC+Cholesterol 10 ³ nM	0.87 ^a	0.14	0.83 ^a	0.14	0.90 ^a	0.10
LC+Cholesterol 10 ⁴ nM	1.98 ^b	0.24	1.94 ^b	0.35	2.81 ^b	0.62
LC+Cholesterol 10 ⁵ nM	3.61 ^c	0.17	2.81 ^b	0.66	3.71 ^b	0.38
LC	0.73 ^a	0.03	0.73 ^a	0.03	0.73 ^a	0.07
LC+Pregnenolone 10 ² nM	0.78 ^a	0.17	0.90 ^b	0.14	0.94 ^b	0.14
LC+Pregnenolone 10 ³ nM	0.90 ^a	0.14	0.90 ^b	0.14	0.97 ^b	0.14
LC+Pregnenolone 10 ⁴ nM	1.87 ^b	0.42	1.98 ^c	0.21	3.33 ^c	0.76
LC+Pregnenolone 10 ⁵ nM	2.95 ^b	1.04	3.02 ^c	1.11	3.57 ^c	0.87
LC	0.73 ^a	0.07	0.73 ^a	0.03	0.73 ^a	0.07
LC+Androstenedione 10 ¹ nM	0.83 ^a	0.14	0.90 ^b	0.14	0.97 ^b	0.10
LC+Androstenedione 10 ² nM	2.01 ^b	0.14	2.63 ^c	0.14	2.91 ^c	0.14
LC+Androstenedione 10 ³ nM	5.69 ^c	0.17	8.36 ^d	0.14	9.12 ^d	0.52
LC+Androstenedione 10 ⁴ nM	8.91 ^d	0.03	9.81 ^e	0.52	11.72 ^e	0.28

¹ Difference in the superscript letters, a, b, c, and d indicating significant difference (t-test, p<0.05) in average testosterone production between two concentrations of the same treatment and species.

Table 2. Comparison¹ of daily average testosterone productions (nM) during the three-day incubation of cultivated Leydig cells (LC; 10^5 cells /ml) purified from hard-antlered male sambar deer, sika deer and muntjacs, and treated with human chorionic gonadotropin (hCG; 0.50 IU/ml), 25-OH-cholesterol (Cholesterol; 10^3 nM), pregnenolone (10^3 nM) and androstenedione (10^2 nM) (sSample size, 3 animals for each of the three species)

Treatments and incubation period (days)	Sambar deer		Sika deer		Muntjac	
	Average	SD	Average	SD	Average	SD
LC (1 day)	0.00 ^a	0.00	0.00 ^a	0.00	0.00 ^a	0.00
LC (2 days)	0.00 ^a	0.00	0.00 ^a	0.00	0.00 ^a	0.00
LC (3 days)	0.69 ^b	0.00	0.69 ^b	0.00	0.76 ^b	0.03
LC+hCG (1 day)	0.69 ^a	0.00	0.69 ^a	0.03	0.69 ^a	0.03
LC+hCG (2 days)	0.83 ^a	0.17	0.73 ^a	0.03	0.87 ^a	0.17
LC+hCG (3 days)	1.39 ^b	0.07	1.42 ^b	0.07	1.56 ^b	0.17
LC+ Cholesterol (1 day)	0.69 ^a	0.03	0.73 ^a	0.07	0.73 ^a	0.03
LC+ Cholesterol (2 days)	0.78 ^b	0.03	0.73 ^a	0.03	0.76 ^a	0.03
LC+ Cholesterol (3 days)	1.46 ^c	0.10	1.49 ^b	0.10	1.70 ^b	0.10
LC+Pregnenolone (1 day)	0.69 ^a	0.00	0.76 ^a	0.07	0.73 ^a	0.03
LC+Pregnenolone (2 days)	0.87 ^b	0.14	0.83 ^a	0.14	0.90 ^b	0.07
LC+Pregnenolone (3 days)	3.47 ^c	0.73	4.47 ^b	0.94	6.24 ^c	0.69
LC+Androstenedione (1 day)	0.94 ^a	0.21	1.04 ^a	0.00	0.94 ^a	0.21
LC+Androstenedione (2 days)	1.63 ^b	0.49	1.39 ^a	0.35	1.80 ^b	0.66
LC+Androstenedione (3 days)	18.13 ^c	0.83	16.92 ^b	0.87	21.95 ^c	2.11

¹ Difference in the superscript letters, a, b, and c, indicating significant difference (t-test, $p < 0.05$) in daily average testosterone productions between two incubation periods (days) of the same treatment and species.

of testosterone (Saez 1994; Dufau 1998).

In this study although the isolated LC spontaneously secreted small amounts of testosterone 3 days after culture, it produced more testosterone at any length of the culture with either one of hCG and three steroidogenic precursors (Table

2). The results demonstrated that there were positive effects of the hCG and steroidogenic precursors on the production of testosterone by deer LC. It has been found that the testosterone production of LC is enhanced with LH or its analog hCG for mice (Scott *et al.* 1989) and rats

(Ciampani *et al.* 1992; Tsai *et al.* 2003; Zirkin and Chen 2000), and with steroidogenic precursors, 25-OH-cholesterol (10^{-5} M~ 10^{-7} M), pregnenolone (10^{-5} M~ 10^{-7} M) and androstenedione (10^{-5} M~ 10^{-7} M) for rats (Tsai *et al.* 2003).

The results of this study also showed that testosterone biosynthesis was enhanced at greater rate by the precursors synthesized later in the steroidogenic pathway than those synthesized at the earlier stages. This was particularly true with respect to androstenedione. Two possible explanations for this phenomenon are provided herein. It was possible that the 3-day incubation period used in this study was too short to allow those products in early steroidogenic process to exhibit their effectiveness. It might be also due to the fact that androstenedione is more important precursor than the others in the biosynthetic pathway of testosterone production.

Finally, we have not only developed a useful LC system to detect androgen production *in vitro* biosynthesis for male deer, but also a technique might be useful for further understanding the functions of the LC of cervids. It might also applicable in studies of the receptor expressions of gonadotropins (LH and FSH), prolactin, and other peptide hormones, as well as of effects of drugs or pollutants on androgen production of LC of animals with reproduction seasonality.

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References

- Allen, J. A., T. Shan Kara, P. Janus, S. Buck, T. Diemer, K. H. Hales and D. B. Hales. 2006. Energized, polarized, and actively respiring mitochondria are required for acute Leydig cell steroidogenesis. *Endocrinology* 147: 3924-3935.
- Asher, G. W., D. K. Berg, S. Beaumont, C. J. Morrow, K. T. O'Neill and M. W. Fisher. 1996. Comparison of seasonal changes in reproductive parameters of adult male European fallow deer (*Dama dama dama*) and hybrid Mesopotamian \times European fallow deer (*D. d. mesopotamica* \times *D. d. dama*). *Animal Reproduction Science* 45: 201-215.
- Bubenik, G. A., E. Reyes, S. Dieter, A. Lobos and L. Bartos. 1996. Seasonal level of LH, FSH, Testosterone and prolactin in adult male Pudu (*Pudu pudu*). *Comparative Biochemistry Physiology* 115: 417-420.
- Blottner, S., O. Hingst and H. H. D. Meyer. 1996. Seasonal spermatogenesis and testosterone production in roe deer (*Capreolus capreolus*). *Journal of Reproduction and Fertility* 108: 299-305.
- Chen, H., M. P. Hardy and B. R. Zirkin. 2002. Age-related decreases in Leydig cell testosterone

- production are not restored by exposure to LH *in vitro*. *Endocrinology* 143: 1637-1642.
- Ciampani, T., A. Fabbri and M. L. Dufau. 1992. Growth hormone-releasing hormone is produced by rat Leydig cell in culture and acts as a positive regulator of Leydig cell function. *Endocrinology* 131: 2785-2792.
- Dufau, M. L. 1998. The luteinizing hormone receptor. *Ann. Rev. Physiol.* 60: 461-496.
- Goeritz, F., M. Quest, A. Wagener, M. Fassbender, A. Broich, T. B. Hildebrandt, R. R. Hofmann and S. Blottner. 2003. Seasonal timing of sperm production in roe deer: interrelationship among changes in ejaculate parameter, morphology and function of testis and accessory gland. *Theriogenology* 59: 1487-1502.
- Gómez, J. A., A. J. Garcia, T. Landete-Castillejos and L. Gallego. 2006. Effect of advancing births on testosterone until 2.5 years of age and puberty in Iberian red deer (*Cervus elaphus hispanicus*). *Animal Reproduction Science* 96: 79-88.
- Kameyama, Y., A. Miyamoto, S. I. Kobayashi, T. Kuwayama and Y. Ishijima. 2002. Annual changes in serum LH and testosterone concentrations in male sika deer (*Cervus nippon*). *Journal of Reproduction and Development* 48: 613-617.
- Li, C., Z. Jiang, G. Jiang and J. Fang. 2001. Seasonal changes of reproductive behavior and fecal steroid concentrations in Père David's Deer. *Hormones and Behavior* 40: 518-525.
- Lincoln, G. A. and R. N. B. Kay. 1979. Effect of season on secretion of LH and testosterone in intact and castrated red deer stags (*Cervus elaphus*). *Journal of Reproduction and Fertility* 55: 75-80.
- Loudon, A. S. I. and J. D. Curlewis. 1988. Cycles of antler and testicular growth in an seasonal tropical deer (*Axis axis*). *Journal of Reproduction and Fertility* 83: 729-738.
- Midzk, A. S., J. Liu, B. R. Zirkin and H. Chen. 2007. Effect of myxothiazol on Leydig cell steroidogenesis: inhibition of luteinizing hormone-mediated testosterone synthesis but stimulation of basal steroidogenesis. *Endocrinology* 148: 2583-2590.
- Monfort, S. L., J. L. Brown, M. Bush, T. C. Wood, C. Wemmer, A. Vargas, L. R. Williamson, R. J. Montail and D. E. Wildt. 1993. Circannual inter-relationships among reproductive hormones, gross morphometry, behavior, ejaculate characteristics and testicular histology in Eld's deer stages (*Cervus eldi thamin*). *Journal of Reproduction and Fertility* 98: 471-480.
- Owen, W. E. and W. L. Roberts. 2004. Performance characteristics of the IMMULITE 2000 erythropoietin assay. *Clinica Chimica Acta* 340: 213-217.
- Payne, A. H. and D. B. Hales. 2004. Overview of steroidogenesis enzymes in the pathway from cholesterol to active steroid hormones. *Endocrine Reviews* 25: 947-970.
- Pei, K., K. Foresman, B. T. Liu, L. H. Hong and Y. L. Yu . 2009. Testosterone levels in male Formosan Reeve's muntjac: uncoupling of the reproductive and antler cycles. *Zoology Studies* 48: 120-124.
- Pereira, R. J. G., J. M. B. Duarte and J. A. Negrão. 2005. Seasonal changes in fecal testosterone concentrations and their relationship to the reproductive behavior, antler cycle and grouping patterns in free-ranging male Pampas deer (*Ozotoceros bezoarticus bezoarticus*). *Theriogenology* 63: 2113-2125.
- Rolf, H. J. and K. Fischer. 1996. Serum testosterone,

5 α -Dihydrotestosterone and different sex characteristics in male fallow deer (*Cervus dama*): Along-term experiment with accelerated photoperiods. *Comparative Biochemistry Physiology* 115: 207-221.

Saez, J. M. 1994. Leydig Cells: Endocrine, Paracrine, and Autocrine Regulation. *Endocrine Reviews* 15: 574-626.

Scott, I. S., H. M. Charlton, B. S. Cox, C. A. Grocock, J. W. Sheffield and P. J. O'Shaughnessy. 1989. Effect of LH injection on testicular steroidogenesis, cholesterol side-chain cleavage P450 mRNA content AND Leydig cell morphology in hypogonadal mice. *Journal of Endocrine* 125: 131-138.

Sempéré, A. J., R. Mauget and G. A. Bubenik. 1992. Influence of photoperiod on seasonal pattern of secretion of luteinizing hormone and testosterone and on the antler cycle in roe deer (*Capreolus capreolus*). *Journal of Reproduction and Fertility* 95: 693-700.

Tsai, S. C., C. C. Lu, C. S. Lin and P. S. Wang. 2003. Antisteroidogenic action of hydrogen peroxide on rat Leydig cells. *Journal of Cellular Biochemistry* 90: 1276-1286.

Yamauchi, K., S. Hamasaki, Y. Takeuchi and Y. Mori. 1997. Assessment of reproductive status of sika deer by fecal steroid analysis. *Journal of Reproduction and Development* 43: 221-226.

Yamauchi, K., S. Hamasaki, Y. Takeuchi and Y. Mori. 1999. Application of enzyme immunoassay to fecal steroid analysis in Sika Deer (*Cervus nippon*). *Journal of Reproduction and Development* 45: 429-434.

Zirkin, B. R. and H. Chen. 2000. Regulation of Leydig cell steroidogenic function during aging. *Biology of Reproduction* 63: 977-981.

A Taxonomical Study of the Genus *Medicago* (Fabaceae) from Mt. Hohuan of Taiwan

合歡山苜蓿屬(豆科)植物之分類

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Abstract

The genus *Medicago* (Fabaceae) comprises 83 to 87 species in the world, of which three species have been reported from Taiwan. These are *Medicago lupulina* L. and *Medicago polymorpha* L., two naturalized species to the northern Taiwan at elevations below 700 m, and *Medicago sativa* L., a cultivated species. We conducted a field survey of *Medicago* at Mt. Hohuan of Taiwan at elevations between 2,500 m to 3,000 m. Four weedy species were found, namely *Medicago lupulina*, *M. polymorpha*, *M. arabica* (L.) Huds., and *M. minima* (L.) Bartal., Among them *M. arabica* and *M. minima* are new records to the flora of Taiwan. This paper briefly describes the four species with a key to the species, their photographs, and draws of two newly recorded species for aiding in identification.

摘要

苜蓿屬植物為豆科的一個屬共有 83-87 種。台灣植物誌第二版記載了 2 歸化種及 1 栽培種，紀錄上 2 歸化種皆分布於 700 m 以下的低海拔。本研究報導合歡山區海拔 2,500~3,000 m 的苜蓿屬植物，共記錄有 4 歸化種，分別為褐斑苜蓿(*Medicago arabica* (L.) Huds.)、天藍苜蓿(*M. lupulina* L.)、小苜蓿(*M. minima* (L.) Bartal.)與苜蓿(*M. polymorpha* L.)，其中褐斑苜蓿與小苜蓿為台灣新歸化種。本文提供合歡山區所產野生苜蓿屬的檢索表，新歸化種素描圖，4 歸化種的描述、分布及彩色照片。

Key words: Fabaceae, *Medicago*, *Medicago arabica*, *Medicago minima*, new records, Taiwan

關鍵詞：豆科、苜蓿屬、褐斑苜蓿、小苜蓿、新紀錄、台灣

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Introduction

Urban (1873) first published a comprehensive monograph of the genus *Medicago* that comprised 46 species worldwide. The number of species in the genus has been expanded recently to 83 to 87 (Small and Jomphe 1989; Lewis *et al.* 2005; Steele *et al.* 2010). *Medicago* belongs to the subtribe Trigonellinae of the tribe Trifolieae in the family Fabaceae which includes two more genera *Trigonella* and *Melilotus*. The native ranges of most of the species are in countries bordering to or nearby the Mediterranean Sea, the Arabian Peninsula, Iraq, and the eastern Balkans (Maureira-Butler *et al.* 2008). Using morphological characters of fruits, flowers and seedlings, Small and Jomphe (1989) developed the most recent classification system of *Medicago* and proposed 12 sections and 8 subsections.

In Taiwan three species of *Medicago* have been reported (Huang and Ohashi 1993). Among them *Medicago lupulina* L. and *Medicago polymorpha* L. are naturalized to northern Taiwan on open sandy seashores and field lands at elevations of less than 100 m for the former and on the open wastelands at elevations to about 700 m for the latter. *Medicago sativa* L. is native to Europe and the western Asia. It is a cultivated species to Taiwan.

We conducted a field survey of *Medicago* at Mt. Hohuan at elevations of 2,500 m to 3,000 m. Four weedy species were found: namely *Medicago lupulina*, *M. polymorpha*, *M. arabica* (L.) Huds., and *M. minima* (L.) Bartal. Among them the latter two species are newly recorded to the flora of Taiwan, while the latter three and *M. sativa* L. (Small and Jomphe 1989) are common to be encountered most likely. This paper briefly describes the taxonomic accounts of the four species of

Medicago from Mt. Hohuan, and provides with a key to the species, their color field photographs,

and draws of two newly recorded species for aiding in identification.

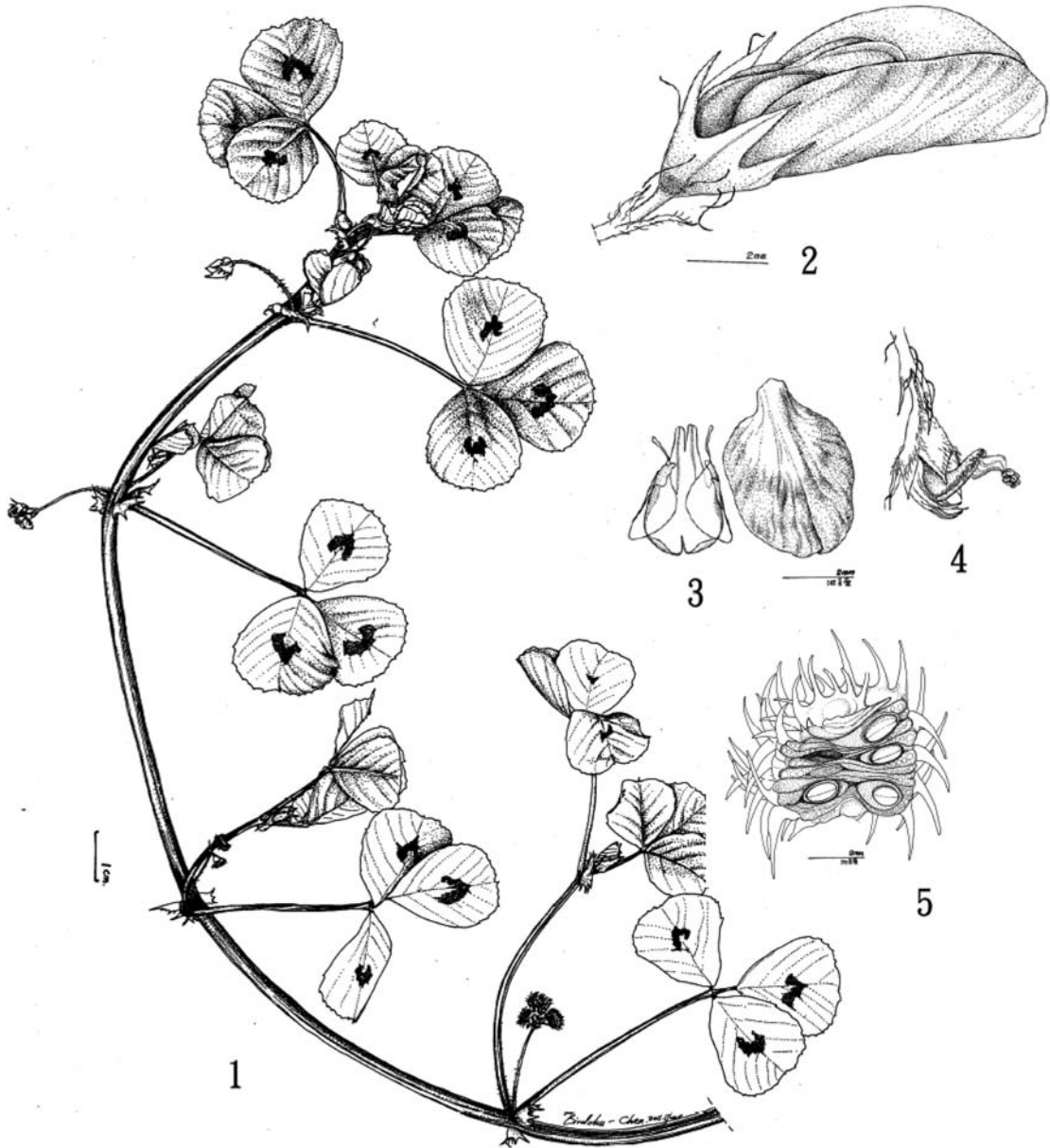


Fig. 1. *Medicago arabica* (L.) Huds. (1, habit; 2, flower; 3, corolla ; 4 and 5, fruits).

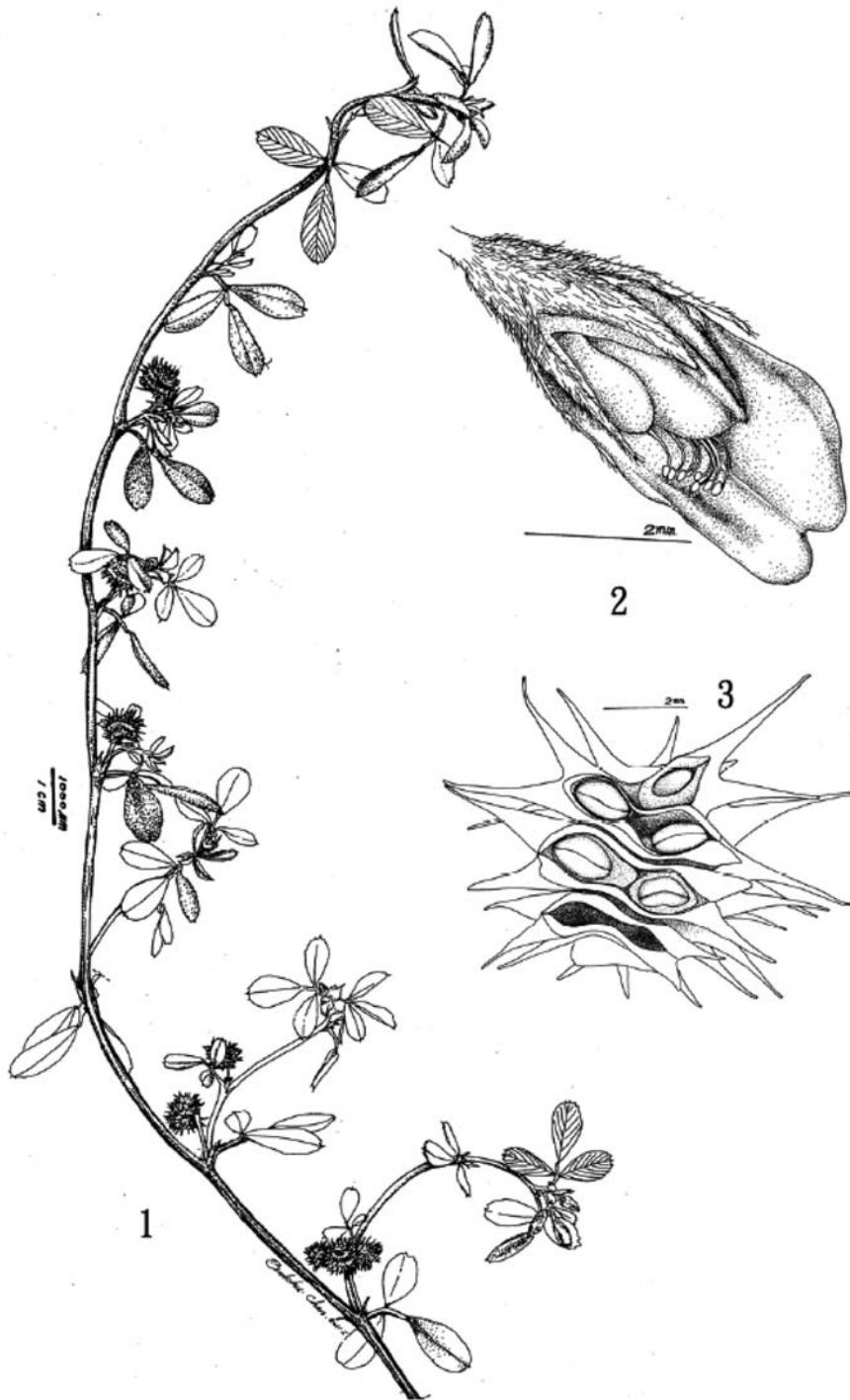


Fig. 2. *Medicago minima* (L.) Bartal. (1, habit; 2, flower; 3, fruit).

Taxonomic Treatment

Medicago L. 苜蓿屬

Medicago L., Sp. Pl. 2: 778. 1753, *nom. et typ. cons.* Type: *Medicago sativa* L.

A key to the species of the genus *Medicago* from Mt. Hohuan of Taiwan

- 1. Pods spineless; invariably 1-seeded.....section *Lupularia*
*M. lupulina*
- 1. Pods spiny; 2-several-seeded.....section *Spirocarpos*
 - 2. Plants pubescent; stipules entire.....*M. minima*
 - 2. Plants glabrous; stipules dissected.
 - 3. Leaflets unblotched; spines on pods straight.....*M. polymorpha*
 - 3. Leaflets often anthocyanin blotched; spines on pods retrorse.....*M. arabica*

***Medicago arabica* (L.) Huds.**, Fl. Angl. 288.

1762. 褐斑苜蓿 Figs.1, 3 (A,B), 4A, 5A

Medicago polymorpha var. *arabica* L., Sp. Pl. 2: 780. 1753.

Lectotype: "*Medica cochleata minor polycarpus annua capsula majore, alba, folio cordato, macula fusca notato*" in Morison, Pl. Hist. Univ. 2: 154. s.2, t.15, f. 17. 1680.

Description: Procumbent herbs. Young stems glabrous, light green, brown pubescent, 4-angled, 2-2.8 mm diameter. Petioles green, cylindrical, ridged, shallowly grooved adaxially, 3-4.5 cm long, 0.7-1 mm diameter. Stipules 2, lanceolate, 8.3-9.5 mm long, 4.3-5 mm wide, margin deeply serrate. Leaves ternate, 5-7.5 cm long, 3.5-4.9 cm wide; leaflets obovate, chartaceous, green on both surfaces, with a V-shaped black blotch at center adaxially, glabrous adaxially, sparsely brown pubescent abaxially, 1.5-2.3 cm long, 1.5-2 cm wide; apex rounded or retuse, mucronate at tip; base cuneate; margin entire 1/2-2/3 proximal to base, obtuse-serrate for the rest; midrib impressed adaxially and elevated abaxially, lateral veins pinnate, ca. 5-7 pairs. Inflorescences axillary, cyme, 14-22 mm long. Peduncles cylindrical, green,

slender, brown pubescent, 9.3-14.8 mm long. Pedicels cylindrical, green, slender, ca. 0.6 mm long. Bract 1, lanceolate, green, glabrous, ca. 1 mm long. Buds elongate-columnar, slightly deplanate, slightly oblique, yellow, 5-5.4 mm long, 1.3-1.6 mm wide, ca.1.2 mm high.

Flowers yellow, papilionaceous. Calyx cupulate, green, sparsely brown pubescent, ca. 1.3 mm long, ca.1.5 mm across; quinque-lobed, each part linear, ca. 1.3-1.4 mm long, green, sparsely light brown pubescent. Standard 1, orbicular, yellow, white at base, ca. 4.8 mm long, ca. 3.4 mm wide, retuse at apex, sessile at base; wings 2, subobovate, slightly oblique, yellow, ca. 2 mm long, ca. 1.4 mm wide, base white and stalked, stalk ca. 1 mm long. Keel 1, yellow, base white, ca. 3.6 mm long, ca. 2.7 mm wide. Stamens diadelphous, borne inside petals; filaments fused into tube, white, glabrous, ca. 3.5 mm long; anthers yellow. Ovary 1, deplanate-columnar, green, hypogynous, ca. 2.3 mm long, ca. 0.6 mm wide, densely and finely white pubescent; style green-white, slightly curved, ca. 0.7 mm long; stigma capitate; parietal placentation; ovules few, globose, translucent.

Pods coiled into globose, ca. 4.8 mm long,

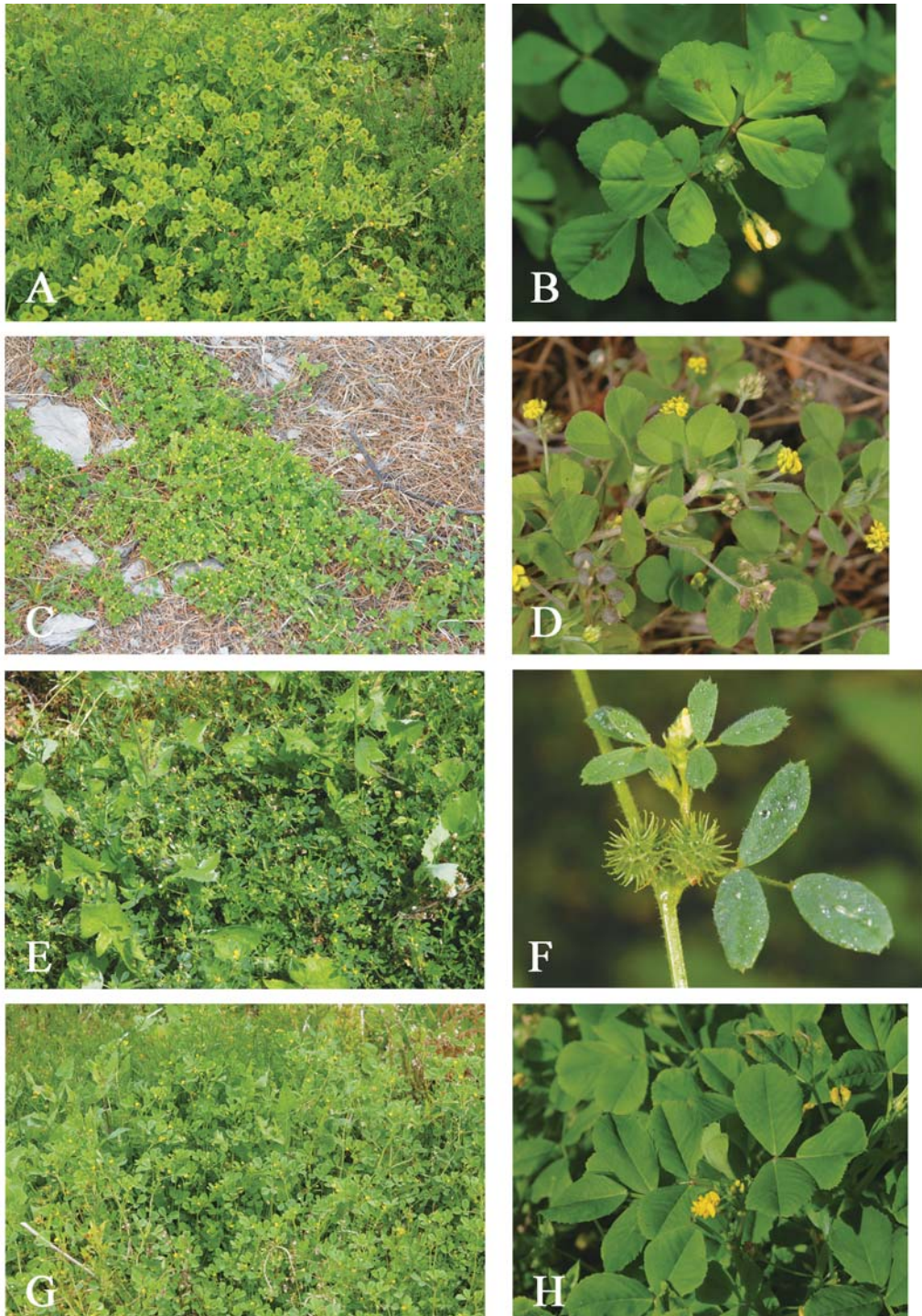


Fig. 3. Habitats of the *Medicago* species (A and B, *Medicago arabica* (L.) Huds.; C and D, *Medicago lupulina* L.; E and F, *Medicago minima* (L.) Bartal.; G and H, *Medicago polymorpha* L.).

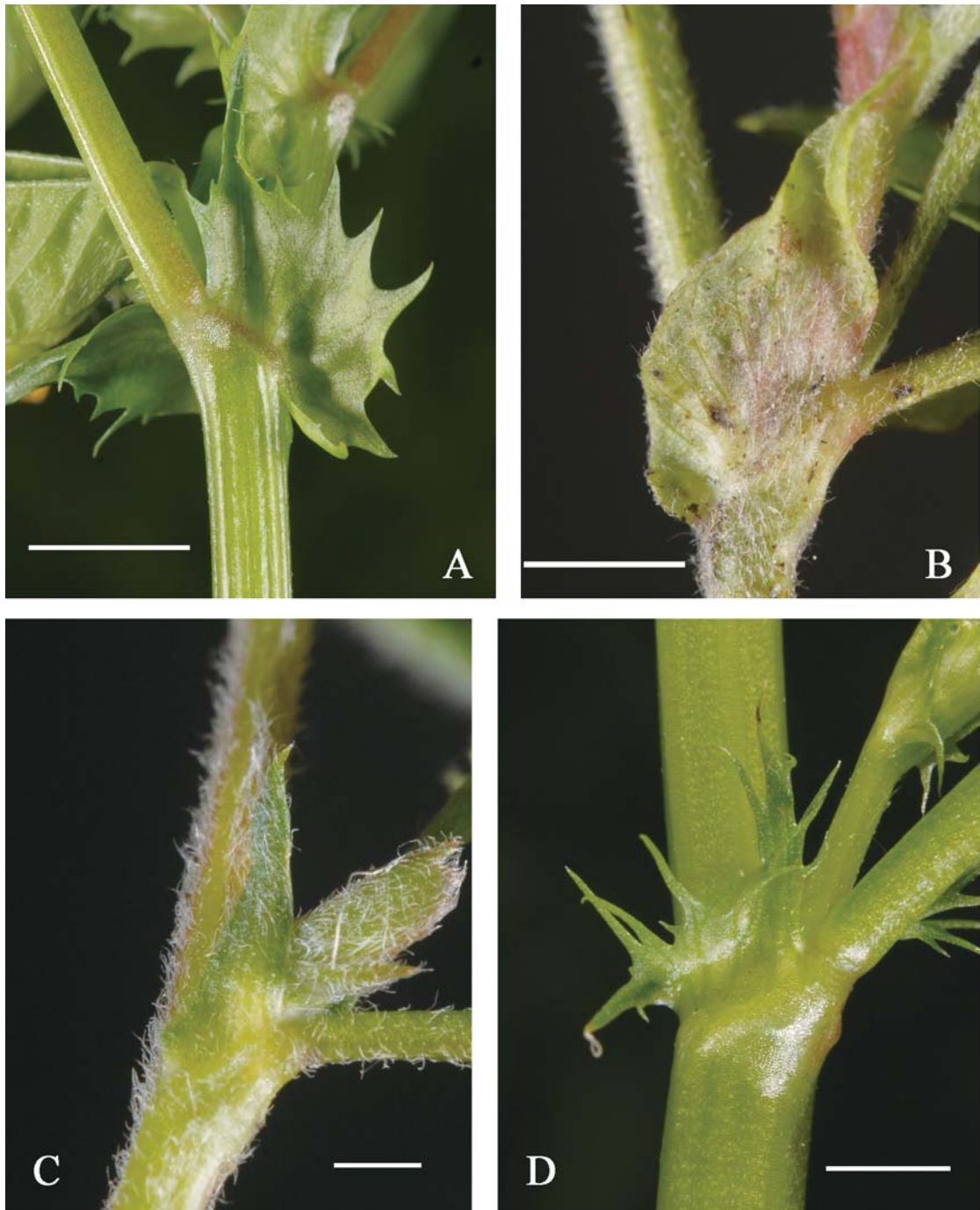


Fig. 4. Stipules of the *Medicago* species (A, *Medicago arabica* (L.) Huds, bar=4 mm; B, *Medicago lupulina* L., bar=3 mm; C, *Medicago minima* (L.) Bartal, bar=1 mm; D, *Medicago polymorpha* L., bar=3 mm).

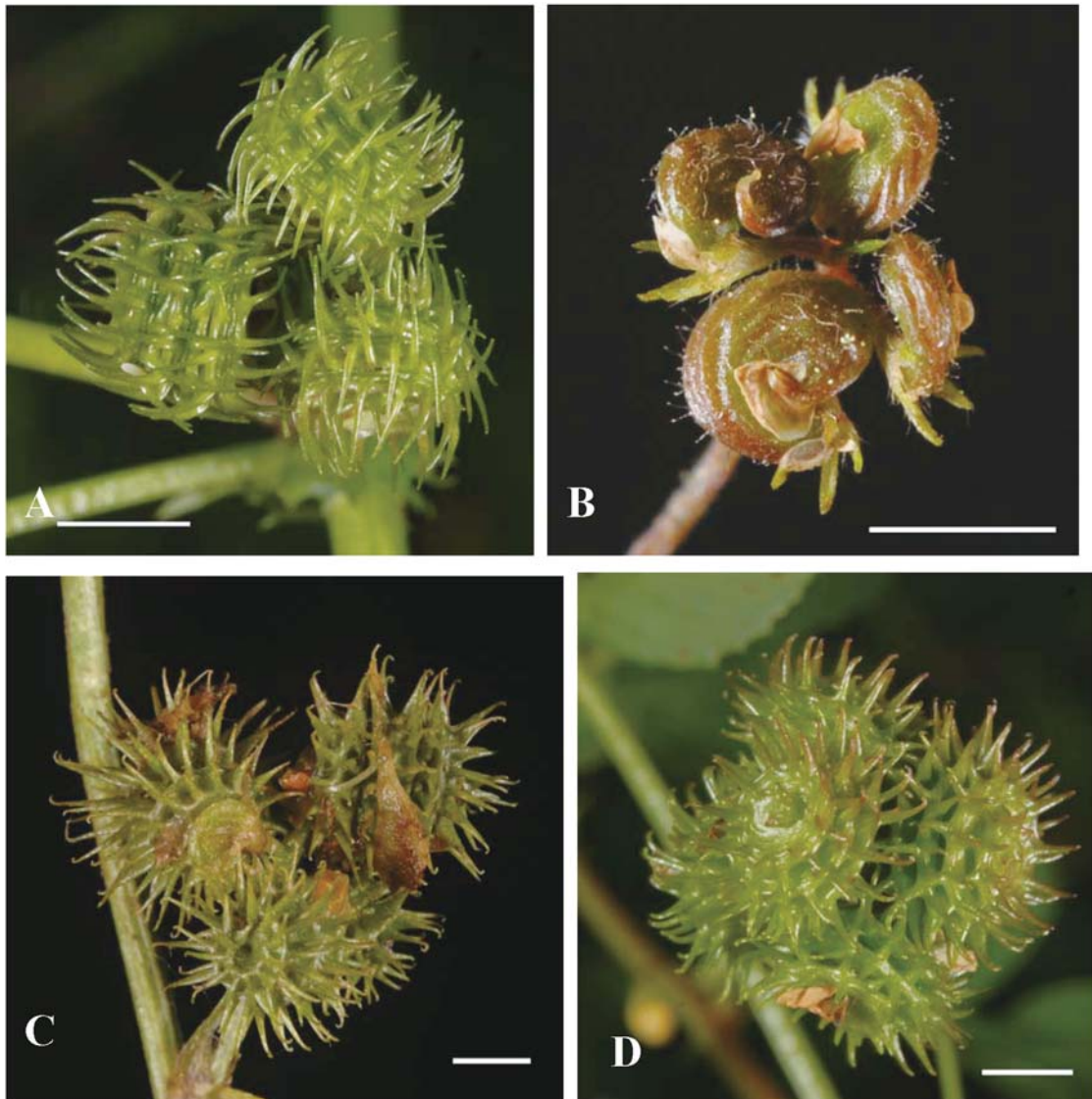


Fig. 5. Fruits of the *Medicago* species (A, *Medicago arabica* (L.) Huds., bar=5 mm; B, *Medicago lupulina* L., bar=3 mm; C, *Medicago minima* (L.) Bartal, bar=2.5 mm; D, *Medicago polymorpha* L., bar=2.5 mm).

ca. 6.4 mm wide; style, calyx, and bract persistent; exocarp green spinose, spines ca. 2.4 mm long. Fruit peduncle ca. 16.5 mm long, ca. 0.6 mm across, sparsely brown villous. Carpodium ca. 1.3 mm long, ca. 0.6 mm across, green, subglabrous. Seeds ca. 6-7, reniform, glabrous, 2.5-3 mm long,

1.5-1.9 mm wide, ca.0.8 mm high.

Specimen examined: TAIWAN. Hualien County: Hsiulin, Hohuan Farm, , 31 May 2011, *Hsu 16913* (TAIE).

Distribution and notes: *Medicago arabica* is widely distributed in Eurasia and Africa (Small and Jomphe 1989). It was collected from the open wasteland at Mt. Hohuan: a new record to the flora of Taiwan. It has been speculated that it was probably introduced accidentally to the Hohuan farm with vegetable seeds. The plants associated with it at its habitat were *Medicago polymorpha* L., *Capsella bursa-pastoris* (L.) Medic., *Rorippa sylvestris* (L.) Besser, *Artemisia indica* Willd., and *Sonchus oleraceus* L.

Medicago lupulina L., Sp. Pl. 2: 779. 1753; Huang & Ohashi, Fl. Taiwan, ed. 2. 3: 332. 1993. 天藍苜蓿 Figs. 3 (C,D), 4B, 5B

Lectotype: Herb. Linn. No. 933.10 (LINN)

Description: Procumbent herbs. Stem 4-angled, green, densely light-brown pubescent, ca. 1.6-2 mm in diameter. Leaves ternate, 1.5-2 cm long, 2-2.5 cm wide. Petioles cylindrical, grooved adaxially, densely light-brown pubescent, 2.7-4.5 mm long, ca. 0.8 mm diameter; petiolules brown, subsessile. Stipules 2, sublanceolate, 4.5-8 mm long, ca. 3-3.4 mm wide, margin green, grading to lighter color inward, 2/3-1/2 basal part fused with petioles. Leaflets orbicular or suborbicular, green on both surfaces, all brown pubescent, 1-2 cm long, 1-1.5 cm wide; Apex rounded and mucronate; base rounded or cuneate; margin entire from base to ca. 2/3, the rest shallowly serrate; midrib impressed adaxially and elevated abaxially, lateral veins pinnate, ca. 5-9 pairs.

Inflorescences axillary, short raceme, ca. 1.3-3 cm long, with flowers ca. 15-18, small. Peduncles slender, cylindrical, green, densely brown pubescent, 12.3-22.9 mm long. Pedicels ca. 0.5 mm long, slender, green, pubescent. Bract 1,

linear-lanceolate, ca. 0.6 mm long. Buds deplanate-subcylindric, slightly oblique, yellow, ca. 2 mm long, ca. 1 mm wide, ca. 0.8 mm high. Calyx tube elongate-cupulate, green, tinged brown at base, ca. 0.9 mm long, ca. 0.7 mm across; lobes 5, partite, linear, green, 1-1.4 mm long. Standard 1, suborbicular, yellow, tinged green at base, ca. 2.1 mm long, ca. 1.8 mm wide, glabrous; wings 2, suboblong, yellow, white-stalked at base, total length ca. 1 mm, ca. 0.4 mm wide, glabrous; keel 1, ca. 1 mm long, yellow, white at base, glabrous. Stamens diadelphous, borne inside petals; filaments fused into a white tube, ca. 0.6 mm long; anthers yellow. Ovary 1, oblate, green, glabrous, hypogynous, ca. 0.4 mm long, ca. 0.3 mm wide; style white-green, cylindrical, slightly curved and hooked, ca. 0.7 mm long, ca. 0.3 mm wide; stigma discoid; ovule 1, ellipsoid, light green, glabrous. Infructescence raceme. Carpopodium ca. 1 mm long, slender, finely pubescent.

Pods slightly curved, discoid, green, exocarp crisp, finely pubescent, ca. 2.9 mm long, ca. 3.2 mm wide, ca. 1.2 mm high, calyx and style persistent. Seed 1, depressed ellipsoid, green, glabrous, 1.5-2 mm long, ca. 1.3 mm wide, ca. 0.6 mm high.

Specimen examined: TAIWAN. Hualien County: Provincial Road 14A, 38 Km, 31 May 2011, *Hsu 16910* (TAIE).

Distribution and notes: *Medicago lupulina* is native to Europe and West Asia (Small and Jomphe 1989). It is naturalized to low elevation areas of Taiwan (Huang and Ohashi 1993). In Mt Hohuan it was found along roadsides.

Medicago minima (L.) Bartal., Cat. Piante Siena

61. 1776. 小苜蓿 Figs. 2, 3 (E,F), 4C, 5C
Medicago polymorpha var. *minima* L., Sp. Pl. 2:
780-781. 1753.

Lectotype: "*Medica echinata, minima*" in Bauhin
& Cherler, *Historia plantarum universalis* 2:
386. 1651.

Description: Procumbent herbs. Stems slender, green, cylindric, 4-ridged; white to light-brown pubescent the whole plant. Leaves ternate, 1.5-2 cm long, 1.5-2.2 cm wide. Petioles hemicylindric, slightly grooved adaxially, green, 2.7-3.2 mm long, ca. 0.8 mm diameter; petiolules yellow, ca. 0.6 mm long, ca. 0.5 mm across, all pubescent. Stipules 2, lanceolate, green, 3.5-4 mm long, ca. 1.3 mm wide. Leaflets elongate-obovate or elliptic, chartaceous, green on both surfaces, ca. 1 cm long, ca. 0.5 cm wide, white pubescent on both surfaces; apex rounded; base cuneate; margin subentire, mucronate and 1-2-fids at apex, 1st fid deeper than 2nd fid; lateral veins pinnate, ca. 6-7 pairs. Inflorescences axillary, umbel, flowers 2-3. Peduncles cylindric, green, white pubescent, ca. 1.7-2.7 mm long, ca. 0.4 mm across. Pedicels slender, cylindric, green, white pubescent, ca. 0.5 mm long. Bract 1, ovate, minute, tripartite, green, white pubescent. Buds ellipsoid, yellow, ca. 3.4 mm long, ca. 1.2 mm wide.

Flowers papilionaceous, yellow. Calyx tube cupulate, green, ca. 1.5 mm high; qinate, each part linear, green, hairy, 2-2.8 mm long, ca. 1.5 mm wide. Standard obovate, yellowish white, ca. 3.4 mm long, ca. 2 mm wide, retuse at apex, glabrous; wing subovate, stalked at base, upper half yellow, lower half white, glabrous, ca. 2.5 mm long, ca. 1 mm wide; keel yellow, glabrous, ca. 2.7 mm long, ca. 1.2 mm wide. Stamens diadelphous; fused filaments ca. 2.2-2.8 mm long,

tube ca. 1.5 mm long, white, glabrous; separate filament ca. 1.5 mm long; anthers yellow. Ovary 1, deplanate-columnar, green, densely white pubescent at central part; style white, slightly hooked; stigma discoid; parietal placentation, ovules ca. 5, green, translucent, globose.

Pod solitary, axillary, coiled into globose, white pubescent, ca. 6.4 mm long, ca. 7 mm across; green spinose, ca. 2.2 mm long; calyx persistent. Carpopodium green, cylindric, white pubescent, ca. 4 mm long, ca. 0.5 mm across. Seeds 3-4, reniform, green to brown, glabrous, 2.8-3.3 mm long, ca. 1.5 mm wide.

Specimen examined: TAIWAN. Taipei County: Tamshui, Shalun Beach, 26 April 2000, *Chia-Hua Lin 164* (HAST); Hualien County: Hsiulin, Hohuan Farm, 18 May 2011, *Hsu 16895* (TAIE).

Distribution and notes: *Medicago minima* is widely distributed in Europe, Asia, Africa, and parts of the New World (Small and Jomphe 1989). It was collected from open wastelands at Mt. Houhuan: a new record to the flora of Taiwan.

***Medicago polymorpha* L.,** Sp. Pl. 2: 779. 1753; Huang & Ohashi, Fl. Taiwan, ed. 2. 3: 332. 1993. 苜蓿 Figs. 3 (G, H), 4D, 5D

Lectotype: Herb. Clifford: 378, *Medicago II* (BM-000646786)

Description: Procumbent herbs. Stems green, 4-ridged; glabrous the whole plant. Leaves ternate, alternate, 2.5 cm long, ca. 4 cm wide. Petioles 1.2-3.1 cm long; petiolule of terminal leaflets 2.0-6.2 mm long; petiolule of lateral leaflets 0.5-1.3 mm long; all green and grooved adaxially.

Stipules 2, ovate, green, glabrous, fused on petiole, 5.6-6.6 mm long, 6.2-8.3 mm wide, margin deeply serrate. All leaflets chartaceous, green adaxially, pale green abaxially, margin entire from base to ca. 1/2, irregularly obtuse-serrate the rest 1/2; midrib impressed adaxially, elevated and sparsely white pubescent abaxially; lateral veins pinnate, ca. 13 pairs. Terminal leaflets obovate, 1.4-2.2 cm long, 1-1.6 cm wide; apex obtuse or sometimes truncate; base cuneate. Lateral leaflets elliptic, 1.3-2.2 cm long, 0.7-1.4 cm wide; apex rounded, base cuneate. Inflorescences axillary and terminal, short raceme, 2-4 flowers clustered. Peduncle slender, green, 12-23 mm long, ca. 0.15-0.26 mm across. Pedicels green, 0-0.8 mm long, ca. 0.16 mm across. Bracts light green, narrowly deltoid, 0.9-1.7 mm long, ca. 0.5 mm wide. Buds curved fusiform, yellow, 4.9-5.9 mm long, 1.9-2.5 mm wide.

Flowers papilionaceous, yellow, semiopen. Calyx tube campanulate, green, 3.3 mm long, 3.3 mm wide, 5-lobed; lobes deltoid, 1.8 mm long, 0.7 mm wide. Standard yellow, folded in half, falcate, 5.6 mm long, 2.6 mm wide; wings 2, yellow, elliptic, bipartite at base, 3.5 mm long, 1.8 mm wide; keel 1, white and bipartite (linear) at base, yellow and bipartite at apex. Stamens diadelphous, filaments white translucent. Basal 1/2 of the nine grouped-stamens fused into a translucent concave sheet, 0.2-0.3 mm long; Filament of the separate stamen slender, white translucent, 1.7 mm long; anthers translucent, punctiform. Ovary 1, curved and slightly helicoid, green, 1-celled, hypogynous; style white, ca. 0.4 mm long; stigma punctiform, light brown; parietal placentation; ovules 5-7, ellipsoid.

Pods solitary or 2-4 in short raceme, clustered. Fruit peduncle green, 2.5-3.5 cm long; carpopodium green, 2.6-4.2 mm long, ca. 0.5 mm across. Pods

spiral-shaped, 2-4-turns overlapped into a cylinder, densely deltoid spinose on abaxial suture; spines 1.3-1.5 mm long, hooked at apex. Pods 6-7.5 mm across, 3-4.6 mm high, turning from green to light brown when ripe, indehiscent. Seeds 4-7, deplanate-ovoid or deplanate-ellipsoid, green, 4-5.1 mm long, 2.1-2.5 mm wide, 1.2-1.7 mm thick.

Specimen examined: TAIWAN. Hualien County: Hsiulin, Hohuan Farm, 21 June 2011, *Hsu 16987* (TAIE).

Distribution and notes: *Medicago polymorpha* is an indigenous to Eurasia and Africa, and widely introduced to be adventive elsewhere (Small and Jomphe 1989). It is naturalized to open wastelands at elevations below 700 m in the northern Taiwan (Huang and Ohashi 1993). In this study it was collected at open wasteland of Mt. Hohuan at an elevation above 2,500 m.

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Literature Cited

- Huang, T. C. and H. Ohashi 1993. Leguminosae. In editionrial Committee of the Flora of Taiwan, 2nd ed., Flora of Taiwan. Vol. 3: 160-396.
- Lewis, G., B. Schrire, B. Mackinder and M. Lock. 2005. Legumes of the world. Royal Botanic Gardens, Kew, UK.
- Maureira-Butler, I. J., B. E. Pfeil, A. Muangprom,

- T. C. Osborn and J. J. Doyle. 2008. The reticulate history of *Medicago* (Fabaceae). *Systematic Biology* 57: 466-482.
- Small, E. and M. Jomphe 1989. A synopsis of the genus *Medicago* (Leguminosae). *Canadian Journal of Botany* 67: 3260-3294.
- Steele, K P, S M Ickert-Bond, S. Zarre and M F Wojciechowski. 2010. Phylogeny and character evolution in *Medicago* (Leguminosae): Evidence from analyses of plastid trnK/matK and nuclear GA3ox1 sequences. *American Journal Botany* 97(7): 1142-1155.
- Urban, J. 1873. Prodröm einer Monographie der Gattung *Medicago* L. *Verhandlungen des Botanischen Vereins für die Provinz Brandenburg* 15: 1-85.

Merremia cissoides (Lam.) Hallier f. (Convolvulaceae),
a Newly Naturalized Plant to Taiwan

台灣旋花科之新歸化植物—蔓生菜欒藤

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Abstract

This paper describes the exotic *Merremia cissoides* (Lam.) Hallier f. as a new record to Taiwan. It is a Neotropical plant whose native home is in tropical America. Recently it was found on the road sides in central Taiwan. A key to its related species in the genus *Merremia* of Taiwan and color photographs taken from its natural habitat are provided for aiding in identification.

摘要

本文記錄原產於中南美洲之外來種植物—蔓生菜欒藤(*Merremia cissoides* (Lam.) Hallier f.)近年已歸化於中臺灣，提供形態描述及彩色照片以利本種實務鑑定之用。

Key words: naturalized plant, *Merremia cissoides*, Convolvulaceae, Taiwan.

關鍵詞：歸化植物、蔓生菜欒藤、旋花科、臺灣

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Introduction

Introduction of exotic plants been rapidly increased recently with human assistance and improvement in transportation. The results are their wide dispersion, even globalization in distribution of some of the species, causing ecological problems in many parts of the world. According to the revised Flora of Taiwan (Staples and Yang 1998), there were 14 genera and 44 species of the morning-glory family Convolvulaceae in Taiwan, 1998. Since then, for 12 years of botanical inventory surveys of the island, seven more species and two more varieties have been added. Up to date there are a total of 53 species including at least 23 alien species of the morning-glory family in Taiwan (Wu *et al.* 2010; Tsai *et al.* 2010).

The genus *Merremia* Dennst. *ex* Endl. is consisted of approximately 80 species worldwide. They are distributed pantropically, and commonly characterized with yellow or white, campanulate corolla, spirally twisted anther thecae and smooth (non-echinate) pollen grains, but a few of the species have yellow corolla, usually funnelform or somewhat less commonly salverform, straight anthers, and spiny pollen like those of *Ipomoea* (Austin 1980; Staples and Yang 1998; Demissew 2001). For *Merremia* in Taiwan seven species

were reported in the first edition of Flora of Taiwan in 1978, and one more species, *Merremia dissecta* (Jacq.) Hallier f. was added as a naturalized species in 2010 (Tsai *et al.* 2010). The delimitation of "alien naturalized species" was still unclear in Taiwan (Chen 2008; Wu *et al.* 2010).

Recently, we found that *M. cissoides* (Lam.) Hallier f. which is a Neotropical species has naturalized to Taichung City of the central Taiwan. So far it was found in two districts, Chingshui (清水) and Shalu (沙鹿), along the top of roadway slopes (Fig. 1 A) of the National Highway No. 3. at elevations of 194-207m. We speculated that it was likely introduced to these location from commercial mixed seeds of grasses used for soil and water conservation. It was first collected in 2008, and has successfully established its population and expanded to nearby areas. *M. cissoides* is easily distinguishable from its con-generic species by having sticky glandular hairs, palmately compound with 5 leaflets, serrated leaf margin and showy white flowers.

This paper provides its taxonomic description, a key to its related species in the genus *Merremia* in Taiwan, and colored photographs taken from its natural habitat (Fig. 1) for aiding in identification.

Taxonomic Treatment

Merremia cissoides (Lam.) Hallier f., Bot. Jahrb. Syst. 16: 552. 1893. 蔓生菜欒藤 Fig.1
Convolvus cissoides Lam., Tabl. Encycl. 1: 462. 1791.
Ipomoea cissoides (Lam.) Griseb., Fl. Brit. W. I. 473. 1864.

Description: Herbaceous vines with milky sap; Stems terete, slender, twining, but often also prostrate, covered in all parts with densely short glandular hairs and scattered long patent hairs; Leaves alternate, long-petiolate, 1-4.5 cm long, palmately compound with 5 leaflets; leaflets sessile, elliptic, ovate or ovate-lanceolate, 4.5-2.2 cm long, margins serrate, apex acute to acuminate, base cuneat. Inflorescences axillary, solitary or 2- to several-flowered cymes (Fig. 1 B); peduncle variable in length; Bracts linear to linear-lanceolate, 1-1.7 cm long, pedicel 4-7 mm long. Calyx with 5 sepals, convex, 1.8-2 cm long, unequal; outer 2 bigger, revolute, deltoid, 9-10 mm wide; apex long-acuminate, base obtuse; middle one asymmetrical, ca. 5 mm wide; inner 2 smaller, ovate-lanceolate to lanceolate, 4-5 mm wide (Fig. 1 C). Corolla white, campanulate, 2.1-2.6 cm across, limb slightly 5-lobed. Pistil included. Ovary glabrous, 4-celled, 4-ovulated, Style 1, stigmas 2-globular, white; stamens 5, included, unequal, anthers light purple, spirally twisted; Capsules depressed-globose, stramineous, 8-10 mm long across, 3- or 4-valved, with persistent sepals (Fig. 1 D); Seeds dark brown to black,

covered with grayish-tomentose. Flowering and fruiting in August to November.

Distribution: Native to Tropical America and naturalized to West Africa (Lejoly and Lisowski 2001), India (Biju and Mathew 1993), Ceylon (Austin 1980), Thailand (Staples *et al.* 2005) and Taiwan.

Specimens examined: Taichung City, Taiwan: Shalu Landfill at 24°14' 05" E, 120°35' 34" N (TWD 97), elevation 207 m; Lifan Village, Shalu District, 26 Aug. 2008, *Y.-N. Ko 1630* (HAST, PPI, TAIF); 24°16' 07" N, 120°35' 24" E, elevation 194 m; Wucho Village, Chingshui District, 11 Nov. 2011, *Y.-N. Ko 1641* (HAST, PPI, TAIF).

Ecology: At the collection site, *M. cissoides* was growing in open grassy fields or along roadsides (Fig. 1A), associated with *Panicum maximum* Jacq., *Rhynchelytrum repens* (Willd.) C. E. Hubb., *Bidens pilosa* L. var. *radiata* Sch., *Ipomoea biflora* (L.) Persoon, *Cynodon dactylon* (L.) Pers. and *Acasia confusa* Merr. It have slender and twining stems, forming thickets or growing over associated plants, even competing with dominant and aggressive weedy species, *P. maximum*, in the Tadusan area. It was found that its seedlings have successfully established (Fig. 1 E.) and expanded to nearby areas. The Global Compendium of Weeds (Randall, 2011) has labeled it as a weed based on five pieces of literature. However, it could not exempt it as a possible noxious invader. A further study is needed to evaluate its impact on natural environments in Taiwan.

A Key to the species of the genus *Merrmia* of Taiwan with leaves palmately compounded and with 5-7 leaflets

1. Corolla yellow.....*M. tuberosa* or *M. vitifolia*
1. Corolla white.
 2. Leaflets irregularly pinnately lobed to parted.....*M. dissecta*

2. Leaflets not irregularly pinnately lobed to parted.
 3. Leaflets entire; outer sepals ovate to oblong.....*M. quinata*
 3. Leaflets serrate; outer sepals deltoid *M. cissoides*

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Literature Cited

- Austin, D. F. 1980. Convolvulaceae. pp. 288-363. *In*: M. D. Dassanayake and F. R. Fosberg (eds.). A revised handbook to the flora of Ceylon. Vol. 1, Oxonian Press Pvt. Ltd., Fari-dabad, India.
- Biju, S. D. and P. Mathew. 1993. *Merremia cissoides* (Convolvulaceae): a new record for India. *Journal of the Bombay Natural History Society* 90: 121-122.
- Chen, S. H. 2008. Naturalized plants of Eastern Taiwan. National Hualien University of Education, Hualien.
- Demissew, S. 2001. A synopsis of the genus *Merremia* (Convolvulaceae) in the Flora of Ethiopia and Eritrea. *Kew Bulletin* 56: 931-943.
- Lejoly, J. and S. Lisowski. 2001. *Merremia cissoides* et *M. quinquefolia* (Convolvulaceae), espèces synanthropiques nouvelles pour la flore du Bénin. *Acta Botanica Gallica* 148: 151-157.
- Randall, R. P. 2011. A global compendium of weeds (<http://www.hear.org/gcw/>).
- Staples, G. W., B. N. Songkhla, C. Khunwasi and P. Traiperm. 2005. Annotated checklist of Thai Convolvulaceae. *Thai Forest Bulletin, Botany* 33: 171-184.
- Staples, G. W. and S. Z. Yang. 1998. Convolvulaceae. pp. 341-384. *In*: T. C. Huang *et al.* (eds.). *Flora of Taiwan*, 2nd ed., Vol. 4. Editorial Committee of the Flora of Taiwan, Taipei, Taiwan.
- Tsai, Y. C., P. J. Lee, Y. H. Chang and T. H. Hsieh. 2010. *Merremia dissecta* (Jacq.) H. Hallier., a newly naturalized species in Taiwan. *Journal of Ecology and Environmental Sciences* 3 (2): 1-7. (in Chinese)
- Wu, S. H., T. Y. Aleck Yang, Y. C. Teng, C. Y. Chang, K. C. Yang and C. F. Hsieh. 2010. Insights of the latest naturalized flora of Taiwan: change in the past eight years. *Taiwania* 55 (2): 139-159.

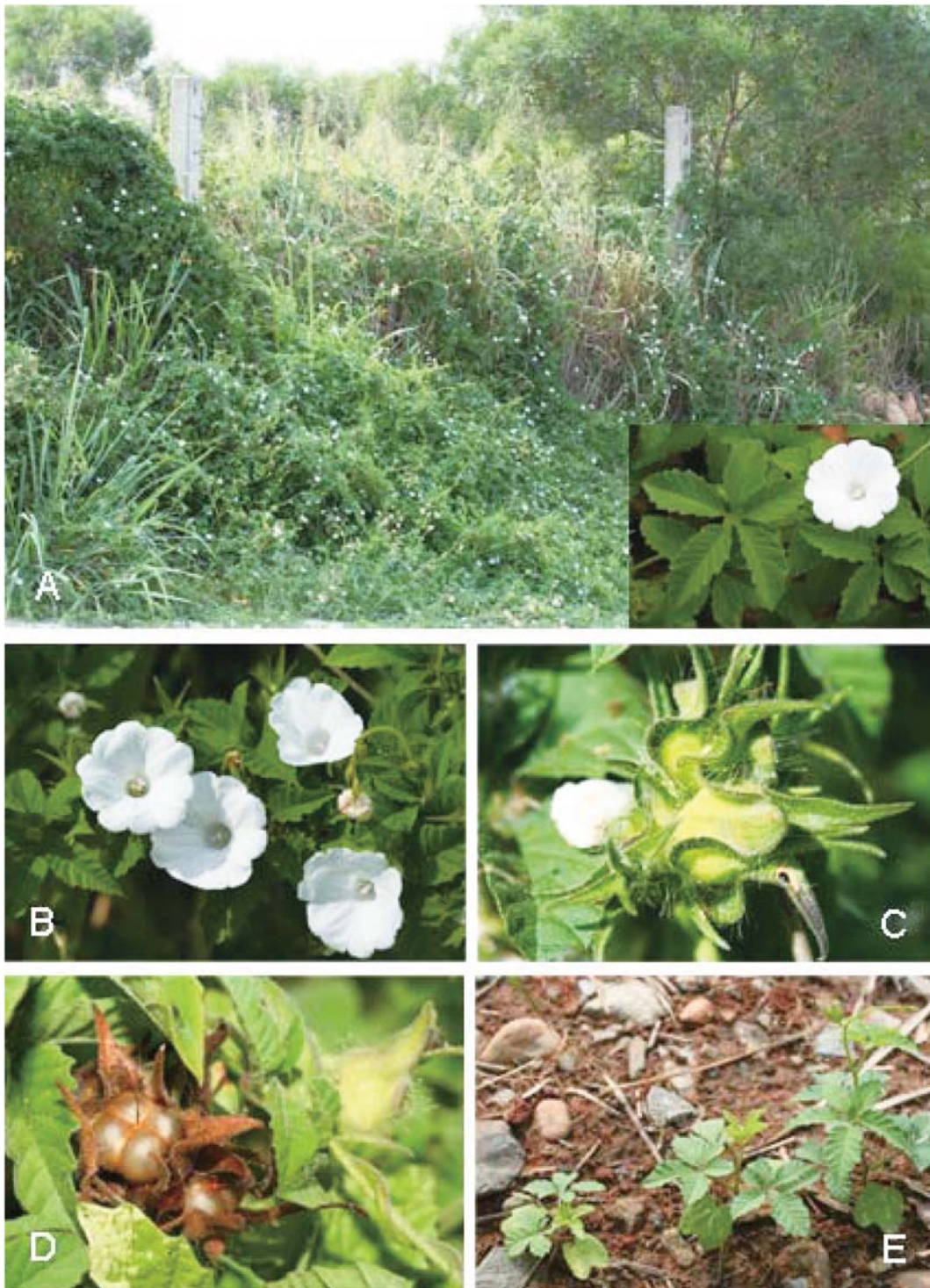


Fig. 1. *Merremia cissoides* (Lam.) Hallier f. (A, habitat; B, inflorescence; C, infructescence; D, capsules with persistent calyx; E, seedlings).

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