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contents

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臺灣新紀錄蕨—腺羽節蕨（冷蕨科）

Gymnocarpium jessoense (Koidz.) Koidz. (Cystopteridaceae), a Newly Recorded Fern in the Flora of Taiwan

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摘 要

本文報導臺灣冷蕨科 (Cystopteridaceae) 新紀錄蕨類植物：腺羽節蕨 (*Gymnocarpium jessoense* (Koidz.) Koidz.)，文中附有此新紀錄物種之形態描述、同物異名、圖片、引證標本、臺灣及鄰近地區羽節蕨屬 (*Gymnocarpium*) 之分類檢索表、分類群之地理分布及分類註記等資訊。

Abstract

This paper reports the fern *Gymnocarpium jessoense* (Koidz.) Koidz. as a newly recorded species in the fern flora of Taiwan. Its morphological characters, synonyms, illustrations, voucher specimens, key to *Gymnocarpium* in Taiwan and adjacent regions, geographical distribution, and taxonomic notes are presented.

關鍵詞：腺羽節蕨、羽節蕨屬、冷蕨科

Keywords：*Gymnocarpium jessoense*, *Gymnocarpium*, Cystopteridaceae

緒言

冷蕨科 (Cystopteridaceae) 羽節蕨屬 (*Gymnocarpium*) 為中小型夏綠蕨類植物。根莖細長橫走，呈黑褐色，被披針形鱗片。葉遠生，為草質或薄草質，葉柄纖細，葉卵圓形、三角狀卵形至卵狀五角形，一回羽狀深裂至四回羽狀複葉，葉片與葉柄交界處以關節相連。葉柄上部、葉軸、羽軸及葉片兩面具腺毛或無。葉游離脈，末裂片側脈單一或二叉，側脈並達邊緣。孢子囊群圓形至長橢圓形，不具孢膜，在裂片兩側各排成一行 (Wang et al. 2013；許等 2019)。

作者們在雪山山脈採集到新的羽節蕨屬物種，其在葉軸和羽軸基部 1-3 對羽片的連接處，具較多的腺毛特徵，檢閱羽節蕨屬分類檢索表之相關文獻 (Wang et al. 2013；Sarvela 1978) 及標本後，確認在雪山山脈所採集到的羽節蕨屬物種，為臺灣新紀錄種：腺羽節蕨 (*Gymnocarpium jessoense* (Koidz.) Koidz.)。

分類處理

羽節蕨屬已知有 10 種，廣布於北半球溫帶 (亞洲、北美洲、和歐洲) (Wang et al. 2013)。臺灣文獻紀錄有 2 種 (許等 2019；TPG 2019)，臺灣鄰近地區之分類群分布為 : 菲律賓 1 種 (Barcelona 2019)，中南半島不產羽節蕨屬物種 (Lindsay & Middleton 2012)，中國有 5 種 (Wang et al. 2013)，韓國有 2 種 (Park 2015)，日本有 4 種 (含 1 雜交種)(Ebihara & Kasetani 2019; 海老原 2017)，如表 1。

本文依據相關文獻 (Wang et al. 2013；Sarvela 1978)，提出臺灣及鄰近地區羽節蕨屬分類檢索表，修改如下 :

1a 葉片為一回羽狀深裂至二回羽狀深裂，孢子囊群長圓形 ……………………………………....(2)

1b 葉片二回羽狀複葉或三回羽狀複葉，孢子囊群較小，近圓形 ……………………………………(3)

2a 葉片為一回羽狀深裂 ………………………..*G. oyamense*

2b 葉片為二回羽狀深裂 …………………*G.* × *bipinnati idum*

3a 葉軸連接處 (關節) 具有較多的腺毛 ………………………………(4)

3b 葉軸通常光滑無毛，不具腺毛或僅具極稀疏的腺毛 ……………………….................(5)

4a 葉柄疏被腺毛，僅在葉軸基部和羽軸基部 1-3 對羽片的連接處 (關節) 有較多的腺毛；裂片上的側脈往往分叉 ....*G. jessoense*

4b 葉柄先端、葉軸和羽軸之遠軸面密被腺毛，其他部分亦具腺毛；裂片上的葉脈通常單一 ………………*G. robertianum*

5a 葉片卵狀五角形，呈三出狀，基部羽片的大小和葉片上部的其餘部分近相近，基羽片的基部下側小羽片和第三對羽片的大小約相等…............…...........….........….................*G. dryopteris*

5b 葉片三角狀卵形，基部羽片遠小於葉片上部的其餘部分，基羽片的基部下側小羽片和第四對羽片的大小約略相等 …………*G. remote-pinnatum*

Gymnocarpium jessoense（Koidz.）Koidz.; Acta Phytotax. Geobot. 5 : 40. 1936. 腺羽節蕨 (新擬中名) 圖 1.

Aspidium dryopteris (L.) Baumg. var. *longulum* Christ, Bull. Herb. Boissier, sér. 2, 2(10): 830. 1902; *Carpogymnia jessoensis* (Koidz.) Á. Löve & D. Löve, Univ. Colorado Stud., Ser. Biol. 24: 8, 1966; *Dryopteris jessoensis* Koidz., Bot. Mag. (Tokyo) 38: 104. 1924; *Dryopteris linnaeana* C.Chr.

var. *jessoensis* (Koidz.) C.Chr., Index Filic., Suppl. Tert.: 89, 1934; *Gymnocarpium longulum* (Christ) Kitag., Rep. Inst. Sci. Res. Manchoukuo 3(App. 1): 33,1939; *Gymnocarpium robertianum* var. *longulum* (Christ) H.Itô ex Nakai, Rep. Exped. Manchoukuo Sect. IV 4: 4, 1936; *Gymnocarpium robertianum* subsp. *longulum* (Christ) Toyok., Mem. Natl. Sci. Mus. (Tokyo) 5: 189,1972; *Lastrea jessoensis* (Koidz.) Akas., Bull. Kochi Women's Coll. 8: 31. 1960; *Lastrea robertiana* (Hoffm.) Newman var. *longula* (Christ) Ohwi, Fl. Japan Pterid.: 101,1957.

物種特徵

根莖細長橫走，葉遠生。葉柄禾稈色，基部疏被褐色鱗片，向上光滑。葉片三角狀卵形，先端漸尖，二回羽狀複葉至三回羽狀裂葉，羽片對生或近對生，斜向上，基部一對羽片最大，下部一至數對以關節著生於羽軸，基部一至二對具柄，其他通常無柄。葉脈在裂片上為游離。葉柄上部、葉軸及羽軸的關節處具有較多的腺毛。孢子囊群圓形，著生於小脈上。

引證標本

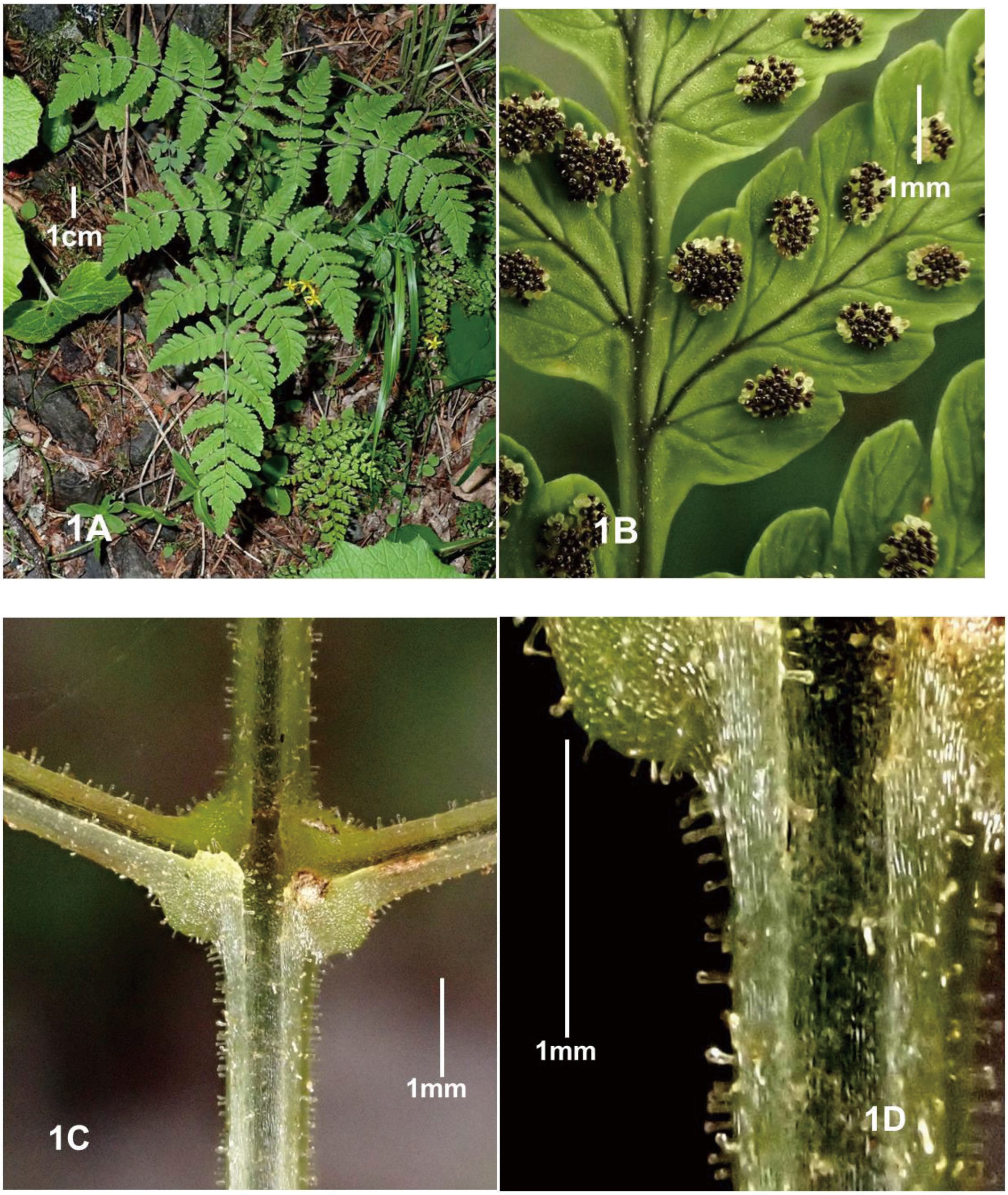
臺灣 : 臺中市 : 和平區，雪山，海拔約 3,310~3,315m，2020-07-09，*M. Y. Shen 6453* (TAIE)；中國 : 四川省，西昌至木里，2017-8-18，張憲春等 *8848* (PE)。

地理分布及生態

分布於阿富汗、巴基斯坦、尼泊爾、喜馬拉雅、西伯利亞、中國、韓國、日本等地區 (POWO 2022)，臺灣為新紀錄物種，生長於雪山山脈高海拔 3,150~3,300 公尺之林緣土坡或岩縫中，所在的緯度為本物種北半球南端。

分類註記

過往部分學者認為細裂羽節蕨 (*G. remotepinnatum*) 在葉片與葉柄交接處，不具腺毛 (Wang et al. 2013)，也有部分學者認為細裂羽節蕨在葉片與葉柄交接處有少數極稀疏的腺毛 (Ching 1933；郭 2001；Sarvela 1978)；本文作者們於合歡山所採集的幾個個體(圖 2)，經與細裂羽節蕨引證標本 (TAIE) 比對，它們都是細裂羽節蕨，在這些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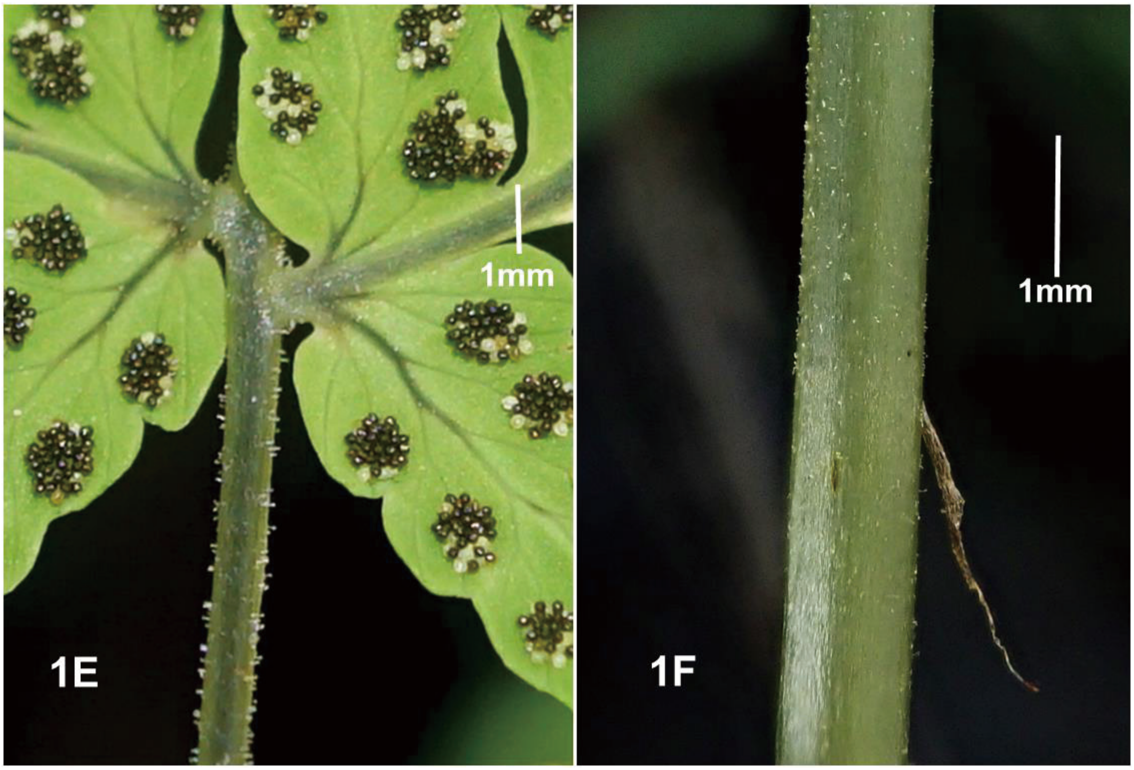

圖 1. 腺羽節蕨 (*G. jessoense*): 1A, 生育地；1B, 葉遠軸面 (孢子囊群近圓形，裂片上側脈常分叉，被稀疏腺毛)；1C, 葉軸與羽軸之關節 (具腺毛)；1D, 圖 1C 之放大 (具腺毛)；1E, 葉軸遠軸面 (具腺毛)；1F, 葉柄 (褐色鱗片)。

Fig. 1. *G. jessoense*: 1A, habitat; 1B, abaxial surface of lamina (sori orbicular, veins often forked, sparsely glandular); 1C, pinnae articulate to rachis (glandular); 1D, enlargement of Fig. 1C (glandular); 1E, rachis abaxial view (glandular); 3F, stipe (scales brown).

表 1. 臺灣及鄰近地區羽節蕨屬分類群分布

Table 1. Distributions of the genus *Gymnocarpium* in Taiwan and adjacent regions

	名稱			**羽節蕨屬分類群之分布**					
	學名	**臺灣**	**中國**	**臺灣**	**菲律賓**	**中南半島**	**中國**	**韓國**	**日本**
1	*Gymnocarpium dryopteris* (L.) Newman		歐洲羽節蕨				**V**	**V**	**V**
2	*Gymnocarpium jessoense* (Koidz.) Koidz.	腺羽節蕨	羽節蕨	**V**			**V**	**V**	
3	*Gymnocarpium oyamense* (Baker) Ching	羽節蕨	東亞羽節蕨	**V**	**V**		**V**		**V**
4	*Gymnocarpium remotepinnatum* (Hayata) Ching	細裂羽節蕨	細裂羽節蕨	**V**			**V**		
5	*Gymnocarpium robertianum* (Hoffm.) Newm = *Gymnocarpium altaycum* Chang Y.Yang		密腺羽節蕨				**V**		**V**
6	*Gymnocarpium* × *bipinnatifidum* Miyam. = *Gymnocarpium oyamense* × *Gymnocarpium robertianum*	二回羽狀羽節蕨							**V**

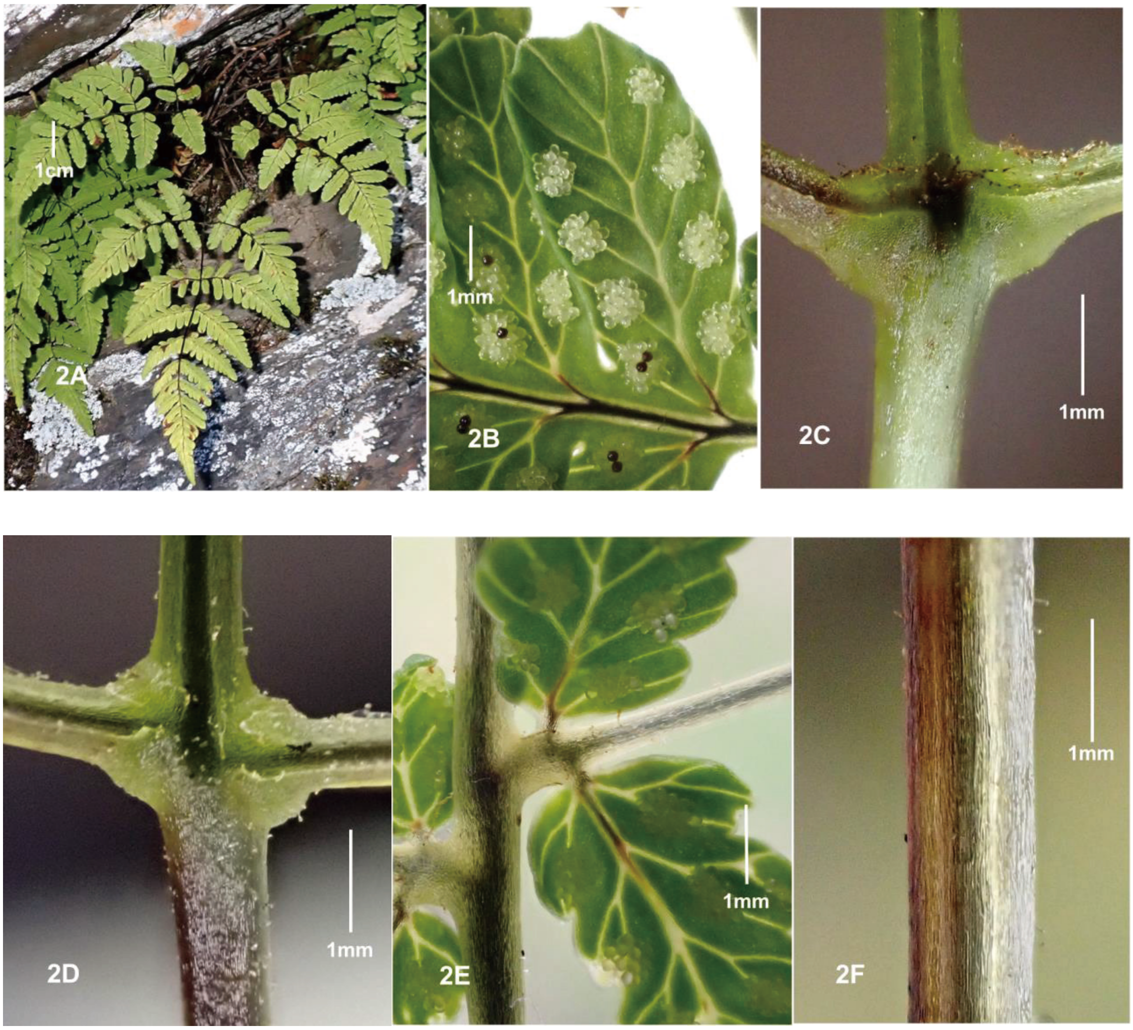

圖 2. 細裂羽節蕨 (*G. remotepinnatum*): 2A, 生育地；2B, 葉遠軸面 (孢子囊群近圓形，近無毛，無腺毛)；2C, 葉軸與羽軸之關節 (無腺毛)；2D, 葉軸與羽軸之關節 (僅具極稀疏的腺毛)；2E, 葉軸遠軸面 (無腺毛)；2F, 葉柄。

Fig. 2. *G. remotepinnatum*: 2A, habitat; 2B, abaxial surface of lamina (sori orbicular, glabrous, eglandular); 2C, pinnae articulate to rachis (eglandular); 2D, pinnae articulate to rachis (scantily glandular); 2E, rachis abaxial view (eglandular); 2F, stipe.

採集的個體中，亦有前述現象，即部分個體葉片與葉柄交接處，光滑不具腺毛，但部分個體則具極稀疏腺毛 (scantly glandular)；相對於本文作者們在雪山山脈所採集的新紀錄物種腺羽節蕨 (圖 1C-1D)，則具有較多的腺毛，此和細裂羽節蕨 (圖 2C-2D)，明顯可以觀察到兩個物種之間，有無腺毛及腺毛多寡的差異。

細裂羽節蕨引證標本

臺灣 : 花蓮縣 : 南投縣 : 信義鄉，郡大山，海拔約 3,000~3,292m，1982-11-14，*B. J. Wang 2499* (TAIE)；臺東縣 : 海端鄉，關山嶺，海拔約 2,800m，1986-07-26，*B. J. Wang 8211* (TAIE)；秀林鄉，落鷹山莊，海拔約 2,740m，1996-11-01，*T. W. Hsu 7969* (TAIE)；高雄縣 : 桃源鄉，埡口 南橫公路臺 20 線 146.3K，海拔約 2,699m，2007-10-03，*T. W. Hsu 13145* (TAIE)；南投縣 : 仁愛鄉，合歡主峰登山口 臺 14 甲線 30.7KM，海拔約 3,223m，2010-10-19，*T. W. Hsu 16378* (TAIE)。

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台灣生物多樣性研究 TW J. of Biodivers.25(3):11-33, 2023

魚塭管理強度影響冬季鳥類群聚

Management intensity of aquaculture ponds and its effects on bird assemblage during winter

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摘要

魚塭經營管理強度可能影響棲息的鳥類群聚。台灣黑面琵鷺保育學會於 2004-2017 年在台南七股地區進行長期鳥類調查；其中的魚塭樣區於 2009 年之前為低度維護管理狀態，2010 年之後則為文蛤養殖池。本研究分析該魚塭樣區十一月至翌年二月冬季鳥類資料，以了解不同魚塭管理強度對冬季鳥類群聚結構的影響。結果發現從低度維護管理魚塭轉變為高強度管理的文蛤養殖池後，鳥種數從平均 21 種減少為 12 種，總個體數從平均 688 隻，驟減為 102 隻；而游禽數量從平均 463 隻遽減為 5 隻，減幅達 99%；涉禽數量則從平均 193 隻減少為 81 隻，減幅約 58%。文蛤養殖池約 3 年曬池 1 次，研究樣區沒有因為曬池形成淺水泥灘而顯著增加涉禽數量。研究結果發現低度維護管理魚塭的鳥種多樣性非常高，應盡力保存。認為魚塭恢復水產養殖後，曬池作業可以增加涉禽的可利用棲地，則是不切實際的想法。

關鍵詞：魚塭、七股、涉禽、游禽

Abstract

Management intensity of aquaculture ponds may affect bird communities distributed in the ponds. The Taiwan Black-faced Spoonbill Conservation Association conducted a long-term bird survey project in Qigu, Tainan, Taiwan, from 2004 to 2017, with one of the sample areas being an aquaculture pond. The aquaculture pond underwent low management intensity until 2009, and was used for clam rearing after 2010. This study analyzed the survey data collected from the pond from November to February of the following year during the project timeframe to understand how different management intensities of the aquaculture pond influence bird assemblage in winter. It was found that the number of bird species decreased from an average of 21 to 12, and the total number of individuals decreased from an average of 688 to 102, while the number of waterfowl individuals decreased from an average of 463 to five, amounting to a decrease of 99%, and the number of wader individuals decreased from an average of 193 to 81, amounting to a decrease of 58%. Aquaculture ponds drained after harvesting can be used by waders. However, in this study, the clam pond was drained approximately once every three years, therefore there was no significant increase in wader abundance in the study area. The results of this study revealed that bird assemblage in an aquaculture pond with low management intensity can be relatively diverse, and this condition should be preserved as much as possible. It is unrealistic to expect that the resumption of aquaculture in ponds and the basking operation will increase available habitats for waders.

Keywords: fish farm, Qigu, wader, waterfowl

前言

近年來，東亞—澳大利亞候鳥遷移路徑 (East Asian-Australasian Flyway) 上的水鳥數量急遽下降，天然溼地的減少或退化被認為是主要因素 (Nebel *et al.* 2008; Amano *et al.* 2010; Hua *et al.* 2015; Piersma *et al.* 2016; Studds *et al.* 2017)。雖然對水鳥來說，天然溼地遠比人工溼地重要 (Ma *et al.* 2004; Sebastián-González and Green 2016)。但在天然溼地不斷減少的情況下，人工溼地在保護水鳥功能上，其重要性有增無減 (Li *et al.* 2013; Bai *et al.* 2018; Jackson *et al.* 2020)。

在台灣，魚塭被認為是遷移涉禽重要的人工溼地之一 (Lu 2004; 黃和薛 2014; Bai *et al.* 2018)。魚塭可以提供遷移涉禽利用的主要原因，在於水產物收成之後的排水曬池，會在初期形成適合涉禽利用的淺灘溼地。但淺水泥灘僅維持約 1 星期，之後就會或注水養殖下一批水產，或因持續曝曬而太乾燥，導致不適合涉禽利用。雖然可利用時間短暫，但當一地區的魚塭數量夠多且曬池時間不同步時，仍足以提供充分的人工溼地。曬池時節多在十月至翌年一月 (黃和薛 2014)，正好是候鳥在台灣的度冬期；因此，常態經營而維持週期性排水曬池的魚塭，對遷移性涉禽而言，就變成非常重要的人工溼地。

魚塭可能因故荒廢或處於低度維護管理狀態。荒廢或低度維護管理魚塭的棲地條件有別於週期性排水曬池的典型經營管理魚塭。這類魚塭通常沒有投餌、沒有水車干擾、池中有水生植物、土堤容易崩壞導致池緣坡度較緩以及水較淺、堤岸有茂密的草本植物及灌木，而且不會排水曬池，因此環境變動小。廢棄魚塭較淺的岸邊水域及濃密植物有利於鷺科 (Ardeidae) 等大型涉禽棲息。Huang (2013) 探討台灣西南沿海鷺科鳥類的棲地利用，即發現大白鷺 (*Ardea alba*) 與蒼鷺 (*Ardea cinerea*) 偏好棲息於廢棄水池。但另一方面，因為缺乏排水曬池，若蓄滿水且池緣植被茂密，廢棄魚塭就難以被小型涉禽利用。另外，因為

堤岸植物茂密且環境干擾低，廢棄魚塭通常是隱密性鳥種，例如雁鴨科 (Anatidae) 游禽的極佳棲地。Lu (2004) 研究台灣西南沿海溼地鳥類，即發現雁鴨類密集使用廢棄魚塭。

為提升再生能源比例，相關單位近年來依據「申請農業用地作農業設施容許使用審查辦法」及「行政院農業委員會養殖漁業經營結合綠能設施專案計畫審查作業要點」規定，正積極推動「養殖漁業經營結合地面型綠能設施專案計畫」，即所謂的漁電共生。漁電共生規定水產養殖收成須維持一定比例。若要在荒廢或低度維護管理魚塭進行漁電共生，則依相關辦法，可能需要復養或提高維護管理強度以增加水產物的產值。此可能改變原本接近天然溼地樣貌的魚塭之環境條件，進而影響棲息的鳥類。廢棄魚塭若復養，會因為修復堤岸與挖深池水而減損大型涉禽的可利用棲地。但也因為週期性曬池，不論大型或小型涉禽，均能增加利用魚塭的機會。

另外，復養的魚塭會清除水生植物及堤岸植被而失去隱蔽性，再加上水車打水、投餌、以及人員巡視等干擾，將使需要高隱密性棲地的游禽數量減少。因此整體而言，廢棄魚塭復養，預期：1. 小型涉禽數量增加；2. 大型涉禽數量維持不變或減少；以及 3. 游禽數量下降。無論如何，廢棄魚塭復養將如何影響其分布的鳥類群聚？那些類群的鳥類可能受益，那些則可能受到負面影響？目前仍難以具體評估。

黑面琵鷺保育學會自 2004 年 8 月起，在台南七股曾文溪出海口北岸魚塭進行定期鳥類調查。該學會調查的魚塭樣區原本為廢棄魚塭 (圖 1a)，但在 2009 年 11 月開始整地 (圖 1b) 並恢復水產養殖 (圖 1c)。此一樣區的鳥類群聚變化，提供了從廢棄到常規經營管理魚塭的轉變過程中，鳥類群聚結構如何受到影響的實證研究機會。

本研究目的在分析該項鳥類調查計畫已公開之資料，以了解魚塭由低到高強度維護管理，對鳥類群聚的影響。

圖 1. 研究樣區在 2009 年之前為 (a) 廢棄魚塭，於 (b) 2009 年 11 月整地準備養殖；2010 年之後為 (c) 有管理的養殖魚塭。(王曉琪 攝)

Fig. 1. The study area was (a) an abandoned aquaculture pond before 2009, which was (b) prepared for aquaculture in November 2009, and it became (c) a managed aquaculture pond after 2010. (Photo by Hsiao-Chi Wang)

由於魚塭主要在冬季期間曬池並形成遷移性水鳥的可利用棲地，因此僅分析冬季調查資料。研究結果將有助於未來在推展漁電共生而規劃恢復廢棄魚塭的水產養殖時，用以評估鳥類群聚受到之衝擊。

研究方法

一、鳥類與環境資料

本研究資料取自「七股地區長期鳥類調查資料集 2004-2017」(Wu and Chen 2019) 當中的 E1 及 E2 樣區 (圖 2)。E1 及 E2 樣區相鄰，位於 23.0754N、120.068E，即曾文溪出海口北岸，黑面琵鷺保護區東側；面積分別為 12 及 6 ha。E1 自 2004 年 8 月，E2 自 2005 年 8 月起，進行定期鳥類調查，每月 2 次；但 2015 年 2 月僅調查 1 次。該資料集提供之調查資料至 2017 年 7 月為止。每次調查由 1 或多名志工，以 8-12 倍雙筒望遠鏡及 / 或 32-60 倍單筒望遠鏡在定點觀察，記錄看或聽到的所有鳥類的種類及數量。

自 2005 年 8 月起，E1 及 E2 的調查在同一日的上午進行，僅 1 次於下午實施；每次耗時 30-90 min。

水深及水域面積影響涉禽可利用棲地。魚池若注滿水，則水域面積大且水深，而不利於涉禽棲息。反之，若水域面積縮減，則水淺且露出較多灘地，使涉禽可利用棲地擴增。本研究引用之資料集，除鳥類資料外，亦包含每次調查時的水域覆蓋比例估值，分為 0/4, 1/4, 2/4, 3/4, 4/4，共 5 個等級；可用以量化涉禽可利用棲地。本研究整理每次調查的水域覆蓋比例，但 2014 年 1 月 11 日及 2016 年 1 月 9 日的鳥類調查日缺乏水域覆蓋比例估值；水域面積很少在短期內劇烈變動，故以該日前後間隔約兩星期的相鄰調查日之水域覆蓋比例估值平均之。由於 E1 與 E2 樣區面積比為 2:1，因此每次鳥類調查時的總水域覆蓋比例 $W_{ratio} = W_{E1} \times 2/3 + W_{E2} \times 1/3$。其中 W_{E1} 及 W_{E2} 分別為 E1 及 E2 每次調查的水域覆蓋比例估值。

二、分析方法

為了解鳥類棲地利用與魚塭管

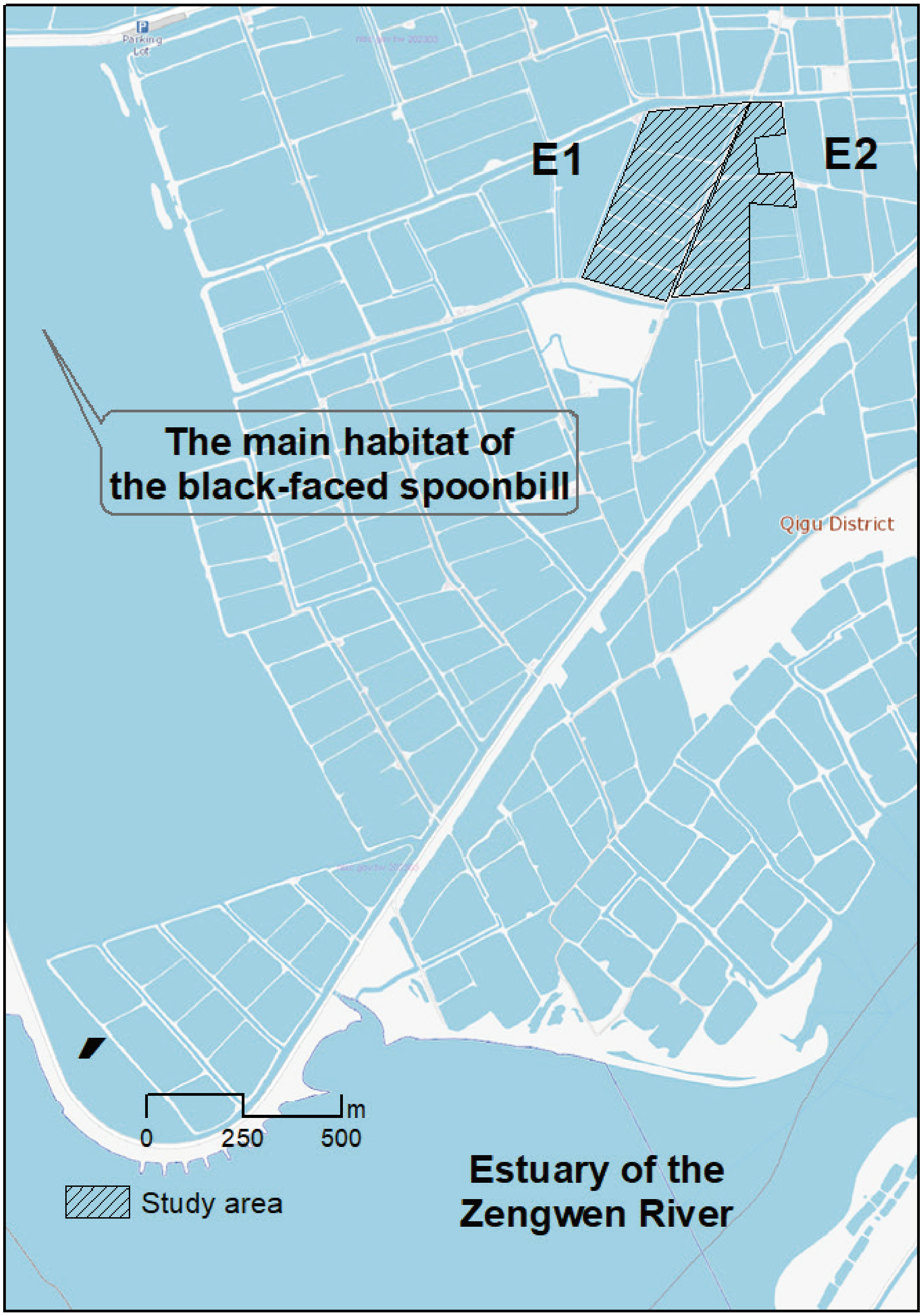

圖 2. 研究樣區位置。圖中藍色區域為水體，白色區域為道路、塭堤、裸露地或草地。

Fig. 2. Location of the study area. The blue areas in the figure are water bodies. The white areas are roads, fishpond dikes, bare land, or grassland.

理強度的關係，將調查到的鳥種依其棲地利用特性分為 6 個棲地同功群 (habitat guilds)：1. 空域鳥類 (aerial birds; 代碼 ARB)，持續在空中覓食，本研究中均為燕科 (Hirundinidae) 鳥類；2. 陸棲鳥類 (terrestrial birds; TRB)，主要在堤岸裸地、草叢、灌木或樹林棲息的鳥種；3. 俯衝食魚鳥類 (fishing birds; FSB)，由水面之上的高處俯衝水面捕食魚類，包括鷗科 (Laridae) 鳥類及翠鳥 (*Alcedo atthis*)；4. 小型涉禽 (small wading birds; SWB)，在泥灘地或淺水域涉水覓食，本研究有長腳鷸科 (Recurvirostridae)、鴴科 (Charadriidae) 及鷸科 (Scolopacidae) 鳥類；5. 大型涉禽 (large wading birds; LWB)，在泥灘地、淺或稍深水域涉水覓食，包括鷺科及䴉科 (Threskiornithidae) 鳥類；以及 6. 游禽 (waterfowl; WFL)，漂浮於水面或潛入水中覓食，雁鴨科、鸊鷉科 (Podicipedidae) 及秧雞科 (Rallidae) 鳥類屬之。

本研究取用 2005 年 8 月至 2017 年 7 月的資料。因為 E1 及 E2 相鄰且這段期間調查是同時進行的，因此合併 E1 及 E2 每次調查結果為 1 個單一樣本。將樣本的物種豐度 (species richness) 及豐富度 (abundance) 對時間作圖 (圖 3)，可以發現鳥類出現高峰在 10 月至翌年 3 月，主要組成物種是冬候鳥。由於 10 月上旬及 3 月下旬亦為候鳥過境期，很多鳥類的出現並不穩定，而有較高的隨機性，導致群聚組成波動大。為減少過境鳥對分析結果的干擾，本研究只分析 11 月至翌年 2 月資料；將這段期間定義為 1 個度冬期。例如 2005 年 11 月至 2006 年 2 月止的鳥類調查樣本，定義為 2005 年的度冬期樣本。每一個度冬期有 8 次調查，視為對該冬季鳥類群聚母體的 8 次抽樣；但 2014 年度冬期僅抽樣 7 次。魚塭在 2009 年 11 月整地，因此以 2009 年為界，將度冬期樣本分為兩階段，一是廢棄養殖池 (abandoned aquaculture pond, AAP)，其度冬期樣本時間為 2005-2008 年；另一則是復養後，有管理的養殖池 (managed aquaculture pond, MAP)，時間 2010-

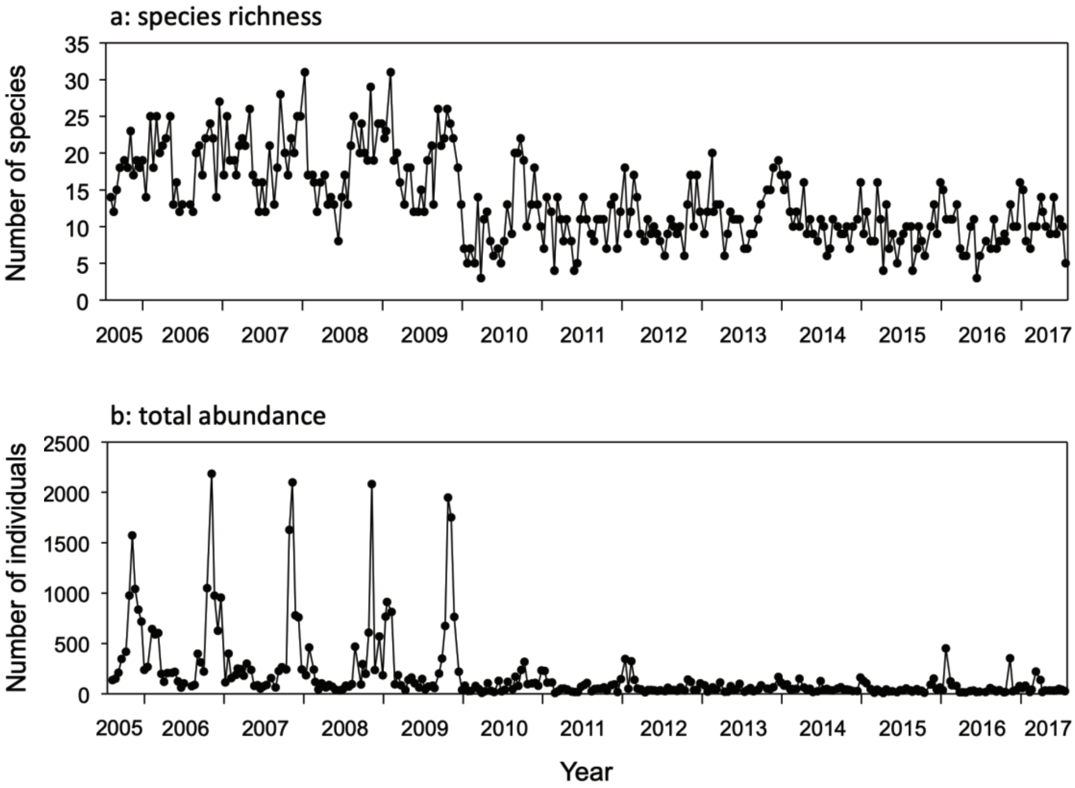

圖 3. 自 2005 年 8 月至 2017 年 7 月，研究樣區鳥類的 (a) 物種豐度及 (b) 豐富度的變化。不論物種豐度或豐富度，在 2005-2009 年之間均呈現規律地年週期變化，在冬季達到高峰，但在夏季則處於低點；惟 2009 年之後，物種豐度及豐富度均大幅減少，年週期變化不明顯。

Fig. 3. Changes in the (a) bird species richness and (b) total abundance in the study area from August, 2005 to July, 2017. Between 2005 and 2009, both species richness and total abundance showed a regular annual cycle with peaks in winter and troughs in summer; however, after 2009, both decreased significantly, and the annual cycle was not obvious.

2016年。至於整地復養的2009年之樣本，則不納入分析。

本研究以降趨對應分析 (detrended correspondence analysis, DCA) 解析 AAP 與 MAP 的冬季鳥類群聚結構差異。分析的資料期間共進行87次調查；刪除僅出現1次的稀有鳥種。鳥類個體數以 log(x+1) 進行數值轉換，再以 DCA 排序。另外，將樣本的每一棲地同功群個體數擬合至 DCA 排序軸，以了解從 AAP 到 MAP，鳥類棲地同功群的變化。

另外，以巢型變異數分析 (nested ANOVA) 比較 AAP 與 MAP 之間，以及各度冬期之間的冬季鳥類群聚的物種豐度、豐富度、各棲地同功群及各鳥種的平均個體數是否相同。各鳥種的個體數在 AAP 與 MAP 之比較，兩時期樣本數均不足10筆以上之物種不予分析。

所有分析均以 R v.4.1.3 及套件 vegan v.2.6-2 (Oksanen et al. 2022) 進行。

結果與討論

廢棄養殖池 (AAP) 與有管理養殖池 (MAP) 的冬季鳥類群聚不同。不論是物種豐度、豐富度或群聚結構 (物種組成與相對豐富度)，AAP 與 MAP 之間均有明顯差異。AAP 冬季的鳥種數及個體數顯著高於 MAP (圖 4)。在 AAP，平均每次調查可以察覺到21.4種鳥，顯著高於 MAP 的12.4種 ($F = 111.9$, $df = 1$, $p < 0.001$)。至於豐富度，AAP 每次可以察覺到688.3隻鳥，但在 MAP 每次只能察覺到101.8隻 ($F = 48.6$, $df = 1$, $p < 0.001$)。群聚結構方面，AAP 及 MAP 樣本在 DCA 前兩軸空間的分布，可以將其沿第一軸清楚劃分為兩群 (圖 5)。由於 DCA 第一軸是群聚結構的主要變異梯度軸 (Hill and Gauch 1980)；可以沿第一軸區分為不重疊的兩群，顯示 AAP 與 MAP 之間的群聚結構存在明顯差異。除了俯衝食魚鳥類豐富度的向量方向不明顯之外，其它棲地同功群的向量方向均偏向第一軸右側，也就是 AAP 樣本

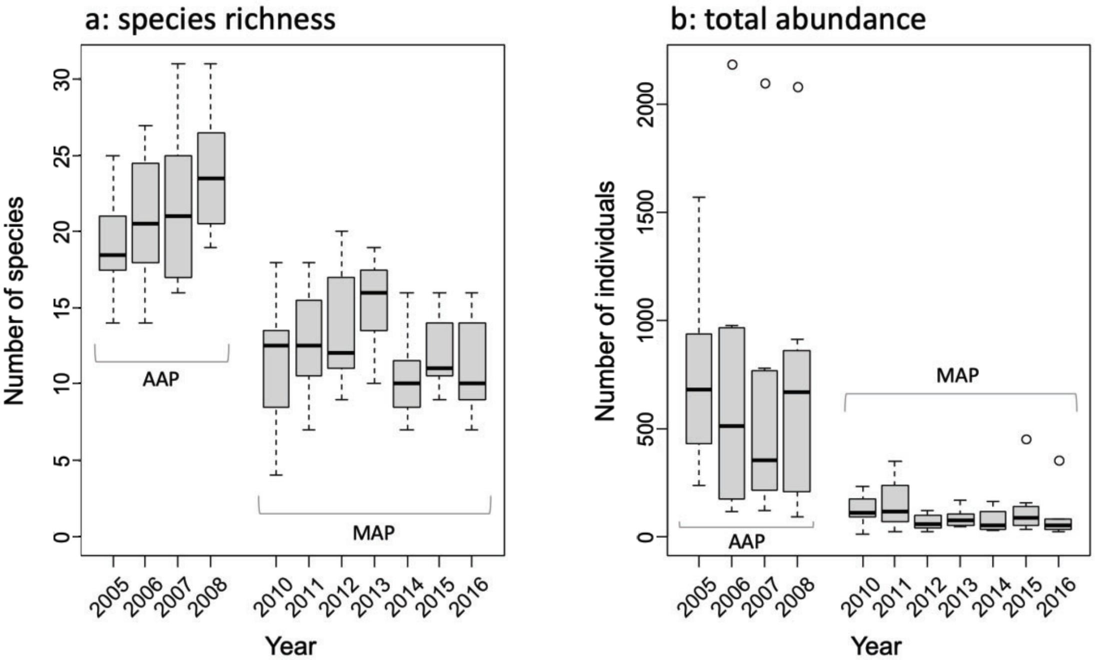

圖 4. 廢棄魚塭 (AAP) 與有管理魚塭 (MAP) 冬季鳥類的 (a) 物種豐度與 (b) 豐富度之盒形圖。不論物種豐度或豐富度，廢棄魚塭均顯著高於有管理魚塭。

Fig. 4. Box plots of (a) bird species richness and (b) abundance of the abandoned aquaculture pond (AAP) and the managed aquaculture pond (MAP) during winters. Regardless of species richness or abundance, AAP was significantly higher than MAP.

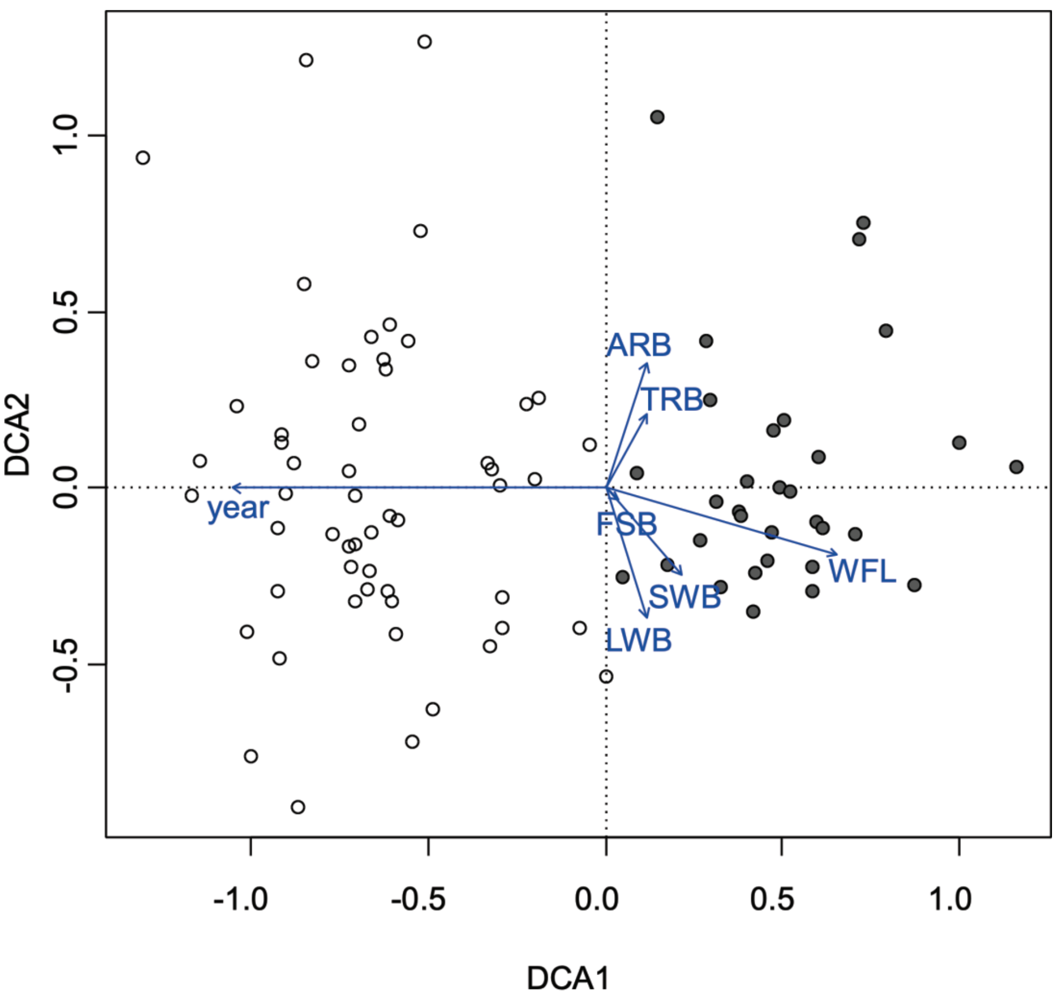

圖 5. 廢棄魚塭樣本 (實心圓) 與有管理魚塭樣本 (空心圓) 在 2005-2008 及 2010-2016 年冬季鳥類群聚的降趨對應分析 (DCA) 前兩軸之空間分布。廢棄魚塭與有管理魚塭樣本沿 DCA 第一軸可以清楚劃分為兩群。除了俯衝食魚鳥類 (FSB)，其他棲地同功群，包括空域鳥類 (ARB)、陸棲鳥類 (TRB)、小型涉禽 (SWB)、大型涉禽 (LWB)、以及游禽 (WFL)，其豐富度的向量方向均偏向第一軸右側，也就是廢棄魚塭樣本分布區域，顯示這些同功群在廢棄魚塭樣本的豐富度相對較高。

Fig. 5. Distribution of samples of the abandoned aquaculture pond (AAP) (solid circles) and the managed aquaculture pond (MAP) (hollow circles) in the first two axes of the detrended correspondence analysis (DCA) of bird community structure during winters of 2005-2008 and 2010-2016. The AAP and MAP samples were clearly divided into two groups along the first axis of DCA. Except for the fishing birds (FSB), the abundances of other habitat guilds—aerial birds (ARB), terrestrial birds (TRB), small wading birds (SWB), large wading birds (LWB), and waterfowl (WFL)—were all vectorially oriented to the right of the first axis, which is the distribution area of the AAP samples. This indicated relatively high abundance of these guilds in the AAP samples.

分布的區域。此意謂這些棲地同功群在 AAP 樣本中的豐富度高於 MAP 樣本。以 nested ANOVA 檢定各棲地同功群個體數在 AAP 與 MAP 之間是否相同，結果除了俯衝食魚鳥類沒有差異之外，其它同功群在 AAP 的平均個體數均明顯高於 MAP；另外，陸棲鳥類個體數在不同冬季之間明顯不同 (表 1)。

廢棄魚塭恢復水產養殖，導致游禽顯著減少。這是 AAP 與 MAP 鳥類群聚結構主要差異之處。隨著魚塭由 AAP 轉變成 MAP，游禽也跟著變少。每次調查記錄到的游禽數量，由 AAP 平均 463 隻，減少為 MAP 的 5 隻，減幅近 99% (表 1)；且所有種類均顯著減少 (表 2)。AAP 全部冬季樣本都有游禽紀錄，也就是說，冬季游禽會穩定出現；但在 MAP 的冬季樣本中，則少有游禽紀錄。游禽在 MAP 大幅減少，符合預期；干擾或受脅應該是主要原因。積極管理魚塭會清除水草及堤岸植被，從而降低水域相對於周圍環境的掩蔽與隱蔽程度；

表 1. 冬季鳥類群聚中，不同棲地同功群在廢棄魚塭 (AAP) 與有管理魚塭 (MAP) 兩種管理模式的平均個體數。以巢式變異數分析檢定管理模式之間與各冬季之間的平均個體數是否相同。

Table 1. Mean number of individuals of each habitat guild in winter bird assemblage under two management modes: the abandoned aquaculture pond (AAP) and the managed aquaculture pond (MAP). The nested analysis of variance was used to determine whether the mean number of individuals was the same between management modes and between winters

Habitat Guilds	Mean number of individuals per survey		Nested ANOVA, p-value	
	AAP (n = 32)	MAP (n = 55)	Between modes	Between winters
Aerial Birds	12.7	5.0	0.03	NS
Terrestrial Birds	16.4	6.9	0.002	0.03
Fishing Birds	3.2	3.5	NS	NS
Small Wading Birds	95.5	41.8	0.001	NS
Large Wading Birds	97.8	39.5	0.012	NS
Waterfowl	462.8	5.0	<0.001	NS

表 2. 冬季各鳥種在廢棄魚塭 (AAP) 與有管理魚塭 (MAP) 兩種管理模式的平均個體數。以巢式變異數分析檢定管理模式之間與各冬季之間的平均個體數是否相同

Table 2. Mean number of individuals of each bird species in winter under two management modes: the abandoned aquaculture pond (AAP) and the managed aquaculture pond (MAP). The nested analysis of variance was used to determine whether the mean number of individuals was the same between management modes and between winters

Chinese names	Scientific names	Mean number of individuals per survey		Nested ANOVA, p-value*		Habitat guilds**
		AAP (n = 32)	MAP (n = 55)	Between modes	Between winters	
琵嘴鴨	*Spatula clypeata*	67	0	<0.001	NS	WFL
赤頸鴨	*Mareca penelope*	102	0.1	<0.001	NS	WFL
尖尾鴨	*Anas acuta*	41.2	0	<0.001	<0.001	WFL
小水鴨	*Anas crecca*	239.3	3.2	<0.001	NS	WFL
小鸊鷉	*Tachybaptus ruficollis*	8	1.7	<0.001	<0.001	WFL
紅鳩	*Streptopelia tranquebarica*	1.1	0.6	NS	NS	TRB
紅冠水雞	*Gallinula chloropus*	2.2	0	0.002	<0.001	WFL
高蹺鴴	*Himantopus himantopus*	18.6	5.5	<0.001	NS	SWB
反嘴鴴	*Recurvirostra avosetta*	16.4	0.05	0.001	NS	SWB
太平洋金斑鴴	*Pluvialis fulva*	0.19	1.4	0.01	<0.001	SWB
東方環頸鴴	*Charadrius alexandrinus*	13	11.8	NS	NS	SWB
紅胸濱鷸	*Calidris ruficollis*	14.3	2.9	NS	NS	SWB
黑腹濱鷸	*Calidris alpina*	16.2	12	NS	NS	SWB
磯鷸	*Actitis hypoleucos*	0.09	0.3	NS	NS	SWB
青足鷸	*Tringa nebularia*	6.2	4.2	NS	NS	SWB
小青足鷸	*Tringa stagnatilis*	6.4	1.8	0.015	NS	SWB
赤足鷸	*Tringa totanus*	0.5	1.4	NS	NS	SWB
裏海燕鷗	*Hydroprogne caspia*	0.3	1.1	0.01	NS	FSB
黑腹燕鷗	*Chlidonias hybrida*	1.1	1.6	NS	NS	FSB
蒼鷺	*Ardea cinerea*	7.1	6.4	NS	NS	LWB

大白鷺	*Ardea alba*	43.7	14.3	0.02	NS	LWB
小白鷺	*Egretta garzetta*	29.4	16.1	NS	NS	LWB
夜鷺	*Nycticorax nycticorax*	1.4	0.13	0.03	NS	LWB
埃及聖䴉	*Threskiornis aethiopicus*	1.1	0.8	NS	NS	LWB
黑面琵鷺	*Platalea minor*	13.4	1.6	0.034	NS	LWB
翠鳥	*Alcedo atthis*	1.7	0.2	NS	NS	FSB
紅尾伯勞	*Lanius cristatus*	0.56	0.04	<0.001	0.04	TRB
褐頭鷦鶯	*Prinia inornata*	2.1	1.1	0.02	0.04	TRB
棕沙燕	*Riparia chinensis*	1	1.8	NS	0.014	ARB
家燕	*Hirundo rustica*	6.1	0.4	NS	NS	ARB
洋燕	*Hirundo tahitica*	4.8	2.4	0.03	NS	ARB
白頭翁	*Pycnonotus sinensis*	1.5	0.9	NS	NS	TRB
綠繡眼	*Zosterops simplex*	6.8	0.2	0.007	NS	TRB
麻雀	*Passer montanus*	0.4	2.7	0.002	NS	TRB

* NS: no significant;

** ARB: Aerial birds, FSB: Fishing birds, LWB: Large wading birds, SWB: Small wading birds, TRB: Terrestrial birds, WFL: Waterfowl.

也會因為人員巡守等積極管理作為，而增加干擾機會。不論是降低隱密性或增加干擾，均可能使雁鴨、小鷿鷈 (*Tachybaptus ruficollis*) 及紅冠水雞 (*Gallinula chloropus*) 的數量減少。過去研究即發現在臺灣棲息的雁鴨科鳥類，通常出現在干擾少而隱密的魚塭或埤塘，而很少分布在積極管理魚塭 (Lu 2004) 。

除了游禽，積極管理魚塭也使涉禽數量減少。全部涉禽從平均 193.3 隻，減少為 81.3 隻，減幅 58%。其中，大型涉禽從平均 97.8 隻減少為 39.5 隻，減幅達 60%；小型涉禽則從平均每次可察覺 95.5 隻，減少為 41.8 隻，減幅 56% (表 1)。就個別鳥種而言 (表 2)，樣本數充足而可以分析的 6 種大型涉禽，其中一半種類，包括

大白鷺、夜鷺 (*Nycticorax nycticorax*) 及黑面琵鷺 (*Platalea minor*) 的數量顯著減少；其餘種類則沒有顯著差異。至於小型涉禽受到負面影響種類的比例則相對較少；分析的 10 種小型涉禽，6 種個體數沒有顯著差異，3 種的個體數減少，僅太平洋金斑鴴 (*Pluvialis fulva*) 1 種的個體數顯著增加。明顯減少的 3 種分別是高蹺鴴 (*Himantopus himantopus*)、反嘴鴴 (*Recurvirostra avosetta*) 及小青足鷸 (*Tringa stagnatilis*)，都是跗蹠較長的種類。其中高蹺鴴跗蹠長 118.7 mm (Shiu *et al.* 2005)，反嘴鴴 86.1 mm (Prater *et al.* 1977)，小青足鷸 52.9 mm (Shiu *et al.* 2005)。相對而言，AAP 與 MAP 數量沒有顯著差異的小型涉禽中，東方環頸鴴 (*Charadrius alexandrinus*) 跗蹠長 27.6 mm，紅胸濱鷸 (*Calidris ruficollis*) 20.3 mm，黑腹濱鷸 (*Calidris alpine*) 27.7 mm，磯鷸 (*Actitis hypoleucos*) 25.9 mm (Shiu *et al.* 2005)，跗蹠都相對較短。

岸堤修整，應該是導致大型涉禽或跗蹠較長的小型涉禽數量減少的原因。一般而言，廢棄魚塭的岸堤會因為長時間缺乏維護而崩壞，致使近池岸地形坡度較緩、泥灘地較多且水較淺，反映出的水域覆蓋比例較低；這種環境有利於涉禽利用，尤其是能同時利用灘地及淺水域，跗蹠較長的涉禽。而魚塭復養過程會挖深池塘、整修堤岸，使水域覆蓋比例增加；此將減少跗蹠較長涉禽可利用的池岸淺水區域面積，從而導致其數量減少。圖 6 是樣區在各冬季的水域覆蓋比例。整體而言，AAP 的水域比例低於 MAP；此意謂 AAP 有較多的灘地，以及較淺的水域，而能提供較多的涉禽可利用棲地。廢棄魚塭轉變為積極管理魚塭，導致涉禽可利用棲地縮減，可能是涉禽數量減少的原因之一。每年冬季平均水域覆蓋比例與平均涉禽個體數之間呈負相關，Kendall’s rank correlation $\tau = -0.45$, $p = 0.06$。

另一方面，當 AAP 轉變為 MAP 時，也可能因為曬池而創造出涉禽短期可利用的棲地。典型經營管理的魚

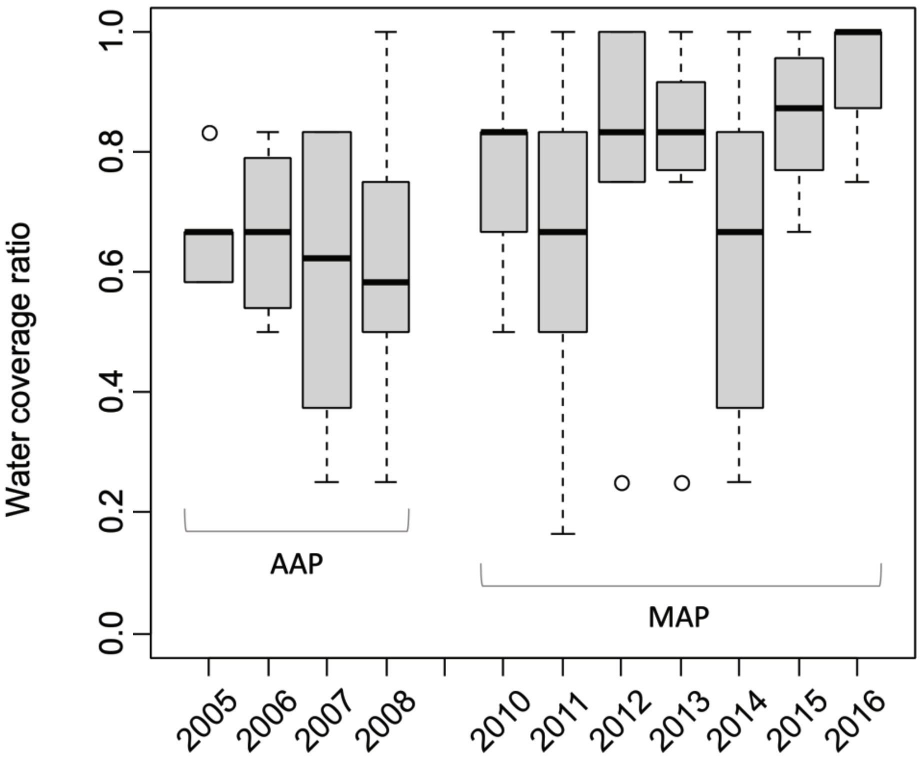

圖 6. 廢棄魚塭 (AAP) 與有管理魚塭 (MAP) 在每年冬季的水域覆蓋比例之盒形圖。有管理魚塭的水域覆蓋比例較高，但在 2011 及 2014 年的比例稍低且變動較大，可能是排水曬池所致。

Fig. 6. Box plots of the water coverage ratio between the abandoned aquaculture pond (AAP) and the managed aquaculture pond (MAP) during winter of each year. The data revealed that the water coverage in MAP was generally higher. However, the ratios in 2011 and 2014 were slightly lower and more variable, which may be due to the basking operation.

塭會定期曬池，形成適合涉禽利用的淺灘溼地 (Yang 2006; 黃和薛 2014)，時間約 1 星期。但對大型涉禽而言，原本 AAP 池岸邊緣可利用的淺水區域之長期損失，很難藉由曬池形成的短暫棲地彌補回來；因此大型涉禽的數量預期將因而減少，或至少持平。相對而言，跗蹠短的小型涉禽在 AAP 能利用棲地本來就不多，故 AAP 轉為 MAP 而導致可利用棲地減少的負面影響相對有限。甚至，還可能藉由 MAP 曬池創造出短暫可利用棲地，而增加小型涉禽的數量。本研究中，一半的大型涉禽數量減少，另一半沒有顯著

差異，另有 3 種跗蹠較長的小型涉禽數量減少，頗符合對跗蹠較長涉禽的預期。但跗蹠較短的小型涉禽，其數量並未如預期增加。原因可能是研究樣區的 MAP 為文蛤養殖池 (王曉琪，私人通訊)，曬池頻度不高所致。

小型涉禽數量並未如預期顯著增加，可能與復養魚塭為文蛤養殖池有關。水產養殖池的池底會因為殘餘餌料及排泄物沉澱，而累積有機物質。有機物質經分解，將提高水中的氨氮濃度 (李等 2019)。氨氮具有毒性，濃度過高會造成水產物死亡。典型的改善方式是在水產物收成之後，將池水排空及清除池底有機汙泥，再灑生石灰；經過曝曬與翻土調整 pH 值之後，即可再度注水養殖。也就是說，將池水排空曬池的必要性，取決於池底有積汙泥的累積量。文蛤為底層濾食性生物，養殖池底的殘餘餌料累積速度緩慢。文蛤養殖池通常 2–3 年才曬池 1 次 (黃和薛 2014)。本研究樣區轉為 MAP 之後，在 2011 及 2014 年冬季分別出現較低的水域覆蓋比，且覆蓋比例的變異也較大，反映養殖池排水與再次注水的曬池操作過程，水域覆蓋比之變動；其它年份則維持較高的水域覆蓋比例 (圖 6)。文蛤養殖池的曬池需求較低，或許是小型涉禽數量沒有顯著增加的原因之一。

廢棄魚塭恢復養殖，對空域鳥類及俯衝食魚鳥類的影響不大。這兩類群鳥類在研究樣區稀少。AAP 樣本中，空域鳥類的豐富度僅佔 1.8%，俯衝食魚鳥類更僅有 0.5% (表 1)。樣本數較充分而可以分析的 3 種空域鳥類中，有 2 種的個體數沒有顯著差異，僅洋燕 (*Hirundo tahitica*) 變少 (表 2)。分析的 3 種俯衝食魚鳥類中，同樣有 2 種沒有差異。而在 MAP 數量顯著增加的裏海燕鷗 (*Hydroprogne caspia*)，平均每次也僅能記錄到 1.1 隻 (表 2)。

陸棲鳥類受塭堤周圍環境變動影響。AAP 變更為 MAP，清除了塭堤因先前長期處於 AAP 而自然演替的小喬木及灌叢 (圖 1b)。樹棲或灌叢活動鳥類，例如紅尾伯勞 (*Lanius cristatus*)、

綠繡眼 (*Zosterops simplex*)、褐頭鷦鶯 (*Prinia inornata*)，數量顯著變少。但地棲的麻雀 (*Passer montanus*) 則相反，因為塭堤植物清理使環境較開闊，因此數量顯著增加 (表 2)。另外，塭堤的陸域棲地在植被清除之後自然演替，則可能使紅尾伯勞及褐頭鷦鶯的平均數量產生明顯年間差異。太平洋金斑鴴是可以接受較乾燥環境的小型涉禽；MAP 的太平洋金斑鴴數量顯著增加，而且各冬季之間的年間變異也顯著，應該也是與塭堤陸棲環境自然演替或植被清除作業導致環境變動有關 (表 2)。

期盼廢棄魚塭復養之後，可以因為曬池作業而增加涉禽可利用棲地，是不切實際的想法。曬池需要額外成本；如非必要，養殖戶不會輕易曬池。魚塭曬池頻率主要受到其水產養殖類別的影響：較頻繁者如虱目魚吋苗池，1 年池水排空 2–3 次；虱目魚池通常 1 年 1 次；而文蛤池則約 3 年曬池 1 次。另外，曬池在水產收成之後；而水產收成時間與水產物的生長狀況及市場供需有關，並非穩定而可預測。黃和薛 (2014) 在七股地區研究涉禽對曬池魚塭的利用情形，即發現連續兩年期間，魚塭曬池高峰有 1 個月的時間差。

長期廢棄魚塭的近天然溼地樣貌有非常高的鳥種多樣性，一旦經過整理並復養，多樣性將大幅降低。對大型涉禽而言，其損失的棲地，並非曬池形成的短暫棲地可以彌補。而就小型涉禽來說，池水排空所形成的可利用棲地並非穩定而可預測，且可利用時間短暫，難以確實獲益。另外，對於需要隱密水域環境的雁鴨而言，因為水塘復養而損失的棲地更不是曬池所能替代。所幸各地的漁電共生環社檢核議題辨認中，均肯定低度維護管理魚塭的生態價值。目前多建議將這些自然度較高的魚塭與其他魚塭整合開發，並規劃為保留區或生態增益區，而將其最高可建置 40% 覆蓋比例的光電板之面積轉移至其他整合開發之魚塭 (e.g., 工業技術研究院 2022)。這或許是一個可行的策略，但後續光電業者是否切實如建議做整體規劃，仍須

關注。另外，鄰近的光電板是否對廢棄或低度維護管理魚塭隱密性鳥種產生負面影響，亦有待未來進一步探討。

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Photosynthetic responses of two mangrove species to salinity immersion and C3-CAM conversion

兩種紅樹林物種對鹽水淹沒的光合反應與 C3-CAM 轉化

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Abstract

Mangrove ecosystems are vulnerable to rising sea levels. When the sea level rises, plants are exposed to increased salinity as well as tidal submergence. In this study, *Kandelia obovata* Sheue, Liu & Yong and *Rhizophora stylosa* Griffith were subjected to different salinity (20‰ and 40‰) and immersion treatments to understand their photosynthesis responses to salinity immersion in mangroves and adaptability to different tidal elevations, gas exchange, and chlorophyll fluorescence parameters. *K. obovata* adapted to immersion stress and outperformed *R. stylosa* under these conditions, indicating that the colonization ability of *K. obovata* took place in the immersive conditions. Immersion and low CO_2 concentration stresses might enable *R. stylosa* to adapt to darkness for CO_2 absorption and exhibit leaf acidity in the early morning. Accordingly, *R. stylosa* exposed to immersion and low CO_2 concentration for one week could adapt to darkness and successfully absorb CO_2. This phenomenon was consistent with that observed in crassulacean acid metabolism (CAM)-type plants, which fix CO_2 at night and exhibit leaf acidity in the early morning. Our results demonstrate that *R. stylosa* displays distinct CAM characteristics under 40‰ of salinity and immersion stress.

Keywords: mangrove species, crassulacean acid metabolism, leaves pH, gas exchange, photoinhibition

摘要

紅樹林生態系統容易受到潮汐的影響，每當海平面上升時，植物會處在鹽度增加以及潮汐淹沒的環境中。為了解適應不同潮位高度的紅樹林鹽分淹水的光合作用，本試驗在不同鹽度（20‰ 和 40‰）與淹水處理下測量水筆仔 (*Kandeliao-bovate*,Liu & Yong) 與紅海欖 (*Rhizophora stylosa*, Griffith) 的氣體交換和葉綠素螢光參數。結果顯示水筆仔能適應淹水壓力並在這些條件下生理表現優於紅海欖。

而紅海欖處於淹水和低 CO_2 濃度處理 1 週後，在夜晚裡能吸收 CO_2，並在清晨時葉片酸度較高，顯示淹水和低 CO_2 濃度等多重逆境可能誘發紅海欖的景天酸代謝 (crassulacean acid metabolism) 的特徵，與景天酸代謝型植物一致。

關鍵詞：紅樹林樹種、景天酸代謝、葉片 pH、氣體交換、光抑制

Introduction

Mangroves are a diverse group of 70 species that grow in saline and tidal wetlands along tropical and subtropical coastlines (Lugo and Snedaker 1974; Odum *et al*. 1982, Hutchings and Saenger 1987; Alongi 2002). Mangrove habitats are typically characterized by high salinity, tidal influence, strong winds, high temperatures, and muddy anoxic soils (Kathiresan and Bingham 2001). Micro-tidal wetlands show strong seasonal soil salinity variation ranged from 0 ~ 1,709 mM of NaCl that are likely to increase in amplitude according to climate prediction models. This may affect the morphology and physiology of mangrove seedlings, and the growth and species composition of mangrove swamps as well (Bompy *et al*. 2014).

Globally, mangrove communities are experiencing changing flood depths and durations due to sea level rise (Woodroffe 1999). The halophytic nature of mangroves creates challenges for scientists to investigate the potential effects of altered hydroperiods. Freshwater inundation alone probably biases flood assessments because optimal growth and physiological activity are attained under saline conditions (Ball 1996, 2002). The effect of increased salinity on mangroves remains unknown. Salinity and fluctuations in flooded elevation are important factors that influence the distribution, niche patterns, and succession of mangrove species (Sabine *et al*. 2011). Mangroves generally have an optimal salinity range of 8–18‰ (Sabine *et al*. 2011) or an optimal seawater concentration range of 5–75% (Krauss *et al*. 2008). In saline environments, *Rhizophora mangle* exhibits crassulacean acid metabolism (CAM) characteristics (Werner and Stelzer 1990), but mangrove species are widely considered to be C3 plants (Venkatesalu *et al*. 2008). Furthermore, photosynthesis and related physiological responses of mangrove species under high salinity are still not unveiled.

C3/CAM shifting requires the induction of certain stress factors. The major ecosystems with CAM plants submerged in aquatic sites have been described by Keeley (1996). The earliest evolution of CAM might have occurred in submerged plants. CAM is advantageous for surviving abiotic stress, rather than for dominance and high biomass production in poor oligotrophic sites (Lüttge 2004). Underwater photosynthesis in submerged aquatic plants is often limited by carbon dioxide availability and thus requires the development of CO_2-concentrating mechanisms (CCMs) that increase carbon fixation of enzymes used by CAM and C4 carbon fixation through the induction of phosphoenolpyruvate carboxylase (PEPC), such as in submerged *Otteliaalismoides* (Huang *et al*. 2020) and *Hydrilla verticillata* (Holaday and Bowes 1980).

Certain plant species can switch from C3 metabolism to CAM either during ontogenetic development or under stress conditions, such as drought (Winter and Holtum 2007, Minardi *et al*. 2014, Holtum *et al*. 2017). In C3–CAM intermediate species, oxidative stress appears to be necessary for triggering a metabolic switch, although oxidative stress alone is insufficient to drive the C3–CAM shift (Lüttge 2004, Niewiadomska and Miszalski 2008). This view is supported by studies in which the C3–CAM plant *Mesembryanthemum crystallinum* was treated with O_3 and SO_2 (Hurst *et al*. 2004, Surówka *et al*. 2007). Osmond (1978) described four distinct stages of CAM in the diurnal cycle. In stage IV, when the malate pool is exhausted at the end of the day, a decrease in the internal CO_2 level promotes stomatal opening, which enables the direct fixation of atmospheric CO_2 by Ribulose-1,5-bisphosphate carboxylase/oxygenase (RuBisCO). However, toward the end of Stage IV, RuBisCO activity declines, and PEPC is activated. Therefore, when the C3–CAM shift occurs, the main physiological indicators are an increase in leaf acidity in the early morning and a decrease in leaf acidity at sunset (Cushman and Bohnert 1999, Maxwell *et al*. 2002, Dodd *et al*. 2003).

The C3-CAM transition correlates with the transcriptional expression of PEPC genes (*Ppc1* and *GapC1*) and increased abscisic acid (ABA) during CAM induction (Cushman and Bohnert 1999). ABA accumulation has been proposed to be involved in CAM induction (McElwain and Bohnert 1992). The switch to CAM is determined by age-dependent development owing to its genetic program (Cushman and Bohnert 1999). Adversity increases physiological leaf age and enhances the rate of ABA catabolism (Cornish and Zeevaart, 1984).

The objectives of our study were to (1) develop an easy, rapid, and nonintrusive method for instantaneous assessment of dynamic photochemical efficiency based on photosynthesis and chlorophyll fluorescence parameters, and (2) measure the pH of leaves with minimal destructive sampling. These parameters reflect a physiological response that could be used to evaluate tidal stress in *Kandelia obovata* and *Rhizophora stylosa*. The obtained data can serve as indicators of plant survival strategies. The hypothesis of our study was that *K. obovata* could adapt to tidal stress, whereas *R. stylosa* would be adversely affected by tidal stress.

Materials and methods

Plant materials and treatments: The

seedlings of *Kandelia obovata* Sheue, Liu & Yong and *Rhizophora stylosa* Griffith in the Tainan Shuangchun Estuary (23°17'38.8"N, 120°06'42.3"E) were collected in 2015 and planted in the Endemic Species Research Institute (23°49'43.0"N, 120°48'04.7"E). The cultivation medium was estuarian sea sand and the seedlings were cultivated in round plastic buckets (diameter, 20 cm; height, 20 cm). Salinity treatment was initiated when the seedlings were two years old, seedling height was 50-60 cm, and ground diameter was 3-4 cm in July, 2017. We prepared two kinds of salinity solutions (20‰ and 40‰) with 20 pots (five for dark period measurements and 15 for standard measurements) of seedlings for each species. The treatment was performed weekly to ensure that salinity was maintained at 20‰ and 40‰ until six months. Moreover, we measured photosynthesis and chlorophyll fluorescence parameters described in detail below.

Whole plant flooding treatment: Flooding treatments were performed for seven days from April to June, 2018. Two year-old plants were exposed to intermittent flooding for four hours each morning (06:00–8:00 h) and afternoon (16:00–18:00 h) to simulate tidal influences. The flooding treatment container was a plastic bucket with a diameter of 56 cm and height of 75 cm. The salinity of the flooding solution remained constant throughout the treatment. The control group received no flooding treatments. During the flooding treatment, we studied the effects of reducing CO_2 supply and salt concentration of the leaves.

Low-CO_2-concentration treatment of leaves: From April to June, 2018, soda-lime was used as a CO_2 absorber or absorbent in the low-CO_2 treatment (0–10 ppm) of leaves for seven days each morning (06:00–8:00 h) and afternoon (16:00–18:00 h) during this intermittent treatment period, the mangrove leaves were exposed to low [CO_2] for four hours to decrease CO_2 supply during tidal flooding and the influence of no-salt on leaf blades during flooding. Control plants were not flooded, and CO_2 supply to these plants was not reduced. In addition, the no-salt leaves were not affected by salt during flooding.

Photosynthesis and chlorophyll fluorescence parameters with a fixed light source:

We divided *K. obovata* and *R. stylosa* seedlings into four groups according to the treatment: (1) 20‰ of salt without immersion, (2) 20‰ of salt with immersion, (3) 40‰ of salt without immersion, and (4) 40‰ of salt with immersion, with five replicates per treatment and species. From April to June, 2018, the seedlings were measured using a gas exchange and fluorescence photosynthesis analyzer (GFS-3000FL; Walz, Effeltrich, Germany). After flooding, photosynthetic parameters were measured at 10:00 h each day.

During the experiment, the gas flow rate was set to 750 μmol s^{-1}, gas-mixer speed to the 7-level, assimilator temperature to 25°C, and relative humidity to 75%, and the photosynthetic photon flux density (PPFD) was adjusted to 800 μmol photons m^{-2} s^{-1}. Photosynthesis, gas exchange, and chlorophyll fluorescence parameters were measured for 90 min of irradiation and then during dark adaptation for 30 min. We recorded one data point every minute for the first 30 min and one data point every 2 min for the final 90 min to measure the photosynthesis, gas-exchange, and chlorophyll fluorescence parameters, and then calculated the following two parameters (Demmig-Adams and Adams 1996, Johnson and Ruban 2011):

Fv/Fm = (Fm –Fo)/Fm, where Fv, Fm, and Fo are values of the minimal (Fo), and maximal ChlF (Fm) of dark-adapted samples were determined using modulated irradiation of a weak light-emitting diode beam (measuring light) and saturating pulse, respectively. Photoinhibition of dark recovery = ($Fv/Fm - Fv_T/Fm_T$) / Fv/Fm, where Fv_T and Fm_T are values measured at 2 and 30 min, respectively, after dark recovery (Wang et al. 2022) measurements.

CO_2 absorption measurement in dark period: From April to June, 2018, five seedlings of *K. obovata* and *R. stylosa* were subjected to (1) immersion, (2) low [CO_2], and (3) no immersion for the measurement of CO_2 absorption in the dark period under 40‰ salinity treatment. A gas-exchange analyzer was used after the leaves submerged in water and treated with low [CO_2] daily. The [CO_2] uptake and gas-exchange parameters were measured in the dark period at 18:00 h every day and recorded every 2 min with a total of 250 records.

Leaf pH measurement: The leaf pH of *K. obovata* and *R. stylosa* seedlings subjected to (1) immersion, (2) low [CO_2], and (3) no immersion were also measured under 40‰ salinity treatment from April to June, 2018. Measurements were performed daily at 06:00 h and 18:00 h. The leaves were ground into powder and mixed with deionized water (10 mL of water per 1 g of sample). After mixing, the samples were vortexed for 5 min. The pH of the mixed solution was measured using a portable pH meter (HQ11d, *Hach*, USA).

Statistical analysis: Statistical analyses were performed using PASW Statistics 18 and SigmaPlot 10.0 software. Gas exchange and chlorophyll fluorescence were analyzed using a single-factor analysis of variance to check for significant differences between the two species. Multiple comparisons were performed using the least significant difference (LSD) method. A Pearson correlation coefficient analysis between gas exchange and chlorophyll fluorescence parameters was also performed.

Results

CO_2 absorption in the dark period and leaf pH

R. stylosa exhibited a night dark-adapted state for CO_2 uptake within 250 min in both low [CO_2] and immersion treatments (Fig. 1). The maximum CO_2 absorption rates under night dark measured for *R. stylosa* were 9.27 μmol CO_2 m^{-2} s^{-1}, which was similar to the rate of CO_2 fixed at night for photosynthesis in CAM plants, as well as the rate in the fourth stage of CAM. Moreover, the pH of the *R. stylosa* leaves measured at 06:00 h was significantly ($P < 0.05$) lower than that at 18:00 h under a dark-adapted state for CO_2 uptake after four hours of treatment with CO_2 supply reduction and daily immersion for one week (Fig. 2). Therefore, *R. stylosa* is characteristically similar to those of CAM plants.

Photosynthesis rate and fluorescence response of photoinduction

In this experiment, 800 μmol photon m^{-2} s^{-1} PPFD was used to induce the photosynthesis rate (P_N) in *K. obovata* and *R. stylosa* and explore the photosynthetic physiological response. Due to the delayed reaction of the P_N, photosynthesis and stomatal conductance (gs) were examined over three time periods: 30 min, 60 min, and 90 min. Figure 3 shows that the P_N and gs values of *K. obovata* and *R. stylosa* seedlings during the 30 min period were relatively lower than both 60 min and 90 min. Regardless of the low [CO_2] or immersion treatment, the P_N and gs of *K. obovata* significantly increased after 60 and 90 min of irradiation. The low [CO_2] and immersion treatment seedlings under 40 ‰ salinity showed significantly higher rates compared to no immersion seedlings ($P < 0.05$). However, in *R. stylosa*, the P_N and gs with no immersion treatment increased significantly after 90 min of irradiation, and the seedlings under 20‰ salinity treatment exhibited significantly higher values than those under the 40‰ salinity treatment ($P < 0.05$). Meanwhile, low [CO_2] and immersion seedlings under 40 ‰ salinity still exhibited low values after 90 min of irradiation, and the values were significantly lower than those of the no immersion seedlings ($P < 0.05$), indicating that low [CO_2] and immersion at high salinity had negative effects on *R. stylosa*.

As shown in Fig. 4*A*, after 40‰ salinity treatment, *K. obovata* seedlings were negatively affected by high salinity. Before irradiation, Fv/Fm values of *K. obovata* seedlings under no immersion, low [CO_2], and immersion treatment were 0.76 ± 0.06, 0.80± 0.01, and 0.78 ± 0.05, respectively. After 800 μmol photon m^{-2} s^{-1} irradiation for 90 min followed by acclimation for 30 min in the dark period, the Fv/Fm values of *K. obovata* seedlings under no immersion, low [CO_2], and immersion treatment decreased to 0.61 ± 0.09, 0.69 ± 0.03, and 0.69 ± 0.04, respectively (Fig. 4A), but the photoinhibition ratio was approximately 20% (Fig. 4*C*). These results demonstrate that decline rate of *K. obovata* was larger in no immersion seedlings compared to low [CO_2] and immersion treated seedlings. The photoinhibition ratio of no immersion *K. obovata* seedlings treated with 20 ‰ salinity was approximately 10%, suggesting that the decline rate of *K. obovata* seedlings in 20 ‰ salinity treatment was greater than that in 40 ‰ salinity treatment.

Fv/Fm values of 40‰ salinity-treated *R. stylosa* seedlings exposed to no immersion, low [CO_2], and immersion before irradiation were 0.73 ± 0.009, 0.69 ± 0.06, and 0.74 ± 0.02, respectively (Fig. 4*B*), demonstrating that *R. stylosa* was affected by stress in a high salinity environment. When the irradiation was adjusted in the dark period, all Fv/Fm values of *R. stylosa* seedlings exposed to no immersion, low[CO_2], and immersion dropped to 0.60 ± 0.03, 0.49 ±.055, and 0.60 ± 0.03, respectively (Fig. 4*B*), but the photoinhibition ratio was approximately 20% (Fig. 4*D*). After 20 ‰ salinity treatment, the decrease in Fv/Fm after irradiation was small, whereas the negative effect of flooding was large. These results show that the long-term exposure of *K. obovata* and *R. stylosa* to high-salinity environments had a negative impact. In addition, significant photoinhibition occurred when the irradiation time exceeded 90 min under 800 µmol photon m^{-2} s^{-1}.

Discussion

C3/CAM shifting is induced by certain stress factors, such as CO_2 concentration reduction due to inundation (Huang *et al*. 2020), drought (Holtum*et al*. 2017), salinity (Gawronska*et al*. 2013), and high light (Hurst *et al*. 2004). Oxidative stress appears to be necessary to induce adaptation to CO_2 uptake in the dark in C3/CAM shifting species; however, stress alone is insufficient to drive C3/CAM shifting, among which need to be induced by other stresses, such as salinity (Lüttge 2004, Niewiadomska and Miszalski 2008).

In our study, dark-adaption in *R. stylosa* induced CO_2 uptake after four-hour treatment of flooding and low [CO_2] treatment daily for one week (Fig. 4*B*). Furthermore, CO_2 absorption under night-dark adaptation in *R. stylosa* was similar to the rates at which CO_2 was fixed at night for photosynthesis in CAM plants at Stage IV (Osmond 1978). When malic acid is depleted at the day-end (Osmond 1978), a decrease in internal CO_2 levels promotes stomatal opening, which enables RuBisCO to fix atmospheric CO_2 directly. Gawronska *et al*. (2013) reported that *M. crystallinum* must be treated under saline conditions to generate factors that induce CAM traits. When *R. stylosa* was exposed to 40‰ salinity treatment for four hours at low [CO_2] and flood for a period of one week, the plant experienced multiple stresses from salinity, oxidation, and excessive light, which enabled it to absorb CO_2 in the dark period. The pH of the leaves measured at 06:00 h was significantly lower than that at 18:00 h. Gawronska *et al*. (2013) treated *M. crystallinum* with 0.4 M NaCl for 12 days and found that transformed photosynthetic system from the C3 system to a CAM system.

Delayed activation of CAM plants was associated with levels of RuBisCO activase protein, which reached a maximum at midday, and may account for this pattern of RuBisCO activation, such as under drought stress or incubation of leaves overnight in an oxygen-free atmosphere, releasing RuBisCO from inhibition early in the light period (Maxwell *et al*. 2002). This is comparable to *R. stylosa*, where P_N and gs remained near 0 under low CO_2 and immersion for 40‰ salinity treatment (Figs. 3*B* and *D*).

The photoinhibition shown in Fig. 4 suggests that photosynthesis was inhibited by the increased photoinhibition under high salt concentrations. P_N and gs of *R. stylosa* were almost completely inhibited under low CO_2 and immersion for 40‰ salinity treatment. Compared with the experimental results of Huang *et al*. (2020), in our study, Fv/Fm decreased when plants switched from C3 to CAM, suggesting that environmental stress affects the results of seedlings.

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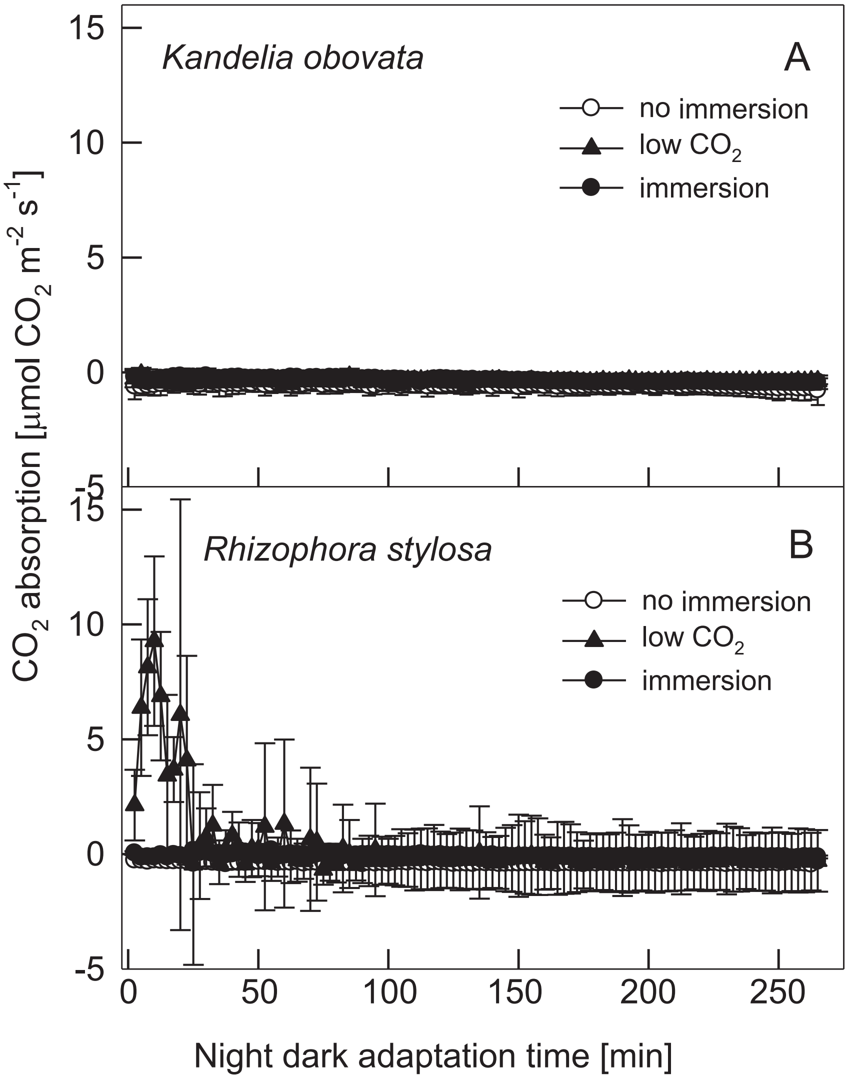

Fig.1. CO2 absorption under night-dark adaptation in Kandelia obovata (A) and Rhizophora stylosa. K.obovata (B) subjected to no immersion, low [CO2], and immersion treatments at 40‰ salinity. The figure shows the changes in CO2 absorption under night dark adaptation. Error bar = standard error (SE); n = 5.

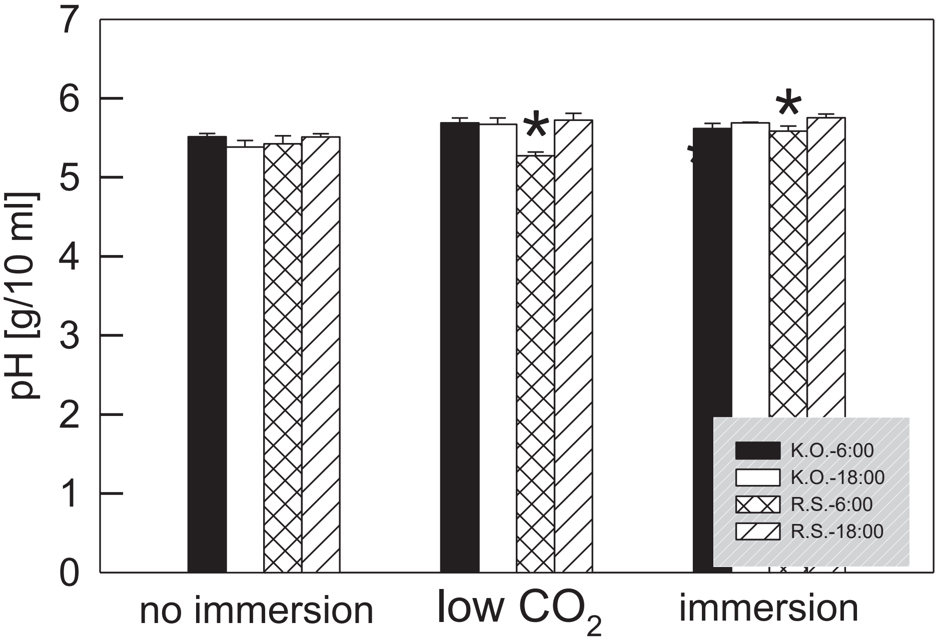

Fig.2. Kandelia obovata and Rhizophora stylosa subjected to 40‰ salinity treatment with no immersion, low [CO2], and immersion provided with daily supply of CO2 for four hours. Changes in leaf pH (1 g/10 mL) were measured at 06:00 h and 18:00 h after one week. Error bar = SE; n = 5. *$P < 0.05$.

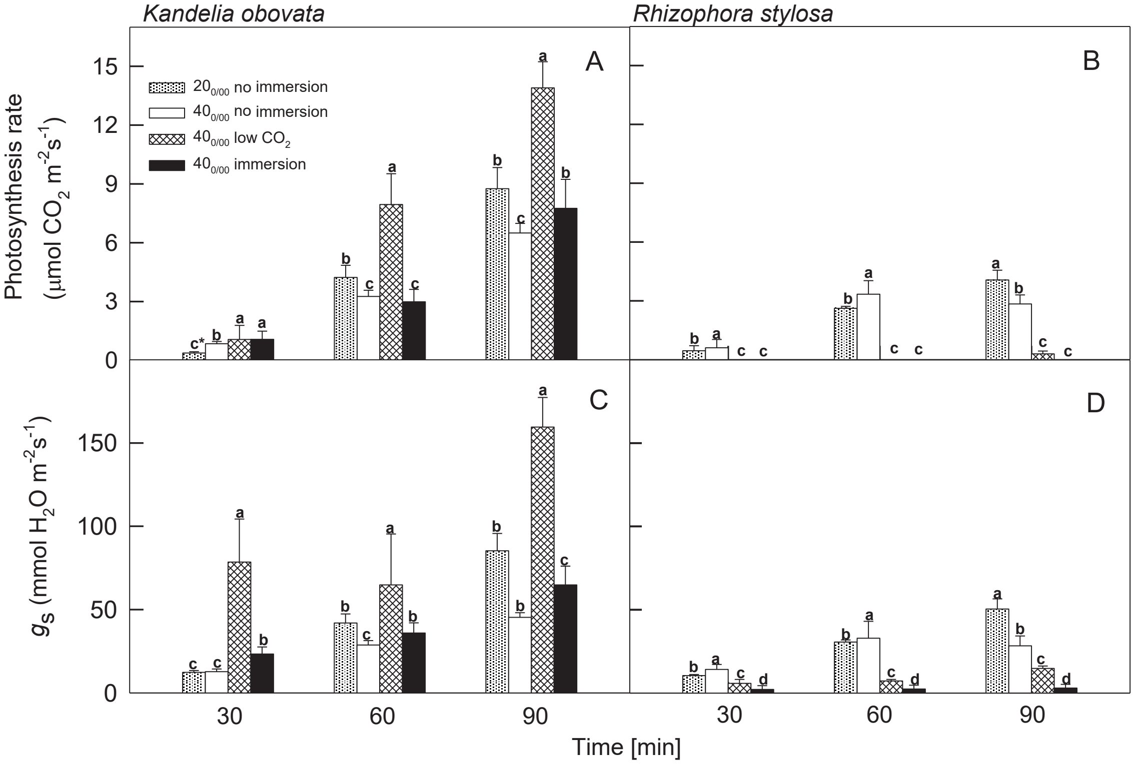

Fig.3. Net photosynthesis rate (PN) and stomatal conductance (gs) of leaves of Kandelia obovata (A, C) and Rhizophora stylosa (B, D) seedlings. Plants were subjected to no immersion at 20‰ and 40‰ salinity, low [CO2] at 40‰ salinity, and immersion at 40‰ salinity treatments under 800 μmol photon m-2 s-1 PPFD after 30, 60, and 90 min of irradiation.

Error bar = SE; n = 5. * Different letters indicate significant differences in the LSD analyses between treatments at different salinity and immersion at the same time ($P < 0.05$).

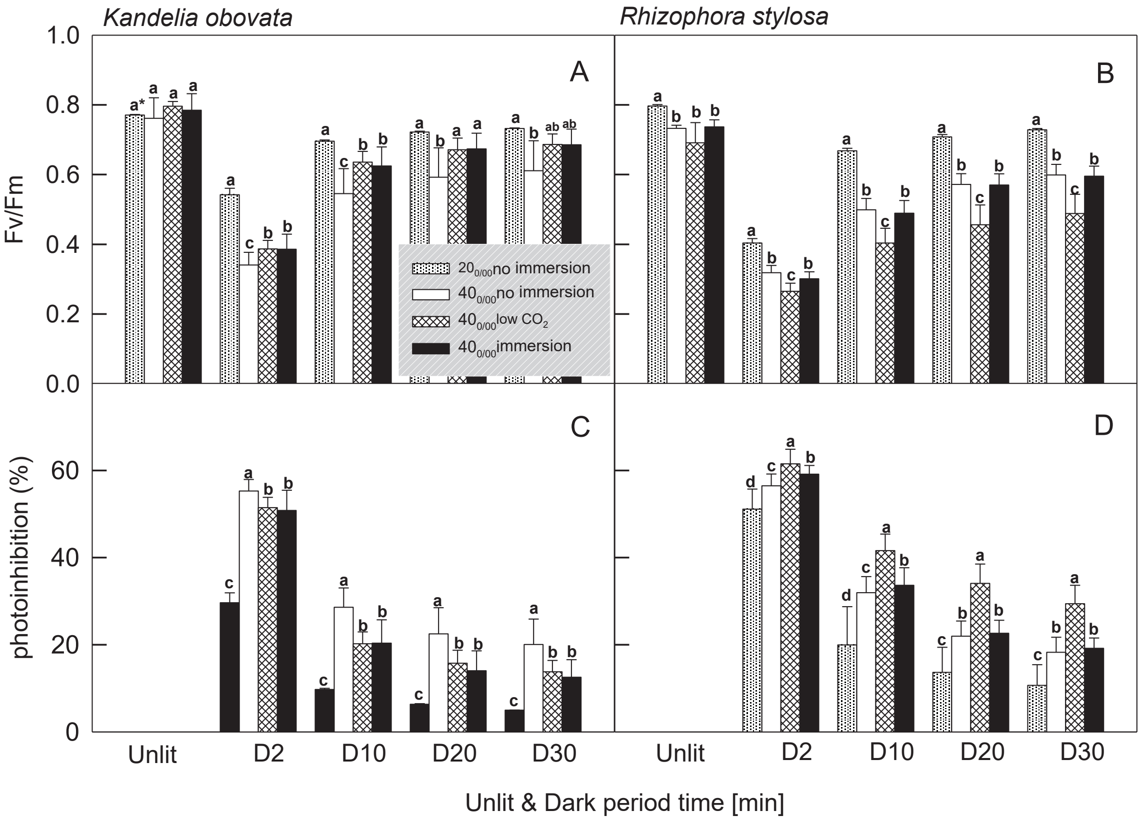

Fig. 4. Fv/Fm and photoinhibition (%) of Kandelia obovata (panels A and C) and Rhizophora stylosa (panels B and D) were measured after 90 min of 800 μmol photon m-2 s-1 irradiation and dark period exposure for 2 min (D2), 10 min (D10), 20 min (D20), and 30 min (D30) under no immersion at 20‰ and 40‰ salinity, low [CO2] at 40‰ salinity, and immersion at 40‰ salinity treatments. Error bar = SE; n = 5. *Different letters indicate significant differences in the LSD analyses between treatments at different salinity and immersion at the same time (P < 0.05).

臺南水雉農藥中毒原因分析

An analysis on pheasant-tailed jacana pesticide poisoning in Tainan, Taiwan

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摘要

農藥為農業中很重要的農作物保護資材，然而不當的使用卻可能對生態環境和非目標生物造成危害。農藥對野生動物影響可分成直接毒害和間接傷害，而直接毒害又可細分成蓄意和非蓄意傷害。殺蟲劑加保扶過去常被違法用於毒殺鳥類以減少農作物損害，本研究即針對於 2017 年 1 月 1 日禁用高含量加保扶成品農藥前後，間隔 8 年之野生鳥類農藥中毒事件調查來分析特定農藥風險減輕措施之成效。特有生物研究保育中心分別於 2014 年及 2022 年接獲臺南地區 15 隻及 16 隻的水雉疑似農藥中毒通報事件。經解剖，於水雉砂囊中均觀察到未消化之去殼米粒及穀粒，採集胃內容物樣本送至農業藥物毒物試驗所進行農藥殘留分析。結

果顯示於 2014 年來自三處不同農地樣品各送驗 1 隻，3 隻胃內容物均驗出農藥加保扶 (0.55-165.00 ppm)，其中 2 隻亦分別驗出得克利 (0.11 ppm) 及福瑞松 (1.80 ppm)；於 2022 年之 16 隻疑似中毒檢體全部送驗，共驗出 13 種農藥，其中 12 隻均驗出高濃度加保扶 (1.41-115.22 ppm)，其餘 4 隻中有 3 隻驗出托福松 (8.39-61.64 ppm)。前述加保扶為鳥類劇毒藥物且驗出濃度大都在致死劑量。此外，在屍體附近發現之穀粒誘餌亦有高含量加保扶 (1159.24 ppm) 顯示此為故意毒殺事件。由此兩年度發生之水雉加保扶中毒事件顯示，加保扶的不當使用並未因 2017 年加保扶 40.64% 水懸劑、44% 水懸劑和 37.5% 水溶性袋裝可濕性粉劑的禁用而遏止，建議有關權責機構應加強風險減輕措施防止野生動物農藥中毒再次發生。

關鍵詞：水雉、農藥、加保扶、托福松、中毒

Abstract

Chemical pesticides are essential for plant protection and ensuring crop productivity. However, inappropriate pesticide use could adversely impact ecosystems and non-target organisms. Pesticides can directly or indirectly cause wildlife death, in which the direct hazards could include negligence or intentional behavior. Carbofuran, an insecticide, was illegally used in the past to minimize crop damage by birds. This study examined two events of pesticide poisoning of wild birds within a span of eight years, occurring before and after the ban of pesticides containing high amounts of carbofuran on January 1, 2017, so as to analyze the effectiveness of the mitigation measures for specific pesticides. The Wildlife Rescue and Research Center of the Endemic Species Research Institute of Taiwan received 15 and 16 cases of suspected pheasant-tailed jacana (*Hydrophasianus chirurgus*) poisoning in 2014 and 2022, respectively. Autopsies revealed that most of the gizzards of the dead jacana contained undigested grains. Samples of these grains and gizzard tissue were analyzed for pesticide residue by the Taiwan Agricultural Chemicals and Toxic Substances Research Institute. Three samples in 2014 from different farmlands were analyzed, all found to contain high concentrations of carbofuran (0.55-165.00 ppm), and two of which were found with tebuconazole (0.11 ppm) and phorate (1.80 ppm). Moreover, 13 pesticides were detected out in all the 16 samples in 2022, 12 of which contained high concentrations of carbofuran (1.41-115.22 ppm), while three of the other four samples contained terbufos (8.39-61.64 ppm). Carbofuran is highly toxic to birds, and the detected concentrations are mostly lethal doses. Finally, baits with a lethal concentration of carbofuran (1159.24 ppm) were found near the corpses' locations, indicating that these poisoning events could be a consequence of intentional behavior. In summary, the wild bird poisoning events in 2014 and 2022 implied that the partial ban on highly-concentrated carbofuran formulations (including 40.64% and 44% carbofuran suspension concentrate as well as 37.5% carbofuran wettable powder in water soluble bag) in 2017 had failed to prevent its misuse. We urge the regulatory authorities to strengthen their risk mitigation measures to prevent further incidents of pesticide poisoning in wildlife.

Keywords: pheasant-tailed jacana, pesticide, carbofuran, terbufos, poisoning

前言

水雉科廣泛分佈於熱帶及亞熱帶開放性的濕地中，主要生活在淡水湖沼中，在浮水植物上覓食及築巢，全世界的水雉科鳥類共有 6 屬 8 種，體型從 15 到 58 公分不等，雌性通常比雄性大（del Hoyo *et al*. 1996, Whittingham *et al.* 2000, Dostine and Morton 2000）。雉尾水雉在臺灣屬於稀有留棲性鳥及少數遷移性候鳥。主要分佈於南亞，自印度、中國東南部到臺灣，臺灣是其分布的北限，南至馬來半島及菲律賓，雉尾水雉是 8 種水雉科中唯一具有繁殖羽（夏羽）及非繁殖羽（冬羽）二種羽色變換和季節性遷移現象的種類（del Hoyo et al. 1996）。在臺灣因棲地消失、噴灑農藥及撿拾鳥蛋等人為破壞，面臨生存危機而逐漸變得稀有，目前已被列為第二級珍貴稀有之保育類動物。根據記載，以往水雉曾廣泛分布於臺灣低海拔的濕地，喜愛棲息於有浮葉植物生長的水澤濕地及埤塘，但隨著臺灣農業生態環境的改變與埤塘消失，許多地方的族群已不復見，目前主要多分布於臺南八掌溪至曾文溪間以種植菱角與稻米為主的水田 (陳 2012，黃等 2016)。臺南市官田區菱角種植區為其在臺灣最大與最主要的族群棲息地，食性以昆蟲、種籽及其他無脊椎動物為食，因常出現於菱角田而有「菱角鳥」及「凌波仙子」的美稱，是臺灣典型的農田濕地生態系代表生物之一。從 1999 年起臺南縣 (現為臺南市) 實施獎勵菱農辦法及劃設官田水雉復育區後，水雉受到較完善的保護而族群有逐漸成長的趨勢，但族群數量增加卻很緩慢。顯然，水雉的保育工作仍有些盲點需要突破 (Ueng and Yang 2008)。

菱角是臺南官田區的特色農產，農作型態農民多半採稻米及菱角輪作，以一期菱角一期稻作方式耕種。當菱角枯萎後，農民會趕著年初種植一期水稻。農民採行直播法種植水稻，收割完後的稻田稍微整地即可再引水淹田銜接菱角栽種 (洪等 2007)。臺灣早期嘉南沿海缺水地區農民就已有採用水稻直播法，只需簡易整地後即可直播，可以節省整地作業的費用，在

過去勞力不足之年代，較為省工的直播方式曾受農民喜愛，試驗改良場所亦曾大量推廣，臺灣 1980 年代之水稻直播栽培面積約為 2 萬至 3 萬 ha，此時為直播栽培之高峰期，但因當時直播技術未能完全克服，直播後的稻種會裸露田間，易受鳥類及鼠類等為害且暴露之稻種若無消毒等措施也會容易招致病蟲害的侵襲下，致使產量低且不穩定，故當時未能大規模推廣 (許及宋 1994)。過去所推行的直播栽培方式是以溼田表面播種為主，將催芽稻種直接撒播於整地後的湛水土壤表面，然而稻種裸露於土表易被野生動物採食，為減少田中播種之穀粒損失達到防鳥或防鼠目的，農民常將稻種與高毒性藥劑混拌處理後直播或放置於周邊田梗當毒誘餌導致鳥類誤食而死亡，造成生態上極大危害 (陳 2012)。當時農民最常使用俗稱好年冬精及蟲包無等加保扶水懸劑摻入穀種使用來防治鳥害，過去臺灣曾有 44% 水懸劑、40.64% 水懸劑和 37.5% 水溶性袋裝可濕性粉劑之高濃度加保扶劑型登記販售，因歸類為劇毒農藥及不當使用造成多次鳥類中毒事件，因而於 2017 年 1 月 1 日禁用多種劑型的產品，目前僅保留分類為哺乳動物急毒性中等毒的加保扶 3% 粒劑、益保扶 4% 粒劑 (含益滅松 2% 和加保扶 2%) 和益保扶 20% 可濕性粉劑 - 水溶性袋裝 (含益滅松 10% 和加保扶 10%) 仍可合法使用。本研究擬藉由野生鳥類農藥中毒事件調查來分析禁用高濃度加保扶農藥措施之成效，並提供權責機構加強管理之參考資料。

材料與方法

1. 中毒水雉樣本來源：

特有生物研究保育中心 (以下簡稱特生中心) 在 2013~2014 年及 2021~2022 年期間，分別接獲 15 隻及 16 隻來自臺南市官田區之野生水雉屍體 (圖 1)。經病理解剖檢視其屍體狀態和胃內容物，懷疑死因為農藥中毒。2014 年採集三處地點各 1 隻檢體胃內容物 2g (圖 2)；2022 年採集 16 隻檢體胃內容物或胃組織各 2g (圖 2) 及 1 件現場採得疑似誘餌穀粒 (圖 3) 送農業藥物毒物試驗所 (以下簡稱藥毒所)

進行農藥殘留分析，樣本來源和採樣情形見表 1。其中拾獲疑似誘餌穀粒來源與樣品 6 位置和時間相同。

2. 樣品農藥殘留檢驗分析方法：

樣品冷凍儲存於 -18°C 下，分析方法參考歐盟 QuEChERS 方法 (European Committee for Standardization 2009, 2018) 萃取淨化後，所得檢液再以氣相層析串聯式質譜儀及液相層析串聯式質譜儀 (gas chromatography/tandem mass spectrometry and liquid chromatography/tandem mass spectrometry) 進行多重農藥殘留定性及定量分析。

結果

送驗的 19 件樣本中，樣本 1 至 3 號為 2013~2014 年疑似中毒之 15 隻水雉樣本中抽驗採得，4 至 19 號為 2021~2022 年疑似中毒之 16 隻水雉樣本，分析結果整理於表 2。多重農藥殘留定性及定量分析回收率介於 61% ~ 123%，回收率的偏差係數 < 20%，定量極限介於 0.004 ~ 0.02 μg/g (ppm)。

2014 年送驗 3 隻水雉胃內容物，總共檢驗出 3 種農藥。3 隻水雉胃內含物均檢測出殺蟲劑加保扶 (carbofuran)，含量為 0.55-165.00 ppm，除加保扶外另有 2 隻分別檢測到殺蟲劑福瑞松 (phorate) 及殺菌劑得克利 (tebuconazole)，濃度分別為 1.80 ppm 及 0.11 ppm。

2022 年送驗 16 隻水雉胃內容物或胃組織，總共檢驗出 13 種農藥。有 12 隻檢體檢出加保扶 (75% 分析樣本)，濃度範圍為 1.4-115.22 ppm；另未驗出加保扶農藥之 4 隻樣品中，有 3 隻驗出有殺蟲劑托福松 (terbufos)，濃度範圍為 8.39-61.64 ppm。其餘 11 種農藥分別有殺蟲劑陶斯松 (chlorpyrifos) 和克福隆 (chlorfluazuron)；殺菌劑待克利 (difenoconazole)、得克利、亞托敏 (azoxystrobin)、撲克拉 (prochloraz)、福多寧 (flutolanil)、滅達樂 (metalaxyl) 及三賽唑 (tricyclazole)；除草劑丁基拉草 (butachlor) 及殺丹 (thiobencarb)。另現場拾獲之穀粒則分別驗出加保扶 (1159.24 ppm)、陶斯松 (0.04 ppm)、剋

安勃 (chlorantraniliprole, 0.06 ppm)、亞托敏 (0.06 ppm)、待克利 (0.53 ppm) 及三賽唑 (0.33 ppm) 共 6 種農藥，其中加保扶、陶斯松及剋安勃是殺蟲劑，餘 3 種為殺菌劑。

討論

農藥是農業中很重要的農作物保護資材。依其用途及防治的對象可簡易分為殺蟲劑（insecticide）、除草劑（herbicide）、殺菌劑（fungicide）、殺蟎劑 (miticides)、殺鼠劑（rodenticide）、植物生長調節劑 (plant growth regulators)、殺線蟲劑 (nematocides) 及除藻劑 (algicides) 等 (蔡 2001)。又可依對為害生物的程度與其毒性、接觸劑量、暴露途徑及暴露時間長短有關來區分危害級別，在急性暴露下，通常會以半數致死劑量 (median Lethal Dose, LD_{50})，即能讓處理之動物產生 50% 比例死亡所需要之化學物劑量作為危害等級分級標準 (附錄表 1)。2014 年和 2022 年之 19 隻水雉樣本的農藥檢出率是 100%，總共驗出 14 種農藥，依其農藥種類可歸納為殺蟲劑、殺菌劑和除草劑三大類，以殺蟲劑加保扶的殘留檢出率 79% 最高 (15 隻)。以農藥有效成分急毒性來區分 (表 3)，殺蟲劑除克福隆外對於鳥類或哺乳動物之危害性較高，屬劇毒或極劇毒農藥；其餘殺菌劑及殺草劑農藥，多數屬於中等毒或輕毒，且驗出濃度相對不高，顯示殺蟲劑為水雉主要致死原因。

本研究水雉樣本和誘餌穀粒共檢驗出加保扶、托福松、福瑞松、陶斯松、克福隆和剋安勃 (僅誘餌檢出) 等 6 種殺蟲劑，主要是用以防除為害作物的昆蟲及其他節肢動物，依其不同化學結構特性而有不同作用機制及毒性 (行政院農委會動植物防疫檢疫局 2018)。加保扶屬於胺基甲酸鹽類，而托福松、福瑞松和陶斯松為有機磷類農藥，兩者作用機制都是透過抑制乙醯膽鹼酯酶而造成神經中毒症狀，於昆蟲、鳥類和哺乳動物具有共通之中毒機制 (Carey 2006)。殺蟲劑福瑞松及加保扶對哺乳類及鳥類動物都有很強的毒性，作用快且所需量少，引起臺灣野生動物的中毒案件也

最多 (Hong *et al*. 2018)。剋安勃屬魚尼丁 (ryanodine) 受體鈣離子通道調節劑，對於昆蟲之魚尼丁受體有高度之專一性和選擇性，對哺乳類動物受體親和力差，因此對哺乳動物安全性較高 (Chen *et al.* 2019)；克福隆屬昆蟲生長調劑，為一種幾丁質合成抑制劑 (inhibitors of chitin biosynthesis)，機制為干擾昆蟲或蟎類之幾丁質合成，而影響蟲卵孵化和幼蟲發育，是依據昆蟲生長發育專屬的特性而開發的藥劑種類對哺乳類及鳥類毒性機制相關性低 (Merzendorfer 2013)。

加保扶在 1970 年代引進臺灣，由於對鳥類有很高的毒性，甚至當時的廣告文宣就將鳥類列為加保扶的防治目標之一，農業官方刊物也曾經推廣用加保扶等劇毒農藥來防鳥害 (洪等 2022)。加保扶經由口服途徑對雞、鴨、綠頭鴨、雉、鵪鶉、野鳥的急性中毒半數致死劑量分別為 6.3、0.415、0.71、4.2、5.0、0.42 mg/kg bw (Gupta，2012; PPDB)，屬於鳥類極劇毒農藥 (表 3)，對禽鳥尤其是鴨和野鳥具有極高之危害性。當食穀性鳥類誤食加保扶粒劑或經加保扶處理過的穀物時，在短時間內含毒的種子仍在食道及嗉囊內就會出現中毒症狀 (Tennakoon *et al*. 2009)。本研究除在水雉遺體驗出致死濃度之加保扶外，在案發現場田埂上拾獲之穀粒送驗結果包括合法登記於稻種消毒之殺菌劑撲克拉、得克利和三賽唑外，更有高濃度之殺蟲劑加保扶 (1,159.24 ppm)。以水雉體重 (雌鳥約 190-250 g，雄鳥約 120-150 g)(翁及王 2000) 和半致死劑量 (0.42 mg/kg bw) 估算，每隻水雉約攝入 0.05-0.11 mg 加保扶，可能會造成死亡；若以田埂上之穀粒內加保扶 1,159.24 ppm 濃度計算，每隻水雉約只需攝入 0.04-0.09 g 穀粒，相當於 2~4 粒穀粒即會造成死亡 (一般水稻穀粒千粒重為 23-26 g 重 (林 2007))。由此可推測為人為蓄意將稻穀混合加保扶製成毒餌撒在田間毒殺食穀性鳥類之毒害事件。

臺灣過去曾有高濃度加保扶劑型登記販售，包括：85% 可濕性粉劑、75% 可濕性粉劑、44% 水懸劑、40.64% 水懸劑和 37.5% 水溶性袋裝可

濕性粉劑，因歸類為劇毒農藥，分別於 1999 年 1 月 1 日 (前兩項) 和 2017 年 1 月 1 日全面禁用。目前僅餘加保扶 3% 粒劑、益保扶 4% 粒劑和益保扶 20% 可濕性粉劑 - 水溶性袋裝登記使用 (行政院農業委員會動植物防疫檢疫局 2022)(附錄表 2)。加保扶在水稻登記害物範圍及使用時機均在苗期施用，防治玉米則於生育初期及抽穗前使用；益保扶則於分蘗盛期前施用，這二種化學農藥之使用方法，並未適用於穀粒，若用於直播法須符合登記之使用方法方能使用 (表 4)。

在歐美地區，加保扶粒劑曾被廣泛運用於種植雜糧，暴露的顆粒容易被鳥類誤判為細砂礫而誤食 (Mineau *et al.* 1999, Parsons *et al*. 2010)。加保扶在國際上已被多國禁止使用，並在 2017 年被鹿特丹公約登錄為附錄 III 禁用或嚴格限用的化學品和危害性高的農藥產品。歐盟因為加保扶產品對於較敏感消費者族群的急性暴露風險高、污染地下水和對哺乳動物、鳥類、魚類、蚯蚓等非目標生物之生態毒性等具有疑慮，自 2007 年 6 月 16 日起不再通過申請，並公告所有含加保扶的植物保護產品需在 2007 年 12 月 13 日前回收；在加拿大，因為加保扶產品對於工作者、綜合飲食暴露和對陸生和水生非目標生物風險超過可接受標準，且在美國和加拿大地區有 33 次環境意外報告，自 2010 年 12 月 31 日起禁用 (Spencer 2006)；赫勒州常設州際抗旱委員會 (Permanent Interstate Committee for drought control in the Sahel) 因為加保扶產品已經影響到生態系平衡和造成益蟲的消失，且觀察到農民不依照標示方法安全施藥、飲用水被污染、對鳥、水生無脊椎生物和淡水魚中均有較高的毒性等因素，自 2015 年 4 月 8 日起禁用加保扶 (FAO and UNEP. 2017, 盧 2020)。另外在美國、澳洲和日本亦無加保扶的登記使用 (Poledníková *et al* 2010)。

而在國內，民眾有意或無意地不當使用加保扶，造成犬、貓或野生動物傷害甚或死亡事件層出不窮。家畜衛生試驗所報告在 2011 至 2013 年受理的 24 件疑似犬隻中毒案件中，有 13 件是加保扶中毒，且高劑量指向人

為故意毒殺 (吳 2013)。屏東科技大學鳥類生態研究室自 2014 年 10 月至 2016 年 9 月期間，共收到 213 則通報。其中有 29 起小型鳥類中毒案件和 7 起黑翅鳶死亡案件送化學分析，其結果在 28 件小型鳥類樣品中驗出加保扶 (0.010–21.640 μg/g)，1 件驗出托福松 (0.075 μg/g)；4 隻黑翅鳶驗出加保扶和 3 隻黑翅鳶驗出殺鼠劑。顯示加保扶為最常使用於農地毒鳥的農藥並有可能透過食物鏈而影響到猛禽 (Hong *et al*. 2018)。由本研究相隔 8 年的鳥中毒調查事件可得知，即使本國於 2017 年 1 月 1 日以後市面上禁售高含量加保扶製劑產品，只保留低含量加保扶產品登記使用，因其對鳥類的高毒性，仍無法杜絕農民或不肖人士蓄意用於毒害野生動物。

在本次農藥種類調查中，分別於 2014 年和 2022 年驗出較高濃度之福瑞松及托福松等兩種有機磷劑殺蟲劑，其中福瑞松不管對鳥類或哺乳類動物均為極劇毒農藥；而托福松對鳥類雖為中等毒性但對哺乳類動物而言為極劇毒性農藥。前述兩農藥檢驗濃度雖未達鳥類半數致死劑量，仍可能造成敏感個體中毒死亡。由於托福松和福瑞松並未核准使用於水稻，為何水雉會在胃內容物中發現穀粒且死於水稻種植區呢？經過尋訪當地農民間接得知，可能有不肖農藥商家教導農友以這兩種農藥用於田地上抑制鼠類及蛇類，此外經查在過去藥毒所之植物保護信箱中亦有民眾詢問可否使用福瑞松、托福松或加保扶化學藥劑來防治鼴鼠；以往也有文獻指出福瑞松及托福松可用來防治鼴鼠 (施錫彬和游俊明 2000)，因此不當使用福瑞松及托福松於鼠害防治的情形存在可能性。推測在本研究中福瑞松或托福松對於田地上覓食鳥類為非蓄意的直接毒害事件，然而對地棲型哺乳類直接性蓄意的毒害事件也必須被關注。

本水雉中毒案件並非僅是臺南官田區個案，毒殺野生動物案件持續發生在臺灣各個角落，除了鼓勵農友們使用友善農法或毒性較低的農藥，地方主管機關應加強宣導毒殺動物觸犯之法律及刑責 (附錄資料)，也應對農藥販賣場所之推廣違法使用農藥之行

為予以查緝。針對不易管理之高風險性農藥如加保扶，主管權責機關應評估完全退場之可行性。

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表 1、臺南市官田區水雉樣本來源、拾獲日期和採集部位

Table 1. The locations, pick-up dates, sampling sites, and sampling dates of the pheasant-tailed jacanas found in Guantian District, Tainan.

編號	拾獲地點	拾獲時間	採樣部位	採集時間	胃內容物
1	葫蘆埤	2013/12/25	胃內含物	2014/1/3	米粒/穀粒
2	瓦窯庄	2013/12/25	胃內含物	2014/1/4	米粒/穀粒
3	葫蘆埤	2013/12/25	胃內含物	2014/1/5	米粒/穀粒
4	官田里	2021/4/30	胃內含物	2022/1/3	米粒/穀粒
5	官田里	2021/4/30	胃內含物	2022/1/3	米粒/穀粒
6	南廍里	2021/12/24	胃內含物	2022/1/3	米粒/穀粒
7	隆本里	2021/12/29	胃內含物	2022/1/3	米粒/穀粒
8	南廍里	2022/1/7	胃內含物	2022/3/1	米粒/穀粒
9	東庄里註 1	2022/1/14	胃組織	2022/3/1	無
10	隆本里	2022/1/14	胃內含物	2022/3/1	米粒/穀粒
11	嘉南里註 2	2022/1/14	胃內含物	2022/3/1	米粒/穀粒
12	隆田里	2022/1/14	胃內含物	2022/3/1	米粒/穀粒
13	隆田里	2022/1/14	胃內含物	2022/3/1	米粒/穀粒
14	南廍里	2022/1/18	胃內含物	2022/3/1	米粒/穀粒
15	隆本里	2022/1/18	胃內含物	2022/3/1	米粒/穀粒
16	隆本里	2022/1/18	胃內含物	2022/3/1	米粒/穀粒
17	隆本里	2022/1/18	胃內含物	2022/3/1	米粒/穀粒
18	隆本里	2022/1/18	胃內含物	2022/3/1	米粒/穀粒
19	東庄里	2021/5/17	胃內含物	2022/1/3	米粒/穀粒

註 1：水雉胃中無內容物，採胃組織送驗；註 2：水雉屍體已風乾。

表 2、水雉胃內容物（組織）驗出之農藥種類及濃度[註1]

Table 2. The types and concentrations of pesticides detected in jacanas' stomach contents or tissues.

編號	送驗時間	檢出農藥種類/名稱(中文/英文)	濃度**(ppm)**
1	2014/1/3	殺蟲劑/加保扶/Carbofuran 殺菌劑/得克利/Tebuconazole	**165.00** 0.11
2	2014/1/3	殺蟲劑/加保扶/Carbofuran	**145**
3	2014/1/3	殺蟲劑/加保扶/Carbofuran 殺蟲劑/福瑞松/Phorate	0.55 **1.80**
4	2022/3/24	殺蟲劑/托福松/Terbufos	8.39
5	2022/3/24	殺蟲劑/托福松/Terbufos	61.64
6	2022/3/24	殺蟲劑/加保扶/Carbofuran 殺菌劑/得克利/Tebuconazole 殺菌劑/三賽唑/Tricyclazole	**4.79** 1.05 0.02
7	2022/3/24	殺蟲劑/加保扶/Carbofuran 殺蟲劑/托福松/Terbufos	**1.41** 0.03
8	2022/3/24	殺蟲劑/加保扶/Carbofuran 除草劑/丁基拉草/Butachlor 殺蟲劑/陶斯松/Chlorpyrifos	**25.74** 0.15 0.03
9	2022/3/24	殺蟲劑/加保扶/Carbofuran 殺菌劑/得克利/Tebuconazole 殺菌劑/亞托敏/Azoxystrobin 殺菌劑/撲克拉/Prochloraz 殺蟲劑/克福隆/Chlorfluazuron	**1.66** 0.28 0.15 0.40 0.04
10	2022/3/24	殺蟲劑/加保扶/Carbofuran 除草劑/丁基拉草/Butachlor 殺蟲劑/托福松/Terbufos	**18.96** 28.96 0.07
11	2022/3/24	殺菌劑/亞托敏/Azoxystrobin 殺菌劑/待克利/Difenoconazole	0.06 0.19

編號	送驗時間	檢出農藥種類/名稱 (中文/英文)	濃度(ppm)
1	2014/1/3	殺蟲劑/加保扶/Carbofuran 殺菌劑/得克利/Tebuconazole	**165.00** 0.11
2	2014/1/3	殺蟲劑/加保扶/Carbofuran	**145**
3	2014/1/3	殺蟲劑/加保扶/Carbofuran 殺蟲劑/福瑞松/Phorate	0.55 **1.80**
4	2022/3/24	殺蟲劑/托福松/Terbufos	8.39
5	2022/3/24	殺蟲劑/托福松/Terbufos	61.64
6	2022/3/24	殺蟲劑/加保扶/Carbofuran 殺菌劑/得克利/Tebuconazole 殺菌劑/三賽唑/Tricyclazole	**4.79** 1.05 0.02
7	2022/3/24	殺蟲劑/加保扶/Carbofuran 殺蟲劑/托福松/Terbufos	**1.41** 0.03
8	2022/3/24	殺蟲劑/加保扶/Carbofuran 除草劑/丁基拉草/Butachlor 殺蟲劑/陶斯松/Chlorpyrifos	**25.74** 0.15 0.03
9	2022/3/24	殺蟲劑/加保扶/Carbofuran 殺菌劑/得克利/Tebuconazole 殺菌劑/亞托敏/Azoxystrobin 殺菌劑/撲克拉/Prochloraz 殺蟲劑/克福隆/Chlorfluazuron	**1.66** 0.28 0.15 0.40 0.04
10	2022/3/24	殺蟲劑/加保扶/Carbofuran 除草劑/丁基拉草/Butachlor 殺蟲劑/托福松/Terbufos	**18.96** 28.96 0.07
11	2022/3/24	殺菌劑/亞托敏/Azoxystrobin 殺菌劑/待克利/Difenoconazole	0.06 0.19

註 1：除樣品 9 檢驗胃組織外，其餘樣本均檢驗胃內容物 (即未消化穀粒 / 米粒)。

表 3、農藥對鳥類及哺乳動物急性毒性數據[註 1]

Table 3. Acute toxicity data of pesticides found in birds and mammals.

農藥種類/中文/英文名稱	鳥類[註 2]	哺乳類動物[註 3]		
	經口 LD_{50} (mg/kg bw)	**經口 LD_{50} (mg/kg bw)**	**經皮膚 LD_{50} (mg/kg bw)**	**經呼吸 LC_{50} (mg/L)**
殺蟲劑/加保扶 /Carbofuran	0.71 (極劇毒)	7 (劇毒)	1000 (中等毒)	0.05
殺蟲劑/托福松 /Terbufos	>185 (中等毒)	1.3 (極劇毒)	1 (極劇毒)	0.0061
殺蟲劑/陶斯松 /Chlorpyrifos	39.2 (劇毒)	66 (中等毒)	1250 (中等毒)	0.1
殺蟲劑/福瑞松 /Phorate	2.25 (極劇毒)	2 (極劇毒)	2.5 (極劇毒)	0.06
殺蟲劑/剋安勃 /Chlorantraniliprole	>2250 (相對無毒)	>5000 (低毒)	5000 (輕毒)	>5.1
殺蟲劑/克福隆 /Chlorfluazuron	>2510 (相對無毒)	>8500 (低毒)	1000 (中等毒)	>2.4
殺菌劑/亞托敏 /Azoxystrobin	> 2000 (相對無毒)	>5000 (低毒)	2000 (中等毒)	0.69
殺菌劑/待克利 /Difenoconazole	> 2150 (相對無毒)	1453 (中等毒)	2010 (輕毒)	>3.3
殺菌劑/得克利 /Tebuconazole	1988 (輕毒)	1700 (中等毒)	2000 (中等毒)	>5.09
殺菌劑/撲克拉 /Prochloraz	662 (輕毒)	1023 (中等毒)	2100 (輕毒)	>2.16
殺菌劑/福多寧/Flutolanil	> 2000 (相對無毒)	>10000 (低毒)	5000 (輕毒)	>5.98
殺菌劑/三賽唑 /Tricyclazole	> 1528 (輕毒)	289.7 (中等毒)	2000 (中等毒)	>1.15
殺菌劑/滅達樂 /Metalaxyl	1466 (輕毒)	>669 (中等毒)	5000 (輕毒)	>3.6
除草劑/丁基拉草 /Butachlor	> 4640 (相對無毒)	2000 (中等毒)	13000 (低毒)	3.34
除草劑/殺丹 /Thiobencarb	> 2000 (相對無毒)	560 (中等毒)	5000 (輕毒)	> 2.43

農藥種類/中文/英文名稱	鳥類[註 2]	哺乳類動物[註 3]		
	經口 LD_{50} (mg/kg bw)	經口 LD_{50} (mg/kg bw)	經皮膚 LD_{50} (mg/kg bw)	經呼吸 LC_{50} (mg/L)
殺蟲劑/加保扶 /Carbofuran	0.71 (極劇毒)	7 (劇毒)	1000 (中等毒)	0.05
殺蟲劑/托福松 /Terbufos	>185 (中等毒)	1.3 (極劇毒)	1 (極劇毒)	0.0061
殺蟲劑/陶斯松 /Chlorpyrifos	39.2 (劇毒)	66 (中等毒)	1250 (中等毒)	0.1
殺蟲劑/福瑞松 /Phorate	2.25 (極劇毒)	2 (極劇毒)	2.5 (極劇毒)	0.06
殺蟲劑/剋安勃 /Chlorantraniliprole	>2250 (相對無毒)	>5000 (低毒)	5000 (輕毒)	>5.1
殺蟲劑/克福隆 /Chlorfluazuron	>2510 (相對無毒)	>8500 (低毒)	1000 (中等毒)	>2.4
殺菌劑/亞托敏 /Azoxystrobin	> 2000 (相對無毒)	>5000 (低毒)	2000 (中等毒)	0.69
殺菌劑/待克利 /Difenoconazole	> 2150 (相對無毒)	1453 (中等毒)	2010 (輕毒)	>3.3
殺菌劑/得克利 /Tebuconazole	1988 (輕毒)	1700 (中等毒)	2000 (中等毒)	>5.09
殺菌劑/撲克拉 /Prochloraz	662 (輕毒)	1023 (中等毒)	2100 (輕毒)	>2.16
殺菌劑/福多寧/Flutolanil	> 2000 (相對無毒)	>10000 (低毒)	5000 (輕毒)	>5.98
殺菌劑/三賽唑 /Tricyclazole	> 1528 (輕毒)	289.7 (中等毒)	2000 (中等毒)	>1.15
殺菌劑/滅達樂 /Metalaxyl	1466 (輕毒)	>669 (中等毒)	5000 (輕毒)	>3.6
除草劑/丁基拉草 /Butachlor	> 4640 (相對無毒)	2000 (中等毒)	13000 (低毒)	3.34
除草劑/殺丹 /Thiobencarb	> 2000 (相對無毒)	560 (中等毒)	5000 (輕毒)	> 2.43

註 1：資料來源為 Pesticide Properties DataBase.

註 2：參考美國環保署農藥鳥類毒性分級：LD_{50}<10 mg/kg bw 屬極劇毒、LD_{50} 為 10-50 mg/kg bw 屬劇毒、LD_{50} 為 51-500 mg/kg bw 屬中等毒、LD_{50} 為 501-2000 mg/kg bw 屬輕毒和 LD_{50} 為 >2000 mg/kg bw 屬相對無毒。

註 3：參考國家標準 CNS15030-17 急毒性物質危害級別和農藥標示管理辦法第十二條附表一農藥急性毒性分類修正 (附錄表一)。

表 4、檢出農藥的分群、登記於水稻使用時機和米之農藥殘留容許量標準

Table 4. The chemical categories, application timing, and MRL on rice for detected pesticides in pheasant-tailed jacanas' stomach.

農藥名稱	農藥分類	於水稻使用時機	米 **MRL (ppm)**
加保扶 Carbofuran	殺蟲劑 氨基甲酸鹽類	孕穗期至齊穗期害蟲防除 育苗箱秧苗害蟲防除	0.1
托福松 Terbufos	殺蟲劑與殺蟎劑 有機磷類	無登記在水稻	無
陶斯松 Chlorpyrifos	殺蟲劑與殺蟎劑 有機磷劑	無登記在水稻	無
福瑞松 Phorate	殺蟲劑與殺蟎劑 有機磷類	無登記在水稻	無
剋安勃 Chlorantraniliprole	殺蟲劑與殺蟎劑 二醯胺類	限育苗箱使用種子處理（水稻瘤野螟）	0.1
克福隆 Chlorfluazuron	殺蟲劑與殺蟎劑 苯甲醯尿素類	無登記在水稻	無
亞托敏 Azoxystrobin	殺菌劑 甲氧基丙烯酯類	無登記在水稻	5.0
待克利 Difenoconazole	殺菌劑 三唑類	紋枯病發生初期開始施藥	0.5
得克利 Tebuconazole	殺菌劑 三唑類	稻種直接消毒 24 小時後，再浸水催芽	0.05
撲克拉 Prochloraz	殺菌劑 咪唑類	稻種直接消毒 24 小時後，再浸水催芽	0.5
福多寧 Flutolanil	殺菌劑 苯基苯醯胺類	紋枯病發生初期開始施藥	1.0

三賽唑 Tricyclazole	殺菌劑 三唑苯併噻唑類	插秧前育苗箱使用 插秧後葉稻熱病 抽穗前穗稻熱病	3.0
滅達樂 Benalaxyl	殺菌劑 醯基丙胺酸類	水稻立枯病，限育苗箱秧苗使用。	1.0
丁基拉草 Butachlor	除草劑 氯乙醯胺類	防治水稻移植本田雜草 直播田移除雜草	0.5
殺丹 Thiobencarb	除草劑 硫代胺基甲鹽類	防除直播田雜草 防除秧田或本田雜草	0.5

註：國內登記狀態 / 使用範圍，資料來源為行政院農業委員會動植物防疫檢疫局農藥資訊服務網 https://pesticide.baphiq.gov.tw/information/Query/Pesticide#

註：MRL 為農藥殘留容許量標準，資料來源為衛生福利部食品藥物管理署 https://consumer.fda.gov.tw/Law/PesticideList.aspx?nodeID=520

圖 1. 懷疑農藥中毒之野生水雉屍體。A.2014 年；B.2022 年。

Fig. 1. The corpses of suspected pheasant-tailed jacana poisoning in 2014(A) and 2022(B), respectively.

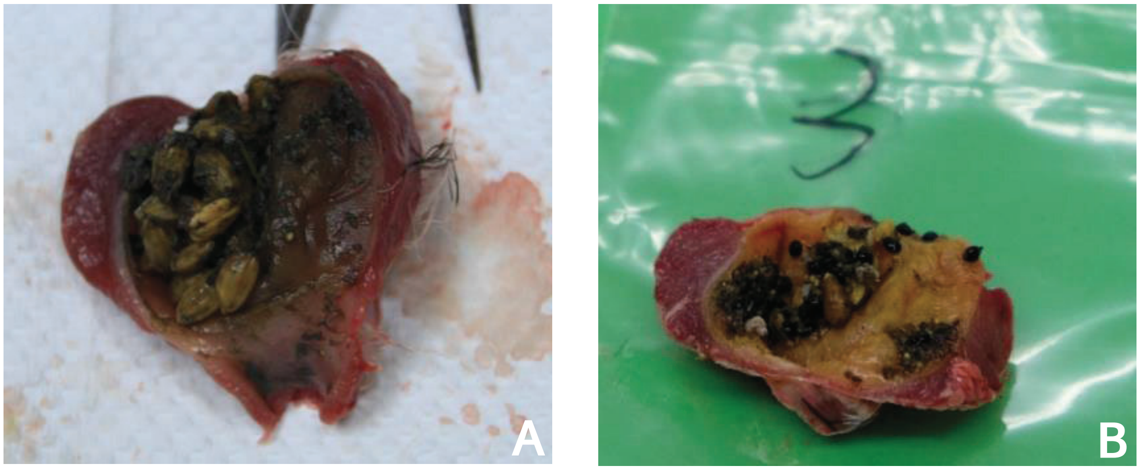

圖 2. 懷疑農藥中毒水雉之砂囊內穀物。A.2014 年；B.2022 年。

Fig. 2. The undigested grains found in the gizzards of suspected pheasant-tailed jacana poisoning in 2014(A) and 2022(B), respectively.

圖 3. 於水雉死亡周邊發現之疑似誘餌穀物。

Fig. 3. The baits found near the corpses’ locations.

附錄表一、國家標準 CNS15030-17 急毒性物質危害級別

Appendix 1. The acute toxicity categories under National Standard CNS15030-17.

毒性分類	第 **1** 級	第 **2** 級	第 **3** 級	第 **4** 級	第 **5** 級
經吞食 **LD_{50}**（**mg/kg bw**）	≤5	>5~≤50	>50~≤300	>300~≤2000	>2000~≤5000
農藥分類[註]	極劇毒	劇毒	中等毒	中等毒	輕毒
經皮膚 **LD_{50}**（**mg/kg bw**）	≤50	>50~≤200	>200~≤1000	>1000~≤2000	>2000~≤5000
農藥分類[註]	極劇毒	劇毒	中等毒	中等毒	輕毒
經呼吸 **LC_{50}**					
氣體（**ppmV**）	≤100	>100~≤500	>500~≤2500	>2500~≤20000	不適用
蒸氣 **mg/L**）	≤0.5	>0.5~≤2.0	>2.0~≤10	>10~≤20	
粉塵和霧滴（**mg/L**）	≤0.05	>0.05~≤0.5	>0.5~≤1.0	>1.0~≤5.0	

註：參考農藥標示管理辦法第十二條附表一農藥急性毒性分類修正規定 (經吞食或皮膚 LD_{50}>5000 mg/kg 屬低毒，未於本表摘錄)。

附錄表二、加保扶成品登記作物範圍

Appendix 2. The scope of crops registered for carbofuran formulations.

農藥名稱	登記作物
加保扶 **3%**粒劑	水稻、玉米、落花生、大豆、十字花科包葉菜類、十字花科小葉菜類、油菜、十字花科根菜類、馬鈴薯、胡蘿蔔、薑、番茄、香蕉、鳳梨、菊
益保扶 **4%**粒劑 (含益滅松 2%和加保扶 2%)	水稻
益保扶 **20%**可濕性粉劑**-**水溶性袋裝 (含益滅松 10%和加保扶 10%)	水稻

附錄法規資料：現行法規中，農藥販賣業者違反農藥管理法第 29 條第 8 款要求：「詢問購買者之用途，非為核准登記之使用方法或範圍者，不得販賣」、農藥使用者違反第 33 條第三項所定辦法中未依「使用農藥者應按農藥標示記載之使用方法及其範圍施藥」，可處 1 萬 5000 元至 15 萬元之罰鍰；而動物保護法中第五條第二項、第六條、第十二條第一項、第二項或第三項第一款規定，使用藥物、槍械，致複數動物死亡情節重大者，處一年以上五年以下有期徒刑，併科新臺幣五十萬元以上五百萬元以下罰金。另野生動物保法中亦有相關規定如果農民對於農作物有受到野鳥危害時，需要進行驅離或獵捕宰 (毒) 殺，應依野生動物保育法第 19 條規定先向當地市府農業局或各區公所申辦申請設置網具電網、陷阱或其他獵具 (租用農田應取得土地租用契約書)，並經同意後才可獵捕。隨意毒害野生動物依據野生動物保育法第 19 條規定：未經許可擅自設置網具陷阱、使用毒物等，獵捕「一般類」野生動物者，依同法第 49 條處新臺幣 6 萬元以上 30 萬元以下罰鍰；如獵捕宰 (毒) 殺「保育類」野生動物，則依同法第 41 條處 6 個月以上 5 年以下有期徒刑，得併科新臺幣 20 萬元以上 100 萬元以下罰金。