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封面圖說／
濱溝馬齒 （ *Peplidium maritimum* (L. f.) Asch. ）分佈於西南部海濱局部淹水的農田。 (許再文攝)

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Contents

臺灣新紀錄苔類—東亞白錦苔

Leucoloma okamurae Broth., A Newly Recorded Moss Species in Taiwan

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摘　要

過去臺灣僅有 1 種白錦苔屬植物—柔葉白錦苔的紀錄，本文報導臺灣新近發現的東亞白錦苔，並提供本種的形態描述、圖片、棲地及分布等資料。東亞白錦苔與柔葉白錦苔的分別在於，東亞白錦苔植物體較小，長約 1 cm 以下、葉不會脫落、葉細胞壁表面有粗疣，以及葉緣在葉中部 4–6 列細胞分化成葉舷。

Abstract

In addition to *Leucoloma molle* (Müll. Hal.) Mitt., *L. okamurae* Broth. was recently found, making the species number of the genus up to two in Taiwan. *L. okamurae* can be distinguished from *L. molle* by its smaller plant, which is shorter than 1 cm in length, scarcely deciduous leaves, median laminal cells with multiple large papillose, and leaf margins bordered by 4–6 rows of linear cells in the middle of leaf.

Here we provide descriptions, illustrations, habitat information, and geographical distribution of *L. okamurae*.

關鍵詞：東亞白錦苔、白錦苔屬、苔類、臺灣

Key words: *Leucoloma okamurae*、*Leucoloma*、mosses、Taiwan

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緒　言

Noguchi (1987)曾報導東亞白錦苔(*Leucoloma okamurae* Broth.)爲日本特有種，其後 Gao & Crosby (1999)則報導了此種在中國廣東及廣西的分布。作者在水社大山發現到東亞白錦苔的族群，爲臺灣第一次記錄此種的分布，加上原先臺灣記錄的柔葉白錦苔 *Leucoloma molle* (Müll. Hal.) Mitt.，讓臺灣白錦苔屬的組成增加到兩種；本文提供東亞白錦苔的形態描述、圖片、棲地與分布等資料。

臺灣產白錦苔屬檢索表

1. 植物體小於 1 cm；葉不脫落；葉中央細胞背面具數個粗疣；葉緣在葉中部 4–6 列細胞分化爲葉舷……………………………………………………………………東亞白錦苔(*Leucoloma okamurae*)
1. 植物體達 6 cm；葉常脫落；葉中央細胞具數個疣；葉緣在葉中部 10–20 列細胞分化爲葉舷……
……………………………………………………………………………………柔葉白錦苔(*L. molle*)

形態描述

東亞白錦苔 *Leucoloma okamurae* Broth., Ö fvers. Förh. Finska Vetensk.-Soc. 62A (9): 2. 1921. 圖 1–3.

植物體長 0.5–0.8 cm，黃綠色、綠色至暗綠色，乾燥時稍微捲曲，濕潤時呈同向(homomallous)生長。莖橫切面無中軸。葉線形，呈鐮刀型彎曲，基部略寬，3–4 mm 長，最寬的地方約 0.2–0.3 mm 寬。中肋達尖。葉中央細胞方形至矩形，7.5–17.5 μm 長，5–6.25 μm 寬，在背面具有數個粗疣。葉緣分化成細長細胞，在葉中部約 4–6 列，往葉尖逐漸窄縮成 1 列，無色。葉角細胞明顯分化爲較大的矩形細胞，25–40(60) μm 長，15–27.5 μm 寬，褐色。孢子體未見。

棲地： 樹幹或腐朽的木頭。
分布： 中國、日本及臺灣。

引證標本： 南投縣：魚池鄉水社大山，樹幹上，海拔 1512 公尺，2015 年 05 月 16 日，N 23˚50′, E 120˚ 57′，*K.-Y. Yao 6255* (CAS, TAIE, TUNG)。

根據日本及中國大陸的紀錄，此種葉緣分化在葉基部可達 10 列細胞寬，臺灣採集的標本也能觀察到越往基部邊緣分化越多列的趨勢，但越往基部靠近中肋一側的分化越不強烈，也因爲靠近中肋的細胞越往基部越爲拉長，且基部疣不明顯而使得分化的界限越趨不明，此份標本觀察到最多列約爲 8 列。Noguchi (1987)與 Gao & Crosby (1999)的物種描述沒有特別強調粗疣出現的位置，根據證據標本的觀察，粗疣大部分出現在細胞背面，腹面偶爾出現一些不甚明顯的疣，這個情形可以在葉的橫切面(圖 3. I)清楚的觀察到，且與 Iwatsuki (2001)的描述吻合。

謝 誌

感謝美國加州科學院的 James R. Shevock 先生，在野外工作上給予的協助及指導。此外，亦要謝謝陳桂珠小姐在植物繪圖上的幫助。

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Noguchi, A. 1987. Illustrated moss flora of Japan, Part 1. 242 pp. Supplemented by Z. Iwatsuki. Hattori Botanical Laboratory, Nichinan.

圖 1. 東亞白錦苔植物體，照片右方白綠色植物爲白髮苔屬植物。

Fig. 1. Plants of *Leucoloma okamurae* associated with whitish green *Leucobryum* sp. on the right side.

圖 2. 東亞白錦苔植物體。

Fig. 2. Individuals of *Leucoloma okamurae*.

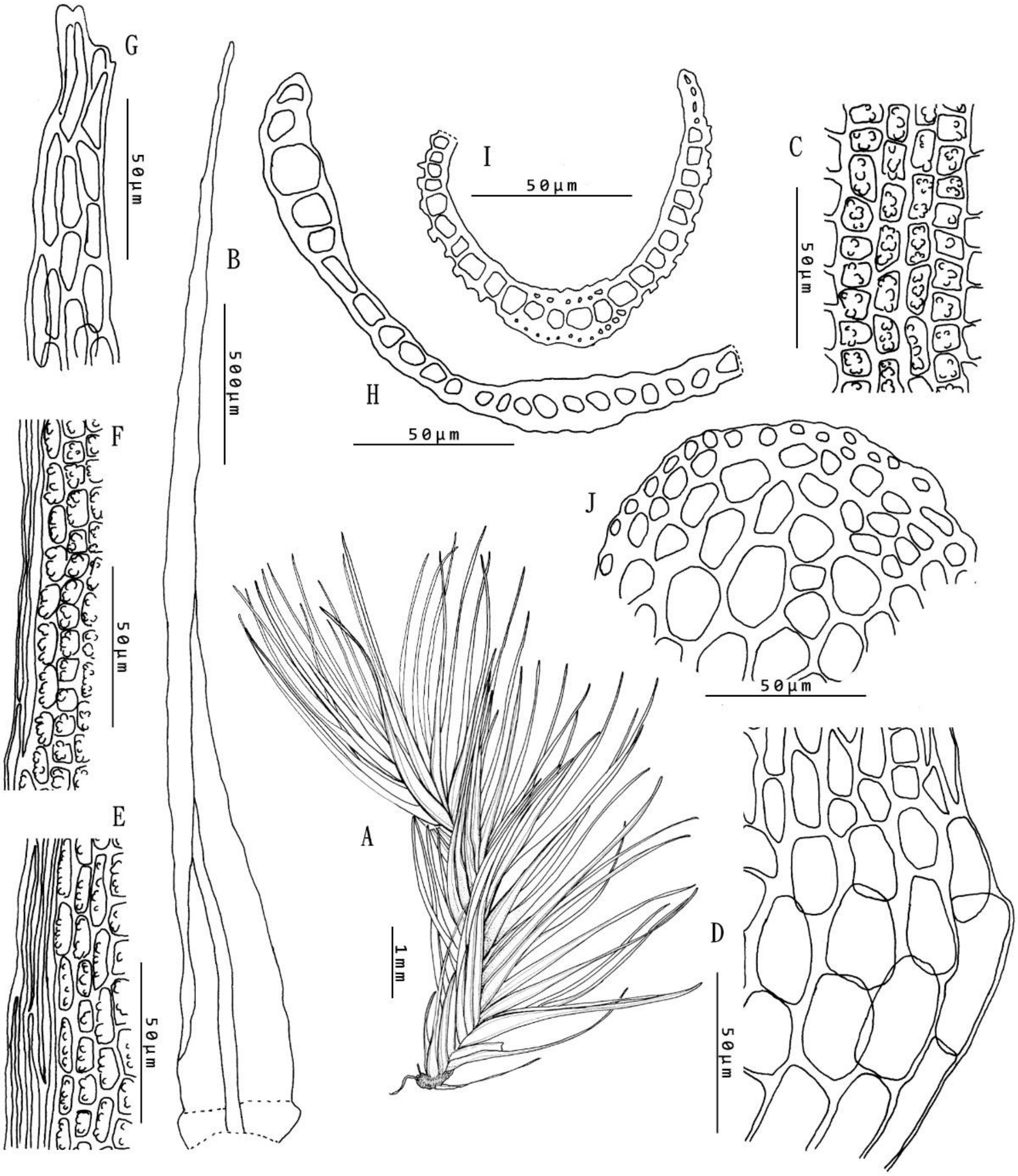

圖 3. 東亞白錦苔。A.植物體； B.葉； C.葉中央細胞(背面觀)； D.葉角細胞； E–F.葉緣(葉中部至上部)； G.葉尖； H–I.葉橫切(葉基部至中部)； J.莖橫切。(繪自 *K.-Y. Yao 6255*)

Fig. 3. *Leucoloma okamurae* Broth. A. plant; B. leaf; C. median cells of leaf (dorsal view); D. alar cells; E–F. marginal cells of leaf (from median to upper part of leaf); G. cells of leaf apex; H–I. cross-sections of leaf (from basal to median part of leaf); J. cross-section of stem. (Drawn from *K.-Y. Yao 6255*)

台灣產蠅毒草科新紀錄植物：濱溝馬齒

Peplidium maritimum (L. f.) Asch. (Phrymaceae), A New Record in the Flora of Taiwan

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摘　要

本文發表台灣南部海邊產的蠅毒草科新紀錄植物濱溝馬齒(*Peplidium maritimum* (L. f.) Asch.)，該種廣泛分布於埃及、伊拉克、印度、斯里蘭卡、馬來西亞與澳洲地區；此發現亦為台灣增添了一個新紀錄屬。本文提供濱溝馬齒的描述、分布、繪圖及彩色照片。

Abstract

A Phrymaceae species previously recorded in Egypt, Iraq, India, Sri Lanka, Malesia and Australia (Barker, 1992), *Peplidium maritimum* (L. f.) Asch. was recently found in coastal regions of southern Taiwan. The discovery adds a new record of this species as well as genus to the flora of Taiwan. This paper provides a taxonomic account of the species, a line drawing and color photographs to aid identification.

關鍵詞：濱溝馬齒；蠅毒草科；新紀錄屬；台灣；分類學

Key words: *Peplidium maritimum*; Phrymaceae; Newly recorded genus; Taiwan; Taxonomy.

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緒　言

玄參科(Scrophulariaceae)植物有 220 屬(Liu 1998)，泛分布於全球各地；部分學者將列當科(Orobanchaceae)併入，使其分類群擴增至 306 屬 5,850 種之多(Fischer 2004)，溝馬齒屬(*Peplidium*)原歸於傳統的玄參科植物(Barker 1992; Darbyshire *et al*. 2009)，近年來根據分子研究結果顯示玄參科並非單系群，分子系統樹上幾個主要分支已被處理爲科的階級，玄參科的範圍也被重新界定(Olmstead *et al*. 2001; Oxelman *et al*. 2005; Angiosperm Phylogeny Group 2009; Reveal 2012)。

溝馬齒屬目前歸於蠅毒草科(Barker *et al*. 2012)，台灣植物誌第二版並未記錄該科(Hsieh *et al*. 2003)，鍾明哲等人於 2005 年首次記錄台灣產該科植物(Jung *et al*. 2005)，並引用文獻指出該科僅有一屬(Hara 1962)，同時指出基於分子資料(Beardsley and Oldstead 2002)發現玄參科的幾個小屬跟蠅毒草屬(*Phryma*)形成單系群(monophyletic group)，目前根據相關研究該科已記錄有 13 屬 188 種(Barker *et al*. 2012)。

溝馬齒屬共有 4 種，主要產於澳洲亞熱帶地區(Barker *et al*. 2012)，本調查發現的濱溝馬齒(*Peplidium maritimum* (L. f.) Asch.)不但是台灣的新紀錄種，也是屬的新紀錄。

分類處理

Peplidium Delile, Fl. Égypte 4. 1813. 溝馬齒屬

Peplidium maritimum (L. f.) Asch., Beitr. Fl. Aethiop. 275, 306. 1867. 濱溝馬齒 Figs. 1, 2

Hedyotis maritima L. f., Suppl. Pl. 119. 1781.

Oldenlandia maritima (L. f.) Roth, Nov. Pl. Sp. 97. 1821.

Peplidium humifusum Delile, Fl. Égypte 4-5. *pl.4:2*. 1813; Spreng. Syst. Veget. 1:43. 1825.

匍匐性草本，輻射狀生長；莖圓柱形，淡綠色，光滑，徑約 0.8 mm。單葉，對生，葉柄扁平條形，淡綠色，長 4.3-5.7 mm，寬 1-1.2 mm，半抱莖。葉圓形或橢圓形，全緣，長 0.7-1.2 cm，寬 0.5-1.2 cm，表面綠色，背淺綠，先端圓或略凹，基部圓鈍，羽狀脈，不明顯。單花或 2 花叢生於葉腋，花梗極短，苞片無。花苞橢圓球形，綠色，長 2.2-2.4 mm，徑約 1.2 mm。花白色，鐘形，花長約 5 mm，徑約 3 mm；花萼合生，圓筒形，綠色，長約 2.6 mm，徑約 1.7 mm，先端截形。花冠基部合生成圓筒形，長約 2.3 mm，徑約 1.1 mm，淡綠色，光滑；裂片 5，近圓形，不等大，白色，長 1-1.5 mm，寬 1-1.9 mm，其中一枚基部具紫紅色斑點；雄蕊 2，著生於花冠筒上，花絲長約 1 mm，花藥 1 室，背著，縱裂，花藥黃色；子房上位，倒卵形或橢圓球形，綠色，高約 1.2 mm，徑約 1 mm，花柱綠色，長約 1.2 mm，柱頭扁平舌狀，遠軸面具一枝狀附屬物，特立基生胎座，胚珠多數。果單生，果梗極短，橢圓球形，高約 3.2 mm，徑約 2.6 mm，綠色；花萼宿存包覆果實，花冠宿存。種子多枚，近圓柱形。

分佈於熱帶非洲(Darbyshire *et al*. 2009)，埃及、伊拉克、印度、斯里蘭卡、馬來西亞與澳洲地區(Barker 1992)。台灣發現於西南部海邊附近。

引證標本：台灣(TAIWAN)：台南市(Tainan City)：七股區(Cigu District)，曾文溪北岸, 15 Oct. 2013, *Hsu18840* (TAIE), 18 Oct. 2013, *Hsu18870* (TAIE), 16 Jul. 2014, *Hsu19562* (TAIE).

濕地植物，僅發現於台南積水農田，2013 年 10 月份首度發現，之後每月份前往調查皆無再發現，直到 2014 年 7 月份才在當地再發現，該物種分佈極廣，從非洲的埃及、伊拉克、印度、斯里蘭卡、馬來西亞與澳洲地區都有發現，推測應該是由遷移性水鳥傳播，2009 年東非也發表該物種(Darbyshire *et al*. 2009)。台灣可能因物種分佈於耕種農田且生命期短，故一直未被採集到，野外觀察該物種發芽後一週內就有生殖能力，第一片葉片就可以發現有開花結實現象，可適應這種短暫的農田輪作耕種，當地部分農田種植洋蔥後會讓農田淹水再進行轉種其他作物，該物種僅見於這種短暫時期。

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本研究由行政院農業委員會與國家科學委員會(MOST 103-2627-B-329-001, MOST 104-2621-B-329-001)提供經費補助。

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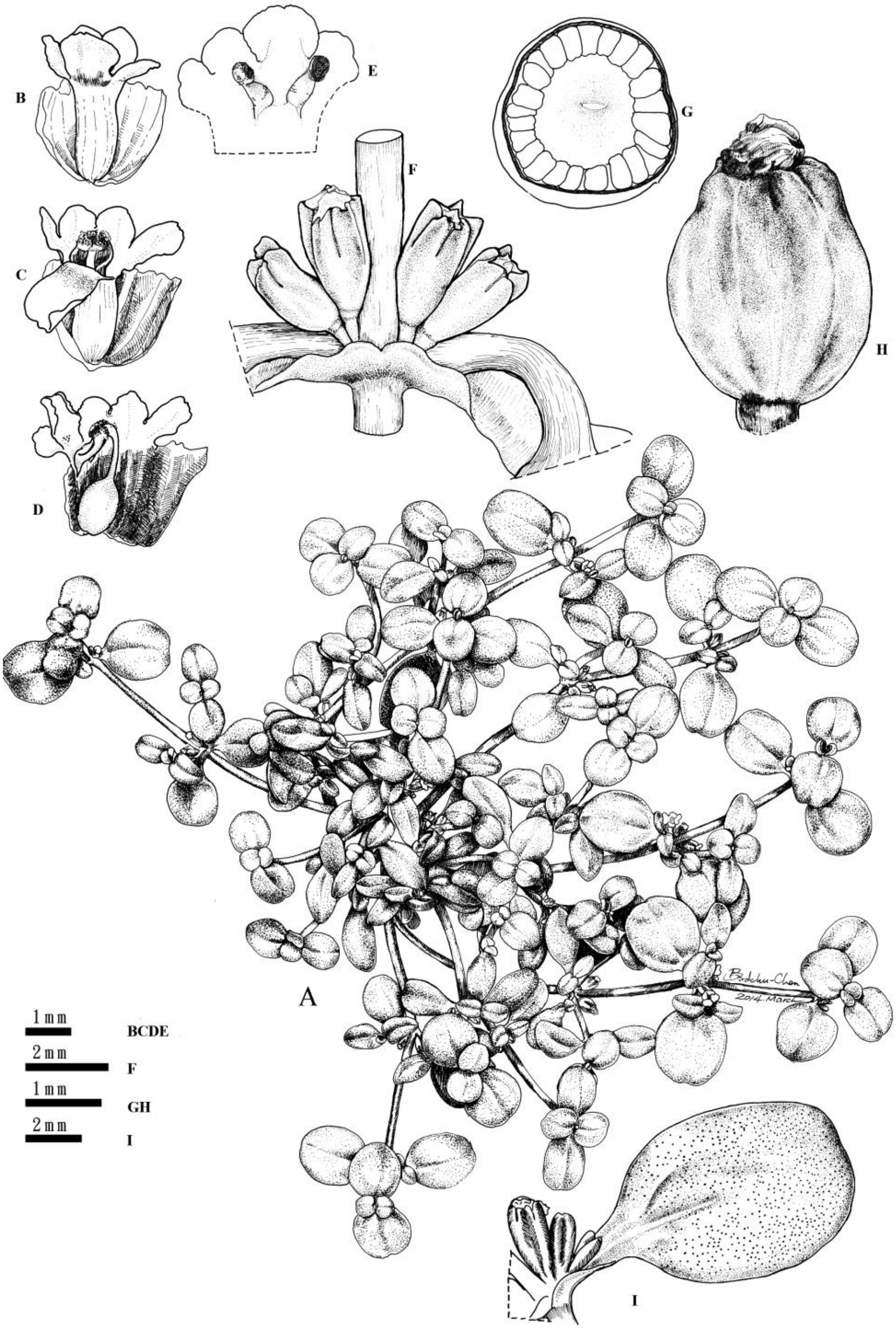

Figure 1. *Peplidium maritimum* (L. f.) Asch. A, Habit; B, C, Flower with dissected calyx in different views; D, Pistil with dissected corolla; E, Stamens on dissected corolla; F, Branch with flowers in bud; G, Fruit cross-section; H, Fruit with persistent perianth; I, Branch with flowers in bud.

Figure 2. *Peplidium maritimum* (L. f.) Asch. A,B, Habit; C, Branch with fruits; D, Flower with dissected calyx; E. Pistil with dissected corolla; F, Fruit; G, Fruit with persistent perianth. (scale bar=1 mm)

芒草在生質能源與植生復育的開發與利用

The Development and Application of *Miscanthus* in Bioenergy and Phytoremediation

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摘　要

C_4植物芒草因極高的光合效率與生物量具有生質能源的潛能，這個原生的雜草是組成台灣的草原生態系重要的物種，從低海拔的荒廢地(五節芒)、高鹽(八丈芒)及高重金屬(白背芒)的棲

地、中海拔的邊坡(台灣芒)一直到高山的草原(高山芒)，都有優勢的族群分布，然而這個台灣的草卻已經是歐洲的寶，透過國際合作，歐盟正式將台灣的芒草種源引入歐洲，作爲生質能源發電的原料；在美國芒草被列爲生產生質酒精的物種之一。台灣在缺乏完整的能源政策下，生質能源一直流於空談，尤其在原油價格直直落的大環境下更是雪上加霜，芒草作爲生質能源有固碳及快速回收的優點，相較於只會產能及釋放二氧化碳的化石燃料，芒草可以從大氣中吸收碳，也就是具有碳吸存的能力，依據歐盟的研究，一公畝的芒草每年約可以固定 1.63 噸的碳。除了火力發電廠的發電，台灣最有潛力的則是利用芒草粒(經乾燥造粒)於鍋爐的燃燒使用，以及透過低氧燃燒產生的生物碳乃至活性碳的製造，環境永續的考量上；種植芒草還有定沙、防止地層下陷以及去除土壤重金屬與戴奧辛的污染，居於整體的考量，台灣應該透過政策推動，開發與利用這種原生的天然資源。

Abstract

Featuring high photosynthetic efficiencies and biomass, *Miscanthus*, a C_4 plants, has become a potential biofuel crop. *Miscanthus* is native to East Asia with high species diversity, including *M. sinensis* Anders. that is widespread in Mainland China and Japan. Taxa in Taiwan are ecologically diverse, with *M. floridulus* (Labill.) Warb. *ex* Schum. & Laut. distributing in wastelands, *M. sinensis* var. *condensatus* (Hack.) Makino in saline-alkali habitats, *M. floridulus* var. *papillayus* Lee in heavy metal areas, *M. sinensis* var. *formosanus* Hack. on slopes of intermediate altitude, and *M. transmorrisonensis* Hayata in grasslands of high mountains. In 1997, the European *Miscanthus* Improvement Project, which is sponsored by the European Union, identified *Miscanthus* as a potential biofuel crop for renewable energy. Via international collaboration, *Miscanthus* seeds were exported officially from East Asia including Taiwan to European Union. *Miscanthus* has been used for combustion in Europe to reduce the usage of charcoal in the fossil-fuel power; in America, *Miscanthus* is used for producing ethanol. Unfortunately biofuel crops have not been well developed in Taiwan due to the lack of sustainable development policies. Compared to fossil fuel, which simply emits greenhouse gases, *Miscanthus* plants fix carbon dioxide from the atmosphere and carbon elements from soil, and transfer to biomass. According to researches conducted by the European *Miscanthus* Improvement Project, one acre of *Miscanthus* farm can fix 1.63 tons of carbon per year. Altogether, this C_4 plant is not only ideal for producing renewable energy, but for fixing carbon from the environment. Practically, *Miscanthus* manufactured as pellets can be directly used in power stations and burners for local industry. Additionally, planting of *Miscanthus* is also helpful for sand fixation, mitigation of land subsidence, and accumulating heavy metals and dioxin from polluted soil. For sustainable development, we suggest developing policy of biofuel in Taiwan.

關鍵詞：生質能源、芒草、植生復育法

Key words: bioenergy, *Miscanthus*, phytoremediation

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前　言

台灣的長遠未來有賴於自然與人力資源的永續使用，不論台灣或全球，人類經濟開發如果取之於自然生產力，這樣的開發則是永續性的。2012 年 11 月在卡達杜哈(Doha)第 18 屆聯合國氣候變化大會暨第 8 屆京都議定書締約國大會所通過的「杜哈氣候途徑」(Doha Climate Gateway)，延續執行京都議定書，不致讓全球僅有的執行溫室氣體減量國際公約中斷，並確認在 2015 年前將達成全球新減量協議的目標時程表。世界各國紛紛投入替代能源的找尋與研究，野生的生質能源植物頓時之間成了全球注目的焦點，其中 C_4 植物的禾本科芒屬植物，因其生長快速的特性，成爲生質能源議題關注的對象之一。台灣本身在地質上缺乏化石燃料的儲存量，長久以來製造業所需要的能量多是依靠進口能源和原材料進行生產，導致每人的平均二氧化碳淨排放量方面，台灣在全世界排名上名列前茅，因此，政府一直致力於提倡綠色再生能源來改善二氧化碳的排放量，能源的來源必須增加來自可再生能源和材料來源的多元化，減低二氧化碳的排放避免碳稅的產生，進而減少對環境的影響。

根據歐盟、英國與美國相關研究團隊的研究，芒屬生長速度快，目前歐盟已有利用芒屬植物所培育的巨芒(*Miscanthus* x *giganteus*)進行商業生產，以 50-50 的比例與煤混合直接燃燒，代替煤炭直接燃燒來發電，直接作爲火力發電廠的燃料。台灣的芒屬植物多樣性極高，英國 Aberystwyth 大學生物環境暨農村科學研究所(Institute of Biological, Environmental, and Rural Sciences)已與台灣依照國際生物多樣性公約的精神，針對採集野生芒類植物資源簽訂協議書，將由台灣提供的野生芒類植物資源種源，進行相關研究，並推展其商業化用途，爲全球環境保護盡一份心力。台灣雲林及彰化縣嚴重地層下陷地區，現今農委會輔導農民從事低耗水性農業及調整生產措施，稱爲農業「黃金廊道」計畫，計畫以彰化縣南部與雲林縣高鐵沿線三公里爲範圍嚴重地層下陷地區，進行建立「省水、省能」的農業黃金廊道，兼顧「生產」、「生態」與「生活」。此地區若是引進低耗水性、適應性強及粗放管理之「芒草」，應具備推廣潛力，因此若要進行零碳排放之生質能源作物開發，由台灣本土原生植物中來選擇，芒草將會是首選植物，因此選育適當芒草品種及分析其生產之經濟效益有其必要性。

一、芒草的分類與育種

芒草在分類上的地位是禾本科黍亞科蜀黍族芒屬(*Miscanthus*)植物，與甘蔗屬

(*Saccharum*)是近緣物種，二屬之間有雜交成功的例子。芒屬植物全世界約有 14 至 20 種，主要分布地是東亞、南亞和環太平洋群島，現已擴展至西非、美洲和歐洲地區。依據新整理的系統，芒屬植物分區為 6 節(Clifton-Brown *et al*. 2010)，其中作為能源作物親本物種主要為荻節(Section Triarrhena)和芒節(Section *Miscanthus*)，荻節包含二物種，分別為荻(*M. sacchariflorus*)和南荻(*M. lutarioriparius*)，此分類群台灣無分布，且此群植物雖高大但是耗水與分蘗少，不適合台灣使用。芒節植物主要區分為 2 大群，第一大群是由中國芒及其變種形成的分類群，第二大群是由五節芒形成的分類群(江等 2008)，二分類群皆可以利用光照溫度控制開花，具有雜交可行性。然而，雜交現象導致芒草在系統分類上的困難度，尤其是在中國芒複合群因為廣域分布和形態特徵差異大，導致分類上的困難與種下階層複雜性(Lee 1964a-d)。

芒節在台灣由海平面分布至高山草原地區，形態變化大，在 2007 年即被英國 Aberystwyth 大學生物環境暨農村科學研究所鎖定為非糧食作物在生物能源的研究之芒類植物的種源取樣地區，已經多次來台採集，並與行政院農業委員會特有生物研究保育中心於 2008 年簽訂「野生芒類植物資源」協議書，同意芒草種原採集，更於 2012 年正式簽訂芒類「使用及利益分享協議書」，同意雙方共同分享研究所得利益，雙方也希望在芒類生物能源作物的開發工作中能持續進行科技合作。然而，篩選高產量、高抗性的育種目標，其基礎研究如分類、繁殖、種原採集、雜交與育種、環境的適應生理、生物量性狀的比較、種植之經濟效益等項目皆是必要之項目，台灣芒草形態變異與環境差異的生理變異已天然篩選出大量生態型，如何運用此項天然資源，以現代遺傳分子標誌加速篩選如高生物量等必要的性狀，為未來的目標與努力方向。

遺傳育種方面，芒草具有高度遺傳變異(Chiang *et al*. 2003)，具有多倍體現象(Clifton-Brown *et al*. 2008)，加上花柱柱頭成熟不同時特性導致傾向異花授粉(Yu *et al*. 2009)，如荻(*Miscanthus sacchariflorus*)可以做為三倍體選拔之親本，現今商業生產使用巨芒即為三倍體。

二、芒草的生質能源潛力

台灣的芒屬植物為多年生植物，栽培容易，生長快速，無任何疾病，亦不需要灌溉，農業試驗所嘉義分所進行田間試驗結果，1 公頃面積可生產芒草乾重達 60 公噸，極具產業發展價值。多年生草本植物芒草具豐富的遺傳變異性和適應力，未來或許可以取代大豆、玉米等作物成為第二代能源作物(以纖維提煉酒精)選項，尤其因應氣候變遷、水資源不足及能源價格攀升之趨勢，發展低耗水性且具產製生質燃料潛力之芒草，評估其發展潛力實有其必要。芒屬物種在因適應性演化造成形態變異大，其植株大小與分蘗數目差異顯著，造成生物量累積速率不同。此生物量性狀屬於數量遺傳性狀，受到遺傳與環境調控，選育高產量芒草過程除傳統作物選拔方式，分子輔助選育將可以縮短生質能作物發展時程，因此利用分子標誌輔助選種以選拔適合環境之高產量的芒草品種為第一要務，所發展的分子鑑定技術亦能作為後續台灣芒草品種保護機制。

因應國際持續增加的壓力，未來以植物生物量作為生物燃料和生物發電可能為未來再生能源相關目標，因此，特用性能源作物

的開發，提高生物量的產量以作爲煤炭替代品或是直接進行生質汽柴油的來源。在過去的十年中，已開發國家因爲主要糧食作物和畜牧業飼料作物因爲由其他來源獲得更便宜的來源，導致本國農業過度生產的困境，例如歐盟架構下歐洲農業、台灣、日本等。因此，各國爲了不同的目的，皆有相關的農地休耕措施，例如歐洲國家的農地休耕是在1988 年推出，以減少生產過剩問題而達到15%的耕地休耕，於 1996 年則降低到 10%，然而，這些休耕的農業土地，應可進行非食品用途的生產，歐洲國家現今利用亞洲來源的巨芒作爲可再生能源的燃料和化學成分的再生生產資源運用。台灣現今農地休耕農地達數十萬公頃，加上因應地層下陷問題，必須要降低農作物對於水資源的使用情形，例如高鐵在雲林嘉義一帶的地層下陷問題，經評估已經造成高鐵使用壽命降低的風險產生，因應此現象農業委員會提出「黃金廊道農業新方案」，其計畫願景即爲打造節水、友善環境、提高農民所得的永續農業，推廣種植旱性作物爲可行方案。植物的生物量(Biomass)中的木質纖維素被認爲是用來替代非可再生能源的燃料和化學品的重要生產資源。芒屬植物由於己糖含量高(40-48%)，被認爲是一種精煉碳水化合物作爲生物燃料或是化學品的再生能源作物(Girisuta *et al.* 2012; 2013; Hayes 2013)。利用酸水解木質纖維素生物質的轉化以釋放糖和分離的木質素(Kang *et al*. 2013; Marcotullio *et al*. 2011; Rong *et al*. 2012; Weingarten *et al*. 2011)，並進一步進行酸水解獲得等量的乙酰丙酸(levulinic acid)和甲酸(formic acid)作爲生物材料來源(Bozell and Petersen 2010)。顯示芒草具有：(1)可再生能源的生物燃料以替代煤炭使用的潛能；(2)二氧化碳固定與排放相等以減少台灣碳排放量的潛能；(3) 酸水解獲得等量的乙酰丙酸和甲酸作爲生物材料來源的潛能。

解決大氣中日益升高的二氧化碳問題，現今技術有以地質碳封存方式，或以光合作用將二氧化碳轉變爲碳水化合物方式，然而，徹底解決的方式以利用植物的光合作用能力來進行，是最重要且是全世界人類的希望，亦因此可再生能源或綠色能源便成爲重要的研究課題。現今，尋找可用的生質能作物，已經由糧食作物轉變成非糧食性作物，多年生禾本科草本植物成爲生質能作物的篩選方向。例如以芒草做爲生質能作物的研究中，英國和歐盟科學家把東亞的二倍體中國芒和四倍體蔗芒人工雜交，形成三倍體的巨芒，它是多年生、具地下莖且快速生長特性的生質能作物，因此成爲一種新興農作物(Purdy *et al*. 2013)。目前，這種芒草已經在歐洲東北部大量種植，供應局部地區發電廠直接燃燒使用，也有做爲生質能基礎工業原料的潛力。在美國伊利諾州的種植實驗中，其生物量最高可達每年每英畝 30 公噸乾重(Dohleman and Long 2009)，歐洲可達20 公噸乾重(Lewandowski *et al*. 2000)，可做爲纖維、火力發電廠燃料等，並達成二氧化碳固定的目的(Clifton-Brown *et al*. 2008; 2010)。

三、土壤重金屬及戴奧辛的去除

數十年以來因人類種種活動所導致的土壤重金屬污染已嚴重影響我們所居住地球的生態環境，並逐步成爲一個全球性所關注的議題。台灣亦不例外，許多土壤重金屬污染的新聞層出不窮，由於過去數十年間從台灣傳統農業導向的社會轉型邁入現今的工商業導向的

社會，在發展過程中高度污染的石化工業亦快速發展，進而葬送了美麗的大自然環境，使得台灣生態保育面臨巨大的浩劫，同時台灣福爾摩沙–美麗之島的美名亦蒙上一層陰影。至於何謂「重金屬」？密度在 5 g/cm^3 以上的金屬統稱爲重金屬，如金、銀、銅、鉛、鋅、鎳、鈷、鎘、鉻和汞等 45 種。以環境污染方面所說的重金屬，實際上主要是指汞、鎘、鉛、鉻以及類金屬砷等生物毒性顯著的重金屬，也指具有一定毒性的一般重金屬如鋅、銅、鈷、鎳、錫等。重金屬可以大面積污染水源河川、大氣和土壤，其中對土壤造成污染後，更會嚴重影響地上面栽植植物或作物的生長，一方面造成土地資源的浪費與直接的經濟損失，更可通過食物鏈危害動物和人類自身的健康。因此，在國際上防治重金屬污染已成爲相當重要的環境保護議題。根據評估全世界至少有 2 千 2 百萬公頃以上的土地遭受重金屬污染(Nasanganwimana *et al*. 2014)，其中歐盟國家約占 409 至 479 萬公頃，美國則有 260 萬公頃，澳洲 6 萬公頃以及中國 810 萬公頃(Evangelou *et al*. 2012)。美國政府更估計需要花費數十億美金，才可能清除國內所有受重金屬污染的土地；然而在台灣亦有許多民眾所耳熟能詳的重金屬污染事件，如台南安順場戴奥辛污染、高雄茄萣以及新竹香山地區綠牡蠣、桃園觀音及蘆竹鎘米事件等。如何將受污染的土地復原成乾淨土地是目前相當困難的挑戰，過往重金屬污染土壤修復技術通常採用物理和化學方法，如排土填埋法、稀釋法、淋洗法、物理分離法和穩定化及化學法等。這些傳統的整治方法雖然治理效果較好且歷時短，但也有許多缺陷，如成本高、難於管理、易造成二次污染以及對環境擾動大等缺點。因此國際上近年來多應用植生復育法(phytoremediation)來解決土壤重金屬污染的問題，此方法主要藉由重金屬高聚積植物的吸收、轉運並積累進而去除土壤中有害的重金屬(Cunninggham *et al*. 1996)，目前則被視爲一種低成本且爲更有效的綠色技術，其中最爲重要的優點在於可良好維護土壤生態系統同時可美化污染地的景觀，因此對環境破壞甚低。

4-1 重金屬高聚積植物(Hyperaccumulator**)**

自然界中植物種類歧異度甚高，即使受到重金屬污染的土地也非全然沒有植被生長，早在 1865 年時，就有學者在德國及比利時發現一種十字花科的植物 *Thlaspi caerulescens*，能適應含鋅量相當高的土地；1948 年在義大利發現另一種可以蓄積大量鎳的十字花科植物 *Alyssum bertolonii*，顯示植物體本身可忍受重金屬環境甚至累積大量重金屬。高聚積植物(Hyperaccumulator)是 Brooks 等人(1977)所提出來的概念，能在體內聚積一定濃度以上的重金屬並大量聚積在莖或葉中、且沒有明顯毒性症狀產生的植物，可稱爲「重金屬高聚積植物」。即鉻、鈷、鎳、銅以及鉛的含量應在 1000 mg／kg 以上，錳與鋅含量應在 10000 mg／kg 以上(Baker *et al*. 1983)。現已發現鎘、鈷、銅、錳、鎳、鉛、鋅、砷和硒等元素的超積累植物高達 400 餘種(Baker and Brooks 1989)。然而依重金屬種類可將重金屬高聚積植物區分爲三大類群：銅／鈷聚積植物、鉛／鋅／鎘聚積植物及鎳聚積植物。目前已有許多重金屬高聚積植物相繼被發現，其中熱帶地區的重金屬高聚積植物大多屬於大戟科，而溫帶地區則是十字花科。許多十字花科的植物可聚積超過 1%的鎳，有些則可聚積超過 1%的鉛及 3%的鋅，而部分水耕栽培的阿拉伯芥屬植物，地上部的鋅濃度可達 32,000 微克／克乾重，甚至有些植物的膠乳中，可累積高達 11%乾重的鎳。全世

界約有 400 種已知的重金屬高聚積植物，然而這些植物都具有生長緩慢以及較低生物量(biomass)的特性。其中 *Thlaspi caerulescens* 已被廣泛認定為鋅的超高聚積植物，並已有許多該物種對鋅的吸收和轉移的研究(Robinson *et al*. 1998; Frey *et al*. 2000; Matthew *et al*. 2008)。而在台灣，根據我們野外的調查，僅有少數能忍受或吸附這些重金屬離子的種類可以在污染地存活或繁衍後代，包括禾本科植物芒屬植物(*Miscanthus* ssp.)、牛筋草(*Eleusine indica*)、白茅(*Imperata cylindrica* var. *major*)與十字花科植物碎米薺(*Cardamine flexuosa*)等。基本上可以有效清除重金屬污染的植物，最好具備下列特徵：生長快速且生物量高、根系能深植土壤、容易收割、能夠容忍並累積多樣化重金屬為最佳選擇。

4-2 植生復育法－以芒屬植物為例

芒草在台灣幾乎隨處可見，其生命力旺盛的特性，使其可廣泛生長於各種環境，甚至於極端惡劣環境，如海邊高鹽地區、乾旱地、高山甚至於雪地，亦能適應不同土壤條件的環境，相對於其他植物而言，事實上芒草是天賦異稟，最主要的原因在於光合作用特性。芒草的光合作用和高粱、甘蔗皆為 C_4 型植物，這類型植物的光合作用最初產物是四個碳的草醯乙酸(oxaloacetic acid)，透過合成草醯乙酸，使植物體能在體內儲備 CO_2，能避免植物體開放氣孔獲取 CO_2 的過程導致水分喪失，所以這樣的過程也間接加強植物對於水分利用效能，造就 C_4 型植物耐旱適應的重要機制。芒草優異的生態習性以及特性，但芒草於台灣卻被視為無用之植物，國外則許多不同品種的芒草不斷被歐美人士所大量改良以及栽種。芒屬植物是高產量且非經濟作物的多年生草本植物，一直以來被認為是作為生質能源良好的植物，植物體本身亦可作為生物性材料或工業上原料(ValBiom, 2009; Acikel, 2011)，顯示芒草具有高度的經濟上價值。芒屬植物中的中國芒(*M. sinensis*)、荻(*M. sacchariflorus*)、五節芒(*M. floridulus*)以及巨芒草(*M.* x *giganteus*)因其經濟效益而被廣泛於歐美地區栽植，其中巨芒草為四倍體的荻與二倍體的中國芒雜交後代(Deuter, 2000)，更被譽為未來可用來取代石化燃料的明星植物。研究顯示栽種於歐洲以及美國的巨芒草在 2-3 年的種植時間內總產量可高達每公頃 15-30 公噸(Picco 2010)，雖然產量以及生長速度會受到物種種類以及基因型、管理方式、土壤以及其他環境因素影響。也由於此些特性近年來芒屬植物除了可取代石化燃料外，亦有許多國家將其視為應用植生復育法解決土壤重金屬污染的選項之一。

一般來說高生物量作物對重金屬積累的含量比較低，但由於其生物量相對大，所以整體上仍具有較高的重金屬積累量。近年來則開始關注利用高生物量的植物來進行植生復育(Díez Lázaro *et al*. 2006)，此外植物生物量本身同時又可做為植物生長在重金屬污染土壤裡健康程度的一個重要標誌(Fayiga *et al*. 2004)，芒屬植物則具有這樣的特性，其他植物如白楊木、向日葵與大麻等亦是(Sebastiani *et al*. 2004)。綜合過往芒屬植物有關重金屬吸附能力或應用於植生復育的研究(表一)，發現大多數試驗主要著重於中國芒、荻、五節芒以及巨芒草此四物種，顯示芒屬植物對重金屬鋅、鉛、銅、鉻、鎳、鈷、鎘以及砷有吸附能力。Kalembasa 以及 Malinowska (2009)以荻為研究材料發現吸附能力依序為鋅 >鉛>銅>鉻>鎳>鈷> 鎘，其他研究也進一步說明根部累積程度略高於地上部(Pidlisnyuk *et al*.

2014; Li *et al*. 2014)。Rosikon 等學者(2015)則利用城市與工業廢水做爲土壤肥料來源來栽種巨芒草，顯示可吸附重金屬以鎘與鋅濃度最高，對鎳吸附能力則略低，該研究亦印證且巨芒草生長一年後重金屬吸附效果達最高。在野外田間試驗部分 Wanat 等學者(2013)則將巨芒草種植於高度污染的土壤中，結果顯示巨芒草可生存於砷、鉛與銻高度污染的地區，但會使其生物量減少，整體而言對其生長沒有太大影響，且根部累積重金屬的程度相對地上部高。Peng 等學者(2006)於中國湘西地區的三個高度污染地區廣泛取樣 125 種植物共 363 個樣本，進行鎘、鉛、鋅與銅重金屬的吸附能力比較，結果顯示其中五節芒對鋅吸附能力最好，鉛次之。綜合上述芒屬植物對鋅吸附效果爲最好，此外對鉛、銅、鉻、鎳、鈷、鎘以及砷仍有吸附能力。此外過往並無相關研究說明芒屬植物可用來分解或吸附世紀之毒戴奥辛，但根據野外調查發現中石化安順廠戴奥辛污染植被呈現單一化，只有芒草生長於上，這也暗示著芒草對戴奥辛有高忍受力，亦有可能對戴奥辛具有吸附能力，但相關推論未來仍需進一步來印證。

四、可能的困難與能源政策建議

替代能源發展最大的限制來自於國際原油的價格，這個客觀的條件讓世界各國的能源研發，尤其在生質酒精的投入上，受到了相當大的限制，加上頁岩油的開採，緩解了能源即時需求的壓力，世界各國開始轉向太陽能、氫能的研發，歐盟則在生質能源的研發上轉向直接燃燒投入火力發電，表面上來看，燃燒芒草帶來的是二氧化碳的排放，似乎與政策違背，然而芒草所替代的是火力發電廠屬於植物化石能源的燃煤，雖然都產熱而釋放溫室氣體，然而芒草需要透過植栽而獲得，植物從種子萌芽那一刻，葉綠體引擎就開始啓動，固定大氣中的二氧化碳，將光能轉換爲化學能，芒草的植栽更將土壤內的碳元素吸附並固定，從碳元素的循環與固定，C_4 植物的芒草無疑地是減碳又產能的最佳物種。

然而芒草生質能源的開發與利用，需要的不只是生物科技的突破，這其中包括高生物量品系的篩選與育種，更重要的是政府政策的配合，包括可用土地的獲得、可用的水源、收購與採收機制、運輸的工具、乾燥場域的覓得、以及芒草壓縮或造粒技術的研發，都需要有完整的配套；同樣地透過芒草植栽，吸附土壤的重金屬與戴奥辛，第一必須排除可食用的作物，以免流入市場造成二度的傷害，芒草以生長快速又能克服困難環境的特質，適合用於被污染土壤的恢復，在過往植生復育法(Phytoremediation)幾乎很少被採用，相對地化學淋洗或移地處理則是較常使用並被認爲是有效的手段，然而隨著環保意識抬頭，污染土地被要求要就地低度污染的處理，利用植栽移除土壤汙染物的方式才開始受到了重視，在美國軍方爲了不洩漏國防機密，軍事基地土壤黃色炸藥的移除這幾年來，採取的是栽培快速生長的白楊樹，這個無性繁殖的樹種，吸附了土壤大量的硝酸根，被送進到焚化爐，以高溫來降解，然而白楊樹屬於溫帶物種，在台灣低海拔地區幾乎無法生長。滿足生長快速又可以有效率吸附土壤的重金屬及戴奥辛的本土植物中，以芒草爲首選，如何選育一個耐性最高又能生長快速的品系，則是下一個階段的任務。

表 1. 芒屬植物於植生復育法之相關研究彙整

Table 1. The Relationships of Phytoremediation in Miscanthus

種類	可吸附重金屬種類及特性	資料來源
M. × *giganteus*	可吸附鎘，且多累積於植物體根部。	Arduini *et al*. 2004
	對鎘、銅、鎳、鉛、鋅與鉻有吸附能力，其中對鋅吸附能力最好。	Fernando *et al*. 2004
	可吸附鎳，且多累積於植物體根部。	Lyubun and Tychinin 2007
	能生存於砷、鉛與銻高度污染的地區，雖生物量減少，但對其生長沒有太大影響，植物體根部累積程度較高。	Wanat *et al*. 2013
	對銅、鎳與鋅有吸附能力，但低於 *Spartina pectinata*，且植物體地下部所含重金屬比例略高於地上部。	Korzeniowska *et al*. 2015
	以城市與工業廢水做爲土壤肥料來源，顯示可吸附重金屬以鎘與鋅濃度最高，對鎳仍有吸附作用，且生長一年後吸附效果達最高。	Rosikon *et al*. 2015
M. sinensis	對砷有高度忍受力，次之爲鋅。	Zhu *et al*. 2010
M. floridulus	分析 125 種植物，其中 *M. floridulus* 對鎘、鉛、鋅與銅其中以對鋅吸附能力最好，鉛次之。	Peng *et al*. 2006
	對鉛、鋅、銅、鎘以及砷有忍受力。	Leung *et al*. 2007
M. sacchariflorus	吸附能力鋅>鉛>銅>鉻>鎳>鈷>鎘。	Kalembasa and Malinowska 2009
	對鋅以及鉻有高忍受力，且多累積於根部。	Li *et al*. 2014
	對鈷與銅有吸附能力，根部累積程度略高於地上部。	Pidlisnyuk *et al*. 2014
Miscanthus spp. (*M.* × *giganteus*, *M. floridulus*, *M. sinensis*)	三物種對鋅皆有吸附能力，其中 *M.* × *giganteus* 能力較好，且植物體地下部所含重金屬比例略高於地上部。	Barbosa *et al*. 2015

五、芒屬植物應用之願景

芒草在最近三年來相關研究快速增長，近五年內已有超過 200 篇科學論文發表，被確認爲是具有全球潛力的能源作物(Brosse *et al*. 2012, van der Weijde *et al*. 2013)。相關研究包含芒草外部形態特徵作爲增加產量識別的模型(Robson *et al*. 2013)、具有高輻射適應、水和氮高效率利用能力(Lewandowski *et al*. 2000)、對於低溫處理具有高度容忍性的芒草四種基因型的外表形態特徵(Purdy *et al*. 2013)、根莖越冬條件(Clifton-Brown and Lewandowski, 2000; Yan *et al*. 2012)、低溫下小苗存活率(Yan *et al*. 2012)、在持續降溫下葉片的伸展狀況或是低溫下維持持續高度光合作用速率(Clifton-Brown and Jones, 1997; Wang *et al*. 2008)。然而，工業上相關研究則以芒草作爲木質纖維素爲主要產品進行後續相關研究(van der Weijde *et al.* 2013)，包含酸水解步驟以釋放糖(Kang *et al*. 2013; Marcotullio *et al.* 2011; Rong *et al.* 2012; Weingarten *et al.* 2011)和乙酰丙酸(levulinic acid)和甲酸(formic acid)作爲生物材料來源(Bozell and Petersen 2010)。

植生復育是一項正處於發展之中且具有應用前景的土壤整治技術，其優點爲安全且對生態有善以及花費低的特性，目前世界上多朝此方向前進，但這樣的技術較爲適合應用於中、低濃度污染土壤的治理。其中利用芒屬植物進行植生復育目前已於中歐、東歐以及美國中部等地廣泛應用，多年生的草本芒屬植物適合種植於污染或其邊緣地區的一類植物，多數研究指出植物體不同部位重金屬儲存的量有所差異，而這樣的差異可能來自受到污染地區的現況不同、土壤狀況甚至於栽植的時間所影響。芒屬植物不論在實驗室或野外試驗都顯示其具有潛力用來移除土壤中重金屬，未來可藉由改良栽種過程來增加芒屬植物於污染地區的生長速度，藉以增加生物量(Kacprzak *et al*. 2014)，如有機物質、螯合劑或生物炭的添加或增加土壤中微生物多樣性等方法；可篩選和培育對重金屬具有高聚積能力的芒屬植物品種或品系；或者可藉由整合基因工程和分子生物技術來解決高聚積植物於污染地生長緩慢和地上部生物量少的缺點。最後重金屬複合性污染土壤的修復，必須從當地經濟可持續發展和土地資源永續利用兩方面來考慮。因此，爲提升環境品質，維護環境資源，追求永續發展，植生復育法搭配生質物再利用仍是一具有潛力的整治技術。

台灣的芒草具有高度的物種多樣性，耐鹽、耐重金屬乃至高山耐寒的生理適應特質讓芒草能夠適應不同的棲地，甚至形成優勢的草原生態，這個光合效率極高的 C_4 植物，提供了發展生質能源以及去除土壤污染極佳的生物材料，過往被用來作爲原住民祭祀、搭建草屋房舍的”野草”，在歐洲已經成了替代植物化石燃料的”寶藏”，而台灣芒草的利用仍處於早期發展的階段，如何提高碳的吸存以及如何提高生物量，需要的生物科技關鍵技術的突破以及政策的配合。

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Description Update of A Rare Spider *Neoscona multiplicans* (Chamberlin, 1924) (Araneae, Araneidae) from Taiwan

台灣稀有種小青姬鬼蛛之描述 (蜘蛛目：金蛛科)

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Abstract

Neoscona multiplicans (Chamberlin, 1924) is widely distributed in Japan, Korea and China, but is rare and poorly understood in Taiwan. This paper provides an updated description and photographs of *N. multiplicans* based on specimens found in Taiwan, as well as a discussion of the species' distribution in Taiwan.

摘 要

小青姬鬼蛛 (*Neoscona multiplicans* (Chamberlin, 1924)) 廣泛分布於日本、韓國和中國大陸等地區，但在台灣爲稀有且尚未被描述的物種。本文根據台灣標本對雌蛛重新描述，並討論其在台灣之分布。

Key words: Araneae, Araneidae, *Neoscona*, Taiwan.

關鍵詞：蜘蛛目、金蛛科、姬鬼蛛屬、台灣

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Introduction

The genus *Neoscona* Simon, 1864 containing 114 species is one of the largest groups of the family Araneidae and has a worldwide distribution (World Spider Catalog 2016). Eleven species have been recorded from Taiwan (Chen 1996). Small to medium in size, members of the *Neoscona* have the following morphological characters: a median longitudinally thoracic groove, anterior median eyes largest and posterior lateral eyes smallest among eyes, both lateral eyes very close to each other and not on a prominent tubercle, chelicera with four promarginal and three retromarginal teeth, leg formula I-II-IV-III or I-IV-II-III, legs of male having a ventral hook at the distal margin of coxa I and many strong prolateral spines on tibia II, epigynum of female having a smooth triangular, ligulate, or elongated scape. They usually construct orb webs in grassland or between shrubs at night, and stay in the hub of snare. *Neoscona multiplicans* (Chamberlin, 1924) is widely distributed in East Asia, including Japan, Korea, and China but had never been recognized from Taiwan except by Tanikawa (2006), who documented a female museum specimen (UMUTZ-Aran-26-2) collected about one hundred years ago (i.e., 1899 A.D.) from Keelung, Taiwan, without description. However, his finding was ignored by recent researchers (e.g., Tanikawa 2009; World Spider Catalog 2016; Zhu and Zhang 2011). Before Tanikawa (2006), *N. multiplicans* had been collected by the junior author in 1996 in Pinglin, Taipei County (now New Taipei City) in northern Taiwan. Until recent, it was re-discovered in neighboring regions, i.e., Hsintien and Wenshan (Fig. 1). Although no male was obtained, the morphology of these Taiwanese female specimens is undoubtedly identical to that of *N. multiplicans* described from neighboring countries in related literatures (e.g., Chamberlin 1924; Song et al. 1997; Namkung 2002; Tanikawa 2009). In this paper, we updated the description of this species based on specimen gathered from Taiwan.

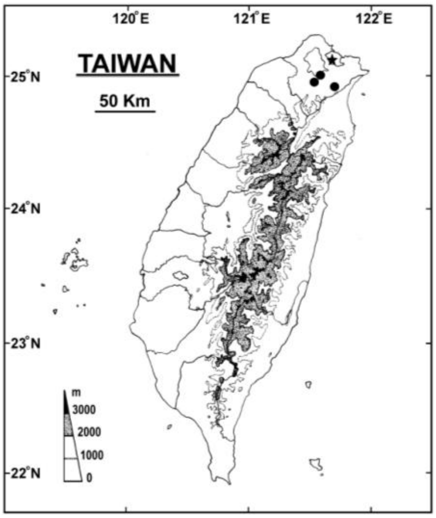

Fig. 1. Collect localities of *Neoscona multiplicans* in Taiwan. Data based on Tanikawa (2006; ★) and the present study (See the specimen examined in text; ●).

Materials and methods

Spiders were obtained by hand in the field. Alcohol-preserved specimens were examined, measured and photographed under a stereomicroscope (Leica M3Z) using an ocular micrometer with up to 80x magnification. Examined specimens were deposited in the Arachnological collection of the Department of Life Science, National Taiwan Normal University (NTNUB-Ar). All measurements given are in mm. Measurements of the palpus are shown as total length (femur, patella, tibia, tarsus). Measurements of legs are shown as total length (femur, patella and tibia, metatarsus, tarsus). Abbreviations used are AER, anterior eye row; ALE, anterior lateral eye; AME, anterior median eye; CO, copulatory opening; MOA, median ocular area; PER, posterior eye row; PLE, posterior lateral eye; PME, posterior median eye.

Results

***Neoscona multiplicans* (Chamberlin, 1924)** (Figs. 1–9)

Aranea multiplicans Chamberlin, 1924: 18, pl. 5, f. 35.
Neoscona scylla: Song, 1988: 129.
Neoscona minoriscylla Yin *et al*., 1990: 123, f. 301–309.
Neoscona multiplicans: Song *et al*., 1997: 1715, f. 17a–c.

Specimens examined.

TAIWAN: TAIPEI CITY: Wenshan, Chihnankung, alt. 250 m., 1 female (NTNUB-Ar 48606), 20-VI-2011, Wen-Jean Huang leg.; 1 female (NTNUB-Ar 48813), 30-VI-2011, Wen-Jean Huang leg. NEW TAIPEI CITY: Hsintien, Ankeng, alt. 20 m., 1 female (NTNUB-Ar 48824), 29-VI-2011, Shyh-Hwang Chen leg.; Pinglin, near Pihu Bridge, alt. 300 m., 1 female (NTNUB-Ar 1525), 13-VIII-1996.

Diagnosis.

Neoscona multiplicans most closely resembles *N. scylla*, but can be distinguished from the latter (characters in parentheses) in having a smaller body length varying from 7 to 13 mm (larger, 12 to 15 mm), and epigynum with a scape broad anteriorly and a narrow tip (not broad anteriorly).

Description.

Female (NTNUB-Ar 48813). Total length 9.69; carapace length 4.00, width 3.08; abdomen length 5.69, width 4.46. Measurements of palpus and legs: palpus 3.23 (0.65, 0.35, 0.78, 1.45); legs I 14.62 (4.62, 5.23, 3.69, 1.08), II 13.77 (4.46, 4.77, 3.39, 1.15), III 8.23 (2.46, 2.92, 1.85, 1.00), IV 14.53 (4.92, 4.77, 3.69, 1.15). Diameters of eyes, AME: ALE: PME: PLE = 0.20: 0.18: 0.18: 0.13.

Carapace (Figs. 2–3) covered with moderately abundant appressed hairs; median groove, cervical grooves and radial grooves distinctive. AER and PER recurved when viewed dorsally. PER longer than AER. AME > ALE = PME > PLE. Distance between AMEs (0.25) shorter than that of AME and ALE (0.43), distance between PMEs (0.13) shorter than that of PME and PLE (0.50). MOA length 0.65, anterior width 0.60, posterior width 0.50. Height of clypeus nearly equal to diameter of AME. Chelicerae stout, geniculate anteriorly; fang groove armed with four promarginal and three retromarginal teeth, with a largest third promarginal one. Endite longer than width. Labium pentagonal in shape, wider than length. Sternum heart-shaped, margin concaved at base of coxa and intruding posteriorly to between coxae IV, and connected with carapace by sclerotized strips between coxae. Leg formula I-IV-II-III. Abdomen ovoid. Epigynum (Figs. 6–9) stout, with copulatory openings adjacent to anterior border of epigastric fold. Scape broad at base, gradually tapering posteriorly, and bent to dorsal side at tip.

Coloration. Carapace light brown, dark in margin; median groove, cervical grooves and radial grooves brown; a pair of white stripes in front of median groove and a large yellowish ivory marking on rear side. Chelicerae, fang, and labium dark brown; endite brown. Abdomen yellowish brown, dorsum with a pale brown folium mixed with five pairs of arch-shaped dark brown markings; venter grayish brown in center, with a pair of remarkable large white spots in between epigastric furrow and spinnerets, and an additional pair of small white spots located in between large spots and anterior spinnerets. Spinnerets brown, tip darker.

Variations.

A total of four females were measured. Variations among females (with mean in parentheses) are: total length 9.69–13.39 (11.59); carapace length 4.00–5.11 (4.64), width 3.08–4.00 (3.62); Abdomen length 5.69–8.51 (6.95), width 4.46–7.02 (5.89). The coloration of abdomen and the folium marking become darker in larger individuals. The additional pair of small white spots in the venter of abdomen are not present in one female (NTNUB-Ar 1525, Fig. 5).

Distribution.

China, Japan, Korea and Taiwan.

Discussion

Neoscona multiplicans has been recorded from middle latitudes of Northeast Asia, i.e., Japan, Korea, and China (from Beijing and Henan to Yunnan and Hainan) (Song *et al.* 1999; Zhu and Zhang 2011). Taiwan is a large continental island very closed to Fujian of Southeast China. The Tropic of Cancer passes through both the middle of Taiwan and South China. The discovery of *N. multiplicans* in northern Taiwan is not a surprise. Tanikawa (2006) first discovered a female museum specimen that was collected in Keelung, Taiwan, in 1899. The specimen is now preserved in the Department of Zoology, the University Museum, University of Tokyo (UMUTZ-Aran-26-2) for more than one hundred years. The junior author re-discovered the second specimen (NTNUB-Ar 1525) two decade ago in 1996. Up to the present, a total of five Taiwanese specimens have been recorded. However, *N. multiplicans* seems rare in Taiwan. In the field, *N. multiplicans* may easily be confused with *N. scylla*, another sympatric and much common species in Taiwan, due to similarities in external features and habit. *Neoscona multiplicans* was found in shrubs along the roadsides or small trails in the low mountain areas of northern Taiwan. As does in *N. scylla*, *N. multiplicans* usually spins a new orb web and stays in the hub to prey insects for food at night. The snare will be destroyed next morning, and the spider hides in foliage next to the destroyed snare during the daytime. Without close examination, *N. multiplicans* can hardly be recognized among large number individuals of *N. scylla*. Due to insufficient investigations and poorly taxonomic studies in Taiwan, it took nearly 20 years to recognize *N. multiplicans* since the first individual collected in 1996. Although *N. multiplicans* is only found in northern Taiwan now, we expect its distribution should include all low mountain areas below 1000 m above sea level. However, this needs to be confirmed by further investigations in the near future.

Acknowledgements

We sincerely thank Wen-Juen Huang, at the Luye Junior High School, Taitung, Taiwan, for collecting specimens. We also appreciate two anonymous reviewers for helpful and invaluable comments. The present study was supported in part by the National Science Council, Executive Yuan (NSC97-2321-B-003-005-MY2).

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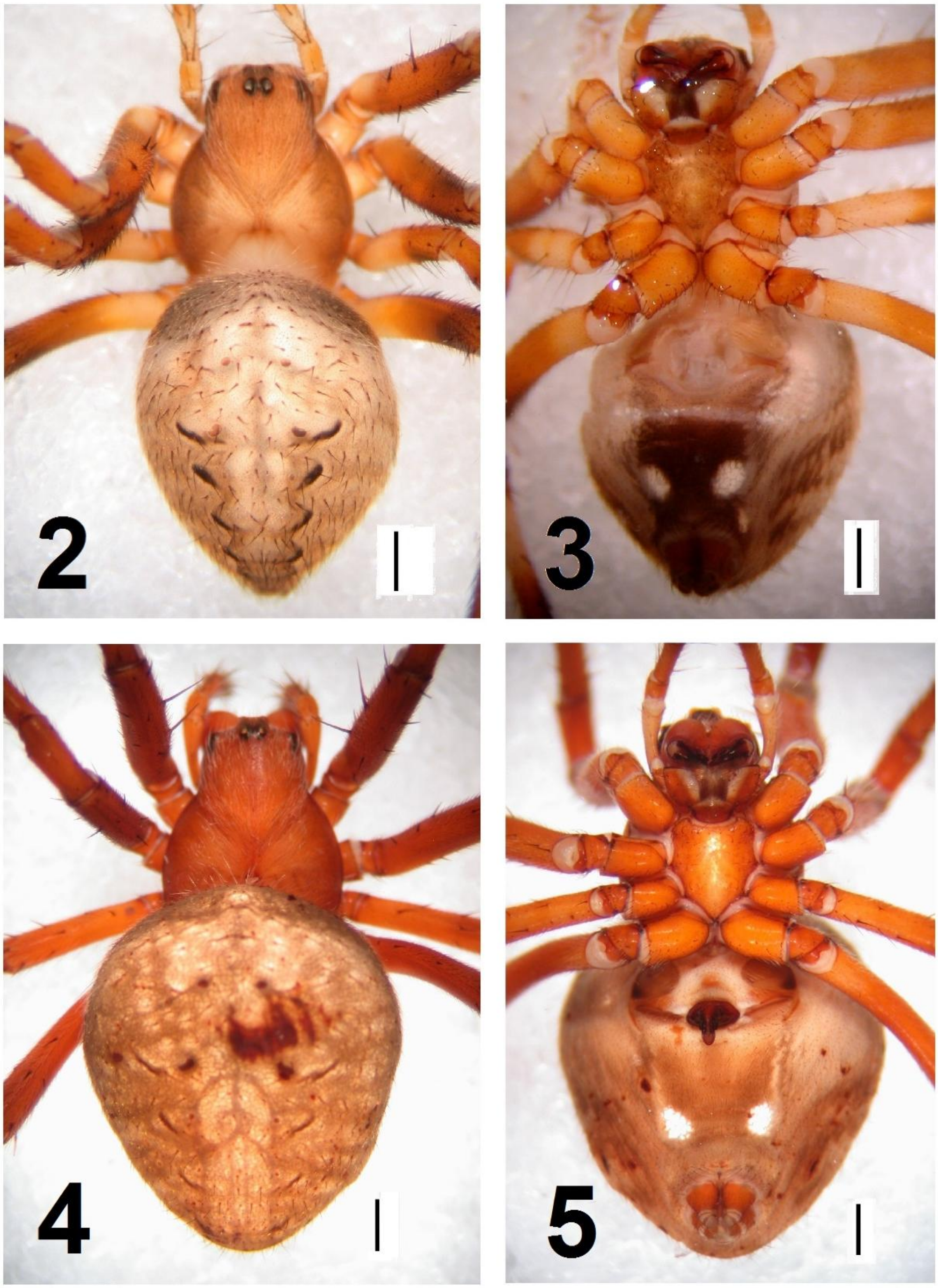
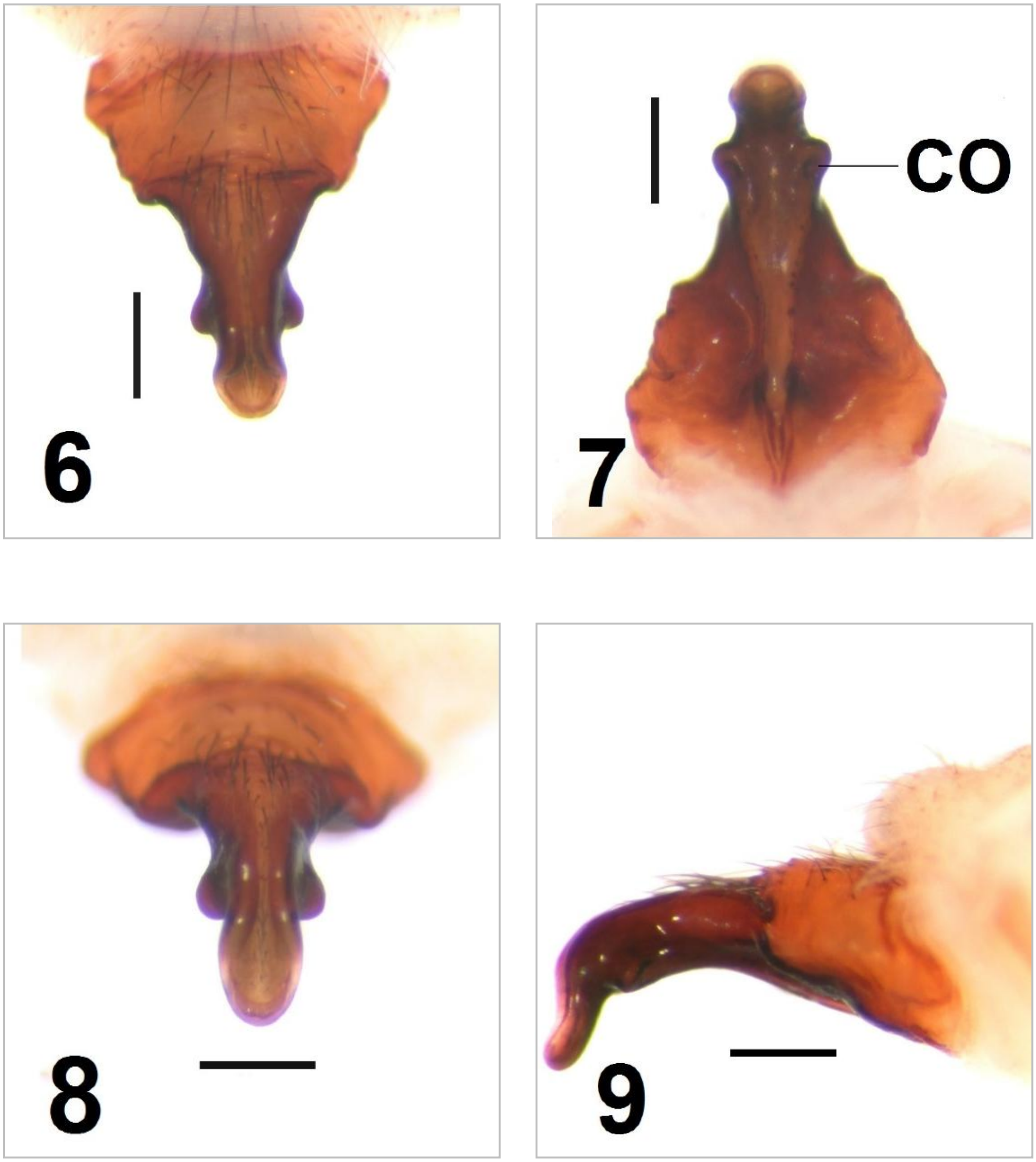


Figs. 2–5. Habitus of *Neoscona multiplicans* (Chamberlin, 1924). 2–3, female from Chihnankung (NTNUB-Ar 48813), epigynum was removed; 4–5, female from Pinglin (NTNUB-Ar 1525). 2, 4, dorsal view; 3, 5, ventral view. Scales = 1 mm.



Figs. 6–9. Female epigynum of *Neoscona multiplicans* (Chamberlin, 1924), NTNUB-Ar 48813. 6, ventral view; 7, dorsal view; 8, ventro- posterior view; 9, lateral view. CO: copulatory opening. Scales = 0.2 mm.

七股地區淺坪虱目魚塭及文蛤池底棲動物相之研究

A Study on theBenthic Fauna of Shallow-water Milkfish Ponds and Hard Clam Ponds in Qigu

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摘　要

本研究自 2012-2013 年於七股針對 9 個淺坪虱目魚塭及 10 個文蛤池進行調查，共採得底棲動物 3633 隻，分 19 科 23 種。各類群中以多毛類 12 種最多，螺貝類 7 種次之。其它生物包含水生昆蟲幼蟲(搖蚊及牙蟲)、端足類及海葵。兩種魚塭底棲動物的組成有顯著差異。虱目魚塭共紀錄 8 種，以小頭蟲(*Capitella* sp.)、栗螺(*Stenothyra* sp.)及搖蚊幼蟲爲優勢。文蛤池共紀錄 21 種，以腺帶刺沙蠶(*Neanthes glandicincta*)及褐皮粗米螺(*Didontoglossa koyasensis*)爲優勢。在群聚結構比較上，文蛤池採得底棲動物的種類數及多樣性較高。虱目魚塭則具較高的平均密度並以小頭蟲等投機物種爲優勢。利用 AMBI(AZTI's Marine Biotic Index)及M-AMBI(Multivariate-AMBI)評估兩種魚塭底土的生態環境品質。兩指標評估的一致性程度屬好的等級。多數文蛤池被歸爲好的生態環境狀態；虱目魚塭則爲中等至差。由底棲動物群聚結構及兩指標評估結果暗示，淺坪虱目魚塭可能承受較高的有機質物，導致底質生態環境品質較差。

Abstract

Nine shallow-water milkfish (*chanos chanos*) ponds and ten hard clam (*Meretrix lusoria*) ponds in Qigu were surveyed for benthic fauna from 2012 to 2013. A total of 3,633 individuals belonging to 19 families and 23 species were collected. Overall, 12 polychaete species and seven mollusc species were found. Others include aquatic insect larvae (chironomidae and hydrophilidae), amphipod, and sea anemone. Benthic fauna communities were significantly different between the two pond types. A total of eight species were found in milkfish ponds, in which *Capitella* sp., *Stenothyra* sp., and chironomid larvae were dominant. A total of 21 species were found in hard clam ponds, in which *Neanthes glandicincta* and *Didontoglossa koyasensis* were dominant. Benthic fauna species richness and diversity were higher in hard clam ponds, but the mean density was higher in milkfish ponds and the dominance of opportunistic species such as *Capitella* sp. AZTI's Marine Biotic Index (AMBI) and Multivariate-AMBI (M-AMBI) were applied to access the benthic ecological status of ponds. A "good" level of agreement was between AMBI and M-AMBI. Most hard calm ponds were classed at "good" ecological quality, but milkfish ponds ranged between "moderate" to "poor". The results of benthic fauna community and the two indices suggest that shallow-water milkfish ponds might have higher organic matter loading, which led to poorer ecological quality status.

關鍵詞：底棲動物、水產養殖魚塭、虱目魚、文蛤、海洋生物指標

Key words: benthic fauna, aquacultural pond, milkfish, hard clam, AMBI

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緒　言

底棲動物是魚塭生態系重要的一環，有些底棲動物的出現會危害養殖目標生物，例如淺坪虱目魚塭中的搖蚊幼蟲於池底築土管破壞藻床，且會與虱目魚競爭攝食底藻(蘇 2007)。文蛤養殖池中孳生大量螺類及貽貝會與文蛤競食，甚至干擾文蛤攝食行爲(劉 2001)。但有些底棲動物則對養殖有正面幫助，例如多毛類透過攝食殘餌及糞便等營養物質改善魚塭底質(Carvalho *et al.* 2007; 邱等 2011; Puigagut *et al.* 2014)，另也是養殖蝦類的重要天然餌料(Nunes 1997; 許等 2007)。

底棲動物也能用來反映養殖環境的品質狀況，例如魚塭中底棲動物組成會因有機質含量不同而有差異(Carvalho *et al.* 2006)。有機質

含量爲養殖環境品質重要指標，因池底累積過多的有機物在經由微生物分解時，會消耗大量氧氣使池底缺氧。而在缺氧環境下，有機物分解會產生一些有毒物質，影響養殖魚蝦生長(Avnimelech and Ritvo 2003)。此外於探討魚塭養殖廢水(Silva *et al.* 2012)及箱網養殖(Borja *et al.* 2009; Martinez-Garcia *et al.* 2013; Valdemarsen *et al.* 2015; Tomassetti *et al.* 2016)對海洋環境造成影響的研究中，也常以底棲動物做爲反映污染的物生物類群。

底棲動物直接生活於底泥中，能直接反映底土環境變化，因此研究人員利用其發展出許多評估海洋或濕地環境狀態的指標，例如 AMBI(AZTI's Marine Biotic Index, Borja *et al.* 2000)、M-AMBI(Multivariate-AMBI, Borja *et al.* 2004)、Bentix(Simboura and Zenetos 2000)、BQI(Benthic Quality Index, Rosenberg *et al.* 2004)等。

Borja 等(2015)透過比較文獻發表數、文獻中使用指標與環境污染間是否有顯著相關性，以及指標在不同地理區使用的普遍度，將 35 個由底棲動物發展的環境評估指標進行有系統的評比及排名。結果顯示 AMBI 及 M-AMBI 在 3 項評比上皆爲前兩名，爲目前使用區域最廣及穩定的指標工具。

AMBI 及 M-AMBI 發展於歐洲地中海區域，目前也應用於美國(Borja and Tunberg 2011)及紐西蘭(Keeley *et al.* 2012)等不同地理區。大陸黃海及渤海等沿海地區近年來也開始利用此兩指標進行環境評估研究，並證實能有效反映人爲干擾(Li *et al.* 2013; Cai *et al.* 2014; Cai *et al.*2015)，然臺灣目前較缺乏相關應用研究。

本研究兩種魚塭皆爲海水養殖，加上池底爲軟質底土構成，符合 AMBI 及 M-AMBI 的使用條件。由於本研究未收集環境資料，無法了解魚塭受有機質的污染程度，因此期應用此兩指標工具，嘗試將魚塭底質的生態環境進行分級，並爲未來相關研究參考。

魚塭中的底棲動物除了上述功能外，黃及薛(2014)研究淺坪虱目魚塭及文蛤養殖池發現，當魚塭晒池時因水位降低，吸引了許多鷸鴴類等水鳥前來利用。鷸鴴類以水生無脊椎動物爲食(Colwell 2010)，底泥中的底棲動物成爲其潛在的食物來源。因此魚塭的底棲動物除了影響養殖本身外，晒池時也提供了度冬及過境水鳥覓食棲地，在水鳥保育策略上具有重要功能。

本研究針對臺南市七股地區的淺坪虱目魚塭及文蛤養殖池進行調查，主要目的爲：(1)分析兩種魚塭的底棲動物組成及群聚結構差異，提供相關養殖管理參考。(2)透過計算底棲動物的 AMBI 及 M-AMBI 值，評估兩種魚塭底土的生態環境品質狀態。(3)建立魚塭底土中水鳥的潛在食物資源，爲後續探討水鳥利用晒池魚塭覓食之基礎。

材料與方法

一、樣區地點

本研究以七股曾文海埔魚塭區及美國魚塭區爲研究地點，北起七股潟湖南至縣道 173，西起七股大潮溝東至西濱 61 快速道路。自 2012-2013 年共針對 9 個淺坪虱目魚塭及 10 個文蛤池進行底棲動物相調查(圖 1)。淺坪虱目魚塭爲吋苗養殖，魚苗放養後育成至 3-5 吋後賣出。文蛤池則會混養魚蝦，以清除池底藻類及螺類。

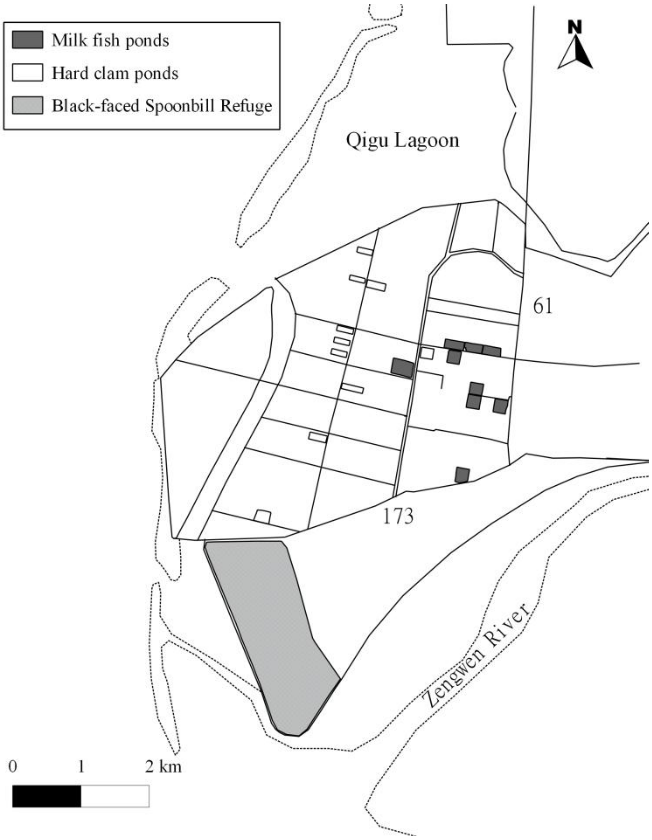

圖 1. 七股調查樣區的魚塭位置。

Fig. 1. The location of studied aquacultural ponds in Qigu.

二、底棲動物採集及分類

選定魚塭於開始晒池的 2 天內進行採集，此時池水多以排出，露出如泥灘濕地的底土。因配合不同晒池時程，淺坪虱目魚塭於 2012 年 10 月(7 池)及 11 月(2 池)調查，共採 9 池。文蛤池則於 2012 年 12 月(1 池)、2013 年 1 月(2 池)、2 月(5 池)及 3 月(2 池)調查，共採 10 池。

每池魚塭只採集 1 次，每次共採 5 個樣點，分別於魚塭四周及中央各採樣一點。每樣點以直徑 7.5 cm 的水管採集表面 10 cm 的底泥，再以 0.5 mm 網目篩網篩洗。過篩後的殘餘物及蟲體以採樣罐收集，並放入薄荷腦進行麻醉，最後再加入中性福馬林固定。

採樣罐帶回實驗室後將底棲動物挑出進行鑑定及計數。如爲不完整之蟲體以頭部數爲計算依據。所有樣本以 70% 酒精保存。採得之動物依台灣貝類資料庫 (http://shell.sinica.edu.tw/) 、陽及孫(1998)、謝等(1999)及王及王(2011)進行分類

及鑑定。

三、統計分析

(一) 底棲動物組成及群聚結構

計算每池魚塭採集到底棲動物的種類數、密度(ind/m^2)及多樣性指數(Shannon-Wiener index)，並以 Mann-Whitney U test 比較上述 3 個值於兩魚塭間是否有顯著差異。兩種魚塭底棲動物群集以 Primer 6 套裝軟體進行分析。每個物種的密度先以開根號轉換，再計算所有魚塭間的 Bray-Curtis similarity，並以 average linkage 法進行階層群集分析。另也利用 MDS(Non-metric Multi-Dimensional Scaling)比較兩種魚塭底棲動物組成差異。最後以 ANOSIM (Analysis of similarities)檢測組成差異是否具顯著性。

(二) 生態環境品質評估

AMBI 概念爲利用軟質底土中的底棲無脊椎動物組成反映環境干擾狀態。Borja *et al.* (2000)依對污染的不同反應將底棲動物分爲 5 個生態群(EGI-干擾敏感類型; EII-干擾不敏感型; EGIII-干擾容忍型; EGIV-次級機會主義型; EGV- 一級機會主義型)。計算公式如下：AMBI ＝ [(0×EGI ％)+(1.5×EGII ％)+(3×EGIII ％)+(4.5×EGIV％)+(6×EGV％)] / 100。計算所得 AMBI 值愈低表示環境品質愈好，並依 Muxika *et al.*(2005)區分爲 5 個生態環境等級：高品質(high quality <1.2)、好(good 1.2-3.3)、中等(moderate 3.3-4.3)、差(poor 4.3-5.5)、壞(bad >5.5)。

目前已有免費軟體(http://ambi.azti.es)可計算 AMBI，並建有資料庫列出各物種的生態群。本研究採集物種若未出現於資料庫，則將其歸於同屬相近物種的生態群。若資料庫也無同屬物種，則不加已分群。另腺帶刺沙蠶在資料庫列爲 EGI，但根據邱(2010)研究認爲其對環境有較高容忍性，成爲七股潟湖最優勢的多毛類。因此本研究將腺帶刺沙蠶歸爲 EGIII。

M-AMBI 亦利用上述免類軟體分析，其則整合了物種數(species richness)、多樣性指標(Shannon's diversity index)及 AMBI，並透過因素分析進行計算(Muxila *et al.* 2007)。所得 M-AMBI 值愈高表示環境品質愈好，並依 Borja *et al.*(2007)區分爲 5 個生態環境等級：高品質(high quality >0.77)、好(good 0.53-7.77)、中等(moderate 0.38-5.53)、差(poor 0.20-0.38)、壞(bad <0.20)。

M-AMBI 分析前需輸入高及壞的環境狀態背景値才能進行比較。由於缺少底質未受干擾的魚塭資料可參考，高品質的環境狀態設定爲所有調查中最高的物種數加 15%、最高的多樣性指數加 15%，以及最低的 AMBI 減 15%(Borja *et al.* 2008; Cai *et al.* 2015)。壞的環境狀態則將物種數及多樣性指數設爲 0，AMBI 設爲 6。

回顧相關文獻 AMBI 及 M-AMBI 評估結果有時未必一致(Liu *et al.* 2014; Nebra *et al.* 2014; Brauko *et al.* 2016)。因此本研究以 weighted Kappa 分析兩指標評的一致性程度。若兩指標一致性高，則較有信心相信評估出的生態環境狀態；但若兩指標一致性低，解釋需較爲保守，並待後續有環境資料比對才能釐清。

一致性程度以 Kappa 値分成 8 個等級(Monserud and Leemans1992)：完全不一致(null < 0.05)、很低(very low 0.051-0.20)、低(low 0.21-0.40)、中等(moderate 0.41-0.55)、好(good 0.56-0.70)、很好(very good 0.71-0.85)、

幾乎一致(almost perfect 0.86-0.99)、完全一致(perfect 1.00)。最後以 Mann-Whitney U test 比較兩種魚塭的 AMBI 及 M-AMBI 是否有顯著差異。

結　果

一、底棲動物組成及群聚結構

(一) 底棲椎動物組成

本研究共採集到底棲動物 3633 隻，分 19 科 23 種(表 1)。各類群中以多毛類 12 種最多，螺貝類 7 種次之。其它生物包含水生昆蟲幼蟲(搖蚊及牙蟲)、端足類及海葵。

兩種魚塭中的物種數量以文蛤池的 21 種較多，虱目魚池只發現 8 種。兩種魚塭的優勢種各異，虱目魚池以小頭蟲(*Capitella* sp.)45.4%、栗螺(*Stenothyra* sp.) 26.3%及搖蚊科幼蟲(Chironomidae)9.6%所佔比例最高。文蛤池則以腺帶刺沙蠶(*Neanthes glandicincta*)33.5%及褐皮粗米螺(*Didontoglossa koyasensis*)33.4%最高(表 1)。

利用底棲無脊椎動物的組成對魚塭進行群集分析，結果顯示相似性在 15%處可將樣本分爲虱目魚塭及文蛤池兩群(圖 2)。檢視 MDS 分布圖，亦可將魚塭被分爲兩群，其中虱目魚塭聚集於右側，文蛤池則於左側(圖 3)。最後以 ANOSIM 檢測兩種魚塭的底棲動物群聚是否有區隔，結果顯示兩者具有顯著性差異(R=0.964, p =0.001, number of permutations=9999)。

(二) 底棲動物群聚結構

兩種魚塭底棲動物的物種數、密度及多樣性皆有顯著差異。虱目魚塭平均每池只能發現 5.56±1.74 種，顯著低於文蛤池的 8.00±2.91 種(Z=-2.113, p=0.035)。然虱目魚塭平均密度(個體/m^2)爲 12786.6±11916，顯著高於文蛤池的 5016 ±3513(Z=-1.982, p=0.045)。多樣性指數(Shannon-Weaver diversity index)比較上，虱目魚塭平均爲 1.05±0.24，顯著低於文蛤池的 1.41±0.41(Z=-2.041, p=0.041)。

將物種數最多的多毛類獨立進行比較，虱目魚塭平均每池只能發現 1.78±1.20 種，顯著低於文蛤池的 5.00±2.11 種(Z=-3.003, p=0.002)。虱目魚塭平均密度(個體/m^2)爲 6916±8409，雖高於文蛤池 2599±1302，但無顯著差異(Z=-0.573, p=0.604)。多樣性指數比較上，虱目魚塭平均爲 0.24±0.26，顯著低於文蛤池的 0.95±0.5(Z=-2.945, p=0.002)。

二、生態環境品質評估

AMBI 及 M-AMBI 分析結果顯示，全部 19 池魚塭中共有 13 池(68.42%)兩指標評估出的生態環境等級相同。兩指標的 Kappa 值爲 0.604，一致性程度屬於好的等級。兩指標於兩種魚塭的比較結果分述於下。

在 AMBI 比較上，虱目魚塭顯著高於文蛤池(Z=-3.553, p<0.001)，表示虱目魚塭底質環境較差。虱目魚塭的生態環境狀態被歸爲好的有 1 池、中等的 4 池、差的 4 池。而文蛤池中，歸爲高品質的有 2 池，歸爲好的 8 池(圖 4)。

在 M-AMBI 比較上，虱目魚塭顯著低於文蛤池(Z=-3.393, p<0.001)，亦表示虱目魚塭底質環境較差。虱目魚塭的生態環境狀態被歸爲好的有 1 池、中等 2 池、差的 6 池。而文蛤池中，歸爲高品的有 1 池、好的 6 池、中等的 3 池(圖 5)。

表 1. 兩種魚塭底棲動物的優勢度、出現頻度及平均密度

Table 1. Dominance (D), frequency (F), and average density (A) of benthic fauna species in two types of fish ponds

	Milkfish ponds (n=9)			Hard clam ponds (n=10)		
	D (%)	F (%)	A (ind/m^2)	D (%)	F (%)	A (ind/m^2)
Cnidaria						
Actiniaria				0.81	30	41±69
Arthropoda						
Amphipoda	4.41	55.6	563±120	7.59	60.0	380±676
Chironomidae	9.60	100.0	1227±703			
Hydrophilidae	4.49	100.0	573±610			
Mollusca						
Laternula sp.				0.27	10.0	14±43
Meretrix lusoria				0.18	10.0	9±29
Potamocorbula fasciata				0.18	10.0	9±29
Thiara riqueti	1.14	22.2	146±405	4.70	20.0	235±579
Batillaria zonalis				0.09	10.0	5±14
Didontoglossa koyasensis				33.36	90.0	1670±2443
Stenothyra sp.	26.25	88.9	3355±5846	0.63	30.0	32±71
Annelida						
Neanthes glandicincta	0.47	44.4	60±90	33.54	100.0	1680±1132
Hesionidae				0.18	20.0	9±19
Goniadid sp.				0.09	10.0	5±14
Marphysa sp.				0.36	40.0	18±23
Scoloplos sp.				2.17	30.0	109±224
Prionospio japonicus				3.71	50.0	186±320
Polydora cornuta	8.26	66.7	1056±2233	5.33	90.0	267±314
Polydora fusca				0.27	20.0	14±31
Pseudopolydora sp.				0.81	30.0	41±69
Capitella sp.	45.38	66.7	5800±6613	2.89	60.0	145±238
Heteromartus sp.				0.90	20.0	45±128
Sabellidae				1.90	50.0	95±165

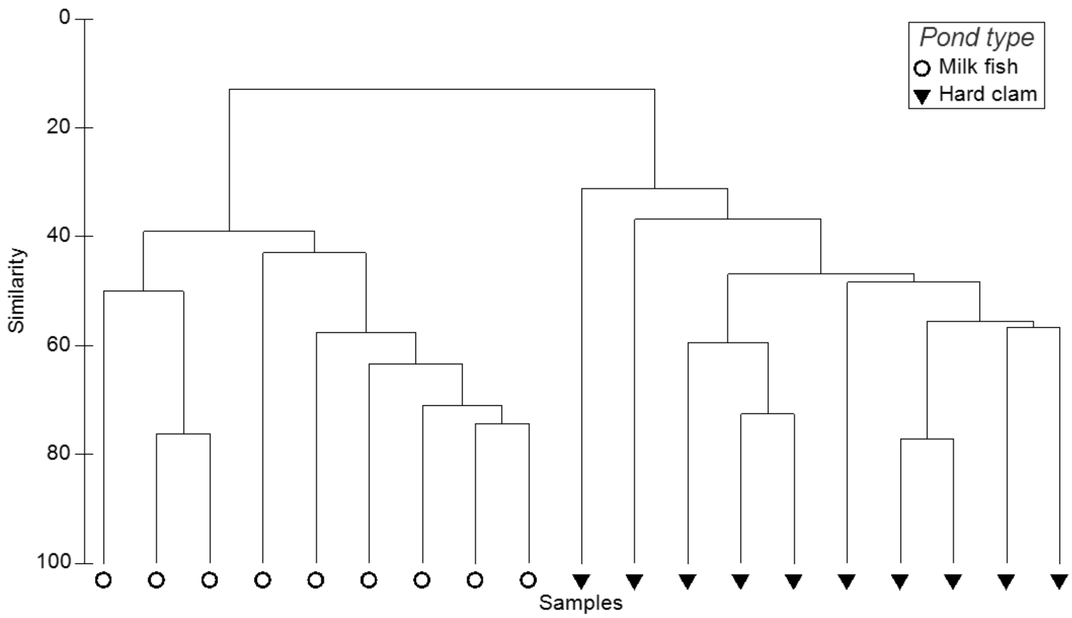

圖 2. 各魚塭底棲動物相階層群集分析樹狀圖。

Fig. 2. The dendrogram for hierarchical clustering of the benthic fauna in fish ponds.

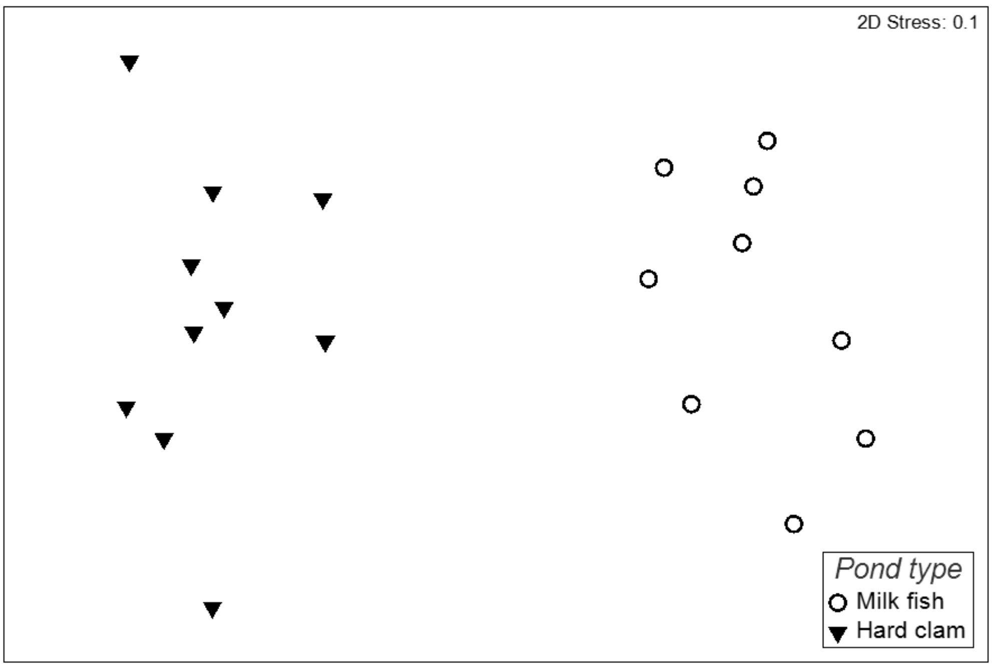

圖 3. 各魚塭底棲動物相群聚組成的 MDS 分布圖。

Fig. 3. The MDS ordination plot of the benthic fauna in fish ponds.

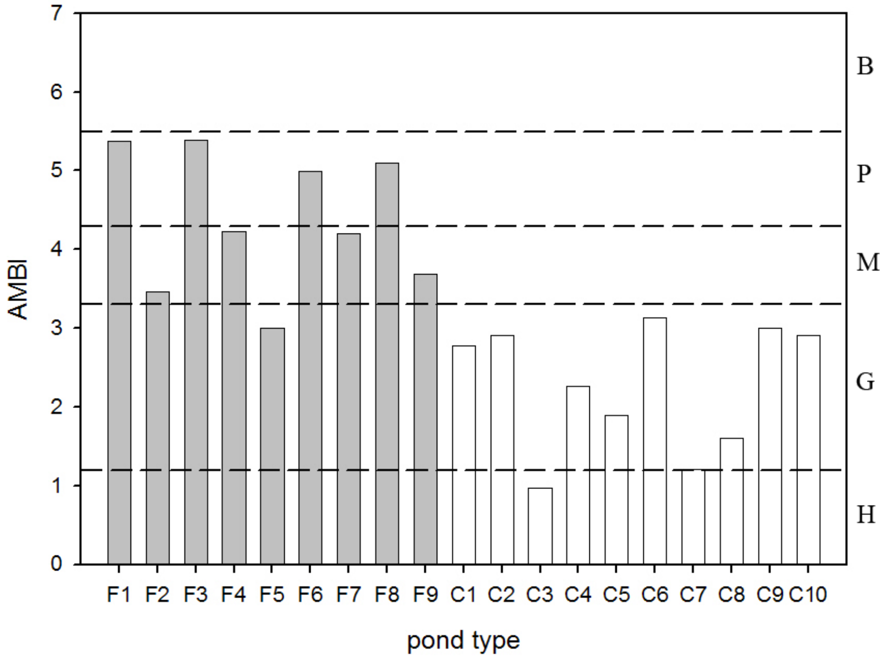

圖 4.兩種魚塭的 AMBI 值。

Fig. 4. AMBI values for two types of fish ponds. F: milkfish ponds; C: hard clam ponds; H: high quality; G: good; M: moderate; P: poor; B: bad.

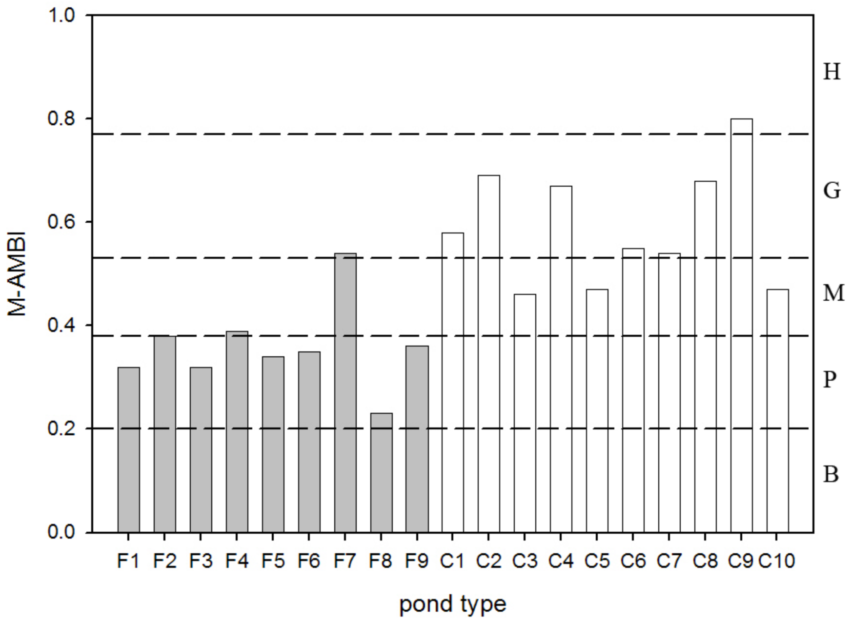

圖 5. 兩種魚塭的 M-AMBI 值。

Fig. 5. M-AMBI values for two types of fish ponds. F: milkfish ponds; C: hard clam ponds; H: high quality; G: good; M: moderate; P: poor; B: bad.

討　論

底土有機物的控制是魚塭養殖很重要的管理工作。魚塭有機物質主要來自殘餌及排泄物。水產養殖動物一般只能蓄積飼料中 5-40% 的養分，剩餘的飼料會沉澱於池底(Avnimelech and Ritvo 2003)。累積的有機物因微生物分解會消耗大量氧氣，使底土逐漸缺氧，進而降低氧化還原電位(周及葉 2013)。研究顯示養殖年代愈久的魚塭，受有機污染愈嚴重，底土氧化還原電位負值也愈高(蘇 1988)。而當池底有機物於缺氧環境分解時，產生的有機酸、還原有機硫化合物、及硫化氫等有毒物質，將導致魚蝦生長受到影響(Avnimelech and Ritvo 2003)。

文蛤等貝類及蝦子因棲息於底土，受有機質的影響最爲直接，而其它非養殖目標的底棲動物亦然。研究指出多毛類群聚組成可反映海洋底土受干擾情況(Samuelson 2001; Tomassetti and Porrello 2005; Dean 2008)，例如小頭蟲(Pearson and Rosenberg 1978; Tsutsumi 1990; Cai *et al.* 2013)及角才女蟲(Dix *et al.* 2005)會大量出現於高有機質環境中，常被視爲有機污染指標生物。

邱(2010)研究認爲七股潟湖屬略受有機質干擾區，多毛類的多樣性高。其資料顯示潟湖每樣點多毛類平均有 7.0±3.0 種，高於本研究文蛤池的 5.0±2.1 種及虱目魚池的 1.8±1.2 種。潟湖每樣點多毛類的多樣性指數(Shannon-Weaver diversity index)爲 1.37±0.5，亦高於文蛤池的 0.95±0.5 及虱目魚塭的 0.24±0.26。魚塭多毛類種類及多樣性較潟湖低的原因應與養殖產生的有機質累積有關。例如箱網漁業的研究已證實，殘餌及魚的糞便會增加魚場下方的有機質，使底棲動物的種類及多樣性降低、投機物種數量增加(Martinez-Garcia *et al.* 2013; Tomassetti *et al.* 2016)。盧及徐(1991)研究也觀察到，每當養殖池底開始惡化時，小頭蟲數量會大增成爲優勢種，其它底棲動物則逐漸減少。

邱(2010)研究指出，當潟湖有機物累積形成污染狀態時，小頭蟲成爲優勢種；當底質環境逐漸改善後，則由腺帶刺沙蠶取代。本研究淺坪虱目魚塭以小頭蟲爲優勢種；文蛤池則爲腺帶刺沙蠶。加上虱目魚塭底棲動物的種類數及多樣性皆顯著低於文蛤池，而其較高的平均密度主要來自數量大增的小頭蟲。因此透過比較底棲動物群集結構，並根據上述前人研究可推論，虱目魚塭的底質生態環境應較文蛤池差。此外利用 AMBI 及 M-AMBI 亦得到相似結果，分析顯示兩指標評估結果一致性高，多數文蛤池底土品質被歸於好的等級；而虱目魚塭則介於中等至差(圖 5、6)。

若虱目魚塭底土環境品質較差，暗示其承受了更大的人爲有機物質干擾。淺坪虱目魚塭放養前會以米糠施肥，並進水培養藻類供虱目魚覓食用(蘇 2007)。因此除殘餌及排泄物外，米糠及死亡後的藻類應也是池底重要的有機質來源。王(2014)於七股進行淺坪虱目魚塭養殖試驗，曾有 1 池魚群大量死亡，其推測原因爲底棲絲狀藻大量死亡後，微生物分解消耗氧氣，形成缺氧環境所致。建議未來養殖前需加強曬池工作，利用翻土或增加曝曬時間，讓底土的有機質充分氧化。另以米糠施肥養藻的用量需斟酌，避免一次過多有機質進入水體。若發現藻類大量死亡現象時則應儘快清除並更換池水。

獵食者捕食壓力及養殖環境穩定性也是影響魚塭底棲動物的重要因素。文蛤池一般會混養虱目魚及蝦子來清除藻類，另也混養鯛科魚類來清除螺類(劉富光 2001)。研究也指出多毛類爲對蝦的重要食物來源(Nunes *et al.* 1997)，養殖池蝦子數量愈高，會降低多毛類的

密度(Nunes and Parsons 2000)。因此文蛤池混養的魚蝦應對底棲動物產生不小的捕食壓力，而混養密度的不同，可能影響底棲動物的組成及數量。另根據漁民訪查，淺坪虱目魚塭一般爲單養。而虱目魚以藻類及飼料爲主食，對底棲動物的捕食壓力相對較低。

根據觀察淺坪虱目魚塭最早於 4 月養殖，最晚於 11 月結束，每年視情況可養 2-3 批魚苗。在每批魚苗採收後，池子常放乾約一周後才入水放養下批。魚塭持續有水時間約只有 3-4 個月，水文環境變動大。小頭蟲因具有生活史短(約 1.5 個月)、生長快速及大量子代特性(林 2004)，能於干擾頻度高的虱目魚塭成爲優勢種。腺帶刺沙蠶則具多年生特性(曾等 1995)，不似一年生多毛類在繁殖後死亡。文蛤池環境變動較虱目魚塭穩定，漁民表示約 2-3 年才進行 1 次晒池整理。因此文蛤池持續有水的時間較長，有利多年生的腺帶刺沙蠶發展爲優勢種。

本研究於晒池魚塭中採得的底棲動物密度相當高，表示可提供水鳥的潛在食物相當豐富。未來將進一步計算各種底棲動物的生物量，以量化魚塭能提供水鳥的食物資源量，探討晒池魚塭於水鳥保育策略所具有的功能。在 AMBI 及 M-AMBI 的應用上，後續可針對臺灣未出現於資料庫的底棲物種群進行生態分研究，以提高評估的準確性。另於採集同時蒐集環境壓力資料(如底土有機質、水體營養鹽及溶氧等)，並將兩指標評估結果直接與環境干擾因子進行統計比較，以驗證兩指標於臺灣海域及濕地的適用性。

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Light Limitation and Phytoplankton Biomass in the Coastal Wetlands of Southern Taiwan

台灣南部海岸溼地浮游藻之光限制與生物量

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Abstract

The biomass of phytoplankton in an aquatic ecosystem is highly unpredictable due to complicated interactions between algal communities and the physicochemical environment. However, given enough observed data, relationships between phytoplankton biomass and certain limiting resources can be established. In this study, a resource-based model was adopted for the simulation of light-limited phytoplankton biomass in coastal wetlands of southern Taiwan. A total of 22 waterbodies, including three tidal wetlands and 19 closed impoundments were surveyed during a year-long study. Light-limiting data were identified and analyzed for the determination of model parameters, including *minimum light requirement* and *critical light requirement*. Results indicate that, light utilization efficiency of the phytoplankton communities in these saline coastal waterbodies were similar to those of freshwater lakes, with critical light requirement ranged from 0.077 to 0.165 mol-photon day^{-1} mg-Chl-*a*$^{-1}$ m and minimum light requirement ranged from 2.51 to 2.72 mol-photon day^{-1} m^{-1}. Impoundments were more productive and more efficient in light utilization than tidal wetlands. Algal cells accounted for 66.9% of water column light attenuation under light-limiting conditions, as compared with 39.6% for non-light-limiting situations. Self-shading presented a major regulating mechanism on the algal biomass of highly eutrophic coastal waterbodies. Under a light-limited condition, algal biomass can be managed to prevent ecosystem deterioration caused by excessive eutrophication through the control of light availability. Measures such as surface shading using wetland plants, and water depth augmentation through hydrological manipulation, can be employed for wetland management purposes. An enhanced water circulation can also lower wetland productivity, as shown in the case of Spoonbill Reserve of this study.

摘　要

光限制水體的藻類生物量受到藻類群聚光照需求，以及水體混合水深與光衰減特性等複雜因素影響，其預測相當困難。然透過大量調查數據的分析，可以判別光限制情況，並使用這些數據建立藻類生物量與光照之相關模式。本研究運用此一概念，探討台南地區海岸溼地浮游藻的光限制，並建立光限制下的浮游藻生物量模式。所選定的水體共 22 個，包括 19 個封閉的池塘與 3 個潮汐濕地，在一年期間每水體進行 2 到 4 次調查，篩選出光限制數據，並據以決定藻類生物量模式參數，包括最小光照(*minimum light requirement*)與臨界光需求(*critical light requirement*)。結果顯示，濱海水體藻類群聚的光利用效率與淡水湖泊相當，臨界光需求在 0.077 與 0.165 mol-photon day^{-1} mg-Chl-a^{-1} m 之間，最小光照在 2.51 與 2.72 mol-photon day^{-1} m^{-1} 之間。封閉池塘的初級生產力以及藻類光利用效率皆高於開放的潮汐濕地。藻類自蔭作用(self-shading)在這些水體的光限制扮演重要角色，藻細胞構成 66.9%的光衰減，遠高於非光線限制水體的 39.6%。初級生產過高可導致水域生態劣化，濱海濕地營養鹽濃度高，其初級生產一般無法透過營養鹽進行控制。瞭解浮游藻的光線限制，可以經由光照調節來維持合適的初級生產，方法包括以濕地植物進行遮光，或透過水文操作提高濕地水位。促進水流循環亦可降低濕地初級生產，如本研究所調查的黑面琵鷺保護區濕地。

Key words: Light limitation, Phytoplankton biomass, Coastal waterbodies, Taiwan

關鍵詞：光限制、浮游藻生物量、海岸濕地、台灣

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Introduction

The biomass of phytoplankton in a waterbody is regulated by a number of environmental and biological factors, with the most important factors being species composition (Domingues *et al.* 2005), water temperature (Boyd *et al.* 2013; Pan *et al.* 2016), and the availability of nutrients and light (Heckey and Kilham 1988; Iachetti and Llames 2015; Pan *et al.* 2016). Predicting phytoplankton biomass of a waterbody is difficult due to complicated interactions between these factors. Two general approaches are usually adopted for the determination of phytoplankton biomass in a waterbody. In a population dynamic approach, physicochemical and biological processes are used to describe the growth and decay of an algal community (e.g. Roelke *et al.* 1999; Siegel *et al.* 2002). On the other hand, the resource-based approach uses simple mathematical equations to relate algal biomass with one or a few numbers of limiting resources (e.g. Grover 1990; Reynolds and Maberly 2002). The phosphorus loading equation is a well-known example of the resource-based model (e.g. Vollenweider 1976; Reynolds and Maberly 2002).

Light limitation occurs regularly in eutrophic aquatic ecosystems where phytoplankton biomass is limited primarily by the availability of light (Cloern 1987; Gameiro *et al.* 2011). The determination of light availability and its relationship with phytoplankton biomass involve a set of bio-optical and hydrodynamic parameters (eg. Kirk 1994; Huisman 1999; Diehl *et al.* 2002; Huisman *et al.* 2004). Loiselle *et al.* (2007) illustrated that the mixed-layer integrated phytoplankton biomass (W, mg-Chl-*a* m^{-2}) of a light limited waterbody can be related linearly to the mixed-layer integrated light energy (Q_t, mol-photon day^{-1} m^{-1}) using:

$$W = \frac{1}{\Psi}(Q_t - Q_{\min}) \qquad (1)$$

where ψ (mol-photon day^{-1} mg-Chl-a^{-1} m) is the *critical light requirement* defined as a ratio between mixed-layer intgrated light energy and phytoplankton biomass. Q_{min} is the *minimum light requirement* analagous to a compensation irradiance under which the productivity of an algal community balances its repspiration. A Lambert-Beer model (Kirk 1976) was assumed for underwater light distribution with the total light attenuation (K_d, m^{-1}) being divided into the attenuation caused by algal cells ($k\omega$, m^{-1}), and a background attenuation (K_{bg}, m^{-1}) accounting for attenuation from all other sources:

$$I_z = I_o e^{-(k\omega + K_{bg})z} \qquad (2)$$

where I_o (mol-photon day^{-1} m^{-2}) is surface irradiance, I_z (mol-photon day^{-1} m^{-2}) is the solar irradiance at a depth z, k (m^{-1} mg-Chl-a^{-1} m^3) is the specific attenuation coefficient for algal cells, and ω (mg-Chl-*a* m^{-3}) is the phytoplankton biomass presented using chlorophyll-*a*. A mixed-layer integrated irradiance can be obtained by integrating equation (2) over depth of the mixed-layer:

$$Q_t = \int_0^{z_{mix}} I_z dz = \frac{I_0}{(k\omega + K_{bg})}(1 - e^{-(k\omega + K_{bg})z_{mix}}) \quad (3)$$

Through sustituting Q_t in equation (1) with equation (3), a light-limited phytoplankton biomass model can be derived:

$$W = 1/\psi \left[\frac{I_o}{k\omega + K_{bg}}(1 - e^{-(k\omega + K_{bg})z_{mix}}) - Q_{\min} \right] \quad (4)$$

The values of ψ and Q_{min} in Eq (4) are evaluated using observed data. In a method proposed by Loiselle *et al.* (2007), data of water column integrated phytoplankton biomass is plotted against light energy. An envelope line is then drawn for the data points, as illustrated in Figure 1. Data points adjecent to the envelope line are considered as under light limitation. For data points below the envelope line, algal growth is limited by factors other than light energy, such as the availability of limiting nutrients. The slope of the envelope line is the critical light requirement (ψ) in equation (4), and its intercept with the x-axis is the minimum light requirement (Q_{min}).

The procedures provide a practical approach for the determination of phytoplankton biomass under light limitation. It has been previously applied for the modeling of light-limitted phytoplankton biomass in highly eutrophic Lake Victoria in Africa (Loiselle *et al.* 2007, 2008; Cornelissen *et al.* 2014). Coastal wetlands are ususally nutrient rich and highly productive where light-limitation occurs quite commonly. Therefore the development of a light-limited algal biomss model is of great interest in the study of this particular type of ecosystem. Therefore, the major purposes of this study was to examine the applicability of resourced based models for the predction of phytoplankton biomass in coastal wetlands, and to evaluate light utilization efficiecy of the algal communities in these waterbodies.

Materials and methods

1. Study area

The study area (Figure 2) situates in the coastal region of Tainan in southern Taiwan. The area is covered primarily by aquaculture ponds, together with coastal lagoons, tidal rivers, and other natural impoundments. A total of 22 waterbodies, including three tidal wetlands and 19 closed impoundments, were surveyed over a period of 12 months. With a surface area of 117.6 ha, Spoonbill Reserve is the largest waterbody included in this study. The wetland situates near the coastline and is connected with the sea through a manmade channel. Exchange of water between the wetland and the coastal sea was substantial due to tidal flushing. Si-Cao and Ding-Shan are two smaller tidal wetlands that were not well circulated. The 19 close impoundments were chosen among natural and manmade ponds based on their sizes, representativeness, and accessibility. Dimensions of the studied waterbodies are provided in Table 1.

2. Field survey and lab analysis

The three tidal wetlands were monitored monthly for a period of 12 months, while the 19 impoundments were each surveyed twice during the period of study. In each survey, the depth and transparency (secchi depth) of each waterbody were measured. Water temperature, salinity, pH, and dissolved oxygen were monitored using a multi-parameter water quality analyzer (YSI-556, Yellow Spring Instruments, USA). Water samples were also taken for laboratory analysis of turbidity, chlorophyll-*a*, total phosphorous (TP), total nitrogen (TN), and total silicate (Si). The diffusive attenuation coefficient of photosynthetic active radiation (PAR) was derived using a non-linear model (Padial and Thomaz 2008):

$$K_d = 2.00 \times SD^{-0.76} \quad (5)$$

For waterbodies where secchi depth was greater than total depth, light attenuation coefficient was determined from turbidity measurements (T, NTU) using an equation proposed by Lin *et al.* (2009) for turbid marine environments:

$$K_d = 0.142 \times T + 0.07 \quad (6)$$

3. Solar irradiance

Monthly averaged daily solar irradiance (SI, kJ m^{-2} day^{-1}) derived by Ou *et al.* (2008) was adopted for this study. The data was derived using records of the Tainan Meteorological Station located approximately 15 km from the study area. A factor of 0.473 was used to convert solar irradiance into photosynthetic active radiation (kJ m^{-2} day^{-1}) (Papaioannou *et al.* 1993). The calculated PAR energy was further converted to photon flux (μmol m^{-2} s^{-1}) using a factor of 1.83 (Sudhakar *et al.* 2013). Monthly averaged values of PAR are given in Table 2. Mixed-layer integrated solar irradiance was calculated for each waterbody from the PAR using equation (3). Since the studied waterbodies were relatively shallow, a mixed-depth equals to total depth was assumed.

4. Determination of model parameters

The mixed-layer integrated solar irradiance as calculated were plotted against mixed-layer integrated phytoplankton biomass. A visually determined envelope line of the data points was then drawn. Light limited data were identified based on their proximity to the envelope line. A linear regression for the light limited data was then performed. The *critical light requirement* (ψ) in Eq (4) was determined from the slope of the regression line. The *minimum light requirement* (Q_{min}) was also determined from the intercept of the regression line with x-axis. The parameters were derived separately for tidal wetlands, closed impoundments, and the pooled data.

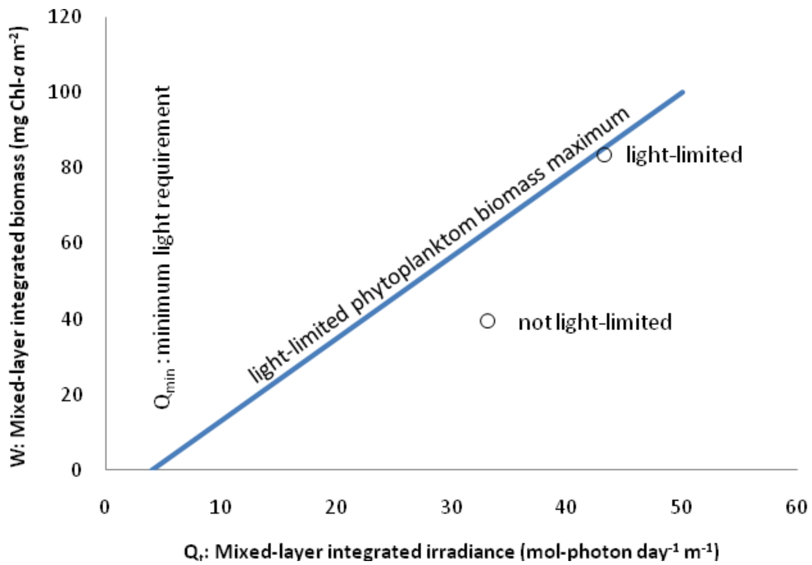

Figure 1. Illustration of a phytoplankton biomass envelop line and the light-limiting and non-light-limiting data points (after Loiselle et al. 2007).

圖 1. 藻類生物量之包絡直線以及光照限制與非光照限制水體判定(摘自 Loiselle et al. 2007)。

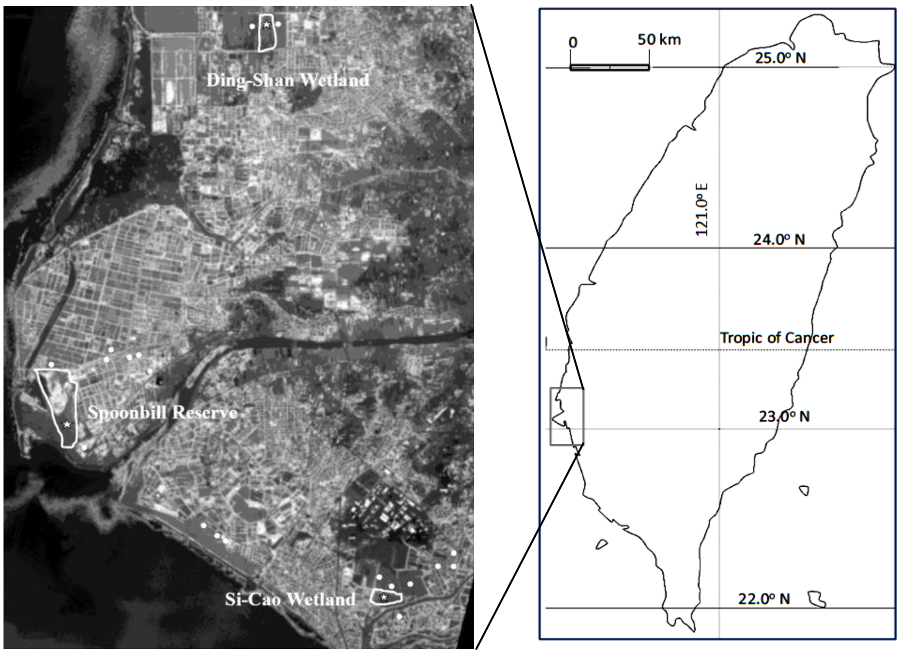

Figure 2. Map of the study area showing locations of studied waterbodies.

圖 2. 調查區域與水體位置。

Table 1. Dimensions of studied waterbodies
表 1. 調查水體之特性

Waterbody	**Type**	**Surface Area (ha)**	**Depth (m)**
Si-Cao Wetland	Tidal wetland	27.8	0.86
Spoonbill Reserve	Tidal wetland	117.6	1.29
Ding-Shan Wetland	Tidal wetland	35.5	0.44
13 impoundments [average (range)]	Closed impoundment	1.29 (0.11-3.58)	0.53 (0.23-1.46)

Table 2. Monthly averaged daily solar irradiance and photosynthetically active radiation (*PAR*) of the study area
表2. 調查區域每月平均日照與光合作用有效輻射

Month	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Solar irradiance (MJ/m^2-day)	6.70	7.52	8.27	9.49	13.92	13.67	13.57	11.36	12.44	13.36	12.26	9.69
PAR (MJ/m^2-day)	3.17	3.56	3.91	4.49	6.58	6.46	6.42	5.37	5.88	6.32	5.80	4.58
PAR (photon) (mol/m^2-day)	20.88	23.43	25.77	29.57	43.38	42.60	42.29	35.40	38.76	41.63	38.20	30.20

Results and discussion

Depth integrated phytoplankton biomass was plotted against depth integrated solar irradiance as shown in Figure 3 through Figure 5, respectively for all data, tidal wetlands, and closed impoundments. Light-limiting data were identified, and values of critical light requirement and minimum light requirement were determined from the regression lines of the selected data points. The numbers derived from this study were compared in Table 3 with those of Lake Victoria reported in two separate studies (Loiselle *et al.* 2007; Cornelissen *et al.* 2014).

1. Critical light requirement

Critical light requirement is a ratio between mixed-layer integrated solar irradiance and phytoplankton biomass. It can be used as the indicator for light utilization efficiency of an algal community. As shown in Table 3, the critical light requirement was 0.084 mol-photon day^{-1} mg-Chl-a^{-1} m when all waterbodies were considered. The values were respectively 0.165 and 0.077 for tidal wetlands and closed impoundments. Critical light requirement of the impoundments was comparable with those of 0.067 and 0.064 mol-photon day^{-1} mg-Chl-a^{-1} m for Lake Victoria, reported respectively by Loiselle *et al.* (2007) and Cornelissen *et al.* (2014). The critical light requirement for tidal wetlands was much higher than that of the impoundments, suggesting a lower photosynthetic efficiency of the wetlands. As shown in Table 4, phytoplankton biomass of the three tidal wetlands differed significantly. The Si-Cao Wetland was highly productive while the Spoonbill Reserve was particularly low in algal biomass due to significant tidal flushing.

2. Minimum light requirement

Comparable vales of minimum light requirement were obtained for the two groups of waterbodies. The numbers were 2.51 and 2.72 mol-photon day^{-1} m^{-1} respectively for the tidal wetlands and the impoundments, and 2.65 for the pooled data. These values are greater than 1.2 as reported by Loiselle *et al.* (2007) but much smaller than a value of 9.01 mol-photon day^{-1} m^{-1} as reported by Cornelissen *et al.* (2014), both using data from Lake Victoria. The minimum light requirement, when divided by mixing-depth, is equivalent to the compensation irradiance. Using average depths respectively for the three groups of data, the compensation irradiance were respectively 4.11, 7.00, and 5.38 mol-photon m^{-2} day^{-1} for the tidal wetlands, the closed impoundments, and the pooled data. These numbers are much higher than a value of 1.1 ± 0.4 mol-photon m^{-2} day^{-1} as reported by Regaudie-de-Gioux and Duarte (2010) using data based on literature review and their experiment conducted at the ocean, where the average light compensation depth averaged 36 ± 9 m. The numbers are also higher than a value of 1.3 reported by Sommer *et al.* (2011) using mesocosm studies conducted at the Baltic Sea. A much lower range of 0.1-0.3 mol-photon m^{-2} day^{-1} was reported by Marra (2004) using literature review and his study at the north Atlantic. In yet another study, Dielh *et al.* (2015) reported a compensation irradiance of 3.2 mol-photon m^{-2} day^{-1} for algal communities in the oligotrophic Lake Brunnsee. The values obtained in this study were consistently higher than those of the ocean and freshwater lakes.

3. Algal self-shading

Planktonic cells constitute significant light attenuation in highly productive waterbodies (Gikuma-Njuru and Hecky 2005; Nicolausi *et al.* 2013). A specific light attenuation is commonly used to relate light attenuation with the density of algal cells in water. A range between 0.01 and 0.02 m^2 mg-Chl-a^{-1} have been proposed for lakes (Priscu 1983; Lee and Rast 1997). Taking a value of 0.02 m^2 mg-Chl-a^{-1}, the light attenuation coefficient from algal self-shading were calculated for light-limiting and non-light-limiting data sets. As shown in Table 5, self-shading constitutes 66.9% of total water column light attenuation (K_d, m^{-1}) under light-limiting conditions, as compared with 39.6% for the non-light-limiting data.

4. Nutrient levels

The growth of phytoplankton in fresh waterbodies is frequently limited by phosphorus (P) and nitrogen (N). Silicon (Si) can also be limiting, particularly in coastal and marine environments (Dortch and Whitledge 1992; Gobler *et al.* 2006). Light limitation occurs when none of the essential nutrients are in short supply. As such, higher nutrient levels are expected for light-limiting waterbodies. Figure 6 compares the nutrient levels of light-limiting and non-light-limiting waterbodies. As can be seen from the figure, the concentrations of N, P, and Si in light-limiting waterbodies were consistently higher than those of the non-light-limiting waterbodies. The differences were statistically significant ($p<0.05$) for all of the three nutrients.

Table 3. Values of light requirement parameters for different types of waterbodies
表 3. 不同類型水體之光需求參數值

Parameter	**This study (Coastal waterbodies)**			**Lake Victoria (Freshwater lake)**	
	All data	**Closed impoundments**	**Tidal wetlands**	**Loiselle *et al.* (2007)**	**Cornelissn *et al.* (2014)**
Critical light requirement (mol-photon day^{-1} mg-Chl-a^{-1} m)	0.084	0.077	0.165	0.067	0.064
Minimum light requirement (mol-photon day^{-1} m^{-1})	2.65	2.72	2.51	1.2	9.01

Table 4. Chlorophyll-*a* concentrations of the studied waterbodies
表 4. 調查水體之葉綠素-*a* 濃度

Waterbodies	**Impoundments**	**Tidal wetlands**			
		All data	**Ding-Shan Wetland**	**Si-Cao Wetland**	**Spoonbill Reserve**
Chl-*a* (mg m^{-3})	54.2 ± 38.2	44.0 ± 40.4	38.8 ± 21.4	88.1± 30.1	5.1± 4.5

*numerical numbers are Mean ± SD.

Table 5. Significance of algal self-shading under light-limiting and non-light-limiting conditions
表 5. 光照限制與非光照限制水體之藻類自蔭作用顯著性

Type of data	**Total attenuation K_d (m^{-1})**	**Attenuation from algal self-shading* $k\omega$(m^{-1})**	**Percent attenuation from algal self-shading $k\omega$ / K_d (%)**
Light-limiting (n=13)	3.18(±1.32)	2.03(±0.73)	66.9(±23.8)
Non-light-limiting (n=58)	2.03 (±0.65)	0.81 (±0.64)	39.6 (±28.5)

*calculated based on ω = 0.020 m^2 mg-Chl-a^{-1}

*numerical numbers are Mean ± SD.

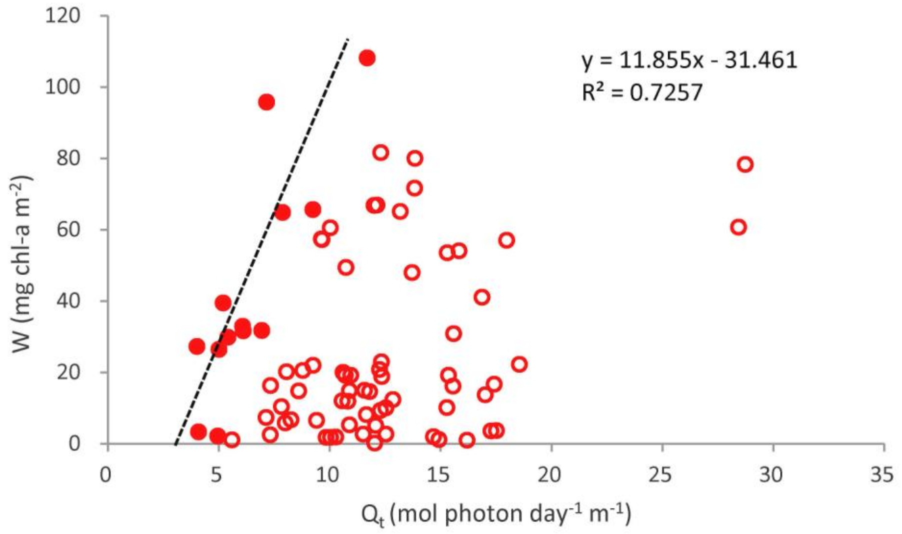

Figure 3. Relationships between depth-integrated irradiance (Q_t) and phytoplankton biomass (*W*) – all data (closed circles are light-limited data points).

圖 3. 混合層光照量(Q_t)與藻類生物量(*W*)之關係—所有數據 (實心圓為光限制數據點)。

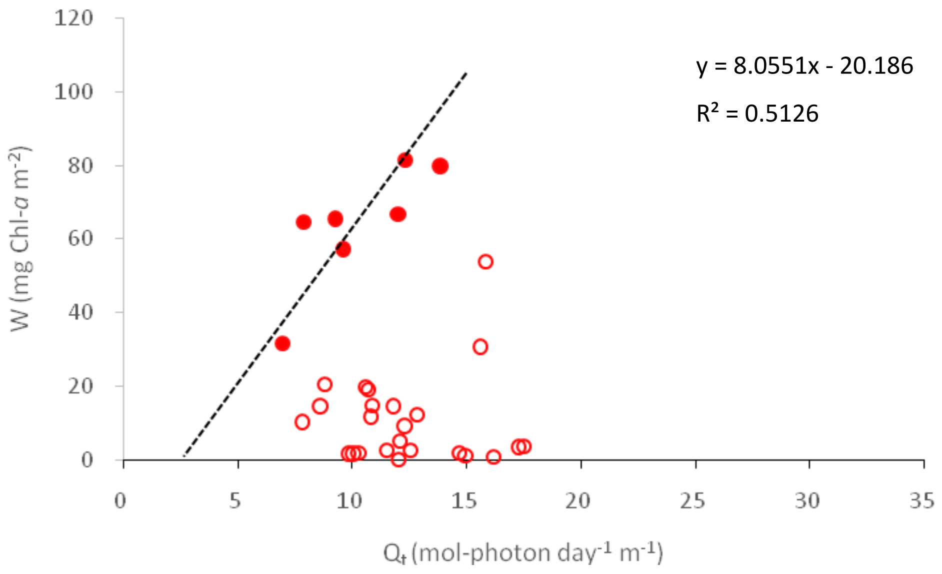

Figure 4. Relationships between depth-integrated irradiance (Q_t) and phytoplankton biomass (*W*) – tidal wetlands (closed circles are light-limited data points) .

圖 4. 混合層光照量(Q_t)與藻類生物量(*W*)之關係—潮汐濕地 (實心圓為光限制數據點)。

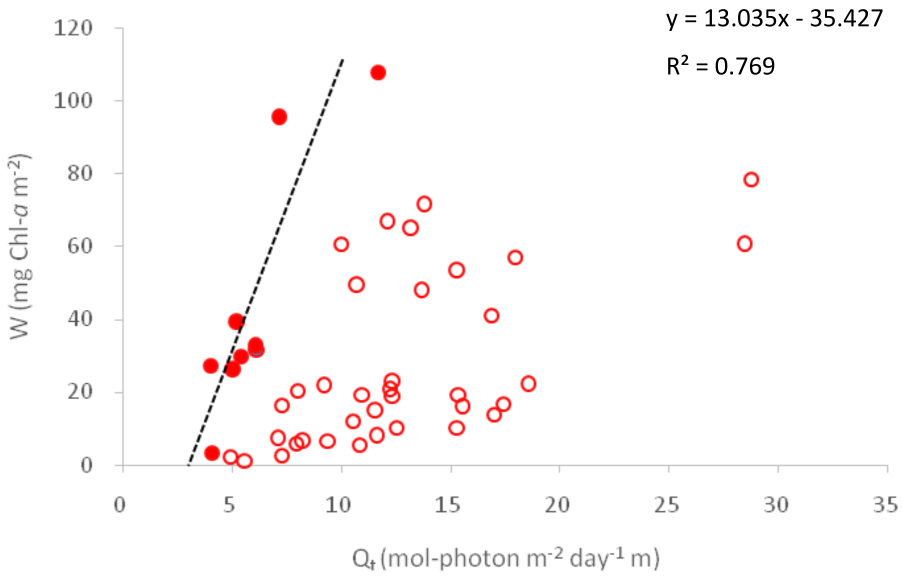

Figure 5. Relationships between depth-integrated irradiance (Q_t) and phytoplankton biomass (*W*) –closed impoundments (closed circles are light-limited data points).
圖 5. 混合層光照量(Q_t)與藻類生物量(*W*)之關係—封閉池塘 (實心圓為光限制數據點)。

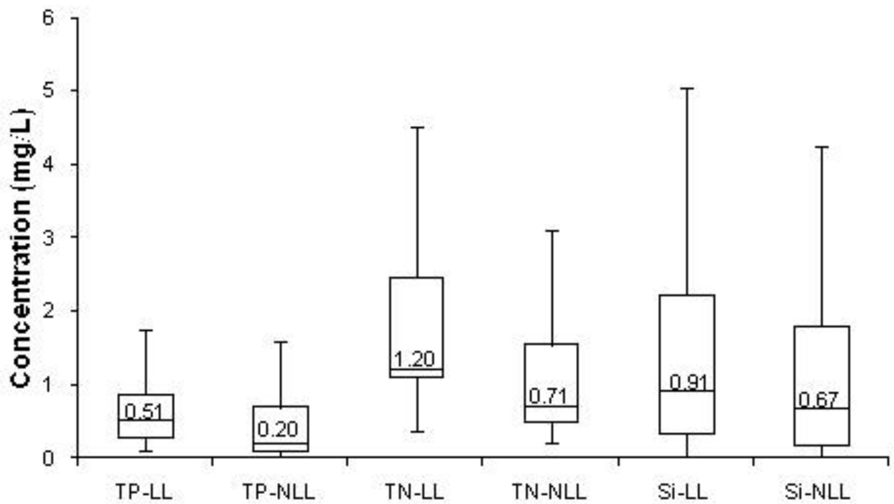

Figure 6. Box plot comparing nutrient levels (TP, mg-P/L; TN, mg-N/L; Si, mg-SiO_2/L) between light-limiting (LL) and non-light-limiting (NLL) waterbodies (max-Q3-median-Q1-min, numerical numbers shown are medians).
圖 6. 光限制水體(LL)與非光限制水體(NLL)營養鹽濃度(TP, mg-P/L; TN, mg-N/L; Si, mg-SiO_2/L)盒鬚圖(max-Q3-median-Q1-min, 數字所示為中位數)。

Conclusions

Phytoplankton biomass in natural waterbodies is highly unpredictable due its dependence with the complicated environmental and biological factors. The methodology proposed by Loiselle *et al.* (2007) presents a practicable procedure for the determination of algal biomass under light limitation. The saline coastal impoundments of this study exhibited similar critical light requirements but very different minimum light requirements as those of the freshwater Lake Victoria. The observations suggest that light utilization efficiency between algal communities of different species composition may not differ as much as the compensation irradiance. However, a closer examination is warranted for such a presumption.

Light-limitation is less likely under certain hydraulic conditions, such as the case of the well-flushed Spoonbill Reserve. Care must be taken to ensure that a light-limited model of algal biomass is developed exclusively using light-limiting data. Consistent with the observations of other studies, algal self-shading is a major contributor to light attenuation in coastal wetlands and impoundments. The negative feedback form self-shading presents a regulating mechanism for algal biomass of the highly productive aquatic ecosystems.

Primary productivity is vital for sustaining an aquatic food chain and maintaining the integrity of an aquatic ecosystem. However, deterioration of ecosystems can occur in over-productive water bodies due to negative effects such as intense diurnal oxygen swing, oxygen depletion of the bottom water, and the blockage of sunlight. Therefore, a moderate productivity is beneficial for the health of an aquatic ecosystem. Coastal wetlands receive nutrients from upland watersheds, therefore are usually highly nutrient-enriched. Lowering wetland productivity through nutrient control is generally infeasible. Knowing that light limitation occur commonly in coastal wetlands, favorable algal productivity can be achieved by manipulating the availability of light through measures such as surface shading using wetland plants, and increasing water depth through hydrological modifications. Wetland productivity can also be controlled by enhanced water circulation, such as the case of the Spoonbill Reserve in this study.

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