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Occurrence of the Earthworm *Drawida barwelli* (Beddard, 1886) in Taiwan

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Abstract

This paper describes the moniligastrid earthworm *Drawida barwelli* (Beddard, 1886) as a new record from Taiwan. It is a small earthworm originated from Southeast Asia. It was collected from coastal plains and hills below 1000 m in elevation in central, southern and Hualien and Taitung (including Lanyu) counties in eastern Taiwan, and has never been found in northern Taiwan. Its occurrence in Taiwan reported herein constitutes the island as the northern extremity of the distributional range of this peregrine species.

Key words: *Drawida barwelli*, earthworm, Taiwan

台灣新紀錄種蚯蚓巴氏杜拉蚓 *Drawida barwelli* (Beddard, 1886)

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摘要

本文描述一原產於東南亞之新紀錄種蚯蚓巴氏杜拉蚓 *Drawida barwelli* (Beddard, 1886)。其為小型蚯蚓，屬於鏈胃蚓科 (Moniligastridae) 杜拉蚓屬 (*Drawida*)，在台灣中南部及東部花東地區(包括蘭嶼)海拔一千公尺以下的海岸平原至丘陵地帶均有分布，北台灣則未曾有採集紀錄，顯示台灣應為此廣布種蚯蚓分布範圍之北界。

關鍵詞：巴氏杜拉蚓、蚯蚓、台灣

Introduction

Drawida barwelli was first described by Beddard (1886) as *Moniligaster barwelli* based on the examination of about 20 specimens obtained by Mr. H. E. Barwell from the neighborhood of Manila, Philippines. According to the original description (Beddard 1886), *Dr. barwelli* is a small earthworm not more than 1.5 inch (about 38 mm) in length. It has thin, delicate and much coiled sperm ducts (vasa deferentia). The so-called copulatory pouches in the 8th segment in the original description were later corrected by Beddard (1887) as spermathecae. Therefore, the spermatheca of *Dr. barwelli* is composed of a small, spherical ampulla and a long, slender, coiled and contorted spermathecal duct (Beddard 1886, Plate II, Fig. 5). Beddard (1886) also mentioned that “The only apertures that I could detect upon the surface of the body besides the mouth and anus were two oval slit-like orifices with tumid yellowish lips, which are the male generative orifices”. However, Beddard (1888; 1891) provided further descriptions together with figures which differ from his original description: the sperm duct is simple, short and not twisted, and the spermathecal duct is simple and quite straight. The presence of dorsal pores was mentioned in Beddard (1891). Apparently, ‘*Moniligaster barwelli*’ described in Beddard (1888; 1891) actually belongs to another species. When the structures of the sperm duct and spermathecal duct depicted in Beddard (1888; 1891) are compared with those of

Drawida beddardii (Rosa, 1890) from Burma, they are not distinguishable (see Beddard 1888, Plate XII, Fig. 12 and Rosa 1890, Plate XII, Fig. 12). In addition, *Dr. beddardii* has dorsal pores (Rosa 1890). Later, Beddard (1893) describes *Moniligaster bahamensis* imported accidentally with plants from the Bahamas to Kew Gardens as a small and slender worm measuring about 25 mm in length. Beddard (1893) states that the sperm ducts are remarkably long and much convoluted in *bahamensis* but misstates that the sperm ducts are very short in both *barwelli* and *beddardii*. Moreover, the structure of spermatheca of *bahamensis* as shown in Beddard (1893, Plate XLV, Fig. 2) is akin to that of *barwelli* (Beddard 1886, Plate II, Fig. 5). It is obvious that Beddard (1888; 1891) mistook *Dr. beddardii* for *Dr. barwelli*, and then Beddard (1893) erected a junior synonym, *Dr. bahamensis*, of *Dr. barwelli*. Due to misidentification by Beddard (1888; 1891; 1893; 1895), *Dr. beddardii* has long been wrongly considered synonymous with *Dr. barwelli* (see Shen *et al.* 2015).

Blakemore (2010), Blakemore and Kupriyanova (2010) and Blakemore *et al.* (2014) synonymized *Drawida glabella* Chen, 1938 from Hainan Island with *Dr. barwelli*. However, body size, structures of spermatheca and male organs and presence or absence of dorsal pores of both species are distinctively different (Shen *et al.* 2018). Consequently, *Dr. glabella* is not synonymous with *Dr. barwelli* and should be recognized as a valid species.

A checklist of moniligastrids with *Desmogaster sinensis* Gates, 1930 and a total of 41 species and subspecies of *Drawida* from East Asia including China, Japan, Korea and far eastern Russia was provided by Blakemore *et al.* (2014). To date, *De. sinensis* and six species of *Drawida* were recorded from Taiwan and its adjacent islands. Except for *De. sinensis*, *Drawida koreana* Kobayashi, 1938, *Drawida beiganica* Shen and Chang, 2015 and *Drawida dongyinica* Shen and Chih, 2015 from Matsu, only three species, namely *Drawida japonica* (Michaelsen, 1892), *Drawida alishanensis* Shen and Chang, 2018 and *Drawida fenqihuensis* Shen and Chih, 2018, were reported from the island of Taiwan. *Dr. japonica* was first documented by Kobayashi (1939; 1940ab) from Hsinchu, northern Taiwan, and has never been found again from Taiwan or other adjacent islands for nearly 80 years. As to *Dr. alishanensis* and *Dr. fenqihuensis*, the finding of the two endemic earthworms at elevations of 1407–1661 m in the Alishan area, Chiayi County is the first time that new species of *Drawida* are discovered from the island of Taiwan (Shen *et al.* 2018).

Drawida barwelli is a peregrine earthworm and has been reported from the Philippines (Beddard 1886; Gates 1965), Singapore (Shen and Yeo 2005), Lombok, Indonesia (Michaelsen 1922), Pacific Islands (Michaelsen 1910a; Kobayashi 1941; Gates 1969; Easton 1984), Central America (Beddard 1893; Gates 1954; 1965; Easton 1984), and Australia (Blakemore 2010; Blakemore and Kupriyanova 2010). Its distributional range has been confounded with

that of *Dr. beddardii* by Blakemore (2010), Blakemore and Kupriyanova (2010) and Blakemore *et al.* (2014) since the two species were wrongly synonymized by these authors. In Taiwan, *Dr. barwelli* was collected from coastal plains and hills below 1000 m in elevation in central, southern and Hualien and Taitung (including Lanyu) counties in eastern Taiwan, and has never been found in northern Taiwan though other species of *Drawida* were obtained (unpublished data). Furthermore, it is absent from the earthworm fauna of Kinmen (Chang *et al.* 2012), Matsu (Shen *et al.* 2015) and Japan (Blakemore 2012; Blakemore *et al.* 2014). *Drawida* cf. *barwelli* found in Korea (Blakemore *et al.* 2012; 2014) is a misidentification of *Drawida eda* Blakemore, 2010 (see Shen *et al.* 2018). Although Beddard (1893) received *Dr. barwelli* alive from Kew, this species is only found in hot greenhouses in Kew Gardens and has never been able to colonize the soils outside of the artificial environments in the UK (Sherlock 2012). Accordingly, its occurrence in Taiwan reported herein constitutes the island as the northernmost range of this species.

The following description is based on 126 preserved specimens deposited at the Taiwan Endemic Species Research Institute, Jiji, Nantou, Taiwan.

Drawida barwelli (Beddard, 1886)

Moniligaster barwelli Beddard, 1886: 94; 1887: 678; 1895: 200 (part).

Drawida barwelli – Michaelsen, 1900: 116 (part); 1910a: 51; 1922: 6; Gates, 1937: 306; 1965: 87; Kobayashi, 1941: 391; Easton, 1984: 112 (part); Blakemore, 2010: 137 (part); Blakemore and Kupriyanova, 2010: 4 (part); Blakemore *et al.*, 2014: 130 (part).

Moniligaster bahamensis Beddard, 1893: 690; 1895: 202.

Drawida bahamensis – Michaelsen, 1900: 118; Gates, 1954: 241; 1965: 85; 1969: 4.

Drawida japonicus bahamensis – Michaelsen, 1910b: 50.

Drawida sp. 3 Shen and Yeo, 2005: 30.

Materials examined.—One specimen collected on the 13 March 2000 along Road 20 (elevation 430 m), Jiasian, Kaohsiung County by C. F. Tsai, S. C. Tsai, H. S. Fang, S. T. Chang, T. J. Lin, H. P. Yang and H. P. Shen (coll. no. 2000-8); three specimens collected on the 16 April 2000 around the lighthouse (elevation 200 m), northwestern Lanyu, Taitung County by C. F. Tsai, S. C. Tsai, H. S. Fang, H. P. Yang and H. P. Shen (coll. no. 2000-36); one specimen collected on the 16 April 2000 from the neighborhood area of the Green Grassland (elevation 42 m), southern Lanyu, Taitung County by C. F. Tsai, S. C. Tsai, H. S. Fang, H. P. Yang and H. P. Shen (coll. no. 2000-38); one specimen collected on the 17 April 2000 around the weather station (elevation 324 m), central Lanyu, Taitung County by C. F. Tsai, S. C. Tsai, H. S. Fang, S. T. Chang, H. P. Yang, Y. C. Chiu, S. L. Hsu, and H. P. Shen (coll. no. 2000-40);

one specimen (amputated) collected on the 17 April 2000 from the valley around the Lung-men Bridge (elevation 18 m), southeastern Lanyu, Taitung County by C. F. Tsai, S. C. Tsai, H. S. Fang, S. T. Chang, H. P. Yang, Y. C. Chiu, S. L. Hsu, and H. P. Shen (coll. no. 2000-42); three specimens collected on the 17 April 2000 from Yung-hsing Farm (elevation 13 m), southeastern Lanyu, Taitung County by C. F. Tsai, S. C. Tsai, H. S. Fang, S. T. Chang, H. P. Yang, Y. C. Chiu, S. L. Hsu, and H. P. Shen (coll. no. 2000-43); one specimen collected on the 17 April 2000 from the neighborhood near the mouth of the Langtao Creek (elevation 8 m), northern Lanyu, Taitung County by C. F. Tsai, S. C. Tsai, H. S. Fang, S. T. Chang, H. P. Yang, Y. C. Chiu, S. L. Hsu, and H. P. Shen (coll. no. 2000-45); one specimen collected on the 12 September 2005 along Road 20 near Baiyun Temple (elevation 600 m), Jiasian, Kaohsiung County by H. P. Chen and H. S. Fang (coll. no. 2005-17); five specimens collected on the 15 September 2005 beside Danan Creek (elevation 170 m), Beinan, Taitung County by H. P. Chen, I. M. Hsiao and S. T. Chang (coll. no. 2005-37); one specimen collected on the 12 June 2007 from roadside ditches along Tienshen Temple toward Douliou (elevation 200 m), Huben Village, Linnei, Yunlin County by M. H. Chen (coll. no. 2007-23); one specimen collected on the 27 June 2007 from Sweet Gum trail (elevation 135 m) near Waihu Creek, Douliou, Yunlin County by S. T. Chang and Y. P. Li (coll. no. 2007-26); one specimen collected on the 27 June 2007

from the neighborhood of Hueichun Temple (elevation 140 m), Douliou, Yunlin County by S. T. Chang and Y. P. Li (coll. no. 2007-28); one specimen collected on the 29 June 2007 around Tienshen Temple (elevation 194 m), Huben Village, Linnei, Yunlin County by T. J. Lin and Y. P. Li (coll. no. 2007-34); two specimens collected on the 18 July 2007 from roadside slope along Fongshuhu South Creek (elevation 150–210 m) near the borders of Douliou and Linnei, Yunlin County by C. H. Chang, Y. H. Lin and T. J. Lin (coll. no. 2007-45); one specimen collected on the 18 July 2007 from Budhi Shrine of White Horse Mountain (elevation 130–144 m), Huben Village, Linnei, Yunlin County by C. H. Chang, Y. H. Lin and T. J. Lin (coll. no. 2007-47); five specimens collected on the 14 August 2007 around Tienshen Temple (elevation 194 m), Huben Village, Linnei, Yunlin County by C. H. Chang, Y. H. Lin and Y. P. Li (coll. no. 2007-52); one specimen collected on the 16 August 2007 from Budhi Shrine of White Horse Mountain (elevation 130–144 m), Huben Village, Linnei, Yunlin County by C. H. Chang, Y. H. Lin and Y. P. Li (coll. no. 2007-66); one specimen collected on the 11 September 2007 from Yuchin Valley (elevation 178–230 m) near the borders of Douliou, Yunlin County and Jhushan, Nantou County by T. J. Lin, Y. P. Li and H. I. Tsai (coll. no. 2007-72); one specimen collected on the 11 September 2007 beside Beishihkeng Creek (elevation 185–204 m), Douliou, Yunlin County by T. J. Lin, Y. P. Li and H. I. Tsai (coll. no. 2007-73); seven specimens collected on the

13 September 2007 from roadside ditches along Tienshen Temple toward Douliou (elevation 200 m), Huben Village, Linnei, Yunlin County by T. J. Lin, Y. P. Li and H. I. Tsai (coll. no. 2007-83); two specimens collected on the 13 September 2007 from roadside slope along Fongshuhu South Creek (elevation 150–210 m) near the borders of Douliou and Linnei, Yunlin County by T. J. Lin, Y. P. Li and H. I. Tsai (coll. no. 2007-85); three specimens collected on the 24 October 2007 around Tienshen Temple (elevation 194 m), Huben Village, Linnei, Yunlin County by T. J. Lin, Y. P. Li and C. H. Chang (coll. no. 2007-96); one specimen collected on the 30 October 2007 from Budhi Shrine of White Horse Mountain (elevation 130–144 m), Huben Village, Linnei, Yunlin County by T. J. Lin, Y. P. Li and C. H. Chang (coll. no. 2007-103); one specimen collected on the 11 December 2007 from Dakeng (elevation 214–290 m), Huben Village, Linnei, Yunlin County by T. J. Lin, Y. P. Li and C. H. Chang (coll. no. 2007-120); one specimen collected on the 4 March 2008 from Yuchin Valley (elevation 228 m) near the borders of Douliou, Yunlin County and Jhushan, Nantou County by T. J. Lin and Y. P. Li (coll. no. 2008-4); one specimen collected on the 12 July 2010 near Gaotai (elevation 245 m), Chenggung, Taitung County by H. P. Chen and C. I. Chang (coll. no. 2010-33); 13 specimens collected on the 13 July 2010 from Chihkoshan (elevation 249 m), Yuli, Hualien County by H. P. Chen and C. I. Chang (coll. no. 2010-35); one specimen collected on the 13 July 2010 near Coastal Mountains *Cycas*

taitungensis Nature Reserve (elevation 490 m), Taitung County by H. P. Chen and C. I. Chang (coll. no. 2010-40); seven specimens collected on the 14 July 2010 along Shantsungliao Road (elevation 373 m), Chihshang, Taitung County by H. P. Chen and C. I. Chang (coll. no. 2010-42); two specimens collected on the 18 October 2010 near Coastal Mountains *Cycas taitungensis* Nature Reserve (elevation 490 m), Taitung County by R. C. Jang, M. H. Chen and L. H. Chen (coll. no. 2010-59); three specimens collected on the 26 May 2011 along Walami trail (elevation 750–840 m), Jhuohsi, Hualien County by S. T. Chang, M. H. Chen and C. I. Chang (coll. no. 2011-12); two specimens collected on the 26 October 2011 along Ningpu Road (elevation 181 m), Ningpu Village, Changbin, Taitung County by H. P. Chen and C. I. Chang (coll. no. 2011-93); two specimens collected on the 26 October 2011 at Tzuchiang Bridge (elevation 133 m), Baliwan Village, Fongbin, Hualien County by H. P. Chen and C. I. Chang (coll. no. 2011-96); five specimens collected on the 27 October 2011 along Road 38-1 (elevation 238 m), Shoufeng, Hualien County by H. P. Chen and C. I. Chang (coll. no. 2011-100); one specimen collected on the 25 May 2016 near the epicenter of the 921 earthquake (elevation 786 m), Guohsing, Nantou County by C. S. Huang and P. H. Lin (coll. no. 2016-17); two specimens collected on the 21 June 2016 around the memorial near the quake lake (elevation 602 m), Guohsing, Nantou County by C. S. Huang and P. H. Lin (coll. no. 2016-23); five specimens collected on

the 22 June 2016 around the giant stone observatory (elevation 730–740 m), Guohsing, Nantou County by C. S. Huang and P. H. Lin (coll. no. 2016-28); ten specimens collected on the 22 June 2016 near the epicenter of the 921 earthquake (elevation 786 m), Guohsing, Nantou County by C. S. Huang and P. H. Lin (coll. no. 2016-29); one specimen collected on the 20 July 2016 around the giant stone observatory (elevation 730–740 m), Guohsing, Nantou County by C. S. Huang and P. H. Lin (coll. no. 2016-38); one specimen collected on the 16 August 2016 near the quake lake (elevation 585–602 m), Guohsing, Nantou County by C. S. Huang and P. H. Lin (coll. no. 2016-42); two specimens collected on the 16 August 2016 around Shimen observatory (elevation 535 m), Guohsing, Nantou County by C. S. Huang and P. H. Lin (coll. no. 2016-43); one specimen collected on the 17 August 2016 around the giant stone observatory (elevation 730–740 m), Guohsing, Nantou County by C. S. Huang and P. H. Lin (coll. no. 2016-47); one specimen collected on the 18 October 2016 near Jiutsaihu Bridge (elevation 647 m), Guohsing, Nantou County by C. S. Huang and P. H. Lin (coll. no. 2016-51); one specimen collected on the 19 October 2016 around the giant stone observatory (elevation 730–740 m), Guohsing, Nantou County by C. S. Huang and P. H. Lin (coll. no. 2016-57); 18 specimens collected on the 19 October 2016 near the epicenter of the 921 earthquake (elevation 786 m), Guohsing, Nantou County by C. S. Huang and P. H. Lin (coll. no. 2016-58).

Description. — Length (clitellates) 25–44 mm, weight 0.02–0.07 g, diameter 1.35–2.23 mm. Segment number 89–119. Prostomium prolobous. Dorsal pores absent. Setae lumbricine (eight setae per segment), minute, closely paired. Clitellum X–XIII, indistinct, whiter than rest of the body, yellowish egg sacs visible through epidermis in the clitellar region. Spermathecal pores one pair in 7/8, in line with seta c, concealed in the intersegmental furrow, occasionally with a small papilla about 0.15 mm in diameter anterior to each pore. Male pores one pair on small, eversible penes across 10/11 (Fig. 1AB). Penes usually wholly concealed in retracted condition with anterior and posterior whitened pads around the secondary male apertures (Fig. 1C). Female pores minute, hardly visible, one pair on anterior margin of XII, each pore lateral to seta b (Fig. 1A). Preserved specimens unpigmented or with translucent pale skin.

Septa 5/6–8/9 thickened, 9/10 to posterior end thin. Gizzards large, three in XIV–XVI, white, shining. Hearts paired in VI–IX. Nephridia holoic. Testis sacs one pair, pear-shaped, each suspended on septum 9/10, about 0.52 mm in length and 0.42 mm in width. Sperm duct long, compact, heavily coiled into a tight ball of loops, with a short, slender, straight

distal end connecting to male atrium on the penial chamber (Fig. 1D). Male atrium small, follicular, cotton-like, about 0.25 mm in length, attached to penial chamber. Penial chamber small, spherical, about 0.28 mm in diameter. One pair of follicular, yellowish ovisacs dorso-lateral on both sides of the digestive tract, occupying three to eight segments in XI–XVIII. Spermathecae one pair, both ampulla and spermathecal atrium posterior to septum 7/8. Ampulla small, spherical, about 0.2 mm in diameter, its duct long, slender, with three or four coils to join the spermathecal atrium (Fig. 1E). Spermathecal atrium small, spherical, about 0.15 mm in diameter. Accessory glands absent.

Remarks. — The characters of the specimen from Caroline Islands examined by Kobayashi (1941) agree mostly with the typical morphology of *Dr. barwelli* except the elongated-oval ampulla, absence of spermathecal atrium and placement of most of the sperm duct in segment IX rather than in X. Additionally, the two specimens from Fiji with much larger body size (length 66 mm, diameter 3–4 mm, 137–163 segments) and short spermathecal ducts and without spermathecal atrium documented by Easton (1984) should belong to some other species, or maybe a new species.

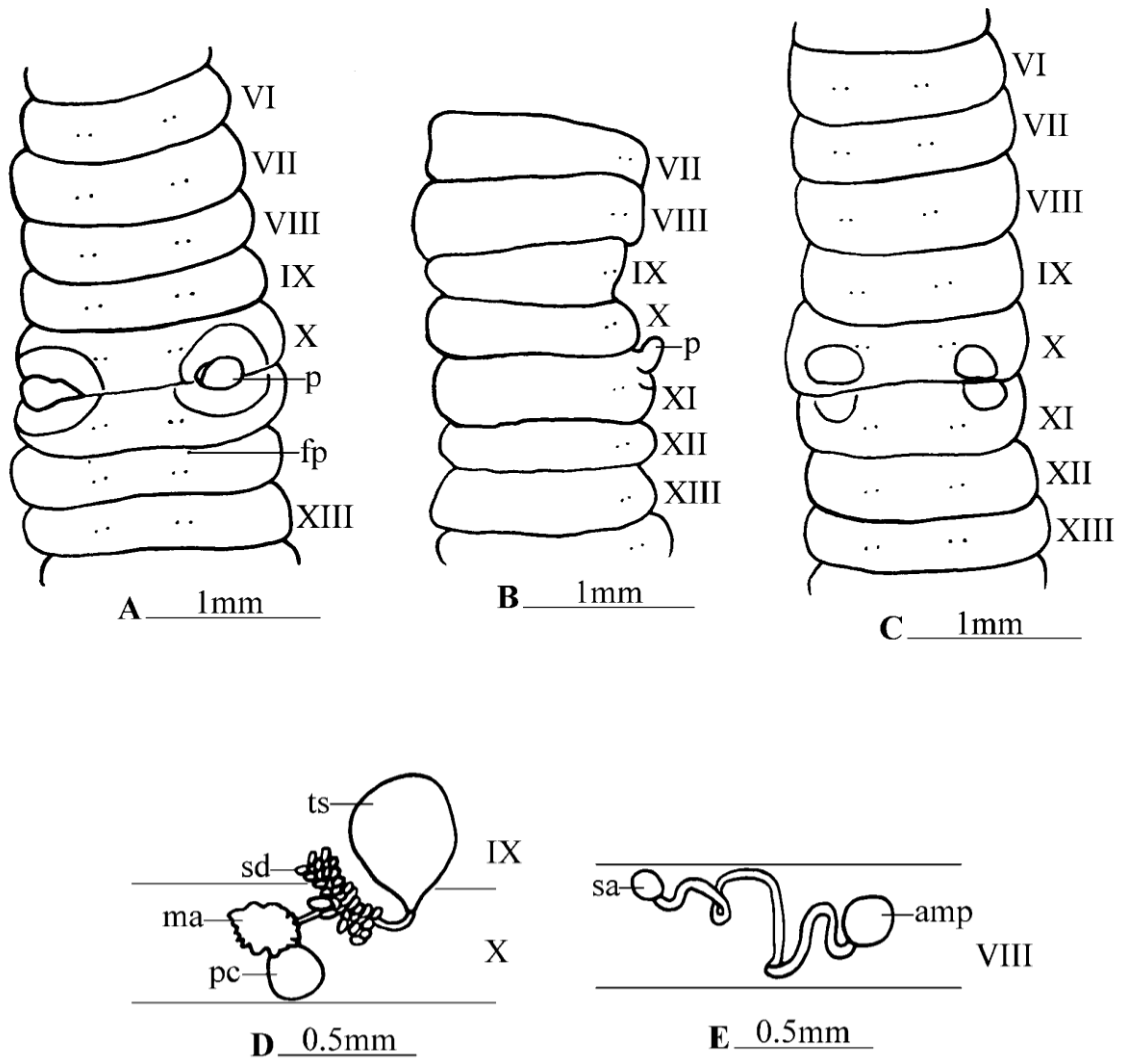


Fig. 1. *Drawida barwelli* (Beddard): A, ventral view of clitellar region (p, penis; fp, female pore); B, right-lateral view of clitellar region; C, ventral view of clitellar region; D, dorsal view of left testis sac (ts), sperm duct (sd), male atrium (ma) and penial chamber (pc); E, dorsal view of left spermatheca (amp, ampulla; sa, spermathecal atrium).

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利用紅外線自動相機進行鳥巢箱之天敵監測

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摘要

本研究於 2016 年 5 月-8 月及 2017 年 4 月-6 月於奧萬大森林遊樂區內以紅外線自動相機進行鳥巢箱天敵之監測，並搭配人力探巢來了解各巢箱之使用與繁殖情形。期間共使用自動相機監測 31 個巢箱，拍攝到的天敵種類有臺灣獼猴 (*Macaca cyclopis*)、臺灣藍鵲(*Urocissa caerulea*)、赤腹松鼠 (*Callosciurus erythraeus taiwanensis*)、條紋松鼠(*Tamias maritimus formosanus*)及無法辨識的鼠類。拍攝到的影像中以臺灣獼猴出現頻度最高，並有記錄到 4 筆臺灣獼猴明確侵擾與破壞巢箱的影像；其次為赤腹松鼠，並記錄到 2 筆侵擾與破壞巢箱的影像，臺灣藍鵲則有一筆侵擾巢箱的影像。在此兩次繁殖季中，共記錄到 144 個繁殖巢，繁殖成功的巢共 34 個，失敗的巢共 110 個。整合繁殖失敗原因，蛋/幼雛不明原因死亡或消失占 40% (n = 44)、判斷為臺灣獼猴掠食占 23.6% (n = 26)、蛇類掠食占 22.7% (n = 25)、親鳥棄巢占 12.7% (n = 14)及經自動相機拍攝確認為赤腹松鼠掠食占 0.9% (n = 1)。臺灣獼猴為本研究中透過自動相機之監測結果發現造成使用巢箱鳥類繁殖失敗較主要的天敵，若欲減少臺灣獼猴對巢箱造成物理上的破壞，建議可在巢箱結構上進行補強。後續可持續以紅外線自動相機記錄奧萬大森林遊樂區天敵侵擾巢箱狀況，並以較密集的人力探巢方式輔助記錄，或嘗試將自動相機設定為縮時拍攝模式，以提高變溫動物天敵的偵測率並增加辨識實際掠食巢箱的天敵物種。

關鍵詞：紅外線自動相機、巢箱、天敵

Use of infrared camera traps to monitor predators of nest boxes

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Abstract

We used infrared camera traps to monitor predators of nest boxes from May to August in 2016 and April to June in 2017 in Aowanda National Forest Recreation Area and checked the breeding stage of each nest box once a week. We recorded the following species of nest predators: Formosan macaque (*Macaca cyclopis*), Taiwan blue magpie (*Urocissa caerulea*), Red-bellied squirrel (*Callosciurus erythraeus taiwanensis*), Formosan striped squirrel (*Tamias maritimus formosanus*) and rodents (*Muridae*). Among the recording images, the occurrence index of Formosan macaque was the highest, and there were 4 records of Formosan macaques which invaded and damaged the nest boxes; the second most frequent species was the red-bellied squirrel, and there were 2 records of red-bellied squirrel which invaded and damaged the nest boxes, and there was one record of the Taiwan blue magpie invaded a nest box. We monitored 144 nests, of which 34 nests were identified as breeding success and 110 as failure during the two breeding seasons. The factors which caused breeding failure included (1) eggs/chicks disappeared or died for no obvious reasons (40%, $n = 44$), (2) predation by macaques (23.6%, $n = 26$), (3) predation by snakes (22.7%, $n = 25$), (4) nest abandonment (12.7%, $n = 14$) and (5) predation by red-bellied squirrels (0.9%, $n = 1$). Therefore, Formosan macaques were the main predator to the birds monitored in our study. In order to prevent Formosan macaque from damaging the nest box, it is necessary to strengthen the structure of the nest boxes. We will continue to use infrared camera traps and frequent nest boxes checks to monitor the breeding success of these birds which use nest boxes, and will set cameras to time-lapse photography mode to increase the detection rate of poikilothermal predators and confirm the actual predator species of nest boxes.

Keywords: Infrared camera traps, nest boxes, predators.

前言

鳥類於繁殖季期間，巢穴易遭受掠食者侵略，導致鳥種繁衍過程失敗，進而影響森林內鳥種群聚結構(Rader *et al.* 2007; Morris and Conner 2016; Söderström *et al.* 1998)。鳥巢遭受掠食者入侵之可能原因眾多，例如：雛鳥乞食聲吸引掠食者注意、棲息地內天敵的族群分布、食性與食物豐富度之關係等(Leech and Leonard 1996; Martin and Joron 2003)。因此對於鳥巢掠食者之物種、族群、掠食方式之情形，確實有其瞭解之必要性，以做為日後該地區鳥種繁殖期之保育策略擬定依據。

奧萬大國家森林遊樂區內鳥種眾多，自2002年起，於園區內設置人工巢箱，其主要目的為提升當地鳥種繁殖率以及觀測其物種之族群結構與行為生態(姚 2005)。經過長時間之紀錄可得知，較常使用人工鳥巢箱做為築巢及育雛之物種為：青背山雀 Green-backed Tit (*Parus monticolus*)、黃山雀 Yellow Tit (*Machlolophus holsti*)、茶腹鵯 Eurasian Nuthatch (*Sitta europaea*)及棕面鶯 Rufous-faced Warbler (*Abroscopus albogularis*)，其中又以青背山雀與棕面鶯兩種鳥類繁殖情形較穩定。依據過往監測資料顯示，影響鳥種利用人工巢箱繁殖失敗之因素主要為遭受掠食者捕食，其天敵包括：

蛇類、舉尾蟻、蠅類等，其中蛇類包括臭青公 Taiwan stink snake (*Elaphe carinata*)與黑眉錦蛇 Taiwan Beauty Snake (*Orthriophis taeniurus friesi*)，而臺灣獼猴、臺灣藍鵲在當時則被視為潛在天敵，並無直接干擾巢位的證據(姚 2010)，赤腹松鼠則在過往並未納入奧萬大主要或次要天敵名單中。靈長目、鴉科以及嚙齒目皆屬於雜食性動物，因此對於雀形目鳥種之築巢與育雛，無論是選擇人工巢箱或是天然洞穴的方式繁衍後代，都具有潛在的威脅(Telleria and Diaz 1995；吳 2003；陳 2007；姚 2010；葛等 2016)。鳥巢中鳥蛋及雛鳥遭受到掠食者捕食時，不僅是造成鳥類繁殖成功與否的重要因素之一，同時亦可能影響其物種的族群結構與豐富度(Söderström *et al.* 1998; Wegge *et al.* 2012)。前人研究對於鳥巢遭受天敵破壞之情況，亦有利用自動相機進行監測之案例(Bayne and Hobson 1997；吳 2003)，本研究於 2016-2017 年奧萬大鳥類繁殖季期間，將有築巢及育雛之巢箱架設紅外線自動相機監測其

動態，藉此瞭解破壞巢箱之天敵物種以及其他物種出沒頻率之高低，期望能提供後續進行鳥巢箱架設及經營管理之參考。

材料與方法

一、研究樣區

本研究樣區為於南投縣仁愛鄉霧社東南方，萬大溪中游北岸，行政區域隸屬南投縣仁愛鄉親愛村，同時也是林務局南投林區管理處濁水溪事業區第 18 及 22 林班，園區內總面積廣達 2,787 ha，海拔高度介於 1,100-2,600 m 之間，地形與地貌屬於高山河谷類型，其中萬大北溪、萬大南溪、清水溪、腦寮溪等支流皆匯流至萬大溪內。

相機架設監測鳥巢箱主要區域為收費站(巢箱樣區：D 區)至遊客中心周圍(巢箱樣區：A 區)，以及賞鳥步道(巢箱樣區：B 區)、平臺區(巢箱樣區：C 區、E 區)最遠至松林區(巢箱樣區：F 區)(圖 1)。

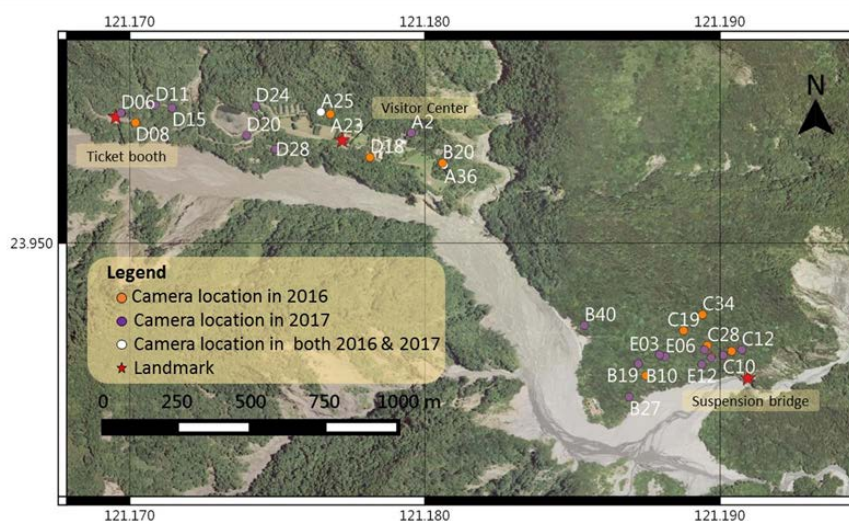


圖 1、2016 年與 2017 年監測巢箱巢箱之紅外線自動相機位置圖。

Fig. 1. The sites of infrared camera traps for our nest box surveys in 2016 and 2017.

二、研究方法

巢箱繁殖狀況監測部分於 2 月-8 月期間，研究人員每星期巡視 1 次所有巢箱，以鋁梯輔助攀爬觀測，將該巢箱之鳥種、築巢、孵卵、育雛、離巢等情形做紀錄，待確定該巢繁殖結束後，再將巢內巢材清空，以利其他個體繼續使用。本研究於 2016 年 5 月 26 日至 8 月 5 日及 2017 年 4 月 5 日至 6 月 29 日期間內架設紅外線自動相機進行監測，選擇架設的巢箱條件為已築巢、下蛋或是育雛中之巢箱，本次研究採用 10 台自動相機架設於不同巢箱進行監測，監測期間若巢箱被破壞或是巢箱內已無個體及鳥蛋，則將相機拆下並再裝置於其它繁殖中之巢箱執行監測。園區內架設巢箱之樹種主要為：楓香(*Liquidambar formosana*)、臺灣欒(*Zelkova Serrata*)、臺灣二葉松(*Pinus taiwanensis*)、山肉桂(*Cinnamomum insularimontanum*)、山櫻花(*Prunus campanulata*)、苦楝(*Melia azedarach*)等類型，巢箱彼此間距約 5 m 以上，相機固定方式為使用彈簧綁帶將相機架設在離巢箱約 3-5 m 以上距離之樹幹，並調整相機高度與鏡頭對準巢箱，每台相機架設完成後並以 GPS 進行定位記錄。由於同型號自動相機數量有限，因此 2016 年分別使用 2 台 Reconyx HC500、5 台 Bushnell 及 3 台 Keep Guard 760NV 等共 10 台紅外線自動相機進行監測，而 2017 年則使用相同型號之 Keep Guard 780NV 共 10 台進行監測。紅外線自動相機設定部分，Reconyx HC500 設定為拍照模式，一次連拍 3 張間隔 15 秒、Keep Guard 760NV 設定為錄影模式，錄製 5 秒間隔 5 秒、Keep Guard 780NV 相機設定為錄影模式，錄製 10 秒間隔 2 秒、Bushnell 相機設定為混和模式，先拍連拍 2 張再錄製 5 秒影片，間隔 5 秒；此外所有相機感應敏感度均調至 High 等級。

三、資料分析方式

造成巢箱繁殖失敗的天敵種類判斷，依據最終繁殖記錄狀態及現場跡象輔以自動相機的資料進行，一般臺灣獼猴在侵擾巢箱過程中，常會將巢箱頂蓋掀開並造成巢箱結構上的損壞，巢箱中的遺留巢材呈現零亂或被丟出至附近地面；而蛇類掠食巢箱一般較少對巢箱內巢材排列或巢箱結構造成明顯改變或破壞，且有時會在蛋殼上遺留吸取蛋汁的小洞或穿孔型蛋殼殘餘；小型哺乳類掠食巢箱通常也較少對巢箱內巢材排列或巢箱結構造成明顯改變或破壞，偶爾會在巢中留下穿孔型或碎裂型蛋殼殘餘(吳 2003)，若無留下蛋殼殘餘，屬較難辨識確認的天敵類型。

各巢箱使用鳥種之繁殖成功率以 Mayfield 方式計算，並參照 Manolis *et al.* (2000)繁殖成功與失敗之依據，來判斷該巢為繁殖成功或失敗，其判斷繁殖成功依據如下：(1)該巢於最後一次監測時，至少有 1 隻雛鳥離巢，(2)當雛鳥羽毛漸長完全並計算雛鳥日齡已接近離巢日時，再次巡視該巢箱，如發現雛鳥已不在且現場沒有受到掠食跡象，即判定為離巢。繁殖失敗判斷則依據：(1)未達該鳥種離巢日齡前，蛋或雛鳥已消失，(2)巢內發現僅剩蛋殼或是雛鳥屍體，(3)該巢箱於繁殖使用期間(確定巢內有蛋或幼雛)遭受破壞或是親鳥棄巢等因素，即為繁殖失敗，其判斷標準則以最後一次監測日期巢況與現場跡象為主。

資料分析與物種個體辨識，依據自動相機內所拍攝到的連續畫面(時間相同)、個體行為、活動方式及體態是否有其它特徵等來進行判定是否為同隻個體。其辨識之有效照片定義為：1 hr 內連續拍攝同隻個體，僅記為一筆有效資料，如同一物種在 1 hr 後又出現，再予以記錄(裴與姜 2002)。

分析方式則採用動物標準化活動量分析為主，依據各巢箱之自動相機所拍攝到的各種動物出現次數，用以計算該干擾巢箱之天敵動物出現頻度 OI 值(頻度指數, Occurrence Index) (裴等 1997)。

其計算方式如下：OI 值 = (一物種在該樣點的有效影片或照片總數量/該樣點的相機總工作時數) $\times 1000$ hr。相機有效工作時數定義為：相機架設開機後測試照最後一張至拍攝最後一張的照片時間，以計算相機工作時數(盡可能減去人為影響因素)，計算單位以 hr 為主，樣點總工作時數則為每次相機工作時數之加總時間，如果相機中途故障或記憶卡損毀則不予以計算。

結果與討論

一、巢箱使用率與繁殖成果

自 2016 年 2 月 21 日至 7 月 14 日及

2017 年 3 月 16 至 7 月 11 日間，研究人員每星期均進行一趟人工鳥巢箱巡視作業，逐個記錄每個巢箱之使用鳥種、築巢、孵卵、育雛、離巢情形等，待確定該巢鳥種繁殖結束後，將巢內巢材清空，以便後續繁殖個體繼續使用。2016 年共架設 185 個巢箱，整體人工巢箱使用率達到 67.6%($n = 125$)；2017 年共架設 175 個巢箱，整體人工巢箱使用率為 51.4% ($n = 90$)。

整理 2016-2017 年繁殖季資料，統計青背山雀、棕面鵯、黃山雀及茶腹鵯 4 種鳥種共 144 巢次繁殖紀錄中，繁殖成功巢共 34 個，失敗的巢共 110 個。整合繁殖失敗原因，依據現場情形無法判斷是否有掠食、蛋/幼雛不明原因死亡或消失占 40%($n=44$)、判斷為臺灣獼猴掠食占 23.6%($n = 26$)、蛇類掠食占 22.7%($n = 25$)、親鳥棄巢占 12.7%($n = 14$)及經自動相機拍攝確定為赤腹松鼠掠食占 0.9% ($n = 1$)，兩年度分別的繁殖失敗情形呈現於圖 2。

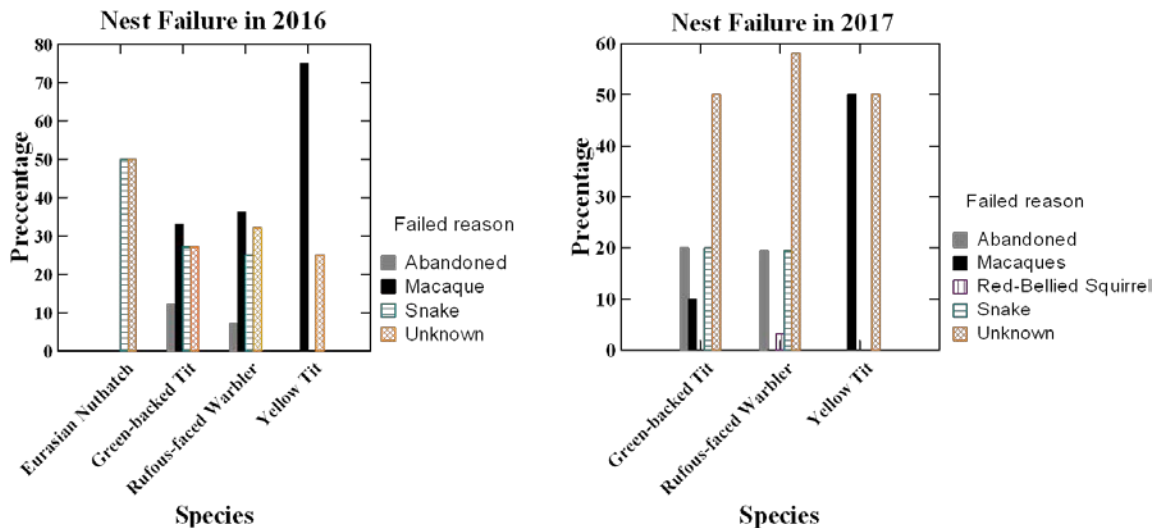


圖 2. 2016 及 2017 年繁殖失敗原因圖。

Fig. 2. Bar charts for reason of breeding failures in 2016 and 2017.

分析兩年度使用巢箱繁殖各鳥種的繁殖成功率，2016 年青背山雀為 0.271(n = 38)，黃山雀為 0.215(n = 5)，棕面鶯 0.366(n = 39)為該年最高，茶腹鵯僅在 2016 年有繁殖紀錄，成

功率為 0.58(n = 6)。2017 年青背山雀的繁殖成功率為 0.445(n = 17)，黃山雀 0.545(n = 4) 為該年最高，棕面鶯為 0.306(n = 35)(各鳥種繁殖巢數及總觀察天數列於表 1)。

表 1、2016 及 2017 年使用巢箱繁殖各鳥種繁殖巢數、觀察天數及繁殖成功率。

Table 1. Number of nests, total observation days and rate of breeding success of each bird species using nest boxes in 2016 and 2017.

Species	2016			2017		
	Nest number	Total observation days	Breeding success (S.E., n=number of nests)	Nest number	Total observation days	Breeding success (S.E., n=number of nests)
Green-backed Tit	38	836	0.271 (0.007, n=38)	17	426.5	0.445 (0.007, n=17)
Yellow Tit	5	116.5	0.215 (0.017, n=5)	4	160	0.545 (0.009, n=4)
Rufous-faced Warbler	39	898.5	0.366 (0.006, n=39)	35	1012	0.306 (0.001, n=35)
Eurasian Nuthatch	6	113	0.580 (0.012, n=6)	--*	--	--

* 茶腹鵯於 2017 年無繁殖紀錄。

* There was no breeding records for Eurasian Nuthatch in 2017.

二、自動相機拍攝之天敵物種出現頻率 (Occurrence Index ; OI 值)

自動相機架設時間為 2016 年 5 月 26 日至 2016 年 8 月 5 日及 2017 年 4 月 5 日至 6 月 29 日，於奧萬大森林遊樂區以 10 台自動相機於輪流於不同巢箱進行監測(例如：監測期間被破壞或是巢箱內已無存活個體及繁殖跡象，則將相機拆下，再裝置於其它繁殖中之巢箱執行監測)，各自動相機架設時之對應繁殖時程與鳥種請參照表 2 與表 3。於 2016 年共計架設 12 台次自動相機進行監測，占該年總繁殖巢箱數的 13.79%(n = 87)，有效拍攝時數達 12,315 hr；2017 年共計架設 19 台次自動相機進行監測，

占該年總繁殖巢箱數的 33.93%(n = 56)，拍攝時數達 13,448 hr(表 2)，年間之各鳥種拍攝時數請參照表 3。期間共記錄哺乳動物 2 目 3 科 4 種，鳥類 1 目 4 科 5 種，包括臺灣獼猴、條紋松鼠、赤腹松鼠、鼠類(無法辨識至種類)、臺灣藍鵲、青背山雀、黃山雀、茶腹鵯及棕面鶯，而本研究將其中之臺灣獼猴、赤腹松鼠、條紋松鼠、鼠類以及臺灣藍鵲定義為使用巢箱鳥類之天敵。天敵物種之定義，除了於本研究中所記錄到確切騷擾繁殖中巢箱之物種，例如臺灣獼猴、赤腹松鼠及臺灣藍鵲，此外亦包含前人文獻中所記錄之物種，如鼠類以及條紋松鼠(蕭 2012)。

表 2、自動相機架設狀況明細。

Table 2. Information of infrared camera traps used in 2016 and 2017.

Year	2016	2017
Number of nestboxes used in breeding season	87	56
Number of cameras	12	19
Working hours of all cameras	12,315	13,448
Camera set up at building nest stage	8	14
Camera set up at laying/incubation stage	2	2
Camera set up at nestling stage	2	3

表 3、2016 年與 2017 年之自動相機監測各鳥種巢箱之拍攝時數。

Table 3. The monitor hours of infrared camera traps of each bird species using nest boxes in 2016 and 2017.

Species	2016		2017	
	Nest number monitored	Working hours	Nest number monitored	Working hours
Green-backed Tit	6	6,750	8	6,449
Yellow Tit	1	919	2	667
Rufous-faced Warbler	5	4,646	9	7,977

由於自動相機有效拍攝張數並不多，在各物種之 OI 值呈現未細分各繁殖時程或個別鳥種，僅以年份區分來呈現。2016 年之天敵物種中，以臺灣獼猴之 OI 值最高(1.62)，鼠類次之(1.42)，再者為赤腹松鼠與條紋松鼠之 OI 值同

為 0.07。2017 年同樣以臺灣獼猴之 OI 值最高(7.06)，赤腹松鼠次之(1.44)，再者依序為臺灣藍鵲(1.01)、鼠類(0.29)及條紋松鼠(0.14)(表 4)。自動相機所記錄之部分天敵侵擾照片以及當時情況描述請參考圖 3 至圖 10。

表 4、2016 年與 2017 年自動相機記錄巢箱天敵之狀況。

Table 4. The nest boxes predators records by infrared camera traps in 2016 and 2017.

Year	2016			2017		
	Image number	OI	ID of nest box recorded	Image number	OI	ID of nest box recorded
Formosan macaque	20	1.62	A23,A25,A36,C19,C38	95	7.06	A25,A36,B40,C08,C09,C10,C12,D06,D24, E03,E06,E12
Red-bellied squirrel	1	0.07	A36	20	1.44	C10,C12,D24
Rodents	21	1.42	A23	4	0.29	E03
Taiwan blue magpie	0	0	-	14	1.01	A02,D20
Formosan striped squirrel	1	0.07	C19	2	0.14	E03

OI: occurrence index.

三、自動相機拍攝各類天敵對巢箱威脅性之探討

臺灣獼猴為透過自動相機拍攝的天敵物種中造成繁殖失敗比例最高者；其食性廣泛，雖然以植物性食物占大部分比例，但在夏季時動物性食物的比例會較其它季節高些，取食對象包括昆蟲、蜥蜴、鳥蛋以及雛鳥(張 1999；Su and Lee 2001；王 2005)，夏季仍屬大多數鳥類的育雛期，因此臺灣獼猴很有機會對活動範圍內之蛋與雛鳥構成相當的威脅，此外甚至也會騷擾如林鵰(*Ictinaetus malayensis*)等大型猛禽育雛，林鵰親鳥若見到臺灣獼猴在巢位周邊出沒，便會進行強力的驅趕，但仍有導致雛鳥被迫提早離巢的案例(林與何 2010)。本研究樣區在 2016 年之前並未有臺灣獼猴侵擾巢箱的確切證據(姚未發表資料)，雖 2016 年之前並無架設紅外線自動相機監測，然而臺灣獼猴侵擾巢箱常伴隨對巢箱結構的破壞，因此若臺灣獼猴有侵擾巢箱之情形，應有相當機會可透過事後巢箱遭破壞情形輔助判斷，可推測 2016 年前巢箱遭臺灣獼猴侵擾機率應不高。賴與張(2008)於 2005-2007 年間透過紅外線自動相機監測，當時即可穩定記錄到臺灣獼猴出沒，顯示臺灣獼猴非近年才開始於奧萬大地

區活動。臺灣獼猴具有相當的學習能力(李 2009)，推測可能其於近年學習將巢箱與食物資源(蛋或雛鳥)產生連結，進而逐漸增加破壞巢箱的機率，然而其確切學習契機為何，尚難有定論。臺灣獼猴在侵擾巢箱過程中常會將巢箱頂蓋掀開並破壞巢箱(圖 3、圖 5)，在所有架設的巢箱中，2016 年就有 34 個巢箱被掀蓋。為避免臺灣獼猴強力破壞巢箱，研究人員於 2017 年開始將有築巢、巢內有蛋或是幼雛之巢箱在外以棉繩綁緊將巢箱固定(圖 11)，以避免臺灣獼猴破壞；雖然 2017 年之臺灣獼猴 OI 值達 2016 年之臺灣獼猴 OI 值 2 倍以上(表 4)，但在所有巢箱中，2017 年則僅有 4 巢確定被臺灣獼猴掀蓋，較 2016 年已減少許多。在巢箱外綁棉繩除了可以減少臺灣獼猴破壞之外，赤腹松鼠亦無法得逞(圖 9)。此外在 2017 年監測時也發現，第二平臺(B 區)有 5 巢末有個體進駐繁殖之巢箱，但仍遭臺灣獼猴將頂蓋掀開破壞，推測原因之一可能為大部分有利用之巢箱皆使用棉繩固定後較難以破壞，進而隨機尋找無綁繩之巢箱搜尋是否有可食物。此外獼猴對搜尋食物具有時空上的記憶能力(Hampton *et al.* 2005)，亦可能將巢箱與食物畫上連結而隨機侵擾巢箱。



圖3. 2016/06/13臺灣獼猴翻倒巢箱，隨後伸手挖空巢內物(巢箱號碼：B6，巢箱內有青背山雀巢材)。
Fig. 3. 13/06/2016 A Formosan macaque overturned this nest box and then dug out the entire contents from the inside. (ID number of nest box: B6, which contained nest material of the Green-backed Tit).



圖 4. 2016/06/21 臺灣獼猴翻動、搖晃巢箱後於鳥巢洞口挖掘畫面(巢箱號碼：C19，巢內有棕面鶯雛鳥)。06/22 巡視時發現 3 隻雛鳥已死亡，推測雛鳥死亡非常可能來自臺灣獼猴之干擾所致。
Fig. 4. 21/06/2016 A Formosan macaque dug into the entrance of this nest box after flipping and shaking the nest box (ID number of nest box: C19) which contained chicks of the Rufous-faced Warbler. The three chicks were found dead in 22/06/2016, and their death was probably caused by the interference of the Formosan Macaque.



圖5. 2017/04/05臺灣獼猴破壞巢箱頂蓋畫面(巢箱號碼：E12，內有5顆青背山雀的蛋，後續繁殖失敗)。
Fig. 5. 05/04/2017 A Formosan Macaque damaged the cover of this nest box (ID number of nest box: E12) which contained 5 eggs of the Green-backed Tit, and the nest failed afterwards.



圖 6. 2017/06/05 臺灣獼猴於鳥巢箱攀爬企圖破壞巢箱蓋未成功畫面 (巢箱號碼：E06，巢內有青背山雀雛鳥，於 6/29 成功離巢)。
Fig. 6. 05/06/2017 A Formosan Macaque tried to break into this nest box but did not succeed. (ID number of nest box: E06) which contained chicks of the Green-backed Tit which fledged successfully in 29/06/2017).

赤腹松鼠與條紋松鼠皆屬於雜食性，若有機會也會取食鳥巢中的鳥蛋(祁 2008)。本研究透過自動相機實際拍攝到赤腹松鼠直接破壞巢箱捕食巢內雛鳥的影像(圖 8)，然而當時現

場人員僅透過巢箱狀況無法確切判定天敵種類，仍須透過自動相機影像輔助判定。蕭(2012)在觀霧地區設置的鳥巢箱，亦曾透過監視器材記錄到條紋松鼠進入巢箱捕食青背山雀雛鳥

的經過，皆印證松鼠科為巢洞型鳥類育雛期的天敵。分布於臺灣山區的鼠類中，刺鼠以及高山白腹鼠都有於樹上活動的觀察報告(張 1991；鄭 2000)，而高山白腹鼠也曾經被發現

棲息於巢箱內(蕭 2012)，因此亦有可能對使用巢箱繁殖的鳥類造成威脅。奧萬大地區以刺鼠的出沒頻度較高(賴與張 2008)，本研究並未直接記錄到刺鼠直接侵擾巢箱。



圖 7. 赤腹松鼠啃食巢箱洞口，在相機影像中發現棕面鶯親鳥來回驅趕(巢箱號碼：C12，紅圈內為棕面鶯)。

Fig. 7. A red-bellied squirrel gnawed at the entrance of this nest box, and the Rufous-faced Warbler (in the red circle) tried to drive it away from the nest box (ID number of nest box: C12).



圖 8. 2017/06/17 赤腹松鼠破壞巢箱蓋，進巢洞內掠食巢箱內雛鳥(巢箱號碼：C12)。

Fig. 8. 17/06/2017 a red-bellied squirrel damaged the cover of this nest box, then broke into the nest box from the top and consumed the chicks (ID number of nest box: C12).



圖9. 2017/5/6~5/14間，赤腹松鼠數度嘗試頂開巢箱，在相機影像中發現青背山雀親鳥不時威嚇或直接攻擊禦敵畫面，威嚇姿勢為身體略微伏低、張開雙翅身體左右擺動、並搭配瞬間振翅(巢箱號碼：D24，紅圈內為青背山雀，巢箱有使用繩索固定頂蓋，赤腹松鼠未能撬開，該巢雛鳥於5/19仍順利離巢)。

Fig. 9. During 06/05/2017~14/05/2017, the red-bellied squirrel tried to open the cover of this nest box several times. The Green-backed Tit (in the red circle) intimidated and attacked the squirrel directly in order to drive it away from the nest box. The posture of intimidation was lowering its body, opening its wings swinging from right and left with constant flapping (number of nest box: D24).

臺灣藍鵲具有捕食其他小型鳥類巢中雛鳥或蛋的習性(劉 2012)，先前於奧萬大地區有繁殖觀察紀錄，並有一筆帶鳥屍塊回巢餵食雛鳥的紀錄(姚 2005)，當時即把臺灣藍鵲定位為

巢箱使用鳥類的潛在天敵。2016 年自動相機並未記錄到臺灣藍鵲，然而 2017 年則確實記錄到臺灣藍鵲頻繁企圖干擾青背山雀繁殖的行為，其過程描述於圖 10 說明。



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圖 10. 2017/4/12-5/1 以及 5/6-5/7 期間，臺灣藍鵲於鳥巢洞口探洞畫面(巢箱號碼：A02，巢箱為青背山雀繁殖使用，人工巢箱外觀並無被破壞之痕跡，雛鳥已於 05/09 成功離巢)。

Fig. 10. During 12/04-01/05/2017 and 06/05-07/05/2017, the Taiwan blue magpie tried to search the inside of this nest box (ID number of nest box: A02) which was used by the Green-backed Tit; however the nest did not have any damage outside, so the chicks fledged successfully in 09/05/2017.



圖 11. 研究人員於巢箱外綁棉繩，防止天敵破壞。

Fig. 11. The researcher used cotton rope to fix the nest box to prevent damage by predators.

吳(2003)指出人工鳥巢於中海拔森林環境中之被掠食率，較低海拔及高海拔來的高，其原因可能為中海拔地區之掠食者種類與數量均較其他海拔地區豐富，此外掠食者的種類則以哺乳動物為主。本研究樣區泛屬中海拔，區內自然環境尚稱完整，賴與張(2008)透過紅外線自動相機監測奧萬大區內動物相，其成果除了本研究已紀錄之臺灣獼猴、赤腹松鼠及刺鼠外，能對使用巢箱繁殖鳥類造成潛在威脅的還有白鼻心(*Paguma larvata*)，然而白鼻心在奧萬大地區出沒頻度較低，可能是本研究尚未有明確紀錄的原因之一。

四、利用紅外線自動相機監測巢箱天敵成效之探討

自動相機應用在野生動物監測具有減少人力負擔、較易偵測到習性敏感動物、資料標準化蒐集等優點，近年臺灣已廣泛使用在野生動物監測作業上(姜 2009)。而在進行鳥類巢位觀察，大多使用錄影設備紀錄(汪 2013；姚 2005, 2008, 2009, 2010；陳 2007；蕭 2012)。過往奧萬大於繁殖季巢箱監測時，亦曾架設小型 DV 攝錄影機(SONY DCR-PC5 和 PC105，JVC GR-DX77U)於育雛期間進行巢內攝影，不僅能完整拍攝到鳥種育雛情形，得以瞭解該鳥種之生殖生物學，亦可同時記錄天敵侵擾巢箱畫面。當時以巢內攝影

及巢被侵略後所留下的殘骸判定蛇掠食幼雛的情形較為嚴重，並也觀察到舉尾蟻、寄生蠅入侵巢箱導致幼雛死亡的案例(姚 2009)。本研究主要目的為監測天敵侵擾巢箱情形，在考量錄影設備成本較高、機動性較低的情形下，因此選擇以相對成本較低、機動性較高的紅外線自動相機進行天敵監測。相較先前以人力探巢，以及架設攝影機監控方式，本次研究多記錄了臺灣獼猴、赤腹松鼠、臺灣藍鵲等物種實際侵擾巢箱的畫面，然而紅外線自動相機之感測機制無法偵測到變溫動物，且侵擾巢箱的物種並不一定會實際造成巢箱的掠食情形，在人力與成本有限的考量下，建議除了可架設紅外線自動相機外，亦可配合較密集的人力探巢方式，以直接目擊或根據現場遺跡輔助辨識可能侵擾巢箱的天敵種類；或將自動相機設定為縮時拍攝模式，透過固定時間間隔拍攝，不但可提高變溫動物天敵的偵測機率並增加辨識實際掠食巢箱的天敵物種。

結論與建議

奧萬大國家森林遊樂區從 2002 年起架設人工鳥巢箱，開始進行系統性的繁殖監測觀察及資料收集，2016 年至 2017 年繁殖季並增設紅外線自動相機輔助監測侵擾巢箱的天敵物種；包括潛在的天敵共記錄到臺灣獼猴、赤腹松鼠、條紋松鼠、鼠類以及臺灣藍鵲等，其中 OI 值最高者為臺灣獼猴，於 2016 年與 2017 年之 OI 值分別為 2.67 及 6.92，並收錄了臺灣獼猴、赤腹松鼠以及臺灣藍鵲侵擾巢箱的過程。臺灣獼猴為本研究中透過自動相機監測造成使用巢箱鳥類繁殖失敗較主要的天敵，若欲減少臺灣獼猴對巢箱造成物

理上的破壞，建議可在巢箱結構上進行補強，以降低臺灣獼猴破壞的可能性。

目前國內關於使用巢箱鳥類的天敵研究仍不多，建議後續可持續以紅外線自動相機累積天敵侵擾巢箱的資料，作為後續巢箱經營管理之參考。由於紅外線自動相機無法感測變溫動物，建議可以較密集人力探巢方式輔助記錄，或嘗試將自動相機設定為縮時拍攝模式，來提高變溫動物天敵的偵測率並增加辨識實際掠食巢箱的天敵物種。

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A new record of *Variola albimarginata* (Teleostei, Serranidae) from the Dongsha Atoll

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Abstract

Variola albimarginata Baissac, 1953, is identified as a newly recorded grouper from the Dongsha Atoll based on four specimens collected by lure fishing. In this study, morphology of *V. albimarginata* is examined and the description based on the Dongsha specimens is reported. The new record of white-edged lyretail in the Dongsha Atoll fills the species' distribution gap between southern Taiwan and the Spratly Islands.

Keywords: *Variola albimarginata*, new record, grouper, Taiwan

東沙環礁新紀錄種白緣星鱸(真骨魚總目:鮨科)

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摘要

本文報導臺灣東沙環礁海域首次紀錄之白緣星鱸(*Variola albimarginata*)。此物種經常被誤判為同屬之星鱸(*Variola louti*)。文中提供以路亞釣法採集的四尾樣本之形值測量、形態描述與其地理分布資訊, 此紀錄填補了該物種在臺灣與太平島之間的分佈空缺。

關鍵詞: 白緣星鱸、新紀錄種、石斑、臺灣

Introduction

The family Serranidae, commonly known as groupers or white-edged lyretail, are a member of the most diversified order Perciformes with 538 species from 75 genera of three subfamilies broadly distributed in tropical and temperate seas (Nelson 2006). The Epinephelinae are one of the subfamilies of the Serranidae, a group of fishes with high values in commercial and sport fisheries. This subfamily is composed of 15 genera, including two important aquaculture genera, *Cephalopholis* and *Epinephelus* (Rhodes and Tupper 2007).

The epinepheline genus *Variola* comprises only two species, *V. albimarginata* Baissac, 1953 and *V. louti* (Forsskål, 1775), inhabiting coral reefs at depths of 4 to 200 m (Lieske and Myers 1994). According to Heemstra and Randall (1993), stomach contents of *V. albimarginata* show this species feeds primarily on fish. Though *V. albimarginata* and *V. louti* are highly similar, these two species can be distinguished by the color pattern of their caudal fin.

Variola albimarginata is widely distributed in the tropical Indo-Pacific region, from east coast of Africa and eastward to the Samoa, and the islands in the central Pacific (Randall 2005). *Variola albimarginata* has also been recorded in southern Taiwan, including Kaohsiung and Pingtung and even in the

Spratly Islands, but it has never been recorded in the Dongsha Atoll (Shao *et al.* 2008). This study is the first report of *V. albimarginata* in the Dongsha Atoll and includes an examination of its morphology

Material and Methods

Four specimens with standard lengths between 173-196 mm were caught by lure fishing in the Dongsha Atoll on 11 August 2016. The specimens were brought back to the laboratory, and a fin clip of each specimen was preserved in 95% alcohol. The remaining specimens were fixed with 10% formalin, then transferred into 70% ethanol solution for preservation. The morphometric measurements followed Smith (1971), and the measurements were implemented using digital caliper, with precision to 0.1 mm, and tape measure, and expressed as proportion in total length (TL) or head length (HL) in Table 1. The specimens were deposited in the Department of Oceanography, National Sun Yat-Sen University, Kaohsiung (catalog number: DOS 02991).

Material Examined

DOS 02991, four specimens, 236-268 mm TL, caught by lure fishing in the Dongsha Atoll by Hsiang-Chun Sun, 11 August 2016 (Fig. 1).



Fig. 1: *Variola albiguttata* from the Dongsha Atoll. DOS 02991(3), 190 mm SL. Photo by Wen-Chien Huang.

圖一：採集自東沙環礁之白緣星鯧。標本號 DOS 02991(3)，標準體長 190 mm。黃文謙攝。

Description of DOS 02991

Refer to Table 1 for morphometric measurements and Fig. 1 for general appearance. Body elongated and fusiform with depth 32.1-35.8% SL. Head relatively large; head length slightly longer than body depth. Eye diameter 14.4-16.8% HL, interorbital slightly convex. Mouth opening large, extending to vertical of posterior orbit with lower jaw slightly longer than upper jaw; upper jaw with a pair of large canine teeth on the front, teeth on both sides villiform with few conical teeth scattered outside; 2 large canine teeth on anterior lower jaw, 1-2 pairs canine teeth on sides of lower jaw with several villiform teeth. Preoperculum margin smooth, 3 flat spines on posterior of operculum. Dorsal fin base long, origin at

approximately 1/3 of TL from snout, outline straight without notch. D.IX.14(2)-15(2). Pectoral fin rounded, slightly ahead to dorsal-fin origin. P.16(3)-17(1). Pelvic fin abdominal and opposite to dorsal-fin origin, longest ray prolonged. V.I.5. Fourth and fifth anal soft rays prolonged reaching caudal fin base. A.III.8. Caudal fin lunate. Body covered by small ctenoid scales, lateral line scale 119-123; 16-20 scales between lateral line to dorsal fin origin, 51-62 scales between lateral line to anal fin origin, predorsal scales 38-45. Circumpeduncular scales 22-26, 9-11+0.5 above lateral line and 9-11+0.5 below lateral line (both not including lateral line row).

Body dark red with yellowish marbled pigmentation, dorsum darker, ventral gradually lighter, scattered by spots bluish dorsally and

gradually turning light purple ventrally. Chin yellowish. Pelvic and pectoral fins yellowish; dorsal, anal and caudal fins red with dots; posterior margins of dorsal and anal fins whitish; posterior of caudal fin with a definite and thin white margin.

Table 1. Morphometric measurements of *Variola albimarginata* (DOS 02991). Meas stands for measurements; pct for percentage; SD for standard deviation. Percentages are in standard length (SL) or head length (HL).

表一、白緣星鱸(DOS 02991)之形態測量形值。Meas 表測量值；pct 表百分比；SD 表標準差。百分比係指測量值佔標準體長或頭長之比例。

Characteristic	DOS02991(1-4)			DOS02991(1)		DOS02991(2)		DOS02991(3)		DOS02991(4)	
	meas.	pct.	SD	meas.	pct.	meas.	pct.	meas.	pct.	meas.	pct.
Total length (mm)	236-268			268		267		253		236	
In SL											
Standard length (mm)	173-196			196		187		190		173	
Body depth	62-66	32.1-35.8	1.65	63	32.1	66	35.3	66	34.7	62	35.8
Body width	27.4-34.7	14.7-17.7	1.43	34.7	17.7	27.4	14.7	30.4	16	30.4	17.6
Caudal peduncle length	23-30	13.3-15.5	1.02	30	15.3	29	15.5	27	14.2	23	13.3
Caudal peduncle depth	26-28	13.9-15.0	0.47	28	14.3	26	13.9	27	14.2	26	15
Snout to first dorsal fin	62-68	33.2-35.8	1.3	65	33.2	67	35.8	68	35.8	62	35.8
Pectoral fin length	43-46	22.6-24.9	1.06	46	23.5	46	24.6	43	22.6	43	24.9
Pelvic fin length	35-38	17.9-20.8	1.27	35	17.9	38	20.3	37	19.5	36	20.8
dorsal fin base	90-103	49.0-54.2	2.36	96	49	98	52.4	103	54.2	93	53.8
Anal fin base	31-39	15.8-20.9	2.33	31	15.8	39	20.9	39	20.5	32	18.5
In HL											
Head length (mm)	67-76.6			73.6		76.6		75.1		67	
Head width	34.4-41.1	45.8-54.7	4.11	34.5	46.9	35.1	45.8	41.1	54.7	34.4	51.3
Snout length	16.7-21.9	23.9-29.2	2.45	17.9	24.3	18.3	23.9	21.9	29.2	16.7	24.9
Interorbital width	12.0-14.1	16.9-19.2	0.96	14.1	19.2	13.5	17.6	12.7	16.9	12	17.9
Eye diameter	10.6-12.6	14.4-16.8	1.13	10.6	14.4	12.6	16.4	12.6	16.8	11.2	16.7

Distribution

The species is known from the Indo-Pacific region, from east coast of Africa and eastward to the Samoa, north to the Ryukyu Islands, south to Queensland and Mozambique (Randall 2005). It is also found in East Andaman Sea (Allen *et al.* 2005). In Taiwan, this species is reported in southern Taiwan, including Kaohsiung, Pingtung, the Spratly Islands, and now in the Dongsha Atoll.

Remark

Although *V. albimarginata* was described in 1953, it was frequently overlooked and had been misidentified as *V. louti* in previous studies (Postel *et al.* 1963; Morgans 1982; Randall and Ben-Tuvia 1983; Heemstra and Randall 1984). Nevertheless, it can be distinguished from *V. louti* by a narrower white posterior margin on the caudal fin (Myers 1999). Our morphometric measurements and meristic counts of specimens match the results of Heemstra and Randall (1993), except for more soft rays of anal fins (9-12 vs. 8) and less soft rays of pectoral fins (16-17 vs. 17-19). The differences might be attributed to individual variations.

The geographical distributions of *V. albimarginata* and *V. louti* approximately overlap, and the latter seems to be a much more common species (Randall 2005; Heemstra and Randall 1993). In the South China Sea, both species have been recorded in Taiwan, Hong Kong, Malaysia and the Philippines (Mohsin and

Ambak 1996; Lou and Li 2000; Broad 2003), and *V. louti* has been recorded from Dongsha. *Variola albimarginata* is known from southern Taiwan and the Taiping Island, but has never been reported in the Dongsha Atoll. The new record in the Dongsha Atoll fills the distribution gap. Because the specimens were caught by lure fishing using mimicking bait on the water surface to attract predatory fish, the habitat uses of both *V. albimarginata* and *V. louti* in Dongsha remain uncertain and may need further studies.

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Photosynthetic capacity of *Miscanthus* species at high and low elevations of sub-tropical Taiwan through different seasons and the relationships with chlorophyll content and stomatal conductance

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Abstract

Net photosynthetic rate (P_n) of *Miscanthus* leaves, with different chlorophyll content (*Chl*), was measured at high (natural habitat-grown *M. transmorrisonensis* and *M. sinensis* var. *formosanus* at 3,000 and 2,100 m a.s.l., respectively) and low (pot-grown *M. floridulus* at 70 m a.s.l.) elevations through different seasons. In the winter, even the leaf temperature (T) drops to 6 °C, the P_n of *M. transmorrisonensis* leaves (*Chl* ranged 0.17–0.46 g m⁻²) that were measured under the photosynthetic photon flux density (PPFD) of 1,200 μmol m⁻² s⁻¹ (denoted as P_{1200}) could retain 0.4–3.2 μmol CO₂ m⁻² s⁻¹. While in the summer, the P_{1200} measured at 19 °C could raise to 3.9–19.9 μmol CO₂ m⁻² s⁻¹. At low elevation, *M. floridulus* could raise its P_{1200} and P_{2000} to the values about 30 and 40 μmol CO₂ m⁻² s⁻¹, respectively, at both 25 and 30 °C. At the same T and PPFD, leaves with higher *Chl* always had higher P_n and stomatal conductance (g_s). Yet, the determination coefficient of P_n – g_s relationship always higher than that of P_n –*Chl*, and the slopes of P_n – g_s relation were closely related to T . Thus, a significant positive linear regression ($P_n = 1.147 + 4.222 \cdot g_s \cdot T$) could be fitted by combining the data measured at different elevation, season and PPFD. The P_n estimated from this equation was closely related to the measured P_n (regression line approximate to 1:1 line, $r^2=0.937$, $P<0.001$). For verifying this equation furthermore, the g_s data of the pot-grown *M. floridulus* at 250 m a.s.l. (from Wong et al., 2014) were conducted to compute the estimated P_n and the results still showed that the estimated value could still correlate to the measured strongly ($r^2=0.856$, $P<0.001$). Due to g_s and T could be determined rapidly and easily by small portable instruments in the field, we concluded this empirical regression model could simulate both the seasonal and diurnal variations of P_n for *Miscanthus* leaves at different elevations.

Key words: chlorophyll content, C₄ plants, *Miscanthus*, photosynthesis, stomatal conductance.

不同海拔及季節下台灣原生芒屬植物之光合作用能力與葉綠素含量及氣孔導度間關係

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摘要

本研究於不同季節之高海拔(供試之物種為：高山芒，*M. transmorrisonensis*，自然分布環境約海拔 3,000 公尺；臺灣芒，*M. sinensis* var. *formosanus*，分布約 2,100 公尺)及低海拔(五節芒，*M. floridulus*，海拔約 70 公尺)地點測量不同葉綠素含量(*Chl*)之芒草葉片淨光合作用速率(P_n)。冬季高海拔山區氣溫(T)下降至攝氏 6 度時，高山芒葉片(葉綠素含量介於 0.17–0.46 g m⁻²)於測定光照強度 1,200 $\mu\text{mol m}^{-2} \text{s}^{-1}$ 下測得之 P_n 值(P_{1200})仍可維持 0.4–3.2 $\mu\text{mol CO}_2 \text{m}^{-2} \text{s}^{-1}$ 。夏季氣溫回升，於攝氏 19 度下測量其 P_{1200} 值可達到 3.9–19.9 $\mu\text{mol CO}_2 \text{m}^{-2} \text{s}^{-1}$ 。低海拔地區之五節芒，於攝氏 25 或 30 度之氣溫條件下之 P_{1200} 及 P_{2000} (於光照強度 2,000 $\mu\text{mol m}^{-2} \text{s}^{-1}$ 測得之 P_n 值)各可高達 30 及 40 $\mu\text{mol CO}_2 \text{m}^{-2} \text{s}^{-1}$ 。於相同測定溫度及光照強度之條件下，葉綠素含量較高之葉片會有較高的 P_n 及氣孔導度值(g_s)。然而， P_n – g_s 之決定係數(r^2)值較 P_n –*Chl* 之值高，且 P_n – g_s 之斜率變化與溫度有密切相關。當結合不同海拔、季節、光照強度下測量之資料後可得到顯著正相關之迴歸方程式($P_n = 1.147 + 4.222 \cdot g_s \cdot T$)，其推估之 P_n 值與實測之 P_n 值呈高度相關(回歸線為幾近於 1:1 之直線， $r^2=0.937$, $P<0.001$)。更進一步以生育於海拔約 250 m 五節芒 g_s 之實測值(數據來自 Wong et al., 2014)驗證前揭迴歸方程式，推估之 P_n 值仍與實測值呈高度相關($r^2=0.856$, $P<0.001$)。鑑於現場之 g_s 與 T 值可藉由可攜式小型儀器快速測得，本研究之芒草屬物種葉片可運用迴歸方程式之模型模擬其於不同海拔高度下 P_n 值之季節及日變化。

關鍵詞：葉綠素含量、C4 型植物、芒草屬、光合作用、氣孔導度。

Introduction

Miscanthus is a genus of rhizomatous, perennial C₄ grass, which could be interbred with sugarcane to obtain new sugarcane cultivars (Chen *et al.* 1993). It recently has been used as a new energy or fiber crop in Europe and investigated for its biomass potential (Dohleman and Long 2009; Zub and Brancourt-Hulmel 2010) with the uniquely cold-tolerant ability (Beale *et al.* 1996; Naidu *et al.* 2003; Naidu and Long 2004; Wang *et al.* 2008), and displays quite a good combination of radiation-, water- and nitrogen (N)-use efficiencies for biomass production (Dohleman and Long 2009; Zub and Brancourt-Hulmel 2010). Yet, the genus *Miscanthus* could achieve dry matter yield in excess of other C₄ crops in temperate climates (Beale *et al.* 1996; Dohleman and Long 2009).

Photosynthesis, one of the major determinants to biomass production and terrestrial carbon budgets, is influenced by many environmental and physiological factors (e.g. Berry and Downton 1982). C₄ plants are usually more sensitive to the low temperature than C₃ plants (Berry and Downton 1982; Sage and Kubien 2007), so there are few C₄ plants or non-existent in cooler climates (Berry and Downton 1982). However, *Miscanthus* is distributed from the tropical Pacific islands to northeastern Siberia, 50° N in the temperate zone (Clifton-Brown *et al.* 2008). In Taiwan (21°55' N–25°18' N) it grows from the coastline up to 3,200 m above sea level (a.s.l.), and forming a pure stand or the dominate species in early

succession stage vegetation. According to the climate data of the Central Weather Bureau of Taiwan (1971–2000), mean temperatures of the warmest and coldest months of Alishan (23° 31' N, 120° 48' E, 2413 m a.s.l.) were 14.2 and 5.7 °C, respectively; while those of Taichung (24° 09' N, 120° 41' E, 84 m a.s.l.) were 28.5 and 16.2 °C, respectively. The atmospheric temperature decreases about 0.5 °C with the increases in elevation about 100 m (Weng *et al.* 2005). *Miscanthus* could maintain green leaves during the cold season from the low land to the sub-alpine zone in Taiwan. Their photosynthesis would face various temperature conditions at different elevations and in different seasons.

In the researches of *Miscanthus* × *giganteus*, it displayed a notable ability to maintain high photosynthetic rate at low temperatures of 14 °C or 10 °C (Beale *et al.* 1996; Naidu *et al.* 2003; Naidu and Long 2004; Farage *et al.* 2006; Wang *et al.* 2008; Dohleman *et al.* 2009), and remained ca. 1/5 of maximum photosynthetic rate (*P*) even at 5 °C (Naidu *et al.* 2003). We (Weng and Ueng 1997) and Kao *et al.* (1998) also found that, in Taiwan, *Miscanthus* showed the cold-tolerant abilities too; and the clones collected from high altitude showed better low-temperature adaptation in photosynthesis than those collected from low altitude. However, these studies were investigated in the laboratory at low elevation, and could not reflect the seasonal variation of photosynthesis at different elevation habitats.

For understanding the biomass production of vegetation grown at different habitats and

conditions, it is necessary to monitor the spatial and temporal variations of photosynthetic capacity. However, the measurement of photosynthetic capacities in the field using traditional manners, such as gas analysis, is not an easy task due to the requirements of highly expensive equipment and intensive labor. In many species including C_4 plants and *Miscanthus*, the leaf chlorophyll content (*Chl*) and net photosynthetic rate (P_n) always closely related (Verhoeven *et al.* 1997; Weng and Hsu 2001; Zhao *et al.* 2005). Stomatal conductance (g_s) is another important limiting factor for photosynthesis. Not only water or moisture deficits, low-temperature and N-deficient stresses as well as low light intensity may also to enhance the closure of stomata (Beale *et al.* 1996; Dohleman *et al.* 2009; Wong, *et al.* 2014). Because *Chl* and stomatal conductance could be determined rapidly and easily by small portable instruments. Thus, the aim of the present study

was to understand the photosynthetic capacity of *Miscanthus* leaves, with different *Chl* at high and low elevations of sub-tropical Taiwan through different seasons; and to elucidate the relationships of P_n to *Chl* and g_s .

Materials and methods

The top 2 fully expanded leaves of 3 *Miscanthus* species, with different *Chl*, were measured at 3 elevation sites in central Taiwan (Table 1). Among them, natural habitat-grown *M. transmorrisonensis* (natural distribution from 2,200 m to 3,100 m a.s.l.) and *M. sinensis* var. *formosanus* (1,000–2,400 m a.s.l.) were measured at 3,000 m a.s.l. (24° 11' N) site and at 2,100 m a.s.l. site (24° 02' N), respectively. While pot-grown *M. floridulus* (0–1,200 m a.s.l.) was measured on the campus of National Chung-Hsing University (24° 09' N, 70 m a.s.l.) (Table 1).

Table 1. Determination coefficient of regressions between net photosynthetic rate (P_n) and leaf chlorophyll content (Chl), and between P_n and stomatal conductance (g_s) of *Miscanthus* species at high and low elevations under different seasonal temperature and 1,200 $\mu\text{mol m}^{-2} \text{s}^{-1}$ photosynthetic photon flux density (PPFD).

表 1. 生長於高及低海拔之芒草屬供試物種，於不同季節之溫度下以 1,200 $\mu\text{mol m}^{-2} \text{s}^{-1}$ 之光合作用光子通量密度(PPFD)測定所得淨光合作用速率(P_n)對葉綠素濃度(Chl)及對氣孔導度(g_s)之值經迴歸分析之決定係數。

Temperature (°C)	Determination coefficient (r^2)		Tested elevation (m)	Tested month	Tested species
	P_n - Chl	P_n - g_s			
6 (6.0)#	0.498**	0.003 ^{ns}	3,000	Dec.	<i>Miscanthus transmorrisonensis</i>
10 (8.9)	0.362*	0.019 ^{ns}	3,000	Mar.	
13 (10.7)	0.628*	0.627*	3,000	Apr.	
16 (11.8)	0.152 ^{ns}	0.730***	3,000	Nov.	
19 (15.8)	0.368*	0.829***	3,000	Jul.	
23 (19.8)	0.571**	0.892***	2,100	Jul.	<i>M. sinensis</i> var. <i>formosanus</i>
30 (28.7)	0.461*	0.888***	70	Jul.	<i>M. floridulus</i>
37 (28.6)	0.411*	0.985***	70	Aug.	

#The numeral inside and outside the parentheses is ambient temperature at 1000 h and leaf temperature throughout measurement, respectively. ***, **, * and ns: $P \leq 0.001$, 0.01, 0.05 and > 0.05 , respectively.

#括號內之數字表示測定當日 10 時 00 分之氣溫，括號外之數字表示現場進行測定時之葉片溫度。

***、**、*及 ns 分別表示迴歸分析 P 值不超過 0.001、0.01、0.05 及大於 0.05。

Sampling and measurements at 3,000 m and 2,100 m a.s.l. site

Due to Chl of natural habitat-grown *Miscanthus* may vary with soil properties, the top 2 fully expanded leaves with different Chl were select as materials. Leaves were sampled from a southeast-facing open stand. Chl was determined by SPAD 502 chlorophyll meter (Minolta, Japan), and 12–16 leaves with different leaf color (Chl ranged about 0.1–0.5 g m^{-2}) were select for the measurements in each measuring period (Fig. 1). To calibrate the relationship between Chl and SPAD value, 3 fresh leaf disks (0.84 cm^2) from each leaf were extracted with 80% acetone and

concentration of chlorophyll were determined by a spectrophotometer (U-2000, Hitachi, Japan) using the absorbance at 440.5, 645 and 663 nm by the equations of Arnon (1949).

All the leaf samples were collected before sunrise at 0530–0600 h and immediately recut under water, then the detached leaves were exposed to 600 $\mu\text{mol m}^{-2} \text{s}^{-1}$ photosynthetic photon flux density (PPFD) by a halogen lamp, and maintained moist by spraying water until photosynthesis measurements were taken. Net photosynthetic rate (P_n) and stomatal conductance (g_s) were measured with a portable, open-flow gas exchange system (LI-6400, LI-COR Inc, USA),

connected to a leaf chamber (6400-02B, LI-COR Inc, USA) and LED light source (6400-02, LI-COR Inc, USA). Measurements were made during 1000–1500 h under $1,200 \mu\text{mol m}^{-2} \text{s}^{-1}$ PPFD, and the leaf temperature (T) was

maintained constant, ca. 2°C higher than ambient temperature at 1000 h which was 6°C (Dec.), 10°C (Mar.), 13°C (Apr.), 16°C (Nov.) and 19°C (Jul.) at 3,000 m a.s.l. site, and 23°C (Jul.) at 2,100 m a.s.l. site. (Fig. 1).

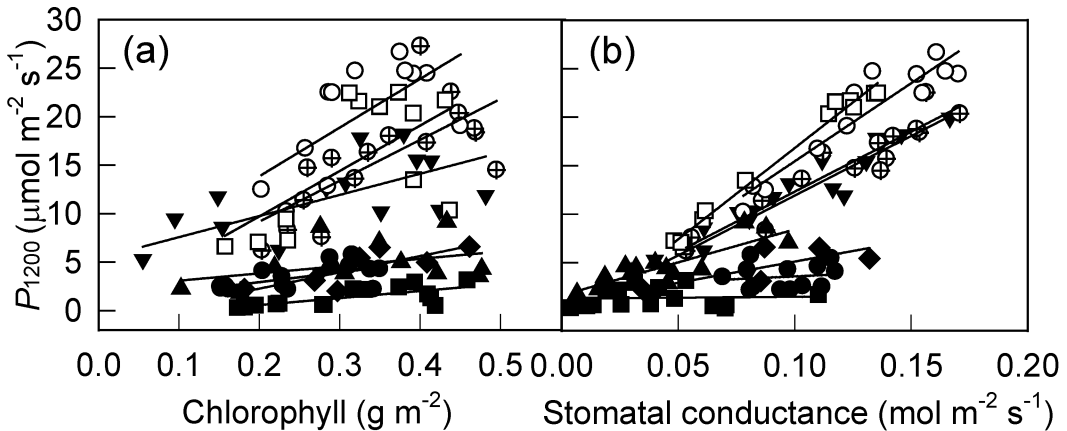


Fig. 1. The relationships of net photosynthetic rate to chlorophyll content and to stomatal conductance of *Miscanthus* leaves measured under $1,200 \mu\text{mol m}^{-2} \text{s}^{-1}$ photosynthetic photon flux density (PPFD) and different leaf temperature. ■: 6°C , ●: 10°C , ◆: 13°C , ▲: 16°C and ▼: 19°C at 3,000 m site; ⊕: 23°C at 2,100 m site; and ○: 30°C and □: 37°C at 70 m site.

圖 1. 供試之芒草屬葉片於不同葉片溫度下以 $1,200 \mu\text{mol m}^{-2} \text{s}^{-1}$ 之光合作用光子通量密度 (PPFD) 測定所得淨光合作用速率 (P_n) 對葉綠素濃度 (Chl) 及對氣孔導度 (g_s) 之變化。測量地點海拔 3,000 公尺，■: 6°C 、●: 10°C 、◆: 13°C 、▲: 16°C 及 ▼: 19°C ；海拔 2,100 公尺處，⊕: 23°C ；海拔 70 公尺處，○: 30°C 及 □: 37°C 。

Cultivation and measurements at 70 m a.s.l. site

M. floridulus collected from lowlands in central Taiwan was potted (38 cm-diameter) in a mix of soil : vermiculite : sand = 1:1:1, and placed outdoors to receive regular water and full sunlight on the campus of National Chung-Hsing University ($24^\circ 10' \text{N}$, 70 m a.s.l.), Taichung, Taiwan. In order to obtain leaf samples with different Chl , 0, 1 and 2 g N fertilizer per pot were applied at 4 and 2 weeks before

measurement, respectively. The P_n and g_s were measured by two methods. The first method was similar to measured at high elevation sites, i.e. P_n and g_s of 12 attached leaves were measured under $1,200 \mu\text{mol m}^{-2} \text{s}^{-1}$ PPFD, and maintained T at 30°C (Jul.) and 37°C (Aug.). The second method was P_n of 3–5 attached leaves with different Chl was measured under 4–5 levels of PPFD, and maintained T at 20°C (Jan.), 25°C (Mar.) and 30°C (Jul.), respectively (Fig. 2).

Initially, the leaves were exposed to 800 or 1,200 $\mu\text{mol m}^{-2} \text{s}^{-1}$ PPFD, then PPFD was raised to 2,000 $\text{mol m}^{-2} \text{s}^{-1}$, and stepwise from high to low levels of PPFD, i.e., 800, 400 and 200 $\mu\text{mol m}^{-2} \text{s}^{-1}$. Under each level of PPFD, P_n and g_s were taken every 5 min until it reaches to steady. The same equipment as measured at high elevation sites was used in both methods.

Results

At the same T and PPFD, the leaves with higher Chl always had higher P_n and g_s (Figs. 1 and 2). For the measurements under 1,200 $\mu\text{mol m}^{-2} \text{s}^{-1}$ PPFD, the slopes of the regression lines

to P_{1200} and P_n-Chl and $P_{1200}-g_s$ were increased with the increase of T (Figs. 1 and 3), and the latter correlation always showed higher determination coefficient (r^2) than the former, especially at high T (Table 1). Even at 6 °C, *M. transmorrisonensis* leaves (Chl ranged 0.17–0.46 g m^{-2}) could retain 0.4–3.2 $\mu\text{mol CO}_2 \text{m}^{-2} \text{s}^{-1}$ of P_{1200} . While in the summer, P_{1200} could raise to 3.9–19.9 $\mu\text{mol CO}_2 \text{m}^{-2} \text{s}^{-1}$, when measured at 19 °C. At low elevation, *M. floridulus* could raise its P_{1200} and P_{2000} (P_n measured under 2,000 $\mu\text{mol m}^{-2} \text{s}^{-1}$ PPFD) to about 30 and 40 $\mu\text{mol CO}_2 \text{m}^{-2} \text{s}^{-1}$, at both 25 and 30 °C, respectively (Figs. 1 and 3).

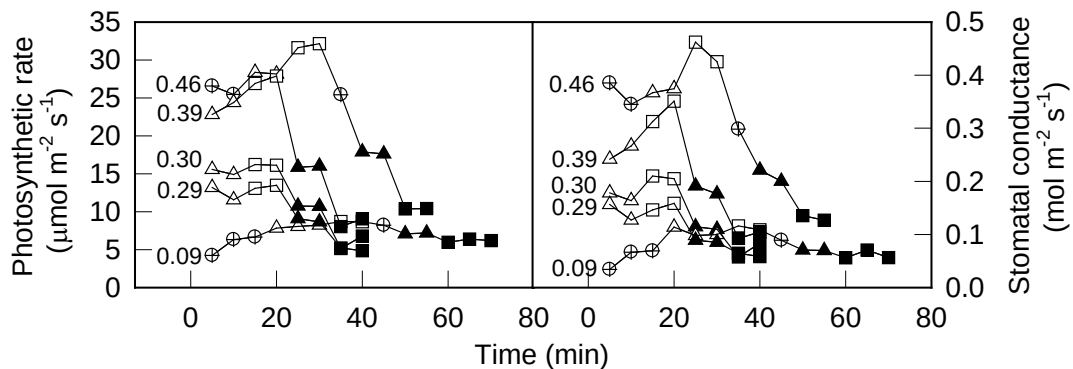


Fig. 2. The variation of net photosynthetic rate and stomatal conductance of 5 *Miscanthus floridulus* leaves with different chlorophyll content, under 20 °C and variant photosynthetic photon flux density (PPFD) (■: 200, ▲: 400, ⊕: 800, △: 1,200 and □: 2,000 $\mu\text{mol m}^{-2} \text{s}^{-1}$). Each line represents the results of a leaf, numeral before each line is the chlorophyll content (g m^{-2}) of a tested leaf.

圖 2. 不同葉綠素濃度之五節芒(*Miscanthus floridulus*)葉片 5 片於固定攝氏 20 度，不同光合作用光子通量密度(PPFD)(■: 200, ▲: 400, ⊕: 800, △: 1,200 and □: 2,000 $\mu\text{mol m}^{-2} \text{s}^{-1}$)下淨光合作用速率(P_n)及氣孔導度(g_s)之變化。圖所示之折線表示 1 片供試葉片之數據，折線起點旁之數字表示該葉片之葉綠素濃度(g m^{-2})。

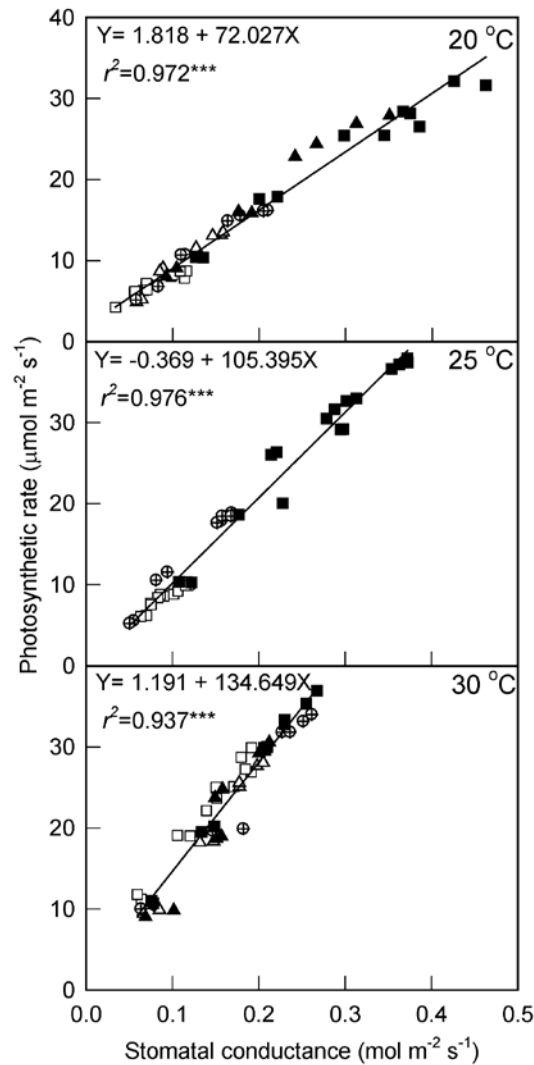


Fig. 3. Relationship between net photosynthetic rate and stomatal conductance of *Miscanthus floridulus* leaves with different chlorophyll content, measured under variant photosynthetic photon flux density (PPFD) and different leaf temperature. The same symbol in each panel represents the same leaf measured under different photosynthetic photon flux density. ***: $P < 0.001$. $n = 3-5$

圖 3. 五節芒(*Miscanthus floridulus*)不同葉綠素濃度之葉片，於不同的光合作用光子通量密度(PPFD)及溫度下淨光合作用速率(P_n)及氣孔導度(g_s)之關係。各小圖內相同的符號表示同一葉片於不同PPFD下所測得之資料。***： $P < 0.001$ 。 $n = 3-5$ 。

For the variation of P_n and g_s under varied PPFD, measured at 20 °C was selected as example shows in Fig. 2. Both P_n and g_s varied closely with the variation of PPFD, and the leaves with higher *Chl* always showed higher P_n and g_s under a the same level of PPFD. Even data obtained from leaves with different *Chl* and at different PPFD were pooled together for analysis, P_n was closely related to g_s . Yet, the slope of the regression equation to P_n - g_s was increasing with T increased (Fig. 3). Fig. 4 also shows that, when merging data measured at different elevation and season, the slopes of the regression equations to P_n - g_s still showed very high positive linear correlation with T .

Due to P_n - g_s relationship always showed higher r^2 than P_n -*Chl* relationship (Table 1), and the slopes of P_n - g_s relationships closely related to T (Fig. 4). For obtaining the "best-fit" combination of P_n with g_s and T , we combined these two relationships to analysis. In other words, the resulting regression equation to P_n and g_s could be fitted as equation (1) (Figs. 1b, 3 and Table 1), and the regression equation to slope (b) and T could be fitted as equation (2) (Fig. 4). Subsequently, equation (3) was obtained by combining equations (1) to (2).

$$P_n = a + b \cdot g_s \quad (1)$$

$$b = c + d \cdot T \quad (2)$$

$$P_n = a + c \cdot g_s + d \cdot g_s \cdot T \quad (3)$$

$$P_n = 1.147 + 4.222 \cdot g_s \cdot T \quad (4)$$

Based on multiple regression analysis, the regression coefficient of equation (3) could be further fitted ($a=1.919$, $c=-35.592$ and $d=5.474$). It showed high determination coefficient ($r^2=0.950$, $P<0.001$), with partial correlation coefficients of g_s and $g_s \cdot T$ to P_n were -0.308 (20%) and 1.255 (80%), respectively. Due to c showed negative value and low partial correlation coefficients to P_n (20%), thus, we used $P_n = a + d \cdot g_s \cdot T$ to fit the relationship between P_n and g_s at varied level of T and PPFD. Obtained result [equation (4)] indicated that P_n showed a very high positive linear correlation with $g_s \cdot T$ ($r^2=0.937$, $P<0.001$, Fig. 5). Fig. 6 shows that P_n estimated from equation (4) was closely related to measured P_n (regression line approximate to 1:1 line, $r^2=0.937$, $P<0.001$). This relationship existed when data were obtained by using leaves with yellow-green to dark-green colors of 3 *Miscanthus* species grown at high and low elevations, and measured at 1,200 or 200–2,000 $\mu\text{mol m}^{-2} \text{s}^{-1}$ PPFD through different season.

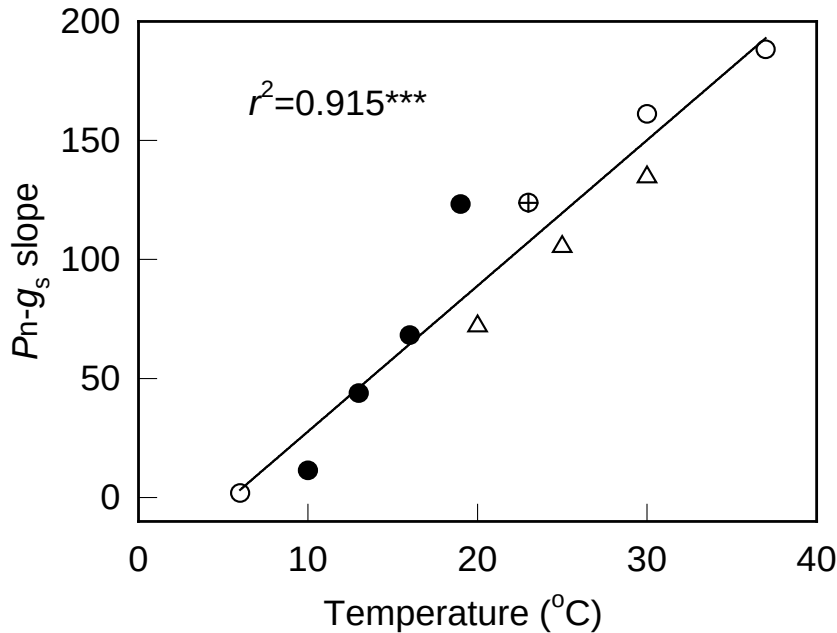


Fig. 4. The relationship of the slope of the regression between net photosynthetic rate and leaf stomatal conductance (P_n-g_s slope) to leaf temperature of *Miscanthus* leaves.

●, ⊕ and ○: Measured under $1,200 \mu\text{mol m}^{-2} \text{s}^{-1}$ photosynthetic photon flux density (PPFD) at 3,000 , 2,100 and 70 m a.s.l. site, respectively (data from Fig. 1b). △: Measured under variant PPFD at 70 m a.s.l. site (data from Fig. 3). ***: $P < 0.001$

圖 4. 供試芒草葉片之淨光合作用速率與氣孔導度資料經迴歸分析後所得 P_n-g_s 斜率對葉片溫度之變化。●、⊕及○：符號依序分別於海拔 3,000、2,100 及 70 公尺之地點，固定光合作用光子通量密度(PPFD) $1,200 \mu\text{mol m}^{-2} \text{s}^{-1}$ 條件下測量之數據(資料來自圖 1b)。△：於海拔 70 公尺之地點，不同的 PPFD 條件下測得之數據(資料來自圖 3)。***： $P < 0.001$ 。

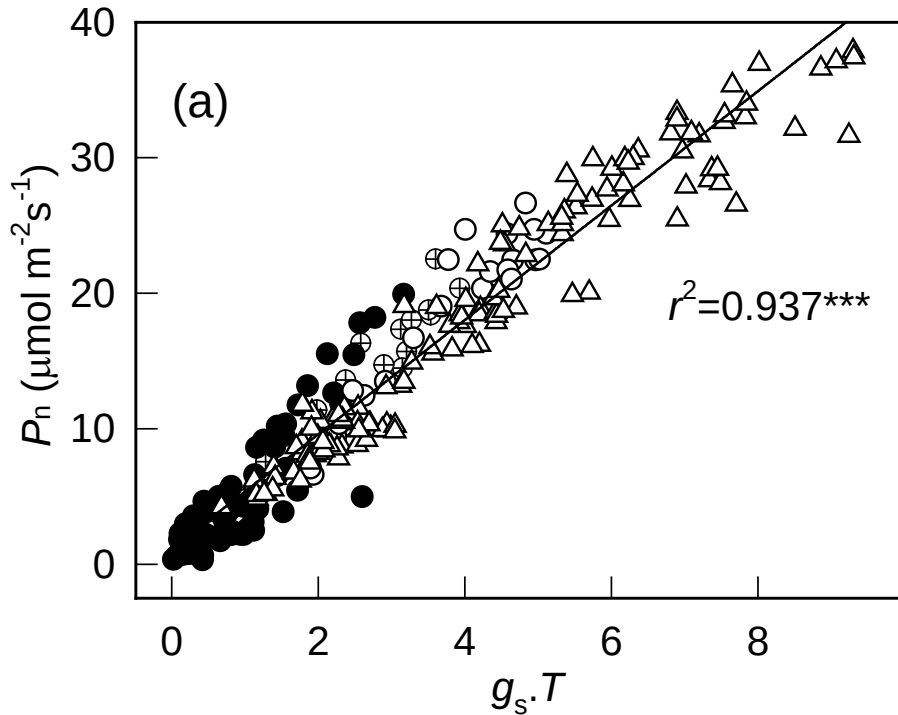


Fig. 5. Relationship between net photosynthesis rate (P_n) and the product of leaf stomatal conductance and leaf temperature ($g_s \cdot T$). ●, ⊕ and ⊙: Measured under $1,200 \mu\text{mol m}^{-2} \text{s}^{-1}$ photosynthetic photon flux density (PPFD) at 3,000, 2,100 and 70 m a.s.l. site, respectively (data from Fig. 1b). △: Measured under varietal PPFD and temperature at 70 m a.s.l. site (data from Fig. 3). ***: $P < 0.001$.

圖 5. 淨光合作用速率(P_n)與葉片氣孔導度及溫度之乘積($g_s \cdot T$)之間的關係。●、⊕及⊙：符號依序分別於海拔 3,000、2,100 及 70 公尺之地點，固定光合作用光子通量密度(PPFD) $1,200 \mu\text{mol m}^{-2} \text{s}^{-1}$ 條件下測量之數據(資料來自圖 1b)。△：於海拔 70 公尺之地點，不同的 PPFD 條件下測得之數據(資料來自圖 3)。***： $P < 0.001$ 。

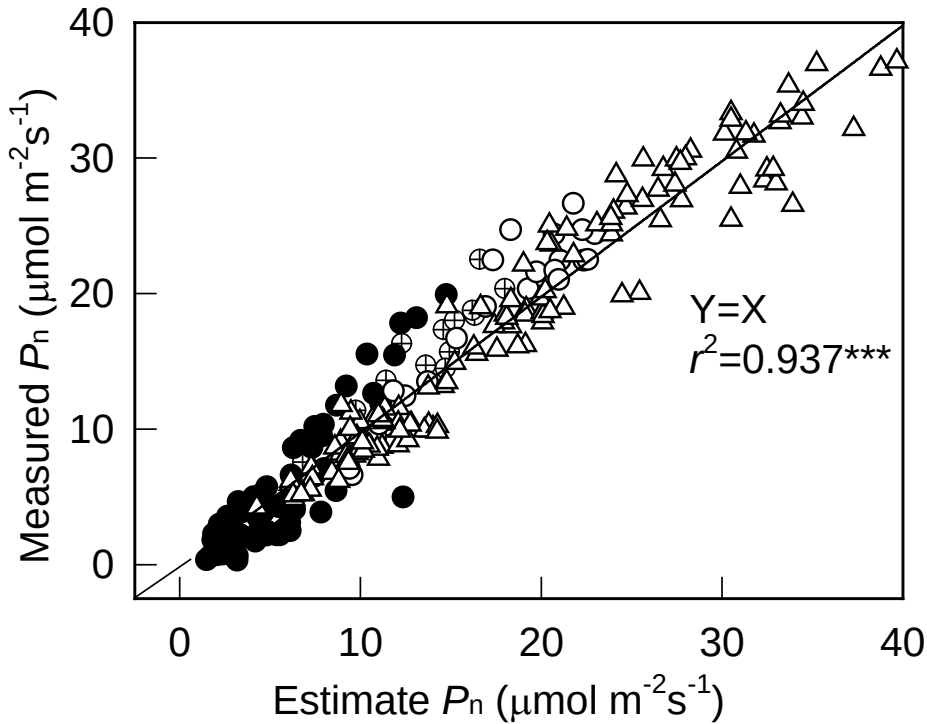


Fig. 6. Relationship between the measured and estimated net photosynthetic rate (P_n), from the equation of $P_n = 1.147 + 4.222 \cdot g_s \cdot T$. g_s and T : Stomatal conductance and leaf temperature, respectively. ●, ⊕ and ○: Measured under $1,200 \mu\text{mol m}^{-2} \text{s}^{-1}$ photosynthetic photon flux density at 3,000, 2,100 and 70 m a.s.l. site, respectively (data from Fig. 1b). △: Measured under 20–30 °C leaf temperature and 800–2,000 $\mu\text{mol m}^{-2} \text{s}^{-1}$ photosynthetic photon flux density at 70 m a.s.l. site (data from Fig. 3). ***: $P < 0.001$.

圖 6. 實測淨光合速率與迴歸方程式($P_n = 1.147 + 4.222 \cdot g_s \cdot T$)推估淨光合作用速率之關係。 g_s 及 T : 分別為氣孔導度及葉片溫度。●、⊕及○: 符號依序分別於海拔 3,000、2,100 及 70 公尺之地點，固定光合作用光子通量密度(PPFD) $1,200 \mu\text{mol m}^{-2} \text{s}^{-1}$ 條件下測量之數據(資料來自圖 1b)。△: 於海拔 70 公尺之地點，葉片溫度 20–30 °C 及 800–2,000 $\mu\text{mol m}^{-2} \text{s}^{-1}$ PPFD 之條件下測得之數據(資料來自圖 3)。***: $P < 0.001$ 。

Discussion

Unlike the lowlands at high latitudes, tropical alpine shows lower seasonal variation of temperature (Smith and Young, 1987). As a result that the summer is cooler and the winter is warmer than in lowlands of temperate region. At 3,000 m a.s.l. site, the monthly mean air temperature of the coldest month (Jan.) is ca. 2 °C, thus, leaves of *Miscanthus* often subject to freezing temperature. Nevertheless, *M. transmorrissonensis* could maintain a lot of activity green leaves through winter at here (Table 1 and Fig. 1), indicating that *M. transmorrissonensis* is uniquely cold-tolerant among C₄ plants.

Pigments in leaves are integrally related to photosynthesis, and can be non-destructively estimated through optical methods. Among them, chlorophyll was considered as a short-term indicator for photosynthetic capacity (Zhao *et al.*, 2005). The results of the present study showed that the leaves with higher *Chl* always had higher P_n , when compared at the same *T* and PPFD (Figs 1 and 2). These results were consistent with the previous papers (Weng and Hsu, 2001; Zhao *et al.*, 2005; Wong *et al.*, 2014). However, as the presents in Table 1, r^2 of P_{1200} -*Chl* regressions always lower than those of the P_{1200} - g_s regressions. This result might be due to *Chl* fail to detect dynamic variations of P_n like those occurring during the day or under certain stress conditions (Nichol *et al.*, 2000; Evain *et al.*, 2004).

Previously, we compared the photosynthetic capacity of 17 *Miscanthus* clones at 3 levels of N application. Results indicated that the saturated P_n was closely related to leaf conductance, even data from all tested clones and N levels were merged to analysis (Weng and Hsu, 2001). Moreover, decreased leaf P_n due to N deficiency was mainly associated with lower g_s rather than carboxylation capacity of leaf chemistry (Zhao *et al.*, 2005). The physiological role of stomata is to prevent water loss and to facilitate CO₂ diffusion to mesophyll cells. To optimize the water use efficiency, guard cells could monitor the plant water status and the CO₂ demand from the mesophyll. Reports have been point out that guard cells respond to the intercellular CO₂ concentration, which is determined by atmospheric CO₂ and by the mesophyll assimilation rate (Vavasseur and Raghavendra, 2005), allowing a tight coupling between g_s and P in many conditions, included changing light intensity (D'ambrosio *et al.*, 2003; Huxman and Monson, 2003), temperature (Pittermann and Sage, 2000, 2001), leaf N status (Weng and Hsu, 2001; Mohotti and Lawlor, 2002) as well as changing conditions due to the diurnal (Hirasawa and Hsiao, 1999; Mohotti and Lawlor, 2002, Cuevas *et al.*, 2006; Ding *et al.*, 2006; Leakey *et al.*, 2006), seasonal (Hirasawa and Hsiao, 1999; Leakey *et al.*, 2006) and genotypical (Ding *et al.*, 2006; Dohleman *et al.*, 2009; Dohleman and Long, 2009) variations.

In the present study, we found that the slope of P_n - g_s regression was increasing with *T* increased (Figs. 1b and 3). What is the reason for

this phenomenon? Reports have pointed out that both g_s and P always decreased with decreasing temperature. In many C_4 plants, the decreasing amplitude of P following the temperature decrease was higher than that of g_s (Pittermann and Sage, 2000, 2001; Kubien *et al.*, 2003; Kościelniak and Biesaga-Kościelniak, 2006). As a result, the sensitivity of P_n to variation in g_s generally decreases at colder temperatures, and this was due to the biochemical controls over P_n at low temperature was less sensitive to changes in intercellular CO_2 concentration. Thus, temperature change may disproportionately alter g_s relative to P_n , and stomatal limitations to C_4 photosynthesis are generally smaller at low temperature (Sage and Kubien, 2007). This reason may lead to the decline of slope for P_n - g_s regression line (Figs. 1b, 3 and 4).

We combined the P_n - g_s relationships under different T , and found that P_n showed a significant positive regression with $g_s \cdot T$. Based on the close correlation (regression line approximate to 1:1 line, $r^2=0.937$, $P<0.001$) between the P_n estimated from the single regression equation (4) and the P_n measured in field, when data obtained from different illumination and seasonal temperature conditions were pooled together for statistical analysis (Fig. 6). Moreover, we used another published data (Wong *et al.*, 2014), with a broad range of P_n caused by different light, humidity, seasonal temperature, phenological stage and N fertilization, to estimated P_n from equation (4). The results showed that the estimated P_n still correlated linearly with the measured P_n

($r^2=0.856$, $P<0.001$, Figure omitted). We, thus, concluded this empirical regression model could simulate both the seasonal and diurnal variations of P_n for *Miscanthus* leaves grown at high and low elevations with different *Chl*. Because g_s and T could be determined rapidly and easily by small portable instruments in the field, this empirical regression model might be of benefit in eco-physiological research and monitoring.

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