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THE JADE-GREEN CICADA, *DUNDUBIA VAGINATA* (FABRICIUS, 1787) IN SINGAPORE, WITH NOTES ON EMERGENCE, BIOACOUSTICS, AND MATING (HOMOPTERA: CICADIDAE: CICADINAE)

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INTRODUCTION

In life, the cicada *Dundubia vaginata* (Fabricius, 1787) exhibits a beautiful, uniform jade-green colour over its entire body, visible through delicate, transparent wings. It is one of the most widespread species in the genus *Dundubia*, having been recorded from India through to China, Japan, throughout Southeast Asia, and extending eastward to Sulawesi and even north Australia (Moulton, 1923; Sanborn et al., 2007). In Singapore, this cicada appears to be largely confined to the remnant forests within the heart of the Singapore Island. Its appearance appears to be periodical, with a transient adult life span of one to two months. We provide documentation on its nocturnal emergence, diurnal bioacoustics, and eventual copulation, based on our local observations of the jade-green cicada at the Bukit Timah Nature Reserve (BTNR) and the Central Catchment Nature Reserve (CCNR) between the years 2009 to 2011.

EMERGENCE

While conducting a nocturnal survey at the Bukit Timah Nature Reserve on 7 Mar.2009, several transect teams simultaneously witnessed the emergence of *Dundubia vaginata* within the forest and beside established hiking trails. The pivotal moments during the eclosion of an individual adult male were photographed sequentially, as soon as it was first encountered at ca. 2135 hours along Lasia Track. The imago had already acquired a firm grip onto a branch of a shrub at eye-level and the adult was suspended, head-down, with its abdomen gently clasped by the mid-dorsal thoracic aperture of the exuvium (Fig. 1). At this point, its wing buds were still tightly curled and highly wrinkled.

Fig. 1. On the night of 7 Mar.2009 (ca. 2135 hours) at the Bukit Timah Nature Reserve, an adult male *Dundubia vaginata* (body length: 40 mm) was first observed to be suspended from the exuvium of its final moult. The freshly everted tracheal threads (arrowed) were clearly visible. Its wing buds were still curled and compressed.

Fig. 2. At 2142 hours, the limbs of the cicada had stiffened sufficiently and began to articulate. It then arched its body forwards and upwards, as it hinged onto the dorsal thoracic opening of the exuvium. The wings had already started to unfold, as they were continuously innervated by turquoise-blue haemolymph.

Fig. 3. At 2143 hours, all three pairs of limbs had secured a firm grasp upon its exuvium, hence facilitating complete extraction of its abdomen. The enlarged operculum (arrowed) is characteristic of males.

Fig. 4. At 2145 hours, its wings had become inflated with such speed that the tips had already surpassed the distal end of its abdomen.

Fig. 5. At 2155 hours, its pair of wings had attained its full dimensions and was maintained at a 180 degree angle for some time. At this point, the male genitalia (arrowed) was momentarily exposed and clearly observed.

The cicada then began to arch itself forwards and upwards at 2142 hours, by which time the wings had begun to unravel (Fig. 2). At 2143 hours, the cicada had grasped onto the empty exuvium with all three pairs of limbs and withdrew its abdomen completely (Fig. 3). The wings had been extending simultaneously and by 2145 hours, the tips had already elongated beyond the apex of the abdomen (Fig. 4). Full extension of the wings was achieved by 2155 hours, as they were maintained at a straight plane (Fig. 5). The genitalic structures of the male cicada were still clearly extruded. This cicada was then left undisturbed and upon return at 2245 hours, its wings had already folded neatly over its body in a roof-wise fashion, with the inner proximal forewing margin tucked into the scutellar coaptative grooves of the scutum (Fig. 6).

On the night of 14 Mar.2009 (ca. 2230 hours), another male jade-green cicada was observed emerging while its exuvium was attached to a tree, at knee-level, beside a trail at BTNR. After complete wing extension, this cicada was then retained as a voucher specimen and preserved at the Zoological Reference Collection (ZRC) of the Raffles Museum of Biodiversity Research (RMBR), with measurements of its body length (BL) and forewing length (FW) taken (ZRC.6.20955, BL: 41 mm, FW: 45 mm). The corresponding larval moult was also preserved (ZRC.6.20955). On the night of 20 Mar.2009 (ca. 2315 hours), a recently emerged female jade-green cicada was encountered and photographed at BTNR.

Subsequently, representative specimens of adult cicadas were collected from the BTNR, as well as from the MacRitchie Reservoir forest region (see: Material Examined, Table 1). In addition, the vacated exuviae of this species were also collected and their individual sex determined (see: Material Examined, Table 2). This collection spanned three years (2009–2011), and was primarily focused during the months of Mar. and Apr., when adult emergence was at its peak.

The emergence of *Dundubia vaginata* was also previously reported in detail from the Thale Ban National Park, Satun Province, South Thailand (Helfert & Sänger, 1993). The entire process was systematically distinguished into four different subprocesses: (i) settling, (ii) apolysis, (iii) ecdysis, and (iv) metecdysis. It is also interesting to note that a relatively high proportion (70%) of emergent cicadas was preyed upon by bats (Helfert & Sänger, 1993)!

Fig. 6. By 2245 hours, its wings had already folded roof-wise over its body, with the proximal interior margins of its forewings perfectly nestled into the scutellar coaptative grooves (arrowed) of its scutum.

BIOACOUSTICS

In Singapore, sound production (or tymbalisation) by *Dundubia vaginata* males is conducted in a consistent, daily schedule. The first calls would commence at ca. 1630 hours each afternoon, initiated by one to two males, then gradually followed by adjacent males in the vicinity joining the concert as the combined volume increases through till evening. After tymbalisation gains momentum, the calling males remain persistent as they broadcast their presence while perched on the trunks of trees from head-level to higher up. Despite their loud sounds, locating individual males can prove to be a challenge, as many cicadas may be perched on the reverse side of the tree trunk, or concealed behind the dense network of leaves. However, once located, it may be observed that calling males exhibit a rhythmical pulsation of their abdomens that is in unison with the characteristic tymbalisation pattern (Fig. 7).

Cicadas have excellent vision, and calling males are not easily approached. When an oncoming observer is detected, the males respond by: (a) ceasing their calls, (b) circling the trunk to hide on the reverse side, or (c) flying away to another tree. Hence, our observations of calling males were often conducted from a respectable distance (ca. 5–10 m away), or carefully approached with extreme caution so as not to startle the cicada. In many instances where the calling males could only be heard, but not seen, observations of its acoustic properties were noted down.

The acoustic properties of *Dundubia vaginata* had been previously examined in detail based on studies conducted in Borneo and Peninsular Malaysia (Gogala & Riede, 1995; Riede & Kroker, 1995; Prešern et al., 2004; Riede, 2007). Notable differences in the tymbalisation pattern of Bornean and Peninsular Malaysian populations were clearly recognised by Prešern et al. (2004). While their calls essentially consisted of a series of bipartite phrases (A – long segment, B – short segment), their sequence differed.

In the Peninsular Malaysia populations, the tymbalisation followed an “AB-AB-AB” sequence, whereas in Bornean populations, a “BA-BA-BA” sequence was employed instead. Furthermore, the B segment in Peninsular Malaysian populations was of a constant frequency, whereas this segment was frequency-modulated in the Bornean populations. Nevertheless, the “BA-BA-BA” sequence was also observed in Peninsular Malaysia, although voucher specimens of these were not collected (Prešern et al., 2004).

Fig. 7. On the afternoon of 18 Mar.2009 at the Bukit Timah Nature Reserve, adult males were incessantly calling loudly from their perches on the trunks of trees, such as this individual (body length: 40 mm) observed and photographed near the junction of Catchment Path and Rock Path (at ca. 1730 hours).

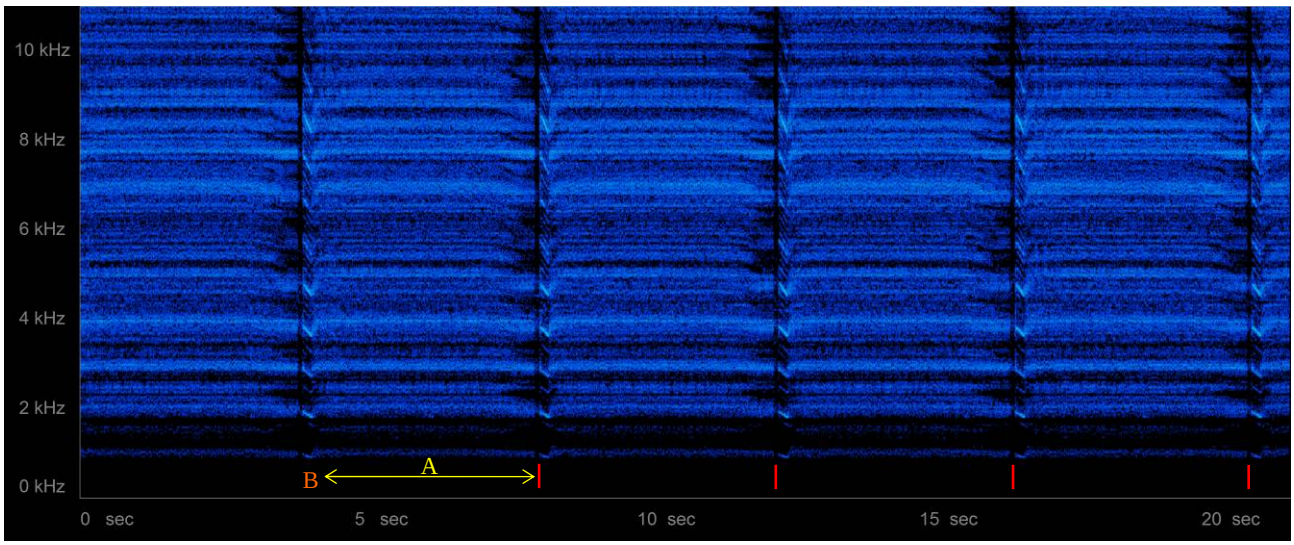

Fig. 8. Representative spectrogram [frequency (kHz) against time (sec)] of a 20-s segment from the call of an individual male *Dundubia vaginata*, recorded along the Rock Path at the Bukit Timah Nature Reserve on 18 Mar.2009 (ca. 1800 hours). The characteristic tymbalisation pattern consists of bipartite phrases repeated in quick succession. Each phrase begins with a brief, frequency-modulated portion (B: 0.17 s), immediately followed by a longer, constant frequency portion (A: 4.0 s). The bipartite phrases are punctuated by momentary pauses (red bars: 0.08 s). Corresponding MP3 sound file available for download.

In Singapore, the calls of *Dundubia vaginata* were recorded in the forests at the BTNR and MacRitchie Reservoir area, using a stereo microphone (Canon S5 IS) with a sample rate of 44.1 kHz. Acoustic analyses of these calls revealed that the tymbalisation pattern agreed closely to the "BA-BA-BA" sequence, rather than an "AB-AB-AB" sequence. A spectrogram (frequency against time) was generated from a tymbalisation recorded at BTNR (18 Mar.2009, ca. 1800 hours) to better visualise this call pattern (Fig. 8; MP3 sound file available for download). From this recording, we could ascertain that segment B had a duration of 0.17 s, and was clearly frequency modulated (descending from 0.96 kHz to 0.90 kHz) within this time frame. The longer segment (A) was of a constant frequency, with its fundamental frequency at 0.96 kHz. The dominant frequency is expressed in the third harmonic (3.94 kHz). The call duration for segment A was ca. 3.9–4.0 s. Each "BA" phrase was segregated by a very brief, but discernible interval of 0.08 s.

If undisturbed, male individuals may call continuously for 15–25 min each time. However, their calls may be terminated prematurely whenever threat from a potential predator or human observer is perceived. Towards the end of its call, the tymbalisation pattern is slightly modified, with the A segments becoming increasingly long drawn as the overall volume is progressively reduced. The concluding episode of a day's tymbalisation efforts may be witnessed at dusk. As the light fades, there is a noticeable reduction in the number and volume of the calls, with absolute silence observed at ca. 1900 hours. This respite lasts for 15 min and at 1915 hours, the cicadas begin their calls once again, up till 1930 hours, which marks the end to their energetic afternoon, as they retire for the night.

Between Mar. and Apr.2011, additional observations of male tymbalisation were conducted at the BTNR, with attempts to document this behaviour on video. On the afternoon of 23 Apr.2011 (ca. 1720 hours), the concluding call sequence of an individual male was successfully recorded (full resolution: 1920 × 1080 p, clip duration: 1:00 min) near the BTNR summit. This video clip was subsequently uploaded (http://www.youtube.com/watch?v=RNEQzs3-HX4). With careful observation, the rhythmic expansion and pulsation of its abdomen may be seen. The progressive lengthening of the A segment may also be noticed towards the end, with visible bodily vibrations as it gradually winds down, then flies away.

Other than *Dundubia vaginata*, the tymbalisation characteristics of other species of *Dundubia* within the Oriental region have also been studied. These include: (i) *Dundubia euterpe* Bloem & Duffels, 1976 in Endau Rompin, Johor, Peninsular Malaysia (Gogala & Trilar, 2004: 75, Fig. 1); (ii) *Dundubia oopaga* (Distant, 1881) in Perhentian Besar Island, Terengganu, Peninsular Malaysia (Gogala & Trilar, 2004: 75, Fig. 2); (iii) *Dundubia feae* (Distant, 1892) in Thailand (Boulard, 2007: 34, Fig. 19); and (iv) *Dundubia terpsichore* (Walker, 1850) in Thailand (Boulard, 2007: 68, Fig. 46).

MATING

While observations of eclosion and male tymbalisation were sufficiently numerous, encounters with mating pairs were rare. Merely two chance encounters were witnessed (once in 2009, once in 2010). At the BTNR (just beside main road to summit, after Simpang Hut, 28 May.2009, ca. 1700 hours), an individual male was heard and seen calling from a

tree, ca. 2.5 m from the ground. At ca. 1705 hours, a female was observed to fly in and land on the same tree, ca. 15 cm below the male. The male immediately responded by making a series of buzzing calls, accompanied by the vibration of its wings. At the same time, it reversed itself in the direction of the female below, and positioned itself on the female's left side. The receptive female then responded by crawling sideways along the trunk, towards the right, for ca. 5 cm, closely followed by the male. As soon as they came to a stop, they brought the apices of their abdomens together, forming a union which resembled a 'V'-shape (Fig. 9).

For just over an hour, the mating pair remained in this posture, only separating at ca. 1810 hours, after which the male flew away. The female remained and rested for a few minutes, before attempting to deposit her fertilised eggs into the same tree. The needle-like terebra was exposed from within the ovipositor and attempted to pierce the superficial layer of the tree's bark. However, the wood was most certainly too dense for a full insertion by the ovipositor, so the female soon flew off (ca. 1820 hours), in search of a more penetrable stem/branch.

On the afternoon of 27 Mar.2010, monitoring of the cicada population and behaviour was conducted by a team of HSBC volunteers (led by TML) at the BTNR. Their efforts were focused on the forest plot delineated by the Catchment Path and Tiup Tiup Path, when a mating pair was sighted at ca. 1800 hours. The pair was high up on the trunk of a tall tree, ca. 10 m above the forest floor. Their abdomens were joined in a similar fashion as witnessed previously (28 May 2009).

Fig. 9. A mating pair of cicadas, perched 2.5 m up on a tree, encountered at the Bukit Timah Nature Reserve on the evening of 28 May 2009. Copulation commenced at ca. 1710 hours and lasted till ca. 1810 hours. The male (at left) is slightly larger than the female.

FURTHER RESEARCH

Other aspects of the natural history of *Dundubia vaginata* remain to be documented in detail. For example, observations of successful oviposition have yet to be observed. We are keen to know if there may be any preference for particular tree branches or stems that best suit oviposition, as well as how high up the tree are their eggs deposited. Post-hatching, the duration of its subterranean larval period would also be a fundamental question worthy of investigation. This naturally leads us to query the seasonality for this species and its generation time.

Fig. 10. A female *Dundubia vaginata* (body length: 35 mm) at the Bukit Timah Nature Reserve, recently emerged on 14 Mar.2010 (ca. 2310 hours). Its ovipositor (arrowed) was clearly visible.

Having witnessed the seasonal appearance of this species in the years 2009, 2010 (Fig. 10), as well as 2011, we are most curious to see if such a similar spectacle may be repeated in the following years/decades, and with what regularity or reliability. The maintenance of accurate, long-term records will thus enable us to make more accurate predictions on its cyclical emergence and possible site specificity for particular batches. Regular estimates of its population abundance would also be a worthwhile method to monitor the health of this species from one emergence year to another. As adults, these cicadas would certainly fall prey to a host of predators, including birds and reptiles. While observing them in the field, the greater racket-tailed drongo (*Dicrurus paradiseus*) was occasionally found in the vicinity, keeping a keen eye (and ear) out for individual cicadas to feed on. As larvae within the forest soil, they may fall prey to fossorial predators, including caecilians (Leong & Lim, 2003). In addition to *Dundubia vaginata*, *Dundubia rufivena* Walker, 1850 is another congener recorded for Singapore (Moulton, 1923; Zaidi & Ruslan, 1997).

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MATERIAL EXAMINED

Table 1. Specimens of adult *Dundubia vaginata* at the ZRC, RMBR. [BTNR = Bukit Timah Nature Reserve, CNR = Central Nature Reserve, M = male, F = female, BL = body length (mm), FW = forewing length (mm)].

Catalogue No.	Sex	BL	FW	Locality	Collector(s)	Date
ZRC 6.20955	M	41	45	BTNR: Taban Loop, fresh emergent.	T. M. Leong et al.	14 Mar.2009
ZRC 6.20965	F	38	47	BTNR: Taban Loop, fresh emergent.	T. M. Leong et al.	20 Mar.2009
ZRC 6.21564	F	36	46	BTNR: beside main road.	T. M. Leong et al.	21 Mar.2009
ZRC 6.21565	F	37	47	Bukit Kallang: CNR office toilet.	T. M. Leong	22 Mar.2009
ZRC 6.21568	F	37	47	BTNR: beside main road, to light sheet.	T. M. Leong et al.	20 Mar.2009
ZRC 6.21616	M	39	45	Bukit Kallang: CNR office, to lights.	T. M. Leong	17 Apr.2009
ZRC 6.21617	F	36	45	As above	As above	As above
ZRC 6.21619	F	36	45	Bukit Kallang: CNR office, to lights.	T. M. Leong	18 Apr.2009
ZRC 6.21621	F	39	47	Bukit Kallang: beside perimeter fence.	V. S. L. Chang	25 Apr.2009
ZRC 6.21750	F	38	47	BTNR: beside main road, fresh emergent.	T. M. Leong et al.	10 Mar.2010
ZRC 6.21758	F	35	45	BTNR: beside main road, fresh emergent.	T. M. Leong	14 Mar.2010

Table 2. Specimens of *Dundubia vaginata* exuviae at ZRC, RMBR. (BTNR = Bukit Timah Nature Reserve, M = male, F = female).

Catalogue No.	Quantity/Sex	Locality	Collector(s)	Date
ZRC 6.20955	1M	BTNR: Taban Loop, fresh emergent.	T. M. Leong et al.	14 Mar.2009
ZRC 6.20956	2M, 6F	BTNR: Cave Path & Taban Loop.	T. M. Leong	16–18 Mar.2009
ZRC 6.20960	2M, 1F	MacRitchie: Petaling Trail & Sime Track.	T. M. Leong	19 Mar.2009
ZRC 6.20962	1M, 1F	BTNR: Taban Loop.	T. M. Leong et al.	20 Mar.2009
ZRC 6.20965	1F	BTNR: Taban Loop, fresh emergent.	T. M. Leong et al.	20 Mar.2009
ZRC 6.20966	7M, 9F	BTNR: Jungle Fall Path, North View Path.	T. M. Leong et al.	21 Mar.2009
ZRC 6.21564	1F	BTNR: beside main road.	T. M. Leong et al.	21 Mar.2009
ZRC 6.21574	3M, 2F	Sime Track & Petaling Trail.	T. M. Leong et al.	24 Mar.2009
ZRC 6.21575	2M, 2F	Bukit Kallang.	T. M. Leong	28 Mar.2009
ZRC 6.21590	2M, 2F	BTNR: Jungle Fall Path.	M. Shunari	27 Mar.2009
ZRC 6.21592	1M	BTNR: Taban Loop.	T. M. Leong	31 Mar.2009
ZRC 6.21595	1F	Bukit Kallang.	T. M. Leong et al.	1 Apr.2009
ZRC 6.21600	2M, 4F	BTNR: North View Path.	T. M. Leong et al.	4 Apr.2009
ZRC 6.21603	1F	BTNR: Senapang Link.	S. H. Chan et al.	4 Apr.2009
ZRC 6.21606	2M	BTNR: Jungle Fall Path.	M. Shunari	5 Apr.2009
ZRC 6.21607	2F	BTNR: Taban Loop.	T. M. Leong	8 Apr.2009
ZRC 6.21615	1F	BTNR: around summit area.	T. M. Leong	16 Apr.2009
ZRC 6.21624	1M, 3F	BTNR: beside main road.	T. M. Leong	23 Apr.2009
ZRC 6.21625	1M, 4F	BTNR: various trails.	M. Shunari	17, 25 Apr.2009
ZRC 6.21638	1M	BTNR: North View Path.	T. M. Leong	23 May 2009
ZRC 6.21641	1M	BTNR: beside main road.	T. M. Leong	28 May 2009
ZRC 6.21725	2M	BTNR: Cave Path.	T. M. Leong	1 Mar.2010
ZRC 6.21726	8M, 7F	Bukit Kallang, Sime Track.	T. M. Leong et al.	2 Mar.2010
ZRC 6.21731	2M	BTNR: Rock Path, Catchment Path.	T. M. Leong et al.	3 Mar.2010
ZRC 6.21732	1M	BTNR: Keruing Path.	T. M. Leong et al.	3 Mar.2010
ZRC 6.21733	1F	BTNR: beside main road.	T. M. Leong et al.	5 Mar.2010
ZRC 6.21735	3M, 2F	BTNR: Catchment Path, Rock Path.	T. M. Leong et al.	5 Mar.2010
ZRC 6.21737	2M, 1F	BTNR: beside main road.	T. M. Leong	6 Mar.2010
ZRC 6.21738	1M	BTNR: Taban Loop.	T. M. Leong	6 Mar.2010
ZRC 6.21739	1M	BTNR: North View Path.	S. H. Yeo & M. Chua	6 Mar.2010
ZRC 6.21740	1M, 1F	BTNR: Jungle Fall Path.	M. Shunari	9 Mar.2010
ZRC 6.21742	2M, 4F	as above	As above	As above
ZRC 6.21743	4M, 1F	BTNR: Rock Path.	T. M. Leong et al.	9 Mar.2010
ZRC 6.21744	1F	BTNR: Tiup Tiup Path.	T. M. Leong et al.	9 Mar.2010
ZRC 6.21745	2F	BTNR: beside main road.	T. M. Leong et al.	10 Mar.2010
ZRC 6.21746	6M	BTNR: Rengas Path, Tiup Tiup Path.	T. M. Leong et al.	10 Mar.2010
ZRC 6.21749	1M, 2F	BTNR: beside main road.	T. M. Leong et al.	10 Mar.2010
ZRC 6.21750	1F	BTNR: beside main road, fresh emergent.	T. M. Leong et al.	10 Mar.2010
ZRC 6.21752	4M, 2F	BTNR: Jungle Fall Path, North View Path.	T. M. Leong et al.	10 Mar.2010
ZRC 6.21757	1M, 1F	BTNR: South View Path.	T. M. Leong	14 Mar.2010
ZRC 6.21758	1F	BTNR: beside main road.	T. M. Leong	14 Mar.2010
ZRC 6.21764	1M	BTNR: beside main road.	T. M. Leong et al.	18 Mar.2010
ZRC 6.21783	2F	BTNR: Catchment Path.	T. D. Harvey-Samuel	12 Mar.2010
ZRC 6.21784	1M	BTNR: beside main road.	T. D. Harvey-Samuel	17 Mar.2010
ZRC 6.21785	1M, 3F	BTNR: Seraya Loop.	T. D. Harvey-Samuel	17 Mar.2010
ZRC 6.21786	2F	Bukit Kallang, TreeTop Trail.	Peihan	18 Mar.2010
ZRC 6.21787	1M	BTNR: Catchment Path.	T. D. Harvey-Samuel	23 Mar.2010
ZRC 6.22151	2M	BTNR: beside main road & Keruing Path.	T. M. Leong	11 Mar.2011
ZRC 6.22152	1F	BTNR: Catchment Path.	T. M. Leong & M. Shunari	13 Mar.2011
ZRC 6.22153	1M, 2F	BTNR: Tiup Tiup Path.	T. M. Leong	13 Mar.2011