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Diphucephala bernhardti sp. nov. *(Coleoptera: Scarabaeidae: Melolonthinae)* from heathlands of north-eastern New South Wales, Australia and its association with *Hibbertia* flowers *(Dilleniaceae)*

by

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Abstract - A new species of *Diphucephala (Coleoptera: Scarabaeidae: Melolonthinae), D. bernhardti* sp. nov., is described from heathlands of the Hastings Point area, north-eastern New South Wales, Australia. The beetle feeds and mates on the large, yellow petals of *Hibbertia scandens* (Willd.) Gilg. *(Dilleniaceae)* and has not been recorded from any other plants in the area. Observations indicate that *D. bernhardti* is not a pollinator of *H. scandens*. The gross morphology and ethology of *D. bernhardti* are compared with those of the closely allied species, *D. quadratigera* Blanchard, which inhabits flowers of *Hibbertia saligna* R. Br. in montane New South Wales. Currently, *D. bernhardti* and *D. quadratigera* are the only *Diphucephala* spp. known to be associated with *Hibbertia* flowers in south-eastern Australia.

Riassunto - Viene descritta una nuova specie di *Diphucephala (Col., Scarabaeidae, Melolonthinae) - D. bernhardti* n. sp. - delle brughiere di Hastings Point, nel New South Wales nord-orientale, Australia. La specie si ciba dei grandi petali gialli di *Hibbertia scandens (Dilleniaceae)*, sui quali avviene anche l'accoppiamento; non è stata rinvenuta nell'area su altre piante. Tuttavia *D. bernhardti* non è un vettore pollinico di *H. scandens*. Morfologia ed etologia della nuova specie vengono messe a confronto con quelle della strettamente affine *D. quadratigera*, che frequenta i fiori di *Hibbertia saligna* nelle montagne del New South Wales. Al momento *D. bernhardti* e *D. quadratigera* sono le uniche specie di *Diphucephala* note per essere associate ai fiori di *Hibbertia* nell'Australia sud-orientale.

INTRODUCTION

The genus *Diphucephala* of the subfamily *Melolonthinae (Coleoptera: Scarabaeidae)* contains many small, metallic green and/or golden beetles which are adapted for feeding on leaves and/or floral parts (MACLEAY, 1886; FROGGATT, 1923; HAWKESWOOD, 1991) and for imbibing floral nectar (BRITTON, 1970; HAWKESWOOD, 1989). There are about 65 described species (HOUSTON & WEIR, 1992), mostly from Australia, but the genus is badly in need of revision and there are comparatively little data available on life-cycles and food plants of the adults. The larvae of most species are unknown. HAWKESWOOD (1989) recently provided evidence that *Diphucephala affinis* Waterhouse, feeds somewhat destructively on the bright yellow flowers of *Hibbertia hypericoides* (DC.) Benth. *(Dilleniaceae)* in coastal districts of south-western Western Australia. Behaviour of *D. affinis* on these flowers tends to contradict earlier reports that it is a pollinator of *H. hypericoides* (KEIGHERY, 1975).

Interactions between *Diphucephala* spp. and *Hibbertia* flowers are of particular interest to evolutionary biologists. Flowers within Section *Hibbertia* of the relict genus *Hibbertia* show many of the floral characteristics associated with ancestral dicots, e.g. numerous to indeterminant number of stamens arranged in bundles, separate carpels and no fusion between different floral whorls (STEBBINS & HOOGLAND, 1976). There is a possibility that some insect associations with relictual dicots may set an ancient precedence (BERNHARDT & THIEN, 1987).

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The insect visitors to flowers of *Hibbertia* spp. in eastern Australia have received only a seminal treatment (ARMSTRONG, 1979; BERNHARDT, 1984, 1986). Fieldwork has been instigated recently by the author and Dr P. Bernhardt on the floral visitors of *H. scandens* (Willd.) Gilg. and *H. saligna* R. Br., two species producing some of the largest, nectarless flowers in the genus in eastern Australia. So far the study has revealed several interesting insects and associations, including two *Diphucephala* species which were collected on the two *Hibbertia* spp. respectively and submitted for identification to the Australian National Insect Collection (ANIC) in Canberra, Australian Capital Territory (ACT). The novel taxon is described below comparing its morphology and ethology with those of *D. quadratigera* Blanchard which has been collected and observed on flowers of *H. saligna* in the Blue Mountains, New South Wales (fig. 6).

MATERIALS AND METHODS

(a) Collection sites

The observations on the association of *D. bernhardti* sp. nov. and the flowers of *H. scandens* (Willd.) Gilg. were undertaken during 5 October to 2 November 1990 at Cabarita Beach, New South Wales (28°17'S, 153°35'E). The *H. scandens* plants at this study site were scattered rather than clumped and grew in a *Banksia integrifolia* L. f. *(Proteaceae)* heathland, with *Banksia robur* Cav., *Persoonia* sp. *(Proteaceae), Acacia sophorae* (Labill.) R. Br. *(Mimosaceae), Leptospermum attenuatum* Sm. and *Eucalyptus* spp. *(Myrtaceae), Casuarina equisetifolia* L. *(Casuarinaceae),* with introduced (naturalized) plant families including *Asteraceae* such as *Senecio* sp. and *Chrysanthemoides moniliferum* (L.) T. Nore, *Onagraceae (Oenothera* sp.), *Oxalidaceae* (*Oxalis* sp.) and *Aizoaceae. Hibbertia scandens* is usually a large herbaceous trailing shrub and climber with broad, semi-succulent leaves 3-8 cm long with large, showy flowers with five thick sepals, five large yellow petals measuring 20-25 mm long and an ovary with 5 carpels and numerous surrounding stamens. In the study area at the time, very few plants of the *H. scandens* populations were in flower. The heathland was severely disrupted by sandmining during the early 1970's. *Diphucephala quadratigera* Blanchard was collected on open flowers of dense, roadside populations of erect, shrubby *Hibbertia saligna* R. Br. adjacent to or within rapidly sloping, open, *Eucalyptus* woodlands on Mt. Tomah, higher Blue Mountains, New South Wales (33°32'S, 150°25'E) during October 1990. All vouchers of both beetle taxa were deposited in the ANIC, Canberra, Australian Capital Territory.

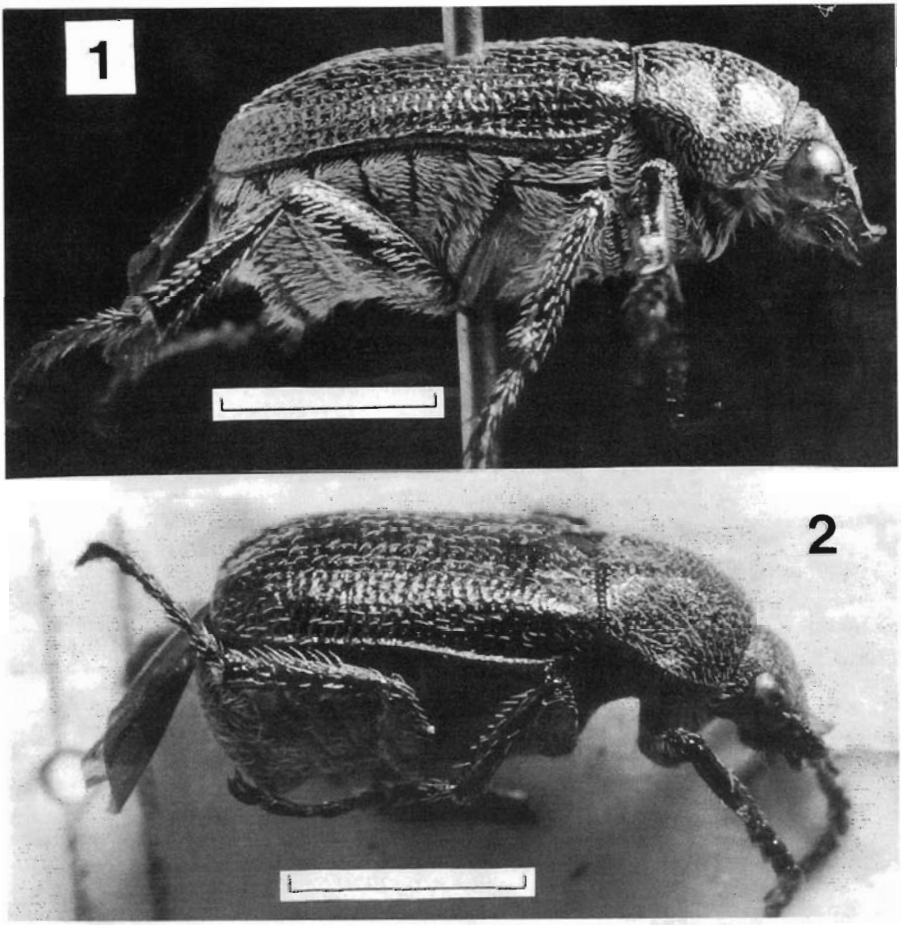
(b) Collection methods and removal of pollen

Ethyl acetate was the preferred killing solution. Individual insects were washed of pollen by placing each specimen on a glass slide and bathing it in two to three drops of absolute ethanol. Following evaporation of the ethanol, the residue on the slide was stained with two drops of Calberla's fluid (OGDEN *et al.*, 1974), omitting melted glycerine jelly, before adding the coverslip. Pollen grains were identified by Peter Bernhardt at the Royal Botanic Gardens, Sydney, New South Wales. As different insects were killed in the same jars and some pollen washed off, a specimen may represent contamination with other specimens. Pollen from any plant taxon was not recorded as present unless a minimum of 25 individual grains or polyads could be detected in the slide sample.

RESULTS

Diphucephala bernhardti sp. nov. Figs. 2, 4, 5a, 5b, 5d, 5e

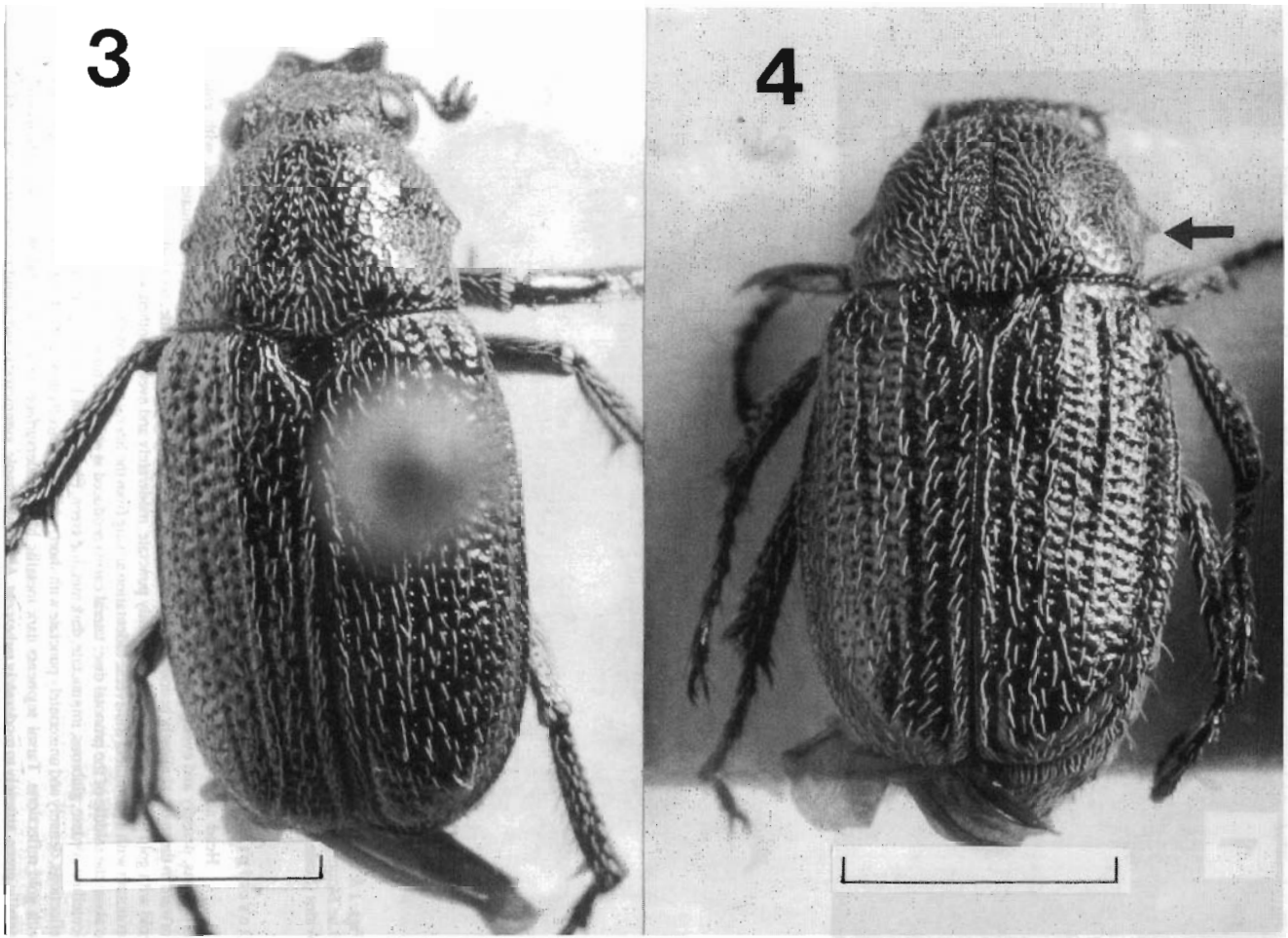
Types - Holotype: Male, Cabarita Beach, 5 km N of Hastings Point, New South Wales (28°17'S, 153°35'E), 23 Oct. 1990, T. J. Hawkeswood, from the flowers of *Hibbertia scandens* (Willd.) Gilg. (in the Australian National Insect Collection, ANIC); Paratypes: 2 males & 5 females, 9 Oct. 1990; 3 males & female, 12 Oct. 1990; 2 females, 14 Oct. 1990; male & female, 15 Oct. 1990, all paratypes with same locality, collector and food plant data as the holotype (all in ANIC).



Figs. 1 & 2. Side profiles of the two *Diphucephala* species. 1: *D. quadratigera* Blanchard, male, Mt. Tomah, higher Blue Mountains, New South Wales (Scale line = 2 mm); 2: *D. bernhardti* sp. nov., male, Cabarita Beach, New South Wales (Scale line = 2 mm) (Photos: J. Plaza).

Description

Head about 1.1-1.3 times longer than wide, bright metallic green or occasionally golden, with gold reflections, densely and evenly punctate, with 15-20 stiff white hairs; clypeus very broadly bisinuate and projected forward in the male, shallowly bisinuate in the female. Pronotum about as long as wide, somewhat bulbous, green and gold with gold reflections, densely and evenly punctate, moderately and evenly clothed with stiff, short, white hairs; pronotum with a prominent transverse indentation arising from the lateral carina at about half its length and extending to about the middle of the pronotal disc; lateral carina produced at about the middle into a sharp process (figs. 5a, b). Scutellum cordate, glabrous, impunctate, dark metallic green. Elytra about 1.5 times longer than wide, green with gold reflections, densely and uniseriately punctate with short, white hairs mostly arranged in longitudinal series. Legs green with gold reflections. Tarsal segments dark metallic blue. Undersurface of body and abdominal sternites mostly metallic green, sparsely to moderately pubescent. Aedeagus simple, symmetrical and slightly curved (figs. 5d, e). Ma-



Figs. 3 & 4. Dorsal views of the two *Diphucephala* species. 3: *D. quadratigera* Blanchard, male, Mt. Tomah, higher Blue Mountains, New South Wales (Scale line = 2 mm); 4: *D. bernhardti* sp. nov., female, Cabarita Beach, New South Wales. Arrow indicates the sharper angular process on the pronotum in this species compared to that of *D. quadratigera* (Scale line = 2 mm) (Photos: J. Plaza).

Table 1. Differences in total body length (clypeus to tip of abdomen) in the males and females of *D. bernhardti* sp. nov. and *D. quadratigera* Blanchard, collected from *Hibbertia* flowers in New South Wales (All measurements in mm).

	D. bernhardti		*D. quadratigera*	
	Male	**Female**	**Male**	**Female**
Range	5.0-5.5	5.2-6.0	5.0-6.0	5.8-7.0
Mean	5.2	5.7	5.7	6.5
SD	0.2	0.3	0.2	0.4
N	7	9	6	14

les slightly smaller (range 5.0-5.5 mm, N = 7) than females (range 5.2-6.0 mm, N = 9). Apart from the differences in the morphology of the fronto-clypeus, genitalia and in body size, the males appear to differ from the females in having a sharper process on the lateral carina of the pronotum (fig. 5b).

Etymology - Named in honor of Dr. Peter Bernhardt, Associate Professor of Botany at the St. Louis University, St. Louis, Missouri, U.S.A. Dr. Bernhardt is a respected authority on the pollination biology of Australian *Hibbertia* spp. and an important contributer to modern theories and reviews of the evolution of insect-flower interactions.

(a) Comparative morphology

Diphucephala bernhardti is closely allied to *D. quadratigera* but may be easily distinguishable by use of the following suite of characters: (a) the indentation on the side of the pronotum is not as deep as in *D. quadratigera;* (b) the sharp, angular process on the lateral carina of pronotum is sharper and more prominent in *D. bernhardti,* (c) the colour of *D. quadratigera* is gold with golden reflections (rarely golden-green), while most specimens of *D. bernhardti* are dark metallic green with golden reflections, (d) *D. quadratigera* is a much more densely hairy species, (e) the parameres of the aedeagus of *D. quadratigera* are longer and straighter than those of *D. bernhardti,* and (f) overall, *D. quadratigera* is a larger species (see table 1). The close affinity in terms of external morphological characters may also be reflected in the similarity of their food preferences (see below).

(b) Ethology

Diphucephala bernhardti was found exclusively on the flowers of *H. scandens* at the Cabarita Beach site. The beetles were somewhat inactive on the open flowers of *H. scandens* even during hot, dry weather (25-30°C) and individuals usually rested on the petals or in the protected region of the floral axis between the sepals and petals. Feeding and mating also occurred in these situations. Beetles tended to consume the petals and occasionally fed on the fleshy bases of the sepals. Feeding on the stamens and the carpels was not observed. Beetles were not observed to contact the receptive stigmas of the flowers and were rarely observed in flight during the day. Only one beetle was observed to land on the stamens but it soon moved off the stamens onto a petal upon which it began to feed. Although one to three beetles / flower were counted on flowers during the observation periods, only two to five flowers within the site each day, contained beetles. A sample of 17 beetles was captured over three weeks for identification and pollen analyses. Only three beetles carried appreciable loads of pollen and only two of these specimens carried the pollen of the host flower, *H. scandens* (table 2).

(c) Comparative ethology

Diphucephala quadratigera was found primarily on flowers of *H. saligna* at the Mt. Tomah site although a few individuals were observed (but not collected) on naturalized, roadside *Asteraceae* and *Leptospermum* sp. *(Myrtaceae)* by P. Bernhardt (1990, pers. comm.). The *D. quadratigera* bee-

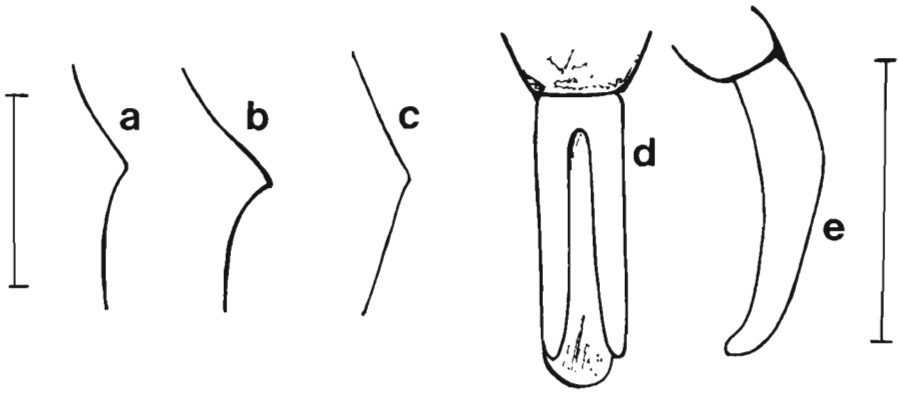


Fig. 5. *Diphucephala* species. 5a-b: Outline of lateral margin of pronotum of *D. bernhardti* sp. nov.; 5a: female, 5b: male. 5c: outline of lateral margin of pronotum of *D. quadratigera* Blanchard. 5d-e: Parameres and penis of *D. bernhardti* sp. nov.; 5d: dorsal view, 5e: lateral view (Scale lines: 5a-c = 1.5 mm; 5d-e = 1 mm).

tles appeared to be more active on, and more destructive to, the flowers of *H. saligna* (fig. 6) than *D. bernhardti* was to *H. scandens* flowers. Feeding and mating occurred between the sepals and the petals, between the petals and the base of the staminal whorl, and between the base of the carpels and the staminal bundles. Individuals of *D. quadratigera* were observed to feed on the petals and on the stamens of *H. scandens*, often decapitating the anthers. Like *D. bernhardti*, *D. quadratigera* was not observed to contact the receptive stigmas of the carpels. Beetles were often observed flying to *H. saligna* flowers on the same shrub and to different shrubs. Beetles commonly landed on staminal bundles before crawling down onto the petals. One to six beetles / flower were counted on flowers during the observation periods. Shrubs growing in full sun were more likely to contain beetles in their flowers than those in shade (P. Bernhardt, 1990, pers. comm.). Thirteen out of 27 *D. quadratigera* collected (76.4%) carried loads of the pollen of *H. saligna* (table 2).

DISCUSSION

Diphucephala bernhardti belongs to a large subsection of *Diphucephala* (*sensu* MACLEAY, 1886: 384). Species within this subgroup are characterized by three morphological features: (a) the emargination of the clypeus which is more or less deep, with the flanges ("angles" *sensu* MACLEAY, 1886) always diverging; (b) the dorsal groove (or channel, *sensu* MACLEAY, 1886: 384) of the pronotum is simple; and (c) the lateral foveae on the pronotum do not extend to the dorsal groove

Table 2. Comparison of pollen types carried on the bodies of *Diphucephala* beetles collected from *H. scandens* and *H. saligna* flowers in coastal New South Wales. Collection / locality data: *D. quadratigera* Blanchard, 27 Sept., 5 & 10 Oct. 1990, Mt. Tomah, Blue Mountains, New South Wales; *D. bernhardti* sp. nov., 9 & 12 Oct. 1990, Cabarita Beach, c. 5 km N of Hastings Point, New South Wales (N.B.: Mt. Tomah material collected by P. Bernhardt, numbers refer to total no. of beetles carrying pollen type).

	Pollen types						
Species	***Hibbertia saligna***	***Hibbertia scandens***	***Pinus* sp.**	***Acacia* sp.**	***Pultenaea scabra***	***Leptospermum attenuatum***	**Unknown monocot**
D. quadratigera	13	-	1	1	2	-	-
D. bernhardti	-	2	-	-	-	1	1

(channel). MACLEAY (1886) recognized 14 species as belonging to this informal subsection, including *D. quadratigera* Blanchard. It is beyond the scope of the present paper to determine all the affinities of *D. bernhardti* with the remaining species in this subsection, or to the other species in the genus. In addition, MACLEAY (1886) did not provide keys to the various species or species groups, so that at present, it is impossible to determine phylogenetic relationships. While *D. bernhardti* is closely allied to *D. quadratigera,* it is distinguished on the combined features of pronotum and aedeagus morphology, physical size and depauperate pubescence. BLACKBURN (1906) provided a simplistic key to all of the species of *Diphucephala* known at that time, but did not recognize the groupings proposed earlier by MACLEAY (1886). By this key, *D. bernhardti* keys closely to *D. quadratigera,* but BLACKBURN's (1906) key is difficult to use as most of the terminology is archaic and not defined in his paper.

Diphucephala quadratigera and *D. bernhardti* are the only *Diphucephala* species in eastern Australia currently linked by both morphological and foraging affinities. Although *D. affinis* Waterhouse, in Western Australia, forages extensively on *Hibbertia hypericoides* (DC.) Benth. (KEIGHERY, 1975; HAWKESWOOD, 1989), it does not appear to be closely allied, at least on morphological grounds, to *D. quadratigera* and *D. bernhardti*. MACLEAY (1886) placed *D. affinis* in a group of five species endemic to Western Australia. This Western Australian alliance is distinguished by a deeply emarginate clypeus with the flanges (angles) scarcely divergent or non-divergent (MACLEAY, 1886). *Diphucephala affinis* Waterhouse was regarded by HAWKESWOOD (1989) as a non-pollinator of *H. hypericoides* because (a) beetles were not contacting the stigmas during feeding bouts, and (b) they did not carry *Hibbertia* pollen. Only three out of 18 beetles (16.7%) that were collected carried *Acacia* pollen, indicating that some *D. affinis* visited other co-blooming plants before visiting the *Hibbertia* plants; in fact, field observations showed that this was so (HAWKESWOOD, 1989). Field observations and analyses of comparative pollen loads on *D. bernhardti* suggest it is more dependent on the perianth segments of its *Hibbertia* host as an adult food source compared to *D. quadratigera. Diphucephala bernhardti* is far less likely to consume the stamens of its host flower and to contact the stamens of co-blooming taxa than is *D. quadratigera.* In contrast, *D. affinis* does not appear to eat the pollen of *H. hypericoides* (HAWKESWOOD, 1989). It is most unlikely that the yellow colour of the petals of *H. scandens* is the only stimulus attracting *D. bernhardti*. At the Cabarita Beach site, *D. bernhardti* ignored the yellow petals of co-blooming *Senecio* sp. and *Chrysanthemoides moniliferum* (L.) T. Nore (both *Asteraceae*), *Oxalis* sp. *(Oxalidaceae)* and *Oenothera stricta* Ledeb. *ex* Steud. *(Onagraceae).* Pollen analysis indicated only one beetle carried *Leptospermum* pollen and that of an unidentified monocot (table 2), which suggests that this particular beetle may have visited the nectariferous white, bowl-shaped flowers of *L. attenuatum* Sm. *(Myrtaceae),* plants of which were also in flower at the start of October in the same area. However, although an unidentified species of *Liparetrus (Coleoptera: Scarabaeidae)* was observed in large numbers on the *L. attenuatum* flowers, no *Diphucephala bernhardti* were observed to utilize the nectar of this plant. It is possible that the presence of *Leptospermum* and monocot pollen on the beetle may have arisen through some kind of contamination. Flowers of *H. scandens* have an unusual odour that seems sweet yet has a pronounced faecal element which may be attractive to some beetles such as *Scarabaeidae*. WRIGLEY & FAGG (1990) recently compared the scent of *H. scandens* to that of animal urine and similar odours have been described by BERNHARDT (1984, 1986) in other *Hibbertia* species.

A. SCHATRAAL (work in progress, pers. comm.) insists that some, as yet unidentified, *Diphucephala* species are important pollinators of some *Hibbertia* species around the Perth region of Western Australia. These beetles become liberally covered with the pollen of the anthers they destroy and their bodies contact the receptive stigmas during the feeding process. *Diphucephala affinis, D. bernhardti* and *D. quadratigera* do not appear to be important pollen vectors of their re-

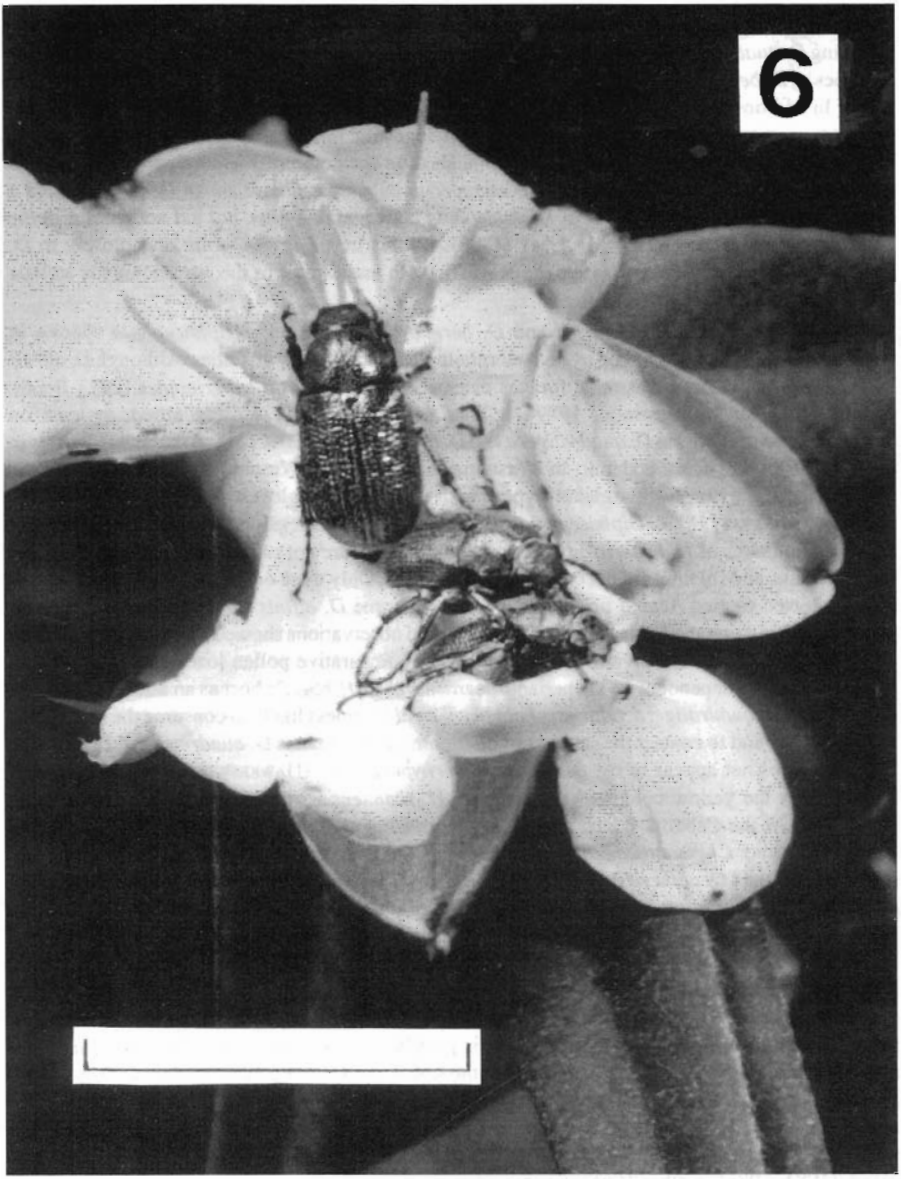


Fig. 6. Adults of *D. quadratigera* Blanchard on the flowers of *Hibbertia saligna* R. Br. *(Dilleniaceae)* at Mt. Tomah, higher Blue Mountains, New South Wales. One male is attempting to mate with the female while she is feeding on one of the petals. The other male is attempting to feed on the anther filaments (Scale line = 10 mm) (Photo: J. Plaza).

spective *Hibbertia* species and may be best regarded as floral predators or parasites. Although the hairiness of *D. quadratigera* makes it a more consistent vector of *Hibbertia* pollen, its foraging behaviour and the floral architecture of *H. saligna* prevents it from significant pollen-stigma contact. Relictual dicots pollinated primarily by *Coleoptera* tend to have extrusive, pollen-shedding anthers (BERNHARDT & THIEN, 1987). The anthers of *Hibbertia scandens* and most *Hibbertia* spp. have inflated, cylindrical, chamberlike anther sacs which open by means of twin, apical-subapical pores. Female bees regularly contact *Hibbertia* stigmas during thoracic vibration of the anther clusters and carry heavy loads of pollen between scopal hairs and ventral hairs at the base of the abdomen (BERNHARDT, 1984, 1986). Flowers of *H. scandens* in New South Wales are visited by hundreds of pollen-bearing, female anthophorids and some halictids (Bernhardt & Walker, 1990, pers. comm.; Hawkeswood, 1983-1991, pers. obs.). Consequently, *Hibbertia* may prove to be a poor genus to use as a model system for understanding beetle-flower co-adaptation.

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