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Introduction of Small Carpenter Bees into California for Pollination.

1. Release of *Pithitis smaragdula*¹,²

HOWELL V. DALY,³ GEORGE E. BOHART,⁴ and ROBIN W. THORP⁵

ABSTRACT

*Pithitis smaragdula* (F.) is a bright green, small carpenter bee which is widespread in the oriental region and is known to pollinate economically important plants, especially legumes and cucurbits. About 300 bees imported from Ludhiana, India, were released 10 April 1969, at Davis, California. Subsequent collecting during the 1st season confirmed that one or more generations of the bees had been reared and that *Trifolium repens* L. was visited for pollen. Although the overwintering bees under observation died from unknown causes, and no living bees were found in 1970, it is possible that the bees survived elsewhere. Ecological factors believed to be important in the establishment of the colony were: few natural enemies, low competition for food, high competition for nesting sites, and a cooler, drier climate than the native habitat. Future releases are planned for warmer areas in the State.

The purpose of this paper is to record the ecological circumstances under which *Pithitis smaragdula* (F.) was released at Davis, Calif., and to evaluate the survival of the bees after the 1st season.

Certain species of wild bees are known to be more effective than honey bees, *Apis mellifera* L., as pollinators of crops such as alfalfa and other forage legumes (Bohart 1957, 1958, 1960; Hobbs 1958; Lecomte and Tirgari 1965; Linsley 1946) and squash (Michelbacher et al. 1964). Until recently the only purposeful introductions of pollinating insects have been: the honey bee from the Eurasian area to many parts of the world, including California, in 1855 (Watkins 1968); the fig wasp from Smyrna, Turkey, to California in 1899 (Essig 1931); and bumble bees from England to New Zealand in 1885 (Hopkins 1914). All of these introductions were initiated before 1900 and are only partially documented. Although each is now quite successful, repeated efforts were required before the insects were established.

The feasibility and problems of introducing foreign pollinators have been discussed (Bohart 1962, Thorp 1965, Michelbacher et al. 1968). Attempts by other investigators are being made elsewhere in the world to release pollinators such as alkali bees, *Nomia melanderi* Cockerell, in New Zealand (P. Palmer and B. J. Donovan, DSIRO, New Zealand, personal communication) and alfalfa leafcutter bees, *Megachile rotundata* (F.) (but see Hurd 1967, for taxonomy), into Chile (R. Gonzalez and P. Arretz, University of Chile, personal communication), Denmark (Holm 1964), and South Australia (K. M. Doull, personal communication).

The potentiality of twig-nesting bees for manipulation as pollinators was anticipated early (Bohart 1947). These predictions were confirmed when leafcutter bees from Europe were accidentally introduced to the United States and proved to be valuable pollinators of alfalfa (Bohart 1958, Stephen and Torchio 1961). The objective of our program is to identify useful pollinators among the twig-nesting small carpenter bees, tribe Ceratinini, and to develop methods for their introduction and management. Thus far, 3 species are known to visit the flowers of economically important plants which require cross-pollination for seed production: *Ceratina laevifrons* Morawitz in Central Asia, *C. flavipes* Smith in Japan, and *P. smaragdula* in India. Popov (1967a) noted that *C. laevifrons* visits lucerne and that populations might
be increased by providing cut reeds for nests. Yasuo Maeta (personal communication) observed *C. flavipes* visiting legumes with small flowers. The agricultural importance and biology of *P. smaragdula* has been well documented by Kapil and Kurmar (1969) who list 21 crops, mainly legumes and cucurbits, visited by this species near Ludhiana, India. *P. smaragdula* was therefore chosen for the 1st purposeful release of an Old World bee to California since the importation of the honey bee.

**Classification and Identification.**—According to Shiokawa and Sakagami (1969), *P. smaragdula* is the most common and widely distributed species of the genus in the Oriental Region, being recorded at various localities from Karachi, Pakistan; and Muzafarabad, Kashmir; to Hangchow, China; and Ambon, Indonesia. It is possible that the range extends west into Iran, since *P. binghami* Cockerell, a species often confused with *P. smaragdula*, was reported by Popov (1967b) from Kerman and Sarbaz. The genus *Pithitis* Klug was considered to be subgenus of *Ceratina* by Vecht (1952), but more recently Hirashima (1966, 1969) and Shiokawa and Sakagami (1969) have treated it as a genus. Although the bees in this genus are best known as conspicuous and colorful elements in the Oriental fauna, other species have been added from the Ethiopian fauna by Hirashima (1969).

*P. smaragdula* belongs to a group of at least 3 bright-metallic-green species (Shiokawa and Sakagami 1969, Hirashima 1969). The females of the different species are closely similar and easily confused, but the males possess distinctive features. Males of *P. smaragdula* possess a single pair of black maculations on each tergum of metasomal segments IV-VI. On closer inspection each maculation is created by a darkly melanized, nonmetallic, and deeply caniculate surface. All the males examined at the Davis site possess these maculations. When compared with the small carpenter bees (Ceratinini) in America north of Mexico, *P. smaragdula* is the only bright-metallic-green species. Both sexes are shiny but coarsely and closely punctured and with yellow maculations. If seen in the field in the United States, *P. smaragdula* may superficially resemble certain native bees such as the metallic-green megachilids, e.g., *Hoplitis* (Chlorosmia) and some *Osmia* (Chenosmia), or the metallic-green halictids. e.g., *Agapostemon* or *Augochlorella*. No other species of Apoidea in North America has black maculations created in the manner just described for the males of *P. smaragdula*.

**Plant Injury.**—Until the discovery that *P. smaragdula* was a valuable pollinator, the small carpenter bees were generally considered of little economic importance. Views conflicted, however, on whether the bees were beneficial as minor pollinators or injurious to plants, especially roses, as a result of their burrows in pruned stems. Over the past 15 years in the eastern United States, bees identified as *Ceratina* have been observed nesting in pruned stems, and their burrows have been associated with the death of the infested portions of the plants (Anonymous 1968, 1965; Bray 1964; Gesell 1961; Jones and Mitchell 1959; Negley 1968; Pepper 1955). In Russia, Popov (1967a) mentioned *C. laevifrons* as damaging catalpa and *Ailanthus* in the nurseries of Tashkent and Samarkand. Careful study has not been made of the origin and nature of the alleged damage. Although the number of species is considerably higher in the western United States, no incidents of injury to plants have been reported by growers. Otherwise, the bees are considered beneficial (Essig 1942: 712, Raghuvir et al. 1961).

As a precaution, tests were conducted at Logan, Utah, by placing the alien bees in cages over raspberry plants with both young and old canes pruned. Nesting took place, especially in the old canes, but no damage was detected; the burrows stopped when the living stem was penetrated.

**Preparation for Release.**—Sixty nests of *P. smaragdula* were sent from Ludhiana, Punjab, India, to Logan, Utah. The 1st shipment arrived in July 1967, and a 2nd shipment arrived in February 1969. It was not practical to follow Remington’s (1968) recommendation to release wild samples directly, because alien natural enemies had to be eliminated by rearing in quarantine. In the greenhouse, cages 4x2x2 m were provided with nesting sticks about 15 cm long from *Ailanthus altissima* (Mill.) Swingle, *Rhus* sp., and *Sambucus* sp. Pollen of *Phacelia* sp. and *Melilotus* sp. was supplied as food. Copulation was observed in the cages, nests with 3-4 cells were constructed, and the 1st generation of 60 adults was 85% female.

A release site was sought in California which would (1) be near a food source including legumes; (2) have abundant nesting media of the kind already used at Logan; (3) be protected from vandalism; and (4) be in an area where interactions with native *Ceratina* could be observed. An isolated grove of *A. altissima* in the Zoology Wild Area west of the main Davis campus of the University of California was selected as meeting these requirements. The broken dead stems of the trees provided abundant nesting sites for twig-nesting insects. The grove was situated along the North Fork of Putah Creek and occupied an area of 1872 m² with maximum dimensions of 28x82 m. The trees ranged up to 20.3 m high and in some areas were sufficiently dense to provide total shade at noon in the summer. A field of Ladino clover, *Trifolium repens*, was adjacent to the south side of the grove, and weedy plants such as *Brassica* sp., *B. geniculata* (Desf.) J. Ball, *Centarea solstitialis* L., *Convolvulus arvensis* L., *Datura meteloides* A. DC., and *Silybum marianum* (L.) Gaertn. were present along the margins of the grove. One to several individual trees of *A. altissima*, as well as *Sambucus* sp., were scattered sparsely along the creek near the grove, but the nearest other groves of *A. altissima* were situated at distances of 0.8 and 3.2 km.

**Release and Survival.**—On 10 Apr. 1969, 248 stems (6-15 mm diam, 18-36 cm long) with burrows containing hibernating bees were brought by automobile to the Davis site from Logan. The stems were divided in 16 cylindrical bundles, each tightly bound with wire. No exact count was made of the bees, since they were concealed in burrows, and it was desirable not to disturb them at the outset. Each burrow probably contained 3-4 bees at most, and the total population was probably not more than 300. Nesting sites naturally occurring in the grove were augmented by 70 unoccupied stems of dimensions similar to the occupied stems. These were drilled at the ends with holes 3x0.3 cm to encourage nesting, and they were bound in 10 bundles. Together with the occupied bundles, the additional stems were attached to trees with wire at about 1.5 m above the ground within a shaded area 15x12 m.
Sixteen of the artificial stems, including those initially occupied and unoccupied, were dissected 2 July 1969 to estimate the progress of the introduction. Two live females of _P. smaragdula_ were found with a dead female pupa in one of the original nests. The bees and the pupa probably were reared in Logan. Since few alien bees were found in the summer, an exact count of the population in the 318 artificial stems was made 6 and 18 Nov. 1969. To expedite the survey, radiographs (15 kv for 18–24 sec depending on thickness) were prepared for the 223 stems showing evidence of burrows. Since the minimum body length for museum specimens of _P. smaragdula_ was 7 mm, all stems with images of bees equal to or greater than 7 mm were sorted for immediate examination. This group contained all the _P. smaragdula_ plus stems with larger individuals of the native _Ceratina acantha_ Provancher. By opening the burrow at the very bottom the bees could be gently blown from the nest, identified, the nests securely closed again with pieces of wood, and the bees re-introduced at the entrance.

Four nests with a total of 28 Ψ and 7 Φ _P. smaragdula_ were found in the fall plus 1 nest with 2 Ψ and 8 brood-rearing cells. The cells contained fully fed larvae, pupae, and an incomplete loaf of pollen from _Trifolium repens_. All the live bees were in the occupied stems originally placed in the grove. Their fresh appearance indicated that they probably were reared at Davis. A dead female and a male were found in burrows in the artificial stems which were initially unoccupied. No alien bees were found in the samples of natural stems elsewhere in the grove (see following). The 4 nests, with 21 Ψ and 6 Φ of live _P. smaragdula_, were returned to the release site 4 Dec. 1969. For the next nesting season, artificial stems with ends drilled were placed in the grove 10 Feb. and 10 Mar. 1970 to provide 205 nesting sites in addition to the natural stems.

On 16 Apr. 1970, a year after the release, the 4 nests known to contain _P. smaragdula_ were opened and 10 Ψ and 5 Φ were recovered dead. A thorough search for survivors was undertaken on 15 June 1970 by preparing radiographs of 117 artificial stems and by dissecting 46 natural stems. No _P. smaragdula_ were found in the stems. Weedy plants and nearby fields of Ladino clover and alfalfa were swept 22 July 1970, with the result that no alien bees were collected.

**Natural Enemies.**—Surprisingly, no evidence of parasitoids such as the cocoon of _Grotea californica_ Cresson or emergence holes of _Eurytoma apiculae_ Bugbee were found in any of the collections at Davis. However, the native predators and parasites are not host-specific and some have already been recorded attacking another alien bee, _Ceratina dallatorreana_ Friese (Daly et al. 1967).

Some very old burrows in natural stems (4, or 3% of 132 nests sampled on 23 Apr. 1969) were partly opened by the feeding activities of a vertebrate, probably a bird such as the Hairy Woodpecker. Damage of the same nature was seen on the artificial stems collected in the fall (3, or 1.8% of 223 nests sampled on 6 and 18 Nov. 1969). The arrangement in bundles limited the exposure to this enemy to the outer stems but at the same time provided a refuge for insects and spiders among the inner stems. When the bundles were observed in the summer, spider webs were common, and aestivating _Hypera brunneipennis_ Boheman were seen among the stems and obstructing the entrances of burrows. When all bundles were opened 6 and 18 Nov. 1969, 1 Ψ and 1 Φ _P. smaragdula_ and 4 Ψ and 1 Φ _C. acantha_ were found dead and entangled in spider webs. They were probably victims of _Phidippus_ sp. or the reduvid _Zelus renardii_ Kolenati which were found in the bundles. The artificial stems deposited in the grove in 1970 were arranged side-by-side in a raftlike manner to reduce shelter for predators and to facilitate the preparation of radiographs.

The dead _P. smaragdula_ which were recovered from nests on 16 Apr. 1970, exhibited no injuries, but were examined for pathogens. Only the following saprophytic fungi were detected: _Gladosporium_ sp., _Penicillium_ sp., and _Rhizopus nigricans_ Ehrenberg.

**Competition for Nests and Food.**—The establishment and management of _P. smaragdula_ was expected to depend largely on its ecological relationships with twig-nesting bees and wasps, especially _Ceratina_. Release in the Great Valley of California has certain advantages, since the bee fauna is reduced in numbers of species when compared with the adjacent mountainous regions (Hurd and Michener 1955, Daly 1966b). While the latter have at least 10 species of native _Ceratina_, only 2 native species, _C. acantha_ and _C. arizonensis_ Cockerell, and the alien _C. dallatorreana_ are commonly collected at Davis. This is probably because portions of the Valley were occupied by the sea during much of the Tertiary (Bailey 1966), and until agricultural activities began the native vegetation was largely tule marshes and steppe (Küchler 1964).

Both native species are polylectic: _C. acantha_ has been collected from the flowers of 109 genera of plants (6 in _Leguminosae_ and _C. arizonensis_ from 43 genera (2 in _Leguminosae_). The Mediterranean _C. dallatorreana_ is largely limited to the Great Valley and is polylectic, having been taken in California on 5 genera, each in a different plant family (1 in _Leguminosae_). Although a taxonomically wide variety of plants serve as nesting media in the Great Valley, the same plant species are commonly used by 2 or more of the prevalent species of small carpenter bees: _A. altissima_, _Artemisia_ sp., _Brassica_ sp., _Foeniculum vulgare_ Mill., _Rubus_ sp., _Rumex_ sp., and _Sambucus_ sp.

_P. smaragdula_ is well known in the Oriental region as a polylectic bee which readily visits introduced species for food and also nests in a wide assortment of plants (Iwata 1938, Rahman 1940, Vecht 1952, Sakagami and Yoshikawa 1961, Shiokawa and Sakagami 1969). Based on our identification of voucher specimens at the University of Kansas, Lawrence, _P. smaragdula_ was reported as _Ceratina binghami_ Cockerell by Batra (1967). In her study, the bees were recorded from flowers of 21 species of plants (4 in _Leguminosae_) at Ludhiana, India. Kapil and Kumar (1969) provided a host list of 21 economically important plants including 8 legumes.

Since the small carpenter bees already resident in the Great Valley visit legumes infrequently, their competition for food with _P. smaragdula_ is likely to be negligible. An analysis of 7 loaves from 5 nests of _C. acantha_ at the Davis site revealed pollen from the following plants in decreasing order of abundance: _Brassica_ sp., _Cirsium_ sp. or _Silybum_ sp., _Convolvulus_ sp., and minor amounts from _Asteraceae_ and _Leguminosae_.

The most plentiful nesting media are already
shared by the resident species, and competition for nesting sites can be expected. Some evidence exists, for example, that the spread of *C. dallatorreana* outside the Valley tends to be limited by the presence of native *Ceratina* (Daly 1966a). Because of their similar body size, *C. acantha* and *C. dallatorreana* are most likely to be the competitors with *P. smaragdula* for nests.

Both *C. acantha* and *C. arizonensis* were present at the Davis site, but only *C. acantha* was found nesting within the grove. A sample of 132 natural stems with burrows was taken 23 Apr. 1969, shortly after the release of alien bees. Of these 108, or 81.8%, were occupied by a total of 124 ♀ and 16 ♂ *C. acantha*, and 1 stem was occupied by adults of *Anictrocercus spilogaster* Cameron. The female bees were evidently dispersing from overwintering aggregations in the parental nests and seeking suitable stems for their own nests. Ordinarily, new nests are excavated, but only 35 of the 108 were clearly fresh, and 30 were possibly parental nests being reused. The remaining occupied stems included 11 with evidence of old nests of *Trypoxylon* sp. and 32 very old, partly decayed burrows. The latter are never seen later in the year with brood. Among the empty burrows of 64♂ and 26♀ of *C. acantha*, in all only 95 burrows plus an unknown number of unexploited stems were available for the 124 ♀ in the sample. We believe the unexploited stems are rather few and that more female *C. acantha* survive the winter than can be accommodated by nesting sites in the spring. This suspicion is born out by the overwhelming invasion of the artificial nests discussed below. Another indication of competition for nests was the discovery of 1 nest of 3 ♀ with a fresh, incomplete loaf of pollen, and 8 nests, each with 2–3 ♀ bees and 1 or more freshly completed cells. These were the only nests showing brood production. Ordinarily, only 1 ♀ is present in the nest when provisioning and cell construction are initiated. However, these exceptional instances may be cases of nest supersEDURE in progress.

When the 16 artificial stems were examined 2 July 1969, *C. acantha* had established 8 nests with brood. By 6 and 18 Nov. 1969, 118 or 52.9% of the 223 artificial stems with burrows were occupied with a total of 199 ♀ and 26♂. The artificial stems where 95 burrows were originally formed included 155 burrows originally excavated by *P. smaragdula* as well as 68 or 97.1% of the extra 70 placed in the grove. Although only 32 or 47% of the 68 still were occupied, virtually all can be attributed to *C. acantha*, since no evidence exists that *P. smaragdula* used the new stems for nests. The whole collection of artificial nests also included evidence of *Trypoxylon bidentatum* Fox (det. A. S. Menke) in 57. Of these, 11 had *C. acantha* as secondary residents, and 13 each had a larva of *Cymatodera ovatus* (Le Conte) (det. F. D. Parker) which is presumably predaceous on the immature wasps. Other insects in the burrows included *Agulla* sp. and *Hypera brunneipennis*. Also in the fall, 52 natural stems with burrows were examined and 20 or 38.4% were occupied with a total of 125 ♀ and 51 ♂ of *C. acantha*. None of the *C. acantha* were returned to the grove to reduce the population competing with *P. smaragdula*.

In spite of the removal of 771 ♀ and 311 ♂ in the fall of 1969, radiographs of 117 artificial stems on 15, 16 June 1970 revealed at least 69 or 58.9% with burrows and 66 of these occupied by 56 bees and brood of *C. acantha*. Dissection of 46 natural stems with burrows revealed 28 or 60.9% occupied with a total of 33♂ and 1♀.
release site. During 8 months at Ludhiana, 6–7 generations are passed by P. smaragdula (Kapil and Kumar 1969) in comparison with 1–2 generations passed by native Ceratina sp. in California. The observed winter mortality of the alien bees is most likely not from disease, but probably from injuries suffered during the sampling procedures in the fall, life history not synchronized with the new seasons, or freezing temperatures. The last may not be critical, because the geographic range of P. smaragdula includes areas of northern India and Kashmir where freezing occurs. Future releases are planned for warmer portions of the State.

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