THE ROLE OF BUMBLEBEES AS POLLINATORS OF RED CLOVER AND LUCERNE IN NEW ZEALAND: A REVIEW AND PROSPECT

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Abstract

Four species of bumblebees, *Bombus* ***horforum,*** *B.* ***ruderafus, B. subterraneus*** and ***B. terrestris,*** are now established and widespread in New Zealand. The long-tongued species, ***B.*** *hortorum,* ***B.*** *ruderatus,* and ***B.*** *subterraneus,* are very effective pollinators of red clover but not of lucerne. *Bombus* ***terrestris*** is short-tongued, "robs" red clover, and is thus less effective as a pollinator of this crop but is a most efficient pollinator of lucerne.

Research on bumblebees in New Zealand was first concerned with identification of the species and their distribution. Since the 1950s biological aspects have received increasing attention and success has been achieved with local enhancement of bumblebee populations—introduction of ***B. horforum*** to Manawatu district and increase of local populations in Mackenzie Country. It is considered that manipulation of populations of the species now present offers most promise for increase in pollination, and hence seed yield, of red clover and lucerne in New Zealand.

INTRODUCTION

BOTH red clover and lucerne are, for all practical purposes, self-sterile and have flowers with specialized pollination mechanisms which require relatively heavy insects to operate them. Only in this way can cross-pollination be effected. The larger bees are the insects best adapted to meet these requirements, There are 20 species of bees native to New Zealand (Tillyard, 1926), but none of these is large enough, and they seldom occur in sufficient numbers to be of any consequence as pollinators of these crops. Neither have any other native insects been shown to pollinate either of these crops effectively. Consequently, both crops are entirely dependent on introduced species of bees for cross-pollination.

Before the successful introduction of bumblebees into New Zealand in 1835, seed set in red clover was negligible-certainly none set on a commercial basis and this in spite of the fact that honeybees had been brought to New Zealand as early as 1839 and soon became established everywhere. Within five years of

the introduction of bumblebees, a thriving population built up and spread throughout the South Island from their point of release near Christchurch; nests and queens were also sent to the North Island where they quickly became established. The effect on seed setting of red clover was immediate and spectacular; yields of 500 or 600 kg/ha were reported from Lincoln College, and yields of 560 kg/ha were reported from Ellesmere (Hopkins, 1914).

The initial spectacular seed yields did not persist, however, probably because so many crops were shut up for seed in the hopes of obtaining the rich returns from these yields of seed that the flowers to be pollinated soon greatly outnumbered the bumblebees available to perform the task of pollination.

New Zealand average seed yields for red clover do not compare favourably with those obtained in most northern hemisphere countries. Dumbleton (1949) gives a ten-year average (1934-43) for red clover seed yields in New Zealand of 167 kg/ha and compares it with various northern hemisphere yields-wales, 330 to 620 kg/ha for Montgomery red clover and 500 to 620 kg/ha for broad red clover; Scania, Sweden, 398 kg/ha (1910-19) and 352 kg/ha (1920-34), whole of Sweden (1921-31), 280 kg/ha; Denmark, 200 kg/ha for early red clover and 300 kg/ha for late red clover, with an average for 60 farms for an eight-year period of 330 kg/ha; Canadian yields are given as 1 I2 to 268 kg/ha for "double cut" and 168 to 336 kg/ha for "single cut" red clover.

More recent figures for New Zealand (L. B. Anderson, pers. comm.) based on data obtained from 24 different South Island and two North Island localities for a six-year period (1965-71) are: 'Grasslands Hamua' broad red clover 296 kg/ha, and 'Grasslands Turoa' Montgomery red clover 136 kg/ha. From Canada in 1970 yields for many cultivars of diverse origin were for "double cut" 376 kg/ha and fo r"single cut" 319 kg/ha.

It is often contended that seed yields of red clover are declining, but although they fluctuate from year to year no such trend can be demonstrated. Indeed, the yields in the sixties indicate the bpposite. New Zealand average yields are, however, lower than those for northern hemisphere countries, especially those in the higher latitudes. This is understandable if insect pollinators are the key determining factor. In high latitudes, where during the clover flowering period there is almost continuous daylight, the pollinators can, and do, work for almost 24 hours of the day. The long, hard winters and short summers ensure that the popula-

tion peaks of the different species are synchronous and coincide with the clover flowering period. Pollination efficiency in these circumstances is at its maximum. Because of New Zealand's geographical position, these conditions do not occur here but they are most nearly approached in the Mackenzie Country and parts of Southland. The seed yields in these areas reflect this, being generally higher than elsewhere, and at times yields of up to 1300 kg/ha have been recorded.

The disparity in lucerne seed yields between New Zealand and North America is even greater than that of red clover. Donovan (1975) discusses this in detail.

BUMBLEBEE SPECIES PRESENT 'AND THEIR DISTRIBUTION

Two species of bumblebee, *Bombus terrestris* (L.) and *B. ruderatus* (Fab.) established from the 1885 introductions (Gurr, 1957b) and their success as pollinators encouraged the Canterbury Agricultural and Pastoral Association to introduce further species in 1906. Hopkins (1914) records that at least four species were imported at this time, and Gurr (1964) has shown that only two of these four species, *B. hortorum* (L.) and *B. subterraneus* ssp. *latreillelus* (Kirby), established. Thus four species became established and are now widely distributed. *Bombus terrestris* and *B. ruderatus* occur throughout the whole of New Zealand, and *B. hortorum* is confined to the eastern side of the main divide south of Amberley in the South Island. *Bombus subterraneus* is also confined to the eastern side of the main divide south of Lake Coleridge but it is an upland species found in numbers only in the Mackenzie Country and Central Otago (Gurr, 1964). *Bombus hortorum* was recently introduced to the North Island (Gurr, 1972) and has established in Manawatu.

RELATIVE EFFICIENCY AS POLLINATORS OF RED CLOVER AND LUCERNE OF THE SPECIES PRESENT

Both red clover and lucerne require large insects to effect pollination because the sexual parts of their flowers are concealed. Red clover has a long corolla tube which surrounds the anthers and stigma, and the nectary is at the base of this tube. An insect with a relatively long tongue can reach the nectar at the base of the tube but a short-tongued insect cannot. Three of the four species of bumblebees present in New Zealand have tongues long enough to reach the nectar of any variety of clover yet produced and this becomes increasingly important with the production of the new tetraploid clovers with very long corolla tubes. The fourth

species, *B. terrestris,* has workers (the bulk of the pollinator force) with tongues which are too short to reach the nectar easily via the mouth of the corolla tube, so they resort to "robbing". They bite a hole in the side of the corolla tube adjacent to the nectary and thus obtain the nectar without contacting the sexual parts of the flower and hence not effecting cross-pollination. The queens of *B. terrestris* are, however, much larger and their tongues are long enough to reach the nectar via the mouth of the corolla tube, and young queens, although relatively few in number compared with the workers, do work red clover in late summer and thus effect cross-pollination. In addition, all castes of *B. terrestris* that gather or eat pollen must obtain it via the mouth of the corolla tube and thus transfer pollen from flower to flower and effect cross-pollination.

Thus, although *B. terrestris* is less efficient as a pollinator of red clover than the other three species, it does effect some pollination of this crop. It is, moreover, in most districts by far the most populous species and by weight of numbers alone must account for a fair proportion of red clover pollination, even if

TABLE 1: COMPARATIVE EFFICIENCY OF BUMBLEBEE SPECIES AS POLLINATORS OF RED CLOVER AND LUCERNE IN N.Z.

Species	*Tongue Length*	*Pollination Efficiency*	
		Red Clover	*Lucerne*
B. hortorum	Long—av. 16.6* mm	-Very efficient at all times	Minimal—obtains nectar, from side of flower without tripping the flower
B. ruderatus	*Long-circa* 14.5†	ditto	ditto
B. subterraneus	Long-av. 13.7* mm	ditto	ditto
B. terrestris	Short-av. *10.2"* mm	"Robs" flowers mostly-when not "robbing" effects pollination	Very efficient at all times -always "trips" flowers

* Ref. A. D. Brian (1954), figures used are those of Stapel (1937).

† Measurements not available but, from observation in the field and of museum specimens, a tongue length intermediate between that of *B. hortorum* and *B. subterraneus* is indicated.

only a fraction of the population contributes towards the transfer of pollen. All castes of all the other species have long tongues and none "robs", consequently all castes effect cross-pollination when visiting red clover flowers while collecting pollen or nectar.

The pollination of lucerne, however, presents a different picture. The flower of lucerne is so constructed that the staminal column is held under pressure within the keel and requires the pressure of a relatively heavy insect on the keel to trip the flower and release the staminal column which strikes the insect visitant and pollen transfers from the plant to the insect and vice versa. Flowers that are not tripped do not set seed (Hadfield and Calder, 1936). All bumblebees are heavy enough to depress the keel if they alight on it and effect tripping. It is, however, possible for a bumblebee to obtain nectar from lucerne without tripping the flower if its avoids the keel when alighting on the flower and inserts its tongue between the standard and wing petals. Nectar gatherers of the long-tongue species learn this method and all castes practise it, whereas *B. terrestris* does not (Gurr, 1955). Table 1 sets out the relationship between species, tongue length and efficiency as pollinators of the two crops, red clover and lucerne.

REVIEW OF RESEARCH ON BUMBLEBEES IN NEW ZEALAND

A chronological review of the research done on bumblebees in New Zealand reflects very accurately the changing attitudes towards the problem of pollination in the two crops under discussion. When concern was first felt for the need to do something about the unsatisfactory seed yields, it was found that even the identification of the species established was in doubt. In spite of this, introduction of new species was strongly advocated. This state of affairs continued until the 1950s.

In 1914, Hopkins published a paper on the history of the bumblebee in New Zealand, its introduction and results. Next, in 1941, a Masterate thesis at Lincoln College (McBurney, 1941, unpublished) dealt with the part played by bumblebees and honeybees in seed setting of red clover and in 1948 two surveys to determine the status of bumblebees in New Zealand were conducted by Dumbleton (1949) and Montgomery (1951).

Another survey was initiated by the author in 1952 to investigate the basic entomological factors affecting seed set in red clover and this is still continuing. This investigation was initially concerned with determining which species were present, their distribution, and relative abundance. Previous publications seemed

to be contradictory and this survey established (Gurr, 1957b, 1964) that four species were present and not three as claimed by Dumbleton (1949), and Montgomery (1951), or five as claimed by McBurney (1941). The survey has shown the distribution of the species and their relative abundance (Gurr, 1964).

Then in the 1950s attention was turned towards biological investigations. Cumber (1953a, 1953b, 1954) published three papers dealing with life-cycles and ecology of bumblebees and related these to yields of red clover seed in New Zealand. The efficiency of *B. ferresfris* as a pollinator of lucerne was investigated (Gurr, 1955) and the seasonal availability of food and its influence on local abundance of species of bumblebees were studied (Gurr, 1957a).

About this time attention was focussed on the relative effectiveness of honeybees and bumblebees in the pollination of Montgomery red clover by Forster and Hadfield (1958) and again in the early 1960s by Palmer-Jones *et* ***al.*** (1966).

The pollinating activities of bumblebees and honeybees in relation to temperature, competing forage plants, and competition from other foragers were discussed by Wratt (1968).

General aspects of red clover and lucerne pollination and life cycle and other ecological factors are discussed by Gurr (1961, 1962) and aberrant life-cycle data for two species, ***B. ruderatus*** and *B. hortorum*, were recorded by Gurr (1973). The end of the 1960s saw the first attempts at local enhancement of population of bumblebees. An account of the introduction of bumblebees in North Island, New Zealand, was given by Gurr (1972) and the results of an attempt to increase bumblebee densities in red clover seed production areas are given by Clifford (1973).

PROSPECTS FOR THE FUTURE AND MANAGEMENT OF BUMBLEBEE POPULATIONS TO INCREASE SEED YIELDS OF RED CLOVER AND LUCERNE

The initial solution to the problem of negligible seed set in red clover proved to be the introduction of suitable pollinators, in this case bumblebees. The immediate effect was a spectacular success. High yields were soon produced. When, however, these yields were not universal or sustained, the immediate reaction was, and has continued to be to the present day, to advocate the introduction of more species in the hope that they will, in some sort of cumulative manner, increase the pollinator population.

The second liberation of additional species in 1905 did result in the establishment of two new species but no record exists of

any resultant increase in seed yields. This is not to say, however, that they did not have an undisclosed effect on seed set.

In 1948 a projected introduction of new species was cancelled after the collection in England of some 400 queens of suitable species was ready for shipment. The refusal of permission to make the introduction was on the grounds that they might introduce the acarine disease of honeybees, This caution was understandable at that time, especially with the limited knowledge of the epidemiology of the disease and the importance of the honey industry in New Zealand. Modern techniques for laboratory rearing of insects and initial isolation and inspection of newly introduced species may now, however, make it possible to ensure disease-free stock for liberation, so these objections to the introduction of new species are no longer valid.

With the present knowledge of the biology of the species already here, the possible interplay between the established and newly introduced species can only be a matter of conjecture, as would be the overall effect on pollination. It would seem, therefore, to be more prudent to study actively the ecology of the present species so that better prognostications could be formulated for the effect of new introductions.

When all the factors that go together to produce harvested seed are considered it may well be found that in some areas the maximum pollinator efficiency is already an accomplished fact. There are now four species of bumblebees present in New Zealand and from time to time and in certain areas they can provide pollination required for high yields of seed in both red clover and lucerne. In other areas, yields are patently unsatisfactory and inadequate pollination may be the determinant. If it is, the manipulation of the local bumblebee population may be possible to improve the situation.

Manipulative techniques involve either modification of the environment, both physical and organic, or population enhancement. The two environmental factors that are the most obvious limiting factors in the population cycle of bumblebees are availability of nest sites and availability of food at the critical period when queens first emerge from hibernation and when they are nest founding.

The provision of artificial nest sites in the field has so far met with only limited success. Although some nest boxes or domiciles are accepted by queens (between 20 and 47% in the experiments carried out in northern hemisphere countries reviewed by Holm, 1966) the size of colonies produced, or unpredictability of accep-

tance, has not justified the effort required to provide them. Not enough pollinating insects are added to the local population to make a significant effect on seed set for the ordinary seed grower. The grower can, however, provide nest sites and spring food for the local population by growing small plots of nectar-producing flowers or flowering trees and shrubs and ensuring that small areas of suitable uncultivated land are left for the bumblebees to hibernate and nest in (Gurr, 1957a).

The most promising development in relation to local enhancement of bumblebee populations is the spring introduction of queens. Clifford (1973) demonstrated that a threefold increase in local peak population densities (from 2000 to 6000 bees/ha) was achievable in three successive years simply by' spring introduction each year of approximately one hundred queens. Furthermore, there was no apparent carry-over effect from year to year, and, when no further queens were released in the area, peak density fell to near its former level. The significance of this aspect assumes great importance when one considers the relative merits of long-tongued and short-tongued bumblebees as pollinators of red clover and lucerne. This enables the selection of the appropriate pollinator for the crop and, if required, a change from season to season to suit the crop. This facility to vary the population size and species composition from season to season introduces a degree of precision into the process-an element seldom available to the applied population biologist.

It is obvious from the brief review of the research to date that much remains to be learnt about the biology of both the pollinators and the plants to be pollinated. Of most importance for the future of manipulation of populations is more knowledge of seasonal cycles of food requirements and especially of the availability of food at the crucial period in spring when nest establishment takes place; of nest site preferences and availability; of individual nest size and composition; of seasonal cycles of caste production and the factors affecting this phenomenon; in short, a thorough knowledge of the species-specific ecology. For the immediate purposes of seed production, a thorough knowledge of the local situation is most necessary; the local population cycle and species composition are of prime importance in timing of flowering of the crop to coincide with the advent of the maximum pollinator force. These factors are especially important to plant breeders in the increase phase of development of new strains of crops. Diurnal rhythms of each caste. in pollen collection and their relative contribution to this task are of interest even if only to make inter-

specific comparisons of the efficiency as pollinators of the different species.

Floral preferences and competition between, crops and wild plants must obviously be considered when formulating management@ procedures. This knowledge is essential to the individual seed grower if he is to make a serious attempt to encourage wild pollinators in the immediate vicinity. of his property and then make the most efficient use of the augmented pollinator population when he wants it for pollination of his seed crops. On a much greater scale it is essential to those concerned with major environmental undertakings-e.g., choice of the appropriate clover to sow on construction scars in areas where major civil engineering schemes are taking place. The right choice could enhance the local pollinator force by providing food at a critical time in the life *cycle-i.e.,* early in the season. It should, however, not be in flower when the seed crop clovers are needing the services of the pollinators. Decisions of this nature could profoundly affect the whole seed growing industry in an area such as the Mackenzie Country.

This very brief account of but one group of pollinators affecting seed production of these two crops merely indicates the complexity of the problem. It discusses only one factor in the chain of events which determine the final seed yield. The skill of the plant breeder, the agronomist and the farmer all contribute. Only by constant research and communication of the findings will the very desirable improvement in seed yields be achieved.

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APPENDIX*

The following key and diagram (after Dumbleton (1949) but altered and added to) give the salient differences between the queens of the four species of bumblebees now known to be present in the South Island of New Zealand. The workers do not show the characters so clearly. In cases of doubt, the queens may be identified by the structure of the inner projection of the sting sheath and the males by the structure of their genitalia. These structures are figured by Richards, 0. W., 1927. The specific characters of the British humble bees (Hymenoptera). *Trans Ent. Soc. Lond., 75: 233-68.*

KEY TO BOMBUS SPECIES IN NEW ZEALAND

(1) A single (anterior) yellow band on the thorax, a prominent broad yellow band on the second abdominal segment, posterior third of 4th and the whole of 5th abdominal segment tawny, short tongued .... ***B. terrestris***

Two yellow bands (anterior and posterior) present on the thorax, long tongued ***2***

(2) Anterior and posterior yellow bands on thorax of equal width, yellow coloration on abdomen confined to 1st abdominal segment and most strongly developed laterally, always interrupted in the middle by more or less black, the posterior margin of 3rd abdominal segment white laterally, 4th and 5th abdominal segments white ***B. ruderatus***

Posterior thoracic yellow band narrower than anterior one, yellow band on abdomen occupying the whole of 1st abdominal segment and extending onto anterior margin of 2nd abdominal segment, bands bright lemon yellow, posterior margin of 3rd abdominal segment white laterally, 4th and 5th abdominal segments white, coat uneven and longer than in *ruderatus,* head more elongated than other species, nearly twice as long as it is broad .... ***B. hortorum***

Posterior thoracic yellow band narrow, half the width of anterior, anterior yellow band invaded in the middle of the hind margin by a darker area, yellow colour on abdomen, confined to lateral margins of 1st and posterior margins of 2nd and 3rd abdominal segments, 4th and 5th abdominal segments white, coat short-very short on basal segments of abdomen, head shorter than *ruderatus* ***B. subterraneus*** ssp. *latreillellus*

* Reprinted from *N.Z. Jl Sci. Technol., 38A:* 997-1001 (1957).

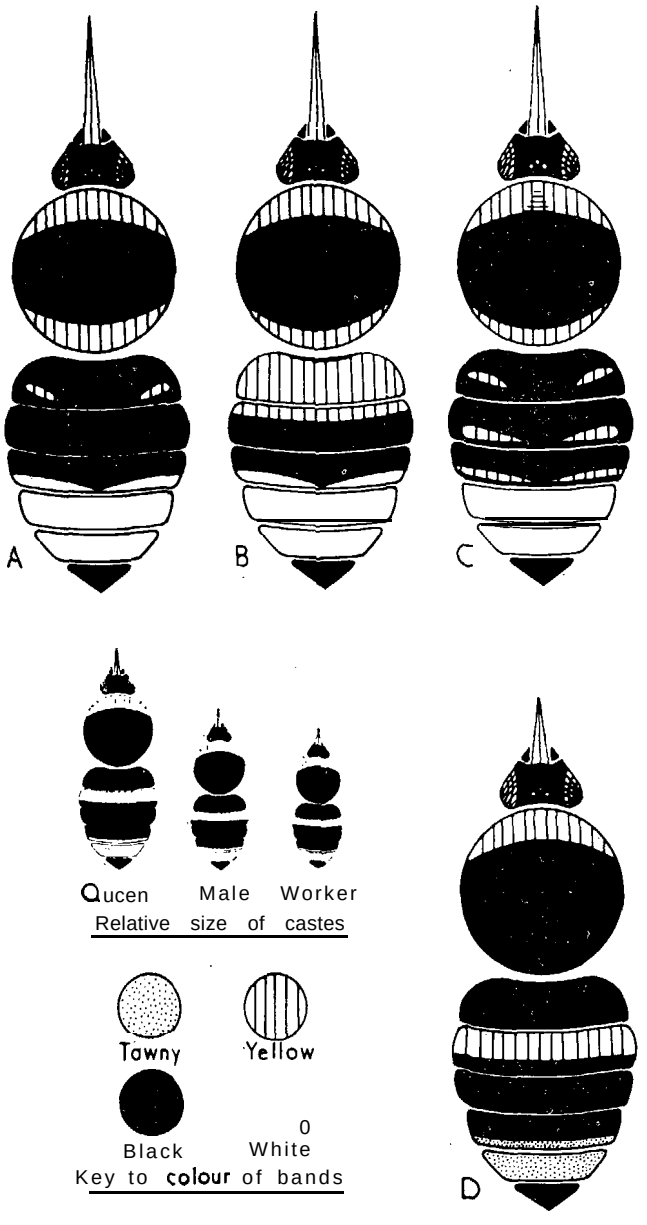

FIG. 1: A. *B. ruderatus.* B. *B. hortorum.* C. *B. subterraneus* ssp. *latreillellus.* D. *B. terrestris.*