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Whatawhata Hill Country - Study site Long 4A is visible at centre background.

TAXONOMIC, BIOLOGICAL, POPULATION DYNAMICS AND BEHAVIOURAL STUDIES ON SOD WEBWORMS (LEPIDOPTERA : PYRALIDAE : CRAMBINAE AND SCOPARIINAE) OF SOME WAIKATO (NEW ZEALAND) HILL COUNTRY PASTURES.

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A thesis submitted in fulfilment
of the requirement for the
Degree of Doctor of Philosophy
in Biological Sciences at the
University of Waikato,
New Zealand.   1982

ABSTRACT

New Zealand has a rich fauna of sod webworms (Lepidoptera: Pyralidae: Crambinae and Scopariinae) which have been implicated in sporadic outbreaks of pasture damage. This study investigates sod webworms of south-facing hill country slopes of some Waikato pastures. Four aspects are considered: taxonomy of the species present; some features of their biology; population dynamics of *Eudonia sabulosella* (Walker) (the most common species); and adult behaviour, especially flight.

Taxonomy is detailed for male and female adults (with accompanying genitalia figures) and for eggs, larvae and pupae where available. Nine species are involved: *Orocrambus flexuosellus* (Doubleday), and *O. vitellus* (Doubleday) (Crambinae); *Eudonia psammitis* (Meyrick), *E. sabulosella* (Walker), *"Scoparia" bisinualis* Hudson, *"S". diphtheralis* Walker, *"S". halopis* Meyrick, *"S". philerga* Meyrick and *"S". submarginalis* (Walker).

A summary of meteorological data including soil moisture content, soil temperature, air temperature, relative humidity and rainfall is given for the main study sites.

Life cycles and generation times with information on the duration of adult seasons are presented for each species. Habitats of eggs, larvae, pupae and adults are defined and selection of oviposition sites by female *Eudonia sabulosella* is investigated. Studies are made on food types, larval growth rates and adult reproductive maturity. Longevity of adults, mating frequencies and female fecundity (taken as the number of eggs found in dissected field collected females) are measured. Egg fertility and viability as well as egg incubation times are investigated.

Life tables are presented for *Eudonia sabulosella* on hill country pasture. Key factor analysis is undertaken to identify major mortality factors. Parasitism by *Aucklandella geiri* (Ichneumonidae) and arthropod and avian predation on sod webworm larvae are studied. Pathogen infection of *E. sabulosella* by nematodes (some of which were *Steinernema bibionis* Wouts *et al.*) and a neogregarine protozoan (*Mattesia* sp.) is investigated. Effects of the protozoan on host size (body weight and length) and female fecundity are measured. Median lethal doses of pathogen are presented for larvae and pupae. Methods of protozoan transmission are discussed.

Adult flight activity is interpreted in relation to air temperature, humidity, rainfall, barometric pressure, wind speed and direction, cloud cover, lunar cycle, reproductive state of the adult, time of day, species and sex. Susceptible pastures are indicated. An understanding of some of the factors affecting the sporadic (temporal and spatial) occurrence of sod webworm infestations has been gained.

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CHAPTER ONE

INTRODUCTION

Pastoral production occupies a significant position in the New Zealand economy achieving some 75% of export earnings. In recent times there has been a shift from agriculture to horticultural crops which at present return higher financial benefits per unit area. As a result of this, much lowland pasture has been converted to horticulture with increasingly more pastoral farming being forced on to hill country. Much of New Zealand's grassland occurs on hills. White (1973) reported that of a total 8 million hectares of sown pasture, over 4.5 million hectares occurs on unploughable hill country. Such land has limited vehicular accessibility which means that stocking levels must be set below the limits of grass production since supplementary feed is difficult to distribute (Pottinger, pers. comm.). It follows therefore that any pasture damage due to the feeding of insect pests has a serious effect on the hill country farm. Damage becomes manifest in many ways as in reduced stock feed; changes in the pasture composition due to selective removal by insects of certain grass species; accelerated erosion caused by reduced plant cover; and deleterious effects on stock condition and health. Hill (1975) stated that the natural control of a population is upset by the practice of agriculture. According to Pottinger (1973) this creates disrupted, simplified ecosystems. The inherent grassland pests frequently reach economic levels of injury.

Hill (1975) defined a pest in the widest sense as "...any animal which harms or causes damage to man, his animals, crops or possessions, or even just causes him annoyance...". In the assessment of pest status economic injury levels and economic thresholds are established. The economic injury level is the lowest population density which will cause economic damage (Stern *et al*. 1959) and this is dynamic since it varies from crop to crop, season to season and area to area. The economic threshold is the population density at which control measures should be started to prevent an increasing pest population from reaching the economic injury level (Stern *et al*., 1959). Control measures aim to suppress the population below the economic injury level. The present study is one of the first to investigate the impact of an insect pest on hill country in New Zealand. The insects involved are commonly known as sod webworms. They are native lepidopterans belonging to the Pyralidae. Under certain conditions they attain some importance as pests of grasslands since the larval stage is phytophagous. Pottinger (pers. comm.) estimates that

500 hectares of North Island pastures are infected with sod webworms resulting in 50% pasture losses. However, the situation is complicated by characteristically sporadic outbreaks (see Stirrett and Arnott, 1931). In New Zealand there have been no studies on the pest status of sod webworms.

The Pyralidae is the largest and most varied family of the Pyralidoidea (Munroe, 1972) and is well represented in forest, prairies, swamps and deserts. Sod webworms are a complex of insects belonging to two subfamilies, Crambinae (also known as grass moths) and Scopariinae. These subfamilies are widespread in distribution and New Zealand is especially rich in this fauna. Both Hawaii and New Zealand show marked degrees of endemism. Of the 55 crambine species (belonging to five genera) represented in New Zealand, 49 are endemic. *Orocrambus* Purdie (48 species) and *Maoricrambus* Gaskin (monotypic) are also endemic (Gaskin,1975a). The Scopariinae are represented by at least 120 species (Dugdale, pers. comm.). The endemic development is mainly specific (Meyrick 1885). *Eudonia* Billberg and *Scoparia* Haworth are represented in New Zealand.

Recently Gaskin (1975a) revised the taxonomy of New Zealand Crambinae. Gaskin (1975b) also studied ten of the *Orocrambus* species in more detail providing information on life cycles and taxonomy of the immature stages. However, in the majority of cases for the Crambinae and virtually all of the Scopariinae, immature forms are unknown (see Hudson,1928, 1939). The taxonomy of New Zealand Scopariinae is based on phenotypy of the adult wing (Meyrick,1885, 1901, 1905, 1909; Philpott,1915, 1917, 1924, 1926, 1927, 1928, 1929, 1930; Hudson,1923, 1928, 1939). Meyrick (1885) accurately summarized the state of the Scopariinae as follows: "...Owing to the small range of colour, and great similarity of markings, which are moreover in most of the species more or less confused and ill-defined, being composed of black, white and grey scales variously blended, the group is a difficult one either to study or to describe...". A real need therefore existed for detailed taxonomic studies on Scopariinae especially those implicated in hill country pasture damage. Wherever possible, any sod webworm larvae sampled during the course of this study were reared to adults for taxonomic verification. Such studies provided both biological and taxonomic information on the different crambine and scopariine species encountered.

Overseas research on sod webworms has been widespread in response to pasture or crop damage. Most work has been carried out in the United States of America with some studies in Australia, Mexico, and the United Kingdom. Significant contributions to the literature have been made by

Ainslie (1916, 1917, 1923, 1927); Bohart (1940; 1947); Wallace and Mahon (1952); Gair (1964); Pass (1965, 1966); Banerjee and Decker(1966a, 1966b); Crawford (1966, 1967, 1968, 1970a, 1970b), Banerjee (1967a, 1967b, 1967c, 1968, 1969a, 1969b); Kamm (1970, 1971, 1972, 1973); Matheny and Heinrichs (1971, 1972, 1975); Quinlan (1972); Reinert (1973, 1974, 1976) and Krehoff (1974). In all cases the insects belonged to the subfamily Crambinae. Most of the research has involved studies on biology with emphasis on the determination of controlling agents. Munroe (1958, 1964, 1972, 1977) has worked extensively on scopariine taxonomy in particular the adult genitalia. Most other work on Scopariinae refers to descriptions of new species but no evidence of any biological work has been found. From that aspect then the Scopariinae component of the present work is unique.

Through biological studies it is possible to gain information on population dynamics. Richards (1961) defined population dynamics as dealing chiefly with ..."short-term fluctuations, especially annual ones, in which climate certainly plays a dominant part, though it often also acts indirectly through biotic agencies"... Ecological life tables are useful in the study of insect population dynamics. Although by themselves life tables provide a description of events in the population, an insight into population fluctuations can be gained by coupling them with an understanding of the mortality factors which affect insect numbers. Such systems of investigation are essential for the assessment of pest status since they elucidate the significance of present controlling agents on insect numbers. This was the approach taken for the study of sod webworms in hill country pasture. During the course of the investigation fluctuating insect numbers meant it was necessary to shift the study plan emphasis. The value of having a flexible programme was fully appreciated.

Adult activity, especially flight behaviour, is related to population dynamics as immigration and emigration both affect subsequent population levels. Joyce (1976) stated that ..."It appears that numbers of insects adequate to constitute, or cause, an outbreak can derive from concentration by wind-fields and not depend on absolute population increase"... Studies on adult flight behaviour especially in relation to weather conditions were therefore carried out to help in understanding why populations increase in certain areas. Williams (1935, 1939, 1940) pioneered extensive light trapping investigations giving information on species composition, flight periodicity, sexual differences in flight and the effect of weather. Ainslie (1917), Williams (1935, 1939, 1940), Cumber (1951, 1960a, 1960b), Crawford and Harwood (1959), Gaskin (1964, 1970), Banerjee (1967a) and Heinrichs and Matheny (1970) reported on light trapping of Crambinae and Scopariinae. However, since light traps rely on the disturbance of normal behaviour for their functioning (Southwood 1978) other means of investigating adult activity were also utilized to provide information on the regulating factors.

One of the problems in assessing the impact of an insect pest is in determining the level of damage that can be tolerated. As stated previously pest status is dynamic, and as Hill (1975) remarked it requires a thorough understanding of the life systems of the pest so that ecological and economic consequences of any action can be predicted. The goal is to design a technology that is mostly self-operating with minimum input (Huffaker *et al.* 1978). As far as possible the present study aims to achieve this for sod webworms on hill country pasture.

In summary, the objectives of this study were:

(i) to identify the sod webworm species implicated in hill country pasture damage and elucidate their importance.

(ii) to provide biological and population dynamics information, at least for the most important species.

(iii) to indicate the type and importance of any mortality factors affecting sod webworm populations on hill country pasture.

(iv) to investigate adult behaviour, especially flight in relation to meteorological events, and thus identify susceptible pastures.

(v) to aid in understanding the sporadic (temporal and spatial) occurrence of sod webworm damage.

(vi) to establish a fundamental basis for further research.

CHAPTER TWO

SAMPLING LOCALITIES AND METHODS

The study was carried out from August 1978 to December 1981.

GENERAL SPECIMEN LOCALITIES

Most of the sampling was based in the Waikato (WO) with small amounts of collecting in other regions e.g. Auckland (AK) and Kaimai (BP). Specimens were received from Whangarei (ND) (Mr L.N. Robertson); the Central North Island Volcanic Plateau (TO) (Mr E.H.A. Oliver); Balclutha (SL) (Dr B.I.P. Barratt and Dr R.P. Pottinger); and Rocklands (CO) (Dr B.I.P. Barratt). Abbreviated specimen localities refer to the codes defined by Crosby *et al* (1976).

Main Sampling Localities

(Refer map of site locations in Appendix I.)

During the winter of 1978 much damage to pasture occurred around the Waikato. This was caused by feeding of sod webworm larvae on grass foliage. The damage was particularly marked on steep slopes with a southerly aspect (see Plates 1-2). On the basis of the observed pasture defoliation several study sites were established. Three, on the Ministry of Agriculture and Fisheries Hill Country Research Station at Whatawhata (WO), 30 kilometres west of Hamilton, were selected for regular sampling. These sites were parts of the Wilsons 2A, Wilsons 2B, and Long 4A paddocks (see Plates 3-5) and were fenced off in late November 1978. Grazing pressure was thus manipulated to gauge its effect on sod webworm populations.

The pasture type in each area consisted of a predominantly rye grass *(Lolium perenne L.)*, clover *(Trifolium repens L.* and *T. pratense L.)*, mixture with oversown browntop (*Agrostis tenuis Sibth.)* and a ubiquitous basis of mosses *(Sphagnum* spp.). Lotus (*Lotus pedunculatus Cav.*) was also present at Wilsons 2C. Each site contained numerous foxglove plants, tree stumps and clumps of rushes (*Juncus* spp.) as well as dandelion (*Taraxacum officinale* Weber). There was a stand of 15 metre high gum (*Eucalyptus* spp.) trees just north of Wilsons 2A. Wilsons 2B had three poplar (*Populus* spp.) trees (three metres high) within the fenced area and a ten metre high kahikatea (*Podocarpus dacrydioides)* near the western boundary. A 15 metre high kahikatea stood by the southern boundary of the Long 4A site. Thistles *(Cirsium vulgare (*Savi*)*. Ten) were selectively removed whenever they appeared.

Plate 1: Damage to south-facing hill country slopes by sod webworm feeding. Damage is confined to the sloping intertrack strata between green stock tracks. This view shows the Te Kowhai study site in September 1978. Hart's property is to the right and Mortimer's to the left of the boundary fence.

Plate 2: Close-up of damage to an intertrack stratum. Note bare patches caused by larval denudation of vegetation. There is also some die back of affected plants since these are attacked at the bases by sod webworm caterpillars.

1

2

Plate 3: Wilsons 2A study site with emergence traps in position. Note the weedy appearance of the unattended foreground.

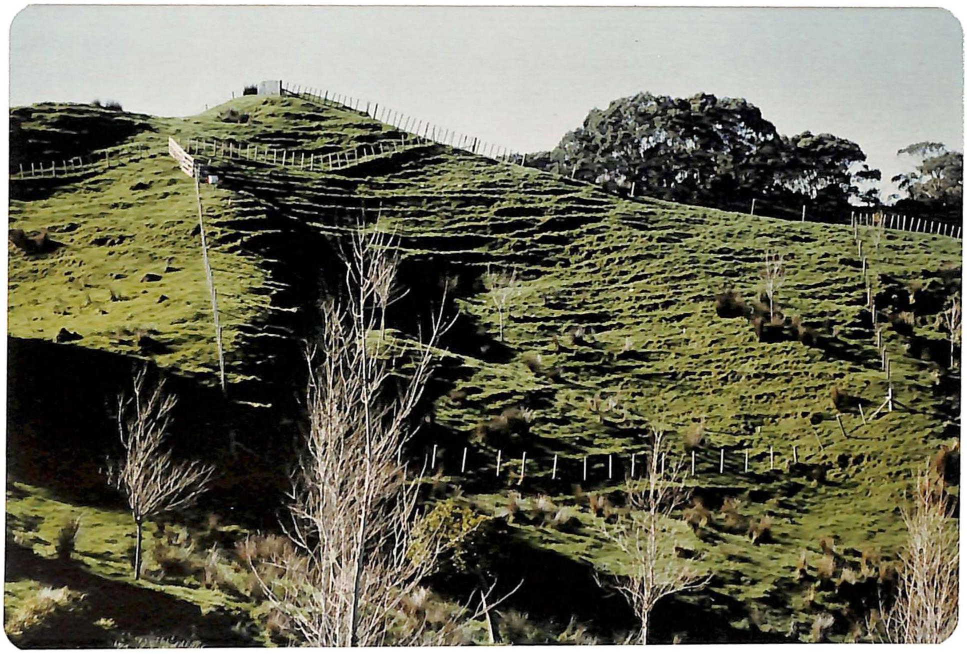


Plate 4: Wilsons 2B study site. This photograph was taken at 1330 hours in mid winter and shaded regions were places of most extensive sod webworm damage in 1978.

Plate 5: Long 4A study site.

The Wilsons 2A site measured 1660 square metres and was of S-SE aspect with a gentle slope (15-25°). The effects of stock tracking were moderate. Ratio of track: intertrack (between track) areas was 1 : 1. The Wilsons 2B site measured 1740 square metres and contained two ridges with SW-SE aspect and a gradient varying from 25-50°. Stock trackings were distinct. Ratio of track: intertrack areas was 1 : 2. The Long 4A site measured 5220 square metres, the large size being a result of the difficulties in fencing hill country. The fence was selected to run around the bases of two hillocks. Again the aspect was SW-SE and gradient varied from 20-55°. The effects of stock tracking were distinct. Ratio of track : intertrack areas was 1 : 2. All sites have a steepland yellow-brown earths (probably Waingaro steepland) soil type and the pasture had been oversown 4-5 years prior to commencement of the study.

Prior to fencing in November 1978 both cattle and sheep grazing had been used in all areas. After fencing it was decided to use sheep grazing only since the areas were relatively small. Cattle trampling could have been extreme under such conditions.

Study sites were also established at Marwood Road Te Kowhai (WO), 25 Kilometres west of Hamilton, on adjacent farms owned by Mr P.H. Mortimer and Mr D. Hart (see Plate 1). Again, these were selected on the basis of pasture damage during the winter of 1978. Two contiguous sites, along the boundary of two farms, were chosen. The western site was on Mortimer's farm; the eastern site on Hart's farm with a fence separating the two. Both sites were of SW-SE aspect and had gradients ranging from 25-50°. Stock trackings were distinct. Ratio of track : intertrack areas was 1 : 2. The pasture was perennial rye grass (*Lolium perenne*) - clover (*Trifolium repens* and *T. pratense*) with oversown browntop (*Agrostis tenuis)* and patches of a mossy (*Sphagnum* spp.) basis. The soil type is brown granular loam (probably Hamilton clay loam).

The sites each measured 1000 square metres but were not fenced off from the surrounding pasture. Cattle grazing was used on both farms. Initially Hart's property was grazed lightly, but from March 1979 it was intensely grazed. Mortimer's property was grazed intensely throughout the study. The sites were selected as a measure of different grazing pressures by cattle during an ongoing farm management regime. The pasture was 10-15 years old at commencement of the study.

Minor Specimen Localities

Sampling was carried out in other paddocks both on the Whatawhata Hill Country Research Station and on the two Te Kowhai farms. A third farm at Te Kowhai, owned by Mr D. Steele was also investigated. Sheep and cattle grazing was used and the property was immediately north of Mortimer's and Hart's. All these samplings were made irregularly as they were scouting estimates to locate populations of sod webworms.

A farm at Wilton Road, Ngaruawahia (WO), owned by Mr Little, and adjoining a Lands and Survey Department forestry area, was checked for sod webworms on several occasions. This land was very hilly with distinct stock tracking and was grazed by sheep and cattle. The soil type belongs to the yellow-brown earths group (probably Kaawa hill soils and Waingaro steepland soils) and the pasture was more than 20 years old. Damage was evident on all SW-SE slopes during the 1978 winter. Again, there was a ubiquitous mossy basis in a ryegrass-browntop-clover sward.

A farm at the summit of the Kaimai Range (BP), 595 metres above sea level, beside a New Zealand Post Office transmitting station was also used for collection of sod webworms. Contact with the farm owner, Mr W. Burchett, was established via David Steele, a Ministry of Agriculture and Fisheries Advisory Officer. The farm was hilly with numerous southern slopes. Mosses (*Sphagnum* spp.) were ubiquitous and prolific. The oversown pasture consisted of browntop (*Agrostis tenuis Sibth*), sweet vernal *(Anthoxanthum odoratum L.*) yorkshire fog (*Holcus lanatus L.*) and lotus (*Lotus pedunculatus* Cav.). State forest formed the southern limit of the farm with many patches of regenerating native bush, especially along gullies. The soil type is yellow-brown pumice (probably Mamaku sandy silt). Sheep grazing was used and stock tracking was only moderately defined since most of the hillocks were of gradual slope (15-25°). The southern pastures were 1-2 years old.

Collection of sod webworms was carried out at two of the golf courses around Hamilton - St. Andrews, five kilometres north of Hamilton; and Westlands, ten kilometres west of Hamilton. St. Andrews is adjacent to the Waikato River and has a man-made (Tamahere gravely sand) soil. There are numerous established trees both native and exotic, and a ubiquitous mossy substrate which was especially marked to the sides of the greens and fairways. The Westlands Golf Course has a clay (probably Whatawhata clay loam) soil type and supported little moss. Both courses had a predominantly ryegrass-browntop sward and are sprinkle-irrigated during summer.

Collecting trips were made to the Ministry of Agriculture and Fisheries experimental farm at Eureka Road, Matangi, 15 kilometres east of Hamilton. This land is relatively flat and has strictly controlled grazing regimes using sheep and cattle. The pasture was ryegrass-clover dominant and the soil type is clay (probably Te Kowhai silt loam).

Adult sod webworm were collected around privately owned residences at Hamilton East and Hillcrest (two and five kilometres east of Hamilton, respectively) and at Mission Bay and St. Heliers (seven and ten kilometres east of Auckland, respectively) by myself and Dr D.R. Cowley.

Collected by Others

Specimens of sod webworm larvae were obtained from four people. Dr B.I.P. Barratt provided specimens from pitfall trapping in tussock country at Waipori (CO) (520 metres above sea level) and Rocklands (CO) (800 metres A.S.L.). Dr Barratt and Dr R.P. Pottinger have both provided larvae from the Balclutha Golf Course (SL) which is adjacent to the Clutha River and on sandy-loam soil. This course is browntop dominant with a strong moss cover and numerous exposed SW and SE slopes. The greens are sprinkle-irrigated during the summer months.

Mr L.N. Robertson provided sod webworm larvae from soil samples collected at Whangarei (ND) and Mr E.H.A. Oliver, larvae from soil samples collected around the pumice country of the Central North Island Volcanic Plateau (TO). Mr RAJ. Mennink supplied several sod webworm adults from Hamilton (WO) and Taumaranui (TO).

Sampling Periodicity

Sampling trips were made to the Whatawhata sites at least once every week from August 1978 to February 1981. After this time and until December 1981 the sites were visited each four weeks. Te Kowhai was sampled at least once every week from August 1978 to December 1980.

Little's farm, Ngaruawahia, was visited each 5-6 weeks during September to November 1978 and June to September 1979. Collecting trips were made to Burchett's farm, Kaimai, in June, July, November and December 1980, and in January 1981.

The St. Andrews Golf Course was sampled each two weeks from July 1980 to February 1981. The Westlands Golf Course was sampled in July 1980. Matangi was visited in September and October 1978, July 1980 and July 1981. Collections of adult sod webworms from Hamilton East, Hillcrest, Mission Bay and St. Heliers were made daily during September to May each year.

Larvae from Rocklands and Waipori were collected from July to October 1977; those from Balclutha related to July to September 1980; from Whangarei - September 1979 and September 1980; and from the Central North Island Volcanic region - July to August 1980 and July to August 1981. Adults from Hamilton and Taumaranui were collected from September 1980 to January 1981.

METEOROLOGICAL INFORMATION RECORDING

Three meteorological recording stations were used. These were established at Wilsons 2B and Long 4A, Whatawhata and at Hart's, Te Kowhai. Each area was enclosed by high tensile mesh fencing to protect the recording apparatus from stock.

Soil Moisture Content

Readings of soil moisture content were made once each week from the three meteorological stations. Two subareas for coring were used at each site to give sunny (and therefore drier) versus shady (wetter) regions. Ten cores, 25mm in diameter and 50mm deep were taken in each subarea - five in the track stratum, five in the intertrack (between track) stratum. Each soil plug was divided into top and bottom halves to give some idea of relative moisture content. Cores were collected into labelled airtight plastic bags and transported to the laboratory. There they were placed in 500 ml manilla brown paper bags and weighed to the nearest 0.01g. The bagged soil was then arranged in trays and put in a "Precision Cabinet" drier at 100°C for 24 hours. After this time they were reweighed to the nearest 0.01g and the resultant percentage weight loss calculated to provide percentage moisture content.

Soil Temperature

Soil temperature readings in degrees Celsius were made once each week (at 0900 hours) at the recording stations, with Zeal 76mm immersion nitrogen filled thermometers (range -10 to +50°C). These were housed in brass holders and were pushed into the soil to a depth of 25mm. This is the depth at which most sod webworm larvae were found and also indicates average daily soil temperature (see Gillingham and Bell 1977). Approximately 15 minutes elapsed before temperatures were recorded. Readings were taken in the intertrack stratum at five different points and averaged even though variations were small.

Air Temperature and Relative Humidity

Recordings of air temperature and relative humidity were made on a standardized seven-day "Trimeight" thermohydrograph. This consists of two probes - one sensitive to air temperature, the other to relative humidity. Although protected by a metal cage, the probes are, nonetheless, open to the surrounding air. Readings are translated to an arm with attached pen which traces the results on to a graph, secured to a rotating drum. A clockwork mechanism rotates the drum according to normal time passage. Once weekly the graph was changed and the clock rewound. The thermohydrograph was housed in a wooden box 750 x 500 x 500mm and set 500mm above the ground on a tanalized post. The box contained numerous ventilation holes to allow passage of air but to protect the apparatus from the full force of the weather. A "Tag-Nacht", maximum-minimum thermometer was included in the meteorological box. Readings were taken once weekly to coincide with thermohydrograph chart changes. Use of the maximum-minimum thermometer allowed for a comparison with thermograph recordings. There was generally little variation between the two.

Rainfall

Rainfall was recorded with perspex "Marquis 600" rain gauges clipped to fence posts using mounting brackets. Two rain gauges were used at each site and were placed one metre above the ground and six metres apart. The two readings were averaged to reduce the effect of errors caused by strong wind (e.g. with the creation of eddies carrying rain away from the gauge). Rainfall measurements could be made directly from the "Marquis 600" rain gauge.

From September 1980 to March 1981 a second type of rain gauge was used. This was the 'professional' sort which consists of an outer open-ended tube into which a smaller one was sited. A funnel was fitted on top of the larger tube to direct rain into the smaller one. The uppermost rim of the funnel was made of brass but the rest of the gauge was of galvanized aluminium. This gauge was set beside the light trap at Long 4A for direct recording of precipitation there. Readings were made whenever the light trap was cleared. Rain was decanted into a measuring cylinder for assessment.

Barometric Pressure

An "Ota Tokyo" barometer was used at the Long 4A site and housed in the James Aviation hut some ten metres from the light trap. Throughout the period of light-trapping a record was kept of barometric pressure in millimetres of mercury (mm Hg). It was also noted whether a change in pressure had occurred, e.g. rise, fall or steady.

Wind

Recordings of wind velocity and direction were made using a hand-held "Ota Tokyo" anemometer. At each light or suction trap resetting three series of 30 second wind speed measurements were made. Direction as indicated by an attached wind vane was also noted. The anemometer records the average speed in metres per second from the rotation of four hemispherical cups. This measurement was converted to kilometres per hour. The average of the three readings was taken to represent wind speed and direction at each trap.

From December 1980 to March 1981 a Lambrecht mechanical anemograph was borrowed from the New Zealand Meteorological Services in Wellington. It was sited two metres from, and at the same height as the light trap (i.e. 1.5 metres above ground) to give direct recordings of prevailing wind conditions. The anemograph was secured on a sturdy mounting. This consisted of a galvanized pipe (2.075m long and outside diameter of 300mm) which was securely nailed to a tanalized post (3m long and 300mm in diameter). The top 75mm of pipe extended above the post. The unit was sunk into the ground to be the same height as the light trap. A level was used to ensure that the arrangement was perpendicular as that is critical for smooth operation of the anemograph wind cups. A 300mm square plywood platform with a central hole was nailed to the post and supported with brackets so that the 75mm of galvanized pipe extruded through the centre. In the base of the anemograph there was a hole with mounting adaptor securing clamp which was tightened around the pipe so that the rest of the base was supported by the mounting platform.

Lambrecht Mechanical Anemograph - Description after N.Z. Meteorological Services wind information leaflet, 1-6-61 to 1-6-71, February 1980. The anemograph consists of a cylindrical body housing the recording mechanism surmounted by two sensing elements. The wind vane and cup anemometer are geared to the recording rollers which are aligned on to a pressure-sensitive wax strip chart. The clock and chart drive mechanism are mounted directly below the recording rollers. The chart is divided into two separate 32mm sections with a 6mm space between. The left section records direction; the right, wind run. By use of the wind speed evaluation ruler, mean speed could be evaluated for any time interval. Instantaneous wind speed including gusts could not be ascertained. The clock spring and chart length cover one month.

Cloud Cover

Cloud cover was assessed during light trapping according to the amount of clear sky visible. Cloud cover of more than 25% was considered "cloudy"; that of less than 25%, "clear". The assessments were made at 2130 hours.

Lunar Cycle

The phase of the lunar cycle was recorded as this may have had some bearing on sod webworm activity.

TAXONOMY

Since little scopariine taxonomy had been clarified, detailed studies of all stages for each species were made. The crambine species encountered were also checked against Gaskin's (1975a) work.

Adults

Scopariinae adults have been variously described on wing characters by Meyrick (1882, 1885); Philpott (1915, 1917, 1928); Hudson (1923, 1928, 1939); Gaskin (1966). However, no work had been done on the genitalia. Adults were identified using the above authors' descriptions, then labelled and placed in a solution of cold 10% potassium hydroxide for 24 hours (Pottinger and Le Roux, 1971). They were then washed thoroughly in distilled water and brushed carefully with sable brushes, soft feathers or forceps as required, to remove scales from around the genitalia. Adults were then dehydrated in a graded series of alcohol for 36 hours, placed in xylene or toluene for another 24 hours and mounted in Canada balsam. Other mountants were used but found to be very unsatisfactory due to the amount of movement and consequent distortion of the specimen as they dried. Left lateral, dorsal and ventral views of female and male genitalia were made. These were then drawn on to graph paper using a binocular microscope with squared eyepiece graticule. The articulations of plates were further checked under a compound microscope and any required adjustments made. Several unmounted specimens were also examined to ensure that any distortions due to mounting had been corrected for.

It is possible to identify female Lepidoptera to species level using the arrangement of the spermathecal duct in relation to the bursa (Munroe,1972; Gaskin,1975a; Dugdale,pers. comm.). Females of each species were therefore dissected and the internal genitalia measured. The length of the sclerotized basal part of the bursal duct was measured as were lengths from exterior opening to origin of the ductus seminis, exterior opening to base of the corpus bursae, and exterior opening to tip of the corpus bursae (or accessory gland where present). At least 20 females of each species were measured. The arrangement of the internal genitalia was drawn using a squared eyepiece graticule and graph paper.

Eggs

Eggs as reared from females of known species were dehydrated in a graded series of alcohols increasing in strength to absolute concentration. They were then placed in xylene/toluene for 24 hours before mounting into Canada balsam, and drawn as previously described. Some eggs were prepared for examination by the scanning electron microscope. These were fixed in 4% glutaraldehyde buffer solution before dehydration. They were then freeze dried and placed on stages for mounting into a Jeol JSM-35 scanning microscope run by Dr C. Beltz, University of Waikato. Photographs were made of the micropylar and non-micropylar ends, general egg shape and aeropyles (cf. Matheny and Heinrichs, 1972) for each species. Aeropylar arrangement and surface sculpturing proved valuable for taxonomic identity. There were many problems with SEM studies, on scopariine eggs in particular. "Drift" occurred at magnifications of around 1000-1500 times. In other words, at higher magnifications the same accelerating voltage as used for low magnifications is confined to a smaller area of the specimen resulting in rapid heating and consequent movement of the surface. Although the photographs obtained are of inferior quality they show taxonomic differences between the eggs of each species.

Larvae

Larvae reared from eggs (i.e. species known) were examined under the binocular microscope. Mounts of the head capsule frontally and left laterally were made as were mounts of mandibles and labrum. Body chaetotaxy was closely examined with measurement of distances between certain chaetae. Any coloration and integumental sculpturing differences were recorded. Drawings of head capsule, mandibles, labrum and left lateral thorax and abdomen were made as described previously for adults.

Larvae fixed in KAA solution for 12 hours and stored in 70% alcohol were most suitable for examination. The KAA was Chu's (1949) KAAD solution without the dioxan.

Pupae

Pupae and pupal exuviae (with identified adults) were drawn using the method as described for adults. Ventral, dorsal and left lateral views were made for males and females of each species.

INSECT SAMPLING TECHNIQUES

EGGS

Mosses and grasses were examined for sod webworm eggs. Small amounts of vegetation were clipped from fields infested with sod webworm adults, transported to the laboratory and immediately searched under a binocular microscope or "Maggi" lamp.

Egg Trapping

Egg trapping was carried out at Whatawhata (Wilsons 2A, Wilsons 2B and Long 4A) during the summers of 1978-79, 1979-80 and 1980-81. Hart's Te Kowhai site was used during the first two summers. Trapping continued until no eggs were recovered for four weeks. Each site was divided into subareas designated according to topography. Wilsons 2A and Hart's each contained one egg-trapping subarea; Wilsons 2B, two; and Long 4A, three.

Traps in each subarea were arranged in parallel in four double rows. Each double row contained a total of ten traps arranged so that five traps, two metres apart, were in the track stratum and the other five traps again two metres apart, were in the intertrack stratum. In each case the egg trap in the intertrack stratum was placed one metre below that in the track stratum. There was ten metres between consecutive double rows. Track and intertack strata were sampled separately in order to ascertain ovipositional preferences.

Egg traps after the design of Pottinger (pers. comm.) were used (see Plate 6). Traps were made from 500 ml white plastic bottles with screwcaps (Plastic Products Moulding Company). The bottles consisted of a 65mm diameter base with a straight tubular section 150mm long at each end of which were 5mm thick circular strengthening ribs. From the top rib to cap the bottle tapered rapidly to 20mm in diameter. The top shaped portion was cut off 30mm below the rib and inverted. The rest of the bottle was discarded once a 15mm thick ring of plastic was cut off the tubular part.

Plate 6: Egg traps with yellow marker flags. Grasses have geen parted and traps slightly raised.

Plate 7: Pitfall trap with cover removed.

Nylon flyscreen mesh (aperture size 1.43mm) was placed across the mouth of the inverted section. The plastic ring was then fitted around the inside circumference of the inverted section to a depth of 10mm. The flyscreen mesh was thus sandwiched at its sides between bottle and plastic ring. Wire was used at four points, equally spaced around the circumference to hold the mesh and plastic ring in place. Drainage holes for the escape of excess water, after rain, were placed 25mm below the lip of the trap.

Approximately 5ml of water was squirted through the mesh into the cap of the egg trap. This was then positioned in an appropriately sized hole in the ground so that its lip was flush with ground level and grasses could be replaced to conceal its presence. Marker pegs were used to indicate the positions of traps. Once every 4-6 weeks when sites were grazed, traps were removed to avoid fouling and damage by stock.

Once weekly traps were cleared. This was a simple operation involving unscrewing the cap from the base of the trap and releasing the contents into a large (1.5 litre) "Agee" preserving jar. The cap was then replaced, fresh water added and the trap repositioned as before. In each subarea the track and intertrack strata egg trap catches were kept separate from each other. The egg trap samples were transported to the laboratory where a few drops of 10% formalin were added. The samples were then sorted by decanting small volumes into a rectangular counting chamber and examing the solution under a binocular microscope.

LARVAE

Soil Sampling

Soil sampling (Healy,1962; Elliott,1973; Southwood,1978) was the main method used for larval collection. Spade squares (150mm x 150mm) to a depth of 50mm were taken. Sod webworm larvae generally inhabit the top 25mm of soil but one larva was found at 40mm, hence the 50mm depth to ensure any such larvae were sampled. A metal frame 3mm thick and inside measurement of 150x150x50mm was used in spade sampling. The frame was sharpened on its lower edges so that it could be driven into the ground then dug out with a spade.

Soil sampling was carried out during the 1978 winter on the basis of line transects. Two transects were taken on each occasion one from the left, the other from the right of each site. The transects were worked from north to south. Ten paired samples were taken along the transect. The second of a pair of samples was always within a radius of 0.5 metres of the first. The distance between consecutive transects was 1.5 metres.

When sampling was instigated in 1978 there was marked damage to pasture caused by sod webworm larvae. Samples from non-damaged areas were compared with those from damaged regions. In 1979, 1980 and 1981, the larval habitat was unknown especially early in the season before any damage had occurred. Soil sampling was therefore carried out on a stratified random basis with proportional allocation to allow for ratios of track : intertrack areas in each site (Elliott 1973; Southwood 1978). Each site was divided into six subareas of equal sizes as follows: - Wilsons 2A, 11 x 12 metres; Wilsons 2B, 12 x 12 metres; Long 4A, 18 x 21 metres. Three paired samples (six turves) were taken in each subarea. The turves were placed in labelled heavy duty plastic bags and transported to the laboratory for extraction of insects.

EXTRACTION TECHNIQUES

Several different extraction techniques were used (Murphy, 1962c; Raw, 1962; Kelsey, 1968; Goldson, 1978; Martin, 1978; Southwood, 1978). Each method was closely monitored for precision relative to time spent achieving this. Generally for soil sampling a 25% standard error of the mean is considered acceptable (Southwood 1978). As far as possible sampling and extraction methods were designed to achieve or better that level.

Heat Treatment

Heat treatment (Martin, 1978; Southwood, 1978) involved the behavioural response of sod webworm larvae to application of heat to the turf. Two "Gallenkamp" 8.7 amp electrical hot plates were used. Each was thermostatically controlled and adjusted by a variable temperature knob. The hot plate measured 400 x 300mm and was 30mm thick. Aluminium foil was placed on the plate in an effort to retain a clean surface and ensure even heating.

Turves were prepared for heating by first clipping off the herbage then bisecting them to hasten heat penetration. The vegetation was examined for arthropods. The turves were then placed on the hotplate and observed so that collection could be made of any animals emerging from the soil as it became heated. Whenever the plates were first turned on it would take 20 minutes for the first turves to be sufficiently heated, but only ten minutes for subsequent ones. The first insects would be driven out after about 15 minutes (five minutes for later turves). After 20 minutes (for first turves; ten minutes for later ones) the turves were removed from the heat and placed inverted on a bench covered with heavy duty polythene. They were left to cool for 15-20 minutes. After this time the moist polythene under each turf was carefully examined for insects and the soil then dry sieved to ensure all specimens had been collected.

Dry Sieving

Dry sieving (Murphy, 1962c; Southwood,1978) does not rely on the behavioural response of an insect for its collection. A series of three sieves of progressively smaller mesh size were used. Aperture sizes were 5.0mm, 3.3mm and 1.67mm. The mesh area measured 300 x 200mm and was set into the base of an aluminium open-ended box frame. The frame sides were 70mm deep with the top 20mm bent out horizontally to form a shelf on which other sieves could be stacked. Sieves were positioned with the largest mesh size on top and smallest mesh size sieve resting on a large white "butcher boy" tray. Each turf was crumbled over the sieves with soil particles and insects retained by the appropriately sized mesh. The catch on each sieve was then hand sorted over a white tray and insects collected and recorded.

Wet Sieving and Flotation

This method (Ladell,1936; Salt and Hollick,1944; Murphy, 1962c; Raw, 1962; Stephenson,1962; Southwood,1978) also does not rely on the insect's behavioural response. A series of sieves as for dry sieving were used. Each turf was crumbled over the top sieve and then washed through using a high pressure hose fitted with an "Aquaspray" hand-held variable pressure nozzle. Sieves and their sediment were then placed into a magnesium sulphate solution of specific gravity 1.12 as measured by a Zeal S15.6 hydrometer. The magnesium sulphate solution was mixed in a ten litre bucket and poured into an aluminum tray 50mm deep and 450mm long by 300mm wide. A wooden spatula was used to gently stir the sediment in case an animal had been trapped under the soil particles. Any arthropods present floated to the surface and were collected.

Aeration and Flotation

Again, this is a method (Southwood,1978) which is independent of the insect's behavioural response. A ten litre plastic bucket containing a solution of magnesium sulphate (specific gravity 1.12) was required. Into the solution was placed a copper pipe 7mm in diameter and 450mm long with 4 holes near its tip. The pipe was connected to a high pressure hose attached by a bayonet fitting to a supply of compressed air (70.37 g/cm² or 10 lb/in²). Air was released into the solution to produce a bubbling effect. The turf was then crumbled into the solution with the result that any arthropods present floated to the surface and were collected and recorded.

Slow Process Saturation

This method (Southwood,1978) uses the insect's behavioural response to artifically raised moisture levels. A slow rate of saturation was used. A series of "Cameron" horticultural trickle lines were set over 150mm square by 200mm deep plastic buckets. The lines were taped to 50 x 10mm wooden slats which rested on the plastic buckets. The trickle lines were made of 10mm diameter black PVC hose and had a series of nozzles placed 300mm apart. The nozzles consisted of brass cups 10mm high by 5mm in diameter. Brass screws placed into the cup were used to vary the rate of water delivery. The lines were attached to a header pipe and hose fed directly from the water supply.

Turves were prepared for slow process saturation by first removing the foliage which was examined for arthropods. The turves were then placed on their sides in the buckets under the trickle lines. One litre of water was slowly dripped on to each turf over a period of four hours. The turves were then left for about four hours before assessment of insect numbers. The sediment and water in each bucket was washed through sieves and placed in magnesium sulphate solution as for wet sieving. The saturated turf was then washed through sieves and treated by flotation to ensure all the animals had been collected.

Staining of the water and sediment produced after saturation was also tried. Rose of Bengal solution and 10% formalin were added to the plastic buckets with turves removed. The stained solutions were left for three days then sorted. The turves were, nonetheless, wet sieved and put through flotation to check that all animals had been collected.

Goldson's Argentine Stem Weevil Technique

The technique used by Goldson (1978) for the collection of Argentine stem weevil (*Hyperodes (=Listronotus) bonariensis*) larvae was used. This involves a behavioural response to artificial drying of grasses, i.e. movement of larvae from an unfavourable environment. The herbage was cut from turves. It was then placed on a wirenetting (aperture size 10mm) mesh supported over a plastic tray 30mm deep and 240mm long by 150mm wide containing glycerine to a depth of 10mm. The prepared labelled trays were then placed in a drying oven at 26°C for 48-60 hours depending on the condition of the grass. Any larvae crawling out of the drying grass would be retained by the glycerine. Whole turves were also placed on the wire mesh and subjected to slow drying in order to investigate the feasibility of slow heat treatment for sod webworm larval collection.

Hand Collection of Larvae

In certain habitats it was possible for larvae to be collected by hand. this was in areas rich in *Sphagnum* spp. moss. Wherever this occurred the soil was usually readily friable and could be easily sorted by hand in the field for sod webworm larvae. When the pasture basis was predominantly exotic grasses the soil was more difficult to sort by hand in the field, hence the spade squares and various extraction techniques described above. For hand collection, regions dense in moss were selected and the mosses simply peeled back. Larvae could be collected from among the mosses and in the top 20-30mm of soil exposed under the moss. This was a feasible means of larval collection at Little's Ngaruawahia; Burchett's Kaimai; and St. Andrews and Westlands Golf Courses, Hamilton.

Pitfall Trapping

During the winters of 1977, 1978 and 1979, Dr B.I.P. Barratt, Invermay (pers. comm.) collected numerous sod webworm larvae while pitfall trapping in tussock country near Dunedin. On the basis of this information it was decided to establish pitfall traps (Fenton and Howell 1957; Thomas and Sleeper 1977; Cameron and Butcher 1979) at the Whatawhata sites in an effort to investigate the mobility of sod webworm larvae there. As well as collecting sod webworms, it would give a representation of the cohabiting pasture arthropod species.

Pitfall traps (see Plate 7) were made from plastic pottles 70mm in diameter and 65mm deep. They were placed in two parallel rows of ten traps each set two metres apart with 20 metres between the parallel rows. The containers were one third filled with a 50% saturated solution of picric acid with a few drops of detergent added as a wetting agent. Holes were made in the soil to exactly accommodate the pitfall traps so that there were no spaces between the lips of the traps and soil surface levels. Any such spaces or holes lead to trapping errors as animals may selectively avoid such regions (Thomas and Sleeper 1977). Each trap was then covered with a lid made of 5mm thick hardboard and measuring 150mm square. The hardboard was supported at its four corners by wooden legs 15mm square by 25mm high. The lid was numbered to give the trap identification and secured over the pitfall trap using four 15mm long pegs.

Once each week the traps were cleared. The solutions in each trap were collected into labelled screw top jars and transported to the laboratory. Fresh picric acid solution was placed in the pitfall containers and they were carefully replaced in the ground with the lids repositioned. At the laboratory the catch was sorted in glass petri dishes under a binocular microscope or "Maggi" lamp and the animals recorded.

Pitfall trapping was carried out from March 1980 to March 1981 at Wilsons 2A, Wilsons 2B and Long 4A, Whatawhata. Twenty traps were used at each site.

PUPAE AND PUPAL EXUVIAE

Soil sampling as described previously, was the method used for collection of pupae and pupal exuviae.

Extraction Techniques

Obviously a behavioural response would not allow for collection of pupae (which are virtually immobile) and pupal exuviae. This meant either dry sieving or flotation techniques had to be used.

Wet Sieving and Flotation

This method eventually proved ineffective for collection of pupae and pupal exuviae. Late instar larvae spin cocoons of soil and silk and it is within these capsules that pupation occurs. Cocoons are attached to grass roots and have exits to the surface. During washing they filled with water, therefore sinking when placed in magnesium sulphate solution. Most pupae were reared to adults for taxonomic identification, but salt solutions injured them (Murphy, 1962a). Hand sorting was therefore required.

Dry Sieving

As described for larvae. This technique was eventually exclusively used for collection of pupae and pupal exuviae.

ADULTS

Several methods of sampling for adults were adopted.

Emergence Traps

The principle of operation of emergence traps relies on the fact that emerging insects move towards the light. Twenty traps each were used at Wilsons 2A, Wilsons 2B, Long 4A (Whatawhata) and Hart's (Te Kowhai) during the 1978-79 and 1979-80 summers. Traps as designed by Mr E.H.A. Oliver (pers. comm.) were borrowed from the Insect Control and Organic Chemistry Group, Ruakura. The base of each trap was 516mm in diameter and tapered to 65mm at the top. A central cone was made of flyscreen mesh (aperture size 1.43mm) and a canvas skirt 100mm wide was sewn to its base. The top of the cone was attached to a tapering canvas sleeve (100mm long) inside which a plastic bag (100 x 200mm) was used as a collecting chamber. A baffle system was required to prevent those insects moving into the bag from returning to the soil. For this, two plastic pottles 65mm deep and 70mm in diameter were used. One had the base cut out, the other had a central 6mm diameter hole cut in its base. The latter was placed inside the mouth of the plastic bag and 20mm of bag turned into the top of the container. The other pottle was then pushed inside this to hold the bag in place. The bag and baffle was then fed into the canvas sleeve at the top of the cone so that some of the bag was extruded and the baffle fitted snuggly in the tapered sleeve. To position the trap a thin (number 11 gauge) wire hoop was placed over the cone on to the basal canvas skirt. Six metal pegs were clipped over the hoop and through the canvas into the pasture beneath. A hook was secured around a knot tied in one corner of the plastic bag, and attached to a piece of rubber which was hooked to an electric standard. This gave a flexible attachment which could withstand strong winds without tearing the bag. At Te Kowhai, pyramidal cages of steel rod and wire mesh were used to protect the emergence traps from stock (see Plate 8).

Traps were checked once weekly. Any trapped adults were collected and recorded. Since it was possible that newly emerged adults had not moved into the collecting bag a black polythene sheet was wrapped around the mesh cone to exclude light. Usually adults moved into the bag within two minutes, after which time the trap was lifted and grasses under it also examined for adults. Traps were relocated fortnightly, over pasture clipped to 20mm long. This was necessary because vegetation grew rapidly under the mesh concealing adults and making their collection difficult.

Usually adults were collected live for experimental work but early in the season a "Vapona" pest killing strip was incorporated in the plastic bag. Adults killed in this way damaged themselves a great deal before dying.

Plate 8: Emergence trap with protective cage at Hart's, Te Kowhai. Note the pasture condition which is open but showing some signs of regeneration. This photograph was taken in November 1978.

Plate 9: Johnson-Taylor suction trap of the exposed cone type.

Sweep Net

Sweep netting (De Long,1932; Fenton and Howell,1957; Callahan et al., 1966; Saugstad et al.,1967; Cothran and Summers,1972) for adult sod webworm and any associated pasture arthropods was carried out each summer (1978-79; 1979-80; 1980-81). Fifty sweeps were taken at each of the sites Wilsons 2A, Wilsons 2B, Long 4A (Whatawhata) and Hart's (Te Kowhai) once a week. Each catch was transferred to a two litre paper lined plastic container with a clip on lid including a ventilating mesh. The catch was then killed with a cotton wool pad soaked in ethyl acetate, placed over the mesh. The container and killing agent were securely tied into a large plastic bag then transported to the laboratory for identification and recording of the sample.

The sweep net frame was made from 4mm thick galvanized metal 1.120 metres long. It was shaped into a hoop of 300mm in diameter with two metal extensions (25mm apart and 100mm long) on one side. These were fitted into lateral grooves at one end of a 25mm diameter and 1.5 metre long dowelling pole. The hoop was secured into the dowelling with two "jubilee" clips. A sweep net bag 400mm deep and 300mm in diameter was made from terylene mesh sewn into a 75mm diameter canvas sleeve which housed the metal hoop frame.

For a particular site, sweeps were taken across the same general path each sampling occasion. This meant a similar area was sampled and could be relatively compared with sweep net catches for that site on other weeks. However, comparisons between sites are difficult because of the lack of standardization inherent in sweep netting. Collection of individual adults, when needed for rearing or experimentation, was made using a sweep net.

Malaise Traps

Malaise traps operate under the same principle as emergence traps, i.e. the response of adults to move upward towards light. Four Malaise traps were used: two at Long 4A and one each at Wilsons 2A and Wilsons 2B, Whatawhata. Traps were of the Townes (1972) design and made from terylene mesh, with a shaped central sheet 1.5m long at ground level, 0.5m high at one side and 1.25m high at the other with a sloping edge connecting these two. At each side and at right angles to them were sections of mesh the same height as the side and one metre wide, i.e. a 0.5m flap at right angles on each side of the central sheet. A roof section was sewn to the sloping edge of the main sheet and to the right angled flaps at each end. This therefore produced a three-dimensional tent-like trap across possible flight paths of insects. Any insect striking the central sheet would fly upwards and in so doing, encounter the roof and by continuing to move up would arrive at the topmost point of the trap. At that point a collecting jar with baffle system (an appropriately sized funnel) was positioned. The insect travelled into this, towards the light visible beyond. The Malaise trap had numerous strings and tapes positioned to hold it securely. Strings were tied to dowelling poles which provided the required height and tapes were pegged down to keep the base of the trap flush with the ground. Whenever it was possible to operate these traps, i.e. winds were light, the collecting jars were changed daily.

Suction Traps

The Johnson-Taylor suction trap (see Plate 9) was used. Three were positioned at Long 4A, Whatawhata, where they were electrically supplied from the mains of the James Aviation hut. Trap one was set on the ridge 15 metres from the hut; trap two in a hollow 20 metres east of trap one; trap three, 20 metres south of trap one. This meant trap one was exposed to winds from all directions; trap two was protected from south-east to west winds; and trap three was protected from west and north-east winds.

Traps were run simultaneously and checked for influence by the light trap situated nearby. Wind speed and direction, air temperature, relative humidity, rainfall, barometric pressure, cloud cover and phase of the moon were recorded for each suction trapping occasion.

The design and operation of the traps is well documented by Johnson (1950a, 1950b); Johnson and Taylor (1955); Taylor (1962a). The trap time switch was set to drop sample-segregating discs once each hour. Each disc was covered with Egyptian cloth so as to seal off the space between its periphery and the collecting tube wall. The discs were coated in a solution of 5% cypermethrin prior to loading. This is a contact insecticide providing for a rapid knockdown of the collected insects. The traps used had a 300mm (12 inch) diameter "Vent-Axia" fan which could be operated at one of three different speeds each sampling a different volume of air. When operating, they were cleared and reset every 24 hours. The cannisters containing the discs with associated hourly insect catches were transported to the laboratory for identification, enumeration and recording.

Sticky Plates

Sticky plates (Johnson,1950b; Mellanby,1962; Taylor,1962c; Southwood, 1978) were established at Long 4A, Whatawhata. A contact adhesive (Mapco

"Stickem" special) was applied to metal vanes positioned across flight paths, so that insects were blown on to, or selectively settled on them. Galvanized metal sheets 2mm thick were made into 300mm wide by 650mm long sections. Pairs of these plates were cut so as to fit into each other at right angles and the contiguous portions were embedded in slits in the end of a 50mm square wooden fencing batton (see Plate 10). A compass was used to orientate one vane N-S, the other E-W so that catches could be assessed in relation to wind speed and direction. On both sides, the plates were painted black or left unpainted, alternately, in areas measuring 300mm wide by 150mm long. Hopefully this allowed for interpretation of gross colour preferences in insects selectively alighting on the plates. Investigation of heights at which adult sod webworms fly and the relation of this to species and sex was made possible by establishing the vanes at 0.15, 0.5 and 1.0 metres (measured to centre of plates) respectively above ground and comparing catches.

Plates were removed at least once every three weeks when the adhesive coat was becoming less sticky. They were transported to the laboratory in a wooden box with slots to hold the plates separate from each other. Here they were clipped into a wooden frame and cleaned with turpentine before recoating with Mapco "Stickem" Special.

In the field note was made of wind speed and direction, as well as other meteorological phenomena. Whenever the light trap was operated and cleared (see later) the sticky plates were examined. Any sod webworms present were removed and placed in a vial with information on date, trap height, direction and side plus panel colour of the vane they were located on. The insects were transported to the laboratory for species and sex determination.

Light Traps

Two types of light trap were used: a fixed one at Long 4A, Whatawhata supplied from the mains in the James Aviation Hut; and a portable one supplied by a 12 volt battery. The latter was used at Buchett's Kaimai, the St. Andrews Golf Course; and privately owned properties at St. Heliers and Mission Bay, Auckland.

(i) The Fixed Light Trap

This was of the Robinson and Robinson (1950) type (see Plate 11) and set 1.5 metres above ground on an eastern slope thus gaining protection from strong west winds. A 150 watt blended light bulb was utilized. The

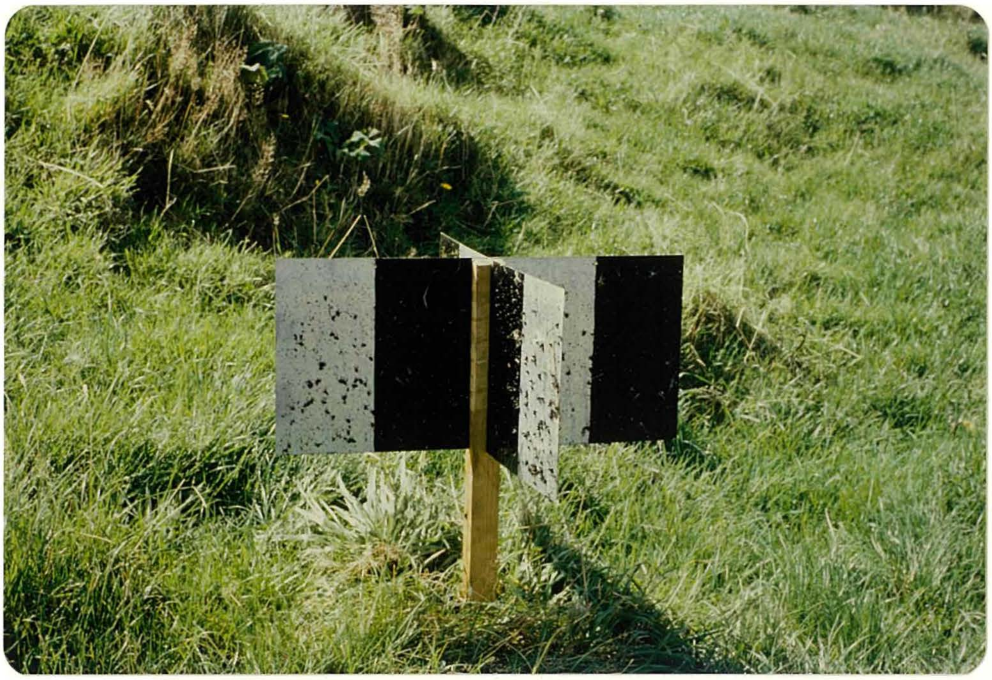


Plate 10: Sticky plates (set 0.35 - 0.65m above gound) showing arrangement of vanes.

Plate 11: Light trap at Long 4A, Whatawhata. Part of the forested area used in Malaise trapping can be seen in the background.

trapping period, governed by a "Sangamo" time switch, was from 2130-2400 hours and 0100-0300 hours. The system of vanes, set in a tapered cone, was housed in an aluminium box (400mm square by 500mm deep) with an open base. This was covered with a sheet of hardboard (5mm thick) containing numerous holes to allow drainage of rain. A sturdy metal frame (1.15 metres high) was pushed into the ground to a depth of 15mm then securely pegged down to provide a rigid supporting framework for the trap. Insects were collected into a terylene bag containing newspaper as a substrate of increased surface area. Usually the catch was collected live but killing agents were included as required (e.g. Perrott 1969).

On each occasion that the light trap was operated the following meteorological readings were made at 0800 hours : wind speed and direction, barometric pressure and rainfall. Air temperature and relative humidity were available for the trapping period from the thermograph charts. Wind speed and direction readings for the same period were made with the Lambrecht anemograph when available. Cloud cover assessment, phase of the moon and ongoing meteorological phenomena (e.g. wind rising, squally conditions of short duration) were also noted.

Usually the night's catch was tranpsorted to the laboratory for analysis. On several occasions the trap was run all night with the bag being replaced every thirty minutes from 2130 to 0600 hours. In these cases the catch was sorted, enumerated and recorded immediately after collection. Meteorological conditions were closely monitored throughout the night so that their effect on the catch could be assessed. Light trapping was used on several nights during the 1979-80 summer and one night's catch per occasion was collected. The trap was run continuously from early September 1980 to mid February 1981 except for three days at the end of October 1980 when the trap had to repositioned after a storm. During continuous operation the collecting bag was changed at least three times a week (i.e. two night's catch per time). Weekly and monthly totals were always made possible by ensuring that samples were collected at the appropriate times for this.

(ii) The Portable Light Trap

The portable light trap consists of a collapsible aluminum box (500mm square x 500mm high) in which the sides and base clip into each other through grooves and the lid rests on the framework made by them. The lid contains a hole 200mm in diameter into which a 200mm diameter plastic funnel is fitted. A six watt ultraviolet/daylight tube 300mm long was fitted between three perspex vanes shaped, at their lower ends, to fit into the funnel. Power was supplied by a 12 volt motorcycle battery which sustained 14 hours running before requiring recharging. Insects attracted to the light moved through the hole in the funnel below the tube and entered the collecting box underneath. A cloth bag containing newspaper was placed inside the box to ensure collected specimens were retained. This trap was run for periods of 2-3 hours each time. As for the fixed light trap, meteorological events were recorded.

Frame Counts

Estimates of adult sod webworm populations over pasture were made using frames during the 1980-81 summer. They were made from number 8 gauge wire to measure 0.5 m square (i.e. 0.25 square metres). Each frame was positioned over the pasture and left for two minutes to allow re-settlement of disturbed adults. The grass within the frame was then closely examined by carefully parting the foliage and numbers of adults ascertained. Initially 20 counts were made once a week at Wilsons 2B and Long 4A, Whatawhata on SW-SE slopes. However, early in December 1980 it became apparent that wind direction was having an effect on adult aggregations. Estimates were therefore made at least once each week and were related to wind speed and direction. Twenty counts each were made on S, SW, E, W and N slopes.

In late December-early January each year, when adult populations were at their peak on hill country pasture, estimates of numbers (per m^2) were made. For these an area of one m^2 was pegged out using the sweep net handle on to which one metre had been marked. The enclosed area was then disturbed and counts made of the number of moths dislodged. Ten such counts were made per area on calm, fine days.

Hand Collection of Adults

Adults were collected from pasture using a sweep net and/or an aspirator (see below). Whenever sod webworm adults were seen at the lighted window of a dwelling they were collected directly into vials. The time of collection was noted and sex and species determined. Specimens were collected in this way at St. Heliers, Auckland from September 1978 to June 1980; at Hillcrest - Hamilton East from September 1978 to March 1981; and Mission Bay, Auckland from June 1980 to April 1982. During the main adult season (October-March) the outsides of these premises were checked daily for resting adults and time, location, species and sex recorded.

Aspirator

The aspirator used was based on the Stringer (1977) design. It consists of a 150mm long by 30mm diameter open-ended glass collecting tube. A rubber bung incorporating a PVC inlet tube was placed in the lower end of this. The top rubber bung contained a countersunk glass tube fitted to a glass expansion chamber (dust filter). The countersunk surface was covered with grade xxx bolting silk to sieve most of the moth scales from the air passing through the collecting tube. Any scales remaining in the inhaled air after passing through the bolting silk were removed in the dust filter. The inlet tube to this chamber was bent so that air impinged against the wall as it was sucked through. Scales adhered to a coating of Mapco "Stickem" Special on the walls and to crumpled filter paper loosely packed inside the chamber. The scale contact surface area inside the chamber was further increased by indentations in the glass. The end of the dust filter was closed with another rubber bung containing the mouthpiece tubing. This provided ready access to the chamber for cleaning. The innermost portion of the mouthpiece tubing was bent towards the dust filter wall and positioned so as to be opposite the inlet tube from the moth collection chamber. This ensured as many scales as possible were removed before inhalation.

Pitfall Traps

As described under larval sampling methods. It was possible that adult sod webworms be collected in pitfall traps. Such trapping was therefore continued during the adult season to assess movement in the epigeal habitat, i.e. that region between soil and grass surface (Shires 1980).

Mating-Attraction Traps

Baited traps as designed by Stringer (1977) were used to assess attraction of the sexes to each other and themselves. The bases of two one-litre clear plastic jars (85mm in diameter and 105mm long) were stuck together and a 25mm diameter hole cut through them. A 100mm long piece of 25mm diameter clear PVC tubing was fitted evenly through the hole. The inside surfaces of the jars were smeared with Mapco "Stickem" Special adhesive and adults were introduced into the central tube, the ends of which were covered with terylene mesh secured with rubber bands.

Adults collected from the field were used to ascertain the attraction of other moths to them. The traps were in position from 1930-0730 hours each occasion and were set ten metres apart but not downwind of each other. Six traps were used so as to have two each with males, females and blanks. The numbers and sexes of entrapped adults were assessed daily. Each baited trap contained 2-3 adults to counteract individual variability. Five trials were made for each species.

REARING TECHNIQUES

Rearing was done at ambient temperatures in a screen house at the Insect Control and Organic Chemistry Group, Ruakura. Ambient temperatures were selected as these replicated field conditions enabling assessment of generation times.

Adults

Hand-collected females were chosen to give a representation of the different species, in good condition. They were labelled with species, date, place and time of collection and individually housed in 15ml glass vials. Lengths of paper towel were included to increase contact surface area. Adults were supplied with a 5% honey-sucrose solution (5g honey and 5g sugar dissolved in 200ml water) which was changed every two days. This solution was absorbed on to pieces of paper towel and placed across the top of each vial under its screwcap. Initially cottonwool was used instead of paper towel but females became tangled in this or oviposited on to it making collection of undamaged eggs virtually impossible. Eggs were removed daily, enumerated, and oviposition date and species recorded.

Eggs

Eggs from known species of adult were reared in 15ml glass vials - ten per container. Colouration changes were noted as these indicate fertility. The number of fertile eggs in each batch was noted as were incubation times and numbers of eclosing larvae, i.e. the viability of the eggs. Every 2-3 days an atomizer was used to spray water into the vial to moisten, but not overwet, the walls.

Larvae

Larvae reared from eggs were transferred to 50ml vials with two larvae per pot. They were provided with cut grasses renewed every two days, or mosses replaced weekly. The atomizer was used to maintain moisture as above. Larvae were carefully checked for signs of becoming moribund and if so were removed for disease studies (see later). Larvae collected from the field were reared separately in 15ml glass vials. These larvae were provided with small clumps of moss and cut grasses. By careful monitoring of feeding rates fresh grasses and mosses could be continually supplied and these usually sufficed to maintain moisture levels.

Pupae

Prepupae and pupae reared from larvae were retained individually inside their soil-silk cocoons in 15ml glass vials. The date of pupation was noted. Pupae were sexed according to a generalized lepidopteran plan whereby the length from anal to genital apertures is much greater in the female than in the male. An atomizer was used as necessary to raise moisture levels. Dates of adult emergence were noted. Prepupae and pupae collected from the field were also treated in this way.

INCUBATION EXPERIMENTS

Batches of eggs oviposited by known species of female sod webworms were subjected to different temperatures and humidities, in temperature controlled rooms, 15°C and 25°C. Eggs were reared as before except that batches of ten eggs oviposited by the same female on the same day were exposed to the different temperatures. Eggs were less than one day old at the start of each trial (cf. Matheny and Heinrichs 1971). The control rooms were operating under a natural daylight schedule. Vials of eggs were placed in racks in the appropriate room and dates of eclosion, fertility and viability noted. Adult females were also placed in the rooms, from time to time, to assess temperature effects on oviposition. Humidity was maintained as described above or varied according to Winston and Bates (1960). Saturated salt solutions of potassium sulphate (K_2SO_4), sodium chloride (NaCl) and glucose were standardized at the two temperatures (15 and 25°C) after Morrison *et al.* (1972) and placed in 600ml sealed jars. Temperature dependent relative humidities of around 98%, 75% and 55% respectively for the above salts were obtained. Madge (1956c) measured the relative humidity at the base of the burrow of *Oncopera fasiculata* (Hepialidae) in South Australia as 95% while it was only 65% at the soil surface. Although such recordings were not made, thermohydrograph readings (0.5m above ground) at Whatawhata and Te Kowhai showed that during the egg laying season (November-February) the average daily relative humidity was rarely below 65%. Sod webworm eggs laid at the soil surface would presumably experience similar humidities hence the chosen humidity values to simulate field conditions. Eggs were housed in aluminium foil cups (10mm deep and 20mm in diameter) or 15 ml vial caps and enclosed in the jars with the appropriate solutions. Fertility, viability and dates of eclosion were again noted.

OVIPOSITION CAGES

Female ovipositional preferences in the field were investigated by using oviposition cages. Each was formed from a number 8 gauge wire framework measuring 300mm square by 300mm high (i.e. a 300mm square with two diagonals 300mm high). The sides and top of the cage were made from terylene mesh and a canvas skirt (100mm wide) was sewn around the open lower edges. Pegs through this secured the system to the pasture.

Each 300mm square plot was divided into four equal areas. The grass within these regions was selectively cut or weeded out to achieve four different types (after Martyn, 1965b): long dense, long sparse, short dense, short sparse. "Long" pasture was more than 75mm high and "short" pasture was clipped to 25mm. Soil was not visible amongst "dense" cover but at least 20% soil was visible amongst "sparse" cover. Ten *Eudonia sabulosella* females were introduced into each cage, left for 24 hours, then removed, and the cage reset at a new locality. The turf from each region was dug up (to a depth of 50mm) and transported to the laboratory for examination for eggs. A total of ten replicates was used.

LARVAL FEEDING

During rearing larvae were provided with different species of grasses to ascertain feeding preferences. Pots of grasses were grown to provide this food and each time it was renewed, any evidence of feeding was noted. Also, where larvae were collected in the field, the pasture species composition was noted especially during the 1978 winter when damage was extreme. In this way, a representation of the feeding requirements of sod webworm larvae was established. Smear preparations of larval gut contents were compared with crushed grass foliage to confirm feeding.

PREDATOR TRIALS

During soil sampling, sweep netting and pitfall trapping a full list of arthropod species was noted. This provided information on cohabitors and possible predators. Predator trials were therefore set up (cf. Eyles,1966; Butcher,1978). In its most basic form this consisted of placing a sod webworm larva in a 50ml glass vial with a small clump of moss and adding either an elaterid larva (*Conoderus exsul* Sharp); a staphylinid adult or larvae (*Thyreocephalus orthodoxus* (Oliff)); or a carabid larva or adult (*Rhytisternus miser* (Chaudoir)). These were deprived of food for 2-4 days prior to trials. The interactions between predator and prey were observed as: no reaction; escape by prey; piercing of prey by predator with mandibles; or devouring prey. Adult sod webworm were also subjected to these predators plus Opiliones and Araneida commonly encountered in the pasture system.

LONGEVITY EXPERIMENTS

Newly emerged adults plus many of unknown age (collected in the field) were set up as described for rearing of adults. The date of emergence or collection and date of death were noted and estimates of adult longevity for each sex and species were compiled. Black polythene pots (150mm square by 200mm deep) were set up to grow mosses, ryegrass, browntop, clovers and flowering weeds separately and in combination with each other. Cages were made to cover the pots. Squares of terylene mesh (300mm square) were draped around arched number 11 gauge wires (150mm high) running diagonally across the pots. The mesh was held in place by elastic. Sexed adults of known age were placed in the cages and longevity recorded. Adults were provided with either water only, 5% honey-sucrose solution (see details under adult rearing techniques), flowering weeds, or combinations of these. Solutions were placed in 15ml vials plugged with cottonwool and laid on their sides within the cage.

FECUNDITY EXPERIMENTS

Newly emerged and field collected adults were set up as for adult rearing. The numbers of eggs laid were recorded and added to the numbers of eggs enumerated on dissection of the females to give a value for fecundity. For all other females fecundity refers to the potential ovipositional ability, as indicated by the total internal eggs since the number of eggs laid prior to collection of the moth was unknown. Eggs from dissected females were placed in Grenacher's borax-carmine solution (Peterson,1959) for 12 hours then into washes of 70% acidulated alcohol to remove excess dye. They were then counted using a rectangular counting chamber and graded according to the following: "small" referred to developing eggs, not of normal size and which stained red; "large" referred to normal-sized eggs which stained red; "mature" referred to developed eggs with a distinct chorion and therefore non-stained.

DISEASE STUDIES

During rearing, especially with field collected larvae, many specimens became moribund and dead. These were removed and kept separately in 15ml glass vials in a cool room at 4°C until disease studies were made. Assistance with techniques for the study of infective pathogens was gained from Dr P.J. Wigley and Mr S. Dhana Insect Virology, D.S.I.R., Mt. Albert, Auckland. Once the presence of infective pathogens had been established in larvae, it was decided more thorough studies were needed. A series through time of all preserved material was therefore examined. This meant an investigation of pathogen build up in relation to sod webworm population density was possible. Larvae, pupae and adults were included. Most of this material had been preserved in 70% alcohol although adults from 1979 onwards had been stored in a freezer. The alcohol preserved material was rehydrated. Holes were made in the specimen's integument to allow for the penetration of water. The insect was then placed in fresh distilled water for 36 hours. After this time the excess water was drained on to paper towels. Measurements of body length, interocular head capsule width (adults only) and body weight were then made. Specimens from the freezer were thawed before measuring and weighing. Next, all adult females were dissected and the number of eggs (categorized according to size as described under fecundity experiments) counted and recorded. Insects were then macerated in a known volume of fresh distilled water (i.e. dilution could be calculated). Initially each larva was placed in the cut-off finger of a thin (imported Canadian) plastic surgeon's glove and macerated by squeezing. The difficulty of obtaining supplies of these gloves resulted in another method being adopted. Each specimen was therefore placed in a small crucible (Sillax A 2/0) and crushed (using a glass rod) in a known volume of water. The resultant solution was decanted into a labelled vial. To assess pathogens present, two methods were used - the water mounts *per se* or triple staining of water mount smears.

Water Mounts

Water mounts were made directly from the macerated solutions on to a haemocytometer (improved Neubauer 1/400 square mm and 1/10mm deep). The solution was transferred to the haemocytometer using a 150mm long Pasteur capillary pipette. To avoid cross contamination, these were used once only before soaking in absolute alcohol, formalin, detergent and disinfectant washes. The haemocytometer cover slip and counting chambers were also thoroughly cleaned after each sample had been counted. At least 100 of the small central squares were scanned under a phase contrast compound microscope. Spore loads could therefore be calculated using the following formula (Dacie and Lewis 1975, Wigley pers. comm.):

$$\text{Number of spores} = \frac{Dx}{NK}$$

where D = dilution factor
x = number spores counted
N = number squares counted
K = volume in ml above one square

Water mounts are suitable for assessment of infections by most Protozoa and Nematoda. However, viral infections require elucidation by staining.

Triple Staining

This system was devised and modified by Dr P.J. Wigley (pers. comm.). Basically, a thin smear of the water mount, covering the full width of a microscope slide is treated in Carnoy's fixative, picric acid, a 0.02μ phosphate buffer, naphthalene black and Improved R66 Giemsa, with various exposure times. There are numerous washes in absolute alcohol and water between application of the chemicals and stains. The picric acid stain completely covers the slide, the naphthalene black to 2/3 and the Giemsa the bottom 1/3 to produce a grade of the three stains each elucidating the infective pathogens differently and thus aiding identification. Viral infections were discernible under phase contrast illumination by this method.

CHAPTER THREE

METEOROLOGICAL DATA

Although meteorological data was recorded throughout the study, results from only two years (1979 and 1980) at Whatawhata are presented here to elucidate seasonal variations. Data from 1978 and 1981 conformed to these patterns, as did meteorological information from Te Kowhai.

Soil Moisture Content

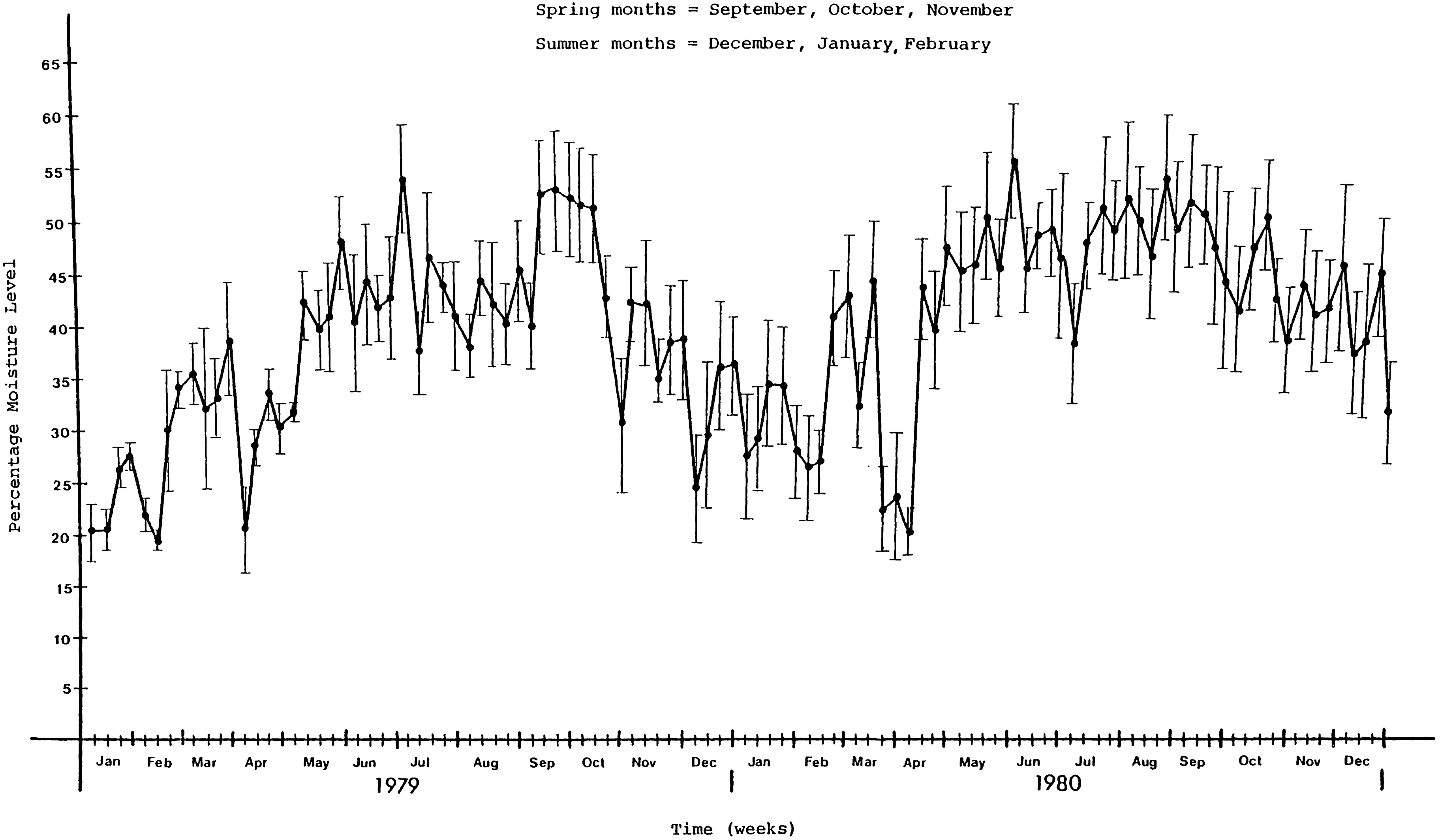
Graphs 1 and 2 represent soil moisture contents for track and intertrack respectively. Readings were made once weekly as described in Methods (Chapter 2, p. 12). The plotted values refer to the combined data for top and bottom halves of each core with 95% confidence intervals. It can be seen that generally the track was wetter than the intertrack. However, there were 16 weeks in which the intertrack soil moisture level was higher than that for the track region. In 15 of these the confidence intervals for track and intertrack overlapped for at least part of their range. Thus only for one week (in August 1979) was the intertrack markedly wetter than the track. The separation of soil cores into top and bottom 25mm sections to assess relative moisture content revealed that in nearly every instance the lower half was 2-10% drier than the top 25mm. Soil moisture patterns followed seasonal changes closely as indicated by comparisons with temperature charts (Graphs 3 and 4). Soil was wetter during the months when temperatures were lower (winter-spring) and drier when temperatures were warmer (summer-autumn). The pattern of change in moisture level and the amplitude of variation was similar for each soil stratum over the two years.

Soil Temperature

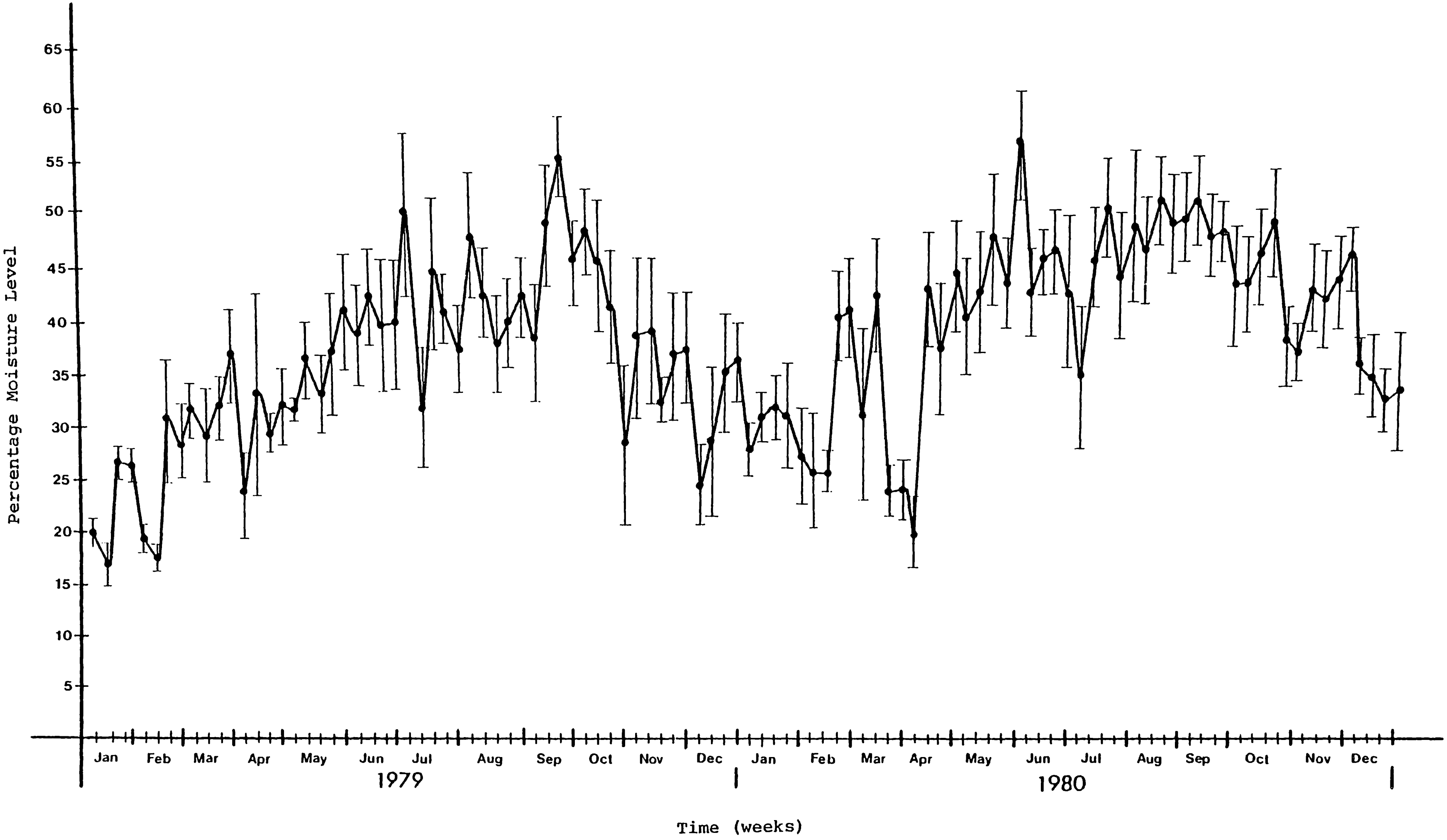
Soil temperature as measured each week (see Methods, Chapter 2, p.12) is plotted in Graph 3. Confidence intervals have not been plotted as these were small ($\pm$ 0.20 to $\pm$ 1.56°C). The maximum and minimum temperature ranges and overall pattern of temperature change was similar for the two years. Graph 3 closely resembles Graph 4 with soil temperatures being intermediate between maximum and minimum air temperatures. The soil habitat is not subjected to as wide a range of temperature variation as the air. This is because soil warms and cools more slowly than air.

Graph 1: Soil moisture content for the track region Whatawhata, measured at weekly intervals. (± 95% confidence intervals).

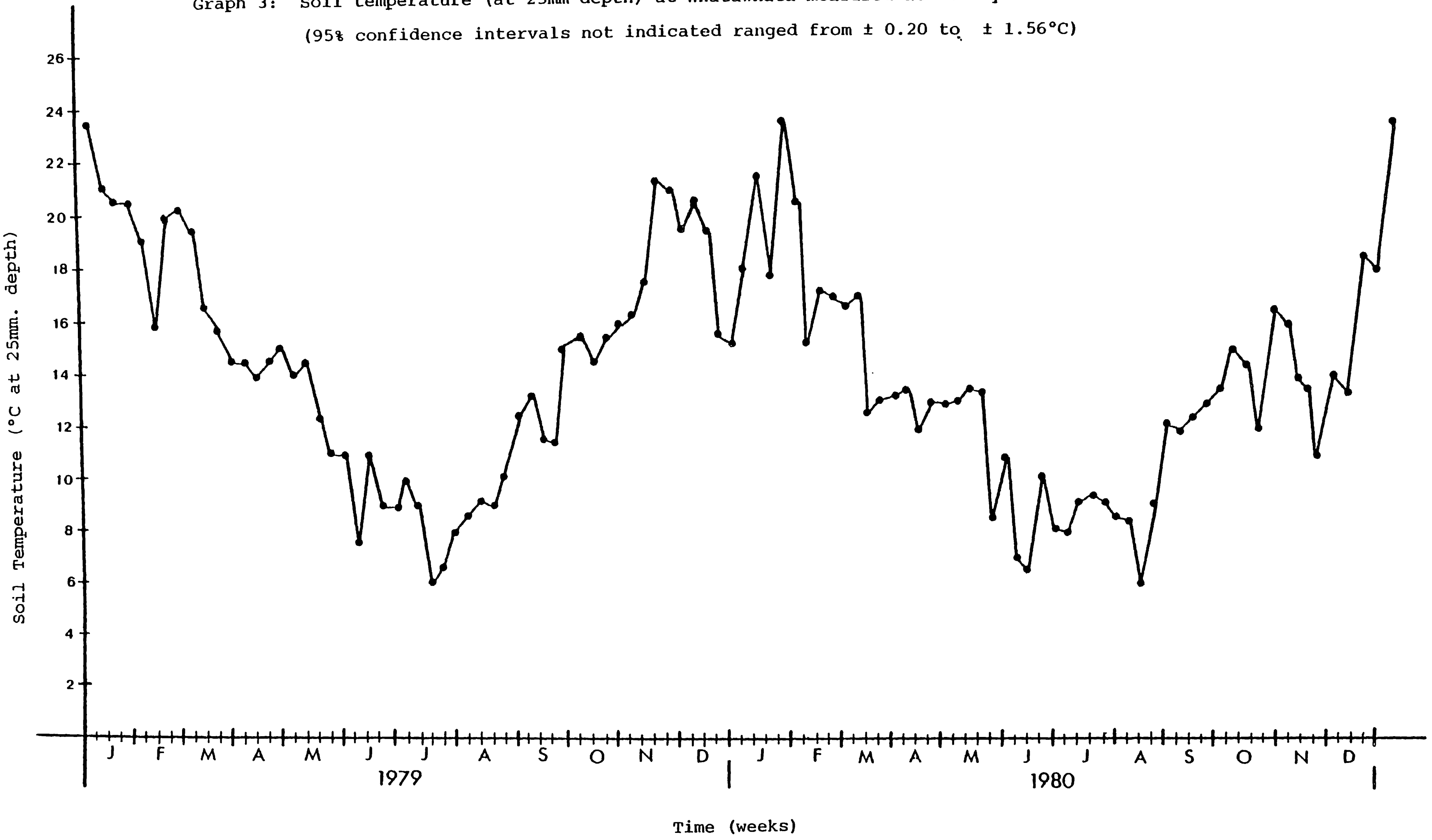
In Graphs 1-7:
Autumn months = March, April, May
Winter months = June, July, August
Spring months = September, October, November
Summer months = December, January, February



Graph 2: Soil moisture content for the intertrack region, Whatawhata, measured at weekly intervals.
(± 95% confidence intervals)



Graph 3: Soil temperature (at 25mm depth) at Whatawhata measured at weekly intervals.
(95% confidence intervals not indicated ranged from ± 0.20 to ± 1.56°C)



Air Temperature

Graph 4 represents the weekly maximum and minimum air temperature (as obtained from thermohydrograph charts and maximum-minimum thermometer see Methods Ch. 2 p. 13). The summer-autumn months were characterized by higher maximum and minimum temperatures; the winter-spring months by lower maximum and minimum temperatures. Both years showed a similar pattern and range of air temperature changes.

Relative Humidity

Graph 5 represents the weekly maximum and minimum relative humidities (obtained from thermohydrograph charts - see Methods Ch. 2 p. 13). The maximum relative humidity was remarkably stable throughout the year with little variation. Maximum humidity was generally slightly less in 1980 during March to December. Minimum relative humidity was rather variable but generally spring-summer minimum humidities were lower than autumn-winter ones. This means that the weekly range in humidity was less during autumn-winter.

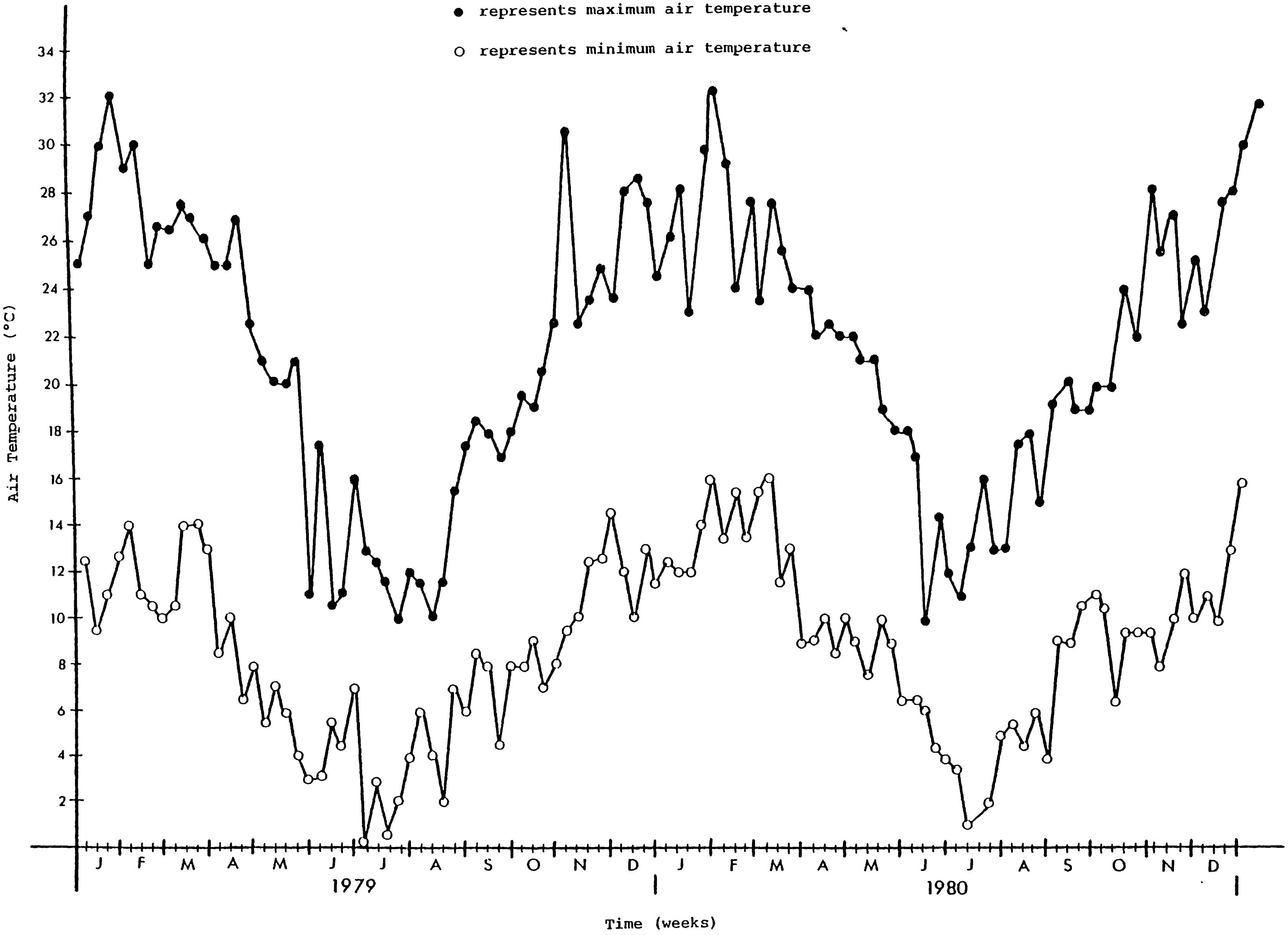
Rainfall

Graphs 6 (weekly rainfall) and 7 (monthly total) refer to rainfall at Whatawhata (see Methods Ch. 2 p. 13). Those confidence intervals not plotted were small (± 0.17 to ± 1.73mm). Rainfall was highly variable throughout the year, but in general winter-spring months were wetter than summer-autumn ones. In both years maximum rainfall occurred in July (Graph 7).

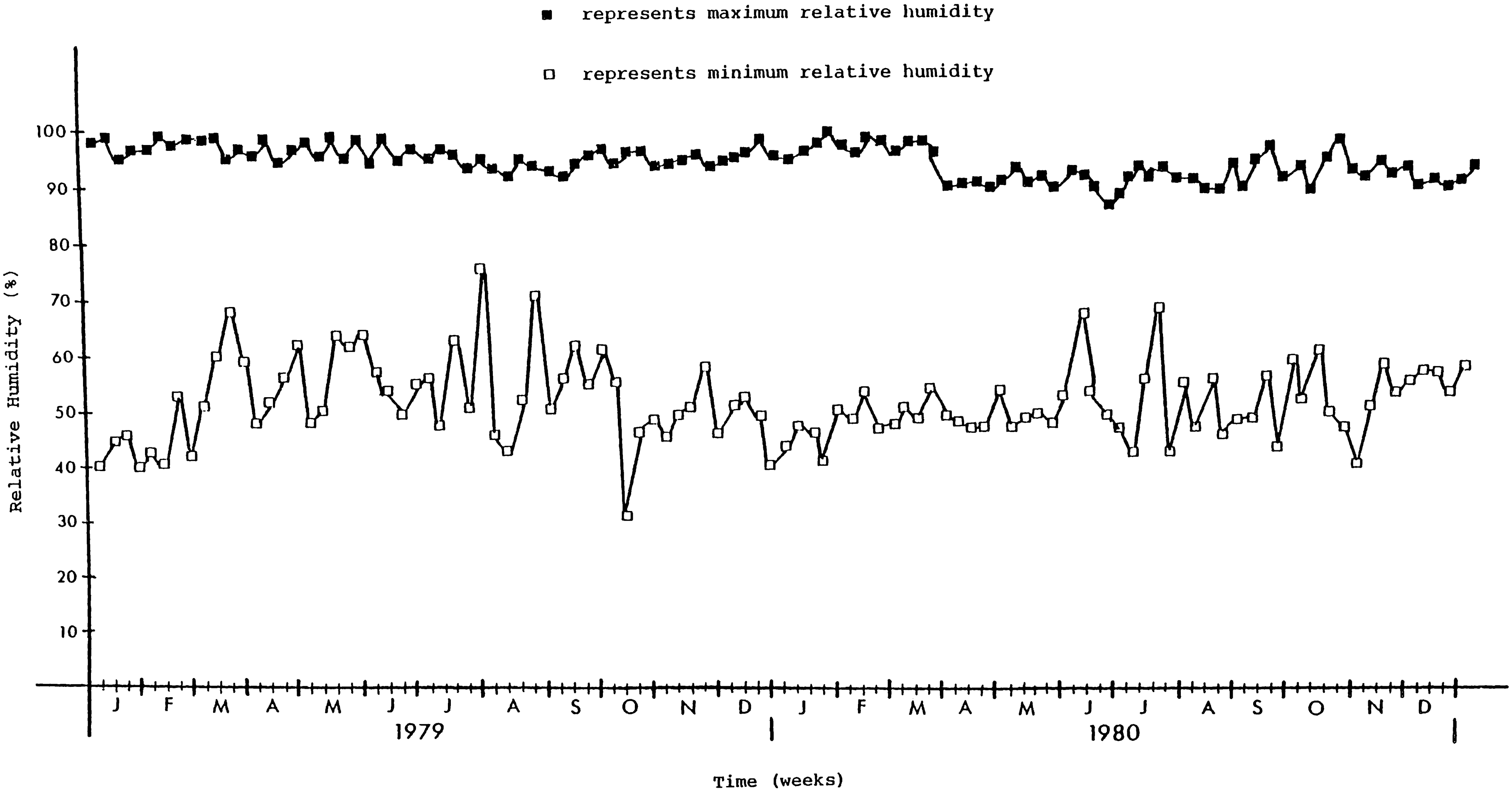
Lunar Cycles

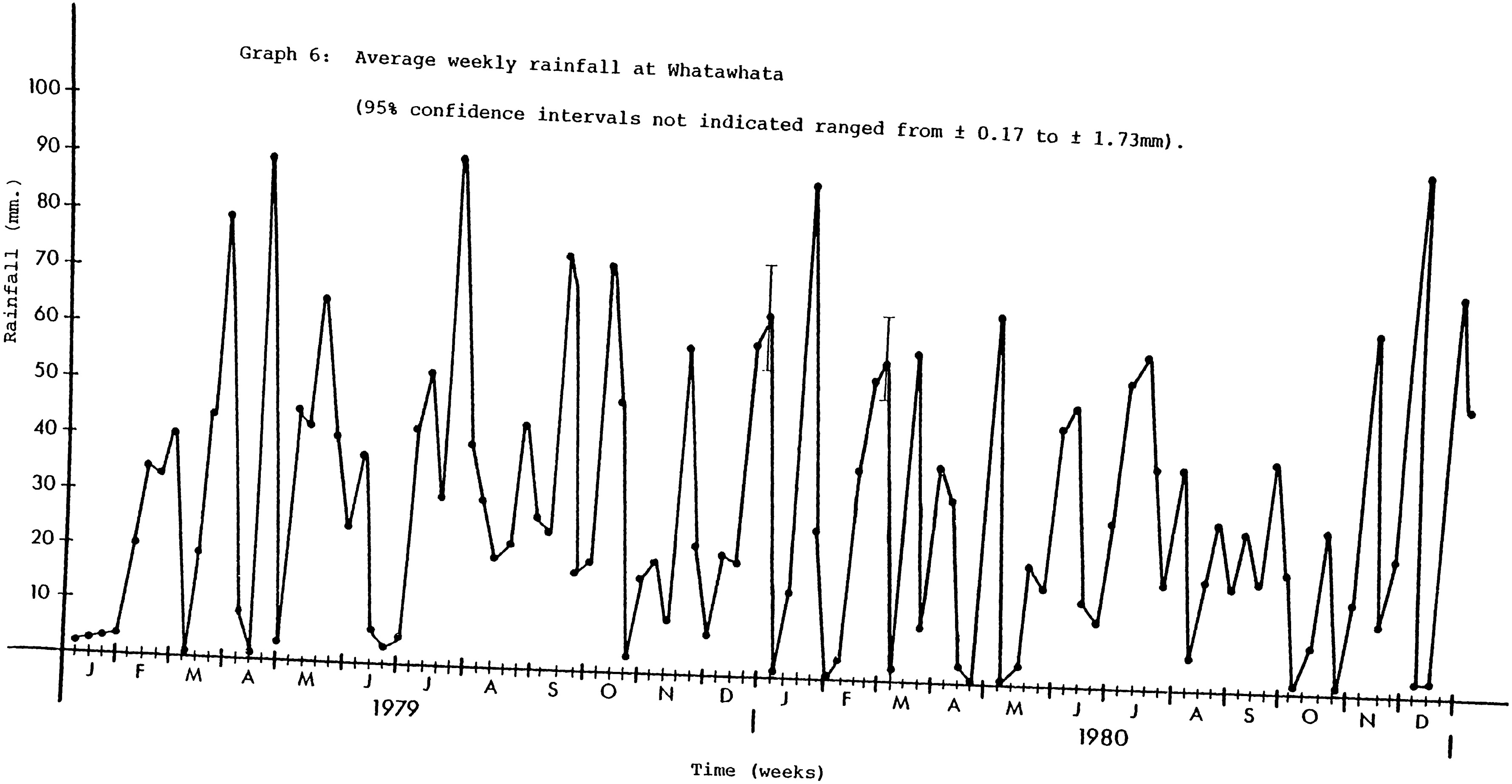
Refer to Appendix II. Information on lunar cycles was taken from the N.Z. Nautical Almanacs (1978-1981). The months listed refer to adult seasons.

Graph 4: Weekly maximum and minimum air temperature at Whatawhata



Graph 5: Weekly maximum and minimum relative humidity at Whatawhata.

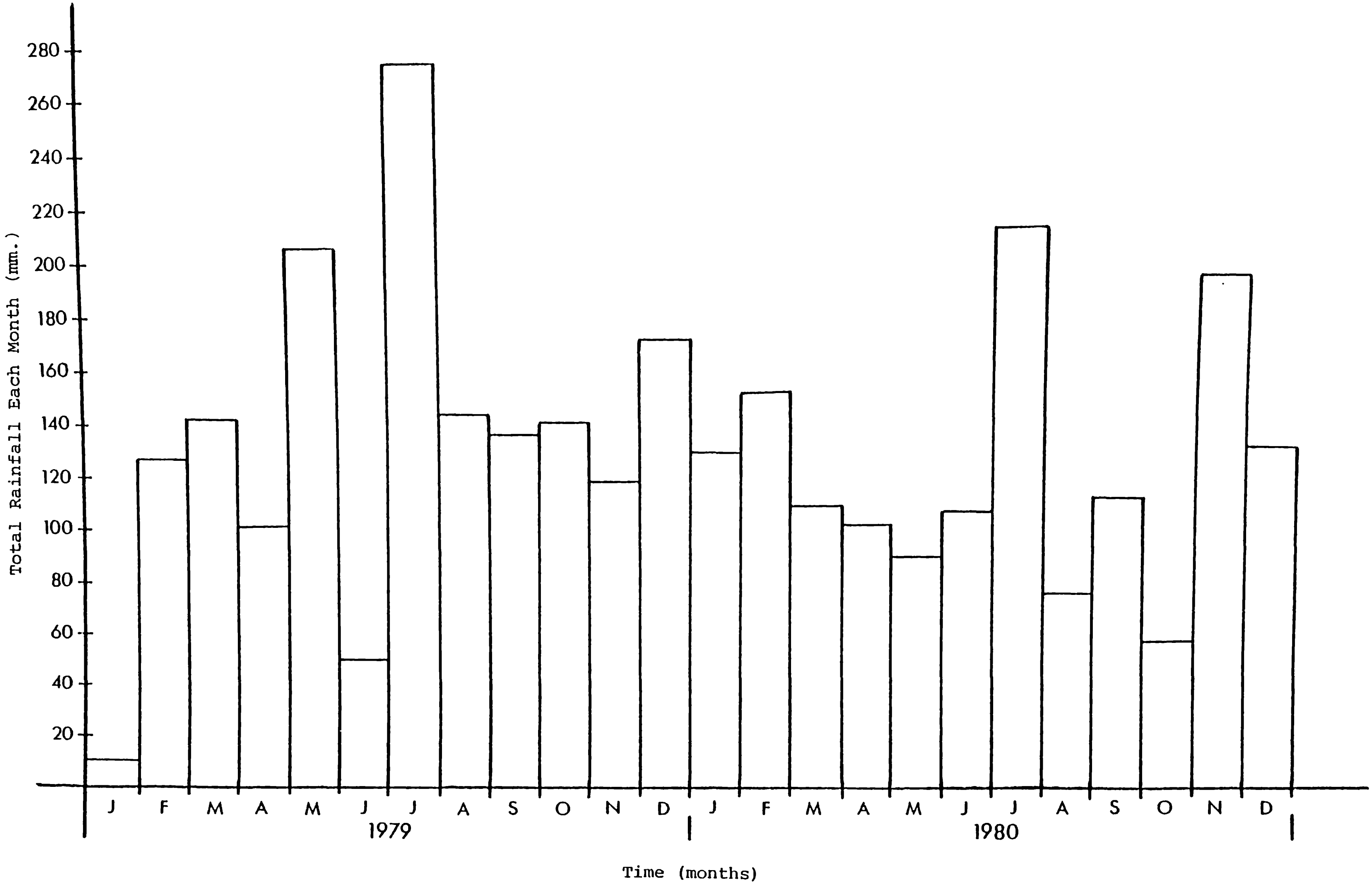




Graph 6: Average weekly rainfall at Whatawhata

(95% confidence intervals not indicated ranged from ± 0.17 to ± 1.73mm).

Graph 7: Total monthly rainfall at Whatawhata



CHAPTER FOUR

TAXONOMY

Introduction

The Superfamily Pyraloidea contains moths of small to moderate size that are in some ways intermediate between the true Microlepidoptera and Macrolepidoptera (Munroe, 1972). It is one of the largest lepidopteran superfamilies second only to the Noctuoidea in number of species. The largest and most varied family is Pyralidae comprising many members of significant economic importance, e.g. the stalk borers, rice borers, sugarcane borers, webworms, banana scab moths and warehouse moths. The Crambinae and Scopariinae (commonly referred to as sod webworms) are related pyralid subfamilies of widespread distribution. Oceanic islands have shown remarkable degrees of endemism in these two groups. New Zealand and Hawaii in particular have especially rich sod webworm faunas, both places showing marked degrees of endemism (Munroe, 1958). In New Zealand *Orocrambus* Purdie (1884) (48 species) and *Maoricrambus* Gaskin (1975a) (monotypic) are endemic crambine genera (Gaskin, 1975a) but scopariine endemic development is essentially specific (Meyrick, 1885). According to Dugdale (pers. comm.) there are at least 120 species (all endemic) of Scopariinae in New Zealand. The main genera are *Eudonia* Billberg (1820) and *Scoparia* Haworth (1812). However, *Scoparia* is an Australian genus and until further studies have been made in New Zealand it should be written as "*Scoparia*" (Dugdale, pers. comm.).

In 1929 Philpott described the genitalia of male Crambinae. Gaskin (1975a) redescribed New Zealand Crambinae including in his work detailed taxonomic drawings of adult genitalia plus notes on the biology of 10 species (1975b). However, Scopariinae had been variously identified on phenotypic wing characters (e.g. Meyrick,1885, 1909; Philpott,1915, 1917, 1928; Hudson,1923, 1928, 1939 and Gaskin,1966). Meyrick (1885) accurately stated in relation to Scopariinae that ..."Owing to the small range of colour and great similarity of markings which are moreover in most of the species moreor less confused and ill-defined being composed of black, white and grey scales variously blended, the group is a difficult one either to study or to describe...". Those that were described were assigned to "*Scoparia*". Dugdale (pers. comm.) suggests that several of these are *Eudonia*. In 1972, Munroe produced a comprehensive manuscript on North American

Scopariinae with taxonomic information of *Cosipara* Munroe, *Eudonia* Billberg, *Gesneria* Hübner and *Scoparia* Haworth. This work was used as a basis for description of New Zealand Scopariinae of hill country pasture around the Waikato. Any Crambinae also encountered were carefully compared with Philpott's (1929) and Gaskin's (1975a and 1975b) works.

TAXONOMIC REVIEW

The main pyralid, crambine and scopariine features are summarized, and followed by descriptions of the genera studied.

Main Features of the Pyralidae (after Chu,1949; Munroe,1972)

Adult: Labial palpi 3-segmented; maxillary palpi small with 3 or 4 rounded segments; proboscis usually prominent; compound eyes large and globular, tending to be larger in males than females; ocelli usually present; antennae simple, filiform. Venation: typically forewing has all veins present except 1A which is reduced to a fold or sometimes a weak tubular vein in terminal part of wing; R_3 and R_4 stalked or rarely, fused. Hindwing with R_5 apposed to or anastomosed with Sc for a distance beyond discal cell which is usually closed; usually 3 well-developed anal veins. Possess pair of tympanic bullae ventrally in basal abdominal segment and in Crambiformes (including Crambinae and Scopariinae) these are apposed along midline and in front of them a median longitudinal chitinous flap or praecintorium hangs down into the cavity between thorax and abdomen effectively dividing it into two chambers.

Pupa: Maxillary palpi distinct; labrum with three lobes; epicranial suture distinct at sides, if not, a deep dorsal groove between 9th and 10th abdominal segments; 8th abdominal segment immobile in both sexes; obtect, appendages fused to each other.

Larva: Cylindrical with well-developed head and prolegs; prominent setae often arising from pinacula; prespiracular pinacula of prothorax never with more than two setae; setae L_1 and L_2 of abdominal segments approximated and usually on a common pinaculum.

Egg: Thin shelled; rarely prominently sculptured.

Main Crambinae and Scopariinae Features (after Munroe, 1972)

Crambinae Adult: Forewing without raised patches of black scales; hindwing cubitus usually distinctly pectinated with hair-like scales. Lateral arms of tegumen of male genitalia strongly narrowed ventrally or much longer than uncus but usually both; uncus usually compressed and strongly curved in vertical plane; gnathos usually long, compressed and decurved; valva often with strong costal process or median armature. Forewing with longitudinal lines, transverse angular bands near end of discal cell, silvery areas, black terminal line broken into dots posteriorly or some combination of these. Hindwing discal cell open, M_1 basally approximated to R_5.

Scopariinae Adult: Forewing usually with weakly raised patches of black scales; hindwing cubitus not distinctly pectinated. Lateral arms of tegumen of male genitalia about as long as uncus, only slightly tapered ventrally; uncus not strongly compressed or decurved; valva sometimes with a ventral process but without strong costal or medial armature; gnathos slender and acuminate. Forewing almost always in shades of grey or brown.

Crambine and Scopariine Larval Features: Hasenfuss (1960) found that for European species crambine and scopariine larvae could be distinguished by the line connecting SD_1 to L_1 of the 8th abdominal segment which runs behind the spiracle in Scopariinae and in front of it in Crambinae. Also setae V_1 of abdominal segment 10 are about as far apart as those of segment 9 in Scopariinae but not more than 0.66x as far apart as those of segment 9 in Crambinae. See generalized setal maps(Figures 1-3).

New Zealand Genera

The main genera present in New Zealand are the crambine *Orocrambus* Purdie (endemic) and scopariine "*Scoparia*" and *Eudonia*. All three genera are represented in hill country sod webworms.

Orocrambus Purdie (after Gaskin, 1975a)

Purdie 1884 *New Zealand J. Science (Dunedin) 2:* 168

Meyrick 1885 *Transactions and Proceedings New Zealand Institute 17:* 133

Gaskin 1975a *New Zealand J. Zoology 2:* 276

Type species: *Orocrambus melampetrus* Purdie 1884 (by monotypy). Labial palpi porrect, tapering, smooth-scaled or hair-scaled, 1.6-2.9x length of head. Forewings often with median white fascia, unicolorous in some species, in others with transverse or variegate markings; dotted subterminal line present in some species but never a sharply angled metallic line; reniform stigma present in a few species. Hindwing unicolorous, occasionally with a dark margin; frenulum always single in male, usually double in female. Venation: R_4 and R_5 typically stalked; M_2 present in fore and hindwings;

Figures 1-3: Generalized lepidopteran larval setal maps (including punctures).

Figure 1: Frontal view of head capsule (after Peterson, 1956).

Figure 2: Left lateral view of head capsule (after Peterson, 1956).

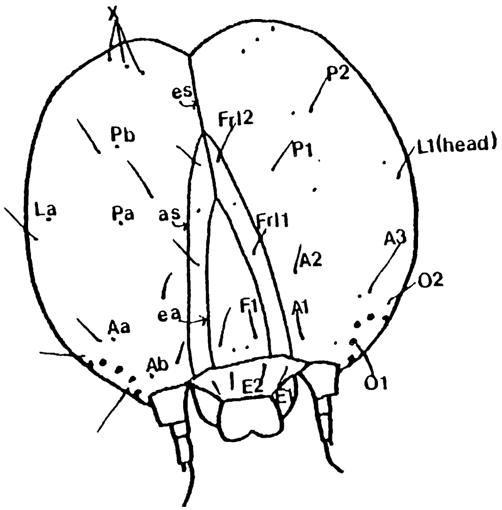
Figure 3: Left lateral view of thorax and abdomen (segments 4-6 omitted) (after Gaskin, 1975a).

Key: a,b - punctures

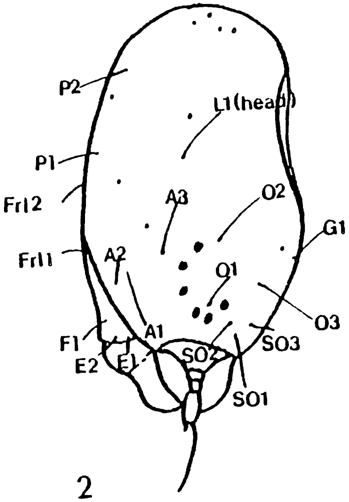
A - Anterior
D - Dorsal
E - Epistomal
F - Frontal
Frl -- Adrontal
G - Genal
L - Lateral
MV - Midventral

O - Ocellar
P - Posterior
SD - Subdorsal
SO - Subocellar
SV - Subventral
V - Ventral
X - Ultraposterior
XD - Cephalic dorsal

as - adfrontal suture
ea - epicranial arm
es - epicranial stem


X
es
Pb
Frl2
P2
P1
L1(head)
La
Pa
as
Frl1
A2
A3
O2
Aa
ea
F1
A1
Ab
E2
E1
O1

1


P2
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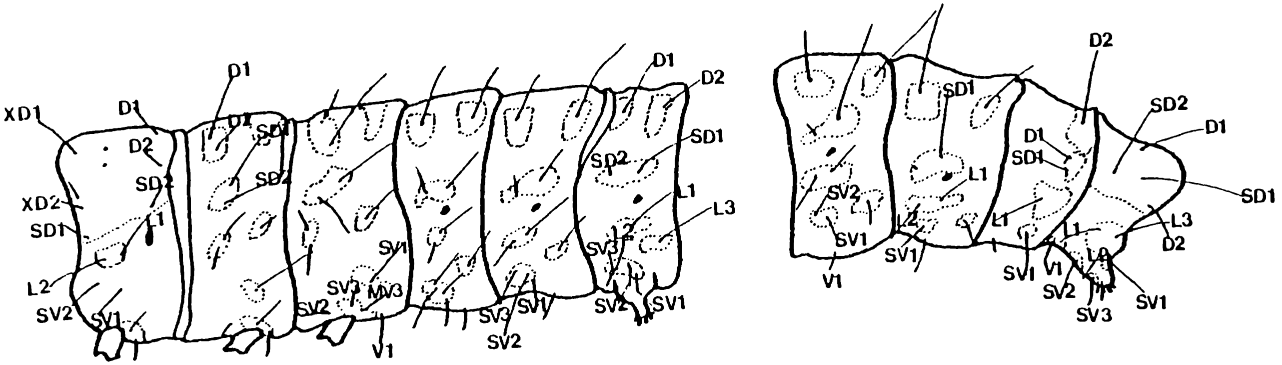
SO2
SO1

2


D1
XD1
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D1
SD1
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XD2
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MV3
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L2
SV1
D2
SD2
D1
D1
SD1
SD1
L1
L1
L3
D2
L0
V1
SV1
SV2
SV3
SV1

3

hindwing discal cell open, Sc and R_1 fused with, or with cross-connection to R_5.

Genitalia

(see generalized Figures 4-6).

Male: Valva rounded, oblongate, costal lobe developed with flange on posterior inner margin drawn in some species to an inwardly directed lobe; sacculus undeveloped or weakly differentiated into a flange on inner posterior margin; uncus tapered, pointed; gnathos pointed or clubbed; aedeagus with or without cornuti and external ornamentation; juxta often absent or vestigial, when present usually a weak crescentic plate or reduced to a pair of slender, curved arms; pseudosaccus present.

Female: Two signa present on corpus bursae, often unequal in size; abdominal sternite 8 a small lunate, oval or triangular plate, strong or weak, or (many species) absent; tergite 8 fused to ostium bursae; anterior apophyses absent or represented by very small triangular projections in lateral midlines of tergite.

Scoparia Haworth (after Munroe, 1972)

Scoparia Haworth 1812 *Lepidoptera Britannica 3:* 498

Scoparia Munroe 1972 in Dominick *et al.* (1972-3). The Moths of America North of Mexico fasc. *13.1* Pyraloidea: 29.

Scopea Haworth 1812 *Lepidoptera Britanica 3:* 498

Eudonea Curtis 1827 *British Entomology 4:* 170

Cholius Guenée in Duponchel 1845 Europae Microlepidopterum Index Methodicus, 94

Tetraprosopus Butler 1882 *Annals Magazine Natural History 9:* 97

Xeroscopa Meyrick 1884 *Transactions Entomological Society London 1884:* 397

Xeroscopa Hampson 1897 *Transactions Entomological Society London 1897:* 226

Type species: *Scoparia arundinata* (Thunberg) (by synonymy). Forewing pattern cryptic in natural surroundings. Labial palpi prominent, porrect; maxillary palpi large ending in tufts of scales; well developed proboscis; frons rounded or flattened and usually smoothly scaled; vertex with rough erect scaling and distinct chaetosemata; large eyes and ocelli. Venation: forewing R_3 and R_4 stalked, R_2 well separated from stalk, 1A absent, 3A weak and free; hindwing Sc and Rs anastomosed for short distance, M_1 usually short stalked with Rs, cell long with strongly curved disocellular and acute posterior angle, M_2 and M_3 arising from posterior angle of cell

Figures 4-6: Generalized lepidopteran genitalia (based on *Eudonia sabulosella*, Scopariinae).

Figure 4: Anterodorsal view of male external genitalia.

Figure 5: Left lateral view of male external genitalia.

Figure 6: Proximal ducts of female genitalia.

Key: Male

ae - aedeagus

c - costa

de - ductus ejaculatorius

g - gnathos

j - juxta

ps - processus of sacculus

sa - saccus

sl - sacculus

sc - sclerites at anellus - aedeagal junction

t - tegumen

ta - tuba analis

u - uncus

v - valva

vn - vinculum

Female

aap - anterior apophyses

as - accessory sac

cb - corpus bursae

db - ductus bursae

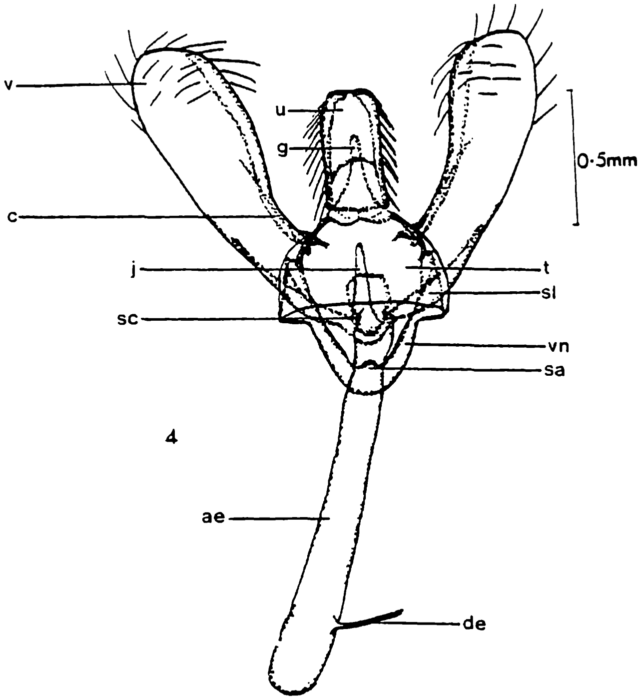
ds - ductus seminalis

ob - ostium bursae

pa - papillae anales

pap - posterior apophyses

si - signum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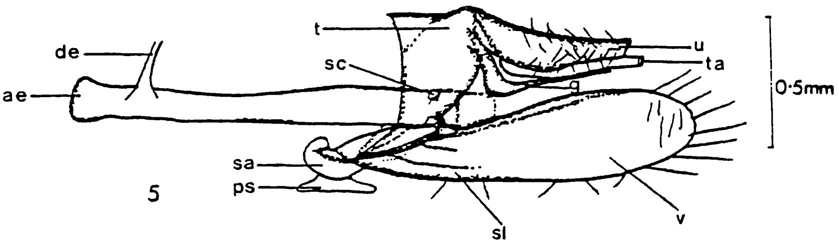
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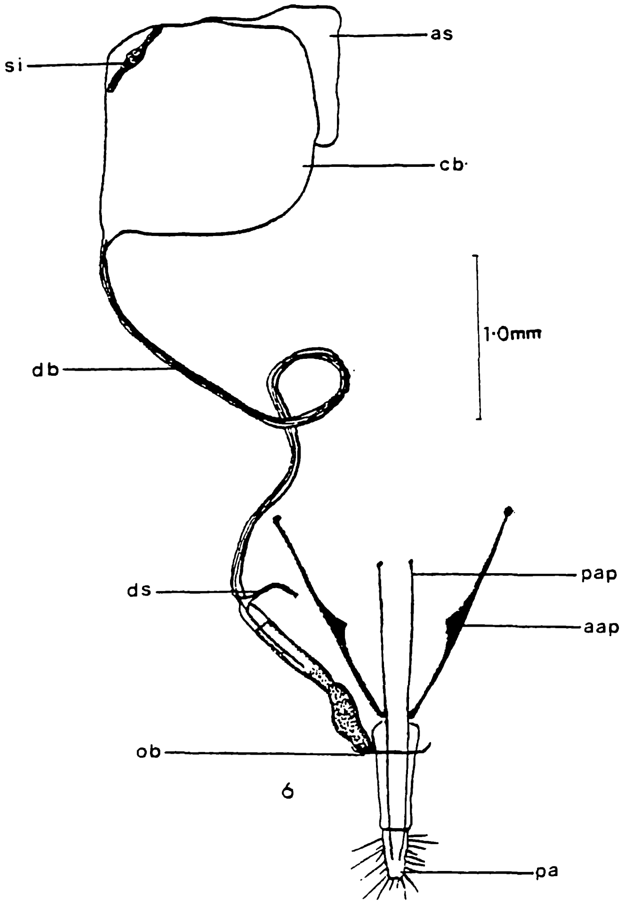
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or stalked, Cu_1 and Cu_2 arising basad of posterior angle, base of Cu pectinated in some species, three anals present.

Genitalia

Male: Valva with slender, sharp process on ventral margin marking end of sacculus; uncus pointed; gnathos slender, Y-shaped, decurved; juxta oblong; aedeagus usually with distinct cornuti.

Female: 7th sternite unmodified; ductus bursae unsymmetrical with short, weak zone of sclerotization, corpus bursae elongate with diffuse, asymmetrical areas of strengthened spinules or scobination.

Eudonia Billberg (after Munroe, 1972).

Eudonia Billberg 1820 Enumeratio Insectorum in Museo Billberg, 93

Eudonia Munroe 1972 in Dominick et al (1972-3). The Moths of America North of Mexico fasc. *13.1* Pyraloidea: 47.

Eudoria Chapman 1912 *Transactions Entomological Society London 1911:* 507

Witlesia Chapman 1912 *Transactions Entomological Society London 1911:* 507

Type species: *Tinea mercurella* Linnaeus (by monotypy)

Very similar in appearance and external structure to *Scoparia* except: labial palpi longer; males usually with thinly scaled or scaleless fovea on forewing between orbicular and reniform spots. Distinguished from *Scoparia* by genitalia.

Genitalia

(see generalized Figures 4-6).

Male: Valva simple, lacking ventral process; uncus more or less oval, strongly decurved and setose at sides, usually tapering posterad, often with mid-apical notch; juxta pyriform; aedeagus cylindrical and only minute scobinations or spinules on vesica, lacking true cornuti, where aedeagus passes through surrounding membrane or anellus, button-like sclerites are present on each side.

Female: Ovipositor lobes weakly developed and sparsely setose; ovipositor strongly retractile and posterior apophyses as long and strong as anterior ones; ductus bursae longer and more slender than *Scoparia* and a fairly long, tubular sclerotized zone not far from ostium, distad of which is a long, slender, membranous zone part of which is arranged into two or more tight coils; corpus bursae small, sharply defined and globular, usually finely spinulose, with a small, round, depressed and more coarsely and densely spinulose area (signum) on one side; globular, membranous accessory sac attached to corpus bursae usually somewhat asymmetrically near its end.

DESCRIPTIONS

The sod webworm species involved in this study and further described here are: *Orocrambus flexuosellus* (Doubleday); *O. vitellus* (Doubleday); *Eudonia psammitis* (Meyrick); *E. sabulosella* (Walker); *"Scoparia" bisinualis* Hudson; *"S". diphtheralis* Walker; *"S". halopis* Hudson; *"S" philerga* Meyrick and *"S" submarginalis* (Walker). Plate 12 shows some of the species studied.

As described in Methods (Ch. 1 p.15) adults were identified using the descriptions of Meyrick (1882, 1885); Philpott (1912, 1914-17, 1926-30); Hudson (1923, 1928, 1939); and Gaskin (1966, 1975a, 1975b). Mr J.S. Dugdale (Systematics Section, D.S.I.R., Mt. Albert, Auckland) verified these identifications against colour slides of type specimens. The terminologies of Klots (1956) and Dugdale (1974) were used for adult genitalia descriptions. For male genitalia "LMB" refers to the length to median breadth ratio. Although measurements were made of male external genitalia it was found to be more appropriate for species identity to use length: width ratios or comparative ratios of certain structures with the uncus (cf. Gaskin, 1975a). "Measurements" of female genitalia refer respectively to: length from ostium to cephalad end of sclerotization of ostiolar region of ductus bursae; length from ostium to point of connection of ductus seminalis to ductus bursae; length from ostium to base of corpus bursae; length from ostium to cephalad end of corpus bursae/accessory sac. Immature stages (eggs and larvae) of certain Crambinae including *O. flexuosellus* and *O. vitellus* have been described by Gaskin (1975a, 1975b) and *O. flexuosellus* eggs by Watt (1914). However, apart from Watt (1914) who also described the egg of *Scoparia cyameuta* (Meyrick) and Chappell (in Hudson, 1939) who described the larva of *S. illota* Philpott there have been no other descriptions of scopariine immature forms. Attempts were thus made through rearing to associate adults with young stages. Setal maps after Peterson (1956) and Gaskin (1975a) were used, see Figures 1-3. Reference is made to the relative positions of setae especially on the larval head capsule. It was found necessary to draw these on to graph paper using a squared eyepiece graticule to allow careful measurements to be made. The size range of eggs refers to length: breadth. The terminal segment of pupae proved the most

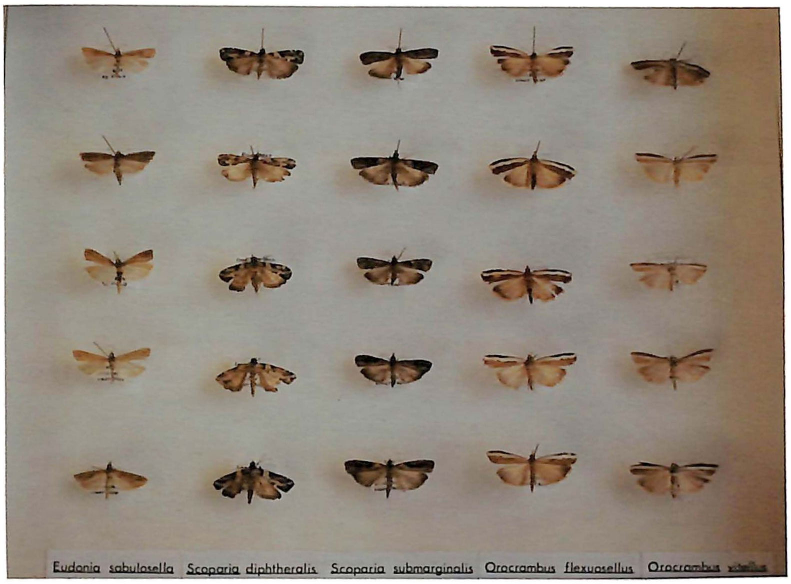


Plate 12: Adults of some of the species studied. From left: *Eudonia sabulosella*, *"Scoparia" diphtheralis*, *"Scoparia" submarginalis* (Scopariinae); *Orocrambus flexuosellus* and *Orocrambus vitellus* (Crambinae). Wingspan range: 22-26mm.

useful for species determination. Except as described above for female ducts, measurements were made from cephalad to caudad.

Subfamily Crambinae

Orocrambus flexuosellus (Doubleday).

For synonymies see Gaskin 1975a *New Zealand J. Zoology 2:* 314
As for Gaskin's (1975a) description except:

Adult: (725 ♂♂, 2803 ♀♀). Wingspan 19-25mm (both sexes); antennae filiform, stouter in male; compound eyes larger in male; tibial spur formula 1, 2, 4 (both sexes); abdomen generally stouter in female and tapered posteriorly, blunt in male.

Genitalia

Male: (n=50) Figures 7-8. Dorsal margin of valvae distally recurved; costae very pronounced, distinctly flanged, tapered proximally, two entally directed costal spines (one dorsodistal, one ventrodistal); both gnathos and uncus distally dentate.

Female: (n=50) Figure 25. Ductus bursae relatively short; ductus seminalis arising slightly anterior to cephalad end of sclerotized ostiolar region and dorso-dextrad of posterior end of reverse loop; reverse loop diving ventrally then dorsocephalad. Measurements: 1.50; 1.67; 2.67-2.83; 3.67-4.83mm; no accessory sac.

Larva: See generalized setal maps (Figures 1-3). Head setae O_2, A_3 and L_1 (head) forming a scalene triangle with $L_1 O_2 > A_3 O_2 > A_3 L_1$; setae A_3, O_2 and O_3 forming an isosceles triangle with $A_3 O_2 = O_2 O_3 < A_3 O_3$; right hand seta Frl_2 dorsad of left hand Frl_2. Abdominal segment 8: seta L_1 very nearly vertically above L_2.

Egg: Oblate; creamy yellow when first laid turning pale red then deep red brown after 36-48 hours. Size range (n=40) 0.46 - 0.48 : 0.29 - 0.31mm. From scanning electron microscope (SEM) studies: aeropyles arranged on longitudinal carinae; no cross striae interconnecting aeropyles between carinae; little surface sculpturing (see Plate 15).

Orocrambus vitellus (Doubleday)

For synonymies see Gaskin (1975a) *New Zealand J. Zoology 2:* 339.
As for Gaskin's description except:

Adult: (86 ♂♂ 157 ♀♀). Wingspan 20-25mm (both sexes); antennae filiform, stouter in male; compound eyes larger in male; tibial spur formula 1, 2, 4 (both sexes); abdomen generally stouter in female and tapered posteriorly, blunt in male.

Genitalia

Male: (n=40) Figures 9-10. Valvae rounded distally, tapered proximally; two entally directed costal spines; uncus beak-like, dentate distally, strongly decurved; gnathos slender, 1.0 - 1.1 x length of uncus, mildly dentate distally; fine scobinations on vesica, aedeagus blunt distally; juxta pronounced, heart-shaped.

Female: (n=40) Figure 26. Ductus bursae with a loose coil slightly caudad of corpus bursae; ductus seminalis arising about midlength. Measurements: 0.67 - 0.83; 2.67 - 3.00; 4.83 - 5.17; 5.50 - 6.50mm; no accessory sac.

Larva: See generalized setal maps (Figures 1-3). Head setae O_2, A_3 and L_1 (head) forming a scalene triangle with $O_2 A_3 > O_2 L_1 > L_1 A_3$; setae A_3, O_2 and O_3 also forming a scalene triangle with $A_3 O_3 > A_3 O_2 > O_2 O_3$; right hand seta Frl_2 subequal in position to left hand Frl_2. Abdominal segment 8 : seta L_1 nearly vertically above L_2.

Egg: Oblate, pale orange brown when first laid turning brown after 36-48 hours. Size range (n=40) 0.44 - 0.48: 0.35 - 0.37mm. From SEM studies: aeropyles arranged on longitudinal carinae; cross striae interconnecting aeropyles between carinae; slight surface sculpturing (see Plate 16).

Subfamily Scopariinae

Larvae: Hasenfuss (1960) described many European Scopariinae larvae (in Munroe, 1972). His description was carefully examined and found to agree in large part with the New Zealand Scopariinae larvae investigated. The sections in full agreement are therefore included below. See generalized setal maps (Figures 1-3).

After Hasenfuss (1960) Scopariinae larvae: "setae Adf_2 (Frl_2) placed above forking of epicranial suture but lower than P_2; setae P_2 more widely separated than P_1. Seta Adf_1 (Frl_1) nearer F_1 than Adf_2 (Frl_2). Ocelli 4, 6 and 5 making a more or less right angle. Seta O_3 considerably closer to SO_3 than O_2. Setae O_1, O_2 and O_3 forming an acute or right angle."

"On the prothoracic shield setae XD_2, SD_1 and SD_2 forming a somewhat obtuse to right angle; SD_1 and SD_2 further apart than SD_1 and XD_2. On mesothorax and metathorax setae L_2 macroscopic and there are macroscopic subventral setae. Prolegs normal with crotchets in a complete biordinal or triordinal circle becoming uniordinal laterally. On abdominal segments 1 to 8 setae D_2 decidedly further apart than setae D_1. Setae L_1 dorsocaudad of L_2. On 8th abdominal segment the line from D_1 to SD_1 runs before and the line from SD_1 to L_1 behind the spiracle. The SV-MV group of abdominal segments 1 and 2 consists of 3 macroscopic setae, that of abdominal segment 7 of two or exceptionally of three. On 9th abdominal segment setae L_2 and L_3 absent. D_1 approximated to the very slender SD_1 and dorsocraniad of it. Setae D_2 on a common pinaculum. Anal shield well developed. Setae D_2 closer to each other than SD_1. SD_2 macroscopic. Setae V_1 of abdominal segment 10 about as far apart as those of segment 9. V_1 further from MV_3 than SV_2 is from SV_3."

Larval abdominal segment 8, anal shield, mandibles, labrum and head capsule (left lateral and frontal views) were drawn on graph paper. Mandibles tended to show wear very readily and were thus not used as a reliable taxonomic feature. However, Koch (1965) used larval mandibular differences to designate species of *Hednota* Meyrick (Crambinae) in Australia. Anal shields and labrum showed minor differences in setal positions but these were minor and thus were not used. The positions of setae L_1 and L_2 of the 8th abdominal segment, head setae A_3, O_2, O_3, L_1 (head) and Frl_2 proved the most useful for species determination and are the ones referred to in the following descriptions.

Eudonia psammitis (Meyrick)

Scoparia psammitis Meyrick *Trans. N.Z. Inst. XVII,* 99

Scoparia leptalea Meyrick (1885) *Trans. N.Z. Inst. XVII,*98

Scoparia leptophaea Meyrick (1902) *Trans. Ent. Soc. Lond. 1902:* 277

Scoparia psammitis Hudson (1928). The Butterflies and Moths of N.Z. p. 194

Scoparia leptalea Hudson (1928). The Butterflies and Moths of N.Z. p. 194

Witlesia psammitis Munroe (1964) *Pacific Insect Monograph 7:* 260-1.

Eudonia (=Witlesia) Munroe (1972). The Moths of America North of Mexico *Fasc. 13.1A*

As for the above descriptions except:

Adult: (109 ♂♂, 138 ♀♀). Wingspan 17-20mm (both sexes); antennae filiform, stouter in male; compound eyes larger in male; tibial spur formula 1, 2, 4 (both sexes); frenulum single in male, triple in female; abdomen generally stouter in female and tapered posteriorly, blunt in male.

Genitalia

Male: (n=20). Figures 11-12. Valvae distally rounded, equally wide for almost whole length with slight tapering proximally, sparsely setose; costa with one dorsal spine proximally; tegumen, vinculum and saccus forming an elongate, ovoid cage; sacculus weakly inflated; juxta pyriform; uncus spatulate, rounded distally, apically notched, decurved and setose, rather short, length: width ratio 2.6 - 2.8 : 1; gnathos strong, very distinctly acuminate, 0.8 - 0.9 x length of uncus; aedeagus 4.9 - 6.5x length of uncus, no armature, LMB ratio 13.6 - 14.0 : 1; anellus junction with sclerites on each side of aedeagus, sclerites flap-like, extended, sparsely setose.

Female: (n=20). Figure 27. Anterior apophyses mildly notched at mid length, clubbed proximally; posterior apophyses clubbed proximally, subequal in length to anterior ones; papillae anales setose; ostium bursae encircled; ostiolar pouch scobinate, sclerotized, cup shaped proximally, tapering to cephalad end of sclerotized zone; ductus bursae medium long with a loop at 0.66x length from ostium and at base of corpus bursae; ductus seminalis arising at anterior end of sclerotized basal section; measurements: 1.33 - 1.83; 1.50- 1.83; 4.83 - 6.00; 6.00- 7.17mm; corpus bursae small, finely scobinate with a densely scobinate signum on one side; signum crescentic with a straight line on its lower edge; asymmetrical apical accessory sac on corpus bursae, thick. Appears similar to *Eudonia sabulosella* but basal section of sclerotized region of ductus bursae distinctly longer and corpus bursae smaller in *E. psammitis*.

Egg: Ovoid, yellow when first laid turning deep red after 24-36 hours. Size range (n=20) 0.41 - 0.46 : 0.28 - 0.29mm. From SEM studies: usually pentagonal - hexagonal arrangement of aeropyles and interconnecting carinae; carinae smooth sided, narrow; only lightly defined, but more pronounced than in *E. sabulosella;* little surface sculpturing (see Plate 17).

As shown by taxonomic figures (11, 12 and 27) the genus is *Eudonia* as differentiated by Munroe (1972). Munroe placed *E. psammitis* in *Witlesia* in 1964 but that genus was synonymized with *Eudonia* in 1972.

Eudonia sabulosella (Walker)

Crambus sabulosellus Walker Cat. XXVII, 178
Scoparia sabulosella Meyrick (1885). Trans. N.Z. Inst. XVII, 106.
Scoparia sabulosella Hudson (1928). The Butterflies and Moths of N.Z. p. 198
Witlesia sabulosella Munroe (1964) *Pacific Ins. Monograph 7:* 260-71.
Eudonia (=Witlesia) Munroe (1972). The Moths of America North of Mexico *Fasc. 13.1A*.

Adult: (1143 ♂♂, 1123 ♀♀) Wingspan 19-23mm (both sexes); antennae filiform, stouter in male; compound eyes slightly larger in male; tibial spur formula 1, 2, 4 (both sexes); frenulum single in male, triple in female; abdomen generally stouter in female and tapered posteriorly, blunt in male.

Genitalia

Male: (n=40). Figures 13-14. Valvae rounded and sparsely setose distally, tapered cephalad with minimum width at 0.3 of length from base and flaring slightly proximally; costae each with single dorsal spine proximally; tegumen, vinculum and saccus forming an ovoid cage; sacculus weakly inflated; juxta pyriform; uncus spatulate, broad, slightly tapering and squared posteriorly, apically notched, strongly decurved laterally, setose, length: width ratio approximately 1.8 - 2.0 : 1; gnathos broad proximally, rapidly tapering posterad, V-shaped, 0.65-0.70 length of uncus; aedeagus 3.0 - 3.5 x length of uncus, LMB ratio about 11-12 : 1, no armature; setose, button-like sclerites at anellus junction on each side of aedeagus.

Female: (n=40). Figure 29. Anterior apophyses notched at mid length, clubbed proximally; posterior apophyses approximately 1.3x length of anterior ones, clubbed proximally, pointed and tapered into papillae anales; papillae anales sparsely setose, elongate; ostium bursae encircled; ostiolar pouch mildly scobinate, sclerotized, cup shaped; ductus bursae of medium length, slender, with one complete coil about midlength; ductus seminalis arising distad of basal sclerotized portion of ductus bursae; measurements: 0.83 - 1.00; 1.00- 1.17; 4.83 - 5.33; 6.67 - 7.67mm; corpus bursae globular, finely spinulose with an elongated, depressed and densely spinulose signum on one side; globular membranous accessory sac asymmetrically dextrocephalad on corpus bursae.

Pupa: Typically pyralid see generalized Figures 34-38. (based on *E. sabulosella*).

Male Terminal Segment. Figures 39-41. Ventral and dorsal view - distinctly notched at 0.25 x length; 4 distal setae. Lateral view - tergum mildly notched at 0.75x length, then slightly flattened posterad; sternum smoothly curving to cremaster.

Female Terminal Segment. Figures 42-44. Ventral and dorsal views notched at 0.25 x length; 4 distal setae. Lateral view - tergum mildly notched at 0.5 x length and squared to cremaster; sternum smoothly tapering to cremaster.

Larva: See generalized setal maps Figures 1-3 and Plates 13-14. Final instar 15-19mm long; pale brown pink with roman sepia pinacula (see colour chart-Smith, 1906), some irrorations and iridescence in preserved specimens; finely scobinate integument, pale brown ventrally. Head capsule well-developed; adfrontals and epicranial stem subequally long, forking 0.3x length of head (from dorsum); setae A_3, O_2 and O_3 forming a scalene triangle $A_3\ O_3 > A_3\ O_2 > O_2\ O_3$; setae O_2, A_3 and L_1 (head) forming an isosceles triangle $A_3\ L_1 = L_1\ O_2 < A_3\ O_2$; right hand Frl_2 dorsad of left hand Frl_2 . Prothoracic shield well-developed, strong in late instars. Abdominal segment 8 : seta L_1 dorsal and posterior to L_2; anal shield well-developed.

Egg: Ovoid; pale orange cream when first laid turning deep red brown after 24-36 hours. Size range (n=40) 0.38 - 0.46 : 0.31 - 0.37mm. From SEM studies : usually pentagonal - hexagonal arrangement of aeropyles and interconnecting carinae; carinae narrow, only vaguely visible; regular, slight surface sculpturing (see Plate 18).

In 1972 Munroe synonymized *Witlesia* with *Eudonia*. Taxonomic figures (13, 14 and 29) support that *sabulosella* is of the genus *Eudonia*.

"*Scoparia*" *bisinualis* Hudson

Scoparia bisinualis Hudson (1928). The Butterflies and Moths of New Zealand. p. 194.

As for Hudson's description except:

Adult: (40 ♂♂ 65 ♀♀). Wingspan 17-20mm (both sexes); antennae filiform, stouter in male; compound eyes larger in male; tibial spur formula 1, 2,4 (both sexes); frenulum single in male, triple in female; abdomen generally stouter in female and tapered posteriorly, blunt in male.

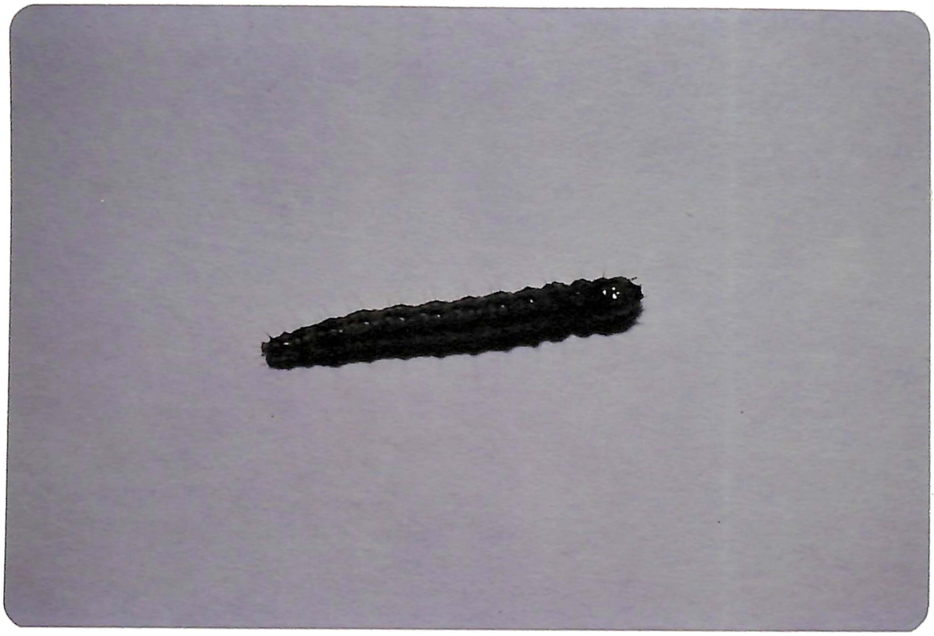


Plate 13: Larva of *Eudonia sabulosella* (15mm long).

Plate 14: *Eudonia sabulosella* larva in moss.

Genitalia

Male: (n = 20). Figures 15-16. Valvae rounded distally, tapered proximally, flared on dorsal edge at about 0.5 - 0.6x length from base, sparsely setose; costae elongate with single dorsal spine proximally; tegumen, vinculum and saccus forming a circular-ovoid cage; sacculus slightly inflated; juxta pyriform; uncus spatulate, rounded distally, not apically notched, length : width ratio 2.5 - 3.0 : 1, decurved laterally, setose; gnathos slender, V-shaped, acuminate, subequal to or slightly longer than uncus i.e. 0.92 - 1.05 x length of uncus; aedeagus 2.2 - 3.1x length of uncus; no armature, LMB ratio 9.3 - 11.2 : 1; anellus junction with spheroid, setose sclerites on each side of aedeagus.

Female: (n=20). Figure 30. Anterior apophyses not notched, clubbed proximally; posterior apophyses distinctly clubbed proximally, 1.3x length of anterior apophyses; papillae anales setose; ostium bursae encircled; ostiolar pouch sclerotized, cup shaped proximally, rapidly tapering to a slender duct; ductus bursae extremely long, slender with 2-3 complete coils just posterior to corpus bursae; ductus seminalis arising at anterior end of sclerotized basal part of ductus bursae; measurements : 1.83 - 2.17; 1.83 - 2.17; 16.67; 18.33mm; corpus bursae spheroid, finely spinulose with elongated, crescentic, depressed and densely spinulose signum on one side; asymmetrical, thick accessory sac apically on corpus bursae.

Pupa: Typically pyralid see generalized Figures 34-38.

Male Terminal Segment: Figures 45-47. Ventral and dorsal views - distinctly notched at 0.2x length, rapidly tapering from the spiracular notches to 0.5x length then parallel sided and rounded into cremaster; 4 distal setae. Lateral view - sternum with bulge at 0.5x length then tapered to cremaster; tergum gently curving into cremaster.

Female Terminal Segment: Figures 48-50. Ventral and dorsal views - distinctly notched at 0.25x length, tapering to 0.7x length where parallel sided before rounding into cremaster; 4 distal setae. Lateral view - both tergum and sternum tapering smoothly to 0.7 - 0.8x length then rounded ventrally, squared dorsally.

Larva: See generalized setal maps (Figures 1-3.) Head well-developed; adfrontal fork narrow; setae A_3, O_2 and O_3 forming a scalene triangle $A_3 O_3 > A_3 O_2 > O_2 O_3$; setae A_3, O_2 and L_1 (head) forming a scalene triangle $L_1 O_2 > O_2 A_3 > A_3 L_1$; right hand Frl_2 very slightly dorsad of left hand

Frl_2 . Prothoracic shield well developed. Abdominal segment 8 : seta L_1 posterior and a little dorsad of L_2.

Egg: Ovoid; pale yellow cream when first laid turning brown after 24-36 hours. Size range (n=20) 0.41 - 0.46 : 0.30 - 0.35mm. From SEM studies: usually subequal pentagonal - hexagonal arrangement of aeropyles and interconnecting carinae; carinae smooth sided and defined; almost smooth surface sculpturing (see Plate 19).

This species has previously been placed in the genus *"Scoparia"*. As seen from adult genitalia descriptions and figures, *bisinualis* conforms to *Eudonia*. As type specimen genitalia have not been examined this has not been confirmed but it appears that this insect should be *Eudonia bisinualis* (Hudson).

"Scoparia" diphtheralis Walker

Scoparia diphtheralis Walker Cat. XXXIV Suppl. 1501

Scoparia diphtheralis Meyrick (1885) *Trans. N.Z. Inst. XVII* 94

Scoparia diphtheralis Hudson (1928). The Butterflies and Moths of New Zealand, p. 192

Scoparia diphtheralis Gaskin (1966). The Butterflies and Common Moths of New Zealand. p. 167

As for the above descriptions except:

Adult: (64 ♂♂, 141 ♀♀). Wingspan 21-25mm (both sexes); antennae filiform, stouter in male; compound eyes about equal size both sexes; tibial spur formula 1, 2, 4 (both sexes); frenulum single in male, triple in female; abdomen generally stouter in female and tapered posteriorly, blunt in male.

Genitalia

Male: (n=20). Figures 17-18. Valvae squared distally, sparsely setose, broad, gradually tapering proximally; costae elongate with single dorsal spine proximally; tegumen, vinculum and saccus forming a subquadrangular cage; sacculus inflated; juxta elongated, pyriform; uncus spatulate, tapering posterad, rounded distally, not apically notched, strongly decurved laterally, setose, length : width ratio approximately 2.0 - 2.5 : 1; gnathos slender, tapering, V-shaped, 0.91 - 0.96x length of uncus; aedeagus 3.5 - 4.5x length of uncus, LMB ratio about 10.5 - 11.0 : 1, no armature; anellus sclerites setose with circular basal section and lateral flattened flaps on each side of aedeagus.

Female: (n=25). Figure 31. Anterior apophyses notched at midlength, clubbed proximally; posterior apophyses subequal in length to anterior ones, clubbed proximally; papillae anales sparsely setose, elongate; ostium bursae encircled; ostiolar pouch sclerotized and longest of any species examined, equally thick, tubular distally, flared proximally; ductus bursae medium-long, moderately thick with three spirals at about 0.65 - 0.70x length from ostium; ductus seminalis arising just cephalad of basal sclerotized portion of ductus bursae; measurements : 2.00 - 2.50; 2.67 - 3.17; 5.83 - 7.33; 8.00- 9.33mm; corpus bursae spheroid, finely spinulose with an elongate, depressed, densely spinulose signum on one side; asymmetrical sac apically on corpus bursae.

Pupa: Typically pyralid see generalized Figures 34-38.

Male only - Terminal Segment: Figures 51-53. Ventral and dorsal views - notched at 0.25x length, gently tapering to 0.6x length then flared slightly and rounded to cremaster; 4 distal setae; inflated, rounded areas each side of genital aperture. Lateral view - slightly and evenly tapering dorsally; sternum curved to 0.5x length then almost straight to 0.85 - 0.90x length from which rounded to cremaster.

Larva: Head capsule well developed; setae A_3, O_2 and O_3 forming an isosceles triangle $A_3\ O_2 = O_2\ O_3 < A_3\ O_3$; setae A_3, O_3 and L_1 (head) also forming an isosceles triangle $A_3\ L_1 = O_2\ L_1 < A_3\ O_2$. Prothoracic shield well developed. Abdominal segment 8 : L_1 posterior and a little dorsad of L_2. Right hand Frl_2 subequal to left hand Frl_2.

Egg: Ovoid; pale cream when first laid turning dark lemon then pale orange brown within 48 hours. Size range (n=30) 0.48 - 0.54 : 0.37mm. From SEM studies: usually irregularly sized pentagonal-hexagonal arrangement of aeropyles and interconnecting carinae; carinae smooth sided and defined; 4-11 small, discrete, defined protruberances within each aeropylar enclosure (see Plate 20).

It is clear from the descriptions given especially of male and female genitalia that *diphtheralis* is indeed not of the genus "*Scoparia*" but *Eudonia*. Type specimens have not been examined but Dugdale (pers. comm.) agrees that this insect should be *Eudonia diphtheralis* (Walker).

"*Scoparia*" *halopis* Meyrick

Scoparia halopis Meyrick (1909) Sub-antarctic Islands of New Zealand, p72.

Scoparia halopis Hudson (1928). The Moths and Butterflies of New Zealand, p. 199.

Scoparia legionara Philpott (1928) *Trans. N.Z. Inst. 58:* 359-70.

As for the above descriptions except:

Adult: (32 ♂♂, 61 ♀♀). Wingspan 19-24mm (both sexes); antennae filiform, stouter in male; compound eyes larger in male; tibial spur formula 1, 2, 4 (both sexes); frenulum single in male, triple in female; abdomen generally broader in female and tapered posteriorly, blunt in male.

Genitalia

Male: (n=20). Figures 19-20. Valvae rounded and enlarged distally, tapered proximally, projection at midlength on ventral surface; two costal spines; tegumen, vinculum and saccus forming a subquadrangular cage; juxta oblong; uncus pointed, slender, setose; gnathos slender Y-shaped, acuminate, strongly recurved, 0.88x length of uncus; aedeagus about 3.0 - 4.0x length of uncus, cornuti directed posterad, one large and 3-4 smaller cornuti; no anellus - aedeagal sclerites.

Female: (n=10). Figure 32. Anterior apophyses notched at midlength, clubbed proximally; posterior apophyses approximately 0.9x length of anterior ones, clubbed proximally, pointed and tapered into papillae anales; papillae anales sparsely setose, mildly elongate; ostium bursae encircled; ostiolar pouch scobinated, cup shaped, lightly sclerotized; ductus bursae short, very thick, no coiling; ductus seminalis arising a little cephalad of basal sclerotized portion of ductus bursae; measurements 0.83 - 1.00; 1.00 - 1.17; 4.83 - 5.33; 6.67 - 7.67mm; corpus bursae globular, small, scobinate with two unequal, elongated, depressed and densely spinulose signa; no accessory sac.

Pupa: Only one female exuviae obtained. General pupa as for Figures 34-38.

Female only - Terminal Segment: Figures 54-56. Ventral and dorsal views - notched at 0.25x length, tapered posterad and rounded to cremaster, 4 distal setae; cremaster squat. Lateral view - tapering to 0.8x length ventrally then rounded to cremaster; tergum tapering to 0.8x length then bulged before again tapering to cremaster.

Egg: Ovoid; pale yellow when first laid turning brown after 24-36 hours. Size range (n=20) 0.52 - 0.56 : 0.37mm. From SEM studies: usually irregularly sized pentagonal-heptagonal arrangement of aeropyles and interconnecting carinae; carinae broad, irregular, wavy sides; diffuse, coalescing protruberances within aeropylar enclosures (see Plate 21).

Of all the Scopariinae examined this is the only *"Scoparia"* as seen from genitalia descriptions and figures. Dugdale (pers. comm.) agrees with this and also suggests that *legionara* Philpott be synonymized with *halopis* according to type specimens.

"Scoparia" philerga Meyrick

Scoparia philerga Meyrick (1885). Trans. N.Z. Inst. 17: 81

Scoparia philerga Hudson (1928). The Moths and Butterflies of New Zealand, p. 183

Scoparia philerga Gaskin (1966). The Butterflies and Common Moths of New Zealand p. 166-7.

As for the above descriptions except:

Adult: (146 ♂♂, 123 ♀♀). Wingspan 16-24mm (both sexes); antennae filiform only slightly stouter in male; compound eyes larger in male; tibial spur formula 1, 2, 4 (both sexes); frenulum single in male, triple in female; abdomen generally stouter in female and tapered posteriorly, blunt in male.

Genitalia

Male: (n=60). Figures 21-22. Tergum 9 notched at junction with uncus; valvae subequal in width, rounded and slightly recurved dorso-posterad; costae each with one dorsal spine proximally; tegumen, vinculum and saccus forming a subquadrangular cage; juxta pyriform; uncus spatulate, slightly tapering and rounded posteriorly, not apically notched, decurved laterally, setose, length : width ratio approximately 3 : 1, gnathos slender, V-shaped and rapidly tapering, acuminate posteriorly, 0.75 - 0.80x length of uncus; aedeagus 3.75 - 4.25x length of uncus, LMB ratio 9-10 : 1, no armature; sclerites at anellus junction on each side of aedeagus with button-like base and extended flattened flaps, setose.

Female: (n=30). Figure 28. Anterior apophyses notched at 0.6x length from cephalad end, clubbed proximally; posterior apophyses subequal in length to anterior ones; papillae anales elongate, sparsely setose; ostium bursae encircled; ostiolar pouch tubular, sclerotized, basally cupped to 0.1x length of sclerotized region, tapering from cupped region to cephalad end of sclerotization and junction with ductus seminalis; ductus bursae of short-medium length, thick, with one spiral about mid-length; measurements: 1.67 - 1.83; 1.83 - 2.00; 4.67 - 5.5; 6.83 - 7.33mm;

corpus bursae globular; signum elongated, spinulose, on one side of corpus bursae; accessory gland apical on corpus bursae.

Pupa: Typically pyralid, see Figures 34-38.

Male Terminal Segment: Figures 57-59. Ventral and dorsal views - tapered caudad to 0.75x length then rounded distally; 4 distal setae. Lateral view - tergum smoothly tapered, sternum slightly tapering posteriorly to 0.75 - 0.81x length then squared to cremaster.

Female Terminal Segment: Figures 60-62. Ventral and dorsal views - rapidly tapering caudad, slightly rounded distally; 4 distal setae. Lateral view - both tergum and sternum subequally and smoothly tapering to cremaster.

Larva: See generalized larval setal maps (Figures 1-3). Head capsule well developed; adfrontal area broad, forking at 0.5 - 0.6x length of head from dorsum; right hand Frl_2 subequal in position to left hand Frl_2 ; setae A_3, O_2 and O_3 forming an isosceles triangle $A_3 O_2 = O_2 O_3 < A_3 O_3$; setae A_3, O_2 and L_1 (head) forming a scalene triangle $A_3 O_2 > L_1 O_2 > A_3 L_1$. Prothoracic shield well-developed, strong in late instars. Abdominal segment 8: L_1 dorsad and posterior to L_2; anal shield well developed.

Egg: Spheroid, creamy white when first laid turning red brown after 24-36 hours. Size range (n=10) 0.37 - 0.41 : 0.29 - 0.31mm. From SEM studies: usually pentagonal-hexagonal arrangement of aeropyles and interconnecting carinae; carinae broadest of any species examined; side of carina slightly wavy; 2-13 well defined, discrete protruberances within aeropylar enclosures (see Plate 22).

The genus should be *Eudonia* as differentiated by Munroe (1972) on adult genitalia and this is supported by taxonomic figures (21, 22 and 28). Dugdale (pers. comm.) also agrees that "*Scoparia*" *philerga* should be redescribed as *Eudonia philerga* (Meyrick).

"*Scoparia*" *submarginalis* (Walker)

Hypochalcia submarginalis Walker *Cat XXVII,* 48
Nephopteryx maoriella Walker *Cat 35,* 1720
? *linealis* Walker *Cat XXXIV* 1503
Scoparia submarginalis Meyrick (1885) *Trans N.Z. Inst. XVII,* 95
Scoparia submarginalis Hudson (1928). The Butterflies and Moths of New Zealand p. 192

Scoparia submarginalis Gaskin (1966). The Butterflies and Common Moths of New Zealand, p. 169.

As for the above descriptions except:

Adult: (93 ♂♂, 318 ♀♀). Wingspan 19-24mm (both sexes); antennae filiform, stouter in male; compound eyes only slightly larger in male; tibial spur formula 1, 2, 4(both sexes); frenulum single in male, triple in female; abdomen generally stouter in female and tapered posteriorly, blunt in male.

Genitalia

Male: (n=30). Figures 23-24. Valvae rounded, sparsely setose, very broad at midlength, tapered proximally; costae elongate with one dorsal spine proximally; tegumen, vinculum and saccus forming a pyriform cage; sacculus slender, mildly inflated; juxta pyriform; uncus spatulate, tapering at 0.6 - 0.7 of its length from base then rounded distally, not apically notched, decurved laterally, setose, length : width ratio about 2.4 - 2.7 : 1; gnathos very slender, acuminate, V-shaped 0.71 - 0.81x length of uncus; aedeagus 3.0 - 4.0x length of uncus, LMB ratio about 12.0 - 15.5 : 1; no armature; anellus junction sclerites setose, circular on each side of aedeagus.

Female: (n=40). Figure 33. Anterior apophyses thickened at midlength, not notched, clubbed proximally; posterior apophyses not obviously clubbed proximally, about 0.65x length of anterior ones; papillae anales sparsely setose, elongate; ostium bursae encircled; ostiolar pouch sclerotized and flared both proximally and distally, evenly thick; ductus bursae medium long and moderately thick with two spirals at about 0.65 - 0.70of its length from ostium; ductus seminalis arises a little cephalad of basal sclerotized zone; measurements : 1.67 - 2.00;1.83 - 2.17; 5.50 - 6.67; 7.17 - 8.83mm; corpus bursae spheroid , finely spinulose with an elongated, depressed and densely spinulose signum on one side; asymmetrical, thick accessory sac apically on corpus bursae.

Pupa: Typically pyralid as in Figures 34-38.

Male Terminal Segment: Figures 63-65. Ventral and dorsal views - notched at 0.3x length; tapered and rounded to cremaster; 4 distal setae; rounded, inflated areas each side of genital slit. Lateral view - dorsum slightly tapering to cremaster but a bulge at 0.6x length; sternum distinctly bulged at 0.5x length and rounded to cremaster.

Female Terminal Segment: Figures 66-68. Ventral and dorsal views - notched at 0.25x length, tapered to 0.75x length then slightly flared and rounded to cremaster; 4 distal setae. Lateral view - slightly tapered dorsally; sternum tapered to 0.75x length then rounded into cremaster.

Larvae: See generalized setal maps (Figures 1-3). Head capsule well-developed; setae A_3, O_2 and O_3 forming a scalene triangle $O_3 A_3 > A_3 O_2 > O_2 O_3$; setae A_3, O_2 and L_1 (head) also forming a scalene triangle $A_3 O_2 > L_1 O_2 > A_3 L_1$; left hand Frl_2 dorsad of right hand Frl_2; adfrontal apex broad and shallow. Prothoracic shield well developed. Abdominal segment 8: L_1 vertically dorsad of L_2. Anal shield well developed.

Egg: Spheroid, pale pinkish cream when first laid turning dark orange brown after 24-36 hours. Size range (n=40) 0.41 - 0.46: 0.37mm. From SEM studies: usually subequal pentagonal-hexagonal arrangement of aeropyles and interconnecting carinae; carinae strongly defined, smooth sided; contiguous but individually discrete protruberances within aeropylar enclosures (see Plate 23).

It is clear from the descriptions given here of male and female genitalia that the genus should be *Eudonia* not "*Scoparia*". Genitalia of type specimens have not been examined but Dugdale (pers. comm.) agrees that this species should be reclassified as *Eudonia submarginalis* (Walker).

Table 1. Summary of larval setal patterns for the species studied (except "*Scoparia*" *psammitis* for which no larvae obtained).

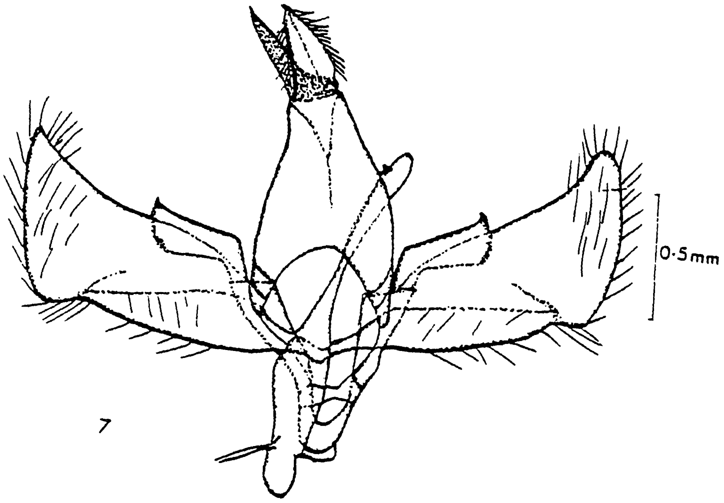
SPECIES	$A_3\ O_2\ O_3$	L_1(head) $A_3\ O_2$	Frl_2	Abdominal Segment 8
Orocrambus flexuosellus	Isosceles $A_3O_2=O_2O_3<A_3O_3$	Scalene $L_1O_2>A_3O_2>A_3L_1$	RHS slightly dorsad of LHS	L_1 vertically dorsad of L_2
Orocrambus vitellus	Scalene $A_3O_3>A_3O_2>O_2O_3$	Scalene $O_2A_3>O_2L_1>L_1A_3$	RHS=LHS	L_1 very nearly vertically dorsad of L_2
Eudonia sabulosella	Scalene $A_3O_3>A_3O_2>O_2O_3$	Isosceles $A_3L_1=L_1O_2<A_3O_2$	RHS dorsad of LHS	L_1 dorsad and posterior of L_2
"*Scoparia*" *bisinualis*	Scalene $A_3O_3>A_3O_2>O_2O_3$	Scalene $L_1O_2>O_2A_3>A_3L_1$	RHS a little dorsad of LHS	L_1 posterior and a little dorsad of L_2
"*Scoparia*" *diphtheralis*	Isosceles $A_3O_2=O_2O_3<A_3O_3$	Isosceles $A_3L_1=L_1O_2<A_3O_2$	RHS=LHS	L_1 posteior and a little dorsad of L_2
"*Scoparia*" *halopis*	Isosceles $A_3O_3>O_2O_3=A_3O_2$	Scalene $A_3O_2>L_1O_2>A_3L_1$	LHS slightly dorsad of RHS	-
"*Scoparia*" *philerga*	Isosceles $A_3O_2=O_2O_3<A_3O_3$	Scalene $A_3O_2>L_1O_2>A_3L_1$	RHS=LHS	L_1 dorsad and posterior of L_2
"*Scoparia*" *submarginalis*	Scalene $A_3O_3>A_3O_2>O_2O_3$	Scalene $A_3O_2>L_1O_2>A_3L_1$	LHS dorsad of RHS	L_1 vertically dorsad of L_2

Discussion

Munroe (1958) in remarking on the distributions of Scopariinae stated that although *Scoparia* has nearly as wide a range as *Eudonia* it has not been as successful as the latter in colonizing oceanic islands. From the small sample of Scopariinae represented in hill country, six of the seven species were *Eudonia*. If this bias towards *Eudonia* persists for other habitats it would certainly substantiate Munroe's comments. Munroe also suggested that the "success" of the group as a whole is related to their moss-eating larvae enabling invasion of most habitats. The species described here were all moss-eating including "*Scoparia*" *halopis*. Considering that the native vegetation of New Zealand (e.g. as evidenced aroung the National Park regions, especially Tongariro and Egmont) has a predominance of tussock grasses and mosses, scopariine larvae have undergone explosive adaptive radiation. The advent of pastoral farming merely served to increase the available palatable grasses and mosses.

Scopariinae moths are very similar phenotypically and it is virtually impossible to identify worn specimens unless dissection of the genitalia is made. Similarly, worn crambines also require genitalia dissection before assigning to species. The differences found in this sample of sod webworms were consistent within a species even over its range of phenotypic variability. Egg colouration changes and size ranges were reasonably reliable though there was some overlap. Larvae proved the most difficult and it was only through detailed drawings of each species that the setal differences (consistent for a species) were isolated. Such patterns require comparison on each side of the body as setae may be lost from one area and not others. A prime example of this was a fully grown "*S*". *diphtheralis* larva which lacked L_1 on the left prothorax but that seta was intact on the right prothorax. Clearly this occurred early in taxonomic studies as Scopariinae do not offer such obvious clues to identiity. Pupal terminal segments provided consistent and moderately distinct species differences.

Figures 7-10: Male external genitalia.
Figure 7: *Orocrambus flexuosellus* anterodorsal view
Figure 8: *O. flexuosellus* left lateral view
Figure 9: *O. vitellus* anterodorsal view
Figure 10: *O. vitellus* left lateral view



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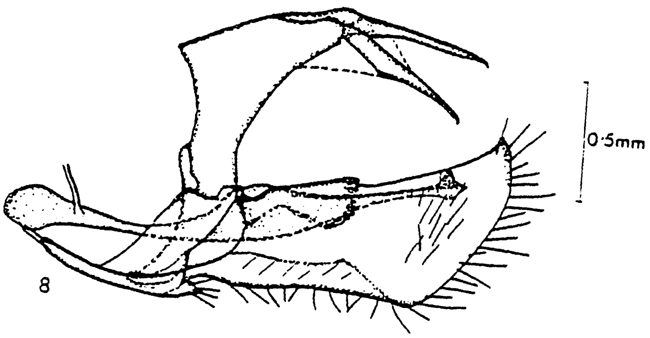

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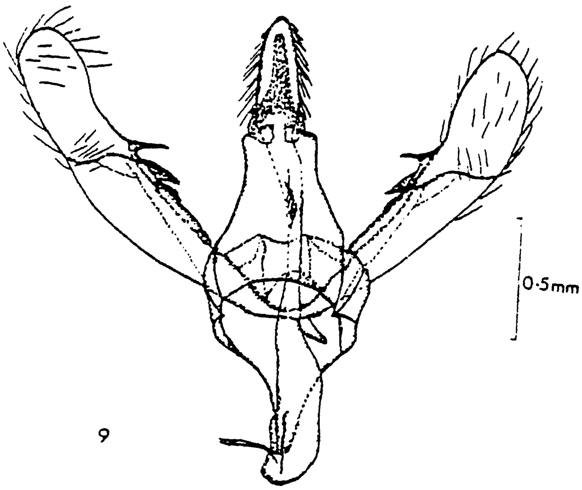

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Figures 11-16: Male external genitalia.

Figure 11: *Eudonia psammitis* anterodorsal view

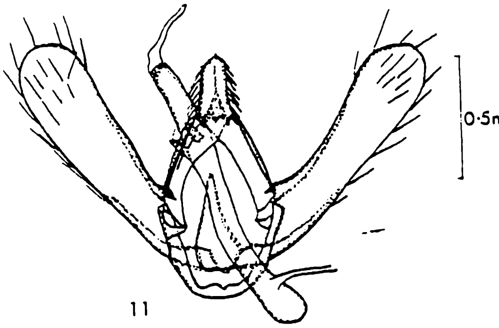
Figure 12: *E. psammitis* left lateral view

Figure 13: *E. sabulosella* anterodorsal view

Figure 14: *E. sabulosella* left lateral view

Figure 15: *"Scoparia" bisinualis* anterodorsal view

Figure 16: *"S". bisinualis* left lateral view



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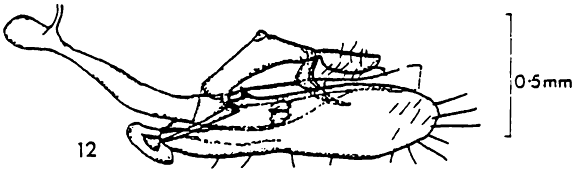

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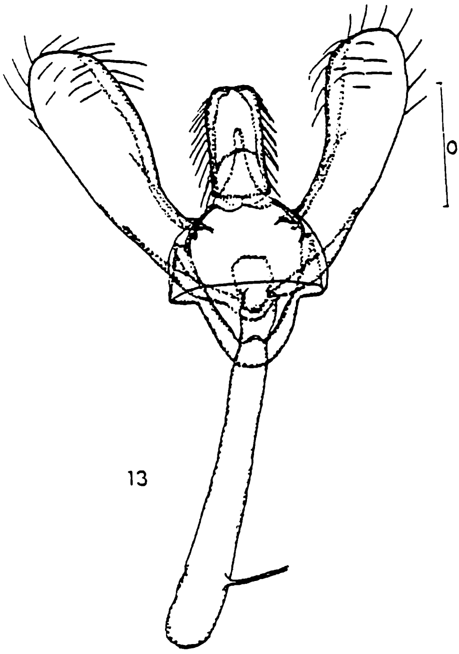

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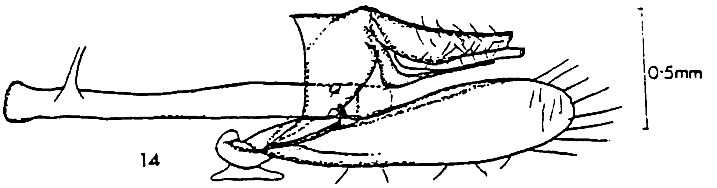

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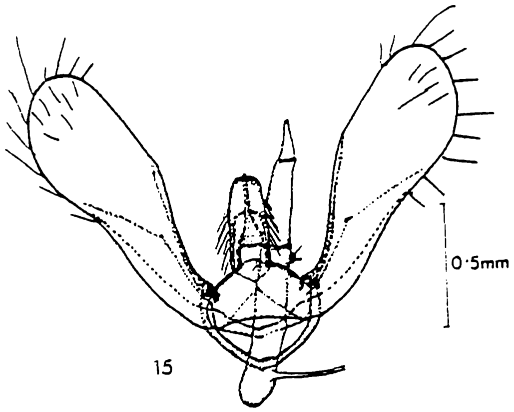

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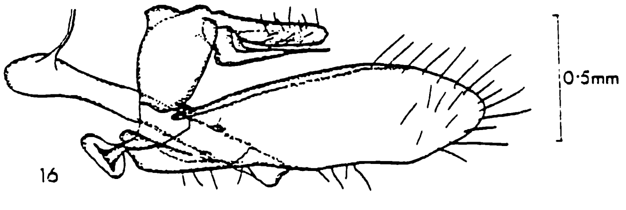

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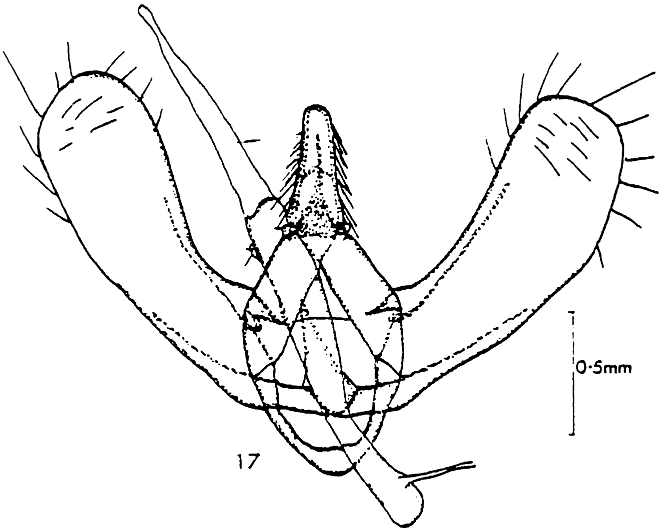
Figures 17-20: Male external genitalia

Figure 17: *"Scoparia" diphtheralis* anterodorsal view

Figure 18: *"S". diphtheralis* left lateral view

Figure 19: *"S". halopis* anterodorsal view

Figure 20: *"S". halopis* left lateral view



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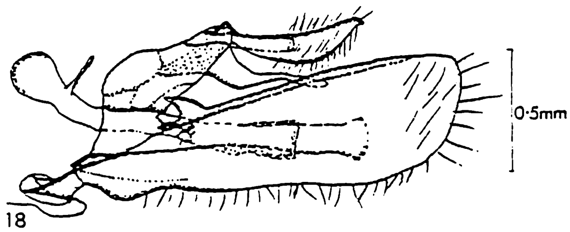

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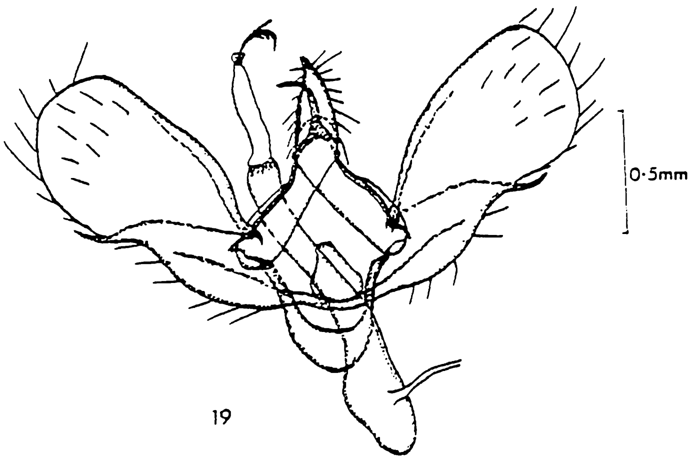

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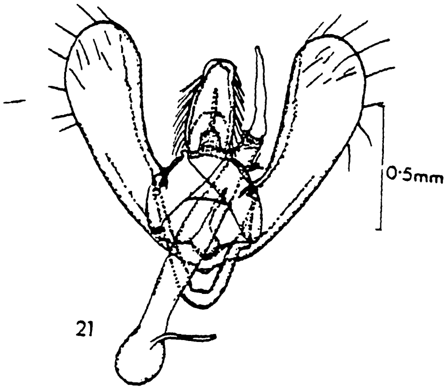
Figures 21-24: Male external genitalia

Figure 21: *"Scoparia" philerga* anterodorsal view
Figure 22: *"S". philerga* left lateral view.
Figure 23: *"S". submarginalis* anterodorsal view
Figure 24: *"S". submarginalis* left lateral view



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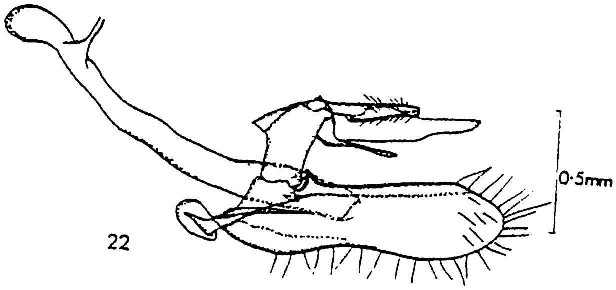

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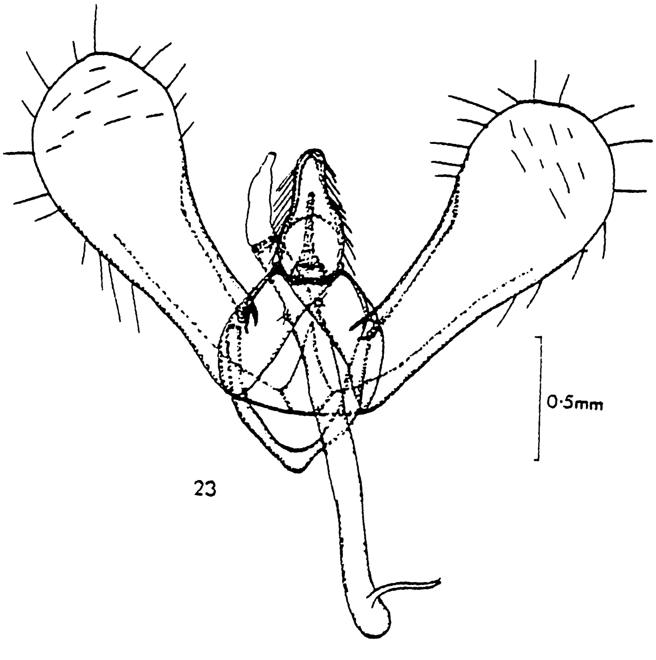

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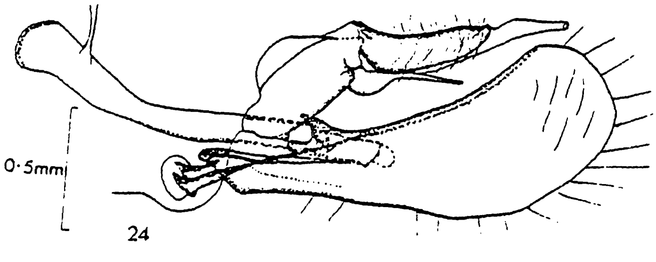

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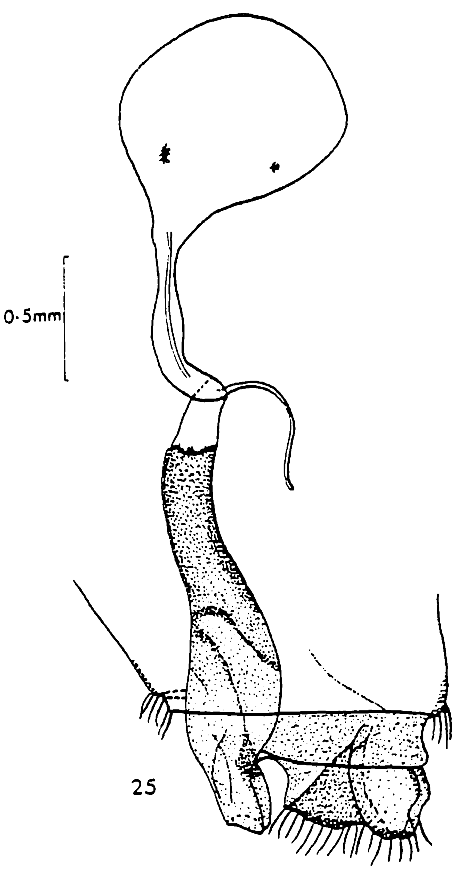
Figures 25-29: Female genitalia (proximal ducts)
Figure 25: *Orocrambus flexuosellus*
Figure 26: *O. vitellus*
Figure 27: *Eudonia psammitis*
Figure 28: *"Scoparia" philerga*
Figure 29: *E. sabulosella*



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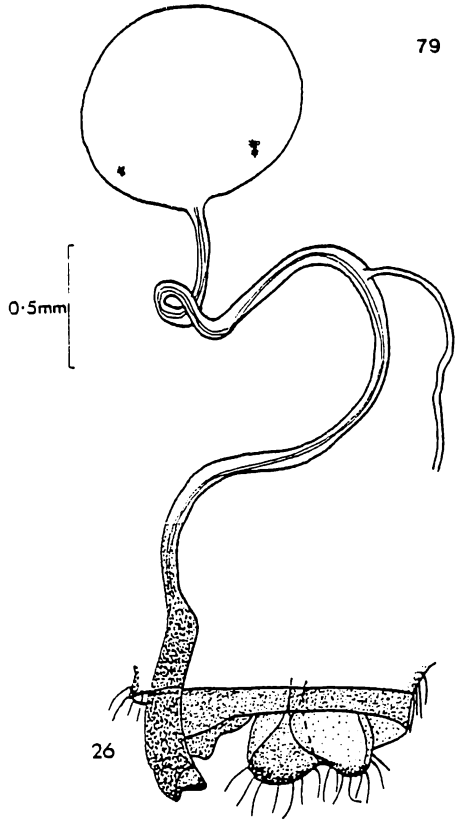

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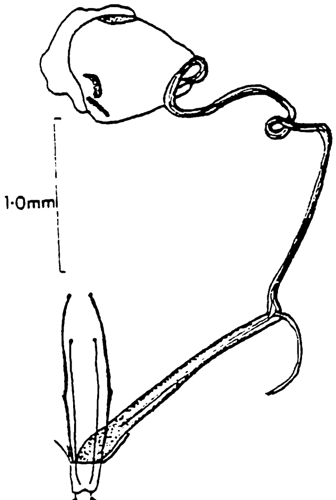

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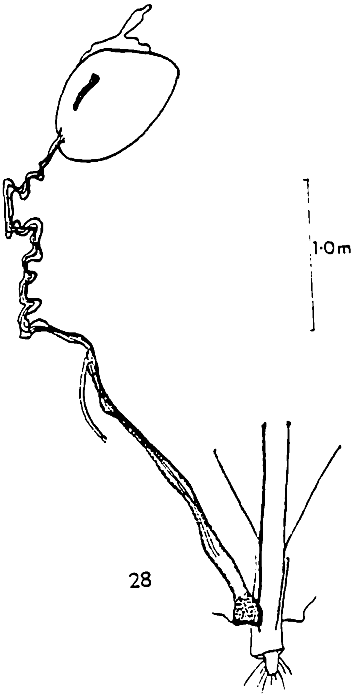

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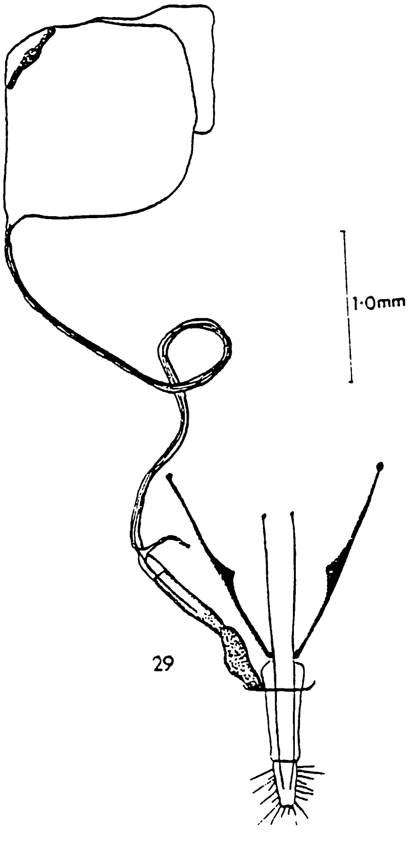

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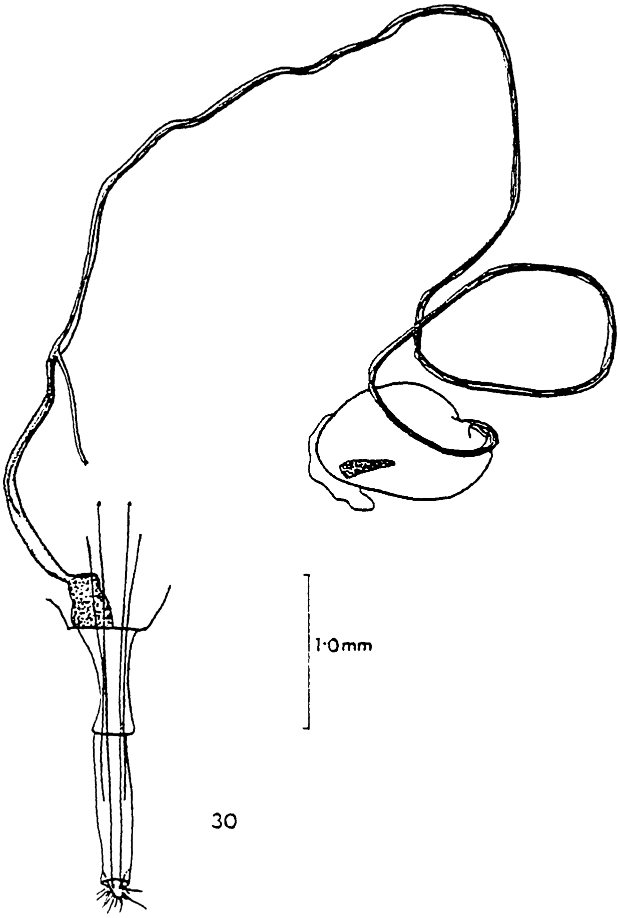
Figures 30-33: Female genitalia (proximal ducts)
Figure 30: *"Scoparia" bisinualis*
Figure 31: *"S". diphtheralis*
Figure 32: *"S". halopis*
Figure 33: *"S". submarginalis*



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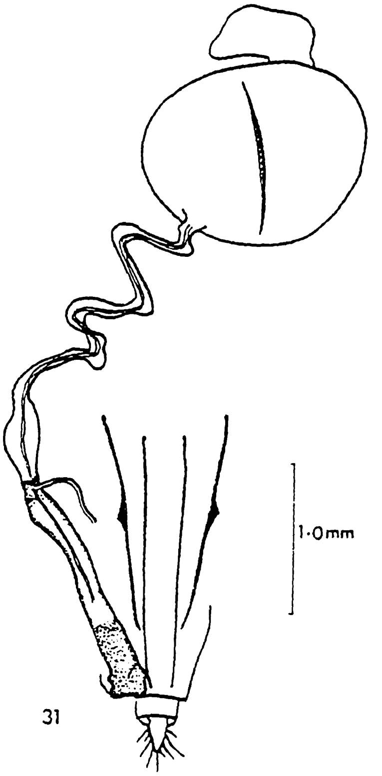

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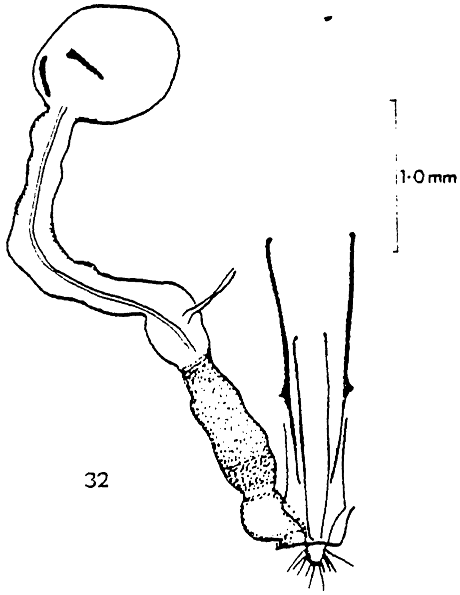

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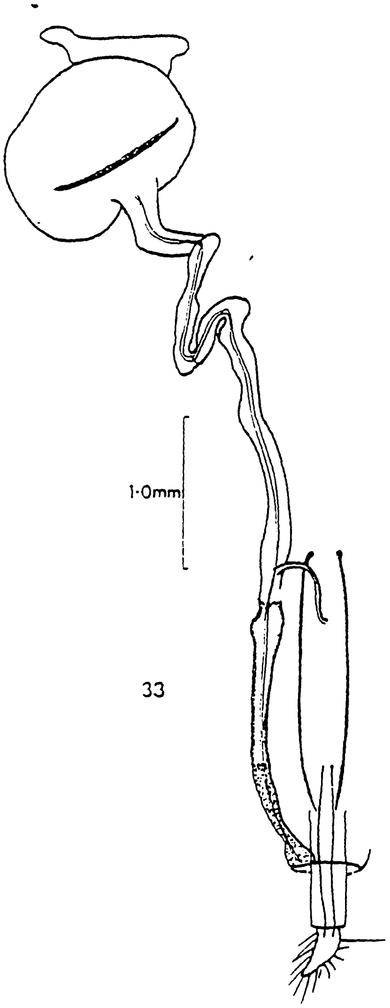

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Figure 34-50: Pupae

Figure 34: Ventral view of female *Eudonia sabulosella*

Figure 35: Ventral view of terminal segment of male *E. sabulosella*

Figure 36: Left lateral view of female *E. sabulosella*

Figure 37: Left lateral view of terminal segment of male *E. sabulosella*.

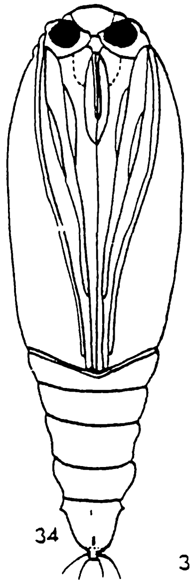
Figure 38: Dorsal view of female *E. sabulosella*

Figures 39-41: Ventral, left lateral and dorsal views respectively of terminal segment of male *E. sabulosella*

Figures 42-44: Same views respectively of terminal segment of female *E. sabulosella*

Figures 45-47: Same views respectively of terminal segment of male *"Scoparia" bisinualis*

Figures 48-50: Same views respectively of terminal segment of female *"S". bisinualis*



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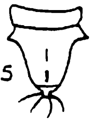

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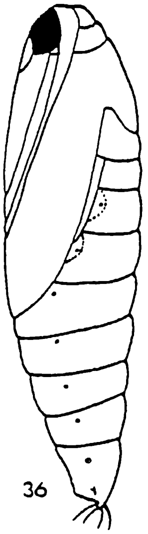

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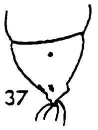

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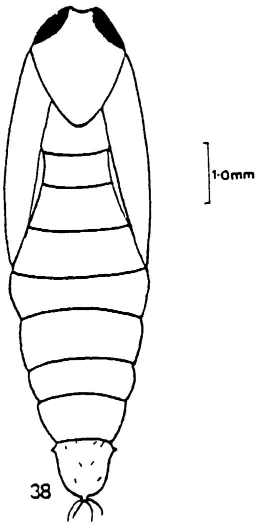

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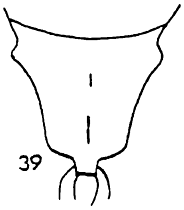

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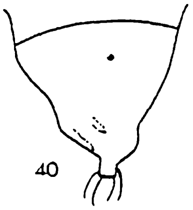

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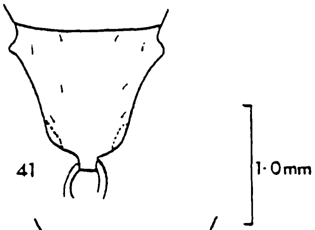

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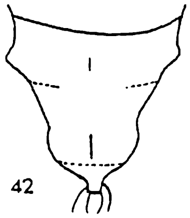

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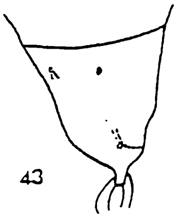

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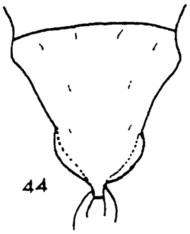

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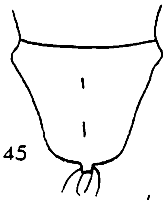

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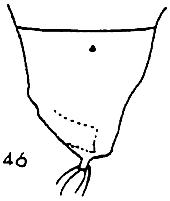

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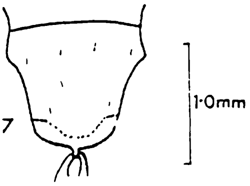

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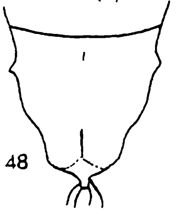

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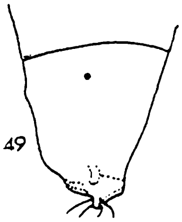

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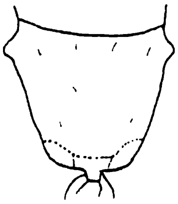

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Figures 51-64: Pupal terminal segments.

Figures 51-53: Ventral, left lateral and dorsal view respectively of male *"Scoparia" diphtheralis*

Figures 54-56: Same views respectively of female *"S". halopis*

Figures 57-59: Same views respectively of male *"S". philerga*

Figures 60-62: Same views respectively of female *"S". philerga*

Figures 63-65: Same views respectively of male *"S". submarginalis*

Figures 66-68: Same views respectively of female *"S". submarginalis*

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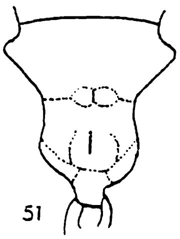

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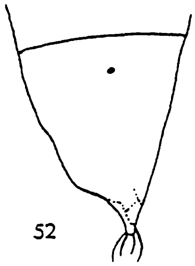

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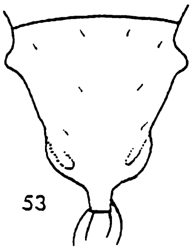

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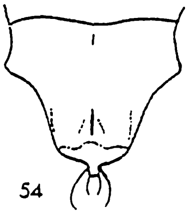

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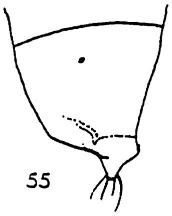

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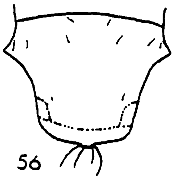

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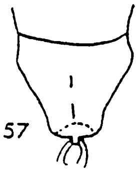

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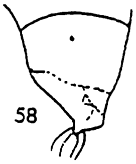

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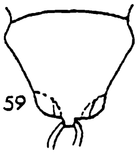

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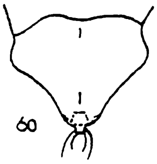

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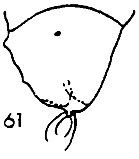

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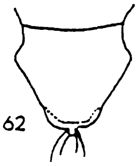

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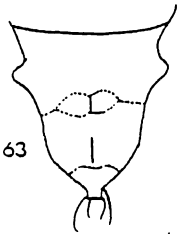

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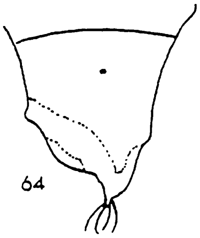

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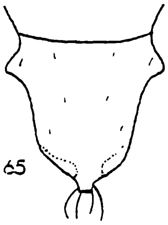

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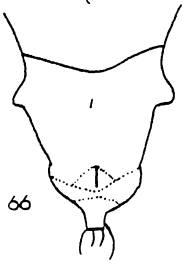

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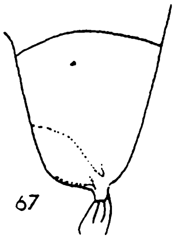

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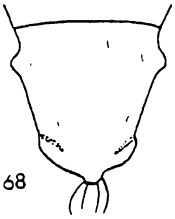

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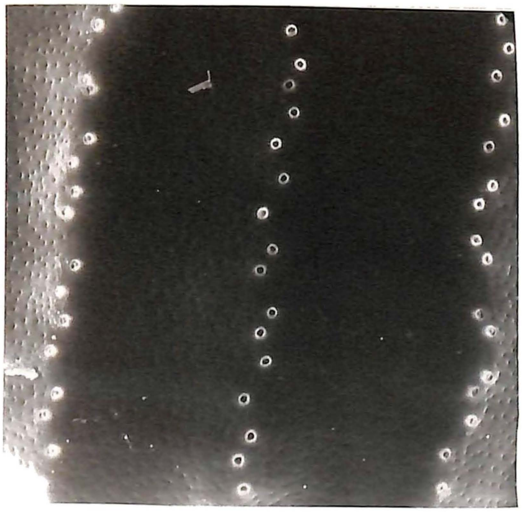
Plate 15: SEM view of aeropyles of *Orocrambus flexuosellus* egg (470x).

Plate 16: SEM view of aeropyles of *O. vitellus* egg (470x).

Plate 17: SEM view of aeropyles of *Eudonia psammitis* egg (1000x).

Plate 18: SEM view of aeropyles of *E. sabulosella* egg (1000x).

Plate 19: SEM view of aeropyles of *"Scoparia" bisinualis* egg (1000x).



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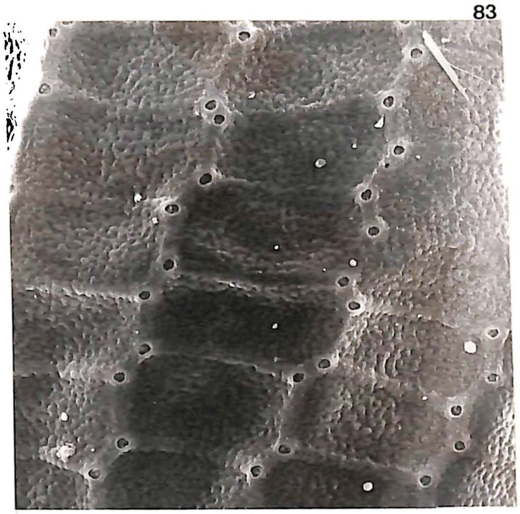

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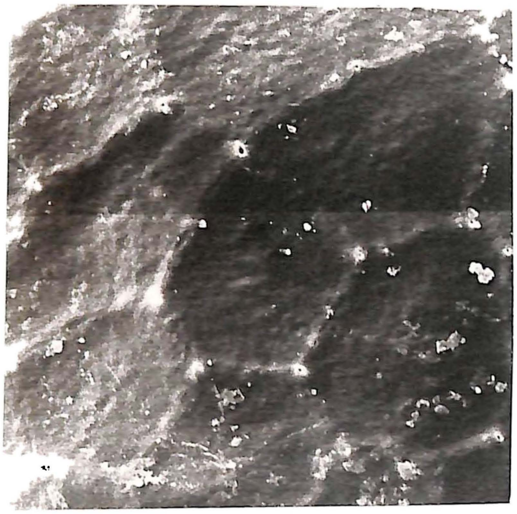

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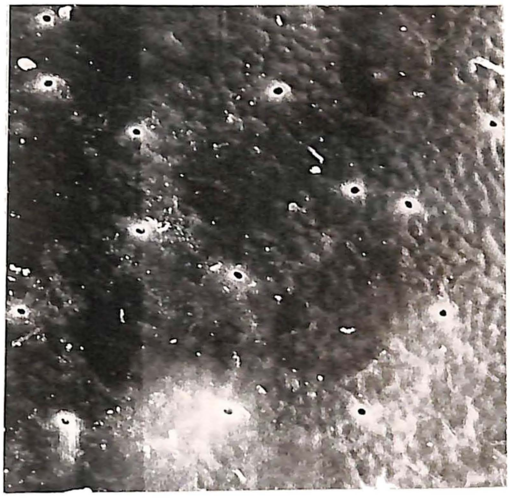

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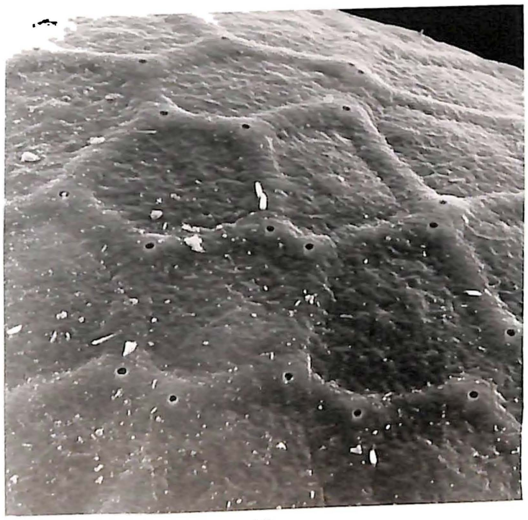

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Plate 20: SEM view of aeropyles of *"Scoparia" diphtheralis* egg (1000x).

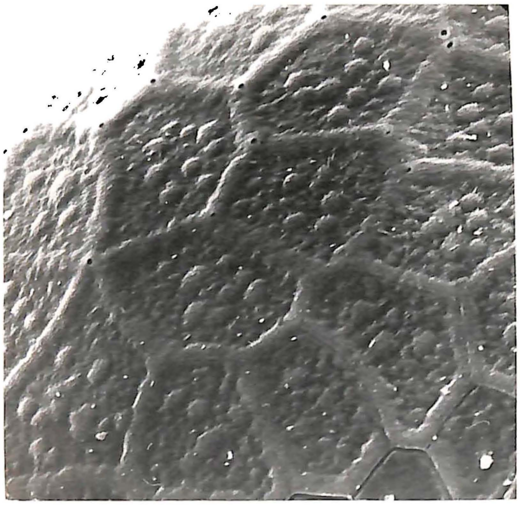
Plate 21: SEM view of aeropyles of *"S"*. *halopis* egg (1000x).

Plate 22: SEM view of aeropyles of *"S" philerga* egg (1000x).

Plate 23: SEM view of aeropyles of *"S"*. *submarginalis* egg (1000x).

Plate 24: SEM view of ovipositor of *Eudonia sabulosella* (240x).

Plate 25: SEM view of ovipositor of *Orocrambus flexuosellus* (120x) at right with the large tubular ostium bursae at left.



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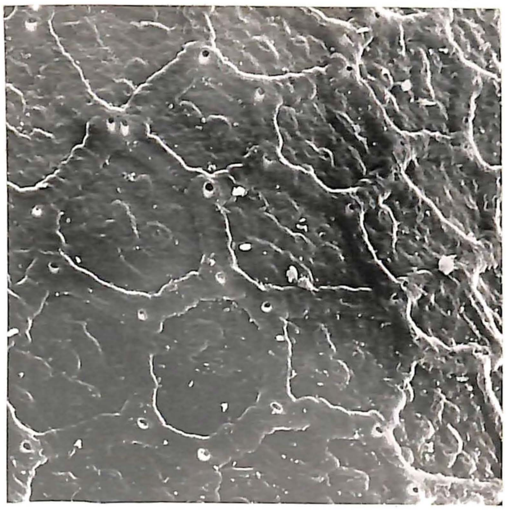

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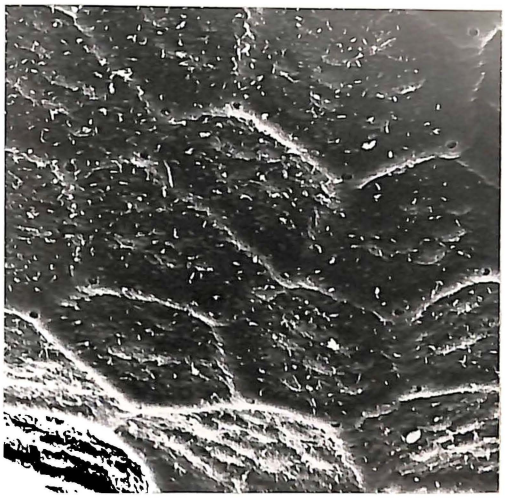

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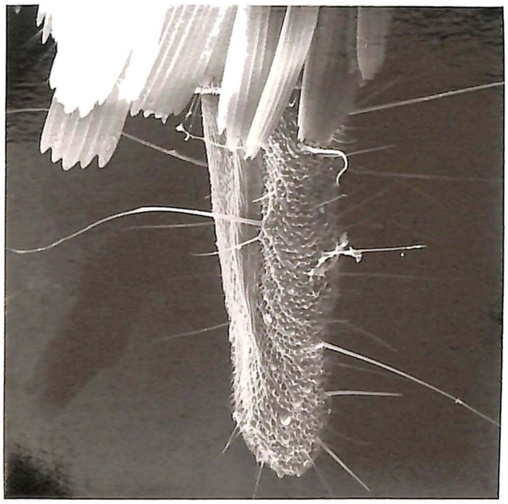

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CHAPTER FIVE

BIOLOGY

Introduction

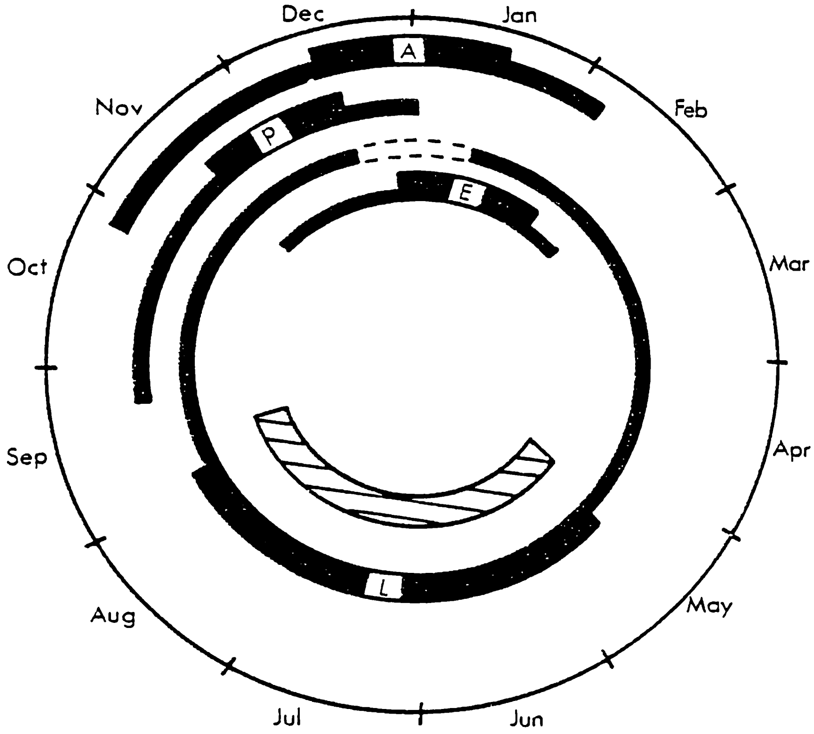
There is much overseas literature on sod webworm biology, especially from the United States of America. All such studies however, have involved Crambinae. The types of investigations undertaken consisted esentially of ascertaining the controlling factors involved in oviposition, egg development, larval growth and reproductive isolation (e.g. Bohart,1940, 1947; Thompson,1942; Gair,1964; Crawford,1966, 1967, 1968, 1970; Banerjee and Decker,1966a, 1966b; Scheibner,1968; App and Kerr,1969; Banerjee,1969a, 1969b; Heinrichs and Matheny,1969; Kamm,1970, 1971, 1972, 1973; Matheny and Heinrichs,1971; Morrison *et al.*, 1972; Heinrichs,1973; Krehoff,1974; and McDonough and Kamm,1979). New Zealand has a real paucity of sod webworm biological literature. Meyrick (1882, 1885) and Hudson (1928, 1939) included information on geographical distribution, associated flora and adult seasons in their taxonomic studies on both Crambinae and Scopariinae. Watt (1914) described the eggs of *Orocambus flexuosellus* (Doubleday) (Crambinae) and *Scoparia cyameuta* (Meyrick) (Scopariinae). Chappel (in Hudson, 1928) reported on the larva of *S. illota* Philpott and Sunley (also in Hudson, 1928) described the full grown larva of *O. simplex* (Butler) = *O. lewisi* Gaskin. Kelsey (1957) and Cumber and Eyles (1961) reported that *O. flexuosellus* larvae tunnelled through grass roots and soil. White (1963 in Gaskin 1975b) reared adults of *O. flexuosellus* and *O. callirrhous* (Meyrick) from pupae located in the bases of tussock grasses and also discussed pupation of *O. ramosellus* (Doubleday) in tussocks. The flight seasons of some Crambinae and/or Scapariinae have been recorded by Meyrick (1882, 1885); Hudson (1928, 1939); Cumber (1951); Gaskin (1964, 1966, 1970, 1975a, 1975b) Wood (1973) and Patrick (1982). Gaskin (1975b) also investigated aspects of the biology of ten species of *Orocrambus*. Apart from these there have been no biological studies on New Zealand sod webworms. While rearing hill country sod webworms to supplement taxonomic studies, the following biological observations were made. Most of the information relates to *Eudonia sabulosella* (Walker) (Scopariinae) which is potentially the most economically important hill country species of sod webworm (see Cowley (1982) and Population Dynamics Ch. 6).

LIFE CYCLE AND GENERATION TIME

Eudonia sabulosella was found to be univoltine on southern slopes of hill country. In the field, eggs were collected between mid-November and mid-February; larvae from mid-January to Mid-December; pupae from late September to late late December; and adults late October to early February. Graph 8 represents this information. The thickened areas in the time span for each stage refer to peak numbers. No soil samples for larval collection were taken between mid-December and mid-January after the 1978-79 season because of the difficulty both in extracting larvae and digging spade squares in the very dry, hard soil. No larvae were found at that time in 1978-79. Most larvae reared from eggs died long before attaining full size. This may have been due to rearing conditions or disease (see Mortality Factors Ch. 7). As a result, larval instars were not determined because of the very few specimens in each size class. "*Scoparia*" *bisinualis* Hudson, "*S.*" *diphtheralis* Walker, "*S.*" *halopis* Meyrick, "*s.*" *philerga* Meyrick, "*S.*" *submarginalis* (Walker), *Eudonia psammitis* (Meyrick) and *Orocrambus vitellus* (Doubleday) were also univoltine as sampled at St. Andrews Golf Course, Hamilton and shown by dissections to assess reproductive development (see later, this Ch.) *O. flexuosellus* was bivoltine if not multivoltine on northern slopes of hill country as well as lowland pastures (cf. Gaskin 1976b). All sizes of larvae of this species were collected between October and April (some of these being provided by Mr E.H.A. Oliver, Insect Control and Organic Chemistry Group, Ruakura Agricultural Research Centre, Private Bag, Hamilton from the Volcanic Plateau of the Central North Island (TO) and Matangi (WO)). Adults of *O. flexuosellus* were collected on northern hill country slopes and lowland pastures from September to April. Adult seasons (see Table II) were markedly affected by locality presumably because of the associated temperature differences. Most species had longer seasons at Auckland than at Hamilton or Whatawhata. Most species appeared earlier and disappeared later than found by other authors with *O. vitellus, E. sabulosella* "*S.*" *bisinualis* and "*S.*" *halopis* being distinctly earlier in the season than previously stated. This disparity may be a result of the longer time span of the present study compared with most of the above authors.

Graph 8: Life cycle of *Eudonia sabulosella* on hill country pasture.

Autumn months = March, April, May
Winter months = June, July, August
Spring months = September, October, November
Summer months = December, January, February



Key:
A represents adults
P represents pupae
L represents larvae
E represents eggs
▨ represents damage occurrence
---- represents small larvae obtained by laboratory rearing.

Thickened areas refer to peak numbers.

TABLE II. Adult seasons for the species studied - compared with other authors

	MONTHS OF ADULT AVAILABILITY						
SPECIES	MEYRICK	HUDSON	GASKIN (G) PATRICK (P)	WOOD (W) CUMBER (C)	WHATAWHATA	HAMILTON	AUCKLAND
O. flex	Dec-Apr	Nov-Apr/May	Sept-May (G)	Oct-June (W) July-June (C)	Sept-Feb	Sept-Mar	Sept-May
O. vit	Jan-Mar	Dec-Mar	Dec-Apr (G)	Nov-Apr (W)	Oct-Mar	Oct-Mar	Oct-Mar
E. psam	Jan-Mar	Sept-Apr	-	-	Dec-Feb	Oct-Jan	Nov-Apr
E. sab	Dec-Jan	Oct-Mar	Oct-Mar (G) Sept-Dec (P)	Oct-Mar (W)	Oct-Feb	Oct-Feb	Oct-May
"*S*." *bis*	-	Dec-Feb	-	-	Oct-Jan	Oct-Feb	Oct-May
"*S*." *diph*	Dec-Mar	Dec-Mar	Nov-Apr (G)	Jan-Feb (C)	Dec-Feb	Oct-Mar	Oct-Mar
"*S*." *hal*	Feb	Nov	Apr-Nov (G)	-	Sept-Feb	Oct-Feb	Oct-Apr
"*S*." *phil*	Dec-Apr	Oct-Mar	Oct-May (G)	-	Oct-Feb	Oct-Feb	Sept-May
"*S*." *subm*	Nov-Mar	Nov-Mar	Dec-Mar (G)	Jan-May (C) Jan-Mar (W)	Nov-Feb	Oct-Jan	Oct-May

See Appendix V for generic name abbreviations.

OVIPOSITION

Overseas literature suggested that sod webworm (at least crambine) eggs are laid in the thatch or area just above the surface of the soil (Matheny and Heinrichs, 1971); freely scattered on the substrate; or dropped in flight (Banerjee and Decker, 1966a; App and Kerr, 1969; Gaskin, 1975b). It was unknown where Scopariinae deposited eggs.

Mosses and grasses were cut from areas infested with populations of adult sod webworms and carefully examined under a stereo microscope. The soil surface was also examined and crambine eggs were found there, but no scopariine eggs were recovered from either region. At this stage the ovipositors of crambine species studied were compared with those of the scopariine species. Both dissection and observation of ovipositing females were made under a binocular microscope and some scanning elctron microscope investigations (with the help of Dr C. Beltz, Scanning Electron Microscope, University of Waikato, Hamilton) carried out (see Plates 24-25). The crambine ovipositor of *O. flexuosellus* and *O. vitellus* is esentially tubular and non-retractile while that of the scopariine *E. sabulosella* is elongate, strongly retractile and sparsely setose distally. The setae may have sensory (e.g. for substrate determination) functions. These observations suggested that Scopariinae were equipped to deposit eggs into small crevices or grass axils while Crambinae would be able to deposit eggs on grass blades or the soil surface. It was not until oviposition experiments were carried out to ascertain whether females selectively oviposit in certain pasture types (after Madge, 1954, 1956a, 1956b, 1957, 1958; and Martyn, 1965a, 1965b, 1965c) that scopariine eggs were located. The methods involved have been described previously (see Methods Ch. 1 p.36). For assessment of oviposition the grass and turf were transported to the laboratory and examined under a Maggi-lamp or binocular microscope. Eggs of *Eudonia sabulosella* were found just below ground level (to a depth of 10mm) adhering to grass or moss stems. This implied that the ovipositor was thrust into the ground at the bases of these plants.

In the laboratory all the crambine and scopariine species studied oviposited just prior to and after darkness. This was observed using a red filter lamp which did not "disturb" females. On one occasion when it was dark by 2015 hours and lights were turned on at 2130 hours, females continued to oviposit but at a slower rate, i.e. the exposure to light appeared to hinder but not stop oviposition. In the field, females were observed to crawl down into grasses from about sunset onwards (presumably to oviposit) but it was very difficult to observe them around the bases of the long stems without "disturbance".

There appeared to be two types of oviposition in *E. sabulosella* and the other Scopariinae studied - one in which eggs were laid singly or in small groups of up to 5 per clump and the other involved "en masse" laying of 10-50 eggs per clump. In the laboratory situation it was the younger females which laid the large masses of eggs with reduced numbers, usually laid singly by other females (cf. Tashiro, 1976).

HABITAT

Eggs

Egg trapping (see Methods Ch. 1 p. 17) was carried out at the Whatawhata and Te Kowhai sites to determine whether females selectively oviposited in either track or intertrack (area between tracks) regions. Results are presented in Table III. In 1978-1979 only one set of track/intertrack traps was set in each area. It was thought that this masked effects due to subareas (i.e. slight topographical differences within each site) hence the more extensive trapping for 1979-1980 and 1980-1981. Te Kowhai egg trapping was discontinued because stock caused much damage to and disturbance of egg traps.

Table III. Summary of seasonal egg trapping data.

	NUMBER OF EGGS PER SITE										
SEASON	WILSONS 2A		WILSONS 2B		LONG 4A		TE-KOWHAI		NUMBER OF WEEKS SAMPLED	WHATAWHATA TOTALS	
1978-1979	13Tr	28In	17Tr	11In	6Tr	8In	1Tr	2In	13	36Tr	47In
1979-1980	25Tr	14In	19TrU	18InU	111TrU	69InU	5Tr	6In	24	271Tr	177In
					57TrR	19InR					
			8TrL	13InL	51TrL	44InL					
			27	31	219	132					
1980-1981	147Tr	236In	56TrU	60InU	28TrU	32InU	-		19	303Tr	402In
					10TrR	11InR					
			29TrL	44InL	33TrL	19InL					
			85	104	71	62					

KEY: In=Intertrack; L="lower" subarea; R="Right" subarea; Tr=Track; U="upper" subarea.

Two-way and single classification Model I ANOVA tests for each year yielded non-significant results ($p>0.05$) for differences between habitats or sites at Whatawhata. However, there were significant differences ($^{**}p<0.01$) between seasons for each site (see also Population Dynamics Ch. 6 p.120). This means that during each season from week to week or month to month ovipositing females were non-selective as to any of the three sites or the two habitats (track or intertrack) they chose. Examination of the Whatawhata totals shows there was a slight bias to the intertrack habitat in 1978-1979; a track bias in 1979-1980; and a definite intertrack basis in 1980-1981. This last marked bias occurred at the Wilsons 2A site with a significant difference between means for the track and intertrack ('t' test $^{**}p < 0.01$). However, this site was the least steep of all three and in places track and intertrack intergraded.

The 1979-1980 and 1980-1981 egg trap samples (since data from these two years are more comprehensive than 1978-1979 where egg trapping was only instituted in December) were further analysed in relation to rainfall for each weekly trapping period. The December-January samples were used as these related to the main egg laying season. There was no correlation ($n=14$ $r=-0.38$ and $r=-0.36$ respectively for track and intertrack; $p > 0.05$ in both cases) between rainfall and egg laying. However, it was clear that seasonal ovipositional effects were masking any relationships. The data were then segregated into two rainfall categories (low or less than 20mm per week; and high or 20mm and above per week) and 't' tests were made of differences between the means of track versus intertrack at the different rainfalls. A significant result ($^{*}p<0.05 > 0.01$) was produced for low rainfall weeks with thus a significant bias to intertrack laying in low rainfall weeks; but a non-significant result (n.s. $p>0.05$) was produced for high rainfall weeks i.e. indiscriminant oviposition with respect to habitat occurred in high rainfall weeks. A 't' test of the track means between low and high rainfall weeks yielded a significant result ($^{***}p<0.001$) and a similar one for intertrack means ($^{***}p<0.001$). This implies that significantly more oviposition occurred in low rainfall weeks with such a trend being more pronounced in the intertrack region. Light rain thus stimulated oviposition. There was no correlation (n.s. $p>0.05$) between pasture length and egg catch for either track or intertrack.

To further check the effects of moisture level or pasture condition on ovipositing females, oviposition cages (after Madge,1956b see Methods Ch. 1 p.36) were used. Four types of pasture cover (long dense, long sparse, short dense and short sparse) were offered to groups of ten caged

Eudonia sabulosella females. Ten replicates of each were used. Table IV is a summary of that information.

TABLE IV. Oviposition in relation to pasture condition

RAINFALL (MM) DURING OVIPOSITION TRIAL	NUMBER OF EGGS FROM LONG SPARSE PASTURE	NUMBER OF EGGS FROM SHORT SPARSE PASTURE	NUMBER OF EGGS FROM LONG DENSE PASTURE	NUMBER OF EGGS FROM SHORT DENSE PASTURE
30.2	14	2	3	0
0.0	6	1	5	1
0.0	11	5	0	2
0.0	7	4	1	0
0.0	3	3	0	0
6.0	12	3	0	0
6.0	6	4	1	0
6.0	2	2	1	1
6.0	2	3	1	1
0.0	8	4	2	1
MEAN NUMBER OF EGGS PER PASTURE TYPE	7.1	3.1	1.4	0.6
STANDARD ERROR OF MEAN	1.260	0.359	0.473	0.209

Single classification ANOVA for equal sample sizes yielded significant results (**$p < 0.01$) i.e. there was a marked added component due to pasture treatment. The different pasture conditions clearly had a significant effect on oviposition with long sparse cover being the most preferred followed by short sparse, long dense and lastly short dense. Long cover was preferred to short and sparse to dense with 't' tests of the difference between means for long versus short or sparse versus dense producing significant results (***$p<0.001$) in both instances.

Larvae

Larvae were found exclusively in the intertrack region during the winter-spring months of 1978 (see Plates 1-2). This was the region that sustained grass damage. Plate 2 shows the type of pasture damage caused by sod webworm larvae with defoliation and denuding of vegetation. In 1979, 1980 and 1981 some larvae were found initially in the track region, but as the season progressed most larvae were once again found in the intertrack. Those found in the track at this time were on the very outside edge of the track at the junction with the intertrack. At that point stock trampling effects were much reduced (see Plates 26-27) compared with the rest of the track region. During winter months track soil compacted more than intertracks (determined from reduced friability of track spade squares) and grass was often smothered in mud (see Plate 28 an extreme case of that). The intertrack on the other hand was virtually free of trampling and not as wet as the track (see Graphs 1 and 2 - Meteorological Data Ch. 3). Larvae were usually found within the top 25mm of soil but one or two were found as deep as 40mm (cf. Gaskin,1975b).

Hibernaculae (cocoons) were made of silk to which fine soil particles and mosses were adhered and being constructed among grass roots, were well camouflaged (see Plate 14). Young larvae were also found in the soil, but nearer to the surface with webbing incorporating frass and plant material serving as a retreat. At the Kaimai, Ngaruawahia and St. Andrews sites moss growth was prolific and even large larvae had merely constructed silken retreats at the base of moss plants. Only prior to pupation did they enter the soil to construct cocoons. Usually the cocoon is 10-12mm long, straight and sac-like (i.e. U-shaped) tapering slightly towards the blind end in which faecal material and the larval exuviae is found. Some sod webworm larvae (species unknown as these died during rearing) at the Balclutha (Pottinger pers. comm.) and St. Andrews Golf Courses made inverted "L" shaped burrows (total length around 35mm). About 10mm of tunnel ran from the surface - opening to 2-5mm below ground surface then turned downwards at right angles to a depth of 20-25mm from the surface. Other burrows adjacent to these were U-shaped. Mosses were simply peeled back to expose burrow entrances.

Pupae

Pupation occurred inside the cocoon constructed by the late stage larva. There was an opening to the surface and adult emergence occurred within the cocoon since the cast pupal exuviae remained there, rather than at the surface as in porina (*Oxycanus* spp = *Wiseana* spp) Kelsey (1951).

Plate 26: Sheep grazing at Wilsons 2B. Stock stand on the tracks and from there graze the sloping intertracks.

Plate 27: Sheep moving along track strata at Wilsons 2B.

Plate 28: An extreme case of overtrampling by cattle during wet weather. The sward is smothered in mud and one of the suction trap enclosures can be seen in the background.

Adults

Adults tended to be found on tall grasses in relatively lush, rank or ungrazed areas especially grasses of 75mm or more long (cf. Crawford,1971; De Rozari *et al.*, 1977) and were readily "disturbed", swarming into the air if grazing stock, dogs etc. walked through such areas. Early in the summer when grass seed heads proliferated adults were seen resting there. Late in summer as grasses died back and the ground developed large cracks, adults were observed to crawl into such crevices. Thus it may have appeared that adult numbers had declined but verification of that was only possible at dusk and 1-2 hours after dark when most adult activity occurred (see Adult Behaviour Ch. 8 p. 199).

All adults sheltered during the day with small flights from one roost to another (cf. Gaskin,1975b). Roosts were discovered in the following places: tall grasses, fencing posts, clumps of rushes (*Juncus* spp) and trees (both under leaves where moths were oriented parallel to the long axis of the leaf (cf. Gaskin,1975b) and in cracks between bark e.g. on *Macrocarpa* spp) which surrounded or occupied study sites. As described later (Adult Behaviour Ch. 8 p. 191) adults congregated leeward of the wind.

GROWTH

For the first few months after eclosion larvae grew very slowly. Although *Eudonia sabulosella* eggs were laid as early as November the resultant larvae only developed slowly when laboratory reared at ambient, 15°C or 25°C temperatures and natural light: dark schedules. By late January such larvae were only 5-7mm long, the same size as caterpillars collected in the field at that time. Three months after hatching *E. sabulosella* larvae were only 7-10mm long. By late May - June most were full grown (15-20mm) and that was the stage at which most pasture damage occurred (cf. Reinert,1973). Grass regeneration in late spring (October) usually disguised the effects of prior insect feeding. Larvae remained active and continued to feed throughout the winter (cf. Spitzer 1970). On one occasion in 1978 there had been a severe frost (-5°C) at Whatawhata and southern slopes (study areas) were iced until 1200-1300 hours. Larvae were quite active under such conditions even though the soil temperature at 25mm (depth at which larvae were found) was only 4°C. In late June - July many larvae constructed hibernaculae or cocoons. The larva binds small and regularly sized soil particles, faecal pellets (when no soil available) or plant debris with secreted silk. If the cocoon was damaged and contained a larva which was nearly prepupal any large soil particles, faecal pellets or available plant material was used as a single mass to patch the hole(s). By late August to mid-September most larvae ceased feeding, became quiescent and thus prepupal with the head bent ventrad accompanied by an overall shortening of the body. At this stage damaged cocoons were not repaired (cf. Gaskin 1975b) because of loss of mobility, due to approaching pupation. Pupation occurred from late September to December. Adults emerged 21-28 days later and collection of cocoons enabled sex determination and species identity to be established (by reference to the terminal pupal segment and head capsule of the larval exuviae).

Many adults, larvae, but only 20 pupae of *Eudonia sabulosella* were measured and weighed as part of disease assessment studies (see Mortality Factors Ch. 7). Those results with appropriate graphs and discussion are included in the disease assessment section to allow direct comparisons of growth in diseased and healthy specimens.

The number of larval instars was not ascertained, largely due to small numbers and, rearing difficulties with associated disease. Gaskin (1975b) reported 6 instars in *Orocrambus flexuosellus* and *O. vitellus*.

FEEDING

Large larvae excised whole blades of grass or sprigs of mosses which were dragged into the burrows and then fed on. Plants are thus attacked at or near the base and eventually a wide area of grass is clipped from around the burrow. All species of Scopariinae that were reared survived best under laboratory conditions on mosses. However, various species of grasses *viz*: browntop (*Agrostis tenuis*); paspalum (*Paspalum dilatatum*); perennial ryegrass (*Lolium perenne*); prairie grass (*Bromus catharticus*); sweet vernal (*Anthoxanthum odoratum*); timothy (*Phleum pratense*); Yorkshire fog (*Holcus lanatus*); and clovers (white, *Trifolium repens* and red *T. pratense*) were readily consumed as evidenced by feeding damage (small circular or elliptical holes on grass blades) and larval gut smears. The two crambine species readily accepted all the above grasses. In rearing any grass with soft leaves served as larval food (cf. Buckner *et al.*, 1969; Tashiro, 1976, 1977). Fresh lush grasses were readily accepted. The broader leaved species were generally more suitable for larval food as excised blades remained palatable longer than those of other grasses. Usually larvae migrated overnight to fresh food as the host material died or desiccated. However, not all sod webworm larvae did that, and these were therefore transferred to fresh material when the old plant food was removed. Artifical diets for sod webworms (Ward and Pass, 1969; Dupnik and Kamm, 1970; Singh, 1977; Anonymous,1980) were not used. Some were tried by Insect Control Group, Ruakura and although larvae pupated successfully most adults were deformed on emergence (cf. Roberts,1979). Larvae were observed to feed at night or whenever burrows were shaded (both in laboratory and field).

Adults of *Eudonia sabulosella, "Scoparia" diphtheralis, "S." philerga "S." submarginalis, Orocrambus flexuosellus* and *O. vitellus* were observed in the field to feed on red and white clover, dandelion and manuka flowers. In the laboratory all species of adult studied fed on free water, honey and sucrose solutions.

LONGEVITY

Longevity or the length of adult life (number of days surviving) was closely linked with feeding. Laboratory experiments were run to ascertain how food types affected the length of adult life. Newly emerged *Eudonia sabulosella* adults were established over potted grasses incorporating flowering weeds and free water; or free water only; or free water and honey-sucrose solutions. Ten replicates (5 males and 5 females) of each were used at ambient temperatures and natural light cycles (see Methods Ch. 2 p.37). Table V gives the results of these experiments.

TABLE V. Summary of longevity of *Eudonia sabulosella* on different food sources.

	FOOD SOURCE		
LONGEVITY	WATER ONLY	FLOWERING WEEDS AND WATER	HONEY-SUCROSE AND WATER
RANGE (DAYS)	3-7	14-22	16-30
MEAN (DAYS)	4.3	16.5	22.7
STANDARD ERROR OF MEAN	0.401	0.803	1.400

For both flowering weeds and water and honey-sucrose plus water treatments females survived slightly longer than males although not significantly so ('t' test n.s. $p>0.05$). Water only survival was the same for both sexes. A single classification ANOVA test for equal sample sizes yielded highly significant results ($^{**}p<0.01$) i.e. the food sources had marked effects on adult longevity. The provision of honey-sucrose plus water resulted in best survival, flowering weeds plus water next best, and free water only in poorest survival times.

Using honey-sucrose solutions many field collected adults were reared (essentially to obtain eggs from females) and longevities were noted. Although such moths were of unknown ages they provided a further indication of the range, especially the upper limit, of adult life span. Table VI is a summary of that information.

TABLE VI. Range and mean longevity for males and females of each species.

	MALE LONGEVITY (DAYS)				FEMALE LONGEVITY (DAYS)			
SPECIES	RANGE	MEAN	STANDARD ERROR OF MEAN	NUMBER OF OBSERVATIONS	RANGE	MEAN	STANDARD ERROR OF MEAN	NUMBER OF OBSERVATIONS
O. flex	4-18	11.0	2.040	5	3-28	15.2	3.154	9
O. vit	19-27	23.0	1.496	5	18-28	23.4	1.590	5
E. psam	6-23	15.2	2.613	5	8-26	15.6	3.269	5
E. sab	4-30	17.5	2.071	15	1-30	11.7	1.929	23
"*S.*" *bis*	10-16	13.6	0.921	5	14-31	24.0	2.993	5
"*S.*" *diph*	4-19	9.0	2.417	5	12-25	18.2	2.161	5
"*S.*" *phil*	5-22	13.6	1.391	13	3-31	18.9	1.629	19
"*S.*" *subm*	9.34	23.6	3.842	5	13-40	20.7	2.267	10

See Appendix V for generic name abbreviations.

"*Scoparia*" *halopis* is not included as most adults were used in taxonomic studies.

There are wide differences in mean longevities of males and females in some species. Often the samples on which such results are based are small and added to that the unknown age of adults at collection means that definitive statements on relative longevity cannot be made. The range of survival is more interesting. Even accepting the unknown ages of specimens, in all cases in Table VI females have as high or a higher upper limit to survival than males, with in one case, a "*S.*" *submarginalis* female lasting 40 days. It thus appears that adults survive at least 4-6 weeks in the field. Field data support for a 4-6 week adult longevity is provided by the observation that some *E. sabulosella* adults emerged at the end of December - early January on hill country and by early-mid February they had disappeared. After the last adult emergences in early January the wing scaling of moths appeared progressively more worn with no fresh new looking specimens being found i.e. no unrecorded emergences occurred. There was no significant difference ($p>0.05$) between numbers of eggs laid or longevity of females of each species when exposed to 15 or 25°C temperatures.

FECUNDITY

(See also Mortality Factors Ch. 7 for effects of disease on fecundity of *Eudonia sabulosella*.) Fecundity was calculated from the number of eggs in dissected females plus any that had been laid (and hence recorded) during rearing. Table VII represents fecundities of the different species for all three seasons (1978-79, 1979-80 and 1980-81) combined.

TABLE VII. Fecundity of field collected females.

SPECIES	*O. flex*	*O. vit*	*E. psam*	*E. sab*	"*S.*" *bis*	"*S.*" *diph*	"*S.*" *hal*	"*S.*" *phil*	"*S.*" *subm*
RANGE (Number of eggs)	20-421	12-391	10-188	3-348	18-243	10-191	48-200	6-220	4-266
MEAN (Number of eggs)	104.5	112.2	77.8	91.2	101.9	105.7	117.8	62.1	119.0
STANDARD ERROR OF MEAN	12.260	20.663	12.079	6.680	14.285	10.771	16.037	12.446	13.444
NUMBER OF FEMALES	41	19	16	102	20	20	10	21	31
WINGSPAN RANGE (MM)	19-25	20-25	17-20	19-23	18-21	21-25	19-24	16-24	19-24

See Appendix V for generic name abbreviations.

The average fecundity values for all species are somewhat similar except for *psammitis* and *philerga* which are the smallest and most divergent. This may merely be a reflection of the fact that these are the two smallest species. Since the results of table VII refer to field collected females (unknown age and ovipositional history) further analysis to indicate species differences would not be meaningful. The fecundity range may provide a better comparison, especially the upper limit of number of eggs per female. As described later (Mortality Factors Ch. 7) the fecundity of *Eudonia sabulosella* is significantly reduced by disease. Only that species was assessed for disease and Table VII refers to eggs per female from healthy and diseased females. The fecundities of *E. sabulosella* were divided into seasons (with healthy and diseased still combined) and average fecundity per season calculated. It was found that mean fecundities with 95% confidence limits for 1979-80 and 1980-81 (62 ± 25 and 63 ± 11 eggs) were not significanlty different ('t' test n.s. $p>0.05$) from each other but did vary significantly from 1978-79 where mean fecundity was 146 ± 33 eggs ('t' test ***$p<0.001$). These differences will be explained later (Mortality Factors Ch. 7). There may be an overall depressive effect on fecundity of other species but this is unknown.

EGG FERTILITY AND VIABILITY

Females of all species oviposited readily (except *"Scoparia" halopis* from which the 20 eggs obtained were used in SEM work). Before preservation of eggs used in taxonomic studies they were reared for 1-2 days so that colouration changes and hence fertility could be noted. Any eggs not preserved were closely observed to note day and proportion of larval eclosion. Percentage fertility was high (cf. Miskimen 1966). All species of eggs (a total of 130 batches with 5-220 eggs per batch) were fertile except for two in a batch of 150 from one *"S." diphtheralis* female; 7 in a batch of 60 from a *"S." submarginalis* female; and 9 in a batch of 40 from a *"S." philerga* female. Infertile eggs failed to change colour (see colour changes for each species, Taxonomy Ch. 4) and within 7 days the chorion had collapsed and the egg shrivelled and desiccated.

The proportion of eclosion of larvae from eggs (viability) was also extremely high. All larvae eclosed except for 3 in a batch of 40 fertile eggs of *"S." diphtheralis;* and 2 in a batch of 34 fertile eggs of *"S." philerga*. The egg was very deeply coloured 2-3 days prior to eclosion, due to the darkly pigmented head capsule of the developing larva. At this stage the larva was clearly visible through the chorion and some movement was discernible. About 5-10 hours before emergence the head was continually mobile, and using the mandibles a hole was cut usually towards one end of the egg or less often (about 1% of the time-based on 5 batches of 40 eggs each) laterally. The larva did not consume its egg shell (cf. Gaskin,1975b) but this was contacted during emergence and that has important implications for the spread of disease (see Mortality Factors Ch. 7 Discussion p. 178). All species of larvae emerged between 0600-1000 hours in the laboratory (cf. Gaskin, 1975b) who observed larval emergence between 0700 - 1200 hours in *Orocrambus* spp). After eclosion larvae usually remained relatively inactive for 2-5 hours before commencing to feed or construct simple silken retreats. Such retreats generally consisted of diffuse intermingled silken strands from the sides of the rearing vials to the food source.

EGG INCUBATION

Egg incubation or the time (days) from egg deposition to larval eclosion was carefully noted as there are species differences for this, at least in New Zealand Crambinae (Gaskin,1975b). Several treatments were utilized to ascertain the relative importance of temperature and humidity on egg development. Temperatures of 25°C, 15°C or ambient (mesh-covered shade house) and humidities of about 95%, 75% and 55% were chosen (see Methods Ch. 2). Both temperature and humidity as well as time of the season had effects on egg incubation periods (cf. Gaskin,1975b). Table VIII refers to the approximate date of earliest egg laying from hand-collected females at Auckland or Hamilton. Adults from Whatawhata, Te Kowhai and Ngaruawahia sites were usually at least two weeks later than this in appearing (see Table II) and egg laying was thus two weeks later than these earliest dates.

TABLE VIII. Approximate dates of earliest oviposition in each species.

SPECIES	*O. flex*	*O. vit*	*E. psam*	*E. sab*	*"S." bis*	*"S." diph*	*"S." hal*	*"S." phil*	*"S." subm*
DATE	15 Oct	8 Nov	6 Dec	2 Nov	20 Oct	10 Nov	16 Nov	5 Nov	7 Nov

See Appendix V for generic name abbreviations.

O. flexuosellus was the earliest species to begin oviposition and *E. psammitis* the latest. Egg incubation times irrespective of seasonal time or treatment effects are presented in Table IX. *"S"*. *halopis* is not included as eggs were used in taxonomy.

TABLE IX. Egg incubation times for each species.

SPECIES	*O. flex*	*O. vit*	*E. psam*	*E. sab*	*"S." bis*	*"S." diph*	*"S." phil*	*"S" subm*
RANGE OF EGG INCUBATION TIME (DAYS)	6-21	14-21	7-12	7-19	13-21	7-20	10-21	14-21
MEAN EGG INCUBATION TIME (DAYS)	13.3	17.9	9.4	14.5	16.0	12.7	12.8	17.3
STANDARD ERROR OF MEAN	1.141	0.640	0.200	1.024	1.327	1.826	1.343	0.850
NUMBER OF BATCHES	19	10	5	15	5	7	8	7

See Appendix V for generic name abbreviations.

An ANOVA test for unequal sample sizes yielded significant results (**p<0.01) i.e. the incubation times of these species are significantly different from one another. This is useful taxonomically and supplements previous information (Taxonomy Ch. 4).

Seasonal, Temperature and Humidity Effects

All eggs (all species) laid before late November took 2-3 weeks to develop at ambient temperatures. Those laid after that date developed rapidly and by mid-January virtually all species required only 6-10 days incubation at ambient temperatures. This effect is marked in *E. psammitis* which oviposited latest (see Table VIII) yet had shortest egg incubation times (see Table IX). Although these can be defined as seasonal reponses they are essentially temperature dependent. Mean daily temperatures in November were around 16°C (thermohydrograph charts) but 22°C in January. Temperature effects were therefore tested by subjecting eggs laid throughout the season to temperatures of 15°C and 25°C (the upper and lower ranges of daily temperatures experienced 10mm into the soil - cf. Graph 3) with natural light - dark cycles. Five batches each of *O. flexuosellus* and

E. sabulosella were divided so that one half of each batch was subjected to 25°C the other half (laid the same day) to 15°C (see Methods Ch. 2 p.35). The incubation of *O. flexuosellus* at 25°C averaged 10.4 days and 19.4 days at 15°C; those of *E. sabulosella* 10.2 days at 25°C and 18.6 days at 15°C. For each species 't' tests of the differences between means for the incubation of eggs at the two temperatures yielded highly significant results (***$p<0.001$). Thus 25°C temperatures stimulated development in both species whereas 15°C temperatures retarded maturation.

Saturated salt solutions (Solomon,1951, 1957; Winston and Bates,1960) were used to maintain the desired relative humidities (standardized after Matheny and Heinrichs (1971) at the two temperatures of 15°C and 25°C) so as to keep the water vapour pressure deficit (saturation deficiency) as small as possible. See also Methods (Ch. 2). Although there was no significant difference between incubation times for a particular temperature for any species those in 99.0% relative humidity (r.h.) at 15°C or 97.5% (25°C) using K_2SO_4 saturated solutions emerged sooner than those at 76.0% r.h. (15°C) or 75.5% (25°C) using NaCl saturated solutions, and these in turn emerged sooner than those at 56.0% r.h. (15°C) or 55.0% (25°C) using glucose saturated solutions. Very high humidities were therefore beneficial to the rapid development of sod webworm eggs. Percentage hatch was not significantly affected by any of the humidities.

SEX RATIOS

Eudonia sabulosella is the only species for which unbiased sex ratio data can be assessed, i.e. sex ratios based on pupae and pupal exuviae. From these there were 42 males and 40 females i.e. 1.05 : 1 or very nearly a 1 : 1 ratio of males : females. Table X represents the sex ratios for each species. Collections by light trap have been segregated from all other methods of sampling as light-trapping often biases sex ratios (Hudson, 1928; Williams,1935, 1939, 1940; Glick *et al.*, 1956; Verheijen,1960).

TABLE X. Sex ratio of each species.

SPECIES	*O. flex*		*O. vit*		*E. psam*		*E. sab*		*"S." bis*		*"S." diph*		*"S." hal*		*"S." phil*		*S." subm*	
METHOD OF COLLECTION	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀
ALL EXCEPT LIGHT TRAP	81	41	13	12	12	13	249	197	24	10	7	15	18	13	120	95	50	10
LIGHT-TRAP	710	2993	74	157	148	208	1039	1066	20	57	108	214	15	44	31	41	46	308
TOTAL	791	3034	87	169	160	221	1288	1263	44	67	115	229	33	57	151	136	96	318

See Appendix V for generic name abbreviations.

This table shows that except for *Eudonia sabulosella* there is a bias (in totals) to one sex in all other species. Such a bias is particularly pronounced in the case of light trapping *O. flexuosellus* where females were extremely common. Hand collection of adults (e.g. from roosts) appeared to be influenced by time of day with more of one sex collected at certain times. Usually more males were collected between 1500-1800 hours and more females between 0700-0900 hours. Thus, temporal differences in flight and differential light attractiveness for each sex appear to bias sex ratios.

REPRODUCTIVE MATURITY

Newly emerged *E. sabulosella* females had small amounts of fat body; few immature or developing eggs; a predominance of large, fully formed eggs with undeveloped chorion and several mature eggs (chorion developed and therefore non-staining in Grenacher's borax carmine solution - see Methods Ch. 2 p.37). Some of the field collected females (Whatawhata and Te Kowhai) which were reared contained no fat body and mostly small, developing eggs with virtually no mature ones at death. Female *E. sabulosella* lived for 4-6 weeks (see longevity, this Chapter p.98) and on emergence most eggs were developed whereas at death most were undeveloped (and in larger numbers than undeveloped eggs in newly emerged females). This suggests the possibility of continued egg production. Field collected females of other species on hill country appeared to confirm the *E. sabulosella* situation. "Fresh" looking (presumably newly emerged or young) females had high proportions of mature or fully developed eggs while dull, worn and presumably old specimens had high proportions of immature, developing eggs and few or no mature ones. Dying females were observed to oviposit, hence the lack of mature eggs.

Newly emerged male *E. sabulosella* had small amounts of fat body but reproductive organs were fully developed. At death males had no fat body. This was also the situation respectively for fresh (young) and old, worn specimens of other species.

MATING

Only one mating pair of *E. sabulosella* was found. This pair was aligned on a perennial ryegrass stem in a vertical position at 0800 hours. Whether this was a new copulation or a pair that had failed to disconnect from earlier morning mating is unknown. One mating pair of *"Scoparia" halopis* was observed at 0200 hours. Despite searching pasture at all hours of the night (using a red filtered lamp which does not "disturb" moths), sweep netting and collecting actively flying moths where two or more occurred, no other mating pairs were found. Such a lack is even more mysterious when it is revealed (Table XI) that on average females are mated more than once as evidenced by the number of spermatophores in the corpus bursae (assuming one spermatophore per mating). Apart from the two observed instances no other direct information on copulation was gained.

In the laboratory at ambient tempertures *E. sabulosella* adults were observed to emerge from pupae early in the morning (0400-0700 hours). If that reflects the field situation, mating may be an early morning activity rather than nocturnal (early evening e.g. Madge, 1954; Banerjee and Decker, 1966a; Crawford, 1971) since newly emerged *E. sabulosella* females collected in emergence traps (with newly emerged males) at 0900 hours and immediately killed had been mated. The corpus bursae contained only one spermatophore in these instances. This also indicates that newly emerged males are reproductively mature (see above). Also this was one time of the day when moths collected by hand (0400-0700 hours) had roughly equal sex ratios.

TABLE XI. Frequency of mating in field collected females

NUMBER OF MATINGS	*O. flex*	*O. vit*	*E. psam*	*E. sab*	*"S." bis*	*"S." diph*	*"S." hal*	*"S." phil*	*"S." subm*
0	0	0	0	0	0	0	0	0	0
1	4	4	3	9	5	1	4	3	1
2	16	9	13	13	13	10	5	14	17
3	8	7	2	9	2	9	12	2	7
4	1	0	2	0	0	0	0	1	0
5	1	0	0	1	0	0	0	0	0
6	1	0	0	0	0	0	0	0	0
MEAN	2.4	2.2	2.2	2.1	1.9	2.4	2.4	2.1	2.2
STANDARD ERROR OF MEAN	0.192	0.162	0.177	0.162	0.128	0.130	0.171	0.150	0.102

See Appendix V for generic name abbreviations

It is clear that multiple mating is the usual situation. There was no correlation (n.s. $p>0.05$) between number of spermatophores and number of eggs in any of the above species. Thus frequency of mating had no apparent effect on fecundity.

Very few insects were caught in baited traps. Five trials per species were used (see Methods, Ch.2). Moths of either sex were not attracted to blanks or males. *E. sabulosella* (3); *"Scoparia" bisinualis* (1); *"S." philerga* (1) and *"S." submarginalis* (2) females attracted males of their own species. Bracketed numbers refer to the total numbers of males caught for the five trials. Males arrived early in the evening (30-60 minutes after dark) or early in the morning (0400 hours onwards) and this coincided with a general increase in adult flight activity (see Adult Behaviour, Ch. 8) at those times. None of the other species of females attracted males. This may have been due to the possible old age of some females, phases of sexual attractiveness or the design of the traps.

CONTEMPORANEOUS SPECIES

Throughout the study any insects or spiders collected at Whatawhata or Te Kowhai while sampling for sod webworms were recorded and identified to family level (where possible). Appendix III represents these specimens divided into three grades of frequency (up to 10 *; up to 100**; more than 100***). There was a great diversity of insect families coexisting with sod webworms in hill country. This list has been compiled by pooling records gained throughout the study from emergence, light, malaise, suction, sticky plate, egg and pitfall traps, sweep netting and soil sampling. Light trapping at Whatawhata attracted many adult aquatic insects from the nearby Woolshed Stream and Waipa River.

DISCUSSION

The finding of univoltinism in *Eudonia sabulosella* on hill country and in *"Scoparia" bisinualis, "S." diphtheralis, "S." halopis, "S." philerga, "S." submarginalis, E. psammitis* and *O. vitellus* at St. Andrews Golf Course compares with overseas research. Koch (1965) found *Hednota* (Crambinae) to be univoltine in Western Australia and Matheny and Heinrichs (1971) found 7 out of 13 crambine species studied in Tennessee (United States) to be univoltine. Gaskin (1975b) reported similar generation times for *O. vitellus* as found in this study. The bi-multivoltinism of *O. flexuosellus* also compares with Gaskin (1975b).

Adult seasons presented in Table II are far longer than previously suggested by Meyrick (1882, 1885); Hudson (1928, 1939), Gaskin (1975a, 1975b except for concurrence with *O. flexuosellus)* and Patrick (1982). *Scoparia philerga* appeared to be multivoltine at Auckland with three distinct peaks in adult numbers, hence the vast span in adult presence. Dissections of adult "S." *philerga* (collected at Auckland) conformed to the findings of *Eudonia sabulosella* for newly emerged through to old adults progressively in each generation. The adult seasons found in this study are far longer than recorded by Wallace and Mahon (1952) where crambine moths were "plentiful" for about three weeks in the S.W. of W. Australia.

Crambine eggs laid on the soil surface experience a wide range of temperatures and humidities (Matheny and Heinrichs, 1971; Morrison *et al.*, 1972). Those of Scopariinae, being laid up to 10mm into the soil would presumably not be subject to such fluctuations. Madge (1956c) measured the relative humidity at the base of the burrow of *Oncopera fasiculata* (Hepialidae) in South Australia as 95% while it was only 65% just above the burrow mouth. This suggests that minimum humidity experienced by scopariine eggs laid in the soil against grass stems would be no lower than the minimum relative humidity (measured on a thermohydrograph 0.5m above ground) at the study sites (i.e. around 50%, see Graph 5 Meteorological Data Ch. 3), and higher than that experienced by crambine eggs on the soil surface. During the egg-laying season (summer) measurements at Whatawhata of temperature at the soil surface were at least 5°C higher than those 10mm into the soil by day and the reverse by night. Scopariine eggs therefore are insulated from the wide range of humidity or temperature fluctuations experienced by crambine eggs.

There have been several studies on the controlling factors of sod webworm oviposition (e.g. Banerjee and Decker, 1966a, 1966b; Crawford, 1966, 1967, 1968, 1970a). Banerjee and Decker (1966a 1966b) found that oviposition usually occurred at the onset of darkness and shortly after dark especially in response to temperature depressions from 25°C to 20°C but Crawford (1966, 1967, 1968) showed that sudden light intensity changes from 2000 to 230 lux did not result in oviposition. Crawford (1970a) proposed that egg laying in response to temperature depressions had adaptive value enabling females to advance oviposition relative to the onset of darkness in late summer. The findings of the present study that the two crambine and seven scopariine species oviposited just prior to and after darkness concurs with the above findings. On the occasion when lights were switched on but oviposition continued, though at a slower rate, an explanation may be that moths were into the second hour of oviposition. Banerjee and Decker (1966a) reported 60% of eggs were laid in the first hour and 90% by the end of the second hour. The observed slower rate of oviposition may thus be totally unrelated to the effects of light. However, it was found that oviposition ceased in these Crambinae and Scopariinae if lights remained on for 15-30 minutes. Thus as with Banerjee and Decker (1966b) it appears that once oviposition has begun in darkness it would continue at least for a time in light. Short exposures to light hindered, but did not stop oviposition.

Oviposition early in the night (as found in the species studied) has the advantage of enabling eggs the full benefits from dew formation on grasses. At Whatawhata, dew formed most nights in summer. It is only for short periods after oviposition that eggs can absorb moisture (Hinton, 1970) so it is essential that water uptake occurs then since lost moisture cannot be replaced from free water as the embryo develops (Madge 1956b).

Tashiro (1976) found in the grass webworm (*Herpetogramma licarsisalis*) that younger females laid large numbers of eggs in masses but older females usually laid singly. This compares with the findings from the present study. The laying of a clump of eggs by newly emerged females has adaptive advantages since gravid females do not fly far, hence these eggs would presumably be laid in the area of emergence. This ensures there is a new generation in the area of previous successful survival. However it also provides a population for the perpetuation of diseases, predators or parasitoids. The single-egg laying, after many of the mature eggs have been deposited and the females are more dispersive and able to fly more freely (e.g. as evidenced in light-trapped females - see Adult Behaviour Ch. 8). serves to increase the chances of locating other suitable environments for sod webworm development.

Ovipositing females were non-selective as to track or intertrack habitats. It was hoped that selective oviposition by females would explain the observance of larval congregations in the intertrack region. It can only be assumed that those eggs laid in the intertrack have a better chance of survival with, for example stock grazing from the tracks minimizing trampling effects in the intertrack region. Soil cores taken to ascertain moisture in each habitat showed that year round the intertrack was always 2-5% drier (see Graphs 1 and 2 Meteorological Data Ch. 3) than the track. Therefore, in wet weather eggs or larvae would be less susceptible to water-logging, and at least in *Oncopera fasciculata* (Hepialidae) excessive wetness results in larval death (Madge, 1957, 1958). The observed congregations of larvae in the intertrack region, especially in winter-spring may be a result of larval migration away from the wetter track regions. Pitfall trapping (see Methods Ch. 2 p. 23 and Population Dynamics Ch. 6 p. 144) to assess larval mobility suggested minimal movement but that may have been a result of low population numbers. There is a balance between habitats that are too dry in the summer and too wet in the winter (Madge 1957, 1958). Most of the Scopariinae studied were confined to dry grassy slopes (Meyrick 1885; Hudson 1928, 1939) but that conflicts with egg or small larval requirements to avoid desiccation. That explains why light rain stimulated oviposition whereas high rainfall had a rather inhibitory effect.

The findings that long sparse pasture cover was the most preferred for oviposition and that sparse cover was preferred to dense and long to short are unlike those of Madge (1956b, 1956c) and Martyn (1965b). Those studies both found preference for long over short pasture but dense was preferred to sparse. However, plant densities were not given and descriptions of pasture cover are therefore subjective. Martyn (1965d) found the reverse of the above trend the following year and related it to soil moisture content rather than pasture type. Since long pasture intercepted light rainfall, soil moisture was greatly reduced that season (Martyn,1965d). Long dense cover generally afforded the greatest resistance to desiccation of eggs and larvae (Madge,1956b, 1956c; Martyn,1965b). The insect they studied (a hepialid) laid eggs on the surface of the soil under pasture cover. Fenemore and Allen (1969) found that porina (Hepialidae) infestations in New Zealand were associated with long pasture at the time of oviposition. *Eudonia sabulosella* oviposits below the surface of the ground, around bases of grasses or mosses. It seems feasible that sparse cover enables these females to penetrate the sward and thus oviposit in the soil whereas dense cover may preclude females from the soil, or hinder penetration of the ovipositor The selection of sparse cover by female *E. sabulosella* has a further implication in population dynamics as it suggests that areas previously damaged by larvae and undergoing grass regeneration are prone to subsequent attacks. This may explain the confinement of *E. sabulosella* to southern hill country slopes where grass growth is more sparse due to climatic and nutritional differences. These slopes are usually cooler (see Gillingham and Bell 1977) as the sun does not reach them till later in the day (e.g. study sites shaded until 1300 hours in mid winter) and animals grazing there usually deposit dung on crests rather than sides of the hill, or tracks rather than intertracks (White, 1973). This results in marked deficiencies in soil nutrient level, grass species composition and pasture production (Suckling,1959; Radcliffe,1968; Rumball and Elser,1968; Saunders and Auld,1969).

The location of adults on tall grasses in relatively lush, rank or ungrazed areas compares with Crawford (1971) and De Rozari *et al.* (1977). Hudson (1928) reported that *E. sabulosella* adults were "abundant" in fields in the midst of cultivation, again supporting the finding of this study, with adult congregations in long grasses. Meyrick (1882, 1885) and Hudson (1928, 1939) reported similar roosting places as found in this study for *O. flexuosellus, "S." halopis* and "S." *submarginalis*. Perhaps the preference for long pasture is related to associated soil temperatures. King (1979) showed that long pasture had an insulating effect so that when air temperatures were high, soil temperatures were cooler under long rather than short pasture. This may be another explanation for most oviposition occurring under long cover.

The initial slow growth of early stage larvae is confirmed by Madge (1956c) and Kamm (1971, 1972). Kamm (1971, 1972) showed that the rate of larval growth increased as day length decreased. Thus the above observed increased larval growth rates in April-June may be explainable as behavioural rather than physiological responses. Increased larval growth also corresponds with the first substantial autumn rains (Madge,1956c) and grass growth. As Kamm (1971) suggested, since larvae are essentially nocturnal feeders, the short days simply enable them to feed for longer periods of time hence they grow faster. He produced three grades of growth rates (1972) with larvae on long day-light schedules growing most slowly, those on decreasing photoperiods distinctly faster, and those on short days with fastest rates of developments. Support for the response being behavioural (i.e. greater amounts of time spent feeding) is derived from observations at Whatawhata of pasture damage at the commencement of this study in August-September 1978. The most severely damaged regions (i.e. showing most evidence of feeding) within the general damaged area, were those to the west which were observed to be shaded from 1330 hours at that time of year. Larvae collected shortly after the onset of shading were found to be feeding. Also these larvae were up to 5mm longer than ones in non-shaded areas, even though numbers per m^2 were the same. There appeared to be no difference in the times of onset of pupation or adult sizes, between the two regions. It thus appears, as suggested by Kamm (1971) that growth rates are accelerated simply by extended feeding periods.

In common with the present study Gaskin (1975b) found the larvae excise whole blades of grass which they dragged back into burrows before feeding upon them. As seen at Whatawhata and Te Kowhai in 1978, plants were thus attacked near or at the base (cf. Crawford and Harwood,1959; Tashiro,1976) and eventually a wide area of grass was clipped from around the burrow (cf. Scheibner,1968). The types of feeding damage observed from rearing the Crambinae and Scopariinae studied i.e. small elliptical or circular holes on grass blades, has also been reported by Bohart (1947) and Gair (1964). Thompson (1942) showed that Crambinae in Yorkshire, England fed on creeping red fescue, sheep's fescue, creeping bent, cocksfoot, Yorkshire fog, sweet vernal and perennial ryegrass. Wallace and Mahon (1952) reported that Crambinae in the S.W. of W. Australia fed exclusively on Gramineae including silver grass (*Vulpia* spp.), barley grass (*Hordeum* spp.) and bromegrass (*Bromus spp.*) also wheat. They did not appear to feed on oats and perennial ryegrass was relatively resistant to attack. Gair (1964) indicated that Crambinae can transfer from grasses to cereals meaning that the usual practice of waiting at least four weeks between ploughing grass and drilling cereal was unsatisfactory. This was because crambine caterpillars "often stop feeding for long periods during the winter months and remain viable in the temporary absence of a host" (Gair,1964). Generally the cereal crops recovered well without the necessity of implementing control measures. Tashiro (1976) listed kikuyu grass and sunturf bermuda as hosts of the grass webworm in Hawaii. Morrison *et al.* (1972) reported that Kentucky bluegrass readily supported populations of *Crambus teterellus* (the bluegrass webworm, Crambinae). Pass *et al.*(1965) showed that pasture management of bluegrass strains significantly affected sod webworm infestations and according to Buckner *et al.* (1969) the strains of bluegrass which were relatively resistant to feeding damage had heavier rhizome weights. In New Zealand, Hudson (1928) found that *Eudonia sabulosella* and *"Scoparia" bisinualis* larvae feed on mosses in winter; Pottinger (1973) reported crambine damage on older brown-top dominant or native grasslands as well as, more recently, on improved pastures; and Gaskin (1975b) found that *Orocrambus flexuosellus* larvae feed on *Poa annua* (perennial ryegrass), *Dactylis glomerata* (cocksfoot), *Festuca rubra* var. *comutata* (chewing red fescue), *Ceratodon purpureus* (moss), *Agrostis tenuis* (browntop) and *Alopecurus pratensis* (meadow foxtail) while *O. vitellus* was "adventively associated" with *Agrostis tenuis* but readily ate all common pasture grasses. The above results compare with the findings of the present study with a wide range of grasses and mosses accepted by the sod webworm species reared.

In view of this wide acceptance of grasses and the fact that Quinlan (1972) found Crambinae in N. Queensland (Australia) readily ate any pasture grass and also Greenblatt *et al.* (1978) "induced" polyphagous webworm caterpillars to feed and develop on non-preferred hosts, the feasibility of using resistant plants for control of sod webworms seems doubtful. As Wallace and Mahon (1952) accurately surmised ... "It is apparent that the presence of webworm may have a considerable effect on growth and botanical composition of the pastures" ... The widespread distribution of sod webworms is thus largely due to the flexibility of larvae feeding on mosses and grasses (introduced and native) (Munroe,1952; Gaskin,1975a).

In rearing, larvae readily accepted fresh, lush grasses. This may explain the observed larval preference for new, lush lawns (cf. Bohart 1940) or improved pastures (cf. Pottinger 1973) expecially in view of the fact (as described previously) that adults congregate over lush, long pastures. The finding that in rearing, most larvae migrated overnight to fresh food compares with Gair (1964), Gaskin (1975b) and Cheshire *et al.* (1977). However as with Tashiro (1977) not all sod webworm larvae did that. Those caterpillars were transferred to fresh material as the old plant food we removed. Such enforced movement of larvae may have accelerated death rates in reared populations as small larvae especially, are very susceptible to injury (Madge,1956c; Gaskin,1975b). As with the present study Kamm (1971), Gaskin (1975b) and Tashiro (1976) also noted larvae feeding at night or whenever the burrow was shaded.

In common with the present study Pottinger and Le Roux (1971) and Tashiro (1977) found that adult longevity was closely linked with feeding. Sucrose solutions (Pottinger and Le Roux) and honey or sucrose solutions (Tashiro,1977) resulted in best survival rates. In this study flowering weeds plus free water resulted in better survival than free water only but was not as good as those reared on honey-sucrose solutions plus free water. The flowering weeds may have become unproductive during the trial hence the intermediate longevity obtained on that food source. It must be remembered that this is a highly artificial situation as adults in the field are free to collect nectar from a variety of flowers over a wide area. There was always an abundance of Hymenoptera (*Apis mellifera, Bombus* spp. and *Leioproctus* spp.) working the clovers, dandelions and surrounding flowering trees at all study sites during the adult sod webworm season which indicates adequate nectar supplies were available.

The finding of a 4-6 week longevity in the sod webworm species studied is quite unlike previous work. Crawford (1971) found a maximum longevity of 8 days in two crambine species in N. Mexico; Kamm (1971) reported that adults of a crambine species in Oregon (United States) lived for 10-14 days; and Tashiro (1976) found average longevities of 13.1 days (males) and 13.5 days (females) for the grass webworm in Hawaii.

The average fecundities for sod webworm species studied here may have related to moth size. For example, Heinrichs (1973) reported that fecundity varied in relation to moth size with ranges of 482 to 32 from largest to smallest sized adult Crambinae in Tennessee (United States). Average fecundities were however, similar to *Agriphila plumbifimbriella* (Crambinae) as studied by Crawford (1971) with 122 eggs per female, but much lower than fecundities of *Crambus harpipterus* (Crambinae) with 255 eggs (Crawford 1971); *Crambus (=Chrysoteuchia) topiaria* with 471 eggs (Kamm 1973) or

Herpetogramma licarsisalis (Pyraustinae) with 249 eggs (Tashiro 1977).

The incubation period of *Orocrambus flexuosellus* eggs at 25°C was 10.4 days and 10.2 days for *Eudonia sabulosella*. These times are very similar to the 10.5 and 11.0 days reported by Matheny and Heinrichs (1971) for egg stage duration in two geographically separated populations of the crambine *Agriphila ruricolella* (Zeller) at 25°C. They also found that short exposures to any temperature did not affect percentage hatch. Eggs are exposed to wide ranges of temperature in the field but the maximum or minimum daily temperature is usually of short duration. In the present study, development was stimulated at 25°C, whereas 15°C temperatures retarded maturation. This compares with Heinrichs and Matheny (1969) where the hatch of three species of crambine eggs could be delayed about two weeks by subjection to 15°C. Otherwise (see App and Kerr,1969; Heinrichs and Matheny, 1969) those eggs would have hatched in 7-10 days. As with the present study Heinrichs and Matheny also found that these temperatures did not affect viability, or the proportions of larval eclosion. Experiments on egg development at three different relative humidities showed that high humidities (about 98%) were beneficial to the rapid development of eggs of the sod webworm species studied. Morrison *et al.* (1972) found differences in egg tolerance to desiccation in different geographical populations of *Crambus teterellus* (Zincken) (bluegrass webworm). They found this coincided with the field conditions experienced by the populations. The New Mexico population was more tolerant of low humidities since it existed in an area of lower rainfall and lower ambient humidity. No such differences were found between eggs from Auckland or Hamilton populations presumably because of the comparatively small geographical separation (120 kilometres) and the relatively high humidity levels investigated. Also, it is only for short periods after oviposition that lepidopteran eggs absorb moisture (very short times in some species) (Hinton,1970) so by the time experiments were set up (usually 1-2 hours after oviposition) eggs may have already absorbed the required amounts of moisture.

The low numbers of undeveloped eggs in newly emerged *Eudonia sabulosella* and few or zero mature eggs in females at death compares with Crawford's (1971) results where only about 10% of eggs were immature in newly emerged *Crambus harpipterus* and *Agriphila plumbifimbriella* (both Crambinae) and few mature eggs remained in the ovaries on death of the female. The observation of some fat body in newly emerged *Eudonia sabulosella* despite mature eggs being present is contrary to the commonly reported view (e.g. Crawford,1971; Gower,1972) that fat body diminishes in relation to egg maturity. That may simply be the result of information based on short-lived adults which are not reproductively mature at emergence so that by the time eggs were mature fat body had diminished. It was suggested (see "Fecundity", this chapter) that egg production may continue throughout adult life. Certainly in the laboratory many females oviposited daily until death, and the greater number of undeveloped small eggs in females at death than in newly emerged females was taken to mean egg production was continuous. However, egg resorption may occur hence the lack of mature eggs and numbers of undeveloped eggs in females at death. That females laid eggs until death indicates no post-oviposition period but a pre-oviposition period of 1-2 days was suggested from the five newly emerged and mated *E. sabulosella* females available for such investigations. The oviposition of females just prior to death has adaptive advantages providing a chance for survival of some larvae since, in the natural environment, females die in grassed areas.

The low incidence of recorded mating pairs compares with Gaskin (1975b) who discovered only one mating pair from the ten *Orocrambus* species he was studying biologically. There was a high frequency of multiple mating in the sod webworms studied (see Table XI) and this may be positively related to their relatively long lives. Banerjee and Decker (1966a) found the crambines *Crambus trisectus* Walker and *C. mutabilis* Clemens mated only once. On the other hand Crawford (1971) found that crambines *C. harpipterus* and *Agriphila plumbifimbriella* frequently mated twice. Tashiro (1976) reported that *Herpetogramma licarsisalis* (Pyraustinae) females had one or two spermatophores in the corpus bursae but some females which "appeared abnormal" had as many as five. It is assumed that there is one spermatophore per mating (cf. Crawford 1971 and "mating" section where newly emerged and mated *E. sabulosella* females had one spermatophore in the corpus bursae).

Few insects were caught in baited traps, which may have been due to the possible old age of some females, phases of sexual attractiveness or design of the traps. Banerjee (1969b) found that 75% of males were attracted for the first 3-4 days of female life and attractiveness decreased with age and ceased after mating. Perez and Long (1964) however found that mated female sugar cane borer moths (*Diatraea saccharalis*) attracted males. The multiple matings of sod webworms studied indicate a continued attractiveness or repeated and discrete phases of sexual attractiveness throughout the relatively long female life. If the latter occurred it could explain the largely negative results of baited trap experiments.

CHAPTER SIX

POPULATION DYNAMICS

Introduction

The soil-pasture habitat is not a homogenous one and leads to clumping of individuals (eggs, larvae and pupae). Such aggregations are further aided by female selection of oviposition sites (see Biology Ch. 5 p.92). This results in reduced precision and accuracy of sampling. As indicated by Morris (1955) and Southwood (1978) the percentage of animals overlooked may vary with density with the possibility of more being missed at the lowest densities. In extraction of insects from samples all errors lie on one side of the true value (i.e. too few will be found = underestimation). Southwood and Jepson (1961) reported 10 to 100 fold population changes in a single season so that a standard error of 25% of the mean would enable doubling or halving of the population to be detected. Life table studies, especially on natural populations require higher levels of accuracy (around 10% Southwood, 1978). However that criterion is a guide for population studies (Morris 1955) and some life tables have been constructed with percentage standard errors even above 20% (King, 1979).

Since methods suitable for extraction of insects at high population densities may not be suitable at lower densities, standard errors of the mean were calculated at each sampling occasion to indicate desirability of the extraction techniques used. Thus constant evaluation was made to ensure precision (i.e. the closeness of repeated measurements to the same quantity, Sokal and Rohlf, 1973) and hence accuracy (i.e. closeness of a measured or computed value to its true value, Sokal and Rohlf, 1973) of the results.

At Whatawhata, Te Kowhai and Ngaruawahia in 1978 all larvae and pupae reared through to *Eudonia sabulosella* (Scopariinae) except for one pupa from Te Kowhai which reared to *"Scoparia" diphtheralis*. In 1979, 1980 and 1981 again all larvae found from soil sampling on southern hill country slopes at the above sites were *E. sabulosella*. On the basis of that information it appeared that this was the most important species economically. Population dynamics studies were thus concentrated on this species. Since larval instars were not determined (see Biology Ch. 2 p.86) and *E. sabulosella* was univoltine on hill country, life tables are based on sampling time intervals of one month.

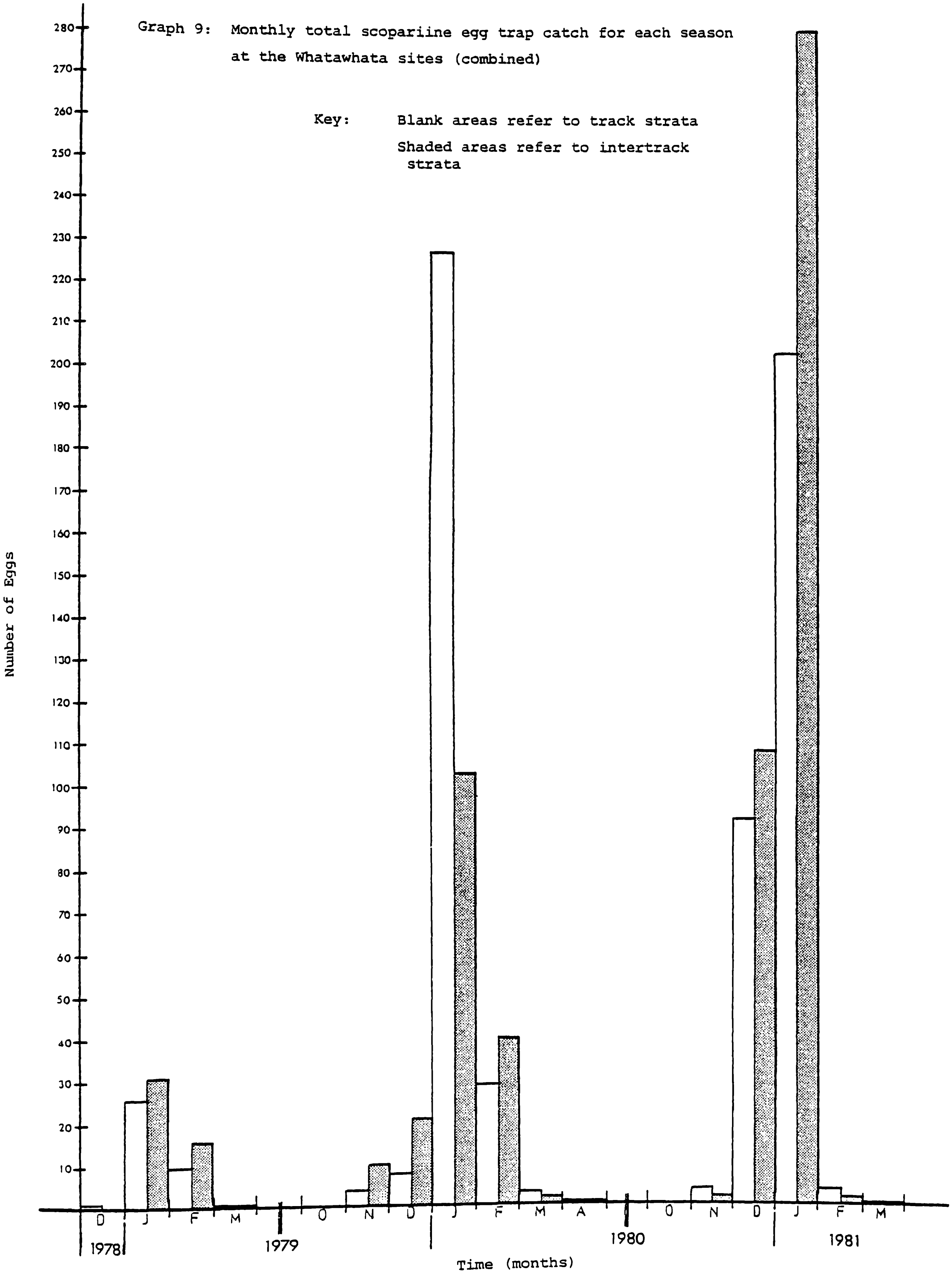
EGGS

Actual Egg Populations

Egg traps (see Methods Ch. 2 p.17) were used at Hart's Te Kowhai, and the three Whatawhata sites (Wilsons 2A, Wilsons 2B and Long 4A). The Te Kowhai site was subject to an on-going farm management scheme and this meant that sheep and cattle grazing was practised in the trapping area. Many problems accrued with fouling of the traps and removal or trampling of them by the grazing stock. As a result trapping was discontinued there in 1980-1981, and results of the other years may be underestimations of egg numbers. The Whatawhata sites will therefore be concentrated upon. No significant difference was found in weekly egg-laying (totals per 20 traps) between the Whatawhata sites (ANOVA for equal sample sizes $p>0.05$ see Biology Ch. 5 p.91). However, the amount of rainfall did significantly affect egg numbers in the track and intertrack strata with a bias to intertracks in low rainfall (below 20mm) weeks, and significantly more oviposition (track and intertrack) in low rainfall weeks (see Biology Ch. 5 p.91). Such results mean that large standard errors of the mean (around 40%) result when egg trap data (per 20 traps per week) are averaged to provide monthly values. Therefore instead of presenting data in that form, total egg populations (track and intertrack separately or combined) for each site, and each year were converted to numbers per m² to indicate the actual population sampled per site and provide a basis for comparison with larval numbers. Expected egg populations were calculated from female numbers (as collected by Malaise, suction, or emergence traps, sticky plates, sweep nets or (1980-81) frame counts) and average fecundity. Such comparisons of expected and actual egg populations served to indicate the magnitude of any discrepancies.

Graph 9 represents a frequency histogram of the monthly total scopariine egg catch for track or intertrack strata combined for the Whatawhata sites. Such pooling of the data was the only way to eliminate the large numbers of zeros in the weekly catches per site. Each site showed the same trend of oviposition as in Graph 9. It can be seen that the main period of oviposition was December - January and February with a peak each year in January. This explains the lack of small larvae recovered in soil sampling in December 1978 and January 1979.

Table XII refers to the total egg catch (converted by means of proportional allocation to numbers per m²) for each of the trapping sites each season. Crambine eggs are not represented but had the following frequencies (all sites combined i.e. including Te Kowhai):



Graph 9: Monthly total scopariine egg trap catch for each season at the Whatawhata sites (combined)

1978-1979	4	*Orocrambus flexuosellus;*	1	*O. vitellus*
1979-1980	6	*O. flexuosellus;*	3	*O. vitellus*
1980-1981	13	*O. flexuosellus;*	6	*O. vitellus*

TABLE XII. Egg catch (number per m^2) for each site, stratum and season.

EGG CATCH PER SITE

SEASON	WILSONS 2A			WILSONS 2B			LONG 4A			HART'S TE KOWHAI		
	Tr	In	Tot	Tr	In	Tot	Tr	In	Tot	Tr	In	Tot
1978-1979	19.59	42.19	30.89	22.27	14.41	18.34	9.04	12.05	10.54	1.88	3.77	2.82
1979-1980	19.82	11.10	15.46	10.70	12.29	11.50	57.89	34.89	46.39	3.97	4.76	4.14
1980-1981	147.67	237.07	192.37	42.69	52.23	47.46	23.77	20.76	22.27	-	-	-

Tr = Track In = Intertrack Tot = Total

As indicated previously (Biology Ch. 5) a single classification (track and intertrack data combined) model I ANOVA for unequal sample sizes yielded significant results (** $p<0.01$) for monthly egg catch per site per season. Using 't' tests of the difference between means (since there were only three seasons to compare using two means for two tests) it was found that the 1978-79 and 1979-80 seasons were not significantly different ($p>0.05$) for both Wilsons 2A and Wilsons 2B but the 1980-81 season was significantly different ($p<0.01$) from the other two seasons for both these sites. Long 4A yielded significant differences between all three seasons with egg catch being maximal in 1979-80 and minimal in 1978-79.

DISCUSSION

Egg trapping is subject to many errors as with pitfall trapping (see Fenton and Howell, 1957; Thomas and Sleeper, 1977; Southwood, 1978; Shires, 1980). The most difficult problem is their use for the estimation of populations largely because of the influence on activity and hence catch of weather conditions or "phase" of the animal. Estimations on total numbers may overcome these biases. However, many of the inherent problems of pitfall trapping (e.g. cover by vegetation, exclusion of some species) do not apply in the case of egg trapping as the traps contained mesh to exclude virtually everything but eggs. The traps were also covered with grasses to conceal their presence in the hope of simulating normal ovipositional behaviour of females. The mesh covering of the egg trap was set 10mm below the upper lip which was itself flush with ground level. This may have encouraged resting by females in the resultant hollow with consequently increased chances of egg deposition in that area. Throughout the trapping periods no females were observed to rest on the egg traps. The pooling of catches from the twenty egg traps for each stratum, topographical habitat and site would partially offset such biases. In each season more than 95% of the total number of eggs trapped were single with some batches of 3-5 eggs and rarely 7-10. As indicated previously Biology Ch. 5 p.90) there were two types of oviposition (at least in *Eudonia sabulosella* and the other Scopariinae studied - except *"S." halopis* from which only few eggs were obtained). Newly emerged females laid clumps of eggs while older females laid eggs singly or in small batches. It thus appears that the egg traps were largely selective of oviposition by older females and if, as suggested previously (Biology Ch. 5 p.110) such females are more dispersive the above estimated egg populations per m² may be gross underestimations.

Crambine eggs were easily identified under a binocular microscope from scopariine ones by chorion characteristics and size ranges. Scopariine eggs were measured and all fell within the range of *E. sabulosella* eggs (see Taxonomy Ch. 4) but there was some overlap with other species (*"Scoparia" bisinualis, "S." philerga and "S." submarginalis)*. Eggs removed from the traps and reared failed to develop.

Expected Egg Populations

Expected egg populations were calculated from adult female populations multiplied by the average fecundity for each season. Adult populations on which these results are based refer to those ascertained by counts during the peak of the adult season (see Methods Ch. 2) divided by the sex ratio of *Eudonia sabulosella* (1 : 1 males : females see Biology Ch. 5 p.104) to provide numbers of females. In other words, two assumptions are made: that half the adults constituting a congregation are females (this is true see Biology Ch. 5 and Adult Behaviour Ch. 8) and that females recorded within an area actually deposit all their eggs there. In 1978-79 and 1979-80 emergence traps (see Methods Ch. 2 p.25) were used at all sites. The total females per site collected in these traps were converted to numbers per m² and adjusted to provide expected egg populations. These results appear only for 1978-79 as no *E. sabulosella* females were collected in emergence traps in 1979-80. Table XIII refers to expected egg populations for each site and each season. The ranges in egg numbers refer respectively to the upper limit (95% confidence level) of average female fecundity for each season multiplied by the upper limit (95% confidence level) of average female numbers per m² and the lower fecundity limit multiplied by lower limit of female numbers per m² i.e. maximal range of expected egg populations.

TABLE XIII. Range of expected egg populations (per m²) at each site in each season

SEASON	RANGE OF EXPECTED EGGS (PER M²) AT EACH SITE			
	WILSONS 2A	WILSONS 2B	LONG 4A	TE KOWHAI
1978-79 based on emergence Trap female numbers	47-74	133-211	41-64	19-31
1978-79 based on female counts / m²	136-340	203-483	203-501	215-519
1979-80 based on female counts / m²	94-305	32-104	32-174	36-122
1980-81 based on female counts / m²	124-274	62-133	47-96	21-67

Discussion - Eggs

It can be seen from Table XIII that expected egg populations based on numbers of adult females in m² counts are far greater than those based on female populations derived from emergence trapping. Comparisons of Tables XII and XIII reveal that actual egg populations are far smaller than the lower limit for expected egg populations, in all cases except Wilsons 2A in 1980-1981, where actual populations fall within the range of expected egg numbers. The assumptions of unity in sex ratio of the adults congregated in each m² area and of females ovipositing most/all their eggs within the sampling area appear to hold for Wilsons 2A in 1980-1981. As already stated it is known that there is unity of the sex ratio in field congregations. Thus it appears to be the second assumption, regarding female egg deposition, which is variable. An explanation may be found in Adult Behaviour (Ch. 8.) especially as affected by wind with augmenting and retention of congregations in certain areas. As indicated previously egg traps may selectively sample oviposition by older females and this could explain the instances of reduced actual egg numbers as compared with expected populations.

LARVAE AND PUPAE

Larvae were sampled fortnightly at each of the Whatawhata and Te Kowhai sites from September 1978 to May 1979. After that time Whatawhata sites were sampled once each month until October 1981 and Te Kowhai sites, once each month until June 1979 then once each two months until June 1981. This change in sampling periodicity was to enable time for searching at other sites because of the low numbers returned from the regular sampling sites. See Methods (Ch. 2.p.19-24) for larval sampling and extraction techniques. In 1978 larval numbers per m² were relatively high. This meant that standard errors of the mean were low (around 10-15%) and various sample sizes were utilized both to provide information on population distribution and precision (hence accuracy) of the different extraction techniques.

Sampling and Handling Time

There was little difference bween the total time to collect and extract insects from soil samples for the various extraction techniques used. Some methods involved two extraction techniques. Overall it took one day (10 hours) to collect and sort the soil samples for a site, each sampling occasion. This meant that four days a fortnight, or later four days a month were spent assessing soil insect numbers from regular sampling sites, before any time was used for sampling at other locations or for studying other aspects of sod webworms. Preliminary work (Sept - Oct 1978) suggested these "costs" would be well returned by gains in population dynamics information.

A 50mm diameter by 50mm deep corer was used for insect sampling from soil and compared with a spade square (150mm x 150mm x 50mm deep). The extraordinarily high number of cores needed to attain similar levels of precision as with spade squares resulted in adoption of the spade for all subsequent sampling. King (1979) found spade squares overestimated black bettle (*Heteronychus arator*) populations per m² because of problems in delimiting sample sizes and with larvae falling into the sampled square from surrounding areas. The spade square sample did not overestimate sod webworm populations relative to the corer as a fixed frame was used to delimit sample size and larvae did not fall into the sample from surrounding areas.

In 1978 when larval populations were relatively high and damage occurred, sampling was stratified within damaged areas. This resulted in increased precision and ease of sample location (cf. East,1972; Southwood,1978). However in 1979-81 whenever damage was not apparent stratified random sampling (Southwood 1978) was undertaken. This meant that equal numbers of sample units were taken in each subarea. Such subareas were permanently marked at each site (see Methods Ch. 2 p.20). Stratified sampling compromises precision as it means that a fixed number of samples are taken per subarea regardless of the density or distribution of the population or the stage of the life cycle. However it was considered a valid approach in view of the available resources for sampling and extracting insects before the level of precision of the population estimates had been determined.

In the following examinations of the various extraction techniques, means and standard errors relate to paired turves. As described in Methods (Ch. 2 p.20) paired spade squares were taken,and each of the paired samples assessed separately so that data could be pooled where necessary to at least partially limit some of the zero counts when population levels were low. It was found that results from paired soil samples resulted in lower coefficients of variation and hence lower numbers of samples (i.e. total number of turves required was less) to provide around 25% standard errors as derived from the equation: Number of samples = $\left\{\frac{\text{Coefficient of variation}}{\text{desired \% std error}}\right\}^2$

Extraction Techniques (See Methods Ch. 2).

It was apparent that hand-sorting was the only possible way to ensure collection of diseased or moribund (inactive) larvae, pupae or pupal exuviae. Also many predators and cohabiting arthropods were not responsive to heat treatment (at least in the time sod webworms took to emerge from the soil upon heat application) and thus were only collected by hand-sorting/dry-sieving.

Dry-sieving/hand-sorting was a little more time consuming than other methods because of the small amount of each turf that was handled at a time. The residue of each sieve had to be hand-sorted and it was found best to use small quantities of such soil spread over a large white tray. This was systematically examined taking care to move larger soil particles to ensure no animals were obscured. Several times insects were seeded into turves (unknown by assessor) and recovery rates examined. At least 95% of animals were recovered from such trials.

Wet-sieving/flotation proved to be a good method for extraction of sod webworms and most predators. There were problems with insects being trapped under soil residue particles in sieves but agitation of the residue in $MgSO_4$ solution freed the insects for flotation and collection. The only problems with wet sieving were that despite washing in fresh water after flotation in $MgSO_4$, insects died and thus could not be used in rearing, and pupal cases sank as these have exit holes to the grass surface for adult emergence. Also it is difficult to distinguish live from dead insects (Murphy,1962). Therefore this method was not employed from mid-September to February when prepupae,pupae and pupal exuviae occurred. During these times dry sieving/hand-sorting was used exclusively. This explains the reason for the great difficulty in sorting the very dry soil in mid-December to mid-January and why sampling was discontinued during that period in 1979-1980 and 1980-1981.

Aeration and flotation yielded highly variable results. Only small amounts of previously crumbled turf could be added at a time and constant agitation of the settling soil was need to ensure release of trapped insects. The problems outlined above with the sinking of cocoons and associated insects as well as the unsuitability of specimens for rearing also applied.

Slow process saturation proved good for collection of sod webworm larvae, expecially small ones. However, once again flotation and wet sieving were needed to ensure collection of predators, and immobile forms required hand-sorting after the above processes.

The Argentine stem weevil heat treatment technique was not suitable for collection of sod webworms. No larvae were collected from desiccating grasses and larvae did not move out of turves subjected to the same treatment although they were collected by wet-sieving these soil samples after the heat treatment. This method of extraction was attempted for the recovery of small larvae since it was known (Gair, 1964; Heinrichs and Matheny, 1970; Gaskin, 1975b) that these construct silken retreats among grasses, rather than in the soil. At Whatawhata and Te Kowhai however, small larvae were collected from the soil of turves from which grasses had been subjected to the above drying technique. This result compares with Mr G.M. Barker's (Insect Control and Organic Chemistry Group, Ruakura) finding (pers. comm.) during assessment of Argentine stem weevil populations of no sod webworm larvae being extracted from cut and heated grasses but found later by wet-sieving and flotation of the associated soil turves.

In 1978 larval numbers were high enough to return precise and accurate measures of population density. However, as numbers decreased it was thought that the extraction technique itself may have been at fault hence the variety of methods used to provide continual checking of results. Essentially it was heat treatment : dry sieving that proved most reliable (see Table XIV). Table XIV refers to standard errors of the various techniques based on 40 turves taken in two different months of the year respectively representing high and low numbers of larvae.

TABLE XIV. Reliability of extraction techniques.

EXTRACTION TECHNIQUE	RANGE IN % STANDARED ERROR OF THE MEAN (UNTRANSFORMED DATA)	
	HIGH POPULATION DENSITY (10 OR MORE LARVAE/m²)	LOW POPULATION DENSITY (LESS THAN 10 LARVAE/m²)
Heat Treatment + Dry Sieving	9-12	16-30
Wet Sieving + Flotation	16-50	60-90
Aeration + Flotation	40-60	60-90
Slow Saturation	18-35	30-60

Clearly heating followed by dry sieving was the best method for extraction of sod webworms. The practice of dry sieving after heat treatment ensured that most larvae were collected and prior heating resulted in increased soil friability, hence ease of sorting. Even at low insect population densities this method usually proved reliable enough to enable estimation of halving or doubling in insect numbers (i.e. 25% standard error of the mean or less) (see Southwood, 1978). Wet sieving and flotation or slow saturation proved reasonably efficient for high population densities but quite unsuitable for low insect numbers. Aeration-flotation was the least accurate technique at both population densities, and was subsequently stopped once its precision had been assessed. Heat treatment followed by dry sieving was the most frequently used technique and slow saturation or wet-sieving and flotation were often employed to provide comparisions on extraction accuracies especially since these may have changed seasonally. Table XIV also indicates that greater precision in estimation of insect numbers relates to high population densities.

Larval, Pupal and Pupal Exuviae Numbers from Soil Sampling

Life table data (including populations per m^2) for each site are presented in Tables XV - XVIII. The numbers refer to totals for each month and as stated earlier larval numbers correspond to size classes (instars not being determined) as follows; February 7mm; March 10mm; April 12mm; May 12-15mm; June to December 15-20mm. The second and third columns of these Tables refer to total numbers of larvae or pupae (i.e. healthy plus diseased). The fifth and sixth columns give the total number of these larvae or pupae that were diseased or parasitized respectively. The eigth column (number of predators) is the combined total of carabid larvae or adults, elaterid larvae (*Conoderus exsul*) and staphylinid larvae or adults as recorded from soil sampling. The ninth column (number of parasitoids) represents the numbers of *Aucklandella geiri* DallaTorre (Ichneumonidae) obtained by any of the sampling methods.

Graphs 10-13 represent the sod webworm populations (per m^2) with confidence limits for each site. The y-axis zero value has been raised above the usual x-axis position to allow a full appreciation of the zero plots. Each site follows a similar pattern of population rise and fall, except that Te Kowhai populations (Graph 10) are much higher in 1978 and much lower in 1980 and 1981.

Wilsons 2A, Wilsons 2B and Long 4A all exhibited dramatically increased populations in 1981 but all showed a marked decline in numbers per m^2 from June onwards. The reason for this is discussed in Mortality Factors (Ch. 7).

Graphs 14-17 represent predator populations (total numbers) as sampled simultaneously with sod webworm populations. The zero value of the y-axis is similarly raised above the x-axis as in Graphs 10-13. Again the three Whatawhata sites show similar patterns of peaks and falls in predator populations. Predator population peaks roughly correspond with peaks in sod webworm populations and are the result not so much of an overall increase in predator population sizes but of changes in distribution. Predators are

TABLES XV - XVIII. Life tables for *Eudonia sabulosella* larvae at Te Kowhai, Wilsons 2A, Wilsons 2B and Long 4A respectively. (Numbers are adjusted for proportional allocation to track : intertrack strata.)

KEY: SWW=sod webworm; CL=confidence limits; pm^2=per metre squared area; double lines segregate generations.

TABLE XV. Life table for *Eudonia sabulosella* at Te Kowhai

MONTH	NUMBER OF LARVAE	NUMBER OF PUPAE	NUMBER OF PUPAL EXUVIAE	NUMBER DISEASED	NUMBER PARASITIZED	NUMBER OF EMPTY CASES	NUMBER OF PREDATORS	NUMBER OF PARASITOIDS	NUMBER OF PAIRED SAMPLES	% STANDARD ERROR OF MEAN	MEAN NUMBER OF SWW (±CL)	RANGE OF SWW pm^2 (±CL)
1978												
Sept	163	0	0	0	0	0	67	0	101	12.6	1.6±0.40	35.56±8.89
Oct	110	4	6	1	0	4	45	0	40	9.8	3.0±0.30	66.67±6.67
Nov	75	29	11	2	1	6	41	0	60	12.7	2.0±0.49	44.44±10.89
Dec	2	8	14	1	0	12	48	1	40	30.1	0.7±0.38	15.56±8.44
1979												
Jan	12	0	12	0	0	0	5	1	40	19.3	0.6±0.22	13.33±4.89
Feb	4	0	0	0	0	0	0	0	40	47.4	0.1±0.09	2.22±2.00
Mar	10	0	0	2	0	0	10	0	36	43.8	0.3±0.23	6.67±5.11
Apr	8	0	0	2	0	0	11	0	36	40.0	0.2±0.17	4.44±3.78
May	0	0	0	-	-	0	0	0	36	-	0	0
June	0	0	0	-	-	0	0	0	18	-	0	0
July	4	0	0	4	0	0	5	0	100	49.0	0.04±0.03	0.89±0.67
Aug	0	0	0	-	-	0	17	0	18	-	0	0
Sept	0	0	0	-	-	0	4	0	18	-	0	0
Oct	0	0	0	-	-	0	2	0	18	-	0	0
Nov	0	0	0	-	-	0	0	0	18	-	0	0
Dec	0	0	2	0	0	0	5	0	18	37.2	0.1±0.21	2.22±4.67
1980												
Jan	0	0	0	-	-	0	0	0	18	-	0	0
Feb	0	0	0	-	-	0	0	0	18	-	0	0
Mar	0	0	0	-	-	0	0	0	18	-	0	0
Apr	0	0	0	-	-	0	14	0	18	-	0	0
May	0	0	0	-	-	0	9	0	18	-	0	0
June	0	0	0	-	-	0	0	0	18	-	0	0
July	0	0	0	-	-	0	0	0	18	-	0	0
Sept	0	0	0	-	-	0	0	0	18	-	0	0
Nov	0	0	0	-	-	0	4	0	18	-	0	0
1981												
Feb	0	0	0	-	-	0	0	0	18	-	0	0
Apr	0	0	0	-	-	0	2	0	18	-	0	0
June	0	0	0	-	-	0	2	0	18	-	0	0

TABLE XVI. Life table for *Eudonia sabulosella* at Wilsons 2A

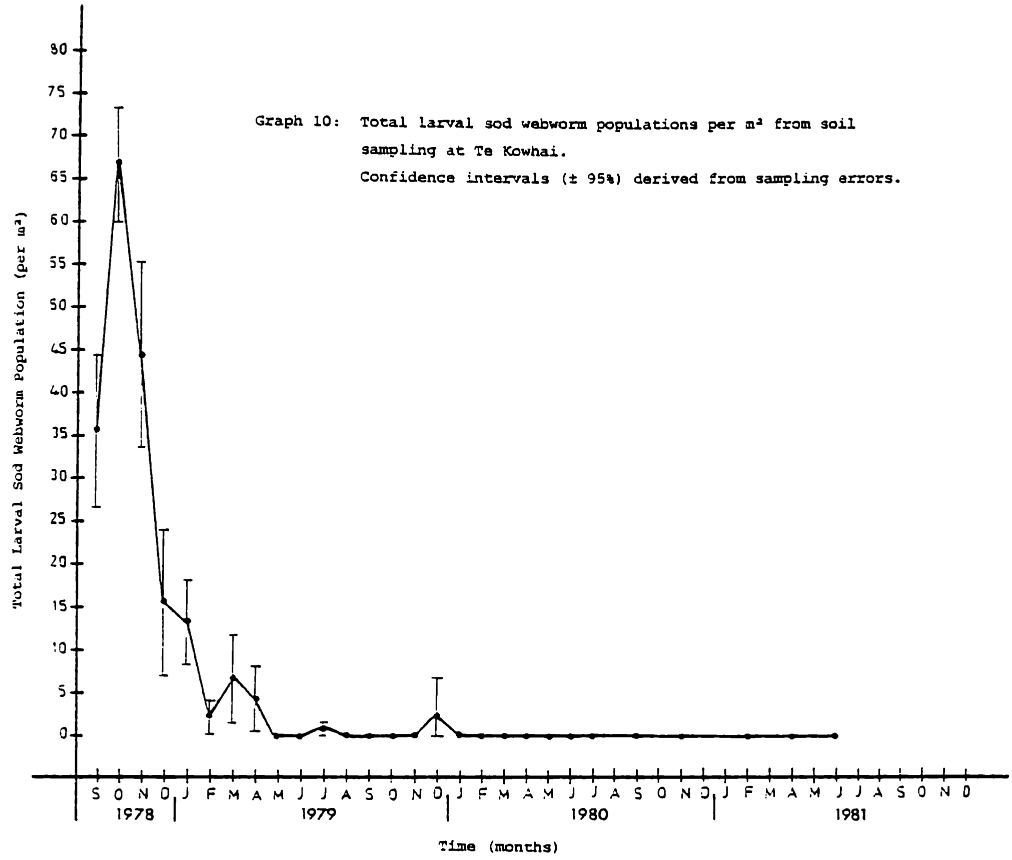
MONTH	NUMBER OF LARVAE	NUMBER OF PUPAE	NUMBER OF PUPAL EXUVIAE	NUMBER DISEASED	NUMBER PARA - SITIZED	NUMBER OF EMPTY CASES	NUMBER OF PRE- DATORS	NUMBER OF PARA- SITOIDS	NUMBER OF PAIRED SAMPLES	% STANDARD ERROR OF THE MEAN	MEAN NUMBER OF SOD WEBWORM (±CL)	RANGE OF SOD WEBWORM m^2 (±CL)
1978												
Sept	48	0	0	0	0	0	2	0	40	30.7	1.2±0.72	26.66±16.04
Oct	24	1	0	1	0	0	7	0	40	19.3	0.6±0.23	13.33±5.11
Nov	9	4	3	2	0	2	15	0	40	23.3	0.4±0.19	8.89±4.22
Dec	6	5	6	1	0	1	8	0	40	26.0	0.4±0.22	8.89±4.89
1979												
Jan	0	0	0	-	-	0	1	1	40	-	0	0
Feb	0	0	0	-	-	0	2	0	40	-	0	0
Mar	4	0	0	1	0	0	2	0	36	66.7	0.1±0.14	2.22±3.11
Apr	1	0	0	0	0	0	7	0	36	87.2	0.1±0.11	2.22±2.44
May	3	0	0	1	0	0	6	0	36	70.7	0.2±0.23	4.44±5.11
June	0	0	0	-	-	0	4	0	18	-	0	0
July	0	0	0	-	-	0	2	0	18	-	0	0
Aug	0	0	0	-	-	0	3	0	36	-	0	0
Sept	0	0	0	-	-	0	3	0	18	-	0	0
Oct	0	0	0	-	-	0	2	0	18	-	0	0
Nov	0	0	0	-	-	0	0	0	18	-	0	0
Dec	0	0	1	-	-	1	7	0	18	87.2	0.05±0.10	1.11±2.22
1980												
Jan	0	0	0	-	-	0	0	0	18	-	0	0
Feb	0	0	0	-	-	0	0	0	18	-	0	0
Mar	0	0	0	-	-	0	2	0	18	-	0	0
Apr	1	0	0	1	0	0	14	0	18	87.2	0.1±0.11	2.22±2.44
May	4	0	0	3	0	0	10	0	36	66.7	0.1±0.14	2.22±3.11
June	1	0	0	1	0	0	3	0	18	87.2	0.1±0.11	2.22±2.44
July	0	0	0	0	0	0	2	0	18	-	0	0
Aug	1	0	0	1	0	0	2	0	18	87.2	0.1±0.11	2.22±2.44
Sept	0	0	0	-	-	0	3	0	18	-	0	0
Oct	0	0	0	-	-	0	3	0	18	-	0	0
Nov	0	0	0	-	-	0	2	0	18	-	0	0
Dec	0	0	0	-	-	0	5	0	18	-	0	0
1981												
Jan	0	0	0	-	-	0	0	0	18	-	0	0
Feb	1	0	0	0	-	0	0	0	18	87.2	0.1±0.11	2.22±2.44
Mar	1	0	0	0	-	0	6	0	18	87.2	0.1±0.11	2.22±2.44
Apr	3	0	0	1	0	0	3	0	18	52.7	0.2±0.17	4.44±3.78
May	10	0	0	3	0	0	9	0	18	32.3	0.6±0.35	13.33±7.78
June	14	0	0	8	0	0	21	0	18	31.6	0.8±0.51	17.78±11.33
July	5	0	0	4	0	0	3	0	18	38.0	0.3±0.20	6.67±4.44
Aug	4	0	0	3	0	0	5	0	18	44.1	0.2±0.19	4.44±4.22
Sept	0	0	0	-	-	0	7	0	18	-	0	0
Oct	0	0	0	-	-	0	3	0	18	-	0	0

TABLE XVII. Life table for *Eudonia sabulosella* at Wilsons 2B.

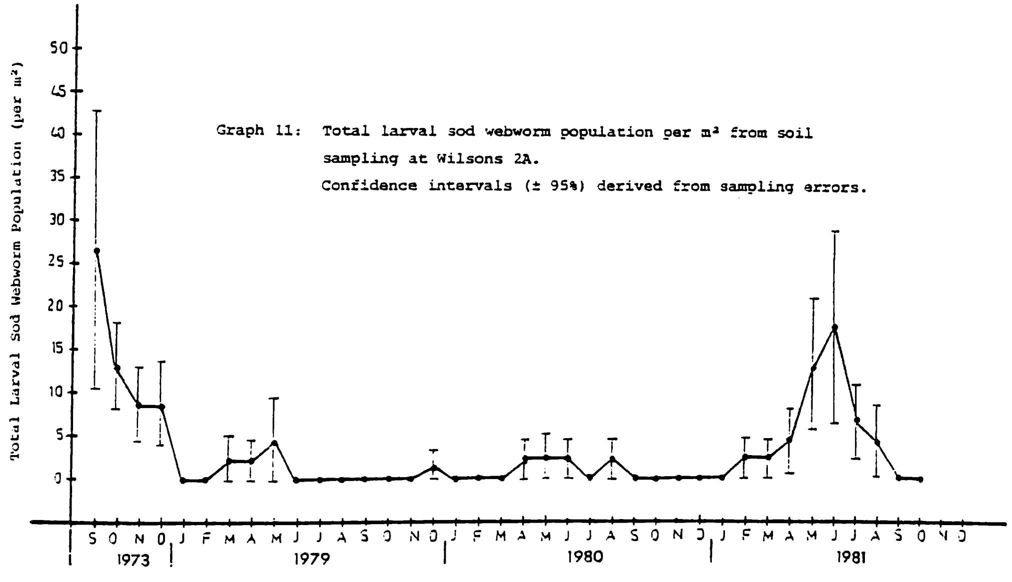
MONTH	TOTAL NUMBER OF LARVAE	TOTAL NUMBER OF PUPAE	TOTAL NUMBER OF PUPAL EXUVIAE	NUMBER DISEASED	NUMBER PARA-SITIZED	NUMER OF EMPTY CASES	NUMBER OF PRE-DATORS	NUMBER OF PARA-SITOIDS	NUMBER OF PAIRED SAMPLES	% STANDARD ERROR OF MEAN	MEAN NUMBER OF SOD WEBWORMS (±CL)	RANGE OF SOD WEBWORM pm^2 (±CL)
1978												
Sept	151	0	0	0	0	0	16	0	80	8.8	1.9±0.32	42.0±7.27
Oct	73	1	0	0	0	2	23	0	40	37.6	1.9±1.36	42.22±30.22
Nov	34	2	0	1	1	4	0	1	40	26.7	0.9±0.44	20.0±9.78
Dec	31	12	9	2	1	11	9	2	40	25.2	1.3±0.61	28.89±13.56
1979												
Jan	1	0	3	0	0	0	0	0	40	47.4	0.1±0.09	2.22±2.00
Feb	18	0	0	1	0	0	2	0	40	32.3	0.5±0.29	11.11±6.44
Mar	2	0	0	1	0	0	5	0	36	68.7	0.1±0.07	2.22±1.56
Apr	4	0	0	2	0	0	12	0	36	58.9	0.1±0.12	2.22±2.67
May	6	0	0	4	0	0	0	0	36	49.9	0.2±0.16	4.44±3.56
June	0	0	0	-	-	0	13	0	18	-	0	0
July	0	0	0	-	-	0	16	0	18	-	0	0
Aug	0	0	0	-	-	0	12	0	18	-	0	0
Sept	0	0	0	-	-	0	13	0	18	-	0	0
Oct	0	0	0	-	-	0	9	0	18	-	0	0
Nov	0	0	0	-	-	0	0	0	18	-	0	0
Dec	0	0	3	0	0	0	8	0	18	70.7	0.2±0.23	4.44±5.11
1980												
Jan	0	0	2	0	0	0	0	0	18	66.7	0.1±0.14	2.22±3.11
Feb	0	0	0	-	-	0	0	0	18	-	0	0
Mar	0	0	0	-	-	0	0	0	18	-	0	0
Apr	2	0	0	0	0	0	21	0	18	66.7	0.1±0.14	2.22±3.11
May	0	0	0	-	-	0	4	0	18	-	0	0
June	1	0	0	0	0	0	2	0	18	87.2	0.1±0.11	2.22±2.44
July	2	0	0	2	0	0	4	0	18	66.7	0.1±0.14	2.22±3.11
Aug	1	0	0	1	0	0	2	0	18	87.2	0.1±0.11	2.22±3.11
Sept	0	0	0	-	-	0	9	0	18	-	0	0
Oct	0	0	0	-	-	0	10	0	18	-	0	0
Nov	0	0	0	-	-	0	5	0	18	-	0	0
Dec	0	0	0	-	-	0	9	0	18	-	0	0
1981												
Jan	0	0	0	-	-	0	2	0	18	-	0	0
Feb	0	0	0	-	0	0	0	0	18	-	0	0
Mar	0	0	0	-	0	0	0	0	18	-	0	0
Apr	4	0	0	1	0	0	2	0	18	56.5	0.2±0.24	4.44±5.33
May	10	0	0	4	0	0	6	0	18	49.4	0.5±0.53	11.11±11.78
June	43	0	0	15	0	0	25	0	18	25.9	2.4±1.21	53.33±26.89
July	18	0	0	10	0	0	16	0	18	38.5	1.0±0.75	22.22±16.67
Aug	15	0	0	72	0	0	4	0	18	31.6	0.8±0.51	17.78±11.33
Sept	1	0	0	1	0	0	4	0	18	87.2	0.1±0.11	2.22±2.44
Oct	0	0	0	-	-	0	1	0	18	-	0	0

TABLE XVIII. Life table for *Eudonia sabulosella* at Long 4A.

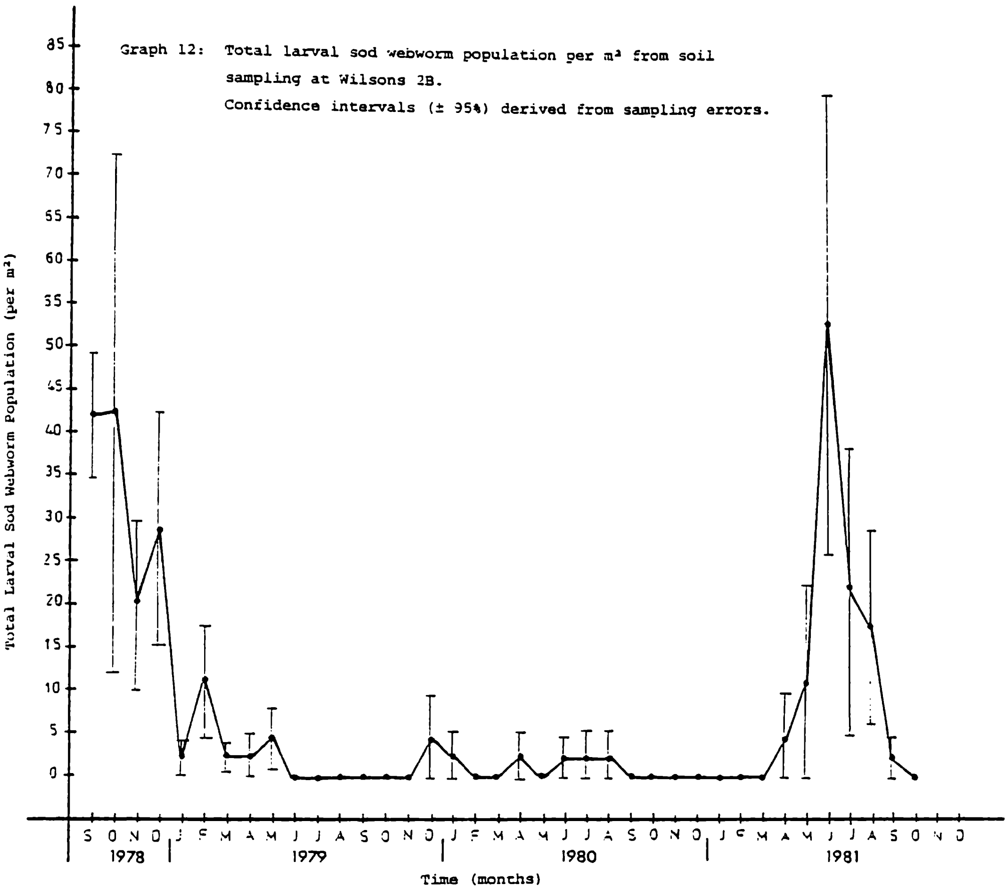
MONTH	NUMBER OF LARVAE	NUMBER OF PUPAE	NUMBER OF PUPAL EXUVIAE	NUMBER DISEASED	NUMBER PARASITIZED	NUMBER OF EMPTY CASES	NUMBER OF PREDATORS	NUMBER OF PARASITOIDS	NUMBER OF PAIRED SAMPLES	% STANDARD ERROR OF MEAN	MEAN NUMBER OF SWW (±CL)	RANGE OF SWW pm^2 (±CL)
1978												
Sept	100	0	0	0	0	0	18	0	80	21.3	1.3±0.50	28.39±11.11
Oct	15	0	0	0	0	1	12	0	40	27.8	0.4±0.20	8.89±4.44
Nov	30	3	0	1	0	15	14	0	40	16.9	0.9±0.28	20.0±6.22
Dec	6	11	14	3	1	18	5	0	40	21.4	0.9±0.38	20.0±8.44
1979												
Jan	0	5	11	0	0	3	8	0	40	31.6	0.4±0.25	8.89±5.56
Feb	4	0	0	0	0	0	2	0	40	68.9	0.1±0.07	2.22±1.56
Mar	0	0	0	-	-	0	4	0	36	-	0	0
Apr	5	0	0	0	0	0	2	0	36	87.2	0.1±0.21	2.22±4.67
May	15	0	0	0	0	0	11	0	36	50.2	0.4±0.41	8.39±9.11
June	2	0	0	2	0	0	0	0	18	66.7	0.1±0.14	2.22±3.11
July	0	0	0	-	-	0	15	0	18	-	0	0
Aug	0	0	0	-	-	0	3	0	18	-	0	0
Sept	0	0	0	-	-	0	3	0	18	-	0	0
Oct	0	0	0	-	-	0	6	0	18	-	0	0
Nov	0	0	0	-	-	0	0	0	18	-	0	0
Dec	0	0	0	-	-	0	4	0	18	-	0	0
1980												
Jan	0	0	0	-	-	0	0	0	18	-	0	0
Feb	0	0	0	-	-	0	6	0	18	-	0	0
Mar	0	0	0	-	-	0	0	0	18	-	0	0
Apr	4	0	0	3	0	0	20	0	36	58.9	0.1±0.12	2.22±2.67
May	10	0	0	8	0	0	6	0	18	32.3	0.5±0.35	12.21±7.78
June	3	0	0	3	0	0	3	0	18	52.7	0.2±0.17	4.44±3.78
July	2	0	0	2	0	0	2	0	18	66.7	0.1±0.14	2.22±3.11
Aug	1	0	0	1	0	0	3	0	18	87.2	0.1±0.10	2.22±2.22
Sept	0	0	0	-	-	0	7	0	18	-	0	0
Oct	0	0	0	-	-	0	8	0	18	-	0	0
Nov	0	0	0	-	-	0	3	0	18	-	0	0
Dec	0	0	0	-	-	0	2	0	18	-	0	0
1981												
Jan	0	0	0	-	-	0	6	0	18	-	0	0
Feb	0	0	0	-	-	0	2	0	18	-	0	0
Mar	3	0	0	1	0	0	5	0	18	52.7	0.2±0.17	4.44±3.78
Apr	10	0	0	1	0	0	3	0	18	87.4	0.6±0.95	13.33±21.11
May	12	0	0	2	0	0	16	0	18	37.3	0.7±0.49	15.56±10.39
June	34	0	0	18	0	0	1	0	18	30.0	1.9±1.10	42.22±24.40
July	19	0	0	14	0	0	3	0	18	27.3	1.1±0.57	24.44±12.67
Aug	1	0	0	1	0	0	13	0	18	84.9	0.1±0.19	2.22±4.22
Sept	0	0	0	-	-	0	3	0	18	-	0	0
Oct	0	0	0	-	-	0	6	0	18	-	0	0



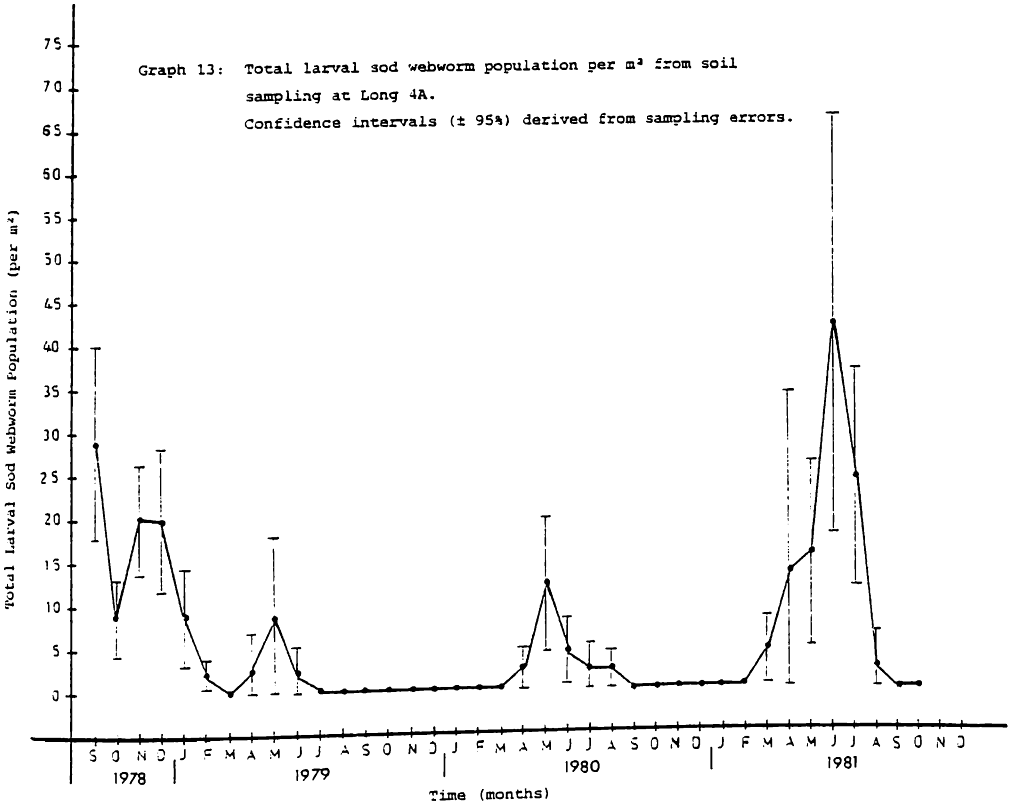
Graph 10: Total larval sod webworm populations per m² from soil sampling at Te Kowhai.
Confidence intervals (± 95%) derived from sampling errors.



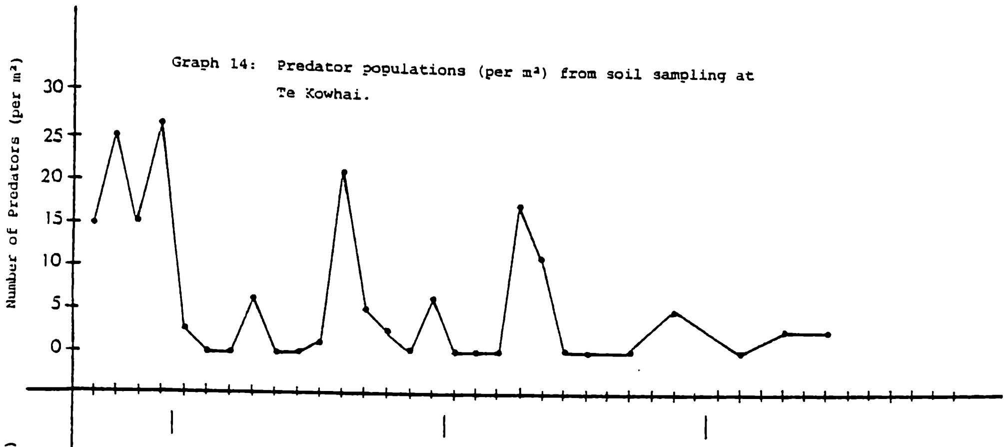
Graph 11: Total larval sod webworm population per m² from soil sampling at Wilsons 2A.
Confidence intervals (± 95%) derived from sampling errors.

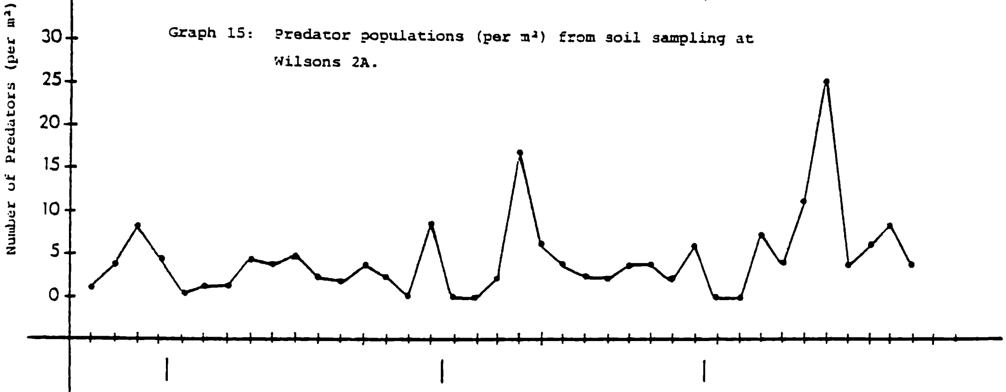


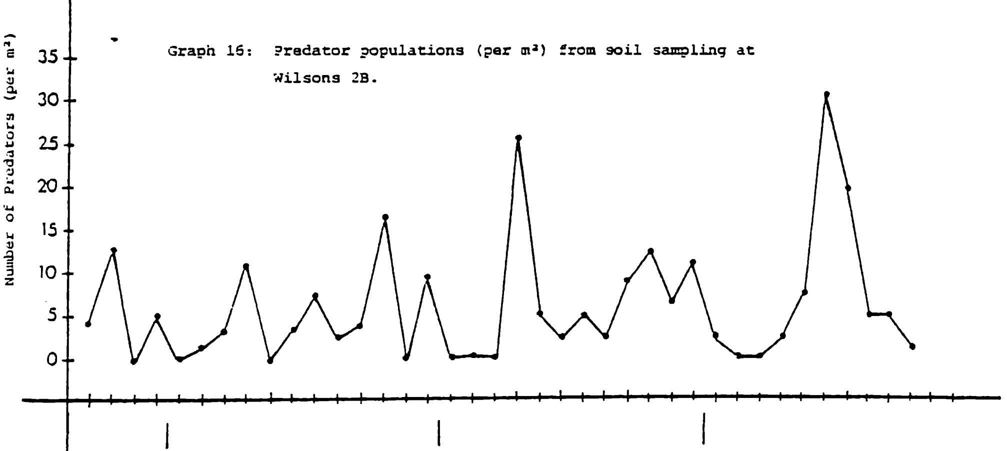
Graph 12: Total larval sod webworm population per m² from soil sampling at Wilsons 2B. Confidence intervals (± 95%) derived from sampling errors.

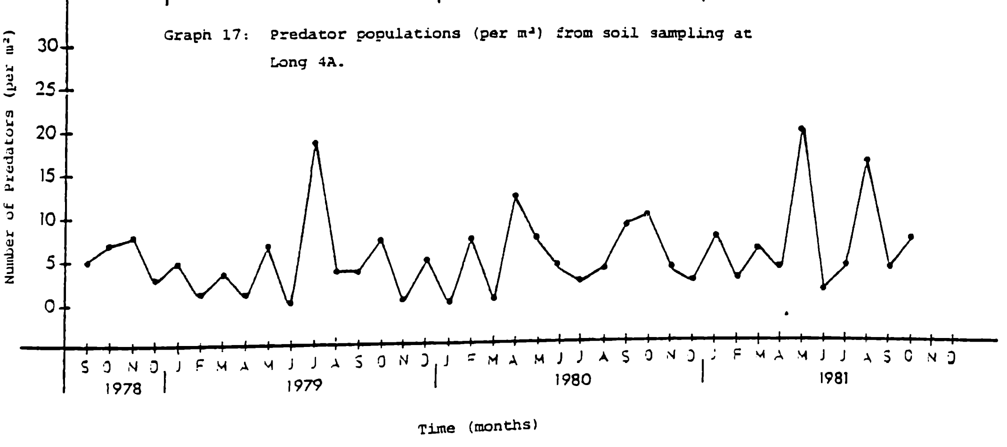


Graph 13: Total larval sod webworm population per m² from soil sampling at Long 4A. Confidence intervals (± 95%) derived from sampling errors.


Graph 14: Predator populations (per m²) from soil sampling at Te Kowhai.


Graph 15: Predator populations (per m²) from soil sampling at Wilsons 2A.


Graph 16: Predator populations (per m²) from soil sampling at Wilsons 2B.


Graph 17: Predator populations (per m²) from soil sampling at Long 4A.

highly mobile and aggregate with prey populations. The higher total predator numbers (per m^2) at certain times thus merely reflected increased chances of food location at those places. The Te Kowhai predator population existed at reasonably high numbers despite the low sod webworm population there. This is because these predators are generalized rather than specialized with respect to prey and are not entirely dependent on only one food source (e.g. sod webworms).

Graph 18 refers to total larval sod webworm numbers per month from soil samples for the Whatawhata and Te Kowhai sites combined. The peak numbers of 1978 were not subsequently attained in 1979, 1980 or 1981. Indeed numbers decreased rapidly from 1978 to 1979, declined a little further in 1979 to 1980, then increased markedly (especially March to August) in 1981. The shaded areas in each histogram (representing diseased larvae) show a marked proportional increase each season or generation in the number of diseased larvae. This is further investigated in Mortality Factors (Ch. 7).

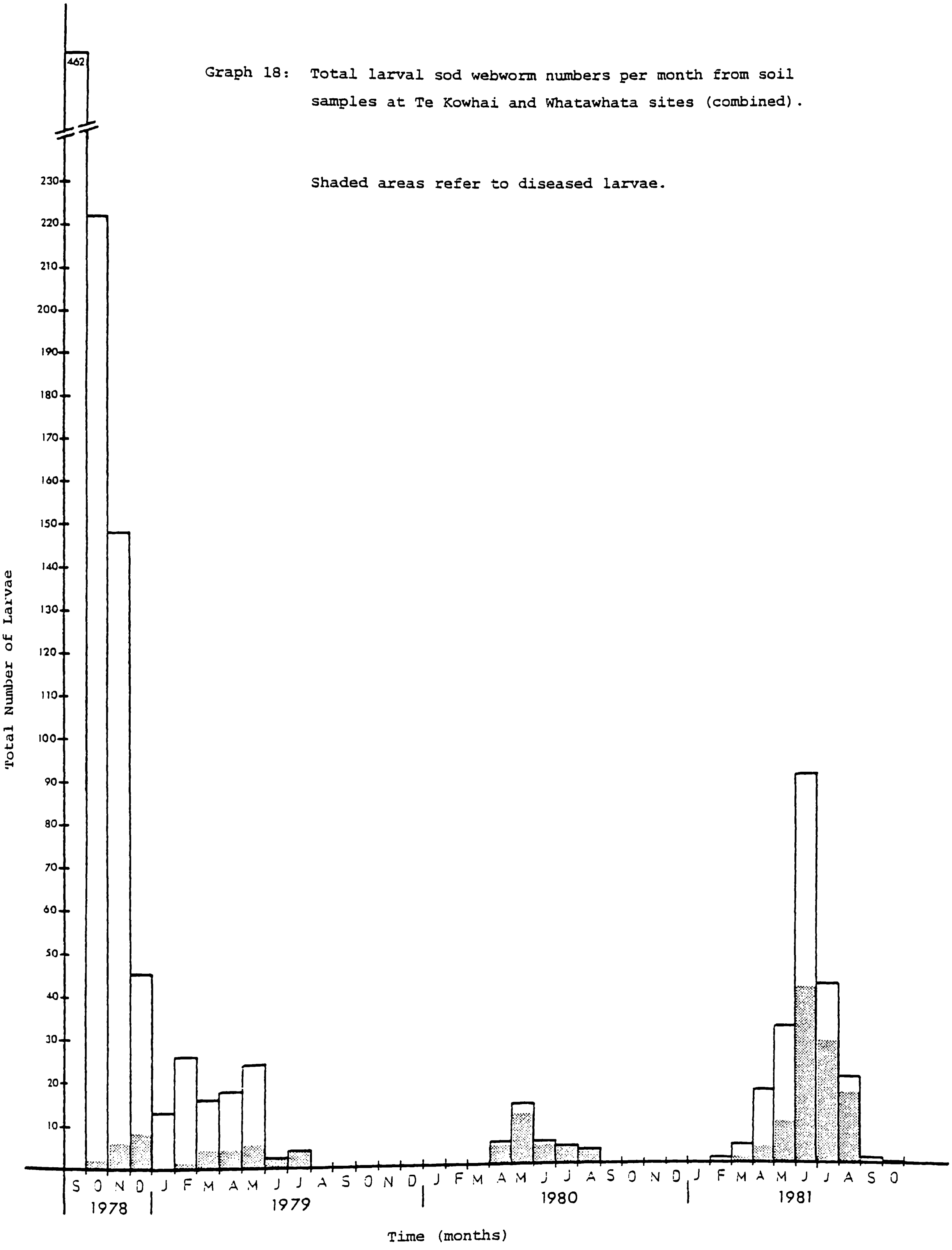
Graphs 19 and 20 refer to total pupal or pupal exuviae populations per m^2 (respectively). The offset peak of Graph 20 (1978-79) relative to the same time in the pupal graph (Graph 19) is a result of progression of the life cycle stages from pupae to adults. Thus maximal exuvial numbers occur after the pupal population peak. No pupae were obtained from soil sampling after 1978 and pupal exuviae were obtained only in the 1979-80 season. Adult numbers used in key factor analysis are thus based on counts from sampling methods other than emergence traps which also yielded no adults after 1978-79.

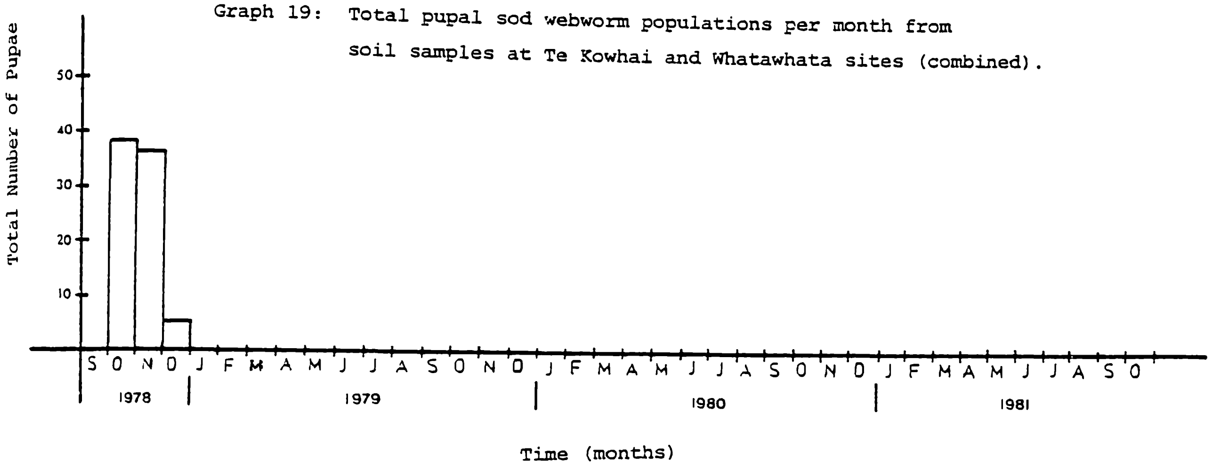
Key Factor Analysis

Key factors (Morris,1959; Varley and Gradwell,1970) refer to those factors which cause a variable mortality and appear to be largely responsible for any observed population changes. Table XIX represents population changes (per m^2) with logarithms enabling mortality factors (k) and total mortality ($K=k_1+k_2+k_3$ etc) to be calculated. Indices of population trend are included.

Graph 18: Total larval sod webworm numbers per month from soil samples at Te Kowhai and Whatawhata sites (combined).

Shaded areas refer to diseased larvae.




Graph 19: Total pupal sod webworm populations per month from soil samples at Te Kowhai and Whatawhata sites (combined).

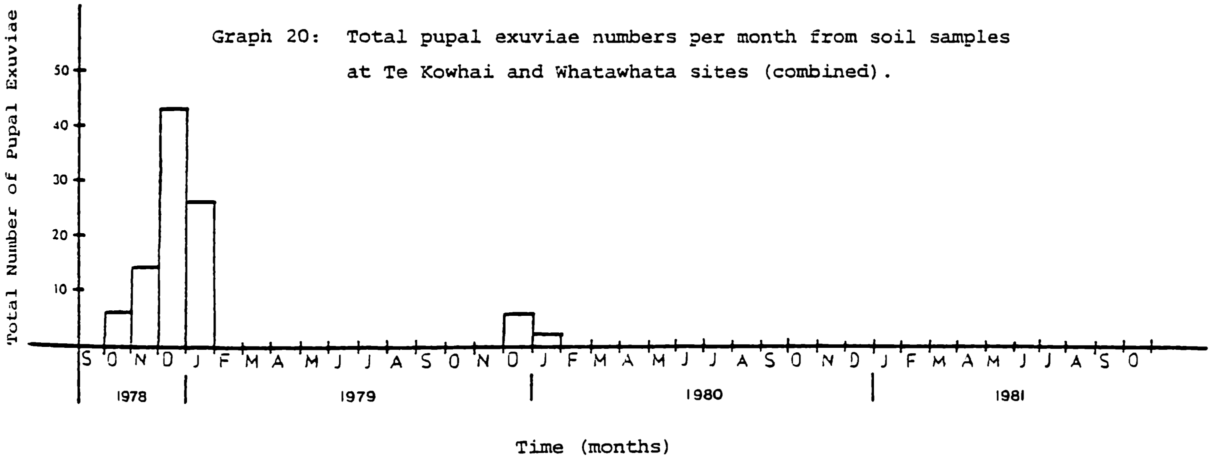

Graph 20: Total pupal exuviae numbers per month from soil samples at Te Kowhai and Whatawhata sites (combined).

TABLE XIX. Calcuation of key factors and indices of population trend for each site and each season/generation.

		TE KOWHAI			WILSONS 2A			WILSONS 2B			LONG 4A		
		$N+1/m^2$	Log(N+1)	k	$N+1/m^2$	Log(N+1)	k	$N+1/m^2$	Log(N+1)	k	$N+1/m^2$	Log(N+1)	k
1978-79	k_1	351.54	2.55	1.97	227.44	2.36	0.86	329.06	2.52	1.23	336.5	2.53	1.47
	k_2	3.82	0.58	-0.09	31.89	1.50	1.29	19.34	1.29	0.75	11.54	1.06	0.35
	k_3	4.70	0.67	0.45	1.61	0.21	0.21	3.47	0.54	0.54	5.11	0.71	0.45
	k_4	1.65	0.22	0.22	1.00	0.00	0.00	1.00	0.00	0.00	1.82	0.26	0.26
	k_5	1.00	0.00	-0.26	1.00	0.00	-0.26	1.00	0.00	-1.37	1.00	0.00	0.00
		1.82	0.26		1.82	0.26		23.22	1.37		1.00	0.00	
		Pop Tr I = 21.01		K = 2.29	Pop Tr I = 98.3		K = 2.10	Pop Tr I = 16.9		K = 1.15	Pop Tr I = 26.5		K = 2.53
1979-80	k_1	74.66	1.87	1.16	223.58	2.35	1.13	56.42	1.75	0.65	89.78	1.95	0.27
	k_2	5.14	0.71	0.71	16.46	1.22	0.82	12.5	1.10	0.84	47.39	1.68	0.95
	k_3	1.00	0.00	0.00	2.54	0.40	0.14	1.82	0.26	-0.16	5.32	0.73	0.19
	k_4	1.00	0.00	0.00	1.82	0.26	0.26	2.64	0.42	0.42	3.47	0.54	0.54
	k_5	1.00	0.00	0.00	1.00	0.00	0.00	1.00	0.00	0.00	1.00	0.00	0.00
		1.00	0.00		1.00	0.00		1.00	0.00		1.00	0.00	
		Pop Tr I = 57.21		K = 1.87	Pop Tr I = 92.0		K = 2.35	Pop Tr I = 182.1		K = 1.75	Pop Tr I = 84.2		K = 1.95
1980-81	k_1	43.14	1.63	1.63	205.75	2.31	0.02	101.92	2.01	0.32	75.78	1.88	0.51
	k_2	1.00	0.00	0.00	193.37	2.29	1.46	48.46	1.69	0.86	23.27	1.37	0.32
	k_3	1.00	0.00	0.00	6.67	0.83	-0.19	6.76	0.83	-0.68	11.29	1.05	-0.32
	k_4	1.00	0.00	0.00	10.46	1.02	1.02	32.27	1.51	1.30	23.22	1.37	1.37
	k_5	1.00	0.00	0.00	1.00	0.00	0.00	1.61	0.21	0.20	1.00	0.00	0.00
		1.00	0.00		1.00	0.00		1.00	0.00		1.00	0.00	
		Pop Tr I = 112.96		K = 1.63	Pop Tr I = 59.8		K = 2.31	Pop Tr I = 107.8		K = 2.01	Pop Tr I = 109.1		K = 1.88
1981-82		47.6			122.4			108.8			81.6		

KEY: N+1 = number per m^2 + 1 ; k = individual mortalities with: k_1 = summer mortality on eggs ; k_2 = late summer mortality on small larvae ; k_3 = autumn mortality on larvae ; k_4 = winter mortality on larvae ; Expected eggs = $\frac{\text{Adults per m}^2}{\text{Ratio for } ♀}$ x av.fec/season ; Pop Tr I = index of population trend. k_5 = late winter-spring mortality on late larvae and pupae ;

It should be noted that populations (per m^2) refer to the total population sampled per time interval to correspond with k values for that period. Even despite such pooling a large number of zero values remained. Such values render key factors analysis futile and were thus adjusted so that logarithms were calculated on N+1 per m^2 rather than N per m^2.

Graphical correlation of the individual mortalities (k) with total mortality (K) (after Varley and Gradwell,1960, 1968, 1970) are presented for each site in Graph 21. The k value which is most closely correlated with K is thus the key factor causing population change. For Te Kowhai it can be seen that k_3 and k_4 correlate most closely with K. At Wilsons 2A there is no clear relationship but k_5 and to a lesser extent k_4 approximate K. For Wilsons 2B, k_4 and k_5 appear similar to K. The Long 4A site shows no clear relationship but k_1 and k_3 are the most similar to K. These visual correlations imply that the key mortality factors (i.e. those accounting for most of the observed population decrease) are those operating in autumn-winter-spring, or late in the life cycle.

The correlation tests of Podoler and Rogers (1975) were employed to check these visual correlations. For these tests individual mortalities are correlated with total mortalities to develop linear regressions such that the key factor is the one with greatest value of b (regression coefficient or slope). These results are presented in Table XX. The primary key factors for the sites are therefore as follows : Te Kowhai k_3; Wilsons 2A k_4; Wilsons 2B k_5; Long 4A k_1. Secondary key factors are : Te Kowhai k_4; Wilsons 2A k_5; Wilsons 2B k_4; Long 4A k_3. These tests support the visual or graphical correlations again indicating it is mortality late in the larval life that is the most important. Only at Long 4A is the egg mortality a key factor, with k_3 (autumn larval mortality) being secondarily implicated. The type of mortalities operating on larvae in particular, will be investigated in Mortality Factors (Ch. 7). It should be noted that Varley and Gradwell (1970) indicated that regression and correlation analyses are valid only when there is no intercorrelation between variables, and if such analyses are undertaken they are largely irrelevant to development of models.

Indices of Population Trend

Table XIX presents indices of population trend or

$$\left\{\frac{\text{Population density of generation } n+1}{\text{Population density of generation } n}\right\} \times 100$$

Graph 21: Graphical correlation of individual mortalities (k) with total mortality (K) for each site.

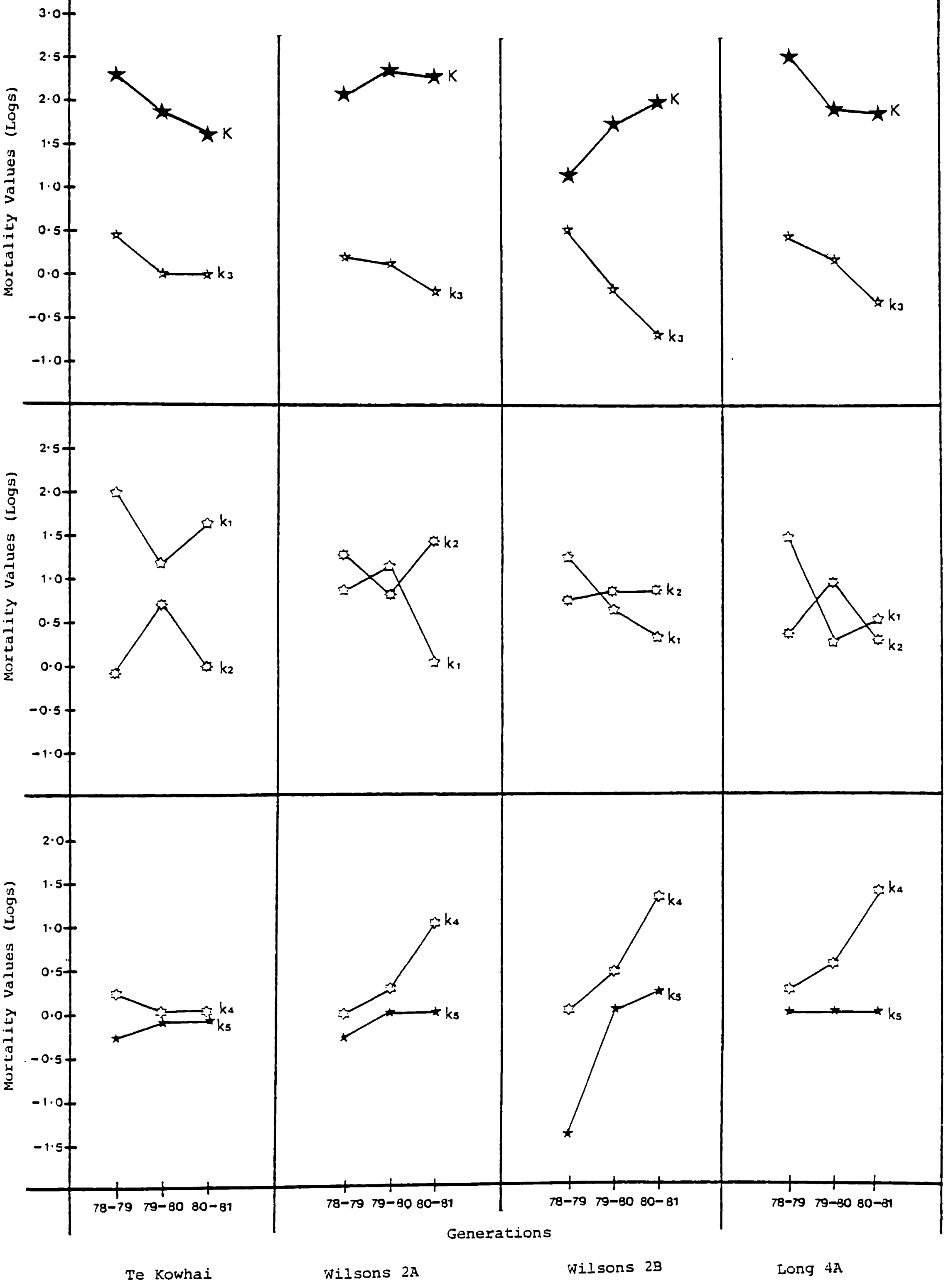


TABLE XX. Correlation tests of individual mortalities (k) with total mortality (K) on linear regression analysis (after Podoler and Rogers, 1975). The key factor is that mortality which produces the greatest value of b (regression coefficient).

SITE	INDIVIDUAL MORTALITY (k)	REGRESSION COEFFICIENT	CORRELATION COEFFICIENT
Te Kowhai		b	r
	k_1	0.45	0.54
	k_2	-0.35	-0.27
	k_3	0.70	0.93 **
	k_4	0.35	0.96 *
	k_5	-0.93	-0.93
Wilsons 2A		b	r
	k_1	-0.50	-0.12
	k_2	-2.00	-0.85
	k_3	-0.75	-0.50
	k_4	2.25	0.60 **
	k_5	1.00	0.89 *
Wilsons 2B		b	r
	k_1	-1.03	-0.98
	k_2	0.13	0.80
	k_3	-1.38	-0.99
	k_4	1.36	0.90 *
	k_5	2.54	0.37 **
Long 4A		b	r
	k_1	1.65	0.94 **
	k_2	-0.35	-0.36
	k_3	0.88	0.81 *
	k_4	-1.19	-0.74
	k_5	0	0

<u>KEY</u>: ** represents most important key mortality

* represents secondary key mortality

k_1 represents summer mortality on eggs

k_2 represents late summer mortality on small larvae

k_3 represents autumn larval mortality

k_4 represents winter larval mortality

k_5 late-winter-spring mortality on late larvae & pupae

These indices were established using mean expected egg populations each generation. A low value indicates a decreasing population; a value around 100 indicates a stable population; and a high value indicates an increasing population. As shown in Table XIX the Te Kowhai site had a rapidly decreasing population from 1978 to 1979; a further decrease from 1979 to 1980; and a more of less stable population from 1980 to 1981. This stable population was thus at a far lower density than the population initially sampled in 1978. Wilsons 2A site had a more or less stable population in 1978, 1979 and 1980 which decreased in 1981. Wilsons 2B site indicates a marked population decrease from 1978 to 1979, a large increase in 1980 and more or less stable state in 1981. The Long 4A site showed a marked decrease in 1979, a further slight decrease in 1980 and approximated stability in 1981.

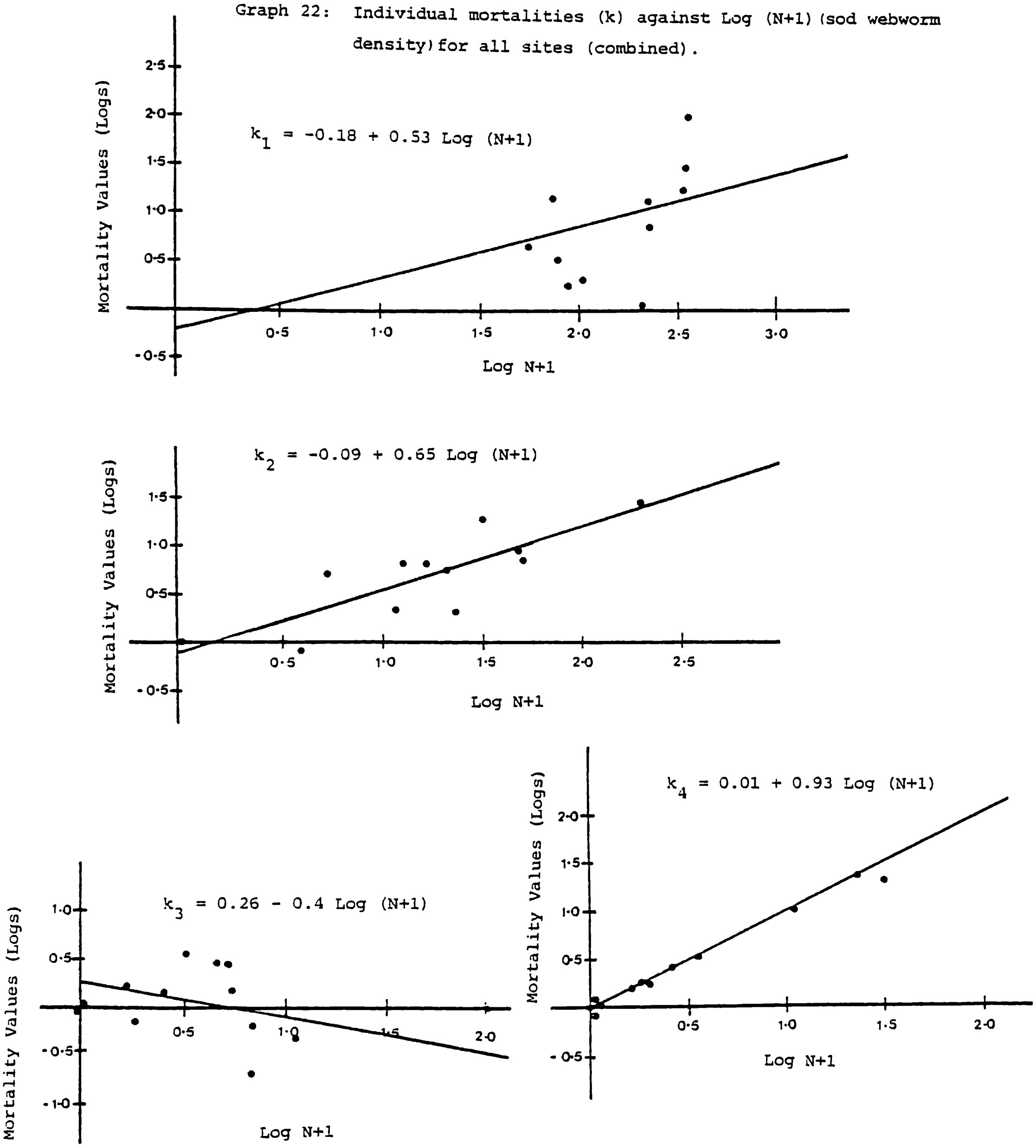
Tests of Density Dependence

Varley and Gradwell (1970) suggested that plotting the individual mortalities against the logarithm of population density and calculating the regression coefficient (b or slope) indicates the type of density dependence of the mortality factors with population numbers. The mortality factors are then represented by the equation $k_i = a + b\ (\log N)$, where k_i = ith individual mortality factor; a = intercept on the y axis; b = slope; logN = logarithm of population size (number per m^2).

If the gradient is positive it suggests density dependence if b is between 0.0 and 1.0 and within this range the greater the slope (closer b approximates 1.0) the more stabilizing the effect of that factor on the population density with all changes in population density being exactly compensated for. A negative slope suggests inverse density-dependence so that the proportion of the population killed decreases with increasing density thus enhancing population instability.

Graph 22 represents the plots of k values with logarithms of population density (adjusted to Log(N+1) to avoid the large numbers of zeros). The data from all sites is pooled. A significant regression relationship (** $p<0.01$) was obtained for k_4 which represents strong density dependence with a marked stabilizing influence on the population. No significant regression relationships ($p>0.05$) were obtained for all other mortalities. The negative slope of k_3 indicates inverse density dependence and may be a result of host population build up exceeding predator or disease population abilities for increase. Alternatively, predator and disease populations remain relatively constant with removal of constant numbers of prey so that as prey numbers in-

Graph 22: Individual mortalities (k) against Log (N+1) (sod webworm density) for all sites (combined).



crease the proportion of the population removed becomes relatively less. Using the suggestion of Varley and Gradwell (1970) the logarithms of predator numbers (per m²) were plotted against individual mortalities (k) in Graph 23. Non-significant regression relationships were obtained in all cases ($p>0.05$). The correlation of k_4 and log predator density was significant ($^{**}p<0.01$) implying that k_4 increases with increased predator density. Correlations of k_2 with log predator density resulted in a significant negative relationship ($^*p<0.05>0.01$) i.e. as log predator density increased, k_2 decreased.

Pitfall Trapping

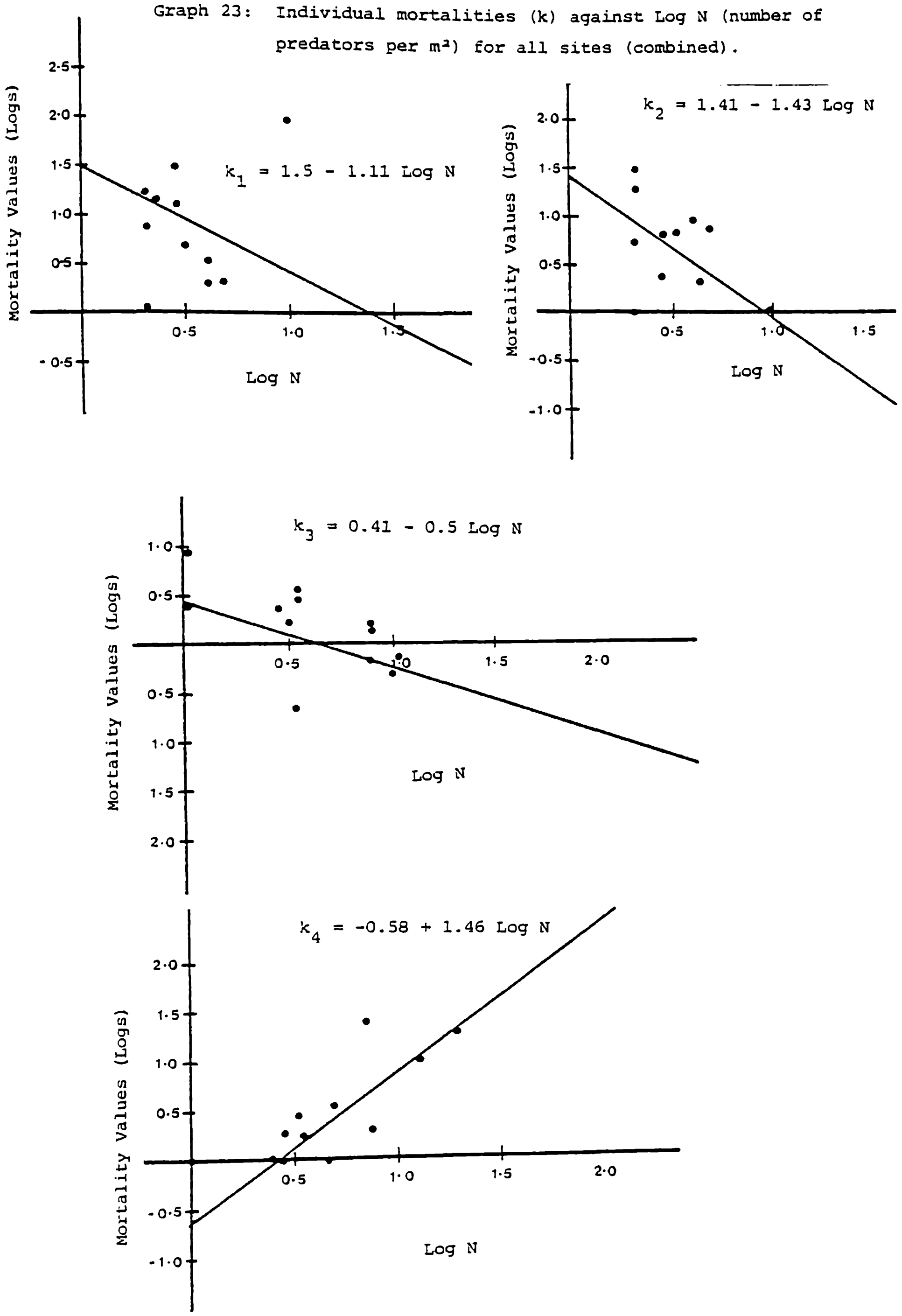
As described in Methods (Ch. 2 p. 23) pitfall trapping was carried out for one year using 20 traps at each of the three Whatawhata sites (i.e. 3120 trap samples). Only two *Eudonia sabulosella* larvae were recovered one at Long 4A in July 1980 and one at Wilsons 2B in August 1980.

Discussion - Larvae and Pupae

The life tables, key factor analysis and indices of population trend for *Eudonia sabulosella* larvae, pupae and pupal exuviae presented in Tables XV-XX reveal a rapidly decreasing population (number per m²) from 1978 to 1979 and 1979 to 1980 but a marked increase in 1981 which attained a maximum in June 1981 and again achieved a very low population density by September 1981. The shaded portions of Graph 18 representing diseased larvae indicate a possible factor implicated in this population decline. This is further discussed in Mortality Factors (Ch. 7). Predator populations at each site (Graphs 14-17) reveal cycles of rise and fall independent of sod webworm population density as well as some coincidence. As indicated previously, predator mobility and generalization of prey food are essentially responsible for these results, i.e. concentration of predator numbers in areas of dense prey populations with searching mobility in less dense prey populations.

Key factor analysis isolated k_4 (winter larval mortality) as a primary mortality at Wilsons 2A, and secondary factors at Te Kowhai and Wilsons 2B. The autumn larval mortality (k_3) was implicated as a primary factor at Te Kowhai and secondary at Long 4A. The mortality on late larvae and pupae in late winter-spring (k_5) was a primary factor at Wilsons 2B and secondary at Wilsons 2A; and summer mortality on eggs (k_1) was considered a primary mortality factor at Long 4A. Density-dependence tests indicated that k_4 was significantly density-dependent and potentially results in stabilizing population size. However, the highly variable individual mortalities are

Graph 23: Individual mortalities (k) against Log N (number of predators per m²) for all sites (combined).



considered important in population change (King, 1979). Reference to Graph 22 would therefore suggest that k_1, k_2 and k_3 are important in population change while k_4 being stable is important in population regulation. It is not possible to measure mortalities accurately due to fundamental errors in sampling for the estimation of population densities on which the mortalities are based. Also potential or expected egg populations on which indices of population trend were based as well as being a basis for key factor analysis are subject to the assumption that females recorded in the study area (i.e. due to immigration) actually laid all their eggs there. The summer egg mortality is calculated on the difference in expected to actual egg populations and as stated previously (this Ch. p.121) these may be gross underestimations of egg density, so that mortality may be less than k_1 values indicate The mortality represented by k_2 which is late summer mortality on larvae may be largely due to sampling errors in collecting small larvae or delayed maturation of the egg in the field because of unfavourable weather conditions, with an apparent small larval population. The mortalities represented by k_3 k_4 and k_5 are most likely due to the effects of parasitism, predation or disease, especially the last (see Mortality Factors Ch. 7) which is shown to be pathogenic and (see Graph 18) particularly important in late stage larvae.

It was hoped that pitfall trapping would provide an understanding of larval sod webworm distributions. *Eudonia sabulosella* populations were observed to be confined to the intertrack regions of hill country despite the fact that numerous eggs were laid in track strata (see Biology Ch. 5). Pitfall traps do not provide accurate estimates of population size (Thomas and Sleeper, 1977; Southwood, 1978) but indicate mobility or dispersal of captured insects. Large pitfall trap catches are characteristic of readily mobile species with migrations from one region to another. The low returns from sampling at Whatawhata mean that either dispersal patterns were obscured because of the very low larval populations (see Tables XVI - XVIII) or larvae were relatively immobile; or larvae in intertrack regions survived better than track inhabiting ones. Due to the extremely low returns from pitfall trapping, conclusive statements cannot be made.

ADULT POPULATIONS

Emergence Traps and Soil Samples for Pupal Exuviae

Emergence traps were established at Te Kowhai and Whatawhata sites (see Methods Ch. 2 p.25) in 1978-79 and 1979-80. The results of this sampling are presented in Table XXI.

TABLE XXI. Emergence trap data (adult *Eudonia sabulosella* only).

SITE	1978-79 SEASON				1979-80 SEASON			
	NUMBER OF MALES	NUMBER OF FEMALES	NUMBER OF TRAPS	ADULTS (per m^2)	NUMBER OF MALES	NUMBER OF FEMALES	NUMBER OF TRAPS	ADULTS (per m^2)
TE KOWHAI	2	6	160	0.24	0	0	400	0
WILSONS 2A	0	14	160	0.42	0	0	400	0
WILSONS 2B	62	42	170	2.93	0	0	400	0
LONG 4A	19	12	160	0.93	0	0	400	0

Although there is some disparity in the sex ratio on a site basis, totals of each sex provide a 1 : 1.12 ratio of males : females. The Te Kowhai site supported the largest larval sod webworm population in 1978 (see Table XV) yet produced the fewest adults in emergence traps. The traps may therefore have sampled too small a unit area with consequent underestimations of adult population densities. In 1979-80 no *Eudonia sabulosella* were trapped, despite sampling over a far larger period than in 1978-79 to ensure early or late emergences were recorded. No other sod webworm species were collected in emergence traps. Due to the low returns from this form of sampling, emergence trapping was not undertaken in 1980-81. The results of Table XXI compare with those presented in Tables XV-XIX where 1979-80 larval and pupal populations were markedly reduced compared with 1978-79. As shown by Graphs 19 and 20 pupal populations were not located subsequent to 1978 and a total of 8 pupal exuviae were recorded after 1978-79. Clearly some larvae survived to emerge as adults but at very low population densities i.e. from pupal exuviae recorded in soil sampling 89/660 or 3.0 per m^2 in 1978-79; 8/144 or 1.23 per m^2 in 1979-80; and 0.00 per m^2 in 1980-81.

Sweep Netting

Sweep netting was used each summer at the main sampling sites (see Methods Ch. 2 p.27). Although subject to numerous errors in standardization of sample sizes (De Long, 1932; Fenton and Howell, 1957; Callahan *et al.*, 1966; Saugstad *et al.*, 1967; Cothran and Summers, 1972) nevertheless it served to elucidate relative differences between sites and seasons. Table XXII refers to monthly totals for each site from sweep netting. Those numbers without letter identifications refer to *Eudonia sabulosella*.

TABLE XXII. Sweep net catches of moths (50 sweeps per week) per month for each site and each season.

	NUMBER OF MOTHS PER MONTH AT TE KOWHAI			NUMBER OF MOTHS PER MONTH AT WILSONS 2A			NUMBER OF MOTHS PER MONTH AT WILSONS 2B			NUMBER OF MOTHS PER MONTH AT LONG 4A		
MONTH	1978-79	1979-80	1980-81	1978-79	1979-80	1980-81	1978-79	1979-80	1980-81	1978-79	1979-80	1980-81
Sept	-	-	0	-	-	0	-	-	0	-	-	0
Oct	0	0	0	0	0	0	0	0	0	0	0	0
Nov	16	2	0	3	0	0	10	0	0	16	3	0
Dec	12	1	0	10	1/+1f	0/+1f	27	0	0	21	0	1/+1f
Jan	3	0	1	5	2/+1v	0	13	2	0	12	0	2
Feb	0	0/+1f	0	8/+3f	1	0	2/+1f	0	0	4/+4f	0	0
Mar	0	0	0	0/+4f	0	0	0/+5f	0	0	0/+2f	0	0

KEY: f=*Orocrambus flexuosellus*; v=*O. vitellus*; all others=*Eudonia sabulosella*

Table XXII presents the same picture as larval and pupal exuvial populations with a marked decrease in numbers in 1979-80 and a further decline in 1980-81. Sweep netting values cannot be converted to numbers per m^2 but relative changes indicate similar patterns for each site. Graph 24 is a histogram for total catch per month pooled for all sites. This pooling was considered necessary because of the high proportion of zero catches in 1980-81 in particular. Peaks in adult numbers occurred in December 1978, November 1979 and January 1981. However subsequent to 1978-79 total adults netted each month declined rapidly rendering interpretation of peak catches, doubtful. (See also Discussion - Adults)

Malaise Traps, Suction Traps, Sticky Plates, Light Traps.

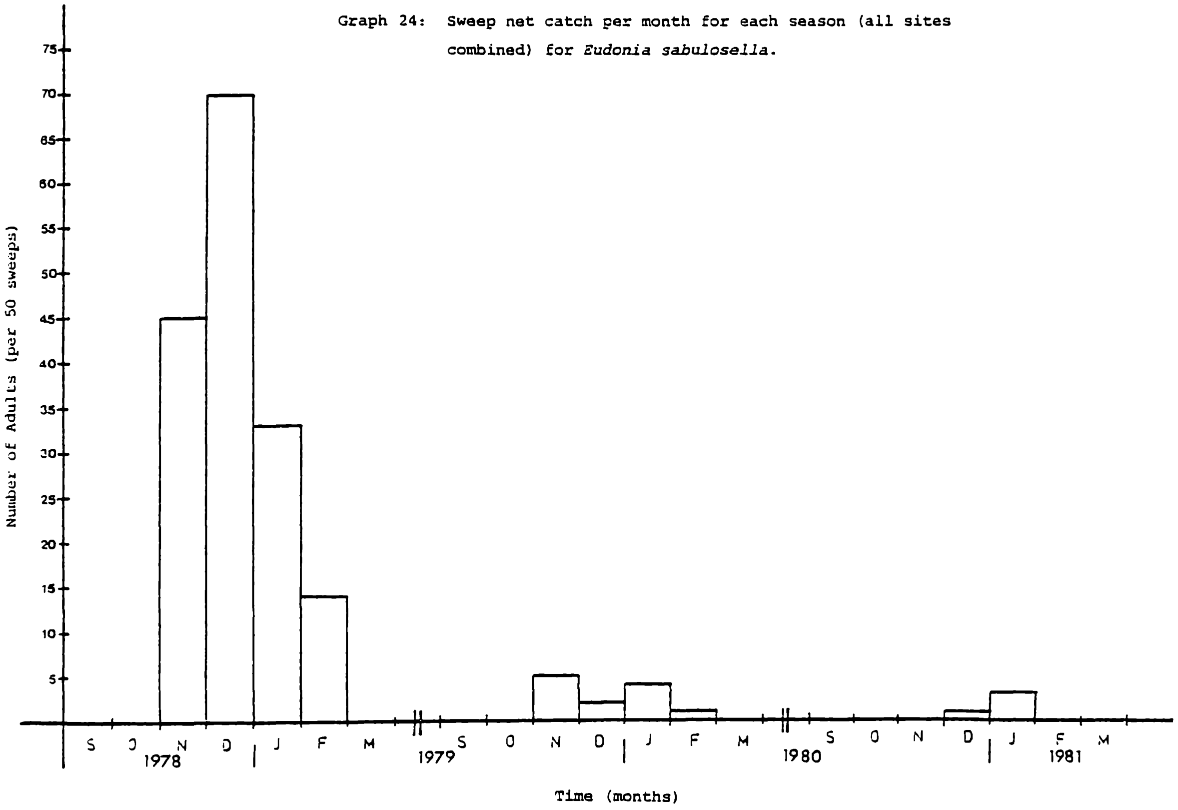
These methods of sampling adult populations do not provide estimates of population size. Rather they indicate flight periodicity which can be related to, for example meteorological events (see Adult Behaviour Ch. 8). The large range of sod webworm species and relatively high numbers of adults collected by these methods suggest substantial migration or movement of adults with aggregations in certain areas. These aspects will be examined in Adult Behaviour (Ch. 8).

Frame Counts

Frame counts (see Methods Ch. 2 p.32) were made to ascertain adult populations per m^2. With the low estimates of adult population sizes gained from pupal exuviae and emergence traps it was clear that adult numbers per m^2 in the field often exceeded these low estimates. Frame counts were therefore made to indicate between site and season differences. These are presented in Table XXIII.

TABLE XXIII. Estimates of adult numbers of *Eudonia sabulosella* (per m^2) for each site and each season based on frame counts.

SITE	RANGE OF ADULT NUMBERS EACH SEASON			
	1978-79	1979-80	1980-81	1981-82
TE KOWHAI	1-7	1-3	0-2	0-3
WILSONS 2A	1-4	0-4	2-8	1-3
WILSONS 2B	2-6	0-3	1-4	1-5
LONG 4A	1-6	0-5	1-3	2-3



Graph 24: Sweep net catch per month for each season (all sites combined) for *Eudonia sabulosella*.

These estimates are higher than emergence traps or pupal exuviae calculations suggest and appear to be the result of adult immigrations. There is not much variation in range between sites or seasons most likely due to the relatively small numbers of adults involved.

Pitfall Trapping

No adults were recovered from pitfall traps.

Discussion - Adults

Even allowing for sampling errors in ascertaining pupal or exuvial numbers there was an overall reduction in adult emergence within the study areas. Relative differences as indicated by sweep netting also confirm the trend of lower adult populations subsequent to 1978-79. Sweep samples were taken each occasion between 0900-1000 hours to permit comparisons between sites and seasons. There are many factors which cause variability in sweep netting to such an extent that it cannot be used to make critical population comparisons (e.g. of peak numbers). It is a suitable method for determining major population trends. Saugstad *et al.* (1967) found that the most important source of variation was between weeks (hence the pooling of data in Graph 24). Cothran and Summer (1972) suggested that the sweep net be replaced or supplemented by other methods when accurate estimates of population levels were required. In the present study frame counts were made to elucidate adult densities. Both Fenton and Howell (1957) and Callahan *et al.* (1965) found the sweep net superior to other methods of population estimation. De Long (1932) listed temperature, wind, sun shadowing the operator, size and condition of the plant, variability of infestation in a field and farm practices as augmenting sweep netting errors. Southwood (1978) listed habitat, insect species being sampled, vertical distribution of the insect on the host plant, weather conditions and daily activity patterns as affecting sweep net catches. Acknowledging these sources of variation it can be seen why sweep netting is unsuitable for the estimation of population size but that qualitative data on population trend can still be gained. As reported previously (Biology Ch. 5) adults were observed to disappear during the day into crevices in the ground and reappear early in the evening. Frame counts made at 0800 hours may thus underestimate adult numbers.

POPULATION DYNAMICS - DISCUSSION

The value of estimating sod webworm populations by more than one method simultaneously, as suggested by Southwood (1978) was realized especially in relation to sweep netting for adults. Habitat differences for the life cycle stages determined the types of collecting methods utilized (see Fenton and

Howell, 1957). Where possible several methods were used concurrently to estimate numbers of particular life stages. For soil sampling, several extraction techniques were used for each set of samples collected at a particular date.

Thompson (1942) studying Crambinae in the United Kingdom and Madge (1956a) studying Hepialidae in South Australia suggested that dense populations may have been the result of build up over one or two seasons. Examination of the trends in sod webworm population build up at the study sites in 1981 (Tables XVI-XVIII, Graphs 11-13 and 18) indicate that sudden sporadic outbreak occurred (cf. Stirrett and Arnott, 1931). What is being defined in this study however, as an "outbreak" (i.e. 10-55 larvae per m^2) is much lower than "dense" populations reported in other studies and converted to numbers per m^2 (for example: Thompson (1942) with 1378 larvae per m^2; Stringfellow (1968) with 136-247 larvae per m^2 which reduced to 2-9 per m^2 after spraying; Quinlan (1972) and Reinert (1976) with rates of 108-215 larvae per m^2 and these increased to 807-1022 per m^2 (Reinert, 1976) after heavy applications of fertilizer to the pasture). The present study had populations similar to Jefferson and Eads (1952) who had 43-75 larvae per m^2 and Pass *et al.* (1965) who had 8-78 larvae per m^2.

In previous publications there has been a suggestion that more than one sod webworm species is implicated in damage (see Pass *et al.* 1965; Banerjee and Decker, 1966a; Heinrichs, 1973) but Thompson (1942) and Kamm (1973) identified one out of a complex of species to be particularly important. Several sod webworm species were sampled as adults at the study sites during the present investigation. Only the one species *Eudonia sabulosella* (Scopariinae) however was implicated in dense populations which were potentially damaging to pasture grasses. This is the first instance of pasture damage by Scopariinae. Quinlan (1972) reported that in Queensland, Australia, one webworm per square foot (i.e. about 11 per m^2) resulted in a reduction of dry pasture production of around 80 pounds/acre or more than 2½ bales of hay, while ten or more webworms per square foot (about 108 per m^2) consumed more than "good" pastures produced in a normal dry season. In the south west of Western Australia, Wallace and Mahon (1952) measured total pasture production losses of around 50% due to dense infestations of sod webworms (Crambinae). These production losses cannot be extrapolated to New Zealand because of differences in insect species, pasture species composition, plant densities and climatic conditions. Unfortunately damage assessment studies (amount of herbage consumed per larva per time) were not possible because of the overriding effect of mortality factors on reared and field populations of larvae.

According to Martyn (1965d) dense populations seemed to correlate with poor survival because the initial number of eggs in a plot significantly affected hepialid survival rates in South West Australia. Greater mortality occurred in denser egg populations and Madge (1956b) found that survival rate was lower when eggs were laid in batches rather than singly. This may explain the lower larval populations in 1981 at Wilsons 2A, relative to the other Whatawhata sites, even though it was the site of maximal egg numbers in 1980-81. There was no significant difference between amount of oviposition in track or intertrack strata for a particular site, though there were significant differences between total amount of oviposition each season. It was hoped that selective oviposition would explain the observed confinement of sod webworm larvae to intertrack strata at the commencement of the study in 1978 and from April-May onwards in later years. Pitfall trapping yielded extremely low returns implying limited larval dispersal. However because of sparse populations, results are not conclusive. If larvae were not very dispersive it appears that those inhabiting intertrack strata had a better chance of survival. The initial egg trap population estimates may be erroneous. In 1981, total egg catch underestimated larval populations obtained in June at Wilsons 2B and in June-July at Long 4A. The total egg catch from Wilsons 2A on the contrary, greatly overestimated larval population size. As indicated previously egg catch estimates may be much lower then actually existed because most oviposition recorded by traps related to older females (i.e. single eggs rather than batches). Perhaps too, such oviposition indicates migration into study sites by dispersive, older females. Steinhaus (1954) reported that insect pathogens produce greater mortality rates in dense populations. According to egg catches, Wilsons 2A certainly supported a dense population in 1981 and was apparently subject to greater mortality, as only relatively few larvae were collected there compared with larval numbers at Wilson 2A and Long 4A (see Tables XVI-XVIII).

As shown by Graph 21 and Table XX mortality operating at k_3 or k_4 was implicated in all sites. These mortalities refer to autumn and winter seasons, and have been identified in Ch. 7 (Mortality Factors) as disease due to the neogregarine protozon *Mattesia* sp. This disease is assessed later (Ch. 7) but shown to be especially important in late stage larvae (see Graph 18). It is also common to k_5. Infected larvae, prepupae, pupae and adults may die, or survive to carry the disease to the next insect life stage. Diseased adults conveyed *Mattesia* to eggs via infected sperm or infected female ovipositor tracts. Eggs from infected females showed high percentages of larval eclosion (cf. Biology Ch. 5 p. 101) but resultant infected larvae developed more slowly than healthy ones and usually died about April-May. Mortality due to *Mattesia* therefore becomes effective from k_3 through to k_5, and as shown previously k_4 is strongly density-dependent (cf. Steinhaus 1954). Predation (arthropod and avian), parasitism and climatic factors also affected *Eudonia sabulosella* populations on hill country. The observed confinement of larvae to intertrack regions in winter-spring months may be due to avoidance of wetter track regions (see Graphs 1, 2, 6 and 7). Scheibner (1968) reported less sod webworm damage during wet seasons and suggested either wetness was not favourable for larval development or grass recovery masked the effects of feeding damage.

Much of the mortality at k_1 and k_2 is probably due to sampling errors but climatic factors (such as summer desiccation of eggs and small larvae) may also be involved. Most oviposition occurred during light rainfall weeks (see Biology Ch. 5 p. 91) which may partially offset desiccation. Also the egg of *Eudonia sabulosella* is laid below the soil surface where temperatures fluctuated less and humidity was higher than at the surface. Stringfellow (1968) reported that heavy rain in May and June (i.e. when eggs and small larvae occurred) enhanced extensive sod webworm infestations in South Florida, United States.

Varley (1972) suggested that adequate population models need to be established to enable understanding of, for example, the effects of insecticide applications or schemes for integrated control. Life tables provide descriptions of events in a population (Holling 1963) and when coupled with an understanding of the effects of, for example, predation, parasitism and competition on the population, fluctuations in numbers can be explained. In the present study life tables were developed for *Eudonia sabulosella* (Scopariinae) on hill country pasture. Although the tables are not of the conventional form and sampling errors are high for most instances, nonetheless trends are indicated for low or endemic levels of a scopariine on hill country. The next section (Mortality Factors) consists of an investigation into the effects of predation, parasitism and disease on *Eudonia sabulosella*.

CHAPTER SEVEN

MORTALITY FACTORS

As indicated previously (Biology Ch. 5 p. 101) the proportion of eclosion from eggs is high. Egg sampling estimates suggested expected field populations far in excess of the actual levels (Population Dynamics Ch. 6 p. 122). Obviously some agent(s) acted on the population to reduce numbers. Predation, parasitism and disease assessment studies were made to ascertain the importance of these three out of a possible continuum of mortality factors.

PREDATION

A species list of coexisting arthropods was established from sweep netting, pitfall, light and suction trapping. Several possible predators emerged - Opiliones, Aranaeida, and certain Coleoptera (Carabidae, Elateridae and Staphylinidae).

Adult sod webworms (*Eudonia sabulosella, "Scoparia" philerga, Orocrambus flexuosellus* and *O. vitellus)* were devoured by Opiliones (harvestmen), Lycosidae (Wolf spiders) and Theridiidae (comb-footed spiders e.g. *Steatoda grossa* (Koch)) in the pasture system. Attempts to escape were futile due to the speed of the arachnids. In the case of *Steatoda grossa,* on one occasion a *"Scoparia" philerga* adult was swathed in ejected silk within five seconds. Adults were also preyed upon by Pholcidae (daddy long legs spiders) and Thomisidae (crab spiders) around buildings. Sod webworm adults escaped from coleopterous predators.

Larval sod webworm were devoured by staphylinid (*Thyreocephalus orthodoxus)* larvae and adults and were attacked (pierced by mandibles so that body fluids oozed through the punctures) by carabid adults (*Rhytisternus miser)* and elaterid larvae *(Conoderus exsul)*. Initially in each case the sod webworm larva escaped by moving backwards (reverse peristalis) from contact by the predator. Capture times ranged from 15-60 minutes (5 trials) for each coleopteran. Mandibles were inserted either behind the head, midway along the body or at the posterior end of the prey (cf. Eyles 1966). Although carabid adults and elaterid larvae did not devour sod webworm larvae within five hours, the latter had become moribund at that stage and would have been more susceptible to diseases especially nematodal (see later).

Chilopoda (centipedes) were recovered from soil sampling. No direct evidence is available for their predation of sod webworm larvae but in three instances chilopods were found inside larval cocoons. It is possible the larvae had been preyed upon. Since the egg is unprotected and laid at the soil-grass interface it would be susceptible to attack by any predators in the epigeal region. Eyles (1966) demonstrated that *Thyreocephalus chloropterus* showed "no interest" in *Wiseana* eggs. By contrast, Martyn (1965c) reported high incidences of predation of *Oncopera intricata* eggs in the field.

During October to December 1978 numerous instances of feeding flocks of birds especially *Sturnus vulgaris* L. (starlings) were observed over pasture at Whatawhata and Te Kowhai. Solitary thrushes were also observed feeding within the study sites. After the flock moved on, examination of ground in the patches of larval sod webworm feeding damage revealed numerous probe holes about 5mm in diameter. It was found from sorting soil samples taken there that the probe holes corresponded with larval cocoons, which were completely empty. The birds were obviously feeding on larvae. According to East and Pottinger (1975) the bill length of starlings is 2.5 to 2.6 cm. As reported under Biology (Ch. 5 p. 93) pupation occurs in a soil-silk cocoon constructed by the larva among grass roots and open to the surface. Such cocoons are always within the top 25mm of soil-ideal for predation by starlings. For October to December 1978 soil sampling results for larvae, pupae and empty cocoons are available. Avian predation was distinguished from arthropod predation by examination of the empty cases and designated as follows:- after avian predation no insect remains were visible and characteristic probe holes seen; in instances of arthropod predation integumental remains were visible. Table XXIV represents the figures for avian and arthropod predation.

TABLE XXIV. Avian and arthropod predation on soil dwelling sod webworms.

	MONTH	TOTAL NUMBER INSECTS & EMPTY COCOONS	EMPTY DUE TO BIRD PREDATION	EMPTY DUE TO ARTHROPOD PREDATION	PROPORTION AVIAN PREDATION	PROPORTION ARTHROPOD PREDATION
TE KOWHAI	October	124	3	1	0.024	0.008
	November	121	6	-	0.050	-
	December	38	12	-	0.316	-
	TOTAL	283	21	1	0.074	0.003
WHATAWHATA	October	116	-	3	-	0.026
	November	91	18	3	0.198	0.032
	December	130	30	-	0.230	-
	TOTAL	337	48	6	0.142	0.018

These results show that the two sites (Te Kowhai and Whatawhata) were subjected to maximal bird predation in December when the larval sod webworm population was at its lowest. By then most larvae had pupated or emerged as adults. Several of the larvae still present were diseased (see Tables XV-XVIII). This is also the time when populations of soil insects (such as grass grub *Costelytra zealandica*) are at low, inaccessible levels. Arthropod predation is slight and drops away because predatory insects (which constitute most of the arthropod predators) were mainly dispersive (aerial) at that time of year. There were higher levels of both types of predation at Whatawhata. Pooling data from Te Kowhai and Whatawhata sites (see Tables XV-XVIII Population Dynamics Ch. 6) shows that avian and arthropod predation was effectively responsible for removal of the following densities of larvae or pupae in 1978: October 1.3 per m^2, November 3.3 pm^2 and December 5.8 per m^2.

Predation as one of a range of mortality factors must be considered to have an important effect on the population dynamics of insects. Potentially arthropod predation operates over the entire generation of a sod webworm with various predators affecting the different life cycle stages. Its effective level is however, very low as indicated above. Avian predation on the other hand, is especially significant as it operates late in the life cycle after the action of mortalities due to a host of other factors (e.g. temperature, humidity, soil moisture, host plant resistance, competition ...). It is also strongly implicated in epizootics* (Entwistle *et al.*, 1977a, 1977b; Wigley, pers. comm.) see "disease" section. Predation by birds on webworms has been recorded by Thompson (1942); Oliver (1964); Pass (1965) Banerjee (1967c); Graham (1967) and Kamm (1973). Litvak (1975) remarked that avian predation has a mainly preventive role, reducing insects enough to maintain a constant equilibrium. East and Pottinger (1975) reported that starling predation gave effective control of grass grub by preventing population density from increasing above a level causing moderate pasture damage. Of particular importance was pasture length as dense rank pasture excluded starlings. In 1978, extreme sod webworm damage to pasture provided ideal conditions for penetration by starlings. It is generally accepted however that bird predation exerts little effect on insect pest outbreaks but may be important at low or endemic levels of an insect population (e.g.

*Epizootics are explosive increases in disease incidence in the insect population at levels much greater than expected in relation to insect density i.e. density independent outbreaks of disease (Cantwell,1974).

Morris *et al.*, 1958; Buckner and Turnock, 1965; Embree, 1965; Graham, 1967; East and Pottinger, 1975). This is because bird numerical increases are limited by comparison with insects. When avian predation was operating on the sod webworm population it was late in the season and most of the adults had emerged. Available numbers of larvae and pupae were low and damage due to feeding had already been done. The effect of predation by birds was thus to deplete the potential adult population and consequently affect the dynamics of the subsequent generation.

PARASITISM

Sod webworms *(Eudonia sabulosella)* were found to be parasitized by *Aucklandella geiri* DallaTorre (Ichneumonidae) identified by Dr. E.W. Valentine, D.S.I.R., Mt. Albert, Auckland. Since the adult is free-living these parasites should be considered as parasitoids (see Vinson, 1976; Vinson and Iwantsch 1980). Four instances of such parasitism were found in 1978; one at Te Kowhai; three at Whatawhata. A total of six adult *A. geiri* were collected from sweep netting (at Wilson 2A, Wilsons 2B, Long 4A and Hart's) at weekly intervals from mid-November 1978 to mid-April 1979. None were collected during 1979-1980 and 1980-1981 sweep nettings. *Aucklandella* is an endemic New Zealand genus of countrywide distribution. The above is the first record of its host. Dugdale (pers. comm.) has found parasitism of sod webworm larvae by Diptera (Tachinidae) e.g. *Herteria* and *Campylia*. Despite rearing or dissecting many larvae no tachinid parasitoids were found at Whatawhata or Te Kowhai. Thompson (1942); Bohart (1947); Banerjee (1967b) and Kamm (1973) reported that sod webworms are parasitized by Ichneumonidae, Braconidae (Hymenoptera) and Tachinidae (Diptera). Thompson (1942) reported that more than a third of *Crambus hortuellus* caterpillars were parasitized. However, Banerjee (1967b) found that the incidence of parasitism in sod webworms is ......"not very significant and that parasites do not constitute an important factor in the natural control of insects"...... In common with Banerjee's study the present one had high incidences of disease (see later) which may have contributed to low rates of parasitism (York, 1961; Clearwater and Wouts 1980; Vinson and Iwantsch, 1980) i.e. the available population for parasitization was low; or parasitized hosts succumbed to disease and died before the parasitoid had developed. The latter is quite possible as *Aucklandella geiri* emerged from late stage larvae and pupae. Whatever the cause, *Aucklandella geiri* was not recorded by any of the sampling methods used, at Whatawhata or Te Kowhai from mid-April to

September 1981. Parasitism thus had little effect on sod webworm population dynamics. No instances of phoresy (see Clausen,1976) were recorded.

DISEASE ASSESSMENT

As described under Population Dynamics (Ch. 6) larval numbers (per m^2) declined dramatically during 1979 onwards. In an effort to locate populations on which damage assessment studies (amount of herbage eaten per time in relation to larval size) could be carried out, other sites were visited for collection of sod webworms. A breakthrough came in June 1980 when large numbers of larvae (25-30 pm^2) were located on Burchett's farm, Kaimai. Many caterpillars were transported to the laboratory for use in pot trials for assessment of damage to various grass species. However, mortality was extreme and within four weeks virtually all the larvae were dead or moribund. Those collected at Whatawhata had reacted similarly. Initially rearing conditions were suspected but the extent of mortality implied some form of disease. Rather than undertaking damage assessment studies, mortality factors were therefore investigated. At that stage regular sampling sites and Kaimai were revisited but few larvae were found in the field and most were moribund i.e. suggestive of an epizootic. Thompson (1942) reported Crambus *hortuellus* larvae were infected with nematodes (*Panagrolaimus rigidus)*; Hall (1952) found the microsporidian *Nosema infesta* in the sod webworm *Crambus bonifatellus*; Jefferson *et al*. (1962) obtained some measure of control of the sod webworms *Crambus sperryellus* and *C. bonifatellus* with the bacterium *Bacillus thuringiensis* var. *thuringiensis*; Banerjee (1968) reported microsporidia (*Nosema* spp and *Thelohania* spp) in sod webworms (*C. trisectus)*; Fowler and Roberts (1972) discovered an iridescent virus infection in *Witlesia* spp (=*Eudonia*) in New Zealand; and Kamm (1973) reported epizootics of *Beauveria bassiana* in *Crambus(=Chrysteuchia) topiaria*. It seemed very probable that the field populations of sod webworms being studied were infected with similar pathogen(s). Dr P.J. Wigley (Virology Section, Entomology Division, D.S.I.R., Mt. Albert) was contacted for advice on assessment techniques and identification of diseases.

Preliminary Investigations

Preliminary tests to establish the presence of pathogens were made from 43 dead or moribund larvae prepared as described in Methods (Ch. 2) except that weights and lengths were not measured hence data from those larvae do not appear on graphs. Sod webworms were found to be infected by a neogregarine protozoan belongong to the genus *Mattesia* (identified by Dr

P.J. Wigley and Professor I.M. Hall, Riverside, California); nematodes (some of which were *Neoaplectana bibionis* = *Steinernema bibionis*, Wouts *et al*. 1982, identified by Dr P.J. Wigley and Dr W. Wouts, D.S.I.R.); and fungi. Table XXV shows the incidence of these and their spore load ranges. Spore load refers to the size of the pathogen population in its host.

TABLE XXV. Pathogen spore load ranges and infective incidence in sod webworm larvae.

PATHOGEN	PROPORTION OF LARVAE INFECTED	SPORE LOAD RANGE
Mattesia sp.	0.419	$2.5\times10^4 - 7.5\times10^7$
Nematodes	0.279	$2.5\times10^4 - 2.8\times10^7$
Fungi	0.233	$4.9\times10^4 - 1.4\times10^7$

It is likely that *Mattesia* sp. caused host death either through septicaemia following multiple perforation of the gut wall, malnutrition, and/or physiological imbalances caused by massive invasions of host tissue (cf. Mercer (1981) with *Nosema* sp. in *Sceliodes cordalis*). Dead sod webworm larvae infected by *Mattesia* were reduced to soupy putrifying cadavers. Live but infected larvae ate little and eventually became inactive or moribund. Transmission occurs by ingestion of spores which are ovoid/lemon-shaped. Larvae have been observed (on slide preparations) with spores in the oral cavity. The pathogen can also be transmitted (see later) transovarially whereby it gains entry into egg or embryo within the host by infection of the parent reproductive organs; or by transovum transmission with the pathogen adsorbed on to or contaminating the exterior of the egg during the birth process and infection resulting when the offspring contacts or eats its own egg case (Anderson and May, 1981).

The nematode *Neoaplectana (=Steinernema)* spp actively invades its host (Welch, 1965) via mouth, anus or spiracles especially moribund or freshly dead specimens (Wigley, pers. comm). It is known (Welch, 1965; Lysenko and Weiser, 1974; Gotz *et al*., 1981) that the nematode injects bacteria into its host. These multiply rapidly in the haemolymph furnishing essential nutrients to the nematode and eventually produce host death through septicaemia (Welch, 1965). Sod webworm hosts containing nematodes were characterized by high bacterial levels (10^8 - 10^9). Axenic nematodes, free of any bacteria, reproduce very poorly in insects (Gotz *et al.*, 1981). *Steinernema bibionis* has a broad host range and widespread distribution within New Zealand (Hoy, 1954; Wouts, pers. comm.).

It is difficult to designate fungal infection as causal of mortality because insects may be secondarily infected, after death (Wigley pers. comm.) and it is a common result of poor rearing techniques. Fungal presence in a sample is therefore not necessarily representative of its incidence in field populations. The high proportion of protozoan infection was unexpected and warranted further investigation in which presence and levels of fungi and nematodes were also noted. A temporal series of specimens was examined in the hope of showing a build-up of pathogens over time from 1978-1981. If this could be demonstrated it would offer some explanation of sod webworm population dynamics.

Build-up of Pathogens over Time

Larvae represented in the 1980 sample were from various species (*Eudonia sabulosella, E. psammitis* and *"Scoparia" submarginalis*). All those in 1978, 1979 and 1981 including all adults were *Eudonia sabulosella.* It was decided to concentrate on this species since all larvae from Te Kowhai, Ngaruawahia and Whatawhata belonged to it and as indicated in Population Dynamics, *E. sabulosella* is the most important sod webworm species economically on hill country pasture (see also Cowley, 1982). Following the convention of Kalmakoff and Crawford (1975), Watanabe (1976) and Mercer (1981) the *Mattesia* sp. as found in *E. sabulosella* and further studied here will be referred to as *Mattesia Eudonia sabulosella* or MES as it is different from the only other *Mattesia* found in New Zealand - in grass grub, *Costelytra zealandica* (Wigley, pers. comm.).

Table XXVI shows the numbers of insects examined and incidences of infection each year for larvae and adults. Those infected by more than one pathogen are recorded only once in the "infected" total although the extreme right column shows the frequency of multiple diseases. Only 20 pupae were examined (see later) as all others were used for taxonomic description or reared to adults. The information presented in Table XXVI refers to combined data for the Te Kowhai and Whatawhata sites.

TABLE XXVI. Number of insects examined and incidences of infection each year in *Eudonia sabulosella* larvae and adults.

	YEAR	NUMBER OF INSECTS EXAMINED	NUMBER INFECTED	PROPORTION INFECTED	PATHOGEN FREQUENCIES
	1978	50	15	0.300	8M 5N 2(M+N)
	1979	22	20	0.909	20M
LARVAE	1980	50	44	0.880	3(M+N) 23M 8N 9F 1(N+F)
	1981	40	39	0.975	19M 17(M+N) 3(M+F)
	TOTAL	162	118	0.728	
	1978	51	22	0.431	19M 3N
	1979	50	26	0.520	24M 2N
ADULTS	1980	81	37	0.457	31M 6(M+N)
	1981	20	9	0.450	9M
	TOTAL	202	94	0.465	

KEY: M=*Mattesia* sp.; N=Nematodes; F= Fungi

The frequencies of nematodal and protozan infections increased from 1978-1981 (except nematodes in larvae in 1979 and in adults in 1979 and 1981). This compares with the results of Beesley (1977) where the proportion of larvae infected increased in each season. Fungal incidence decreases. The 1981 larvae with fungal disease also have MES so it is possible here (as suggested previously) that fungal infection is secondary after death of larvae. However, that does not appear to be the case for 1980 larvae. One of the problems with assessing pathogens by microscopic methods is that it does not allow detection of low spore loads (10^3 - 10^4 or less). Actual pathogen frequencies may thus be higher than indicated i.e. underestimation occurs. Table XXVII shows spore load ranges for MES and nematodes in adults and larvae for 1978-1981.

TABLE XXVII. Spore load ranges of *Mattesia* sp. and nematodes in *Eudonia sabulosella* larvae and adults.

	YEAR	*Mattesia* SPORE LOAD RANGE	NEMATODE RANGE
LARVAE	1978	$2.4 \times 10^4 - 3.5 \times 10^6$	$2.5 \times 10^4 - 2.7 \times 10^5$
	1979	$2.4 \times 10^5 - 7.1 \times 10^6$	-
	1980	$2.5 \times 10^4 - 7.5 \times 10^7$	$2.5 \times 10^3 - 2.8 \times 10^7$
	1981	$4.3 \times 10^5 - 4.0 \times 10^8$	$7.0 \times 10^4 - 8.6 \times 10^6$
ADULTS	1978	$7.2 \times 10^4 - 2.5 \times 10^8$	$2.9 \times 10^4 - 1.2 \times 10^6$
	1979	$1.4 \times 10^5 - 4.2 \times 10^7$	1.5×10^4
	1980	$3.5 \times 10^6 - 6.0 \times 10^7$	$6.5 \times 10^5 - 5.0 \times 10^6$
	1981	$1.9 \times 10^6 - 2.1 \times 10^8$	-

The protozoan *Mattesia* sp. did not appear in the population until 17 October 1978 and then at the low level of 2.4×10^4 in one larva that died during rearing. From mid-October to December 1978 15 of the 50 larvae examined contained pathogens, with higher spore loads of MES towards the end of the larval season (December) i.e. theoretically the pathogen had longer to multiply and thus attain higher population levels within its host. Adult MES spore loadings were maximal in 1978 although the lower limit of the range (as with larvae) increased from year to year, through 1978-1980. MES carries through from larvae to adults so that only those larvae with sublethal spore loadings successfully pupated and emerged as adults. The median lethal dose or LD_{50} was 8.15×10^6 for larvae and 9.05×10^6 for pupae. The actual lethal doses were variable (see Table XXVIII which gives frequencies of larvae dying with each spore load) but $10^6 - 10^7$ appears to be critical as no larvae survived with spore loads equal or greater than these. This is supported from examination of pupae.

TABLE XXVIII. Frequency of larval *Eudonia sabulosella* dying with each spore load of *Mattesia* sp.

MES SPORE LOAD	NUMBER OF LARVAE DYING WITH THAT LOADING
10^4	1
10^5	9
10^6	22
10^7	24
10^8	4

Eight of the 20 assessed had MES (spore load range 7.2×10^6-2.5×10^8) and all had died during rearing. The variability in lethal MES dose is possibly a result of host "condition" e.g. fat body reserves, nutrition, behaviour (Milner, 1973; Mercer, 1981) which is important in determining the effect of a pathogen.

Nematodes (including *Steinernema bibionis*) were first recorded in the population in one larva on 16 November 1978. The frequencies and loadings of nematodes (Tables XXVI and XXVII) increased from 1978-1981 (except loadings from 1981 larvae and 1979 adults). It is interesting to note that nematodes attained higher incidence levels simultaneously with higher levels of MES. In the cases of joint MES-nematode infection in larvae the MES spore loads ranged from 10^6-10^8 i.e. critical-lethal doses. This supports the idea (outlined previously) of secondary nematodal invasion of inactive or moribund larvae. Conversely the higher incidences of MES reflect the probability that there is less chance of locating a host not already infected by MES. As mentioned under "Predation" the immobilization of sod webworm larvae by carabid adults and elaterid larvae would also render the first susceptible to invasion by *Neoaplectana (Steinernema)*.

Further Investigations of the Effects of *Mattesia* sp.

Because of the high incidences of MES and the fact that pathogens are known to affect body weight, body length, head capsule width, longevity, oviposition, fecundity and fertility (Windels *et al.*, 1976; Anderson and May, 1981; Mercer, 1981) it was decided to investigate further the effects of spore load of *Mattesia* sp. on body weight, body length, head capsule width (adults only) and fecundity. Methods have been described previously.

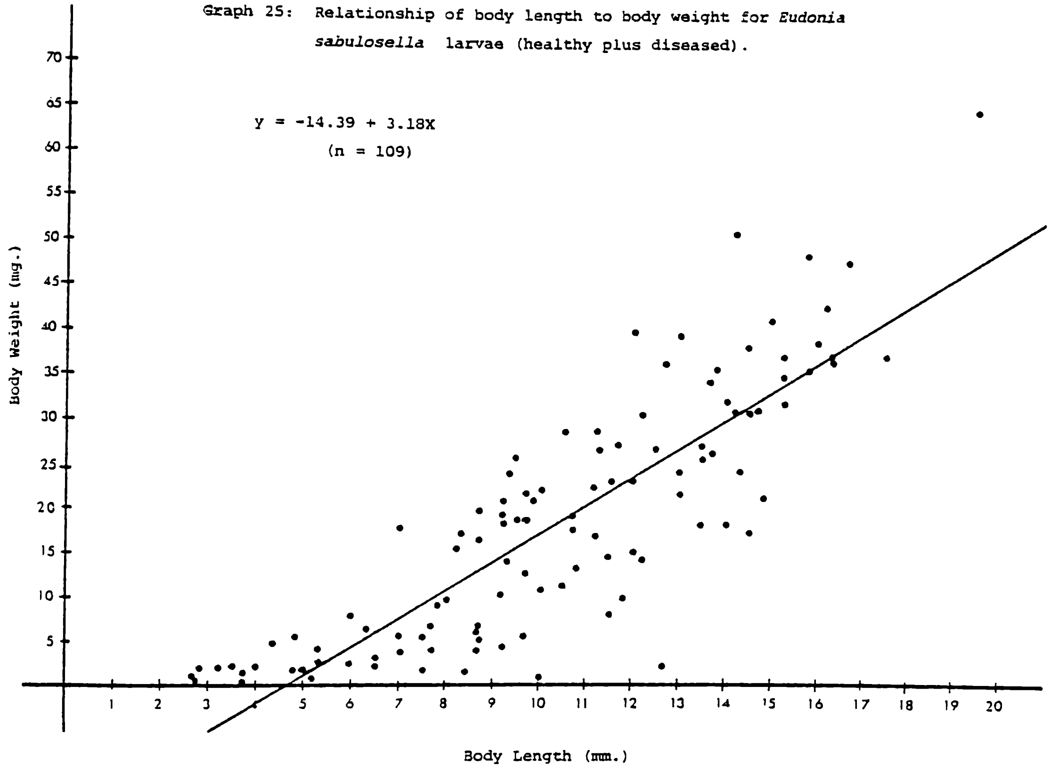
MES in Larvae

There was a significant positive correlation ($r=0.85$ $^{**}p<0.01$ $n=109$) between body weight and body length in larvae i.e. the two variables covary. Graph 25 shows the length-weight relationship for all larvae with appropriate regression line fitted to the points. This can be compared with Graphs 26 and 27 which represent the same data separated into larvae infected by MES or uninfected (healthy) larvae respectively. Significant correlations still hold ($r=0.91$ $^{**}p<0.01$ $n=36$ for healthy and $r=0.82$ $^{**}p<0.01$ $n=73$ for diseased larvae). Mean body length was 11.86mm in healthy and 9.67mm in diseased larvae. Mean body weight was 27.18 mg in uninfected and 14.42mg in infected larvae. 't' tests of the difference between means for body weight or body length yielded significant results ($^{***}p<0.001$) in both cases. This means that infection by MES greatly reduces growth rates and thus has good potential as a biological controlling agent. Since smaller (or indeed any infected) larvae eat less, less damage to pasture would result from similar population densities of infected as compared with healthy larvae.

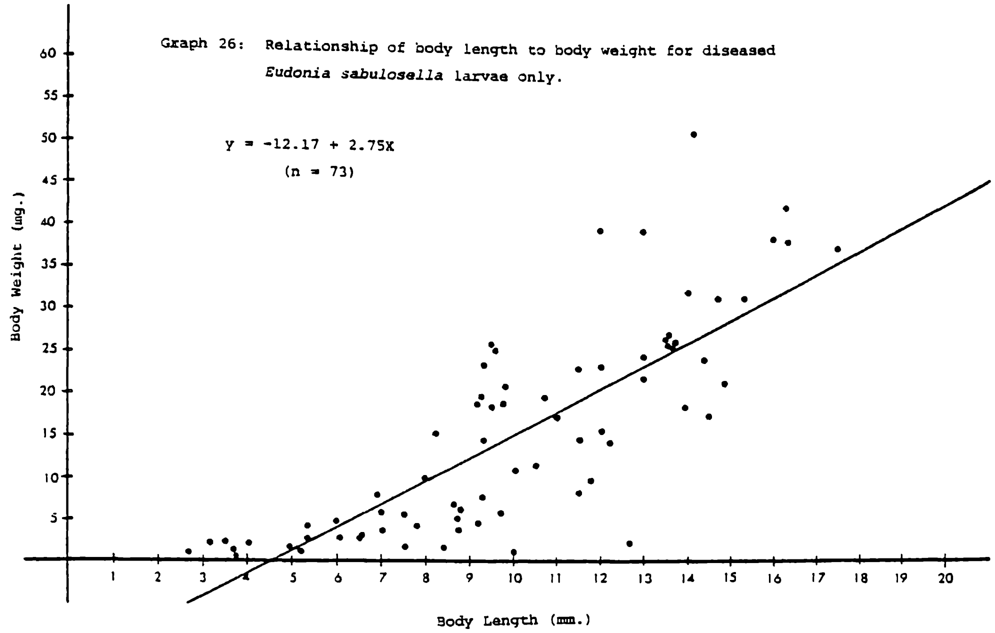
An attempt was made to correlate body weight of diseased larvae with spore load of MES (which has a good relationship for adult females - see later). However a non-significant result ($p\gg0.05$) was obtained. The variability in spore loads with respect to body weight could be due to time of infection. Assuming that higher spore loadings indicate a longer period of pathogen build-up within the host, it is clear that larvae of any size can be infected since large larvae had spore loads ranging from 10^4 to 10^8. If only the higher levels had been found it would have suggested early instar infection with a long pathogen incubation period. It is known that some insect larvae became less susceptible to infection as they age (Ashford, 1970; Milner, 1973; Wilson, 1978; Mercer, 1981). Since the present study was based on field populations i.e. reared larvae were not artifically disease inoculated, the relative susceptibilities of different instars is unknown.

MES in Adults

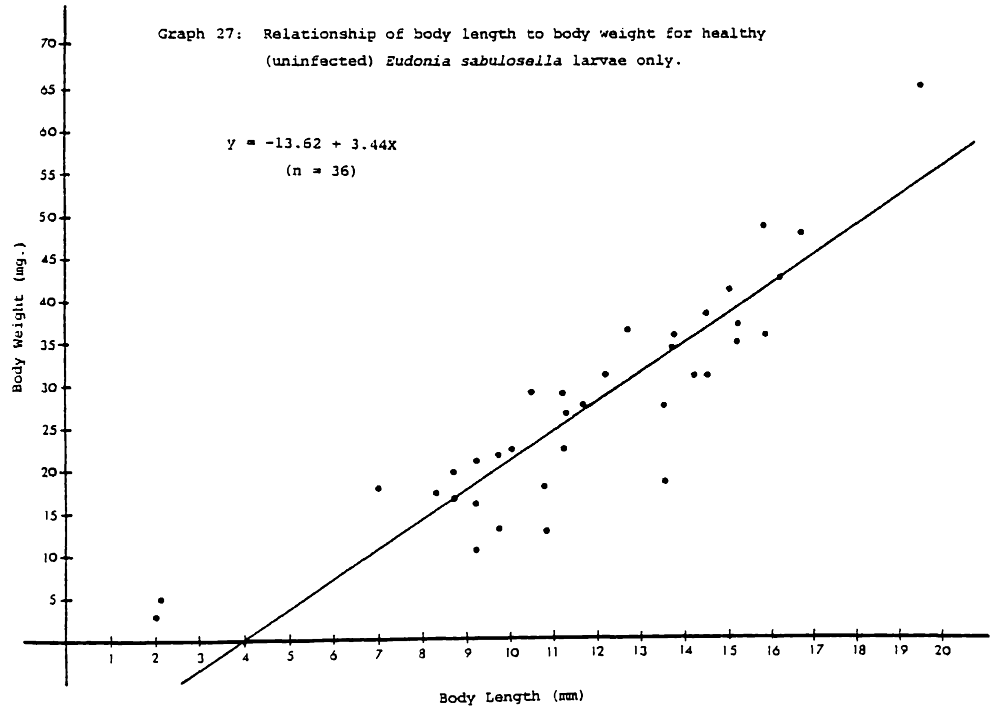
Adult interocular head capsule widths showed little variation and thus were not used in further analysis. As with larvae there was a positive correlation ($r=0.24$ $^{*}p<0.05>0.01$ $n=100$ for males and $r=0.35$ $^{**}p<0.01$ $n=102$ for females) between body weight and body length in adults. Graphs 28 and 29 represent the relationships of body length to weight, with regression lines fitted, for males and females respectively. Both infected and healthy adults are included in each case. The mean body length was 10.43mm in



Graph 25: Relationship of body length to body weight for *Eudonia sabulosella* larvae (healthy plus diseased).

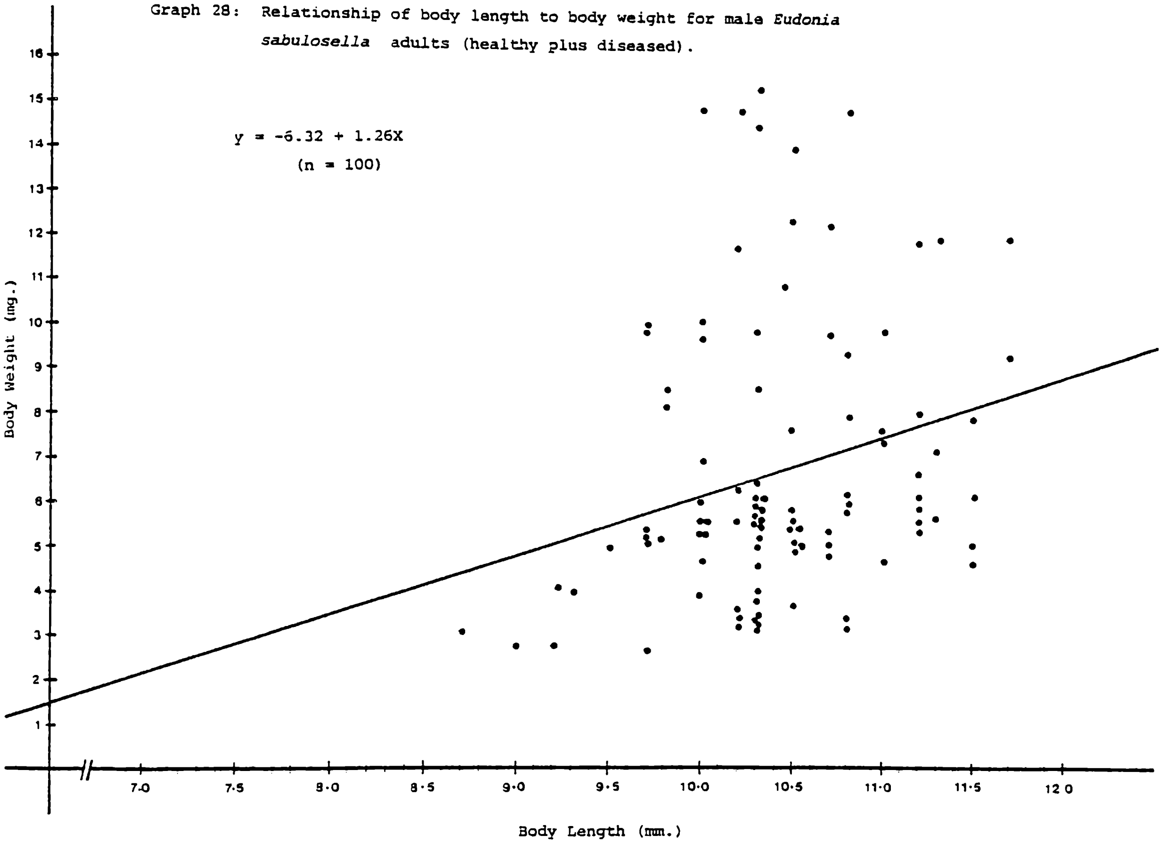


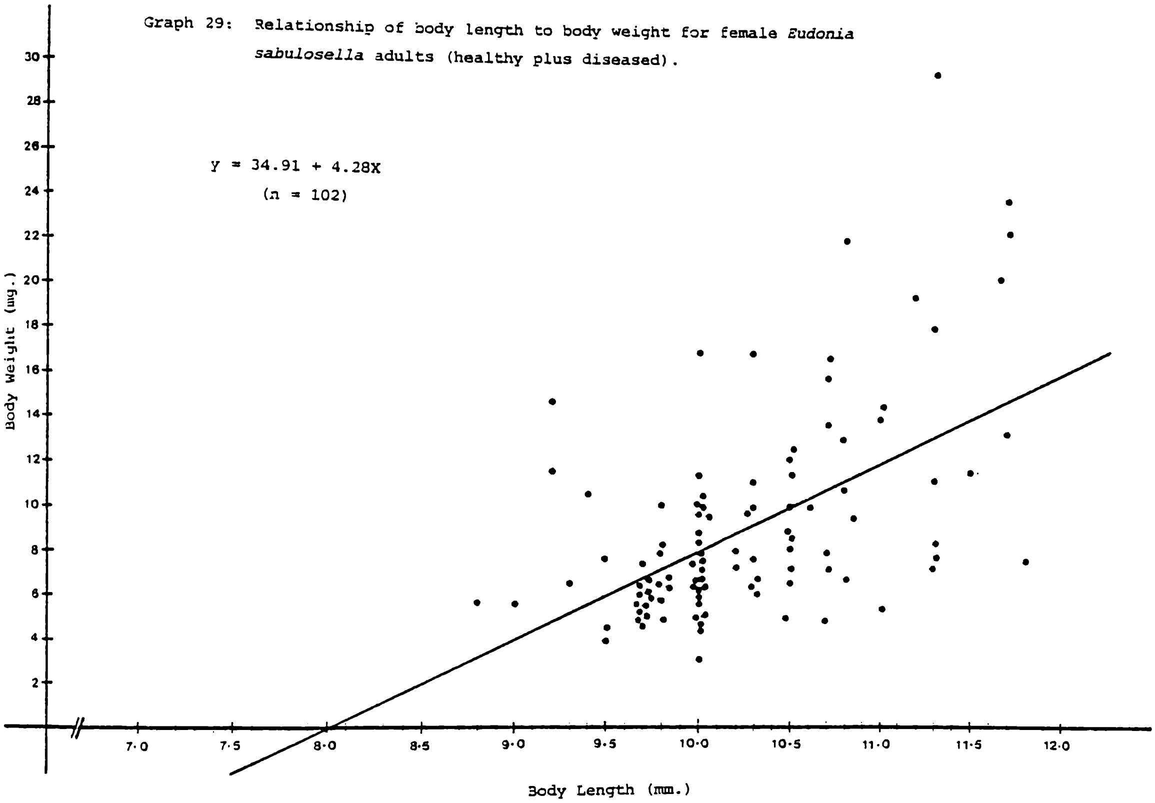
Graph 26: Relationship of body length to body weight for diseased *Eudonia sabulosella* larvae only.



Graph 27: Relationship of body length to body weight for healthy (uninfected) *Eudonia sabulosella* larvae only.

Graph 28: Relationship of body length to body weight for male *Eudonia sabulosella* adults (healthy plus diseased).



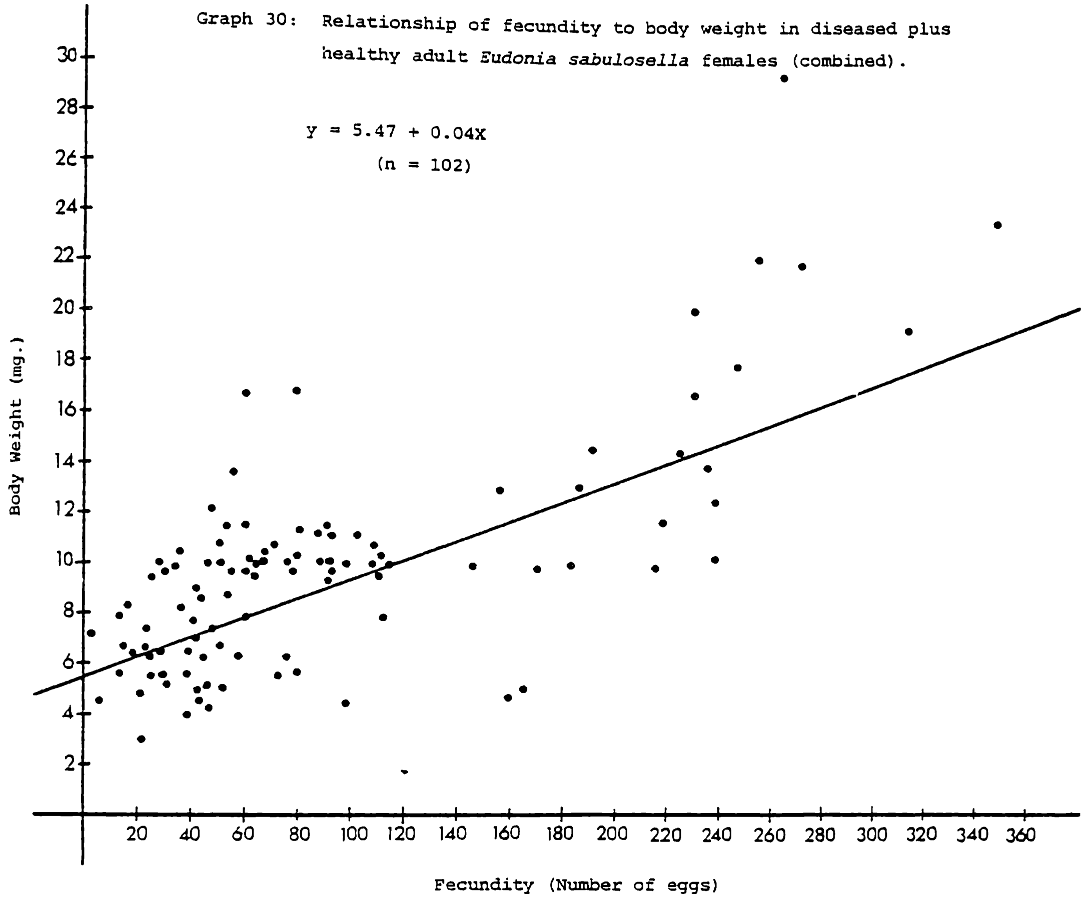


Graph 29: Relationship of body length to body weight for female *Eudonia sabulosella* adults (healthy plus diseased).

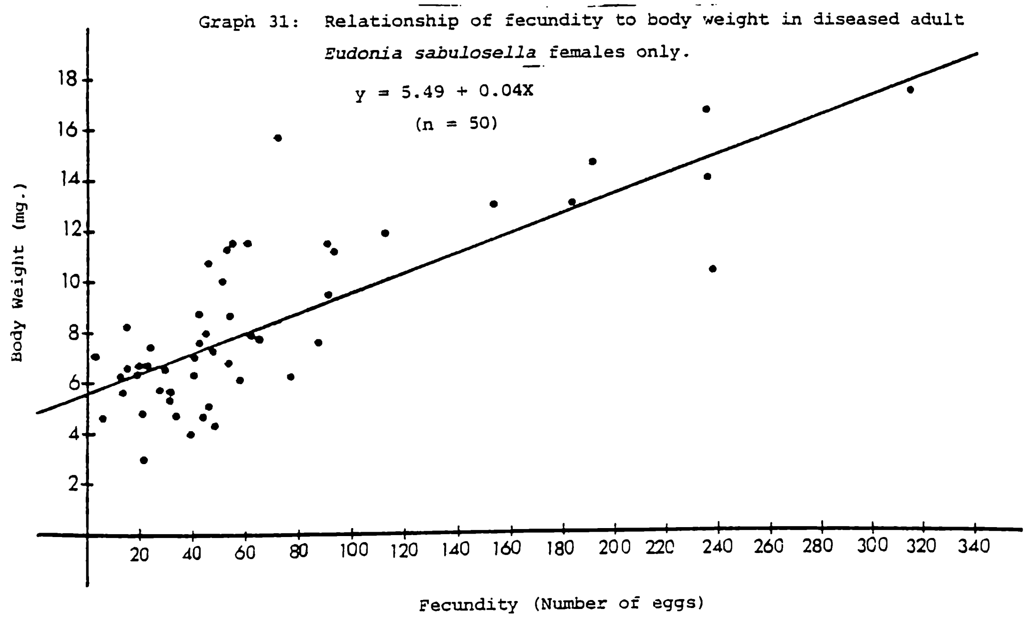
males and 10.28mm in females. The mean body weight was 6.79mg in males and 9.12mg in females. 't' tests of the difference between means produced results that were not signiciant ($p > 0.05$) for body length but significant (***$p<0.001$) for body weight. Thus although females were slightly shorter, they were much heavier. There was no significant difference in the male population between body weight or length for infected or healthy adults. This could be a result of the relatively small number of infected males (n=38) depressing the effect of any variations.

MES in Females

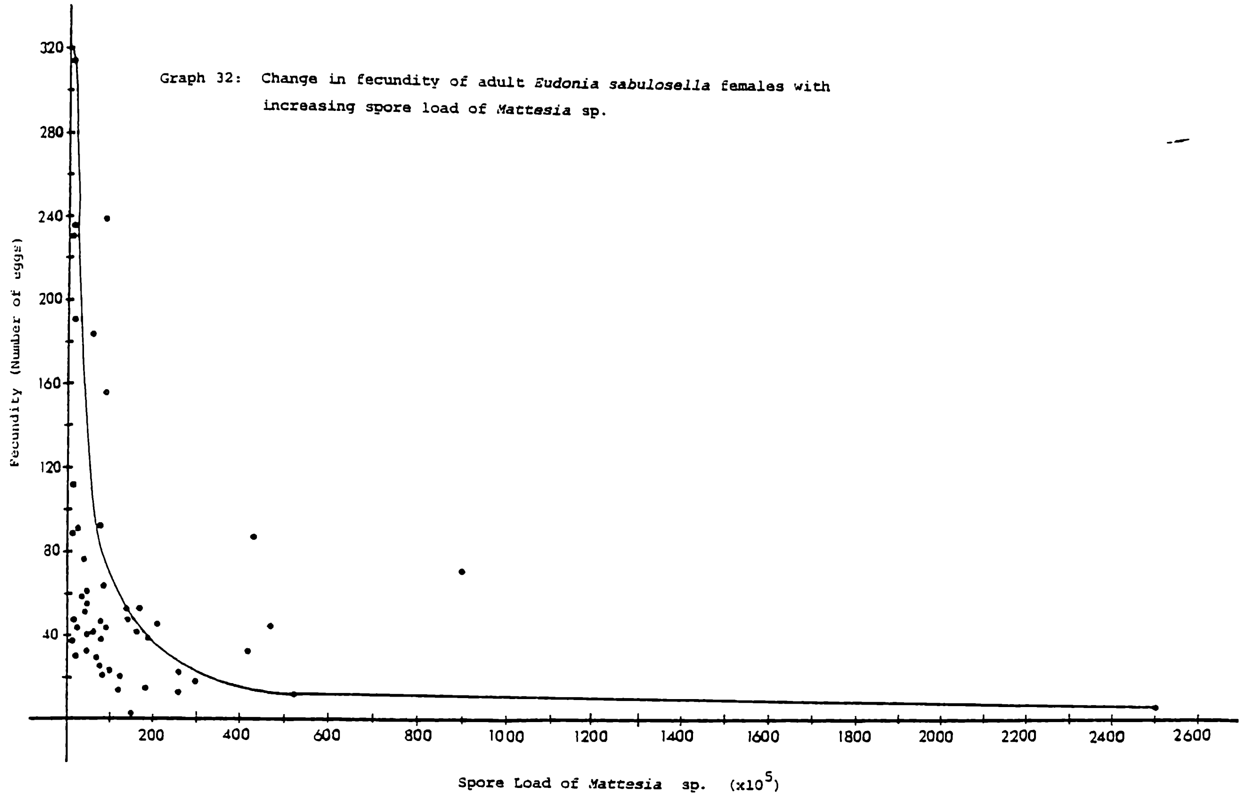
Female body weight is positively correlated with fecundity (r=0.44 ** $p<0.01$ n=102). This is well documented in insects with heavier females producing more eggs e.g. Martyn (1965a). Graph 30 shows this relationship for all females and Graph 31 represents diseased females only. The mean fecundity for all females was 91 (±13) eggs; for infected females 69 (±15) eggs; and for healthy females 113 (±26) eggs. The mean body weight of all females was 9.12mg; for diseased females 8.38mg; and for uninfected females 9.83mg. 't' tests of the difference between means for fecundity or body weight in infected vs healthy females yielded significant results (***$p<0.001$) in each case. Both body weight and fecundity were severely reduced in diseased females. Infection by *Mattesia* sp. thus significantly affects the population dynamics of *Eudonia sabulosella* with infected females producing fewer eggs and hence a lower population in the new generation. The magnitude of this depressive effect on fecundity can be seen by examining seasonal fecundities of *E. sabulosella* (see Biology Ch. 2) where the 1978-79 average fecundity was 146 (±33) eggs but only 62 (±25) in 1979-80 and 63 (±11) in 1980-81. Combining adult and pre-adult disease incidences (Table XXVI) it can be seen that in 1978, 0.37 of the population was infected; 0.64 in 1979; 0.62 in 1980 and 0.80 in 1981. Thus as disease incidence increased, fecundity has been more than halved. Graphs 32 and 33 show the relationship between spore load and fecundity or weight respectively. There is a rapid decrease in fecundity/weight with increasing spore load producing a characteristic 'L' shaped curve. The fall-off in the "weight" graph is not as dramatic as that of the "fecundity" graph. This is because, as is generally accepted there is a minimum weight threshold below which moths are unable to survive pupation. Conversion of values for spore load to logarithms results in straight lined graphs (Graphs 34, fecundity and 35, weight). Thus in diseased females fecundity and weight are positively

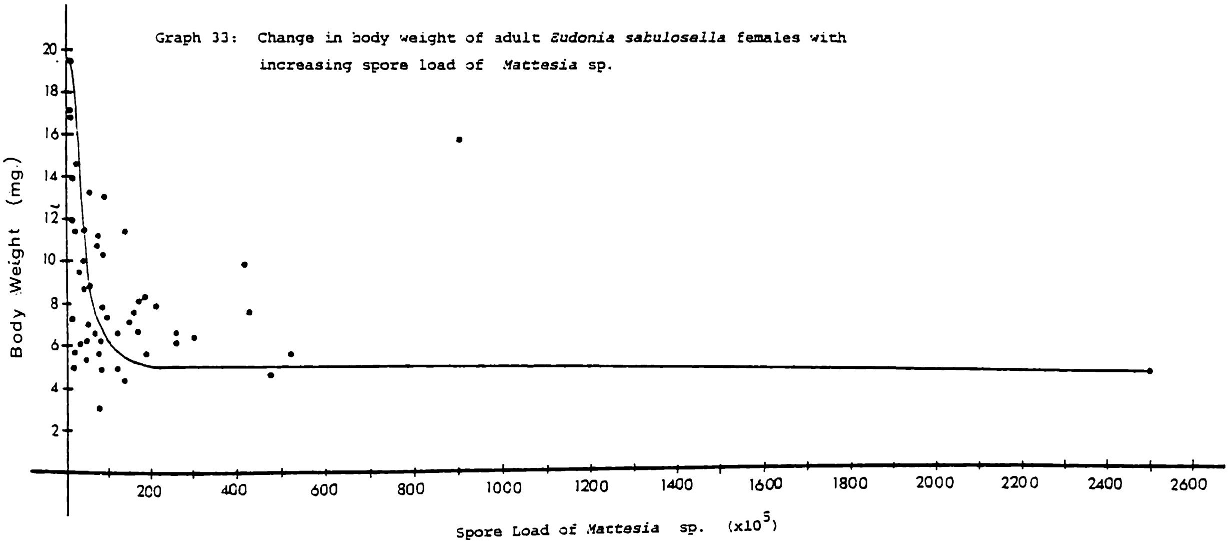


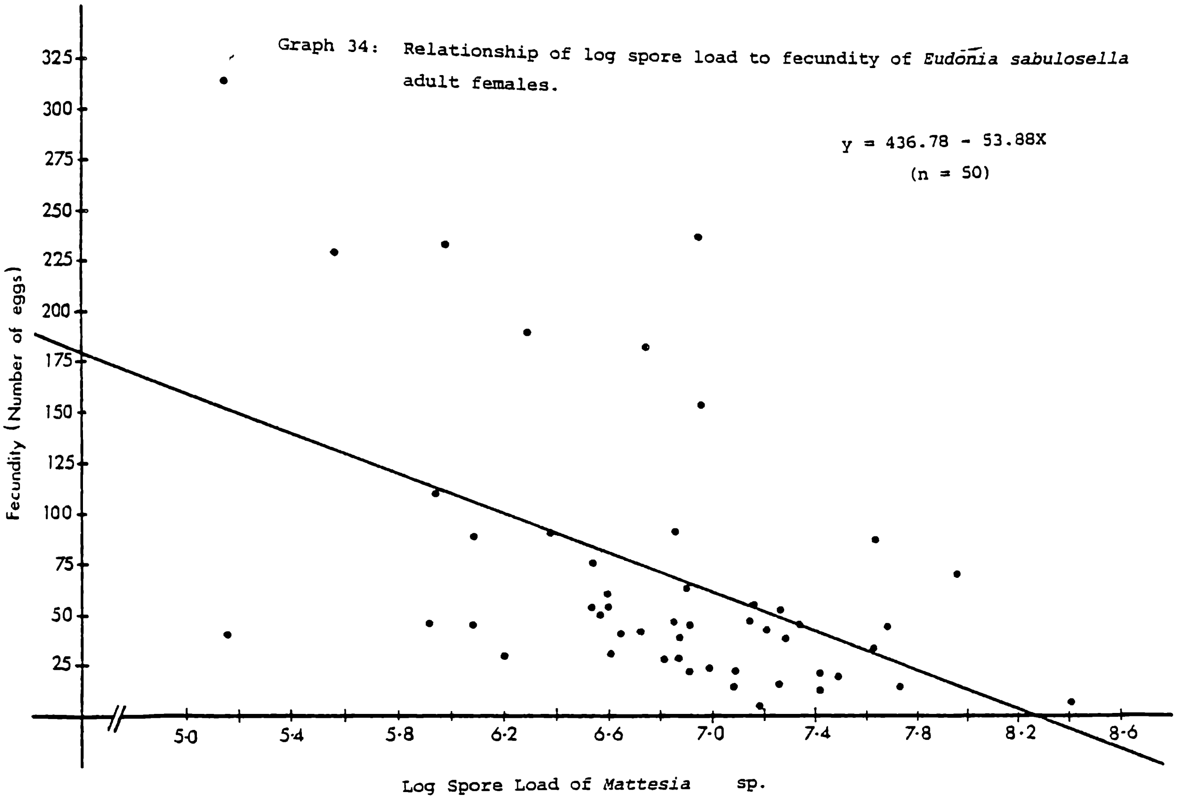
Graph 30: Relationship of fecundity to body weight in diseased plus healthy adult *Eudonia sabulosella* females (combined).



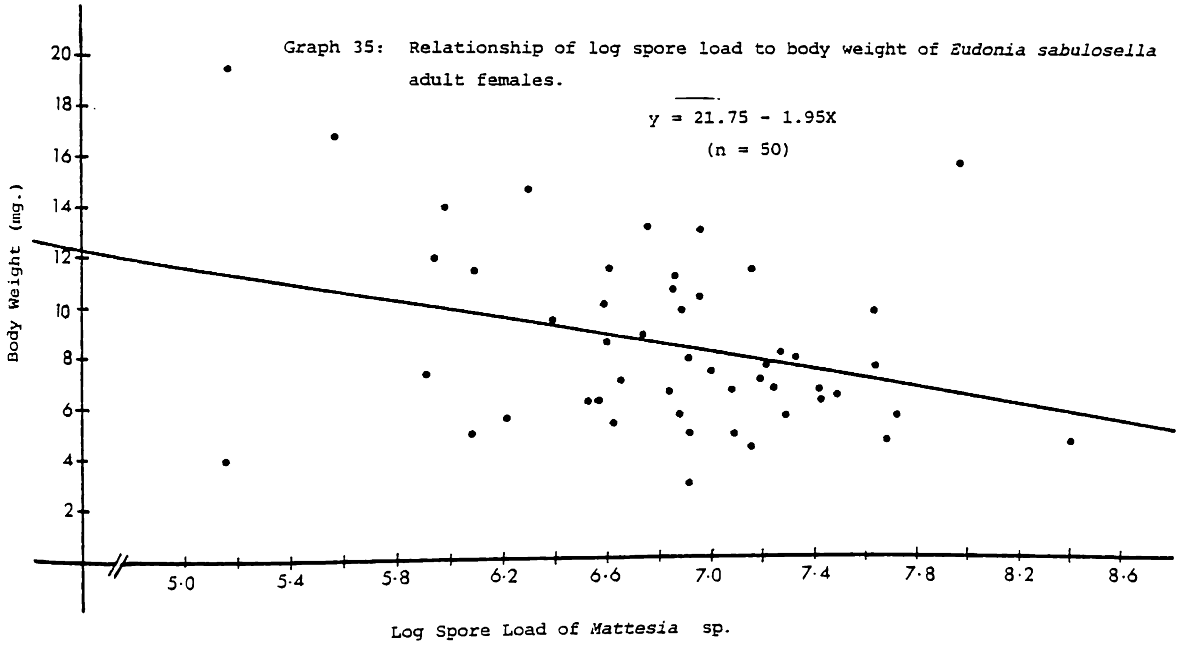
Graph 31: Relationship of fecundity to body weight in diseased adult *Eudonia sabulosella* females only.


Graph 32: Change in fecundity of adult *Eudonia sabulosella* females with increasing spore load of *Mattesia* sp.


Graph 33: Change in body weight of adult *Eudonia sabulosella* females with increasing spore load of *Mattesia* sp.



Graph 34: Relationship of log spore load to fecundity of *Eudonia sabulosella* adult females.



Graph 35: Relationship of log spore load to body weight of *Eudonia sabulosella* adult females.

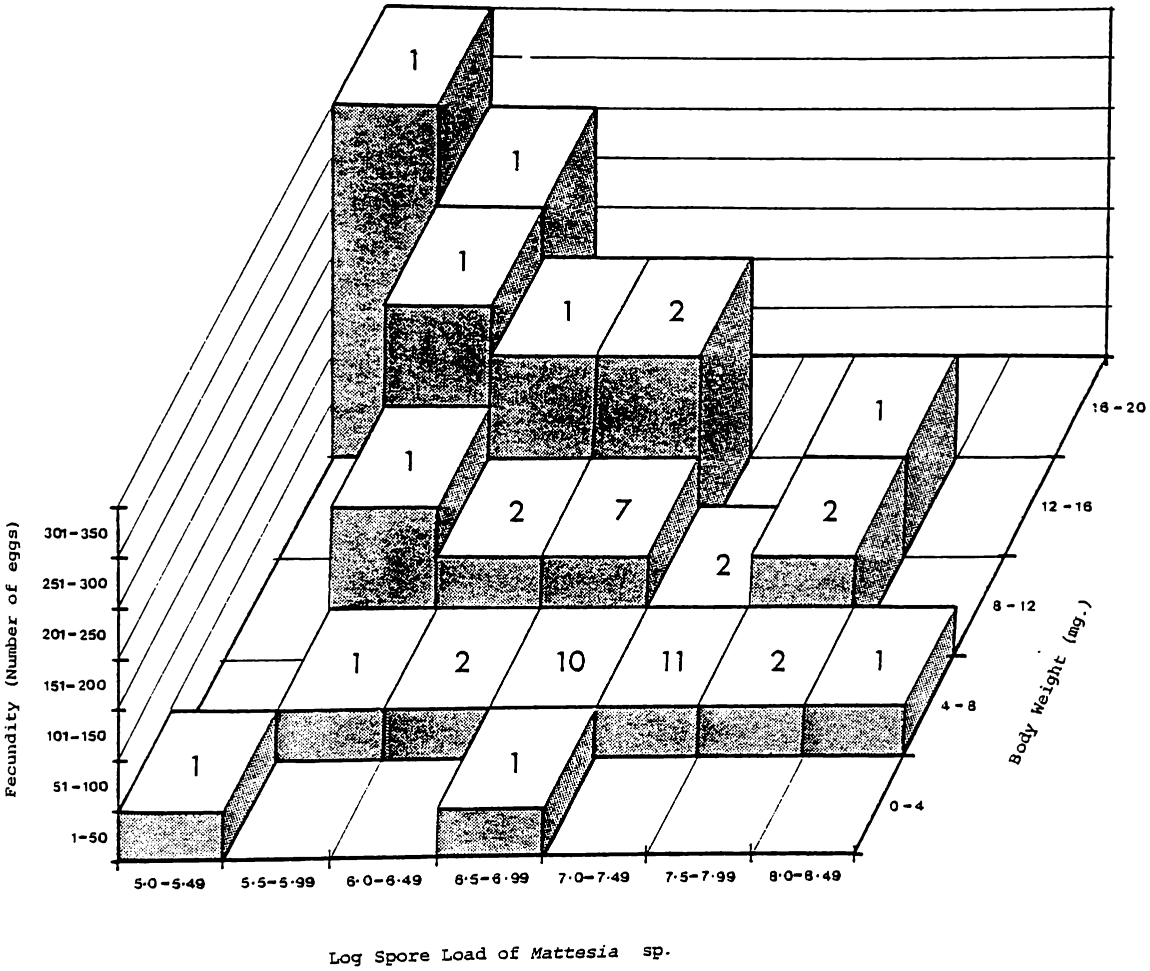
related to each other i.e. they covary (r=0.81 **p<0.01 n=50) and both are negatively related to log spore load i.e. they covary inversely (r=-0.52 **p<0.01 n=50 for log spore load with fecundity; r=-0.36 **p<0.01 n=50 for log spore load with body weight). This can be represented on a three-dimensional histogram (Graph 36) in which females are grouped into ranges of log spore load, weight and fecundity. The numbers on each histogram block refer to the number of females in that category. In four instances, for a particular log spore load-weight category, fecundities fell into two ranges and in one instance, three ranges. In such cases fecundity was averaged. The histogram shows a gradual decrease from back to front and left to right. In other words highest weights and therefore highest fecundities (positively related) are found for lowest spore loads. Lowest fecundities and lowest weights are representative of highest spore loads (negative relationship). There is obviously a marked detrimental effect of MES on adult females. It must be remembered that these data refer to field populations of *Eudonia sabulosella* with fecundities estimated "in situ" (See Methods Ch. 2) in dissected females.

Incidence of Infection

Combining all data on adults it was found that 42.0% of males were infected by pathogens (n=100 39.0% with MES; 5.0% with nematodes; 2.0% with infection by both MES and nematodes) and 52.0% of females (n=102 50.0% with MES; 6.0% with nematodes i.e. 4.0% infected by both). This does not conform with other findings of a similarity of infectivity of the sexes (Weiser 1976; Mercer 1981). 69.8% of pre-adult (larval plus pupal) stages were infected with pathogens (n=182 56.7% with MES; 19.8% with nematodes; 7.7% with fungi; 14.3% with multiple infection) but only 49.5% of adults (n=202 47.0% with MES; 5.4% with nematodes; 3.0% with multiple infection). These results also differ from previous work (Milner 1977; Mercer 1981) where a similarity of infective incidence was found in pre-adult and adult stages. Nematodal infection rates are far lower than those obtained by Bedding and Miller (1981) where over 99% of currant borer *(Synanthedon tipuliformis)* larval mortality was due to the nematode *Neoaplectana (=Steinernema) bibionis*.

There are two reasons for the lack of conformity of pathogen incidence levels (between males and females or pre-adult and adult stages) in this study. The first is transmission of pathogens from males to females; the second is that different life cycle stages of the sod webworm are unequally susceptible to the various pathogens. Considering firstly the differential

Graph 36: Three dimensional histogram showing the relationships between log spore load of *Mattesia* sp., fecundity and body weight of diseased *Eudonia sabulosella* adult females. Numbers on each block refer to the number of females in that category. (Total number of females = 50).



degrees of incidence in male and female adults - thus is most likely due to transmission of *Mattesia* sp. to the female in the spermatophore (cf. Shapas *et al.*, 1977; Henry, 1981). In reviewing the percentage incidence of each pathogen the MES value is much higher in females (50.0%) than males (39.0%) with nematodal values somewhat similar in each sex. On dissection, females (and males) infected by MES were observed to have parts of the body atrophied and blackened. Several spermatophores were similarly affected. If this was representative of infection an idea of disease transmission could be gained. Blackened areas were thus selectively removed and smear preparations made to ascertain the presence of MES proved positive. Such blackening occurred in the fat body, malpighian tubules, gut, ovaries, oviducts, bursa and spermatheca. Blackened spermatophores were found in otherwise disease-free females i.e. females were not responsible for spermatophore infection by immigration of pathogens from surrounding tissues. Several instances were found in which infected spermatophores were associated with various degrees of blackening of the corpus bursae, such females being otherwise free from MES i.e. suggestive of male transmission of the disease. This accounts for the higher percentage of infective incidence in females.

Reviewing the values for percentage disease incidence in pre-adult and adult stages it can be seen that 19.8% of larvae and pupae were infected with nematodes compared with only 5.4% of adults. Nematodes *(Neoaplectana (=Steinernema)* spp) have free-living forms inhabiting the soil and since larvae and pupae are surface-soil dwellers they have a far greater probability of nematodal invasion. Adults on the other hand are essentially aerial though they do shelter at the grass-soil interface. Fungal infection was also encountered in larvae but not adults (except 3 instances directly attributable to rearing conditions). Even accounting for these differences there is still a greater MES incidence in pre-adults (56.7%) than in adults (47.0%). This suggests that mortality rates are higher in larvae and pupae than in adults. Rearing supported this idea with many larvae dying long before becoming full grown or pupae failing to develop to adults. The pre-adult MES value is also more than the comparatively high value for MES in adult females, an overestimation relative to pre-adult rates due to the additive effects of disease transmission from males to females. Larval infectivity incidences (72.8% total; n=162; 58.6% with MES; 22.2% with nematodes; 8.0% with fungi; 16.0% with multiple infections) when compared with male adult values (i.e. assuming there is no disease transmission from females) should indicate the extent of mortality due to MES i.e. 58.6% in larvae versus

39.0% in male adults. In other words almost one third of the larvae infected with MES succumb to its effects, the others surviving to pass on the disease to the adult population. This inductive result agrees with the actual degree of mortality 60/162 or 37.0% found in 1981 in reared larvae assessed for disease. MES is thus responsible for significant mortality in pre-adult stages. Essentially it is larvae that pick up microsporidian spores with ingested plant material (Cantwell, 1974). Pupae being non-feeding and adults being nectar feeders are protected from that form of pathogen contamination. Protozoans are therefore either passed on from larvae to pupae to adults i.e. sublethal doses for successful insect development to occur, or introduced into the body (females) at mating.

Mating Success of Females

During assessment of fecundity the female corpus bursae was dissected and the number of spermatophores recorded. In some cases atrophy due to MES made such estimations impossible. It is known (Miskimen, 1966) that mating can stimulate egg production and this could explain the lower fecundity in diseased females i.e. reduced mating (due to MES-impaired pheromonal or behavioural signals) resulting in fewer eggs being produced. However a non-significant ($p>0.05$) correlation was found in *Eudonia sabulosella* for number of eggs with number of matings. Table XXIX shows the frequencies of mating.

TABLE XXIX. Mating frequencies of diseased or healthy *Eudonia sabulosella* adult females.

HEALTHY FEMALES n=44		DISEASED FEMALES n=46	
NUMBER OF SPERMATOPHORES	NUMBER OF FEMALES	NUMBER OF SPERMATOPHORES	NUMBER OF FEMALES
0	-	0	-
1	20	1	18
2	12	2	20
3	11	3	7
4	-	4	1
5	1		
Average $\bar{X}$	1.86	Average $\bar{X}$	1.80

A 't' test of the difference between means yielded a non-significant result ($p \gg 0.05$) i.e. healthy or infected females are mated to similar extents. Mating success as measured by deposited spermatophores in the female corpus bursae is therefore unaffected by the presence of MES disease.

DISCUSSION

Anderson and May (1981) stated that the influence of pathogens on host population dynamics tends to have been either ignored or dismissed as relatively unimportant. Where any long term studies have been made, diseases seem to persist although their prevalence may vary seasonally and characteristically there are sudden changes or epidemics. Maddox (1975) discussed the difficulty in studying epizootics in the field where the pathogen, host and environment are continually interacting and changing. If it can be understood how and why natural epizootics occur it should lead to accurate prediction of their occurrence and manipulation in pest management programmes with induction at times prior to their probable natural occurrence. The present study is one of the first of its kind on naturally occurring epizootics and leaves many unsolved problems such as the protozoan, *Mattesia* sp., itself - its biology, description, taxonomy, longevity of free-living stages etc. as it was the effect of this pathogen on *Eudonia sabulosella* that was of prime concern.

Any diseases useful in biological control programmes need not necessarily be the most pathogenic (Anderson and May, 1981) as that may lead to extinction of the pathogen rather than its host. However, highly pathogenic microparasites with large numbers of long-lived infective stages give rise to non-seasonal cyclic changes in host abundance and disease prevalence. Microsporidians are generally extremely pathogenic causing high rates of host mortality. Those acting to reduce fecundity further increase their effectiveness.

According to Anderson and May the general features of population cycles driven by host-parasite associations are:-

(i) the peak in infection occurs shortly after the peak in host abundance

(ii) there are many long-lived transmission stages which enable the pathogen to survive while the host population is low

(iii) disease seems to disappear for a time

(iv) there is a quick rise and slow decline in the population of infective stages.

The sod webworm populations studied appear to have been "driven" by their relationship with *Mattesia* sp. The peak in infection occurred in 1979 (refer Table XXVI) after the extreme degrees of damage and associated high larval numbers in 1978 (cf. Beesley,1977). The transmission stages must be relatively long-lived since the 1979 larval numbers were very low yet the disease persisted in the population. The disease seemed to disappear for a time i.e. occult infection. This occurred early in 1981 when relatively high numbers of apparently disease-free larvae were recorded at Whatawhata with signs of minor pasture damage. However in reared larvae by August-September 1981 disease was again widespread with another epizootic. The disease did attain a rapid rise in incidence (see Table XXVI) and a slow decline (cf. Beesley,1977). Thus a good approximation to the features of Anderson and May's (1981) model holds for infection of *Eudonia sabulosella* by *Mattesia* sp.

It is clear that MES does regulate *E. sabulosella* populations as the criterion that "net death rate of infected hosts exceed their birth rate i.e. a raised death rate, depressed birth rate of infected hosts or a combination of both effects" (Anderson and May) is satisfied.MES does cause significant death in the pre-adult population and results in infected females producing significantly fewer eggs. The protozoan maintains itself by : free-living infective stages e.g. resistant spores released on to plant material by decaying cadavers, in the faecal material of infected individuals or by parasites transferring the pathogen from one host to another; occult infection where the disease is present but has no obvious deleterious effects or at least does not cause death and thus carries through to the next generation; or by vertical transmission involving both transovarial and transovuum modes. As regards vertical transmission eggs from infected females were examined and found to contain MES both on the surface and internally. The transovarial or internal contamination is derived from infected female nurse cells or male sperm (from infected spermatophores); the exterior or transovuum transmission from infected female egg-laying tracts. Although the egg case is not eaten, emerging first instar sod webworm larvae contact it during hatching and (Tinsley,1979; Anderson and May,1981) that is sufficient to cause infection.

When the 1978 larvae became infected by MES this was most likely *via* horizontal transmission (e.g. breakdown of cadavers, in faecal material of infected larvae or from parasites - but sod webworm parasite numbers were very low, see Parasitism this Ch.). However, the subsequent epizootic resulting in a more widespread disease incidence than expected by density dependent means suggested other factors were involved. Entwistle *et al.* (1977a and 1977b) and Wigley (pers. comm.) invoked the importance of birds in epizootics. In 1977a they found that during an epizootic of nuclear polyhedrosis virus (NPV) in sawfly larvae in Wales, 16 species (comprising 6 families) of birds were found to disperse infective NPV in their faeces. Entwistle *et al.* (1977b) suggested the carriage by birds of innoculum was made at least to a distance of six kilometres from the area of general infectivity. It certainly is timely that avian predation occurred at the study sites late in the larval season in 1978. Since most entomophagous pathogens are resistant to bird gut enzymes (Wigley, pers. comm.) it is possible that avian predation contributed significantly to the MES epizootic in *Eudonia sabulosella* at Whatawhata and Te Kowhai in 1979. Further tenuous support derives from the Kaimai site where a disease epizootic was observed in 1980. Late in 1979 the sod webworm damaged areas were also subjected to avian feeding flocks (Burchett, pers. comm.) and it seems a very strong coincidence that this was followed by a disease outbreak in 1980.

A prime difficulty is the initial introduction of the infective material. Passive dispersal by birds is an ideal mechanism. Also Kalmakoff and Crawford (1976) reported that stock are important in spreading disease from dead larvae or bird faeces over the pasture and thus aid the development of epizootics. Once an area has been invaded disease perpetuates for long periods. Entwistle and Adams (1977) showed that infected sawfly larval remains persisted on foliage, as well as in soil, into the new generation and probably beyond. Ferron (1978) injected a fungal spore suspension into soil creating an epizootic 16 months later which persisted at least into the following generation of *Melolontha melolontha*. Thompson and Scott (1979) recorded polyhedra in soil for many years with subsequent pest outbreaks of Douglas fir tussock moth (*Orgyia pseudotsugata)* being less severe. Welch (1965) referred to nematodes surviving for long periods at low host densities. However Hoy (1954) indicated that the nematode (*Neoaplectana leucaniae)* did not pesist for long in the field. These results are important as they indicate the viability of manipulating pathogen levels in insect pest management.

Mason (1981) discussed the fact that natural diseases (viruses) do not regulate populations over a range of densities in the usual density-dependent way because other mortality factors related to overcrowding and food stress dominate. He proposed that diseases may be better regulators in outbreaks of moderate density where these stresses are not involved. Population outbreaks are thus due to failure of natural diseases to develop an early regulatory role (also cf. Kamm, 1973). An epizootic is therefore a signal to discontinue chemical controls (Maddox 1975). Miln and Carpenter (1979) reported higher mortality from insecticides of infected individuals and Persing (1965), Stern (1973) and Luckmann and Metcalf (1975) reported pest "resurgence" may occur after spraying. No doubt this is due to the selective removal of diseased individuals from the population. The need for care in the timing of chemical controls cannot be overstressed.

The pasture system is an ideal environment for the regulation of insect numbers by naturally occurring diseases. Dry feed supplements can be provided where necessary (at a much lower outlay than the cost of sprays) and unlike export crops some degree of damage can be tolerated. This allows for a residual larval population to exist in equilibrium with disease and provide continuous pathogen production (cf. Crawford and Kalmakoff 1977). In New Zealand, Kalmakoff and Moore (1975) found that 87% of pastures over 5 years old which had not been cultivated contained viruses, compared with only 10% in pastures less than 5 years old. They suggested it was better to oversow when improving older pastures as cultivation destroys the insect-disease equilibrium. Thus newly sown and recently cultivated pastures tend to be the most susceptible to insect attack (cf. McCrae, 1975). The sod webworm populations studied which caused damage were on newly sown (e.g. Burchett's, Kaimai 1-2 year old pasture) or recently oversown areas (e.g. Whatawhata, Te Kowhai and Ngaruawahia). Pasture management strategies therefore markedly affect the host-pathogen equilibrium (cf. McCrae, 1975) i.e. pest control decisions require a thorough understanding of the interactions between host, pathogen and environment.

The effectiveness of *Mattesia* sp. as a control for *Eudonia sabulosella* must rate highly. Pasture does sustain some damage but since infected larvae eat less and are smaller than healthy ones, *Mattesia* does provide an efficient means of population regulation. This compares with Roome (1975) where an NPV took longer than carbaryl sprays to control *Heliothis armigera* larvae on sorghum in Botswana. Since most damage is caused by late instar larvae, the NPV still killed them before significant damage had been caused. Also the NPV-infected *H. armigera* consumed only 50% of the normal quantity of food. Beeman (1982) reported that certain insecticides also inhibit feeding. The fecundity of female *E. sabulosella* with MES was severely reduced and infected females laid none or few eggs in the laboratory situation. Perhaps MES, apart from reducing fecundity even depressed oviposition. Disease did not affect mating as there was no significant difference between number of spermatophores in the corpus bursae of infected or healthy females. Apparently, diseased males were able to copulate as healthy females contained infected spermatophores. In extreme cases MES (10^8 spores) results in distorted adults.

Most natural epizootics occur after economic loss had been caused. Although they drastically reduce large insect populations, they are usually sporadic and difficult to predict. Satisfactory levels of control can be caused by generating artifical epizootics each year (Tinsley,1979). Such manipulation requires knowledge of the damage threshold (about 20-25 larvae per m^2 for *E. sabulosella* on hill country) and the most important diseases in the insect population (the protozoan, *Mattesia* sp.;and to a lesser extent the nematode, *Steinernema bibionis)*. It seems that MES and *Eudonia sabulosella* rapidly attained some sort of equilibrium after the 1979 epizootic with a smaller epizootic actually observed in progress during the 1981 larval season. The potential of MES as a biological controller of sod webworms on hill country is highly promising.

CHAPTER EIGHT
ADULT BEHAVIOUR

Introduction

Although this section is headed "Adult Behaviour" it will deal almost entirely with flight seasonality, flight periodicity and the influence of meteorological events on adult activity. Without information on pest aggregations it is impossible to ensure crop protection. Lawson (1958) suggested that one of the major difficulties in entomology was to predict pest outbreaks, largely because of complex interrelationships with the environment. Hurnard (1978) noted that climate, especially seasonal weather conditions, largely determined insect distribution and species composition within an area. Studies of insect flight in relation to pest control are of prime importance for crop protection (Joyce,1976). Joyce also stated that investigations of the nature of pest outbreaks required consideration of the effects of windfields which either concentrated or dispersed insect populations. There are numerous publications advocating the importance of the effects of wind speed and direction on insect flight activity (e.g. Williams,1940; Glick *et al.*,1956; Lawson,1958; Lewis,1964; Haskell, 1966; Banerjee,1967a; Johnson,1969; Bowden and Gibbs,1973; Close and Tomlinson,1975; Hurnard,1978; Southwood,1978; Cowley,1982). With the aim of investigating adult sod webworm aggregations and hence susceptible hill country pastures, flight activity was studied using light, suction and malaise traps, sweep nets, frame counts and sticky plates (see Methods Ch. 2). Meteorological events were measured during the trapping periods and related to catch size variability.

ORIENTATION

Eudonia sabulosella adults assumed a geonegative orientation (facing directly away from the centre of the earth, Fraenkel and Gunn,1961) on grasses or other resting places. The same orientation was observed in the other Scopariinae:- *E. psammitis, "Scoparia" bisinualis, "S." diphtheralis, "S." halopis, "S." philerga* and *"S." submarginalis*. These adults were seen to alight in a geonegative position. Crambine adults, however, were geopositive (orientation facing directly towards the centre of the earth, Fraenkel and Gunn,1961). Whenever *Orocrambus flexuosellus* or *O. vitellus* adults alighted in a geonegative position they rapidly turned through 180° to the geopositive orientation. This behaviour has also been observed by Crawford (1970b) in some Crambinae in Oregon and New Mexico. Crawford stated that such positioning renders the animal "fairly inconspicuous to the human observer and presumably to predators as well". On hill country around the Waikato, scopariine and crambine moths were repeatedly disturbed and settling-resting orientations noted. There appeared to be no difference in orientation between males and females of each species. *Eudonia sabulosella* adults were found more frequently on light coloured (drying) grass seed heads whereas *Orocrambus flexuosellus* adults rested more frequently on grass stems. In both cases adults were well camouflaged so that to locate subsequent resting places it was necessary to observe disturbed moths carefully.

Crawford (1971) found that two webworm species (*Crambus harpipterus* and *Agriphila plumbifimbriella* - Crambinae) in N. New Mexico feigned death by dropping to the ground when disturbed. This behaviour was observed frequently in *O. flexuosellus, O. vitellus, E. sabulosella, "S." bisinualis, "S." philerga* and *"S." submarginalis*. As such it proved helpful for hand collection of adults as they simply dropped into vials. In the field whenever feigning of death occurred, moths flew away rapidly (within two-five seconds) if the disturbance continued. This behaviour was remembered when frame counts were made (see Methods Ch. 2).

On windy days (wind speed above 15 k.p.h.) adults moved towards the bases of grasses or rushes, or to the leeward sides of trees to shelter. Moths were more widely distributed on calm days. These behavioural differences will be discussed later in the context of meteorological effects on adult flight expecially as measured by frame counts.

SPECIES COMPOSITION OF CRAMBINAE AND SCOPARIINAE

The information presented here on crambine and scopariine species composition is derived from the various adult collection methods listed above (Introduction) as well as hand collection. As suggested by Southwood (1978), several methods were utilized concurrently for estimation of populations. The value of such investigation cannot be over-emphasized since some adults were collected by only one method. Similar findings were made by Matheny and Heinrichs (1975) collecting sod webworms in Tennessee, where some species were caught in light traps but never by hand.

TABLE XXX. List of species collected with locality reference.

SPECIES		LOCALITY COLLECTED					
		Whatawhata	Te Kowhai	St. Andrews	Hillcrest	Kaimai	Auckland
CRAMBINAE	*O. flexuosellus*	P	P	P	P	P	P
	O. vitellus	P	A	P	P	P	P
	O. ramosellus	A	A	A	A	P	A
SCOPARIINAE	*E. psammitis*	P	A	P	P	A	P
	E. sabulosella	P	P	P	P	P	P
	"S." bisinualis	P	A	P	P	A	P
	"S." diphtheralis	P	P	A	P	A	P
	"S." halopis	P	A	P	P	A	P
	"S." philerga	P	A	P	P	A	P
	"S." submarginalis	P	P	P	P	P	P
	"S." aspidota	P	A	A	A	P	A
Miscellaneous Scopariinae (unidentified 7? species of 2-3 specimens each)		P	A	A	A	A	A

KEY: A:represents absence of a species; P:represents presence of a species.

In table XXX the species represented by "miscellaneous, unidentifed" refer to light-trapped adults collected at Whatawhata. These adults appeared to be badly worn and genitalia did not conform to the above species listed in Taxonomy (Ch. 4). Since scopariine adult description has centered almost entirely on wing characters (see Meyrick 1885; Hudson 1928, 1939) the identity of these species remain unknown. No adults from these "species" were collected by any of the other methods of sampling. *"Scoparia" aspidota* occurred at very low frequencies (light trap) and also was not collected by other methods of trapping. Only 11 adults (six males, five females) of this species were obtained. *O. flexuosellus* and *E. sabulosella* were the only species of adults obtained from Ngaruawhaia (hand collected or sweep netted).

Eudonia sabulosella was the most abundant species over pature on Waikato hill country. *"Scoparia" aspidota, "S." bisinualis, "S." halopis, "S." philerga* and *E. psammitis* were only collected by light trapping at Whatawhata. *E. sabulosella* and *O. flexuosellus* were sampled by all methods (except Malaise trap - *O. flexuosellus)*. The other species were obtained by hand, light or suction trapping as well as Malaise trapping (*"S." submarginalis)* or sweep netting and sticky plates (*O. vitellus)*. At Te Kowhai, Hillcrest, Kaimai and Auckland, adults were obtained by hand collection, sweep netting and light trapping.

Around mossy areas (such as St. Andrews Golf Course and Auckland sites) *"Scoparia" philerga* and *"S." submarginalis* predominated. Where mossy regions were being replaced with pasture grasses (e.g. Kaimai, Ngaruawahia, Te Kowhai and Whatawhata sites) *E. sabulosella* occurred, particularly on southern slopes. *Orocrambus flexuosellus* appeared to predominate on northern and lowland pastures where there was little moss. Samples in such regions yielded relatively few *O. flexuosellus* larvae and no feeding damage was observed. This finding is supported by that of Kelsey (1957) who found little evidence for damage to pasture by *O. flexuosellus*. It is possible that this species attains pest proportions under certain conditions and continued monitoring is therefore required.

MALAISE TRAPS

Malaise traps (see Methods Ch. 2 p.27) were used at the three Whatawhata sites. Two traps were utilized at Long 4A and one trap each at Wilsons 2A and Wilsons 2B on ten occasions in 1979-80 and 15 in 1980-81. Only nine *Eudonia sabulosella* (five males and four females) and one *"Scoparia"* *submarginalis* (male) were collected by Malaise trapping. Adults arrived early in the morning or late in the afternoon. It was only possible to operate the traps when wind speed were below ten kilometres per hour. Results presented here therefore relate to catches during those relatively calm conditions. At higher wind speeds the central, collecting area of the trap vibrated. Any *Eudonia sabulosella* adults about to settle were observed to fly away from the traps at those times. Adults were seen to fly towards then up and over the trap. Bidlingmayer and Hem (1979) recorded similar behaviour in mosquitoes which they described as avoidance of large and conspicuous objects. Sod webworm adults may have avoided the Malaise trap or simply followed the slip stream over and away from it. There were numerous problems in establishing the trap in open pasture without shelter. The sod webworm collection may thus have been affected by the trap situation. A sheltered site adjacent to pasture in the forested area, Whatawhata was then selected. Five trials were made there (using two traps set for two days at a time) but no moths were obtained. It appears that Malaise trapping is not a very satisfactory method for collection of sod webworm adults.

STICKY PLATES

Sticky plates (see Methods Ch. 2 p. 28) were used at Long 4A, Whatawhata from mid-November 1979 to mid-April 1980 and early November 1980 to early-February 1981. Although plates were examined whenever light trap catches were collected to provide comparison of flight activity, weekly totals of trapped insects were recorded. However, due to the frequent zero catches such data have been pooled on a monthly basis for each season. Table XXXI is a summary of that information.

Table XXXI shows that more adults were collected on the plates set 0.35-0.65m above ground than on the others and there was a bias towards females especially at this intermediate height. *Eudonia sabulosella* adults were collected between November and January each season. Using the total catches each month for *E. sabulosella* and combining results from males and females for November to January each season, a Model I single classification ANOVA test for equal sample sizes was performed. This yielded a significant result (**$p<0.01$) and it was shown that Traps 1 and 3 were not significantly different from each other (n.s. $p>0.05$) but they were significantly different from Trap 2 (*$p=0.01$). This meant that markedly more adults were collected from the zone 0.35-0.65m above ground.

TABLE XXXI. Sticky plate catches for each month and season.

	MONTH AND YEAR	TRAP 1 (0.00-0.30m)		TRAP 2 (0.35-0.65m)		TRAP 3 (0.85-1.15m)	
		MALES	FEMALES	MALES	FEMALES	MALES	FEMALES
1979-80 SEASON	Nov 1979	1e	2e	1e	2e	1e	1e
	Dec 1979	3e	2e	6e	6e	1e	4e
	Jan 1980	2e	2e	4e	6e	1e	1e
	Feb 1980	0	1v	0	0	1v	0
	Mar 1980	0	0	0	0	0	1f
	Apr 1980	0	0	0	0	0	0
1980-81 SEASON	Nov 1980	0	2f	1e 1f	2e 3f	2f	1e 2f
	Dec 1980	0	1e	1e	2e 1f 1v	2e 1f	2e 1f
	Jan 1981	5e	1e	0	6e	3e	0
	Feb 1981	0	0	0	0	0	0

KEY: e=*Eudonia sabulosella;* f=*Orocrambus flexuosellus;* v=*O. vitellus.*

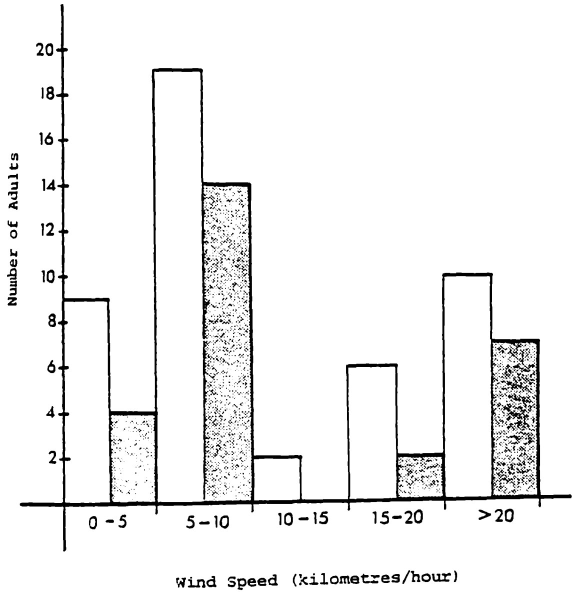
As outlined in Methods (Ch. 2) sticky plates consisted of alternate light and dark bands. Since it had been observed (see Orientation) that *E. sabulosella* adults settled on light coloured seed heads it was thought such selection could be further investigated with the banded sticky plates. This was also related to wind speed. Table XXXII summarizes these findings.

At each wind speed there was a bias to light coloured plates, but that bias was least for the highest wind speed (see Graph 37) suggesting insects were blown against the plates rather than selecting colours. Field observation of aerial adults indicated that in four out of five instances when wind speed was in the range 5-10 k.p.h. adults approached the plates, moved to the leeward side , hovered, then settled on a light coloured band. When wind speeds were above 20 k.p.h. few adults were airborne. Any flying were usually found very high above the ground.

TABLE XXXII. Analysis of colour preference by *Eudonia sabulosella* adults (males and females combined) in relation to trap height and wind speed. (Data are pooled for each sex and each season).

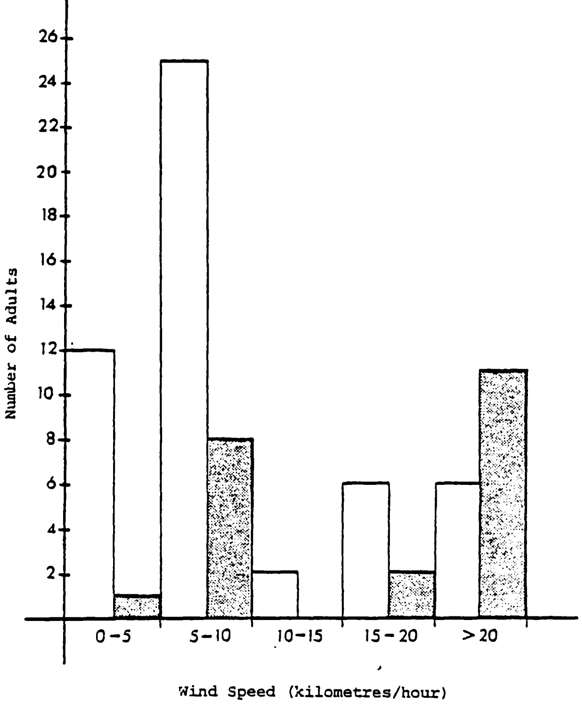
WIND SPEED (Kilometres/hour)	TRAP 1 (0.00-0.30m ABOVE GROUND)			TRAP 2 (0.35-0.65m ABOVE GROUND)			TRAP 3 (0.85-1.15m ABOVE GROUND)		
	Number of Adults on Light Coloured Plates	Number of Adults on Dark Coloured Plates	Total Number of Adults	Number of Adults on Light Coloured Plates	Number of Adults on Dark Coloured Plates	Total Number of Adults	Number of Adults on Light Coloured Plates	Number of Adults on Dark Coloured Plates	Total Number of Adults
0-5	1	0	1	6	4	10	2	0	2
5-10	6	6	12	10	5	15	3	3	6
10-15	1	0	1	1	0	1	0	0	0
15-20	2	0	2	1	1	2	3	1	4
Above 20	2	1	3	4	5	9	4	1	5

Graph 37: Colour preference in settling *Eudonia sabulosella* adults in relation to wind speed.



Blank areas refer to light coloured plates.
Shaded areas refer to dark coloured plates.

Graph 38: Leeward or windward settling of *Eudonia sabulosella* adults in relation to wind speed and direction.



Blank areas refer to leeward settling.
Shaded areas refer to windward settling.

Under such conditions moths nearing the plates tended to be blown directly on to them. Thus little or no colour selection occurred and frequencies of adults trapped on light or dark bands were almost equal, for the very high wind speeds (above 20 kilometres/hour). Table XXXIII represents frequencies of settling on leeward or windward sides of the sticky plates at each wind speed.

TABLE XXXIII. Settling of adult *Eudonia sabulosella* (males and females combined) on sticky plates in relation to wind speed and direction for each trap (both seasons pooled).

WIND SPEED (Kilometres/ hour)	TRAP 1(0.00-0.30m ABOVE GROUND)		TRAP 2(0.35-0.65m ABOVE GROUND)		TRAP 3(0.85-1.15m ABOVE GROUND)	
	Number of Adults Leeward	Number of Adults Windward	Number of Adults Leeward	Number of Adults Windward	Number of Adults Leeward	Number of Adults Windward
0-5	1	0	9	1	2	0
5-10	9	3	12	3	4	2
10-15	1	0	1	0	0	0
15-20	0	2	2	0	4	0
Above 20	1	2	4	5	1	4

The information presented in Table XXXIII is summarized in Graph 38.

It can be seen from Table XXXIII and Graph 38 that at the highest wind speed, more adults were collected from the windward side of the sticky plates. At the two lowest wind speeds many more adults settled on leeward sides indicating active seeking of "shelter". This experimental result agrees with observational data where adults rested on leeward sides of trees, for example. Graphs 37 and 38 show that maximum aerial density of adults occurred in 5-10 kilometer/hour winds, next highest density in winds above 20 k.p.h., followed closely by 0-5 k.p.h. winds. These findings suggest that light winds (5-10 k.p.h.) stimulate flight while at very high wind speeds aerial density is largely due to windborne adults which have little control over flight direction or height. It is possible that many of the latter group of adults were initially blow from grasses or resting places. These aspects will be considered in relation to light trap catches (see later, this section).

FRAME COUNTS

In early December 1980 during the course of making regular frame counts to estimate adult populations of *Eudonia sabulosella*, it was apparent that much variability in numbers occurred from day to day. Adults were observed to congregate at different compass orientations within the 180° arc described from east through south to west. Aggregations occurred leeward of the wind. Five sets of 20 counts were therefore made at N, E, W, S and SW compass orientations whenever the light trap was reset (see Methods Ch. 2). Counts were initially made over all ranges of pasture heights from 10-150mm. From 16 December onwards counts were confined where possible to pastures of 75mm or more high as these were the regions of congregation by *E. sabulosella* (i.e. over long, lush or rank grasses - see Biology, Adult Habitat Ch.5). Table XXXIV is a summary of some of these frame counts converted to numbers of adult *E. sabulosella* per m^2. The results presented refer to counts made during the peak months of adult numbers (i.e. December and January), and taken one week apart on the given dates. These results were selected to allow comparison with seasonal changes in adult numbers (see Graph 24, Population Dynamics and Light Trapping - this section).

TABLE XXXIV. Frame counts of *Eudonia sabulosella* adults (numbers per m^2) on hill country pasture (Whatawhata) with N, E, W, S or SW orientation, in relation to wind speed and direction.

Date Counts Made	Number of *E. sabulosella* adults/m^2 on each slope orientation					Wind direction and speed (Kilometres/hour) when counts made
	N	E	W	S	SW	
2 Dec 1980	0.0	0.0	1.0	1.0	1.8	SSE 5.1
9 Dec 1980	0.0	0.0	4.2	3.6	5.2	SE 9.3
16 Dec 1980	0.0	1.0	4.2	3.8	4.8	SE 4.6
23 Dec 1980	0.0	0.0	4.4	4.0	4.8	SE 23.8
30 Dec 1980	0.0	2.0	4.8	3.8	4.4	SE 3.2
6 Jan 1981	0.0	4.0	0.0	0.0	0.0	SW 10.3
13 Jan 1981	0.2 1.0f 0.4v	0.0	3.4	4.6	3.2	NE,E 13.8
20 Jan 1981	0.0	0.0	1.0	4.2	4.0	S,SE 5.3
27 Jan 1981	0.0	0.0	0.0	0.8	0.4	S,SSE 6.4
3 Feb 1981	0.0	0.2	0.0	0.0	0.0	W 13.2

KEY: f refers to *Orocrambus flexuosellus* adults; v refers to *O. vitellus* adults; all others represent *Eudonia sabulosella* adults.

It can be seen from Table XXXIV that aggregations of *E. sabulosella* were confined to slopes ranging from east through south to west. Largest populations (per m²) occurred on those slopes leeward of the wind direction. However only one *E. sabulosella* adult was found on northern slopes and this was at a time when *O. flexuosellus* and *O. vitellus* adults were also recorded there. The almost complete lack of *E. sabulosella* on northern slopes may have been partly due to the shorter pasture characteristically found there, since sheep in particular spend more time grazing such areas. *Orocrambus flexuosellus* and *O. vitellus* achieved higher densities on northern slopes (especially in September to November) than elsewhere. At those times *O. flexuosellus* populations were around 1.2 per m² on northern slopes and 0.4-0.6per m² on southernslopes. *O. vitellus* populations ranged from 0.6 per m² on northern slopes to 0.2 per m² on southern slopes. Table XXXIV shows that SE winds occurred most frequently at the study sites at Whatawhata and resulted in densest aggregations of *E. sabulosella* adults on SW slopes i.e. diametrically opposite the wind direction. On 6 Jan 1981 when the wind was SW all adults were confined to E slopes. Table XXXIV also shows the relationship between restriction of adults to certain slopes in response to wind speed. Where wind speed was below five kilometres per hour (16 Dec 1980 and 30 Dec 1980) adults were found over a wider range of compass orientations (including slopes to windward). With higher wind speeds no adults were found on windward slopes and overall dispersion was thus reduced, with moths being confined to leeward areas. It appears, therefore, that wind speed and direction have important implications in the population dynamics of sod webworms (in particular *Eudonia sabulosella)*. Adults seem to be congregated and confined by windfields.

SUCTION TRAPPING

As described in Methods (Ch. 2 p. 28) suction trapping was carried out at Long 4A, Whatawhata using three Johnson-Taylor Vent Axia exposed cone 304.8mm (12 inch) diameter suction traps. Catches were segregated into 24 hourly samples and following Taylor (1962b) and Southwood (1978) converted to aerial density of sod webworm adults (i.e. the number of moths per 10^6 cubic metres of air). Graphs 39-50 represent suction trapping information. A total of only 64 sod webworms (species representation as in Table XXXV) were collected in the two seasons (1979-80 and 1980-81) from 70 nights trapping. A night's trapping was considered to be one trap operated for one night so that on those occasions when three traps were run simultaneously they were regarded as three night's trapping. On the majority of nights only one or two traps were operated since numerous mechanical problems developed, ranging from non-release of the discs which segregated hourly catches, to malfunction of the fans which meant that traps required continued maintenance.

TABLE XXXV. Numbers of sod webworms collected by suction trapping (both seasons pooled).

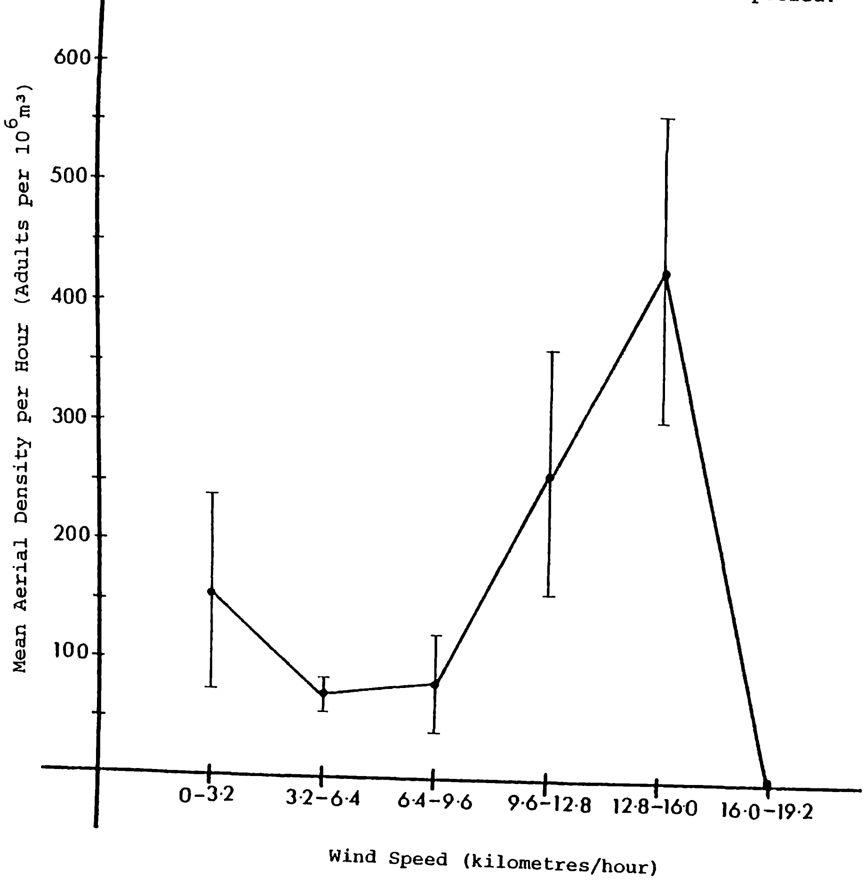
SPECIES	*O. flexuosellus*	*O. vitellus*	*E. psammitis*	*E. sabulosella*	*"S." diphtheralis*	*"S." submarginalis*
Number Collected	31	3	2	21	4	3
Number of Males: Females	18:13	2:1	2:0	14:7	1:3	2:1

Table XXXV shows a predominance of males were collected by suction trapping (ratio of 1.64:1 males:females). Since it does not reflect the usual ratio of males to females (See Biology Ch. 5) it suggests that males were more active than females. Because suction trapping does not depend on any response of the insects (e.g. attraction as for light trapping), it is considered to provide an accurate value for aerial density (Johnson, 1950a).

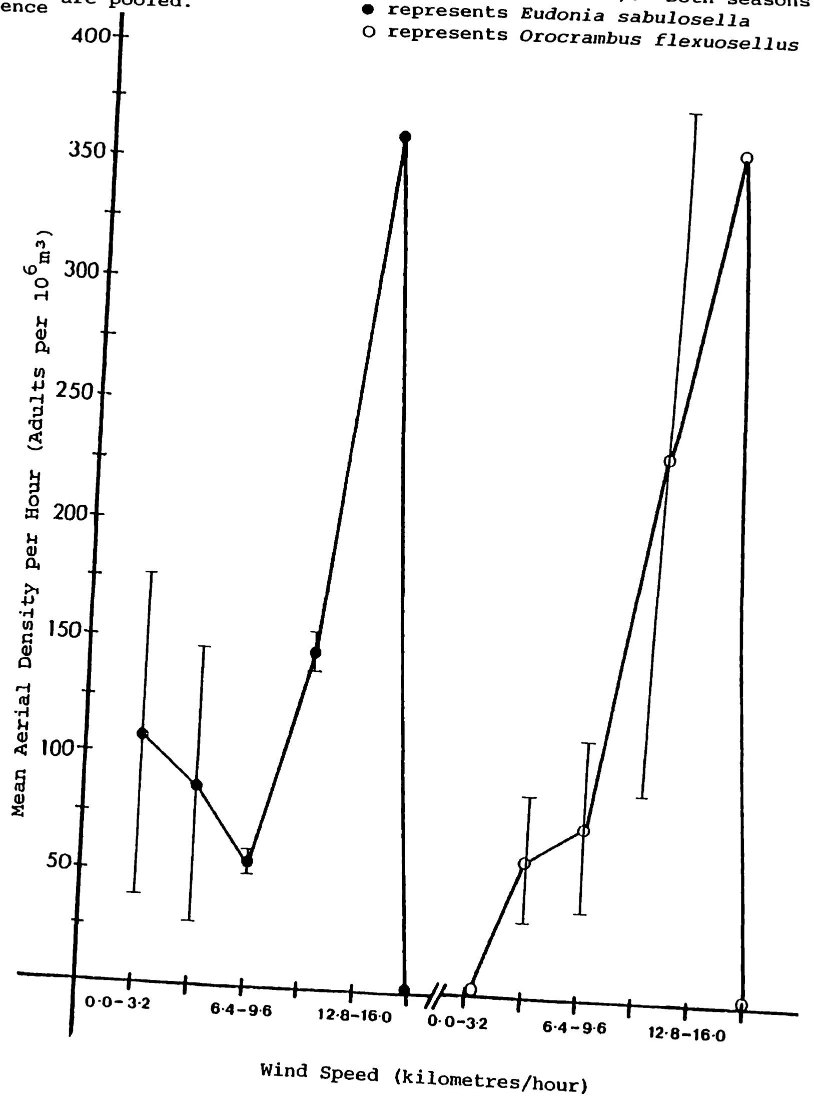
Effect of Wind Speed, Air Temperature and Time of Day on Suction Trap Catches

Graphs 39 and 40 represent mean aerial densities of sod webworm adults (per 10^6 m^3) pooled for both seasons and related to wind speed. The results from both seasons were pooled because of the small numbers of adults involved. Graph 39 represents all species of sod webworm while Graph 40 shows the patterns for *E. sabulosella* and *O. flexuosellus*. Correlation and regression analysis yielded non-significant results ($p>0.05$) indicating no marked relationship between mean aerial density and wind speed. Graphs 39 and 40 show moderate-low densities of moths at low wind speeds and maximal density at 12.8-16.0 kilometres per hour (k.p.h.) winds followed by a complete lack of airborne adults in winds above 16 k.p.h. Graph 41 shows the pattern for mean aerial density (all sod webworm species) in relation to air temperature (°C) as measured by a thermohydrograph adjacent to the suction traps (see Methods Ch. 2 and Meteorological Data Ch. 3). A correlation test for temperature against mean aerial density produced a non-significant result

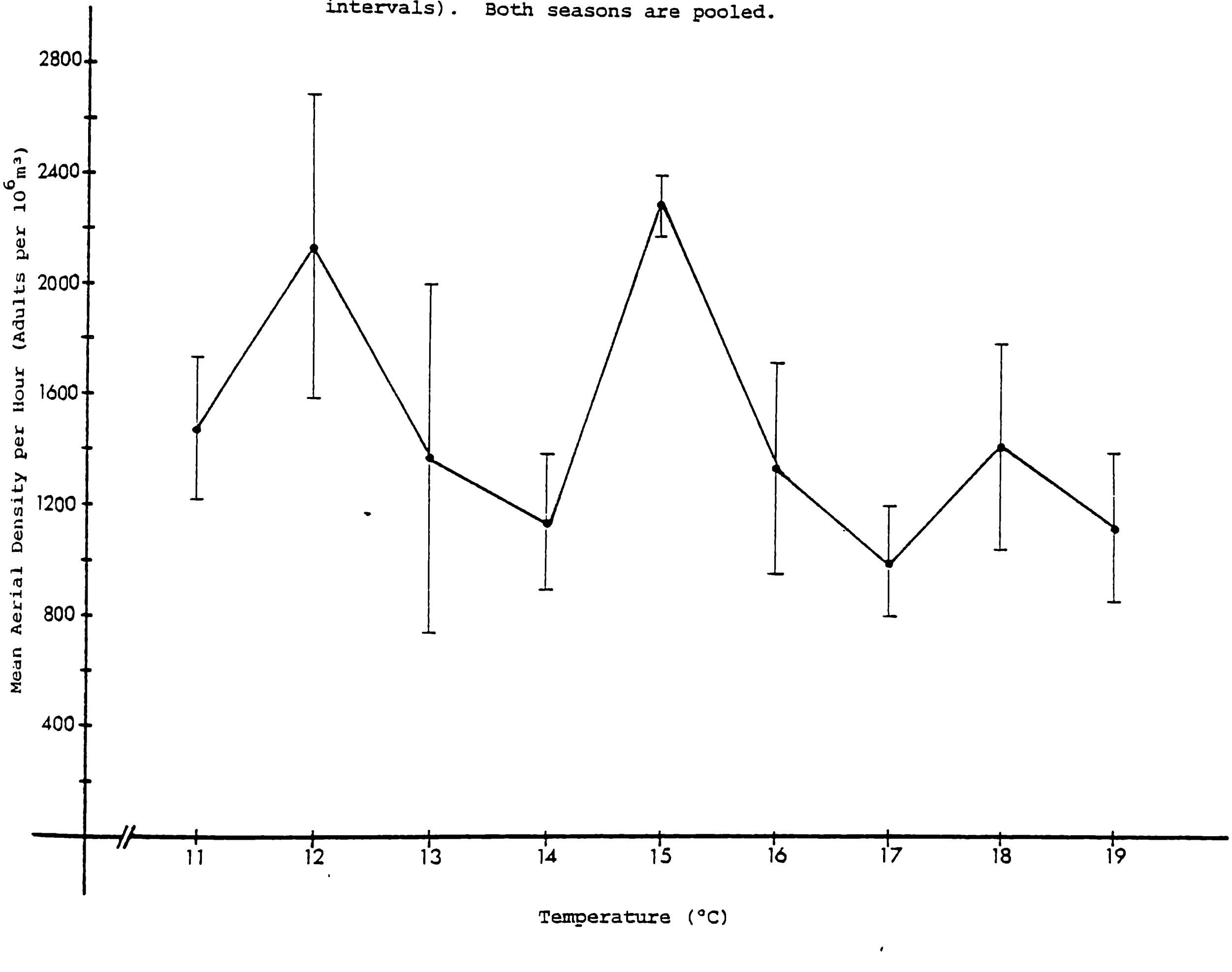
Graph 39: Change in mean aerial density of moths (all species) collected at different wind speeds by suction trapping. (± 95% confidence intervals). All sod webworms and both seasons are pooled.



Graph 40: Change in mean aerial density of moths (*Orocrambus flexuosellus* and *Eudonia sabulosella* only) collected at different wind speeds by suction trapping. (± 95% confidence intervals). Both seasons are pooled.

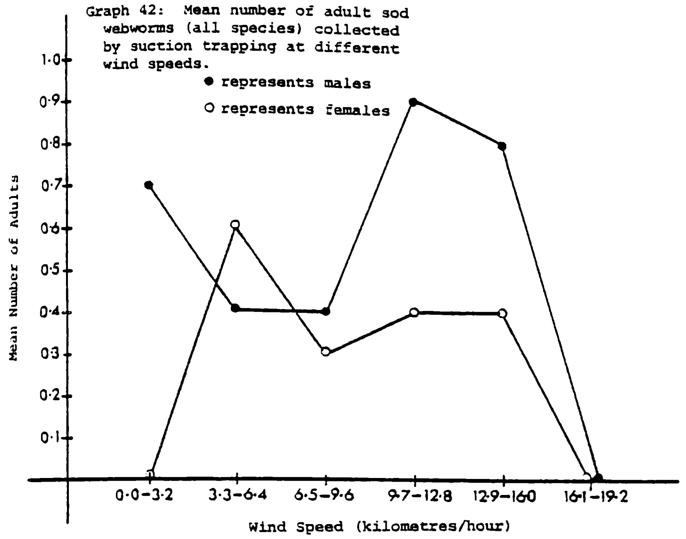


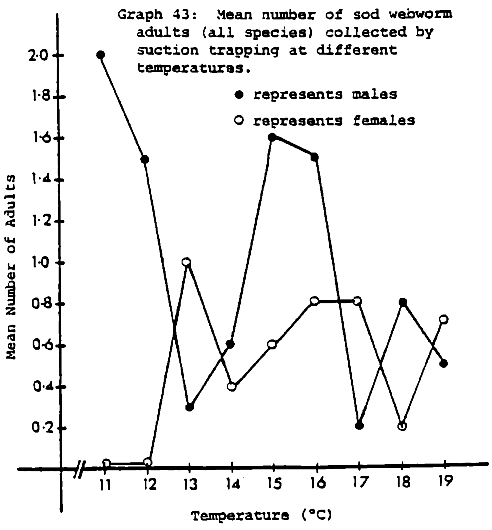
Graph 41: Mean aerial densities of adult sod webworms (all species) collected at different temperatures by suction trapping. (± 95% confidence intervals). Both seasons are pooled.

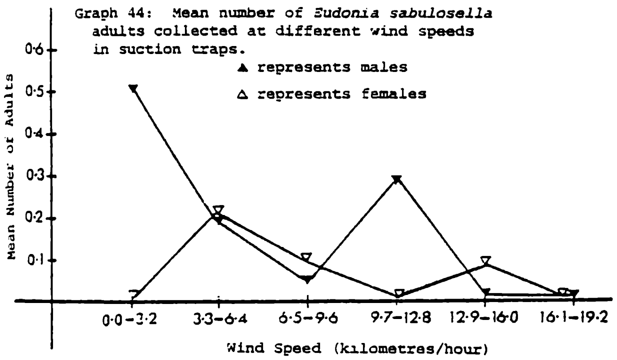


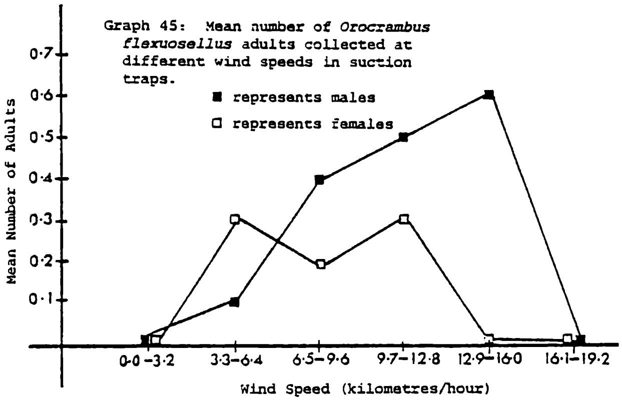
($p>0.05$) i.e. there was no marked relationship between temperature and numbers of moths flying. Graph 41 shows peaks at 12 and 15°C, suggesting that these were optimal tempertures for sod webworm flight. The variation at the 15°C temperature as indicated by the 95% confidence intervals is very small which implies a discrete peak in activity at that temperature. The adjustment of actual catches to aerial density (i.e. correcting for the effect of wind speed on performance of the trap) seems to markedly alter the actual flight patterns of sod webworm as indicated by other methods of sampling. For example, Graphs 39 and 40 show an increase in aerial density with increasing wind speed but only six moths were collected at wind speeds of 12.8-16.0 k.p.h. compared with 21 moths at 3.2-6.4 k.p.h. Since the numbers of adults involved were low, Graphs 42-47 refer to the means of actual catches of moths in relation to wind speed and temperature. Confidence limits are large and approximate the mean value hence have not been drawn in. Graphs 48-50 refer to actual numbers of moths in relation to times of collection. From these graphs, activity trends can be established.

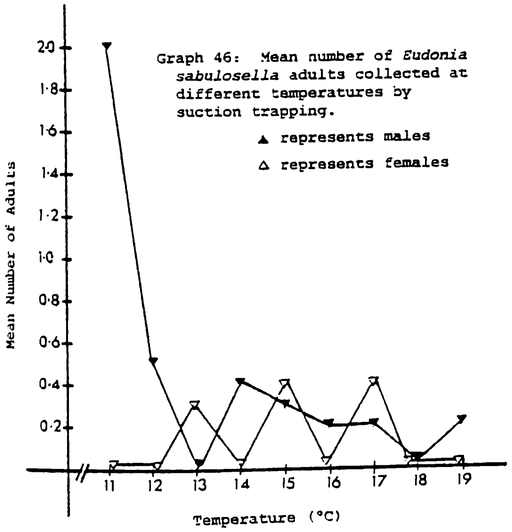
Graph 42 shows maximal female activity occurred in moderate wind speeds (3.2-6.4 k.p.h.) with a decrease in 6.4-9.6 k.p.h. winds followed by a slight rise in numbers in 9.6-16.0 k.p.h. winds. There was a lack of females in winds above 16.0 k.p.h. Males were quite active in low winds (0-3.2 k.p.h.) and maximal numbers occurred in 9.6-16.0 k.p.h. winds. Males too were not recorded in winds above 16.0 k.p.h. Graph 43 shows marked activity by males at 11, 15 and 16°C but with activity at all the temperatures which occurred during sampling. Female activity commenced at 13°C and continued, though at variable levels, for all temperatures above this. Graphs 44-47 represent the relationships for *E. sabulosella* and *O. flexuosellus* with wind-speed and temperature. Graph 44 indicates maximal activity by male *E. sabulosella* at the lowest wind speeds (zero to 3.2 k.p.h.) with a smaller peak at 9.6-12.8 k.p.h. Maximal female activity occurred in winds of 3.2-6.4 k.p.h. and to a lesser extent in 12.8-16.0 k.p.h. winds. The only activity recorded in *E. sabulosella* at 12.8-16.0 k.p.h. was one female collected by suction trapping. As suggested previously the conversion of such low numbers to total aerial densities (mcths per 10^6 m^3) as in Graphs 39 and 40 may be misleading. Graph 45 shows maximal activity by male *O. flexuosellus* in wind speeds of 12.8-16.0 k.p.h. Males of this species showed increased degrees of activity with higher wind speeds between 3.2 and 16.0 k.p.h. Females of *O. flexuosellus* were more active in 3.2-6.4 k.p.h. and 9.6-12.8 k.p.h. winds. Below wind speeds of 3.2 k.p.h. and above 12.8 k.p.h. winds,

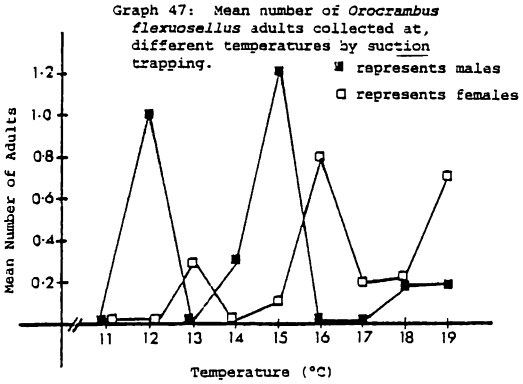

Graph 42: Mean number of adult sod webworms (all species) collected by suction trapping at different wind speeds.


Graph 43: Mean number of sod webworm adults (all species) collected by suction trapping at different temperatures.


Graph 44: Mean number of *Eudonia sabulosella* adults collected at different wind speeds in suction traps.


Graph 45: Mean number of *Orocrambus flexuosellus* adults collected at different wind speeds in suction traps.


Graph 46: Mean number of *Eudonia sabulosella* adults collected at different temperatures by suction trapping.


Graph 47: Mean number of *Orocrambus flexuosellus* adults collected at, different temperatures by suction trapping.

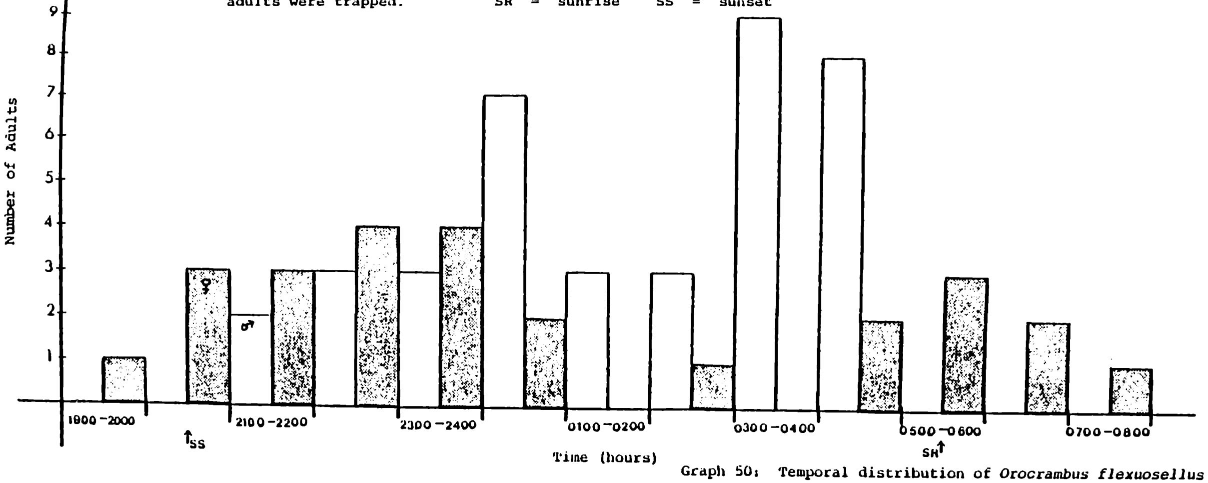
no females were collected. Graph 46 reveals activity by male *E. sabulosella* at all temperatures from 11-19°C except 13 and 18°C. Most activity occurred at the relatively low temperature (11°C). Female *E. sabulosella* were active at 13, 15 and 17°C with most moths collected at warmer (15 and 17°C) temperatures. Graph 47 represents activity of male and female *O. flexuosellus*. Males were collected at 12, 14, 15, 18 and 19°C, with a large peak at 15°C and a smaller one at 12°C. Female *O. flexuosellus* were sampled at 13, and 15-19°C with peaks at 16 and 19°C. Graphs 44-47 therefore show that males were less affected by wind speed than females, in which activity was more confined. Also *E. sabulosella* males and *O. flexuosellus* females were less affected by temperature (i.e. active at a wider range of temperatures) than *E. sabulosella* females and *O. flexuosellus* males.

Graphs 48-50 refer to temporal distribution of sod webworm adults. From Graph 48 it can be seen that female activity occurred mainly in the premidnight and dawn periods. Males were more active around midnight and predawn These patterns are more definite when viewed on a species basis (Graphs 49 and 50). *E. sabulosella* females were active until midnight and around dawn, while males of this species showed some activity after sunset and from midnight to before dawn. There was a peak in male activity around dawn when female activity recommenced. Virtually all the activity by *O. flexuosellus* females occurred from around sunset to midnight with some activity at 0200-0300 and 0600-0700 hours. Activity in male *O. flexuosellus* was confined to 2200 and 0500 hours, with a peak at midnight. This peak in male numbers occurred just after the period of maximal female numbers. There was no correlation (p>0.05, not significant) between time and aerial density of moths. Because of the low numbers of moths involved, suction trap catches have not been related to humidity, rainfall, barometric pressure and lunar cycles. However the three weeks with maximum total catches of sod webworm adults corresponded with the last quarter of the moon.

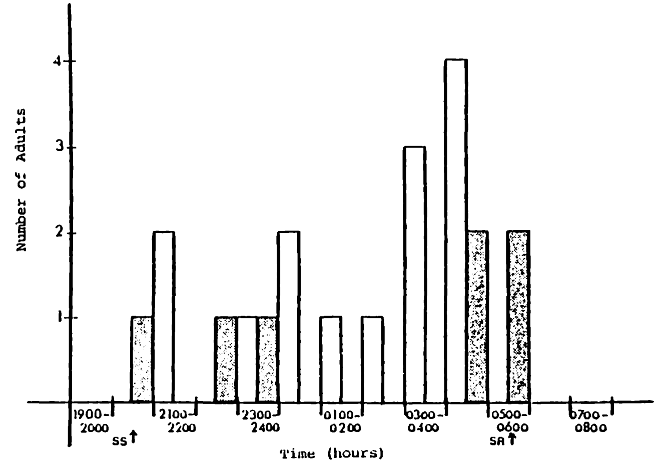
LIGHT TRAPPING

As described in Methods (Ch. 2 p. 29) light trapping was carried out at Long 4A, Whatawhata using a fixed Robinson and Robinson trap; and at St. Andrews, Hamilton; Burchett's farm, Kaimai; and Mission Bay, Auckland using a portable trap. Unless otherwise stated the following information relates to catches from the fixed light trap at Whatawhata. On six occasions in 1980-81 light trapping was continued for a full night and the collecting bag was changed every 30 mins to enable species distribution, sex differences and peak numbers to be assessed. Table XXXVI refers to the species of sod webworms

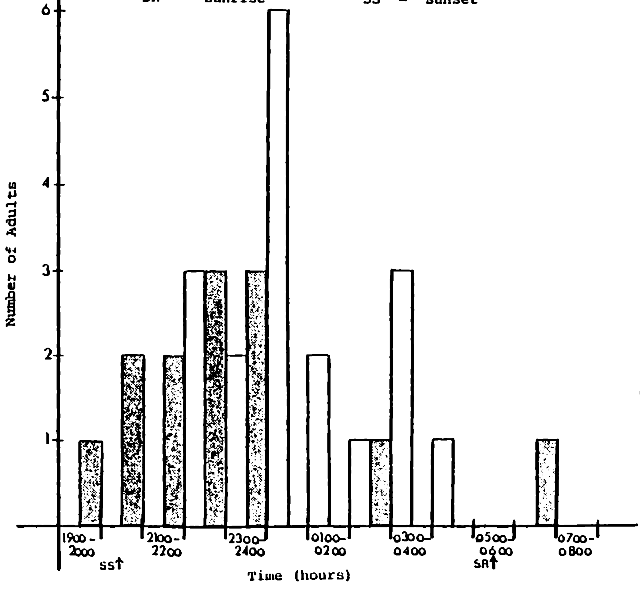
Graph 48: Temporal distribution of sod webworm adults (all species) as sampled by suction traps. All species are combined. Sunrise and sunset times fell within the time intervals indicated during the period adults were trapped. SR = sunrise SS = sunset



Graph 49: Temporal distribution of *Eudonia sabulosella* adults as sampled by suction traps. Sunrise and sunset times fell within the times intervals indicated during the period adults were trapped.
Blank areas represent males. Shaded areas represent females.
SR = sunrise SS = sunset



Graph 50: Temporal distribution of *Orocrambus flexuosellus* adults as sampled by suction traps. Sunrise and sunset times fell within the times intervals indicated during the period adults were trapped.
Blank areas represent males. Shaded areas represent females.
SR = sunrise SS = sunset



collected in the fixed trap at Whatawhata.

TABLE XXXVI. Sod webworm numbers collected by light trap at Long 4A, Whatawhata.

SPECIES	*O. flex*	*O. vit*	*E. psam*	*E. sab*	*"S." bis*	*"S." diph*	*"S." hal*	*"S." phil*	*"S." subm*	*"S." asp*
Number of Specimens	3703	231	356	2105	77	322	59	72	354	11
Number of Males: Females	710:2993	74:157	148:208	1039:1066	20:57	108:214	15:44	31:41	46:308	6:5

See Appendix V for generic name abbreviations.

It can be seen that there is a marked disparity in sex ratios obtained by light trapping in all species except *E. sabulosella,"S." aspidota* and to a lesser extent *"S." philerga*. Light trapping is subject to many sampling errors with an important variation being caused by differential attractiveness of the light to different species or each sex. Nonetheless, light trapping is useful to indicate trends in flight activity and supplements information gained by other means of sampling.

Flight Seasons

Light trapping was carried out from late November 1979 to late February 1980 and early September 1980 to mid February 1981. Appendix IV refers to the dates and numbers of weeks during these trapping periods. The same weeks were used each season for segregation of catches to enable direct comparisons to be made. Table XXXVII is a pooling of light trap data over the two seasons to provide information on time spans of the different species of adults and times of peak numbers.

TABLE XXXVII. Time span and times of peak populations of adults of each sod webworm species (For week number reference see Appendix IV).

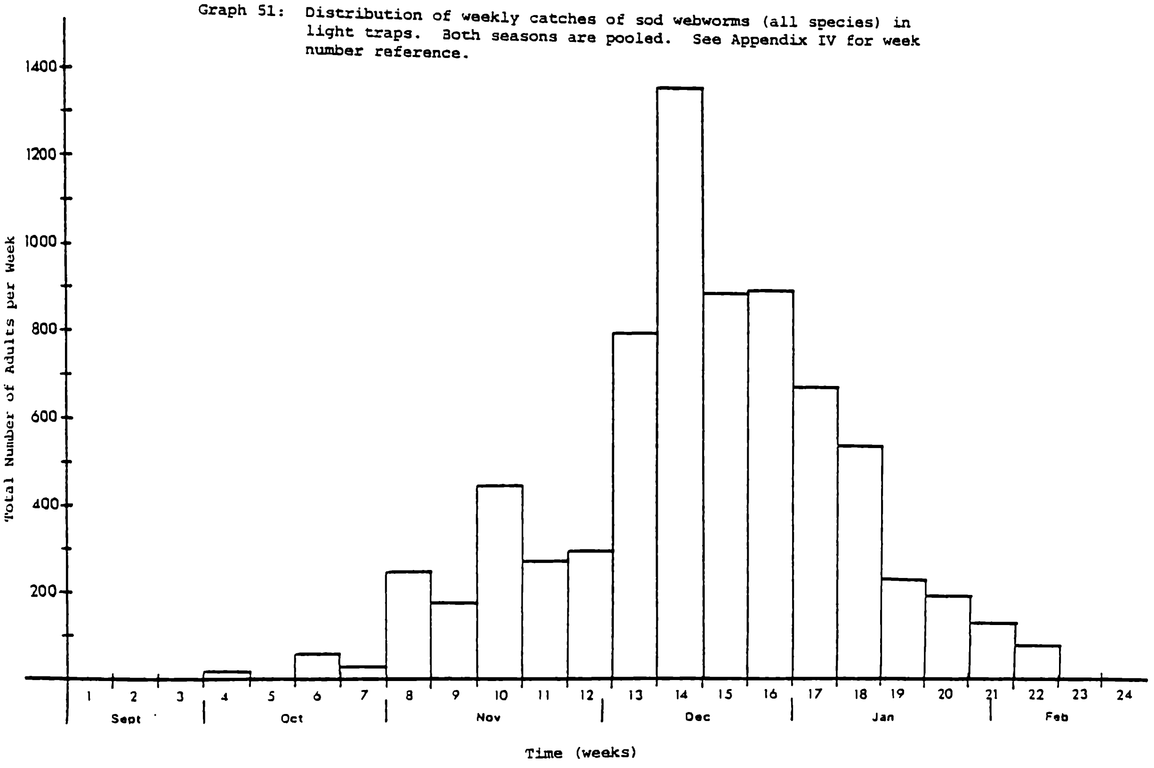
SPECIES	*O. flex*	*O. vit*	*E. psam*	*"S." phil*	*E. sab*	*"S". bis*	*"S." diph*	*"S." hal*	*"S." sub*	*"S." asp*
TIME SPAN (WEEKS)	1,4-22	4,6,8-22	12-22	5-19,21-22	7-22	6-18,20-22	13-22	3,7,12-22	10-22	14,16-17,22
TIME OF PEAK NUMBERS (WEEKS)	8-16	14-18	15-18	10-13	13-18	10,18	15-18	17-18	17-20	14-16

See Appendix V for generic name abbreviations

In most cases peak populations occurred during two to five weeks, but *O. flexuosellus* adults remained plentiful for much longer (see Table XXXVI). Peak numbers of all species were found in December and/or January. In all sod webworms except "*S.*" *bisinualis* peak numbers occurred over several consecutive weeks. "*S.*" *bisinualis,* however, showed two discrete peaks. This species was collected in relatively small numbers (see Table XXXVII) and it was difficult to assign any particular time as coinciding with densest adult populations, whereas the other species collected in low numbers yielded the bulk of the adults sampled during confined periods. Graph 51 represents weekly sod webworm catches pooled for both seasons and all species. It shows that numbers of adults peaked in week 14 (mid-December) and remained at relatively high levels from week 13 (early-December) to week 18 (mid-January). Each season considered individually also peaked at week 14. As shown in Graph 51 numbers built up relatively slowly over September to early November, and fell away rapidly in late January and February. Graphs 52 and 53 refer respectively to *E. sabulosella* and *O. flexuosellus* (the two most abundantly light trapped species) total weekly catches. Again peak numbers occurred in week 14 in both cases (see Graphs 52 and 53). As with Graph 51 there was a slow build up and rapid decline after the attainment of peak numbers. The fall off in numbers was especially marked in *E. sabulosella*.

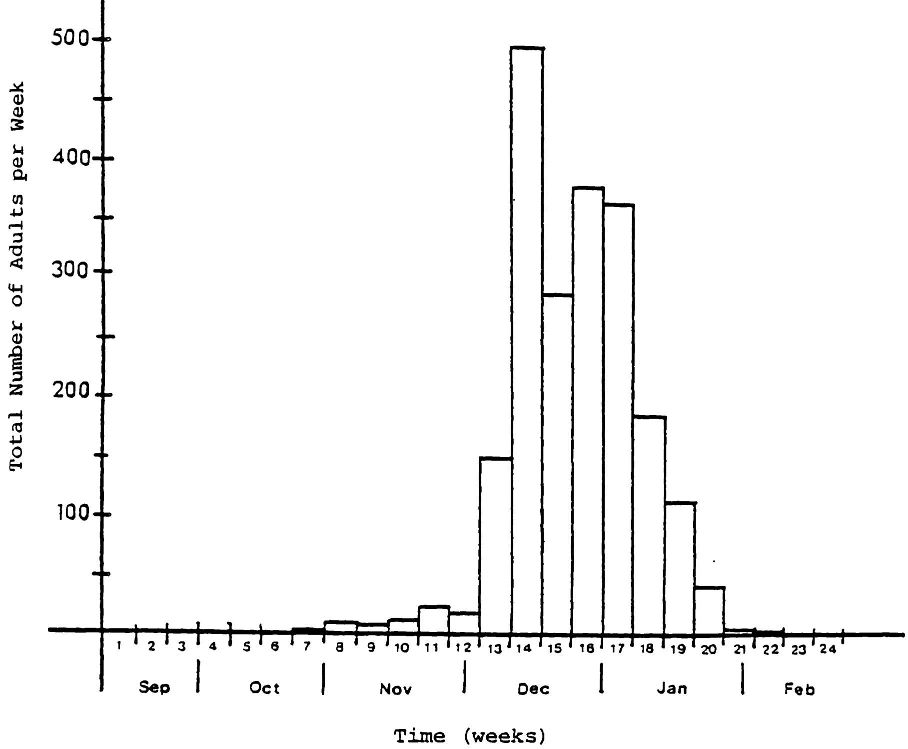
Species and Sexual Differences in Time of Arrival at Light Trap

This information is based on six nights of light trapping during low (0-5 k.p.h.) medium (8-12 k.p.h.) and strong (around 20 k.p.h.) winds (two nights each) in late December-early January i.e. at the time of peak sod webworm adult numbers. The light trap collecting bag was replaced every 30 minutes to enable assessment of time-segregated samples. Graphs 54 and 55 shows the distributions of numbers of *E. sabulosella* and *O. flexuosellus* respectively during the 30 minute intervals for the six nights pooled. The last time interval was 60 minutes long since skies were rapidly becoming lighter during that period. The flight activities of *E. sabulosella* and *O. flexuosellus* as shown in Graphs 54 and 55 are somewhat different. *E. sabulosella* was more active until just after midnight, whereas *O. flexuosellus* was more active from 0100 hours until just before dawn. Most of the *O. flexuosellus* collected were females as compared with a prominence of males of *E. sabulosella*. Both species of females showed two peaks of activity one premidnight (2300-2330 hours in *E. sabulosella* and

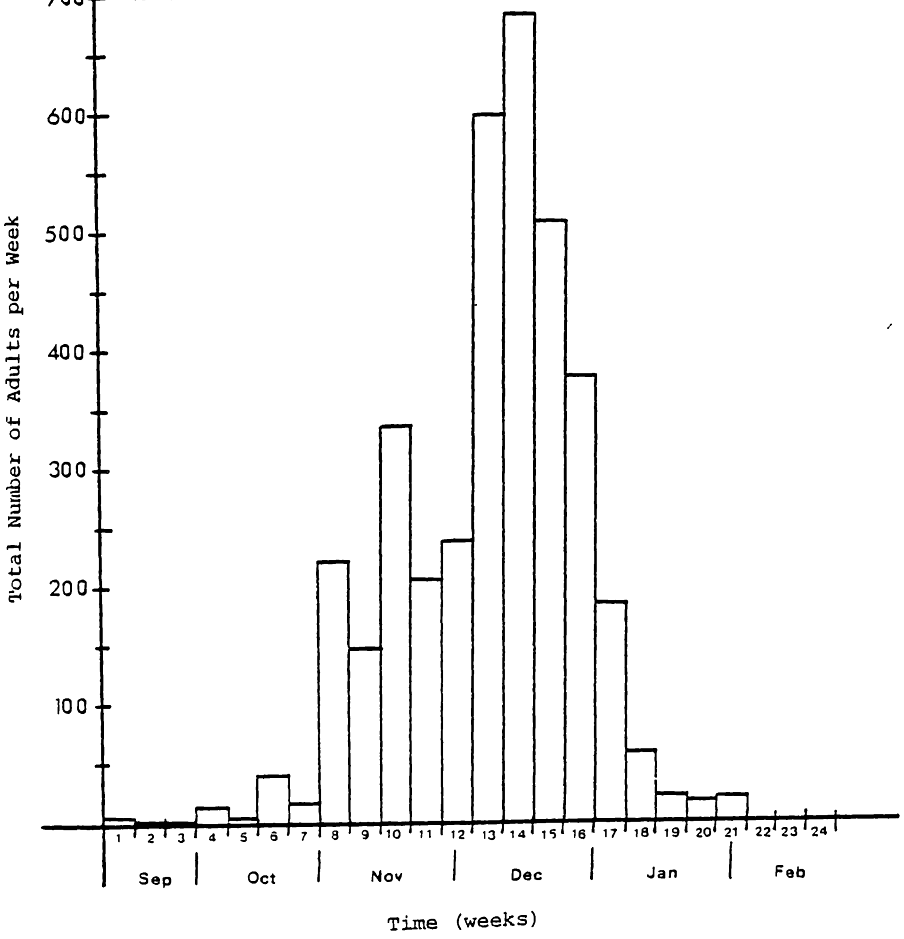


Graph 51: Distribution of weekly catches of sod webworms (all species) in light traps. Both seasons are pooled. See Appendix IV for week number reference.

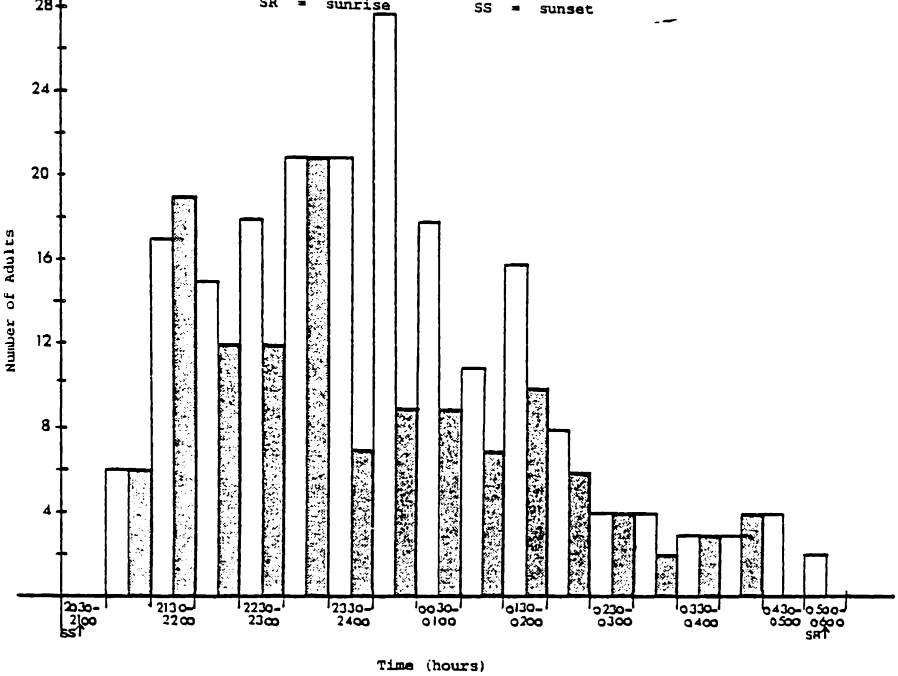
Graph 52: Distribution of weekly catches of *Eudonia sabulosella* in light trap. Both seasons are pooled. See Appendix IV for week number reference.



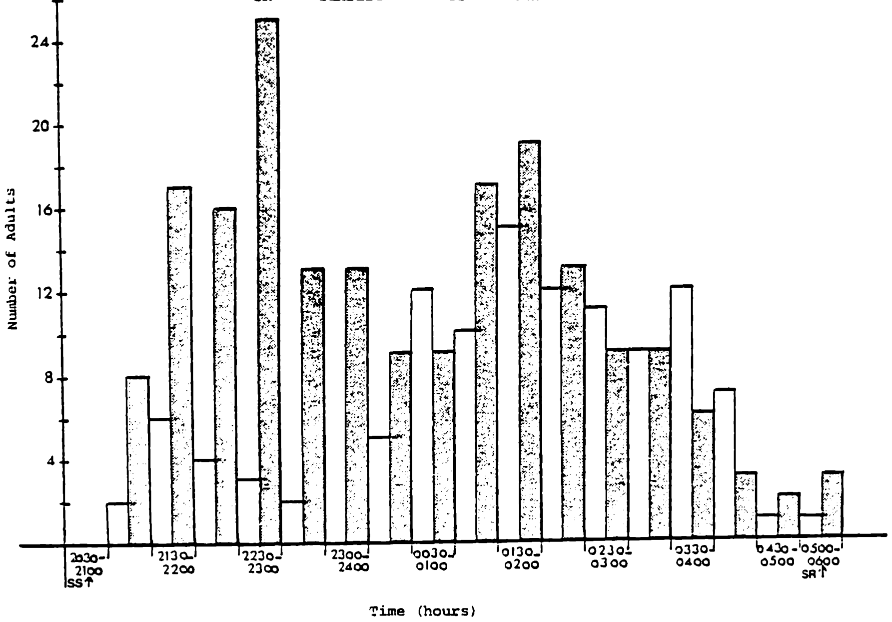
Graph 53: Distribution of weekly catches of *Orocrambus flexuosellus* in light trap. Both seasons are pooled. See Appendix IV for week number reference.



Graph 54: Temporal distribution of *Sudonia sabulosella* adults collected by light trapping. Sunrise and sunset times fell within the times intervals indicated during the period adults were trapped. Blank areas represent males. Shaded areas represent females
SR = sunrise SS = sunset



Graph 55: Temporal distribution of *Orocrambus flexuosellus* adults collected by light trapping. Sunrise and sunset times fell within the times intervals indicated during the period adults were trapped. Blank areas represent males. Shaded areas represent females
SR = sunrise SS = sunset



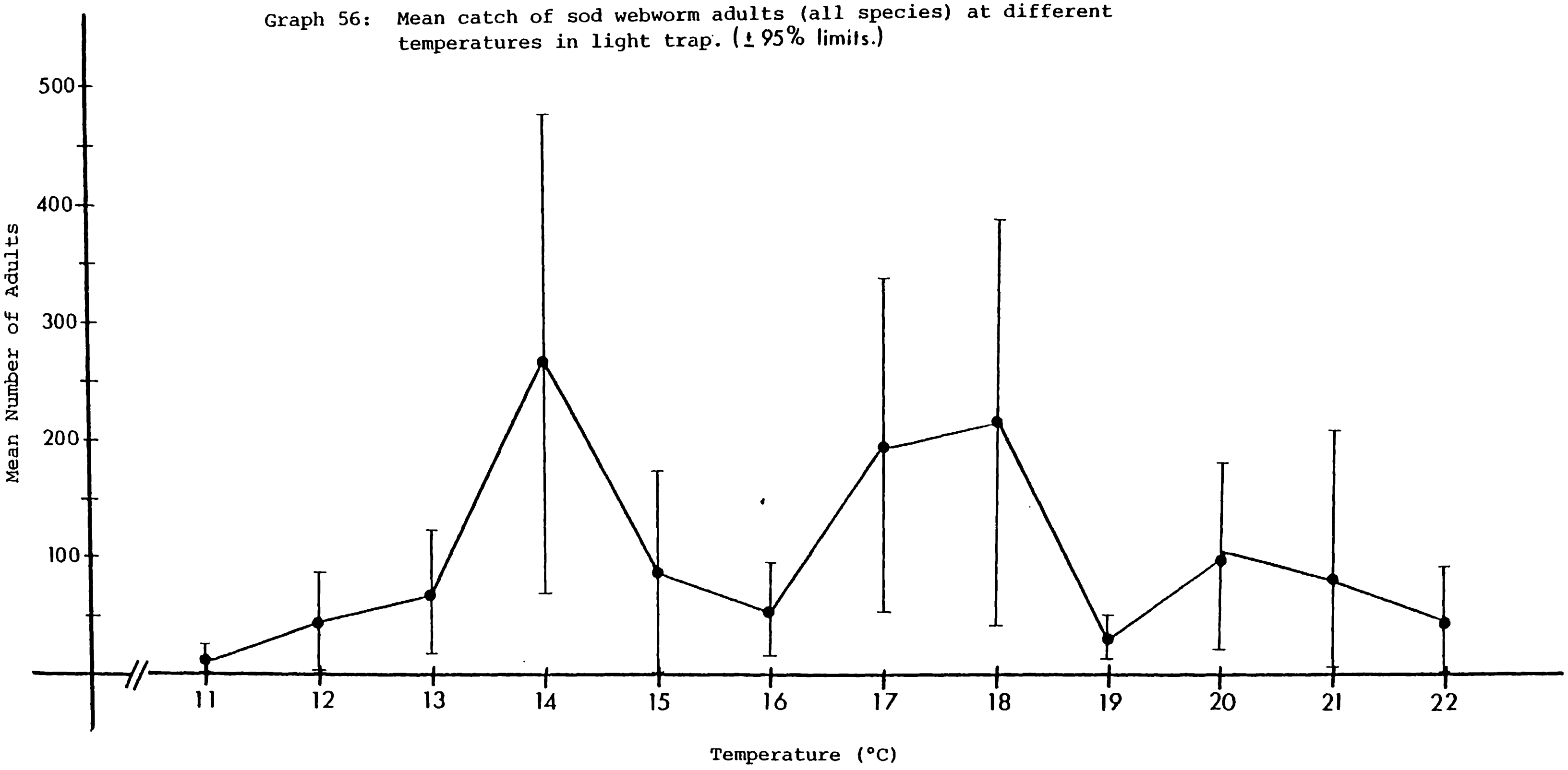
slightly earlier, at 2230-2300 hours in *O. flexuosellus)* and the other early in the morning (0130-0200 hours in both species). This second peak in *E. sabulosella* was only about half the size of the premidnight one. In *O. flexuosellus* the second peak was about three-quarters the height of the earlier one. A 't' test of the difference between means showed that there were significantly more (***$p<0.001$) *O. flexuosellus* than *E. sabulosella* females active throughout the night. *E. sabulosella* males were most abundant at midnight (2400-0030 hours) but premidnight numbers were higher than post-midnight ones. *O. flexuosellus* males attained highest numbers at 0130-0200 hours which coincided with the second activity peak of females of that species. Post-midnight collections of *O. flexuosellus* males were much greater than pre-midnight ones. There were only four time intervals during which male numbers exceeded female collections of *O. flexuosellus* i.e. 0030-0100 hours, 0230-0300 hours, 0330-0400 hours and 0400-0430 hours. Apparently the light as a stimulus is far more attractive to female *O. flexuosellus* than males as collection ratios were 1:1.7 males:females. For most of the night male *E. sabulosella* arrived in equal or larger numbers than females of that species i.e. only at 2130-2200 and 0400-0430 hours were female numbers higher than male ones. ANOVA tests showed that there was no significant difference in numbers of *O. flexuosellus* females and *E. sabulosella* males or *O. flexuosellus* males and *E. sabulosella* females (n.s. $p>0.05$) but there were significant differences between males and females of a species with significantly more *O. flexuosellus* females than males or *E. sabulosella* males than females (***$p<0.01$). The other species of sod webworms arrived in relatively small numbers during the trapping periods. *O. vitellus* females were collected in larger number in the pre-midnight period whereas more *O. vitellus* males arrived post-midnight to dawn. Both males and females of *E. psammitis* arrived in higher numbers in the post-midnight to dawn period with more males slightly earlier in the morning (0030-0100 hours) than females (0130-0200 hours). *"Scoparia" philerga* females were more abundant at dawn than at other times. *"S." submarginalis* females (11 collected) were all pre-midnight. Because other species (or sexes) arrived in very low numbers, trends were not discernible.

Effect of Meteorological Conditions on Light Trap Catches

Temperature

There was no correlation (n.s. $p>0.05$) between temperature and mean catch of sod webworm adults in a light trap. Graphs 56-58 refer to the patterns of change in mean catch with temperature. Graph 56 represents all species of sod webworms with both sexes combined. It can be seen that there were three peaks in catch over the temperature range sampled. At 14°C the peak

Graph 56: Mean catch of sod webworm adults (all species) at different temperatures in light trap. (± 95% limits.)



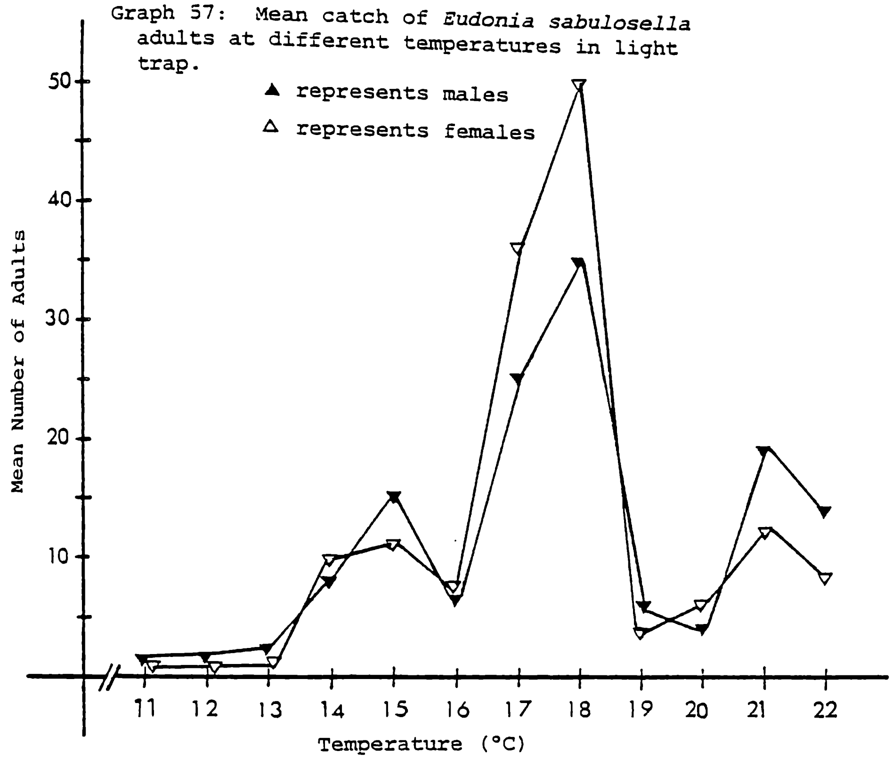
was largest with the smallest one at 20 and 21°C. The mean catch at temperatures of 17 and 18°C was intermediate between these two. There was an overall trend towards decrease in catches at the temperatures above 14°C. Graphs 57 and 58 refer to *E. sabulosella* and *O. flexuosellus* respectively. In these graphs mean catches of males and females have been segregated. Graph 57 shows that in *E. sabulosella* both males and females were trimodal with closely similar patterns of change. The main difference between the sexes was the amplitude of variation in mean catch with temperature. Peaks occurred at 14-15°C, 17-18°C and 21-22°C. Female activity was more confined with respect to temperature than that of males. From 17 to 18°C female mean catches greatly exceeded those of males, but at all other times were either equal to, slightly less than or only slightly above those of males. These findings are similar to those reported for suction trapping (this Chapter) where male *E. sabulosella* were less affected than females by temperature. Graph 58 shows the *O. flexuosellus* females were far more active at a light trap than males of that species. Again the patterns for each sex are markedly similar except that in all cases the amplitude of variation in the female graph greatly exceeds that of the male graph. Peaks in activity occurred for both sexes at around 14°C, 17-18°C and 20-21°C i.e. this species attained highest numbers at lower temperatures than *E. sabulosella*. Female *O. flexuosellus* were more active than males over the range of temperatures sampled. That result also compares with the findings from suction trapping of *O. flexuosellus* (this Chapter).

Humidity

Single classification Model I ANOVA for unequal sample sizes was used to investigate the relationships between different humidities and catch of sod webworm adults in the light trap. Non-significance ($p \gg 0.05$) was obtained for relationships of humidity with all species of adult pooled, or *E. sabulosella* (males and females separately or combined) or *O. flexuosellus* (males and females separately or combined). Species considered separately conformed to the pattern for all species pooled. There was a trend for more adults to be collected at 85% relative humidity followed by 75 and 80%, with fewer adults at 65, 70, 90 and 95% levels.

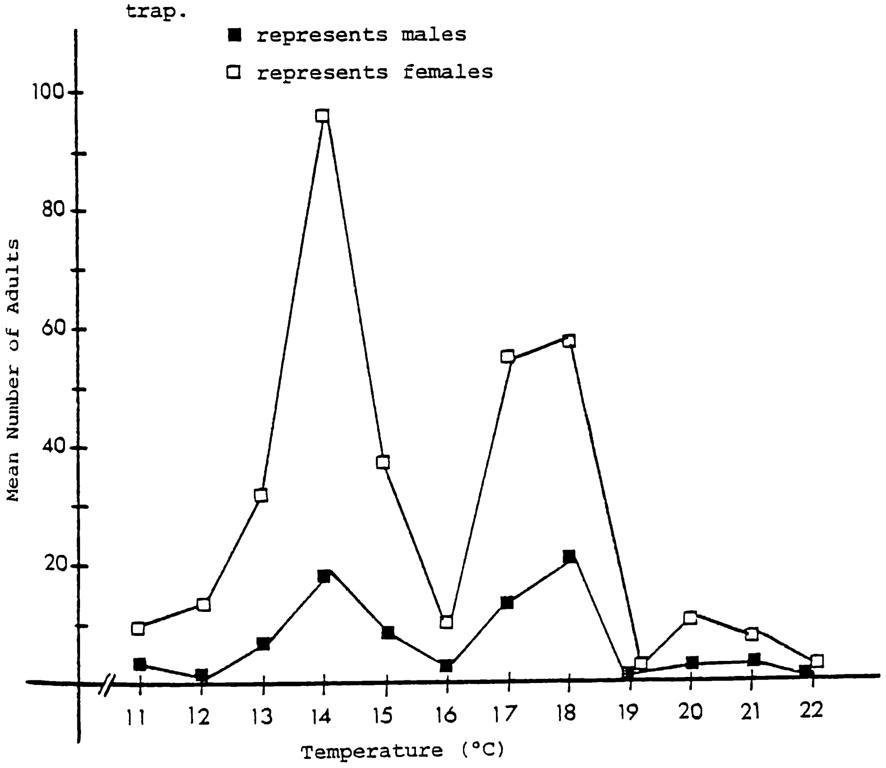
Rainfall

Rainfall during the light trapping period was categorized as shown in Graph 59. A correlation test for mean catch of adult sod webworms in the light trap for each rainfall category provided a significant negative result

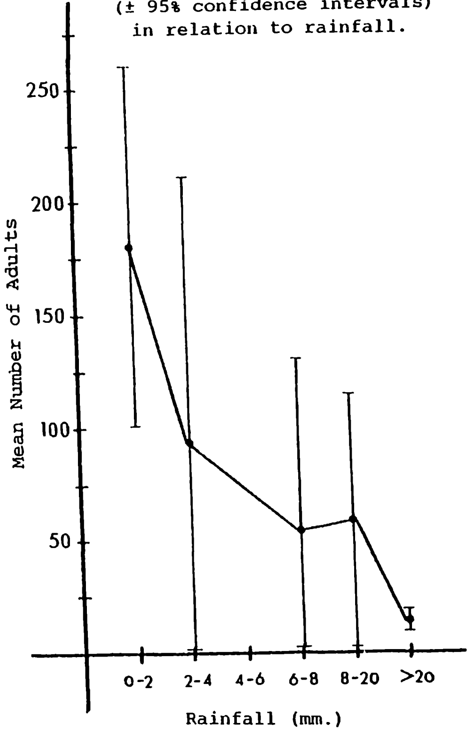


Graph 57: Mean catch of *Eudonia sabulosella* adults at different temperatures in light trap.

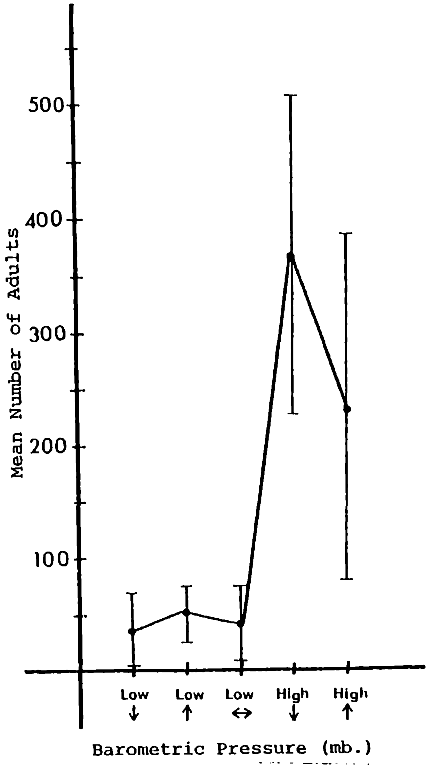
Graph 58: Mean catch of *Orocrambus flexuosellus* adults at different temperatures in light trap.



Graph 59: Mean adult catch in light trap (± 95% confidence intervals) in relation to rainfall.

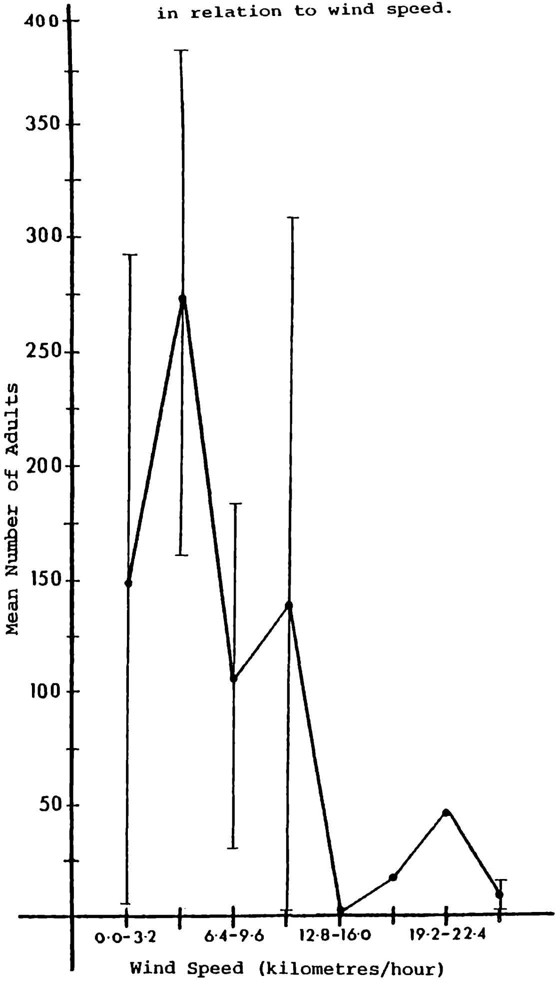


Graph 60: Mean adult catch in light trap in relation to barometric pressure. (± 95% confidence intervals).



Key: Low barometric pressures set as 990-1109 mb.
High barometric pressures set as 1010-1030 mb.
↑ represents a rising barometer
↓ represents a falling barometer
↔ represents a steady barometer

Graph 61: Mean adult catch in light trap in relation to wind speed.



($r=-0.89^{*}$ $p<0.05>0.01$). This indicates that mean catches were highest at lowest rainfall levels. Thus light rain stimulates flight whereas heavier rain inhibits activity. The catch : rainfall trends of *E. sabulosella* and *O. flexuosellus* approximate that of Graph 59 and similarly produced significant negative correlations (*$p<0.05>0.01$). Further evidence for the stimulation of flight activity by light rain was gained during one of the all-night light trapping sessions. On that one night between 0015 and 0045 hours there was light rain (0.8mm). This produced an immediate increase in numbers of *O. flexuosellus* adults (see Graph 55) at 0100-0200 hours and a slightly delayed increase in *E. sabulosella* (see Graph 54) at 0130-0200 hours. The increase in activity was spectacular such that while changing the light trap bag at 0130 hours I was bombarded with aerial insects. Virtually all the adults shown in Graphs 54 and 55 for the period 0100-0200 hours relate to that one sampling occasion.

Barometric Pressure

Barometric pressure was categorized as high (1010-1030mb) or low (990-1009mb). It was also noted whether a rise (↑), fall (↓) or steady (↔) reading was obtained. Graph 60 refers to mean catch of all species of sod webworm adult collected in a light trap in relation to barometric pressure. A single classification Model I ANOVA for unequal sample sizes yielded a significant result (*$p<0.05>0.01$). It was further found that all catches during low barometric pressure (whether on a rising, falling or steady barometer) were not significantly different from each other (n.s. $p>0.05$) but they were significantly different from catches during a high barometer (***$p<0.001$). Thus markedly more moths were collected during high barometer readings than low ones. However there was a further significant difference between high and rising versus high and falling barometer readings such that markedly more moths were collected during high, falling barometer readings (***$p<0.01$). This finding agrees with the above result where rainfall increased flight activity. A high, falling barometer is most often associated with a passing cold front which usually yields rain. The possibility exists of insects' sensing the associated ionic changes (cf. Helson and Penman,1970). As shown in Biology (Ch.5 p.91) light rainfall also coincides with increased oviposition.

Wind Speed and Direction

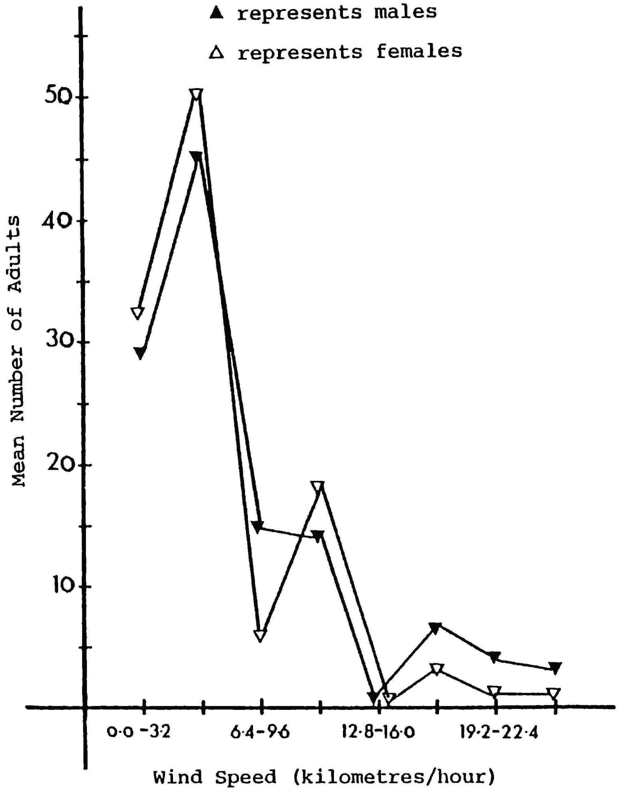
As described in Methods (Ch. 2) wind speed and direction was measured during the trapping period using an anemograph. Wind speeds were categorized into the same intervals (3.2 k.p.h.) as used in suction trapping, to allow direct comparison. Graph 61 refers to the change in mean sod webworm adult catch in relation to wind speed. A significiant negative correlation ($r=-0.82$ $^{*}p<0.05>0.01$) was obtained. This indicates highest catches in the light trap during lowest wind speeds, as shown in Graph 61. As can be seen there was a marked drop - off in catch of adults at the highest wind speeds. Graphs 62 and 63 refer to the above factors for *E. sabulosella* and *O. flexuosellus* respectively. Female and male *E. sabulosella* have closely similar reponses to wind speed as do *O. flexuosellus* males and females except that the magnitude of response in female *O. flexuosellus* far exceeds that for males of that species. This is mainly due to the previously stated predominance of female *O. flexuosellus* attracted to the light trap. Graphs 62 and 63 can be compared with Graphs 44 and 45 for suction trapping. *E. sabulosella* males present a similar trend for both light and suction trapping (Graphs 44 and 62). Female *E. sabulosella* produced a second activity peak in 9.6-12.8 k.p.h. winds with light trapping compared with 12.8-16.0 k.p.h. winds with suction trapping. Apart from that difference *E. sabulosella* presented similar wind-related responses for both suction and light trapping except that the catch magnitude differed greatly. *O. flexuosellus* females presented similar responses to wind speed for both suction and light trapping (see Graphs 45 and 63), with peaks in each case at 3.2-6.4 k.p.h. and 9.6-12.8 k.p.h. winds. Male *O. flexuosellus* showed quite different responses to wind speed for each sampling method. During light trapping males showed maximal acitivity at 3.2-6.4 k.p.h. winds (i.e. coinciding with females) and an overall decrease of higher wind speeds. The suction trapping graph (Graph 45) shows *O. flexuosellus* males increased activity levels in winds of up to 12.8-16.0 k.p.h. with a rapid decrease at higher wind speeds.

There was a significant difference between means of adult catch for easterly or westerly wind directions (*** $p \ll 0.001$) with more moths collected during winds from the east. Also, a Model I ANOVA for unequal sample sizes yielded a significant result ($^{**}p<0.01$) for catch size in relation to NE, NW, SE or SW winds. Significantly more moths were collected during SE winds; second most during NE winds; and about equal but lower numbers during NW or SW winds.

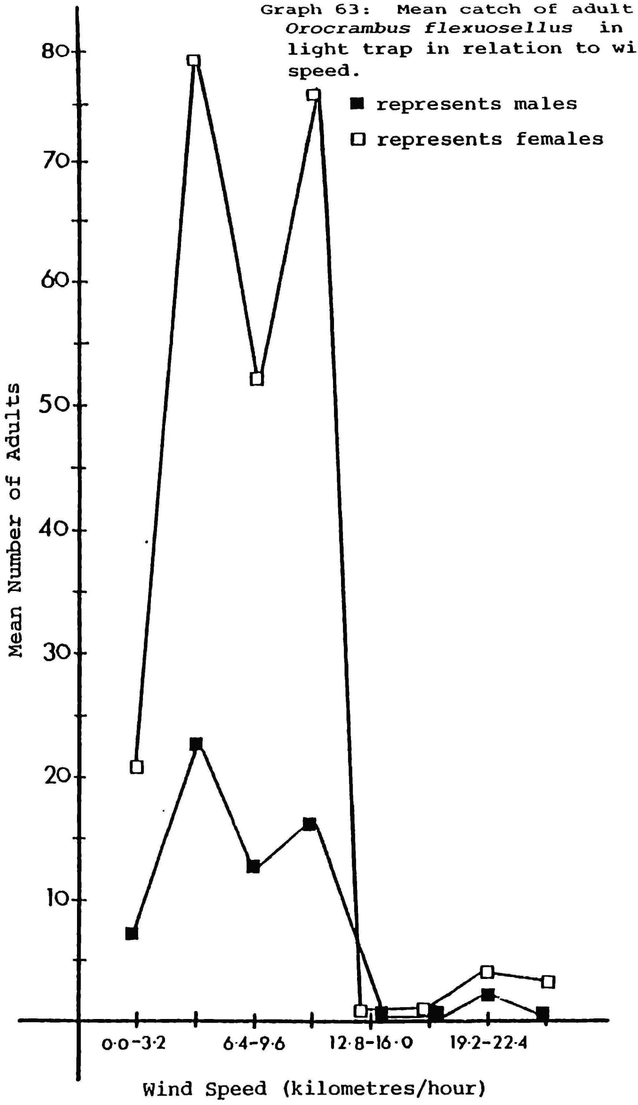
Cloud Cover

There was a significant correlation ($^{**}p<0.01$) between cloud cover and catch of sod webworm adults in a light trap. More moths were collected by the trap on cloudy nights (i.e. when there was more than 25% of the visible sky

Graph 62: Mean catch of adult *Eudonia sabulosella* in light trap in relation to wind speed.



Graph 63: Mean catch of adult *Orocrambus flexuosellus* in light trap in relation to wind speed.



obscured by cloud - see Methods Ch. 2). It was observed that on clear nights (i.e. up to 25% cloud cover) there seemed to be as much activity by moths over pasture but fewer adults were attracted to the light trap. On cloudy nights the sky was generally darker so the contrast with the light trap may have been heightened possibly rendering the trap more attractive.

Lunar Cycle

Graph 64 shows the weekly total catch of sod webworm adults in the light trap. Superimposed on the graph is the lunar cycle for those weeks (as derived from the N.Z. Nautical Almanac, see Appendix II). As can be seen from Graph 64, peak catches corresponded either with the first or last quarter i.e. prior to or proceeding full moon weeks. In 1979-80 there was a definite lunar pattern in the weekly sod webworm adult catches. Peaks at weeks 14, 18 and 22 corresponded with the last quarter moon phase and there was a definite catch reduction at weeks 17 and 21 coinciding with the full moon phase. In 1980-81 peaks at weeks 6, 10 and 14 corresponded with the first quarter of the moon and those at weeks 8 and 16 with the last quarter. At weeks 15, 19 and 20 catch decreases coincided with the full moon.

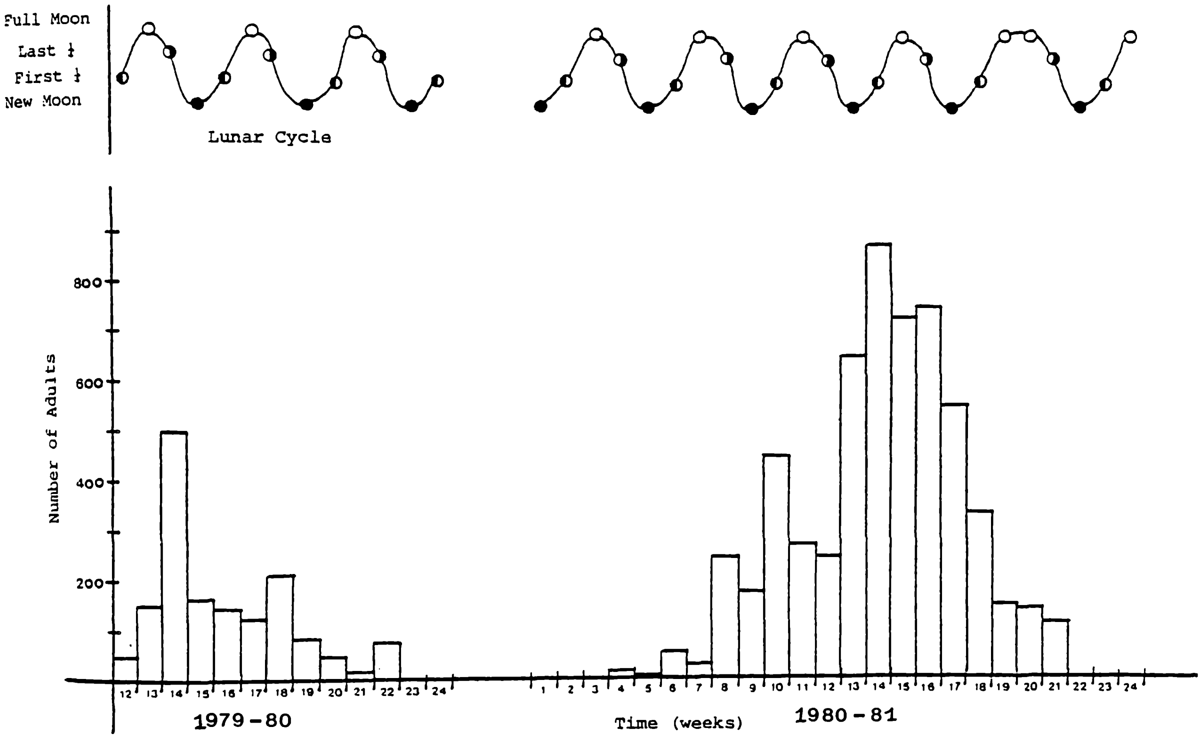
Reproductive State of Entrapped Females

Throughout the season up to five females collected each light trapping occasion were dissected. Most of those collected by suction trap were also dissected. All females had been mated (usually several times, see Biology Ch. 5) and contained few large or mature eggs, suggesting they were older adults rather than newly emerged ones. This finding also supports the previously stated observation of older females, which had laid most or all their mature eggs, being more actively flying. The fact that females were collected in the suction trap which was set 1.5m above ground and "supposedly non-attractive" (Johnson, 1950a) indicates they were flying freely. Young females were collected by hand from the region 0-0.5 metres above ground and usually flew for only short distances before landing. Older females flew higher into the air and travelled greater distances before settling. Females collected on sticky plates up to 0.65m above ground were all characterized by large numbers of mature eggs. Those females on the trap up to 1.15m above ground had some, though fewer, mature eggs.

Portable Light Trap

The portable light trap was used as stated previously at St. Andrews Golf Course, Hamilton; Burchett's farm, Kaimai; and at private residences in

Graph 64: Weekly total catch of sod webworm adults in light trap compared with lunar cycles. See Appendix IV for week number reference.



Mission Bay and St. Heliers, Auckland. This trapping was undertaken to provide an indication of species compositions at these localities which was supplemented by other methods of collection. Also it provided adults in good condition for taxonomic or rearing purposes. The same patterns of species and male or female arrival at the trap occurred with the portable trap as reported above for the fixed one at Whatawhata.

DISCUSSION

The Malaise trap did not appear to be very suitable for the collection of sod webworm adults. Bidlingmayer and Hem (1979) noted attraction of mosquitoes to large conspicuous objects. However, avoidance reactions occurred in close proximity to them. The observance of sod webworm adults at Whatawhata travelling towards then over the Malaise traps may have been avoidance behaviour. Malaise traps should provide unbiased collections as they do not rely on lures or mechanical action (Clark, 1979) for the capture of insects. However, such traps do rely on the insect's behaviour from the initial landing on the central sheet area to the upward movement into the collecting vial. Any avoidance reactions or movement in the slip stream over and away from the trap would result in vast reductions in the numbers of insects captured.

Sticky plate captures are subject to numerous errors (Johnson,1950b; Taylor,1962c; Southwood,1978). Clearly, the habitat in which sticky surfaces are located affects the species composition of the catch (cf. Mellanby, 1962). Neglecting the effects of turbulence, impaction and momentum of insects in sticky surface catches as well as assuming that insects are not diverted by the slip stream around the trap still leaves errors due to wind speed and insect size (Johnson,1950b, Southwood,1978). Johnson (1950b) stated that aerial density usually changes in inverse order to wind speed, with trap efficiency varying with changes in wind speed. Taylor (1962c) showed that for small sized insects the sticky plate was almost constantly efficient in winds from 3.2-16.0 kilometres per hour (2-10 m.p.h.) such that an insect's behaviour played little part in its capture. However larger insects seriously affected trap efficiency at all wind speeds by their avoiding or alighting reactions (Taylor,1962c). Because sod webworm adults (*Eudonia sabulosella,* in particular) were observed to alight on sticky plates their value in the assessment of numbers is doubtful. However, by using traps at different heights an indication of the relative proportions of adults, species or sexes in each zone was gained. It was noted whether colour preference was exercised and how that changed with wind speed. At higher wind speeds there appeared to be no colour choice indicating the adults were blown on to the plates. At lowest wind speeds there was a definite trend towards settlement on light coloured plates indicating selective alighting. Preference for the lighter plates suggests that camouflaging is important. Scopariine adults were observed (see Orientation) to settle on lighter coloured seed heads and were thus difficult to locate. In common with Crawford (1970b) the inconspicuosness of settled crambine adults was also noted. Significantly more adults were collected from the traps in the 0.35-0.65m zone. Also more of these adults were females compared with similar numbers of each sex obtained from the traps set at other heights. Such a finding suggests that females were more usually engaged in "trivial" flights i.e. within the boundary layer of air and only travelled short distances in flights quite near the ground. Characteristically those flights are representative of gravid females implying that many of the females within an area, of necessity, oviposit there.

Frame counts revealed that *Eudonia sabulosella* was indeed the most common sod webworm species on southern hill country slopes. *E. sabulosella* was almost exclusively confined to slopes of east through south to west compass directions, with significantly more moths on west, southwest or south facing slopes (***$p<0.001$). The most important factor which limited the dispersion of adults appeared to be wind speed and direction or any factors correlated with changes in wind. When wind speeds were below five kilometres per hour adults were found over a wider range of slopes of various orientations for east to west. When wind speeds were above that level, more moths were found on leeward slopes with largest aggregations on slopes diametrically opposite the wind direction. It appears that sod webworm adults are congregated and retained in certain areas by the wind (or factors positively correlated with wind). Again, there is a high probability that adults recorded within an area breed there. The daily variability in dispersion of adults was considered in relation to sweep netting (see Population Dynamics Ch. 6). For this, sweeps were made on the same day and across slopes of the same orientation at each site to enable comparisions between sites. Table XXXIV revealed greatest dispersion of adults and highest numbers per m^2 during 9-30 December. These findings, corresponding to weeks 13 to 16 or 17 (Appendix IV) support the light trap results of Graphs 51 and 58 which showed maxima during those times. Frame counts produce absolute population levels whereas light trapping is a relative method (Southwood 1978). The fact that trends from each type of sampling coincide suggests that light trapping may accurately indicate population changes of hill country sod webworm adults.

There was no indication that sod webworm adults avoided the suction traps. Although only three adults were actually observed to be collected, no avoidance reaction occurred in close proximity of the trap. The moths merely continued to fly until removed from the air by suction. Sod webworm adults were collected in winds of up to 16 kilometres per hour (k.p.h.) and traps were operated in winds of up to 19.2 k.p.h. It was suggested by Johnson and Taylor (1955) that the type of suction trap used (Vent Axia) should be operated within three metres of the ground or where winds were less than 24 k.p.h. Both these aspects were observed for the operation of suction traps at Whatawhata. According to Johnson (1950a) the trap samples a constant rate of air in winds up to 20 k.p.h. Taylor (1955) listed several factors which affect the operation of suction traps such as the fans themselves being rarely, if ever, identical and therefore sampling different volumes of air; resistance of the cone altering air flow through the trap; the speed of the motor which may vary with changes in the electrical supply with time of the day or year, or length of cable used; and wind across the trap altering pressure system, air densities etc. Taylor (1962b) provided formulae for conversion of the number of insects collected to log catch (aerial density) taking account of wind speed, size of insects collected and trap size. These formulae were used in the calculation of aerial densities of sod webworm adults at Whatawhata.

The suction trap is valuable for sampling over a wide variety of insect densities in nearly all climatic conditions (Taylor,1962a). Williams and Singh (1951) found that in light or suction trapping there was a peak in catch size shortly after the new moon. However Williams *et al.* (1956) could not prove conclusively the effect of moonlight on catch size. Bowden and Gibbs (1973) found that moist southerly air streams associated with frontal conditions produced increased insect activity. Temperature, time of day and wind speed were found by Goldson and Emberson (1977) to be correlated with flight activity in the potato moth (*Phthorimaea operculella*). Activity of that moth was reduced in wind speeds above 21.6 k.p.h. (6 m/sec). In the present study relatively few sod webworm adults were collected by suction trapping. No significant relationship was found between adult numbers and temperature, time of day or wind speed. The three weeks with maximal catches of sod webworm adults corresponded with the last quarter moon phase. This may have been a lunar effect as found by Williams and Singh (1951) but since adult numbers were low no definite trends can be developed.

Light trapping is subject to numerous errors (see Verheijen,1960; Southwood,1978). Serious variations in trap efficiency occur from insect to insect or night to night since light trap functioning relies on the disturbance of "normal" behaviour (Southwood,1978). Several of the problems listed by Southwood relate to contrast of the trap with the surroundings which depends on e.g. cloud cover, moonlight, shadowing from nearby objects, or adjacent lighting; withdrawal by the insect in close proximity to the trap; and the insect's ability to change its approach reaction to avoidance which is dependent upon its size and flight speed. The "phase" of an insect refers to its susceptibility to be caught or to respond to a trapping stimulus and according to Southwood (1978) that may change with age. Light trapping therefore produces relative estimates of population size, being essentially a measure of the proprotion of individuals in "phase" to respond to the trap and actually doing so under given climatic conditions during a particular level of trap efficiency. Unfortunately trap efficiency is an unknown factor. Verheijen (1960) suggested that the best considerations for night-flying insects collected by light were : use of an isolated source of light; use of wavelengths to which insects were most sensitive; dark nights without moonlight; trapping in a dark environment; and a light field without shadows from nearby objects. Although trapping was continued during all phases of the moon all the above factors were utilized at Whatawhata. At the collecting site, apart from the light trap, no lights were visible except the distant glow of Hamilton city (more than ten kilometres away in a direct line). Despite the above misgivings light trapping was used extensively at Whatawhata to indicate, in particular, the types of meteorological conditions which resulted in large catches of sod webworm adults. It was thus hoped that patterns of adult congregations and dispersals could be understood to indicate those pastures susceptible to sod webworm attack.

Williams (1935, 1939, 1940) carried out comprehensive studies on insect flight activity as indicated by light trapping. His work revealed distinct species and sex differences in temporal distribution of flight activity. However there was no definite relationship between temperature or rain and catch size. High relative humidity and a high barometer produced more activity and catches were better under cloud or in non-full moon weeks (see also Williams and Singh (1951) and Williams *et al.* (1956) as discussed above) as well as when wind speed was below 32 k.p.h. (20 m.p.h.). Glick *et al.* (1956) showed that moonlight increased general activity although Lepidoptera appeared to be more active on dark nights and in winds below 9.6 k.p.h. (6 m.p.h.). Bowden and Gibbs (1973) suggested that apparent lunar periodicity in catch size may be due to the decreased efficiency of the trap (reduced contrast) but if it was a real effect could serve to synchronize life cycle processes. Bowden and Morris (1975) reported steady declines in catches of Pyralidae in Africa from new to full moon. However, most taxa were trapped more frequently around full moon. The problem therefore is to apply some correction factor to catches to compensate for trap efficiency variations. Perhaps the best check is to use several methods of collection simultaneously (Bowden and Morris 1975; Southwood 1978). This approach was taken for the study of sod webworm adults.

Ainslie (1917) studied Crambinae at lights and showed that catches depended on the time of the life of the moth i.e. most females had laid their eggs before attracted to lights. In sudies of sod webworm adults at Whatawhata most females had few mature eggs i.e. they were older specimens. The suggestions therefore of the use of light traps to control insect populations have little advantage for sod webworms. Ainslie found increased numbers of moths after rain but showed that catches were not dependent on temperature or humidity. Most females appeared at dusk while later in the night virtually the entire catch was composed of males. Banerjee (1967a) also studied Crambinae by light trapping and found most females arrived in the pre-midnight period but most males were collected post-midnight. Strong wind (speed was not defined) was found to be restrictive on flight and rain inhibited activity. In the present study, sex ratios varied with species due to differential receptivity to the light stimulus (see Southwood 1978). Times of arrival of the different species varied as did activity of each sex. Most *Eudonia sabulosella* adults arrived pre-midnight but peak activity occurred in females at 2300-2330 hours and in males at midnight (2400-0030 hours). Most female activity therefore occurred just after oviposition (see Biology Ch. 5 p.89). Most *Orocrambus flexuosellus* females arrived pre-midnight (2230-2300 hours) while most males of that species arrived early in the morning (0130-0200 hours). It is therefore important to identify species and determine sexes in light trap collections. There was no correlation between catch size and temperature but the same patterns of activity were observed for both light and suction trapping. Male *E. sabulosella* and female *O. flexuosellus* were less affected than their counterparts by temperature. There was a trend towards higher catches at relative humidities of 75 to 85%. Rainfall significantly affected catch size such that light rain stimulated while heavier rain reduced flight activity (cf. Cumber,1950; Cowley,1982). This finding also corresponds with increased ovipositional activity in low rainfall weeks (see Biology Ch. 5). A high but falling barometer (i.e. most usually associated with rain) caused increased activity. Wind speed had a marked effect on catch size and similar responses were obtained with both light and suction trapping for male and female *E.* sabulosella and female *O. flexuosellus*. Usually, light winds (to about ten k.p.h.) stimulated activity whereas high winds (above 16 k.p.h.) reduced activity.

Smaller catches at higher wind speeds may have been due to the wind carrying adults away from the trap. Under calm or light wind conditions adults were observed to fly to the light trap then simply drop into it. However, at high wind speeds (16.0 k.p.h. and above) moths were observed to move past the trap in the direction of the wind. Usually however, few moths were airborne in very strong winds as most remained at the bases of grasses. However, any moths resting higher up grass stems or flying within 0.5 metres of the ground were seen to be carried (or stimulated to fly) high into the air on wind turbulence eddies. Winds from easterly directions (especially south-east) resulted in larger catches than those from westerly directions. Better catches occurred under cloud cover and the first or last moon quarter indicating the light trap may have been more efficient at such times because of the darker skies. It must be stressed that any correlations with a single meteorological event are misleading as these factors often do not operate alone i.e. any particular factor is usually interrelated with other conditions, and a correlation with a single factor also means a relationship with the interrelated or inseparable variables (see Hurnard,1978). If nothing else light trapping provides a useful survey of the presence of sod webworm species even though many of those collected may not be economically important (see Heinrichs and Matheny,1970; Matheny and Heinrichs,1975). In common with the present study Cumber (1950, 1951) and Gaskin (1964, 1970) also found *O. flexuosellus* to be the most frequently light trapped species.

The association of flight activity and weather changes may be due to the perception by insects of ionic variations in atmospheric electricity which occur before and during weather changes (Uvarov,1931; Wellington,1957; Richards,1965). Helson and Penman (1970) monitored the diurnal cycle of ions and found a peak in ionic activity about 30 hours prior to rain. They found that adults of Hepialidae, Noctuidae, Crambinae and Tipulidae emerged at that time.

The factors which appear to exercise the most control over sod webworm activity (at least in *Eudonia sabulosella* and *Orocrambus flexuosellus)* are windspeed and direction, rain and a high but falling barometer. Wind speed and direction (as seen from frame counts, suction trapping and light trapping) are especially important, aggregating sod webworm adults on east-south-west facing slopes and retaining populations there when wind speed exceeds about 16 k.p.h. Many of these adults may have travelled considerable distances to the trap. For example, on one occasion when wind speeds were around 29.5 k.p.h. and from the SW to W direction a marine caddis (*Philanisus plebeius* see Appendix III) appeared in the light trap collection for that night. In a direct line, the west coast at Raglan (nearest possible habitat for that species - D.R. Cowley, pers. comm.) to the light trap is at least 15 kilometres. Cumber (1950) released marked noctuid adults 800 metres (0.5 miles) from a light trap at Paiaka (New Zealand) and recorded them in the light trap collection the same night. There were numerous occasions on which a NE wind resulted in large collections of *Aoteapsyche catharinae* (see Appendix III) which inhabits large rivers such as the Waipa (D.R. Cowley, pers. comm.), around five kilometres in a direct line and NE of the light trap. In these particular instances where insects with special requirements have been collected by the light trap, their direction of travel from habitat to light trap coincides with the wind direction. It is possible that sod webworm populations were similarly affected. Wind speed and direction appears to be especially significant in sod webworm population dynamics on hill country pasture.

CHAPTER NINE

CONCLUDING DISCUSSION

This study was instigated in August 1978 in response to the extreme damage caused by sod webworms on some south-facing hill country slopes in the Waikato, New Zealand. At that stage it was thought that damage was attributable to *Orocrambus flexuosellus* (Doubleday) (Crambinae). Several species of sod webworms were collected on hill country and taxonomic studies undertaken on eggs, larvae, pupae and adults indicated that Scopariinae were also involved. The species collected were *Orocrambus flexuosellus* and *Orocrambus vitellus* (Doubleday) (Crambinae); *Eudonia psammitis* (Meyrick), *Eudonia sabulosella* (Walker), *"Scoparia" bisinualis* Hudson, *"Scoparia" diphtheralis* Walker, *"Scoparia" halopis* Meyrick, *"Scoparia" philerga* Meyrick and *"Scoparia" submarginalis* (Walker) (Scopariinae). On lowland mossy regions (such as St. Andrews Golf Course, Hamilton) all the above species occurred but *"S." submarginalis* was the most common. Lowland pastures with little moss and north-facing hill country slopes supported populations of *O. flexuosellus* and *O. vitellus* though always at low densities during this study. *Eudonia sabulosella* was economically the most important species on south-facing hill country slopes and was the only species involved in damage in 1978. It seems that species dominance changes in relation to pasture species composition (especially the moss content) and topography (aspect). Continued monitoring of these endemic lepidopterans is therefore of prime concern in New Zealand.

An understanding of some aspects of the biology and population dynamics (the latter exclusively for *Eudonia sabulosella)* was gained. The life cycle and growth rates of *E. sabulosella* on hill country were determined. Life cycles were also established for the other species. It was ascertained where *E. sabulosella* oviposited and habitats of the other life stages were identified. Host plant ranges of larvae were investigated for most species and found to be very broad, a factor enhancing the widespread distribution of the species complex. Adult longevities were far longer than overseas studies on sod webworm (Crambinae) indicated. Female fecundities were lower than in overseas crambine studies, but in the present investigation these were determined from field collected females because of high mortalities in reared populations. There is no comparable work on Scopariinae. Egg fertility and viability levels were very high indicating most mortality occurred later in the life cycle. Effects of moisture and temperature on egg incubation times were studied and showed that high humidity, and temperatures around 25°C resulted in the most rapid development. Sex ratios were markedly affected by collection methods. Huge disparities in sex ratios occurred for most species of light trapped adults. Reproductive maturity and mating were also studied and most females were found to be mated several times. Lists of contemporaneous species on hill country were also compiled.

Population dynamics studies with the production of life tables for *Eudonia sabulosella* on hill country pasture were made for three generations at four sites. These were not of the conventional life table form due to the very low or endemic levels of the populations studied. However, it was possible to identify key mortality factors especially those affecting late stage larvae. These are the first life tables developed for sod webworms or indeed, for a hill country insect in New Zealand. Empirical evidence suggested 20-25 larvae per m^2 were sufficient to cause pasture damage. Due to the collapse of sod webworm infestations in 1979 (i.e. just after sampling programmes had been fully established) damage assessment studies were not possible in the course of this research.

Investigation of mortality factors in *E. sabulosella* revealed that parasitism by *Aucklandella geiri* DallaTorre (Ichneumonidae) occurred only at very low incidence. Arthropod and avian predation also existed with the latter being especially marked in December. Disease due to the neogregarine protozoan (*Mattesia* sp.) occurred at very high levels with epizootics in 1979 and 1981. This suggested that once present in an area the protozoan maintained itself even at low host densities. Both transovum and transovarial disease transmission occurred. All insect stages (eggs, larvae, pupae and adults) were affected, median lethal doses being 8.15×10^6 spores in larvae and 9.05×10^6 in pupae. Most larvae with less than 10^6 spores survived to pupate and emerge as adults but in infected females fecundity was found to be severely reduced. Males transferred the disease to females and eggs *via* infected sperm. *Mattesia* sp. was thus extremely effective in markedly depressing the population size of *E. sabulosella*. Nematodes (some of which were *Steinernema bibionis* Wouts *et al.)* were present at moderate levels (around 20-30% incidence) in pupae and larvae but only at low frequencies in adults (about 5%). Reduction of *E. sabulosella* population size by *Mattesia* or nematodes occurred for the particular environmental factors operating at the study sites during the period of investigation.

With the above results in mind it appears that spraying to control sod webworms should be avoided as it removes diseased members for the population (see Miln and Carpenter 1979) and can result in marked increases in pest numbers.

Because on hill country, topography precludes application, spraying is not practical. At present very little chemical is utilized against pasture pests, in New Zealand. In winter, food is critical on hill country farms, especially if conserved supplies (such as hay) or pasture growth for winter grazing are not available. At these times, sod webworm infestations on individual farms can be of concern. Present controls in such cases amount to spray application. Since specific chemicals are not registered in New Zealand for sod webworm control, insecticides recommended for porina are used.

It was found in this study that adult *Eudonia sabulosella* were reponsive to wind speed and direction, aggregating on east through south to west slopes, particularly those of SW orientation, when wind speed was less than ten kilometres per hour (k.p.h.). At higher wind speeds adults were confined to leeward slopes within the 180° arc. More adults were active during easterly and northerly winds than westerly and southerly ones. This meant that for the conditions operating during this study susceptible hill country pastures were those within the 180° arc and leeward of winds greater than ten k.p.h. which persisted for several days. Light rain also stimulated flight and oviposition. Wind speed and direction plus rain are especially important in determining the distribution and density of sod webworm populations. Female adults congregated and confined by wind fields potentially oviposit many of their eggs in those regions especially if grasses are lush and long. Since egg trap catches were assessed on a weekly basis the effect of strong winds confining females and resulting in increased oviposition in such areas was not measured. It appears that grazing susceptible pastures (as defined above) to remove the favoured sward type may well reduce egg and larval populations surviving there.

An understanding of the sporadic (temporal and spatial) occurrence of sod webworm damage was gained. The pastures affected during the study were either young (Kaimai, 1-2 years old) or oversown (4-5 years prior to the commencement of the study). Presumably the latter group had been subject to sod webworm damage previously. Infestations are confined to damp (in summer) southern slopes. Females need definitive sward conditions for oviposition (long sparse cover being most preferred). In the absence of pathogens, predators and adverse grazing management sod webworm populations rapidly build up to damaging levels. Eventually severe infestations are eliminated by natural density dependent mortalities and the species survives in isolated or less favourable habitats. Once the pathogen dies out, and favourable climatic and sward conditions prevail, another sod webworm infestation may occur. *Eudonia sabulosella* and the other species studied are ideally suited to survive the above conditions by their long lived adult stage, capacity for dispersal, high fecundity (relative to other New Zealand pasture pests) and ability to select oviposition sites. Perhaps the seasonal differences in oviposition found in this study were the result of different climatic and sward conditions allowing "high" oviposition in some years only.

In the long term a knowledge of *E. sabulosella* may aid in the development of management systems so as to adversely affect oviposition, survival of larvae or recovery of damaged swards. One strategy for farmers entirely dependent upon grass feeding could be to spray high producing areas and leave disease epidemics and damage to occur on the remainder. However, sod webworm damage does not become apparent until May-June which means that spraying at that time to kill larvae does not allow for compensatory pasture growth. The best options may thus be either to buy in hay, and feed on infected areas or to graze animals away from the property. Improvement of pasture (by oversowing high quality pasture feed) to produce dense swards and preclude oviposition by females is another strategy.

As shown by this work the continuation of qualitative assessment through low or endemic levels of infestation can be just as important as studies during times of dense pest populations. There is a need to continue this work during epidemics as different mortality factors may emerge during such times. Prior to this study little was known of the biology, seasonality, pest status, population dynamics and flight behaviour of sod webworms. Despite the collapse of field populations this preliminary study has provided insight into these aspects and established a broad basis for future research.

ACKNOWLEDGMENTS

I am extremely grateful to Professor J.G. Pendergrast, Dr R.P. Pottinger and Dr R. East for supervision and valuable discussions throughout the study; also to Dr M.A. Chapman for supervision from July 1978 to July 1979. Dr P.J. Wigley, Dr W.M. Wouts and Mr S. Dhana provided identifications and advice for assessment of infective pathogens. Dr E.W. Valentine identified Hymenoptera and Mr J.S. Dugdale kindly gave advice and help with taxonomic identifications of sod webworms. Mr P.L. Singleton identified soil types and Dr C.K. Beltz carried out scanning microscope preparations and photographs. I wish to thank Dr B.I.P. Barratt, Mr RAJ. Mennink, Mr E.H.A. Oliver, Dr R.P. Pottinger and Mr L.N. Robertson for collections of some sod webworms. Mr E.H.A. Oliver, Mr J. McClusky and Mr B. Willoughby provided fencing of small areas and help with the installation of heavy equipment. Mr J. Clayton and Mr J. McLean supervised grazing and fencing of study sites at Whatawhata. Hart's,Little's, Mortimers; St. Andrews and Westlands Golf Courses, granted permission to collect on their land. The Ministry of Agriculture and Fisheries allowed accesss to the Whatawhata Hill Country Research Station as well as use of small plot space and equipment at Insect Control and Organic Chemistry Group, Ruakura. I wish to thank Professor E.C. Young for office space in the Zoology Department, University of Auckland while completing writing up this thesis. I gratefully acknowledge the many valuable discussions on experimental designs with Mr E.H.A. Oliver. Lastly, but by no means least, without the continued support, interest and great patience of my husband Don, this study would not have been possible.

Funding of the study was made by the University Grants Committee (Postgraduate Scholarship) and Ministry of Agriculture and Fisheries Research Contract (travel grant).

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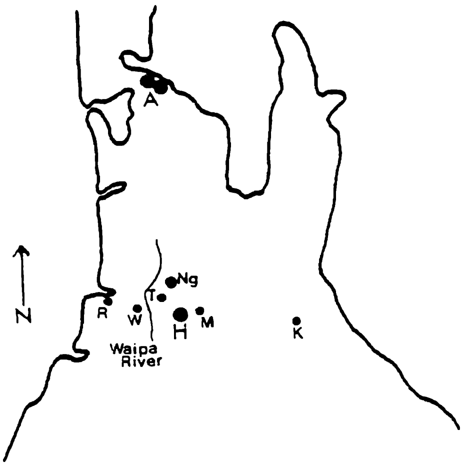
APPENDIX I

Location Map of Main Sampling Sites



Key:
A = Auckland
H = Hamilton
K = Kaimai
M = Matangi
Ng = Ngaruawahia
R = Raglan
T = Te Kowhai
W = Whatawhata Hill Country Research Station

APPENDIX II

Lunar Cycles

(after N.Z. Nautical Almanac). The months listed refer to adult sod webworm flight seasons. Time and day of each lunar phase are listed. The times are adjusted for day-light saving.

		PHASE OF THE MOON							
		NEW MOON		FIRST QUARTER		FULL MOON		LAST QUARTER	
YEAR	MONTH	DAY	HOUR	DAY	HOUR	DAY	HOUR	DAY	HOUR
1978	Sept	2	04	10	15	17	07	24	17
	Oct	2	19	9	22	16	18	24	13
	Nov	1) 30)	09) 21)	8	05	15	09	23	10
	Dec	30	09	7	14	15	02	23	07
1979	Jan	28	19	6	00	13	20	22	00
	Feb	27	06	4	14	12	16	20	14
	Mar	28	15	6	04	14	09	21	23
	Sept	21	22	29	16	6	23	13	18
	Oct	21	14	29	02	6	08	13	09
	Nov	20	07	27	10	4	19	12	05
	Dec	19	21	26	18	4	07	12	03
1980	Jan	18	10	25	03	2	22	11	01
	Feb	16	22	23	13	1	15	9	21
	Mar	17	07	24	01	2	09	10	12
	Sept	9	22	18	02	25	00	2	06
	Oct	9	15	17	16	24	09	1) 31)	15) 06)
	Nov	8	10	16	05	22	20	29	23
	Dec	8	04	15	15	22	07	29	19
1981	Jan	6	20	13	23	20	21	28	17
	Feb	5	11	12	07	19	12	27	14
	Mar	6	23	13	14	21	03	29	08

APPENDIX III

Contemporaneous Species on Hill Country

KEY: *refers to less than 10 specimens
**refers to 10 or more: 10 but less than 100 specimens
***refers to 100 or more specimens

PHYLUM ARTHROPODA

Class Insecta

Collembola**	
Ephemeroptera	Leptophlebiidae**
Odonata*	
Plecoptera	Austroperlidae - *Acroperla trivacuata**
Orthoptera	Acrididae - *Phaulacridium* spp**
	Gryllidae - *Pteronemobius* spp***
	*Teleogryllus commodus***
	Blattidae - *Platyzosteria novaeseelandiae**
Hempitera	Aphidae***
	Corixidae - *Sigara arguta***
	Jassidae**
	Lygaeidae**
	Miridae**
	Nabidae**
	Pentatomidae**
	Ricaniidae - *Scolypopa australis**
Thysanoptera*	
Neuroptera	Coryadalidae - *Archichauliodes diversus**
	Hemerobiidae - *Micromus tasmaniae***
Lepidoptera	Lycaenidae - *Zizinia otis labradus****
	Pieridae - *Pieris rapae**
	Geometridae***
	Hepialidae - *Aenetus virescens***
	Wiseana spp***
	Hyponomeutidae - *Plutella xylostella***

Noctuidae including - *Agrotis ipsilon aneituma****
*Chrysodeixis eriosoma***
*Mynthmnia separata****
Melanachra spp***
*Spodoptera litura****
Oecophoridae**
Pyralidae including - Crambinae -
*Orocrambus flexuosellus****
*O. vitellus****
Scopariinae -
*Eudonia psammitis****
*E. sabulosella****
*"Scoparia" bisinualis***
*"S." diphtheralis****
*"S." halopis****
*"S." philerga****
*"S." submarginalis****
*"S." aspidota***(only 11)
Pterophoridae*
Tineidae including - *Opogona omoscopa****
Tortricidae***

Trichoptera (Det. Dr D.R. Cowley)

Hydropsychidae - *Aoteapsyche catharinae***
*A. colonica***
*Orthopsyche fimbriata***
Hydroptilidae***
Leptoceridae - *Hudsonema amabilis****
*Triplectides cephalotes***
*T. obsoleta**
Oeconesidae - *Oeconesus maori**
*O. zealandensis***
*Pseudoeconesus hudsoni***
*P. stramineus***
Philanisidae - *Philanisus plebeius**
Polycentropodidae - *Polyplectropus aurifusca**
P. puerilis**

Rhyacophilidae - _Costachorema psaroptera_**
C. xanthoptera**
Hydrobiosis copis**
H. parumbripennis***
H. soror***
_H. spatulata_*
Hydrobiosis spp**
H. umbripennis***
Neurochorema confusum**
_Psilochorema bidens_*
_P. donaldsoni_*
_P. leptoharpax_*
P. minicum***
Tiphobiosis veniflex**
Conoesucidae - _Beraeoptera roria_*
Olinga feredayi***
Pycnocentria evecta**
Pycnocentrodes aeris***
P. modesta***

Diptera

Anisopidae including - _Sylvicola_ spp***
Anthomyidae***
Asalidae**
Bibionidae***
Calliphoridae including - _Lucilia sericata_**
Chironomidae***
Culicidae**
Dolichopodidae**
Drosophilidae**
Muscidae**
Mycetophilidae***
Phoridae**
Psychodidae***
Sarcophagidae including - _Hybopygia varia_***
Simuliidae**
Stratiomyidae including - _Inopus rubriceps_***

	Syrphidae including -	*Melanostoma spp***
	Tachinidae**	
	Tipulidae***	
Hymenoptera	Apidae including -	*Apis mellifera***
		Bombus spp.**
	Colletidae including -	*Leioproctus* spp***
	Ichneumonidae (Det Dr E. Valentine) including -	*Netelia ephippiata***
		Ophion spp*
		Aucklandella geiri *
	Formicidae***	
Coleoptera	Apionidae -	*Apion ulicis**
	Carabidae including -	*Rhytisternus miser****
	Cerambycidae including -	*Prionoplus reticularis**
	Coccinellidae**	
	Curculionidae including -	*Graphognathus leucoloma****
		*Listronotus bonariensis****
	Dermestidae**	
	Dytiscidae including -	*Rhantus pulverosus***
	Elateridae (Det. Mr L. Roberts) including -	*Agrypnus variabilis****
		*Conoderus exsul****
	Lucanidae**	
	Scarabaeidae including -	*Costelytra zealandica****
		*Heteronychus arator****
		Pyronota spp***
	Staphylinidae including -	*Thyreocephalus orthodoxus****
	Tenebrionidae**	
Class Arachnida		
Acarina*		
Araneida	Araneidae**	
	Lycosidae**	
	Pisauridae**	
	Salticidae*	
	Theridiidae including -	*Steatoda grossa***
	Thomisidae**	
Opiliones***		
Pseudoscorpionida**		

Class Chilopoda**

Class Diplopoda***

PHYLUM ANNELIDA
Class Oligochaeta
Lumbricidae***

PHYLUM MOLLUSCA
Class Gastropoda
Sub-class Pulmonata (slugs)***

APPENDIX IV

Dates of weekly Intervals used for Light Trapping at Long 4A, Whatawhata.

Week Number	Dates
1.	9-16 September
2	16-23 September
3.	23-30 September
4.	30 September - 7 October
5.	7-14 October
6.	14-21 October
7.	21-28 October
8.	28 October - 4 November
9.	4-11 November
10.	11-18 November
11.	18-25 November
12.	25 November - 2 December
13.	2-9 December
14.	9-16 December
15.	16-23 December
16.	23-30 December
17.	30 December - 6 January
18.	6-13 January
19.	13-20 January
20.	20-27 January
21.	27 January - 3 February
22.	3-10 February
23.	10-17 February
24.	17-24 February

APPENDIX V

Abbreviations of Sod Webworm Generic Names as Used in Tables

O. flex = *Orocrambus flexuosellus*

O. vit = *O. vitellus*

E. psam = *Eudonia psammitis*

E. sab = *E. sabulosella*

"S". bis = *"S". bisinualis*

"S". diph = *"S". diphtheralis*

"S". hal = *"S". halopis*

"S". phil = *"S". philerga*

"S". subm = *"S". submarginalis*

"S". asp = *"S". aspidota*