Effect of temperature and photoperiod on growth, development and reproduction of *Nysius huttoni* White (Heteroptera: Lygaeidae)

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Xiong Zhao He

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Abstract

The influence of temperature, host plant and photoperiod on *Nysius huttoni* White growth, development and reproduction was investigated under laboratory conditions.

The growth and development rate increased in linear fashion with temperature over the range of 15-30°C. The estimated lower temperature thresholds for all life stages were above 10°C except for the third instar on shepherd's purse (*Capsella bursa-pastoris* (L.) Medik.). *Nysius huttoni* completed its life cycle at 20, 25 and 30°C on twin cress (*Coronopus didymus* (L.) Sm.) and shepherd's purse, but could not develop through to the adult stage at 15°C on any of the test host plants or on chickweed (*Stellaria media* (L.) Vill.) at any of the test temperatures. Thermal requirement for completing the life cycle in *N. huttoni* was 625.00 degree-days on twin cress and 714.29 degree-days on shepherd's purse. The time needed for a life cycle of both sexes was similar but the adult longevity decreased as temperature increased. The estimated lower temperature thresholds for mating and oviposition on twin cress were 12.3°C 16.8°C, respectively. Females failed to lay eggs when both nymphs and adults were fed with shepherd's purse. Sunflower seed was conducive to sexual maturity and fecundity.

The growth and development of *N. huttoni* slowed down as photoperiod decreased. Adults and fifth instar nymphs were sensitive to diapause-inducing photoperiod. When fifth instar nymphs and sequential adults were held at 12:12 and 10:14 h (L:D), 100% of females entered diapause. Females that had oviposition breaks over 50 days at 10:14 and 12:12 h (L:D) apparently entered diapause. However, exposure of the entire life cycle to 10:14 and 12:12 h (L:D) gave a significantly lower diapause incidence. The critical photoperiod for diapause was estimated between 13:11 to 13.5:10.5 h (L:D). Fecundity appeared to decrease with the decrease in photoperiod. The time needed for a life cycle and the longevity of both sexes were similar at a given photoperiod but increased as photoperiod decreased.

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General introduction

1.1 Introduction

Bergroth (1923) recognised 44 families of the Heteroptera of the world, of which 19 are represented in New Zealand. The Lygaeidae is one of the most speciose heteropteran families in New Zealand (Myers 1926). Myers (1926) listed three species of *Nysius* in Lygaeidae: *N. huttoni* White, *N. anceps* White and *N. clavicornis* (Fabr.). However, Eyles (1960a) considered *N. huttoni* as the only species of *Nysius* recorded from New Zealand.

The New Zealand wheat bug (*N. huttoni*) was described by White (1878). It is endemic to New Zealand and occurs throughout the North and South Islands (Myers 1926, Usinger 1942, Gurr 1957, Cumber 1959, Eyles and Ashlock 1969). It is also found in some adjacent islands such as Stephens Island (Myers 1926), Chatham Islands (Kirkaldy 1909) and Three Kings Islands (Woodward 1954).

1.2 Host plants and habitats

Nysius huttoni is a very adaptable feeder and when the necessity arises can live on many cultivated plants as well as a variety of weeds (Gurr 1957). Some of the largest populations have been found in association with shepherd's purse (*Capsella bursa-pastoris* (L.) Medik.), twin cress (*Coronopus didymus* (L.) Sm.) and Curnow's curse (*Calandrinia caulescens* H.B.K) (Gurr 1952, 1957). The known host plants and habitats are shown in Table 1.1.

Table 1.1: The known host plants and habitats in New Zealand of *N. huttoni*

Common name	Botanical name	Importance of host	Author
Broom	*Cytisus scoparius* L.		Gurr 1957
Brown top	*Agrostis tenuis* Sibth.	Major autumn shelter host	Eyles 1965b
Catchfly	*Silene gallica* L.	Medium spring and summer host	Eyles 1965b
Catsear	*Hypochaeris redicata* L.	Shelter host	Eyles 1965b
Chickweed	*Stellaria media* (L.) Vill.	Spring host	Farrell and Stufkens 1993
Curnow's curse	*Calandrinia caulescens* H.B.K.		Gurr 1957
Linen flax	*Linum usitatissimum* L.		Gurr 1957
Lucerne	*Medicago sativa* L.	Minor summer host	Myers 1921, 1926
Moss	*Triquetrella papillata* Broth.	Medium host	Eyles 1965b
Nasella tussock	*Nasella trichotoma* (Ness) Hack.		Gurr 1957
Onehunga weed	*Soliva sessilis* Ruiz & Pav.	Medium summer, autumn and winter shelter host	Eyles 1965b
Paspalum	*Paspalum dilatatum* Poil.	Minor autumn shelter host	Eyles 1965b
Perennial ryegrass	*Lolium perenne* L.	Major winter shelter host	Eyles 1965b
Red clover	*Trifolium pratense* L.	Minor summer host	Myers 1921, 1926
Sand spurrey	*Spergularia rubra* L.	Major summer host	Eyles 1965b
Scarlet pimpernel	*Anagallis arvensis* L.	Minor summer host	Eyles 1965b
Sheep's sorrel	*Rumex acetosella* L.	Major spring and summer host	Eyles 1965b
Shepherd's purse	*Capsella bursa-pastoris* (L.) Medik.	Major spring and summer host	Gurr 1957
Subterranean clover	*Trifolium subterraneum* L.		Gurr 1957
Suckling clover	*Trifolium dubium* Sibth.	Major spring host	Eyles 1965b
Toad rush	*Juncus bufonius* L.	Shelter host	Eyles 1965b
Twin cress	*Coronopus didymus* (L.) Sm.	Major spring and summer host	Gurr 1957
White clover	*Trifolium repens* L.	Major summer host	Eyles 1965b
Wireweed	*Polygonum aviculare* agg.	Major spring and summer host	Eyles 1965b
Yorkshire fog	*Holcus lanatus* L.	Major winter shelter host	Eyles 1965b

Nysius huttoni is a migratory insect. When the annual host plants begin to die off, or before the winter, the bug migrates seeking food (Eyles 1965b) or overwintering sites (Farrell and Stufkens 1993).

The summer is the major feeding and fast developing season for *N. huttoni*. Eyles (1965b) stated that *N. huttoni* lived on or very close to the ground and had often been observed under 3 mm of leaf litter and under small stones. During the warmest part of the day, both nymphs and adults seek the shade of host plants, and sometimes move into the edge of thicker vegetation; at night they shelter under leaf debris (Eyles 1965b).

In the autumn, the bugs become sluggish and tend to shelter more under grass straw, leaf litter, and at the bases of tufts of brown top (Eyles 1965b). In the winter, the adults shelter under vegetable debris, and at the bases of weeds and grasses (Gurr 1957) where much dead leaf litter is around the bases, giving good protection to the insects. In the early spring, overwintered adults migrate to patches of annual weeds, and feed and reproduce (Farrell and Stufkens 1993).

1.3 General ecology

In all Heteroptera, there are usually five nymphal instars (Myers 1926). The life cycle of *N. huttoni* includes eggs, five nymphal instars, and adults. The variation in adult and immature stages of *N. huttoni* was described by Eyles (1960a). He indicated that the population of this species consists of three size groups, the large, medium and small individuals (Table 1.2); and moreover, in both the large and medium groups, there are three forms, the macropterous, sub-brachypterous and brachypterous. Thus, there are seven different "kinds" of individuals depending on size and wing-form (Eyles 1960a). Fig. 1.1 shows the mating adults of *N. huttoni*.

Table 1.2: The three different sizes (mm) of individuals in *N. huttoni* population

	Female		Male	
Group	length	width	length	width
Larger individual	3.74-4.34	1.61-1.75	3.55-3.86	1.32-1.39
Medium individual	3.36-3.74	1.44-1.53	3.00-3.48	1.15-1.32
Small individual	2.47-3.19	1.20-1.32	2.38-3.00	0.94-1.15

Fig. 1.1: Mating adults of *N. huttoni*.

1.3.1 Preimaginal development

The colour of freshly laid eggs is creamy white (Gurr 1957). Egg laying occurs from 8 a.m. until 7.30 p.m. with a peak early in the afternoon (Eyles 1963a), and 95% of the hatching occurs in the morning with a peak between 8 a.m. and 9 a.m. and nymphal moulting occurs at any time during daylight hours (Eyles 1963b).

Eyles (1963a,b) observed the egg incubation period, nymph evelopment, fecundity and oviposition rhythms in an unheated greenhouse. He reported that when eggs were placed in refrigerators at 3°C, none of them hatched for two months; however, transferred to the greenhouse (in March) after 32 d, some of them hatched in 16 d. Ninety percent of eggs hatched at 45.2°C, indicating that this temperature was not the upper limit of temperature tolerance for eggs. In the first generation, the length of the stadium for each instar decreased generally from first instar to adult: 15, 14, 13, 12 and 10 d; in second generation, the average of stadium was 6 d per instar; and in the third, it usually needed about 16 d per instar. Therefore, the total nymph development duration of each generation was about 64, 30 and 90 d, respectively. However, Those parameters have not been reported under controlled temperature and photoperiod conditions, making correct forecast of pest outbreaks difficult.

1.3.2 Adult reproduction

Some details of courtship and copulation were described by Eyles (1965b). For previously unmated adults there is a courtship period of from five minutes to three days; and for experienced males, courtship is brief or non-existent (Eyles 1965b). In all generations, maturity in the males is reached a little earlier than in females, and copulation may occur at any time (excluding winter) (Eyles 1963a) and is repeated many times (Eyles 1965b). Copulation normally continues for several hours but may be for only several minutes (Eyles 1965b).

Eggs of *N. huttoni* were found in soil (Gurr 1957, Eyles 1965b) but not in or on plants where the bugs congregate (Gurr 1957). However, Farrell and Stufkens (1993) reported that eggs were attached to flowers of chickweed and shepherd's purse in the field. Eggs were also found on axillae and growing points of twin cress in the laboratory (He and Wang 2000).

Female has 14 ovarioles but the maximum number of eggs laid per day ranged from 17 (Eyles 1963a) to 30 eggs (Gurr 1957). Food affects female fecundity. Under laboratory conditions, each female deposits an average of 75.6 $\pm$ 20.3 eggs when fed on the shepherd's purse (Gurr 1957) and 98.6 $\pm$ 10.6 eggs on grains of milky-ripe wheat (Farrell and Stufkens 1993). The influence of history that females have experienced on the fecundity (total egg number per female), daily egg production (daily output per female) and longevity was observed by Eyles (1963a) with very small samples (Table 1.3). The mean number of eggs per female laid after winter was greater than that laid before winter, while daily number of eggs per female laid after winter was fewer than that laid before winter.

Table 1.3: Reproductive parameters and longevity of *N. huttoni* females (data from Eyles 1963a)

		Reproductive phase (d)				Daily egg	
Female source	No.	Preovi.	Ovi.	Postovi.	Fecundity	production	Longevity (d)
Before winter:							
from 5th instar nymphs	3	14	18	13	48	2.4	55
from field	4	----	20	2	41	2.2	----
After winter:							
from 5th instar nymphs	5	155	64	1	63	1.2	203
from field	2	----	56	1	69	1.2	----

*Preovi. = preoviposition period, Ovi. = oviposition period, Postovi. = postoviposition period

The longevity of both sexes was similar. Overwintered females lived more than twice as long as those of first generation (Eyles 1963a).

Eyles (1963a) reported the presence of a male was not necessary for the formation of eggs, virgin and mated once females producing the normal total number of eggs but virgin females having longer oviposition periods (Table 1.4). One mating per week increased the number of eggs laid per day on the days of mating or immediately following days (Table 1.4). One mating is sufficient to fertilise a female for life; the female may carry viable sperm over winter and remain fertile for a complete oviposition period (Eyles 1963a).

Table 1.4: Effect of mating on reproductive parameters and longevity of *N. huttoni* females (data from Eyles 1963a)

Female	No.	Reproductive phase (d)			Fecundity	Daily egg	Longevity (d)
		Preovi.	Ovi.	Postovi.		prediction	
Permanently paired	6	6	81	13	204	2.7	97
Virgin	1	5	104	13	178	1.7	122
Mated once	2	10	76	6	203	2.8	94
Mated once/week	1	----	107	-----	323	3.0	115

*Preovi. = preoviposition period, Ovi. = oviposition period, Postovi. = postoviposition period,

1.3.3 Overwintering and diapause

There are three to four generations a year in the field. It is likely that late emerged adults of the second and third generations overwinter with the fourth generation (Eyles 1965b). The adults start to overwinter at about the end of April and become active again at about the beginning of August in the Nelson district (Gurr 1952). Farrell and Stufkens (1993) noted that the flight activity recorded in sticky traps in the vicinity of overwintering sites was slight in winter, increased in late August and reached a peak in mid September in Canterbury. Therefore, the coincidence of population decline in overwintering sites and peak flights in their vicinity suggests that overwintered adults migrate to new habitats in mid September (Farrell and Stufkens 1993). Only adults have been seen at the beginning of the spring, it is thus likely that in Nelson only adults survive the winter (Gurr 1952). However, the overwintering fifth instar was also recorded in Palmerston North (Eyles 1963b). Farrell and Stufkens (1993) found that adults of the second generation migrated to overwintering sites in the autumn and aggregated under dead leaves of woolly mullein (*Verbascum thapsus* L.), under bark of dead pinus radiata (*Pinus radiata* D. Don), in gorse hedges (*Ulex europaeus* L.), and swards of browntop grass (*Agrostis capillaris* L.) in Canterbury. However, for the females, only those emerging late in the season and not laying eggs before winter are able to survive (Eyles 1963a). Whether this relates to energy requirement of reproduction and oviposition before winter is unknown. Moreover, Farrell and Stufkens (1993) reported that no gravid females were found on overwintering sites in 1990, and only 5-10% of females in bark sites were gravid in later August-early September in 1991.

The overwintering *N. huttoni* undergo quiescence and diapause. Eyles (1965b) stated that when female fifth instar nymphs were taken in the field in early May and placed in a constant temperature of 24°C, they moulted to adults in 5 d and oviposited after further 15 d; and adult females taken in the field at the same time completed ovarian development at the warmer temperature and oviposited in 20 d. Overwintering *N. huttoni* did not remain in one position throughout the winter. During the less intense quiescent period, i.e., before and after June and July, *N. huttoni* often moved to the tops of the grasses to bask in the sunshine, whereas during the coldest four weeks from min-June to min-July the majority of the time was passed motionless in the refuge (Eyles 1965b).

Reproductive diapause is induced by the shortening photoperiod of late summer; diapause is defined as the absence of oviposition for 30 d after adult emergence (Farrell and Stufkens 1993). Farrell and Stufkens (1993) reported that a high proportion of second generation females did not develop eggs during February and March. When the third and fourth instar nymphs in the second generation collected on 17 January (14.4:9.6 L:D) were transferred to a long photoperiod (16:8 L:D) in the laboratory, eighty-two percent of adults commenced oviposition on average 15.9 d after emergence; whereas, when exposing to a short photoperiod (12:12 L:D) condition, no oviposition occurred during the first 30 d. Sixty-four percent of females commenced oviposition an averaged of 27.1 d after being transferred from short photoperiod to long one following 30 days' diapause; whereas, only one female (7%) laid one egg 75 d after adult emergence under the continuous short photoperiod regime. Ovipositing females laid an average of 98.6 ± 10.6 eggs under long photoperiod and 43.0 ± 11.9 eggs under short/long photoperiods.

1.4 Economic importance

Nysius huttoni is well known as a pest that attacks wheat grains in the milky-ripe stage and causes sticky dough in wheat-flour (Morrison 1938, Blair and Morrison 1949, Gurr 1952 and 1957). Similarly, Every *et al.* (1990) stated that wheat is most vulnerable to damage at the flowering and grain-filling stages of growth in late November and early December. Some mature wheat crops in Mid Canterbury were found to be infested at a rate of 500 grains/m^2 in early January 1989 (J. Farrell unpubl. data) and yielded severely bug-damaged grain (D. Every pers. comm., cited by Farrell and Stufkens 1993). There have been five major outbreaks of damage since the problem was first reported in 1936; in the worst outbreak in 1970 about 10,000 tonnes of wheat was damaged (Swallow and Cressey 1987). In 1950, 98 (7%) of 1400 samples were defined as 'bug wheat' at the Wheat Research Institute in Christchurch (Gurr 1957). Gurr (1957) stated that as little as 1% of bugged wheat used in the production of a flour has made it unusable for baking, whereas Meredith (1970) stated 0.3% and Blair and Morrison (1949) stated 5% of damaged wheat is sufficient to ruin good wheat. When feeding, *N. huttoni* injects into plants saliva, contain powerful enzymes that digest the grain carbohydrate and/or protein so that solubilised nutrient can be drawn through the styli. The *N. huttoni*-damaged grains contain a *N. huttoni* salivary proteinase (Cressey 1987, Cressey and McStay 1987, Every 1993) or a high level active protease (Every *et al.* 1992). The salivary enzymes can cause serious problems in bread baking, such as runny, sticky dough, and poor quality loaves (Morrison 1938). In the past 20 years, no major outbreaks of bug damage have occurred on wheat in New Zealand. Swallow and Cressey (1987) stated that the diminished damage might be the result of the development of more resistant cultivars.

In contrast with wheat, which is not the preferred food of *N. huttoni* and is attacked at the edge of the maturing crop only after weeds around the crop have died off in summer, a crucifer crop is a suitable habitat for *N. huttoni*, and the plants are readily attacked from the seedling stage (Gurr 1957). Gurr (1957) reported that *N. huttoni* thrived best under hot and dry conditions and preferred situations where the direct sunlight struck through to the ground. The spacing of plants makes a young crucifer crop suitable for *N. huttoni*, which is a pest particularly in areas of the South Island that have very dry summers, such as Marlborough, Mid Canterbury, and Central Otago (Gurr 1957).

The damage to rape (*Brassica napus* L.), chou moellier (marrow-stem kale) (*Brassica oleracea* L.) and some species of turnips has been reported in Marlborough, Mid Canterbury, and Central Otago (Gurr 1957). The feeding punctures are made around the stems of the seedlings at ground level and cause a cankerous growth of the tissue (Gurr 1957). In recent years, *N. huttoni* has caused serious damage to brassica crops that are used as winter fodder for stock by many farmers in Maniototo and Central Otago (Ferguson 1994). The bugs preferred the stems of the swede (*Brassica napus rapifera* Metzger) seedlings (He and Wang 1999, 2000), and up to 70% of immature plants could be lost through wind breakage (Ferguson 1994). In addition, some adults may migrate to strawberries and kiwifruit, where their presence on harvested fruit cause a contamination problem (W. Thomas pers. comm., cited by Farrell and Stufkens 1993). Moreover, although *N. huttoni* does not feed on apples, it has been observed to occur in apple packages (Lay-Yee *et al.* 1997). It is thus also a pest causing quarantine problems for the apple export industry of New Zealand.

1.5 Pest management

Eyles (1965a) stated that in 1957 and 1958, there were none or very low numbers of *N. huttoni* on the field crucifers at Palmerston North. He suggested that the thick pasture swards in that district, and the vigorous growth of grass and weeds around the edges of the crops did not favour this pest; or probably as the areas were in pasture previously and were surrounded by pasture, the chance of infestation was small. In a sweep-sampling survey of North Island pasture insects, Cumber (1959) only collected 24 *N. huttoni* out of 221 samples, and in a survey of North Island fodder crops, Eyles (1960b) only took one specimen of *N. huttoni*. The habitat requirements of *N. huttoni* may prevent it from becoming a pest of crucifers in Palmerston North. High populations of *N. huttoni* in shepherd's purse, twin cress and Curnow's curse were reported by Gurr (1952, 1957). When cultivated crucifers were grown adjacent to suitable habitat for *N. huttoni* in areas of the North Island that are dry in summer, damage by this pest may result; in the wetter areas, unsuitable environment probably prevents *N. huttoni* from becoming a pest (Eyles 1965a).

Ferguson (1994) reported that application of insecticide (isazophos) could successfully control *N. huttoni* in direct drilled swede seedlings. In his field observation, 87% of plants were damaged in the untreated areas, and only up to 1% damage was observed in the areas with single or double applications of isazophos. However, in a nearby area of swede sown after cultivation at the same time as the direct drilled crop, no damage was observed. This suggests that the damaging population of *N. huttoni* was associated with the drilled crop.

1.6 Aims of the project

The ecology of this pest has been studied in natural and unheated greenhouse conditions; however, under controlled conditions, the effect of temperature, photoperiod and host plant on the development and reproduction of *N. huttoni* has not been reported. This knowledge is essential to modelling the population dynamics of this insect and to developing management strategies for producers because most growers can be easily trained to use the heat–unit accumulations in timing control in crop systems. Such data will also help manage risk from this serious quarantine pest.

On the basis of these observations, I initiated the project aiming at:

(1) determining the effect of temperature and food on growth, development and reproduction;

(2) investigating the influence of photoperiod on growth, development, reproduction and diapause.