# Final Report for DAW2107-001RTX: Determining the economic impact of Native Budworm (*Helicoverpa punctigera*) in cereal crops in the Western Region

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# Determining the economic impact of native budworm (*Helicoverpa punctigera*) in cereal crops in Western Australia

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## Abstract

*Helicoverpa punctigera*, commonly known as the native budworm, is a major pest of crops in Australia. While its agricultural host species are well known, recent reports from growers and advisors in Western Australia suggested that *H. punctigera* larvae were being found in wheat crops, a non-traditional host, with population estimates exceeding 20 larvae per 10 sweeps of an insect sweep net and damage evident to flag leaves and heads. Through pheromone-based moth trapping, crop inspections, glasshouse trials and a field cage trial, we investigated the behaviour of *H. punctigera* moths and larvae on, and potential economic damage to, wheat crops in the northern grainbelt of Western Australia. Surprisingly, we found similar or more moths detected in traps in wheat crops compared to nearby canola or lupin host crops during 2021 and 2022. However, glasshouse trials showed that moths are deterred from laying eggs on tillering or heading wheat whether paired with a traditional host such as faba bean or lupin or isolated with wheat only. Choice and no-choice trials with larvae indicated a preference for traditional hosts over wheat, but with some damage to flag leaves and glumes experienced when wheat was in head. When isolated with wheat only, most larvae starved to death and survivors had smaller pupae, indicating reduced performance. Results support the preference-performance hypothesis that species choose hosts that provide the best larval development. Field cage trials with either 5 or 10 larvae per square metre consistently showed relatively minor damage to wheat. Based on this data, economic thresholds are calculated. Although results point to agronomic practices such as wild radish weed control influencing the likelihood of *H. punctigera* larvae presence in wheat crops, we suggest that climate change, especially increased summer rainfall in central Australian migration source areas, is increasing moth pressure onto traditional, and now non-traditional, crops further down the migration route. This information is important for ensuring the successful economic production of wheat.

## Key messages

- Native budworm moths frequently fly into wheat crops, but they are deterred from laying eggs on wheat plants.
- Native budworm moths prefer to lay eggs on wild radish and (volunteer) lupins in wheat crops so weed control is a critical part of preventing damage to wheat.
- Larvae prefer to feed on wild radish over vegetative (tillering) wheat but prefer to feed on wheat heads in advanced wheat over wild radish.
- Larvae either starve to death or have reduced performance and smaller pupae when forced to feed on wheat, indicating that wheat is not a preferred host.
- Thresholds for native budworm larvae in wheat are likely to be higher than 50 per 10 sweeps or 5 per square metre.
- At a density of 5 per square metre, larvae account for a yield loss of $1.71 per ha loss given a 2 tonne/ha crop valued at $360/tonne.
- Field inspections of wheat crops during 2022 showed presence of both native budworm and armyworm, so it is important to identify species in the field.

## Introduction

*Helicoverpa punctigera* (Wallengren), commonly known as the native budworm or the Australian bollworm, is a significant pest of crops in Australia (Oliveira et al., 2022). This moth species has a wide host range and is known to cause significant damage to crops such as cotton, chickpeas, sorghum, canola, lupins, and sunflowers (Zalucki *et al.*, 1986; Cunningham & Zalucki, 2014). In Western Australia, *H. punctigera* is a major threat to agriculture, particularly in the grain-growing regions of the state. Over the past few decades, *H. punctigera* infestations in Western Australia have become more frequent and severe, leading to significant economic losses for farmers. However, the increase in severity did not pertain to non-traditional host crops such as wheat. The increasing prevalence of this pest has led to the development of various management strategies to control its population and minimize the damage caused to crops.

In Western Australia, the most common types of caterpillars which damage cereal crops during winter or spring are lesser budworm (*Heliothis punctifera*) and armyworms (multiple species) (Murray et al., 2013). In 2018, DPIRD staff received reports of budworm-like caterpillars in wheat crops causing mostly minor, but sometimes major chewing damage to leaves and glumes and into developing seeds during spring. It was initially thought that the caterpillars were likely lesser budworm as cereals are a known host and they occasionally cause leaf chewing damage in wheat crops. Secondly, it was supposed that caterpillars could be an abnormally high number of corn earworm (*H. armigera*), which is known to occasionally cause damage to cereal crops in Queensland. *H. armigera* caterpillars have not been reported damaging crops in WA, even though pheromone trapping during 2017 revealed that low numbers of *H. armigera* moths do migrate to the north, central and southern parts of the WA grainbelt. Thirdly, we hypothesised that the caterpillars were *H. punctigera*, native budworm. As cereals are not typically a host of native budworm, it was suspected that moths migrated into cereal crops to lay eggs on preferred host plants within the crop such as uncontrolled self-sown pulses or lupins or wild radish weeds. Here we postulated that the larvae from these eggs then transferred onto wheat plants as a result of the preferred host plants being killed off with herbicide.

Initial crop investigations by DPIRD staff were made at the properties of two growers who reported high numbers of budworm in their wheat crops in August 2019, Dan Birch of Catalina Farms at Coorow, and Mark McGuire at Ballidu. Wheat crops at each property were sampled extensively using sweep nets for caterpillars. Microscope examination of the specimens revealed that over 99% of the caterpillars from both properties were identified as *H. punctigera*, while less than 1% were *H. punctifera*. The most obvious diagnostic difference between *H. punctigera* and *H. punctifera* is the hair colour, being black and white, respectively. Representative caterpillar samples were submitted to DPIRD diagnostic laboratory services for molecular barcode screening, which can differentiate all Heliothine moth species in Australia (Mitchell & Gopurenko, 2016). This was conducted to confirm species identification given the possibility that other species may be present. Molecular barcoding results confirmed initial microscope identification of *H. punctigera* caterpillars.

The fact that native budworm was confirmed and sometimes in very high numbers in wheat crops caused some concern given they are not traditionally a pest of cereal crops, but rather of pulse and canola crops. For the past 3 years native budworm has been identified as the main species of lepidopteran grain pest which growers and advisers are detecting feeding on wheat crops in the Western Region (Fig. 1). Growers and consultants have also reported that wheat crops which had uncontrolled wild radish tended to have more native budworm. DPIRD staff confirmed that patches of wild radish in wheat at Coorow and Ballidu WA in 2020 had much higher numbers of budworm than the surrounding wheat plants.

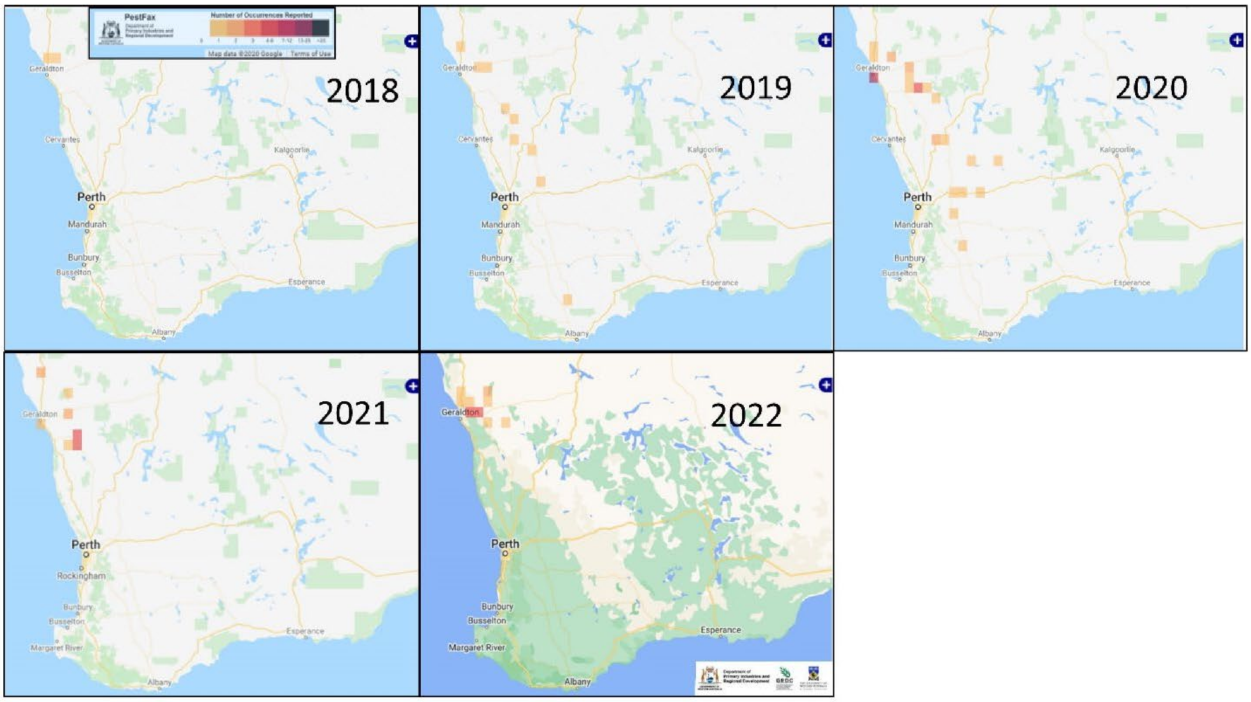



Figure 1. PestFacts WA Map showing reports of native budworm larvae found in wheat crops during 2018 to 2022.

Native budworm actively feeding on cereals has not been an issue for growers or industry in the past, and considering the recent detections, growers and western region industry networks have voiced that they would like support on this issue, especially regarding sampling techniques and spray thresholds. To achieve this, we investigated this new behavioural trend and the population numbers required to cause economic yield losses to determine if and when management is required in non-traditional cereal hosts.

Through pheromone-based moth trapping, crop inspections, glasshouse trials and a field cage trial, we investigated the behaviour of *H. punctigera* moths and larvae on, and potential economic damage to, wheat in the northern grainbelt of Western Australia.

## Methods

### Field surveillance Geraldton port zone

#### 2021 field season

A total of 20 sites were established to monitor native budworm moth and larvae populations in wheat crops located across nine Shires in the Geraldton port zone during the 2021 season (Fig. 2). Ten sites were paired with (nearby) canola crops and eight sites paired with lupin crops. Paired canola and lupin crops were also monitored for native budworm moths and caterpillars to provide a comparison to wheat crops.

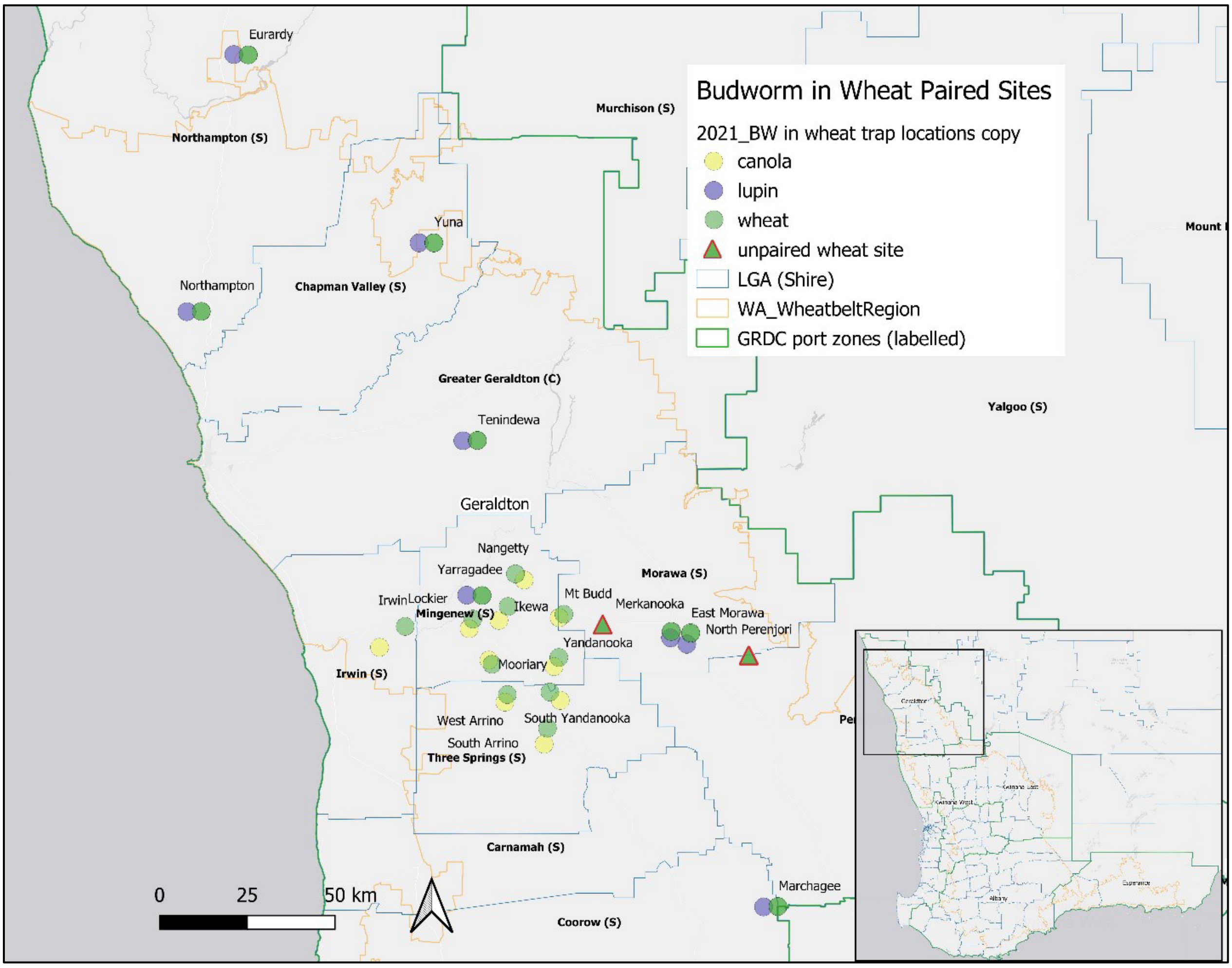



Figure 2. Native budworm surveillance sites in wheat crops paired (or unpaired) with nearby canola or lupin crops in the Geraldton port zone in 2021.

Moths were trapped in a total of 63 pheromone-based traps across sites. These were either automated (TrapView®) or manual (funnel) Noctuid moth traps containing a species-specific native budworm pheromone lure which was replaced monthly (Fig. 3). Sites with automated traps also had at least one manual funnel trap installed (Fig. 4). Unfortunately, TrapView® traps produced results inconsistent with manual traps and only manual trap results were used from this trial. Larvae populations were monitored in the wheat, lupin and canola canopy by sweep netting and, where plants were too small to sweep, a visual assessment of damage and larvae presence was performed.

Figure 3. Funnel (left) and automated TrapView®(right) Noctuid moth traps with native budworm pheromone lures.

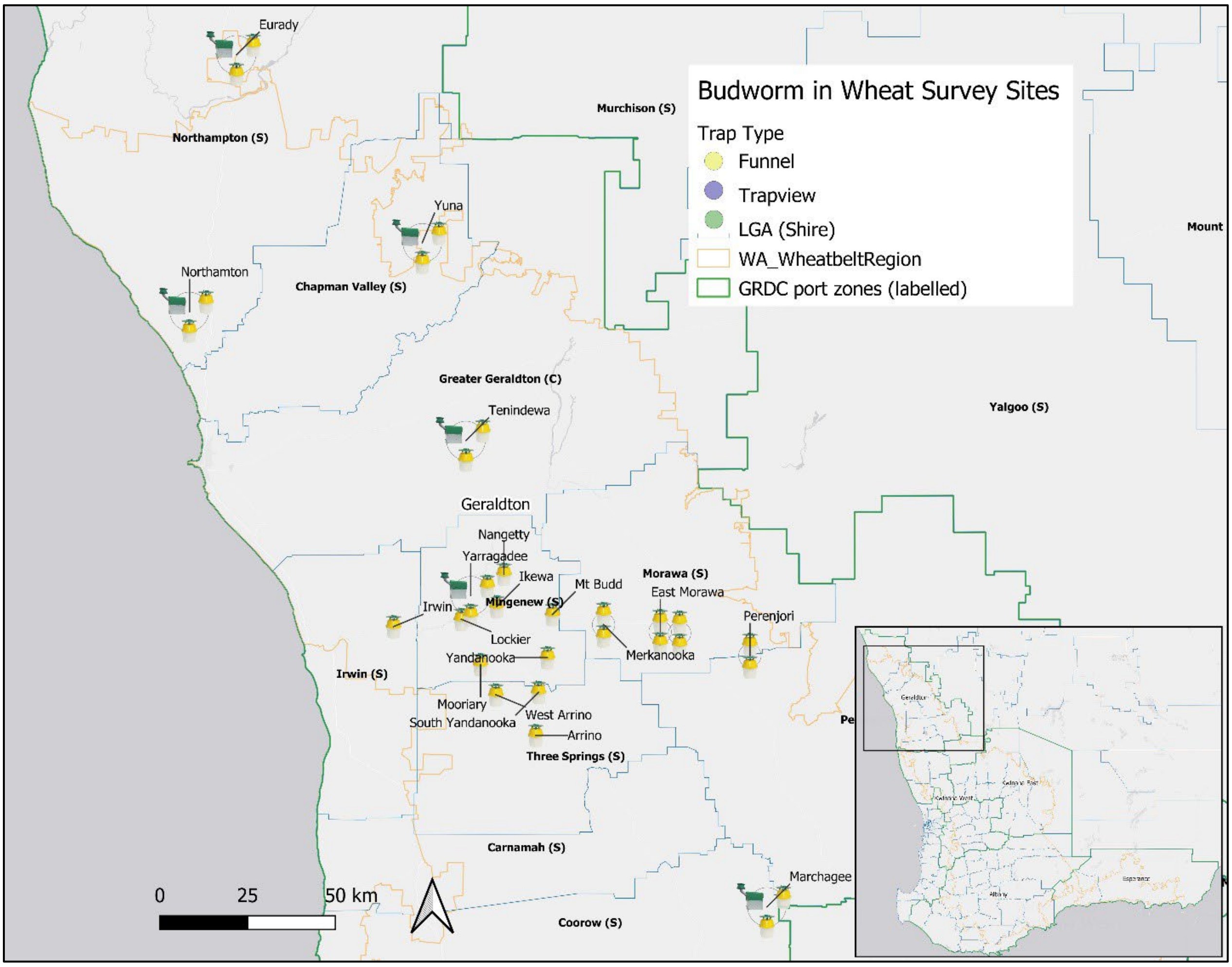



Figure 4. Locations of automated (TrapView®) and manual (funnel) native budworm moth traps in wheat crops in the Geraldton port zone in 2021.

**2022 field season**

In 2022, 15 new sites were established to monitor native budworm moth and larvae populations in wheat crops across 6 Shires in the Geraldton port zone (Fig. 5). Five of these sites were paired with (nearby) canola crops, five with lupin crops and five sites were paired with both canola and lupin crops. Moths were trapped using a total of 55 manual (funnel) pheromone-based traps across 15 sites (Table 1), and lures were replaced monthly. Caterpillar populations were monitored in the wheat, lupin and canola canopy by using sweep netting and visual assessment of damage and larvae presence when plants were small.

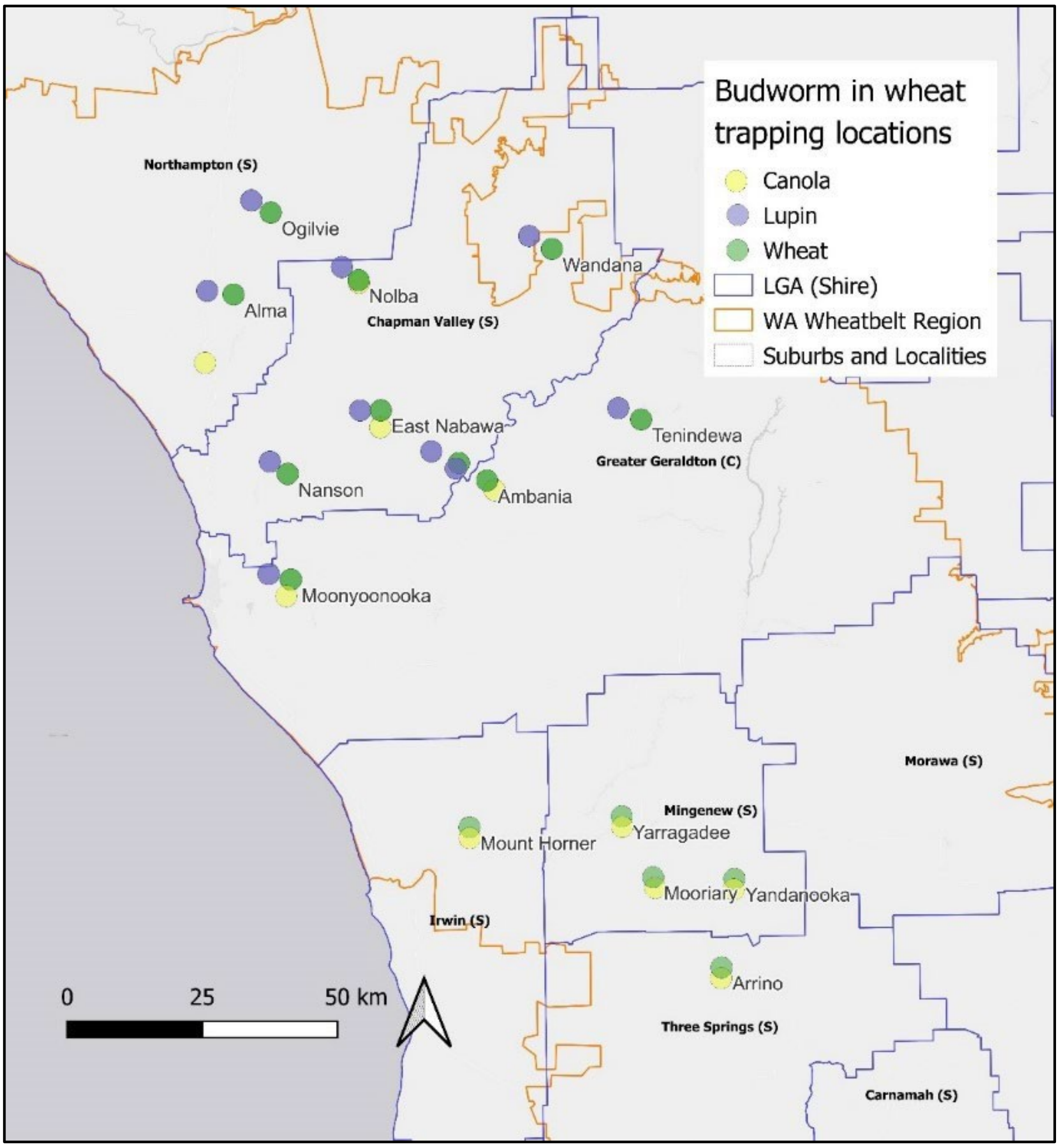



Figure 5. Native budworm surveillance sites in wheat crops paired with nearby canola and/or lupin crops in the Geraldton port zone in 2022.

Table 1. Native budworm moth traps monitored in each Shire in the Geraldton port zone of WA during 2022.

| LGA (SHIRE) | Site Location | Canola | Lupin | Wheat | Trap Total |
|---|---|---|---|---|---|
| Chapman Valley | East Nabawa | 1 | 2 | 2 | 5 |
| | Nanson | | 2 | 2 | 4 |
| | Nolba | 1 | 2 | 2 | 5 |
| | North Eradu | | 2 | 2 | 4 |
| | Wandana | | 2 | 2 | 4 |
| Greater Geraldton | Ambania | 1 | 2 | 2 | 5 |
| | Moonyoonooka | 1 | 2 | 2 | 5 |
| | Tenindewa | | 2 | 2 | 4 |
| Irwin | Mount Horner | 1 | | 1 | 2 |
| Mingenew | Bundanoon | 1 | | 1 | 2 |
| | Yandanooka | 1 | | 1 | 2 |
| | Yarragadee | 1 | | 1 | 2 |
| Northampton | Alma | | 2 | 2 | 4 |
| | Ogilvie | | 2 | 2 | 4 |
| | Sandy Gully | 1 | | | 1 |
| Three Springs | Arrino | 1 | | 1 | 2 |
| Total traps | | 10 | 20 | 25 | 55 |

**Glasshouse trials**

Ten glasshouse trials were conducted during 2021 and 2022 at Northam DPIRD glasshouse facilities to investigate under controlled conditions the behaviour of native budworm larvae or moth egg laying when given a choice (or no choice) of the non-traditional host wheat and a known traditional host such as lupin, faba bean or wild radish. Insect-proof Bugdorm cages were used to isolate plants and insects (Fig. 6).

Figure 6. Bugdorm insect-proof cages used in native budworm glasshouse trials.

### Trials 1-2, larva no-choice, wheat or lupins

A larvae no-choice trial was conducted to assess the extent of damage budworm larvae can cause to wheat relative to lupins, a traditional host commonly grown in the Geraldton port zone. Small budworm larvae (approx. 10-20 mm) were placed on either late booting/heading wheat (GS55-65) or early flowering lupins within individual insect-proof cages, with ten replicates of each treatment in randomised block design. Plants were inspected three times per week to assess larva length and plant damage until all larvae had either died or pupated. One week after trial end, pupae were carefully extracted from soil, weighed, and placed in petri dishes until the pupae either died or moths emerged.

This trial was repeated to strengthen the data, however, larvae mortality occurred in 80% of both wheat and lupin treatment groups. It was presumed that the larvae sourced from initial field populations may have been compromised with disease.

### Trial 3, larva choice, wheat or faba beans

A larvae choice trial was conducted to assess the behavioural preference of budworm larvae for wheat and a traditional host plant and the extent of damage the larvae can cause to either wheat or faba bean when given a choice. Pre-flowering faba beans and stem elongation wheat (GS30-39) were paired within individual cages with small budworm larvae (approx. 10 mm) placed between plants, using ten replicates in randomised block design. Plants were inspected three times per week to assess larva length, plant damage and caterpillar location until the larvae commenced pupating. This trial was not repeated because the data showed a clear preference for faba bean.

### Trials 4-5, larva choice, wheat or wild radish

A larva choice trial was conducted using wheat and wild radish to assess the feeding behaviour of budworm larvae when given a choice of wheat or wild radish, based on reports of patches of wild radish in wheat crops having much higher numbers of budworm than the surrounding wheat plants. This trial was repeated with different growth stages, ten replicates and randomised block design.

The first trial consisted of early flowering wild radish and stem elongation wheat (GS30-39) paired in cages with small (10 mm) budworm placed between and equally distant from plants. The second trial consisted of flowering wild radish and late ear emergence/flowering wheat (GS59-69). Plants were inspected three times per week to assess larva length, plant damage and caterpillar location until the larvae commenced pupating.

### Trials 6-7, moth egg laying choice, wheat or faba bean

A moth choice trial was conducted to assess the preference of female native budworm moths to lay eggs on either wheat or a traditional host faba bean when given a choice. Colony-reared pupae were produced using artificial diet and sexed under microscope. Male and female pupae were paired within cages containing single wheat and faba bean plants. Moths emerged and mated before commencing egg lay. Plants were inspected three times per week for moth emergence and numbers of eggs laid on plants were documented until eggs began to hatch into larvae. The trial was conducted twice each with ten replicates in randomised block design.

### Trial 8, moth egg laying choice and no-choice, tillering or heading wheat versus lupin or wild radish

A moth choice trial was conducted to assess the willingness of female budworm moths to lay eggs when given only tillering or flowering wheat as well as preference of female budworm moths to lay eggs on either tillering wheat paired with lupin (to simulate the volunteer lupin in wheat crops scenario) or flowering wheat paired with wild radish (to simulate the wild radish in wheat crops scenario). These four treatments were replicated 10 times in randomised block design in the glasshouse.

Colony-reared pupae were produced using artificial diet and sexed under microscope. Male and female pupae were paired within cages. Moths emerged and mated before commencing egg lay. Plants were inspected three times per week for moth emergence and numbers of eggs laid on plants were documented until eggs began to hatch into larvae (Fig. 7). The trial was conducted once.

Figure 7. Amber Balfour-Cunningham counting budworm eggs in a wheat / lupin choice treatment.

### Trial 9-10, larvae feeding no-choice trial with barley, oats and wheat

A larva choice trial was conducted to quantify budworm damage and identify preferred plant growth stages and plant parts, of advanced barley, oats and wheat in regard to pest management in other cereal crops. As with previous larvae no-choice trials, young larvae approx. 10 mm long were placed onto individual plants within individual cages. Plants were inspected three times per week for larva length, plant damage and caterpillar location until the larvae commenced pupating. This trial was conducted twice in randomised block design, the second including a faba bean treatment for comparison.

**Native budworm field cage trial, Geraldton WA**

A field cage trial was undertaken to investigate the association between larval populations and economic damage in wheat which could lead to threshold determination for management actions against native budworm in wheat. The trial was conducted at Geraldton DPIRD Research Support Unit (-28.779513, 114.657562) in wheat (Vixen, InterGrain) sown on 16th May 2022. No insecticides were applied at the site. Pre-sowing and post emergent herbicides were applied.

Ten field emergence cages (100cm*100cm*110cm, BT2008, Megaview, Taiwan) were installed when the wheat reached dough stage. Cages were arranged in two rows of five maintaining 5m distance between each cage and row (Fig. 8). Each cage encompassed a 1m x 1m quadrant with five wheat rows, which was cleared of insects prior to introducing budworm through visually inspecting and bashing plants.


Figure 8. Field cage trial set up at DPIRD Geraldton Research Support Unit, Images by Saleh Adnan (DPIRD).

Native budworm used in the trial were sourced as 6th generation eggs from a colony established and maintained in the entomology laboratory at DPIRD Northam. The colony was maintained in a controlled environment at a temperature of 24–26°C and a photoperiod of 12:12 (L:D). Eggs were obtained from panmictic mating of approximately five pairs of adult native budworm moths housed in a 47.5 × 47.5 × 93 cm mesh cage (Bugdorm 4F4590, Megaview, Taiwan). Adult moths were provided ad libitum access to 10% sugar solution fed through a cotton wick in 70 ml container. Young adult moths were placed in a mesh cage with a faba bean plant which was checked regularly for oviposition. Once the females laid sufficient eggs, the freshly laid eggs along with the faba bean plant were transported to Geraldton DPIRD laboratory for further rearing. The overall larval rearing was maintained at a temperature of 24–26°C and a photoperiod of 12:12 (L:D) in a controlled environment room at Geraldton DPIRD laboratory.

The eggs were maintained in the Bugdorm on plant material and checked daily for hatching. Once the egg masses hatched on faba bean plants, neonates were kept on faba bean plants for the first 34 days. As soon as larvae became 3-4mm in size, neonate larvae were individually housed in a 30ml plastic container and sealed with a lid to avoid cannibalistic feeding. In each container, larvae were provided 2-3 young fresh faba bean leaves. Rearing containers were checked every 48 hours and foliage was replaced and frass was removed as needed. Larvae that were 10 mm or greater were selected for the field cage trial. Plastic trays holding larval rearing containers were placed in a cool esky to transport to the field cage site at DPIRD Geraldton RSU from the laboratory.

On 20th September 2022, two treatments of either five or ten larvae with five replicates of each, were introduced into the field cages with a sterilized paint brush.

After introduction of larvae, field cages were monitored twice a week for 3 weeks to confirm that larvae were present, and cages were secure. On 11th October 2022 cages were removed. Total number of heads in each 1 m row within every cage were counted, and 50 wheat heads were randomly collected from the wheat paddock outside the cages and counted later to represent the average number of glumes in wheat heads and to assess for damage as a control. Total number of damaged heads and glumes were recorded for each 1m length.

Following this, all the damaged heads found in each 1m row were collected and observed for glume damage. Later the total number of damaged glumes within each infested head for each 1 m row was counted. In addition to glumes, damage to flag leaves as well as other leaves for each 1 m row were also observed. For flag leaf damage, the number of damaged flag leaves was counted for each 1 m and was divided by total number of flag leaves in 1 m to estimate the % flag leaf damage for 1 m length wheat. If any damaged flag leaf found, the proportion of damage to flag leaf area were approximately estimated with a measurement scale and their average was presented in the table.

For each cage, we recorded five 1 m length assessment on % head damage, % glume damage, and % flag leaf damage. Finally, any damage being found on other leaves and their numbers were also noted for each 1 m length.

The extent of head damage was determined following the formula and expressed as percentage:

**% Head damage in 1 m length wheat = number of damaged head in 1 m length/ Total number of heads in 1 m wheat *100**

Therefore, we calculated % glume damage for two separate larval numbers in 1 m length of wheat following the equation:

**% Glume damage in 1 m length = Total number of damaged glumes in 1 m row/ (Average glume numbers /head × Average number of heads in 1 m row) × 100**

**Field investigation of chewing damage by native budworm on wheat crops in the Geraldton port zone 2022**

Fifteen wheat crops were monitored fortnightly by DPIRD and Mingenew Irwin Group (MIG) staff from 2nd of June 2022 until harvest for the presence of native budworm moths and larvae (refer Fig. 5).

Native budworm moths were trapped in manual funnel traps installed in the crop with a species-specific pheromone lure (Richard Vickers). At sites monitored by DPIRD, two traps were established in each crop at least 50 m from the crop edge and at least 50 m apart. Sweep netting was conducted throughout each focus paddock to assess for budworm larvae, with five lots of 10 sweeps at the crop centre and edge.

During 2022, no reports of native budworm damage or larvae presence in wheat were received from local growers, grower groups or agronomists which could be followed-up on in the field. However, native budworm larvae were detected in significant numbers in sweeps at three of the 15 wheat crops, located at Nanson, North Eradu and East Nabawa, on the 27th and 28th of September 2022 (Fig. 9). In addition, more than two native budworm per 50 sweeps were found in wheat at DPIRD's Geraldton Research Station. The four sites where native budworm were detected in numbers greater than one in fifty sweeps were assessed during a follow-up investigation in early October (Table 2). Assessments included native budworm larvae presence and chewing damage to wheat heads, glumes, flag leaves and other leaves.

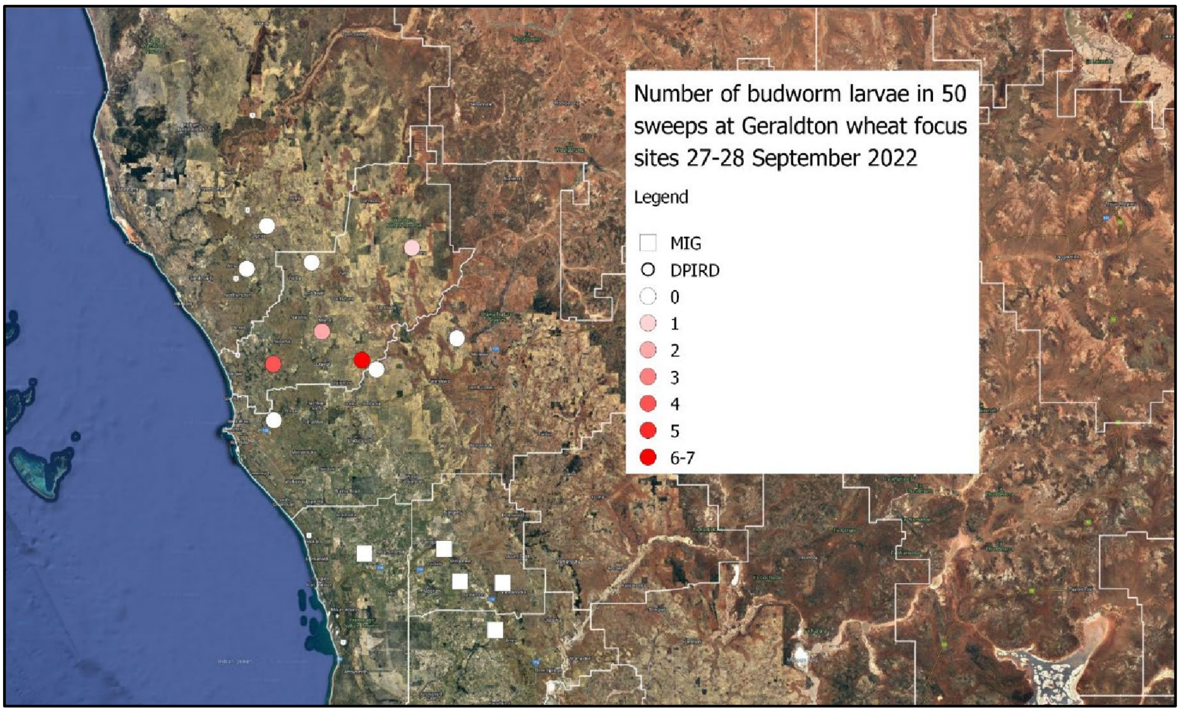



Figure 9. Total number of native budworm larvae in five lots of 10 sweeps in the Geraldton Port Zone wheat monitoring sites in 2022 (excluding the Geraldton RSU site).

Table 2. Focus wheat sites assessed for native budworm chewing damage in the Geraldton port zone in 2022, including crop rotation, insecticide spray history and additional paddock history information.

| Site No. | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| **Location** | North Eradu | Wandana | Nanson | Geraldton RSU |
| **Wheat growth stage** | Watery ripe | Watery ripe | Dough | Watery ripe |
| **Previous rotation** | Canola | Lupins | Lupins | Lupins |
| **Previous rotation** | Canola | Lupins | Lupins | Lupins |
| **Crops next to paddock** | Lupin | Lupin | Lupin, canola, pasture | Fallow |
| **Paddock size (ha)** | 800 ha | 520 ha | 57 ha | 5 ha |
| **Volunteer hosts present?** | None | None | None | Volunteer lupins podding scattered throughout crop |
| **Host weeds present?** | Small numbers of wild radish along road edges, none in crop | None | Wild radish and biserulla along road edges and some edge areas of crop. | None in crop, however wild radish in clear area next to paddock. |
| **Row spacing (mm)** | 254 | 250 | 305 | 254 |
| **No. field assessments/ quadrats** | 32 | 30 | 20 | 10 |
| **Insecticides applied** | Post emergent, Trojan | None applied | NA | None applied |

At each focus crop requiring further investigation, a number of 10m x 10m randomly selected quadrants were surveyed (Fig. 10). Due to the small size of the Geraldton RSU paddock (5 ha) 10 quadrants were assessed at this site. In each 10m x 10m subsection, one lot of 10 sweeps with a sweep net was completed and five lots of 1m rows of wheat plants were assessed for head, glume and leaf damage and in situ native budworm larvae (Figs. 11a and 11c). In addition, 100 heads were randomly collected from each paddock to determine the average number of glumes per head. At Site 1, only 10 lots of 1m cuts were collected from 3 locations in the paddock to do additional investigation of head and glume chewing damage.

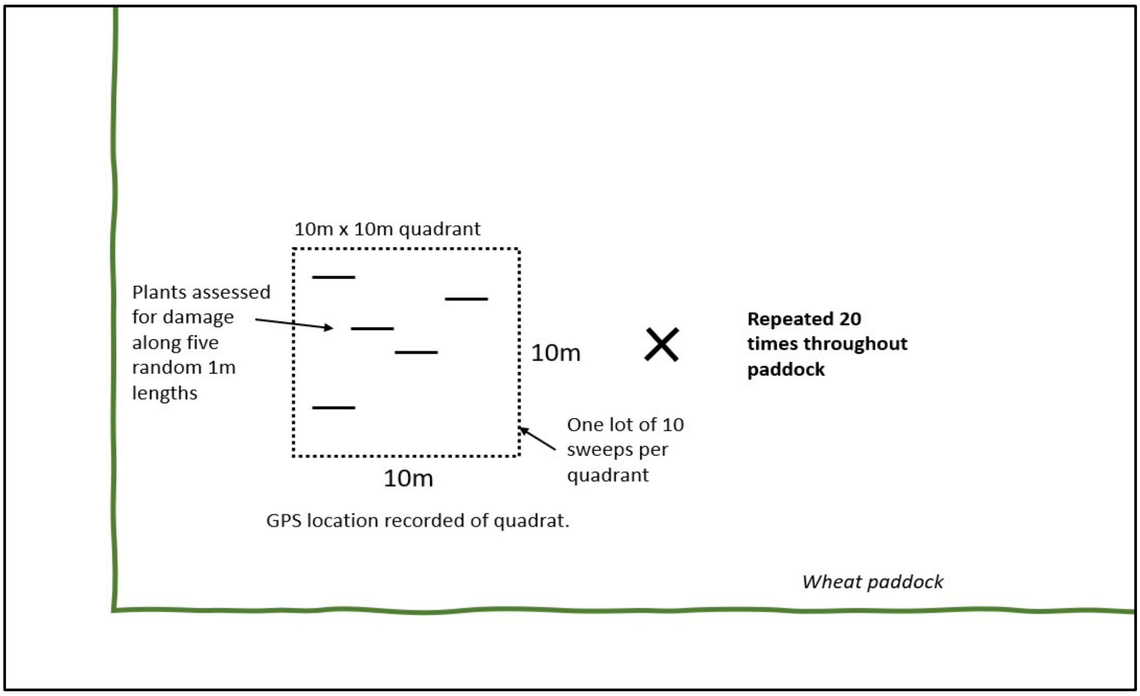



Figure 10. Quadrat assessment of native budworm population and wheat damage that was repeated throughout edges and centre of focus wheat crops.


Figure 11. Metre row assessments for wheat head and leaf damage (a). Photo courtesy of Amber Balfour-Cunningham (DPIRD). Amber Balfour-Cunningham assessing 1 m rows within a subsite at a budworm affected wheat crop in North Eradu (b). Photo courtesy of Saleh Adnan (DPIRD). Christiaan Valentine sweep netting wheat at Nanson wheat focus site (c). Photo courtesy of Amber Balfour-Cunningham (DPIRD). Budworm funnel trap with pheromone lure in wheat focus site at Mingenew (d). Photo courtesy of Courtney Humphrey (MIG).

## Results

### Field surveillance Geraldton port zone

#### 2021 season

Budworm moths were trapped at every wheat survey site in 2021, including those paired with nearby lupin and canola crops, and numbers ranged from one moth at Perenjori to 269 moths at Northampton (Fig. 12). Cumulative moth counts indicated greater than 50 moths trapped during July in the shires Northampton, Mingenew and Irwin followed by an increase to greater than 100 total moths in early August at Three Springs (Fig. 13). Relatively low numbers of moths were trapped at sites in the shires of Perenjori, Chapman Valley, Morawa and Coorow, and these occurred later in the season during September and October.

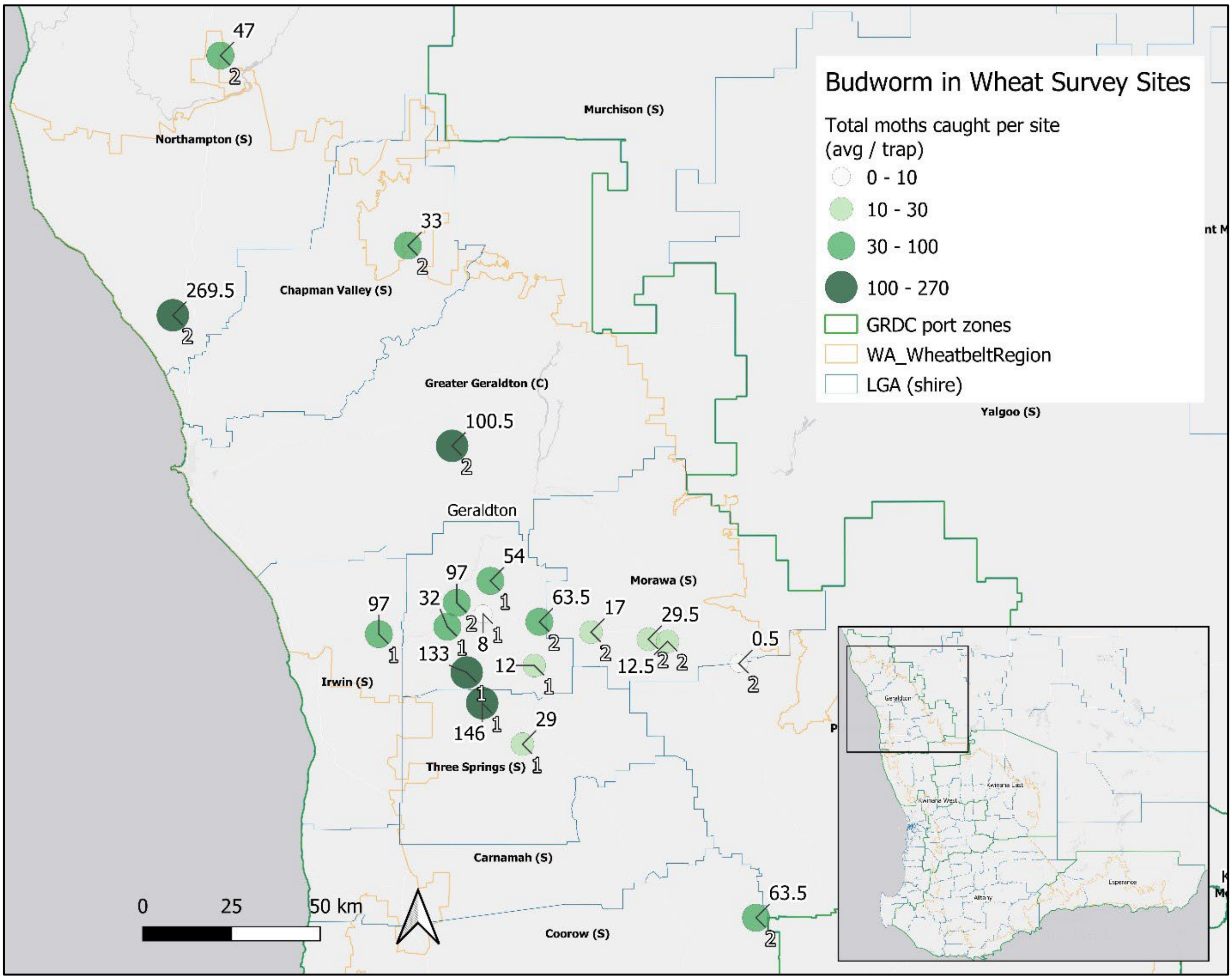



Figure 12. Total moths trapped per site from 10 May to 27 October 2021 (numbers were averaged if multiple traps per site). Black numbers with white buffer show the total number of moths trapped per site. White numbers with black buffer show the number of manual funnel traps at each site.

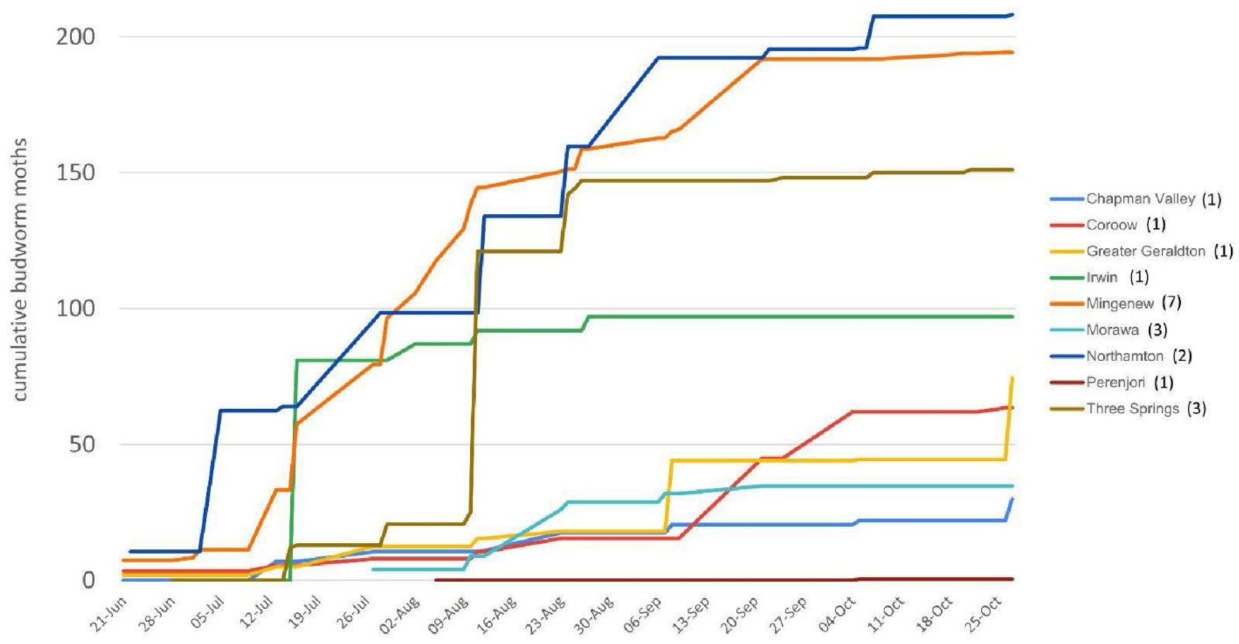



Figure 13. Cumulative average native budworm moth trap catch in wheat crops in each shire during 2021 (multiple traps were averaged per shire).

The number of moths trapped in lupin crops was generally greater than in nearby wheat crops, however, it appears there could be a correlation with moth numbers recorded in wheat crops paired with lupin crops. When moth numbers increased in lupin crops the moth numbers in nearby wheat also increased, and conversely, they decreased as moth numbers in the lupin crops decreased (Fig. 14). On the contrary, more moths were trapped in wheat crops than nearby canola crops for most sites and months (Fig. 15). This is surprising and may indicate a preference by moths to fly into wheat crops over canola crops.

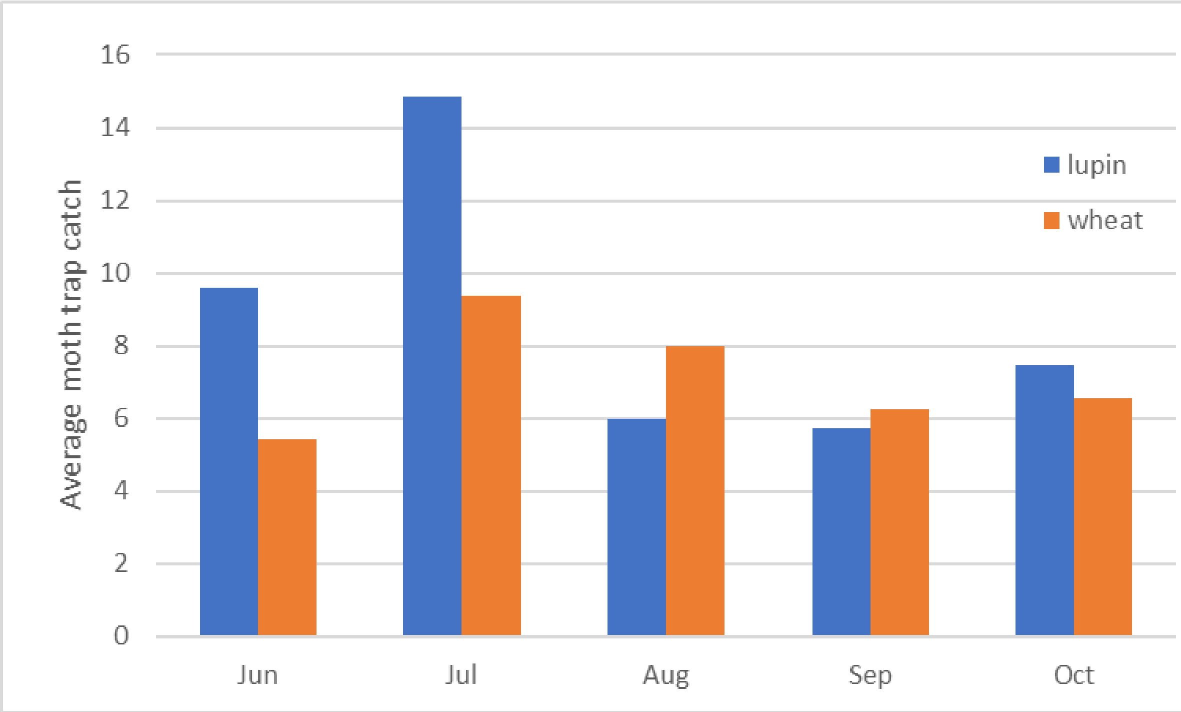



Figure 14. Average number of native budworm moths caught per trap each month at focus paddocks for lupin wheat paired sites (8) in the Geraldton port zone during 2021.

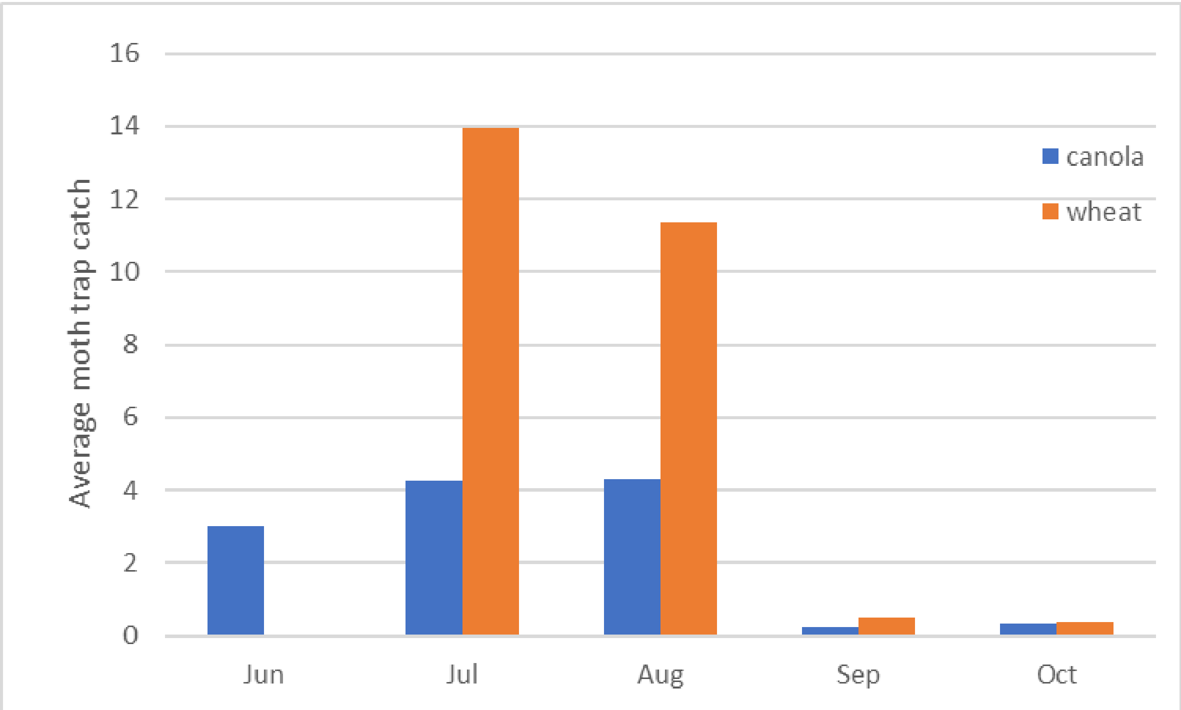



Figure 15. Average number of native budworm moths caught per trap each month at focus paddocks for canola wheat paired sites (10), in the Geraldton port zone during 2021.

### 2022 season

Native budworm moths were trapped at all wheat survey sites in the Geraldton port zone in 2022, and numbers ranged from 34 moths at Chapman Valley to 636 moths at Three Springs (Fig. 16). Overall, similar numbers of moths were recorded in wheat crops compared to nearby traditional hosts lupin and canola (Fig. 17). This occurred during July, August and September, indicating that they are just as likely to be flying into and throughout wheat crops as they are lupin and canola crops. Interestingly, similar numbers of moths were trapped in wheat crops in June compared to canola crops, but these were both higher than in lupin crops. By October relatively few moths were being caught in traps in wheat and lupin crops and these were very similar, while moths trapped canola crops had increased.

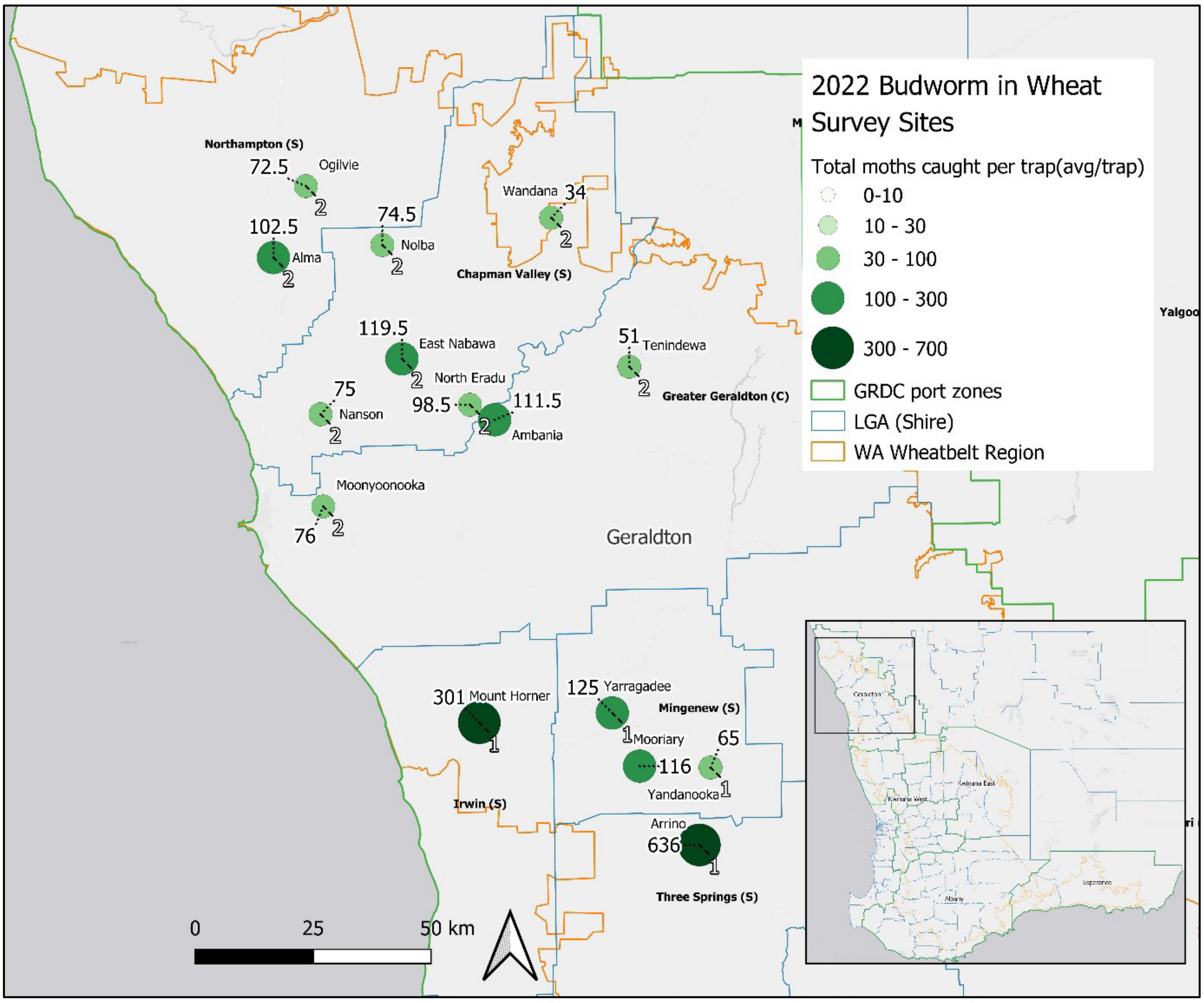
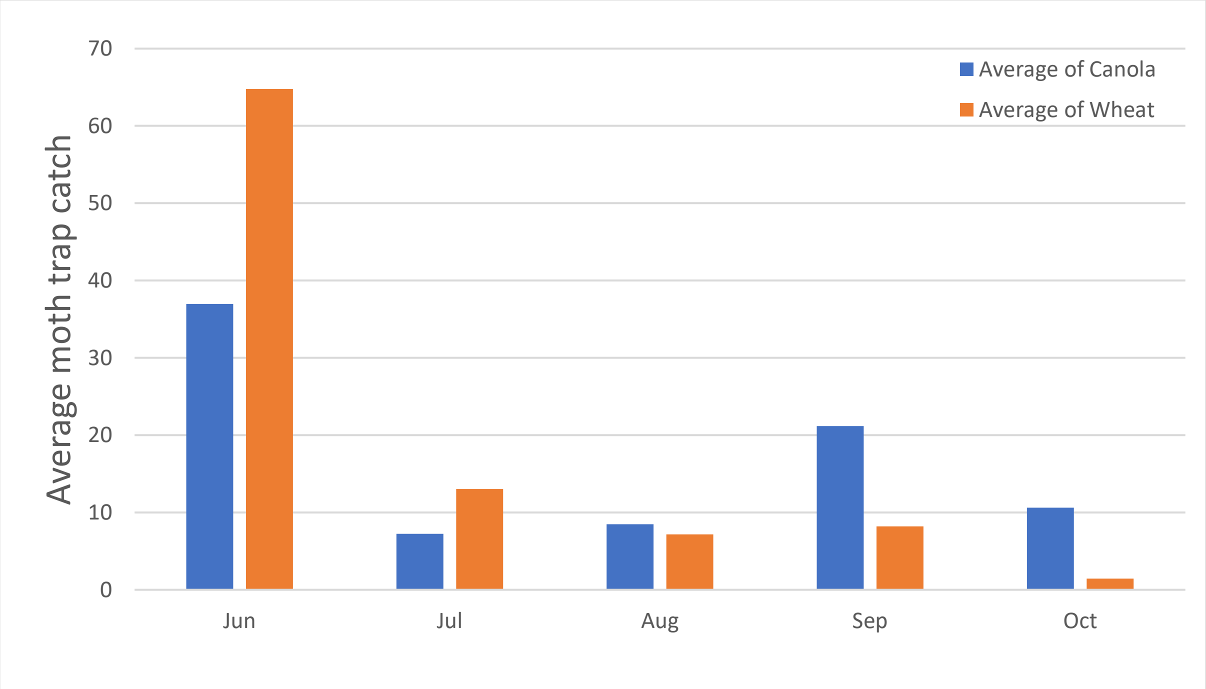



Figure 16. Total moths trapped per site from June to October 2022 (numbers averaged if multiple traps per site). Black numbers with white buffer show the total number of moths trapped per site. White numbers with black buffer show the number of manual funnel traps at each site.



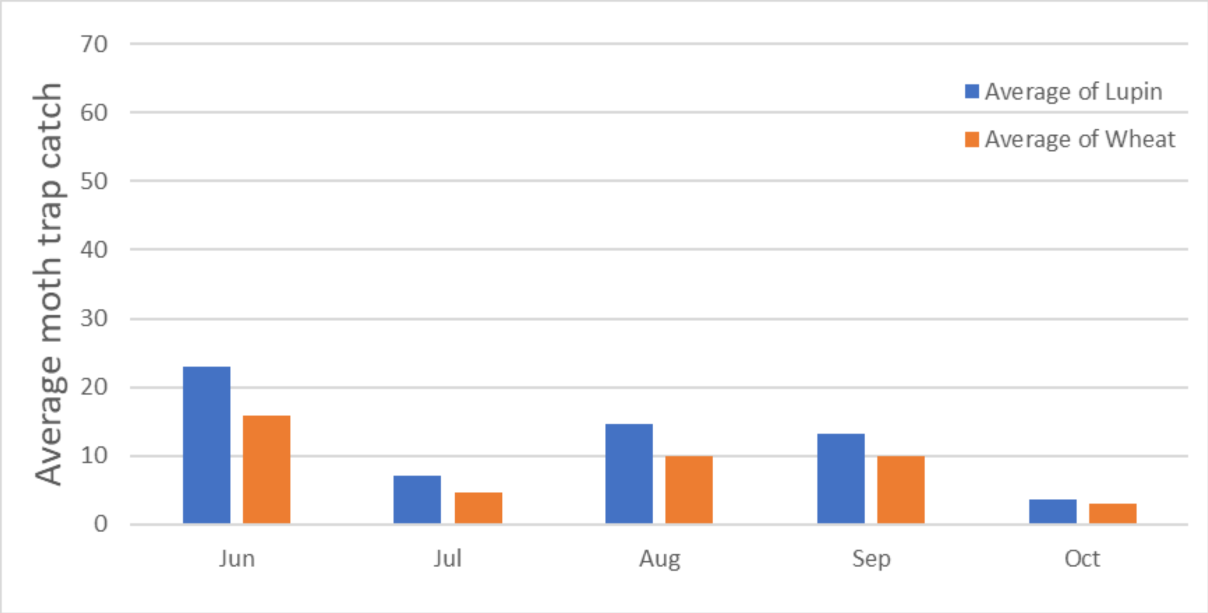




Figure 17. Average number of native budworm moths caught per trap each month at focus paddocks for canola wheat paired sites (10), and lupin wheat paired sites (10) in the Geraldton port zone during 2022.

When comparing moth and larvae numbers across sites, it was found that moths were detected very early (June) in high numbers then decreased throughout July and August, but most of the larvae detections occurred late September and October (Figs. 18, 19, 20). Likewise, budworm moths were detected in lupin crops from early June with numbers dropping through July and August and budworm larvae were detected in reasonable numbers starting early September. Similar trends with moth numbers occurred across the 10 canola crops, but interestingly larvae were detected from mid/late June through to September reaching over 3 per 10 sweeps on average.

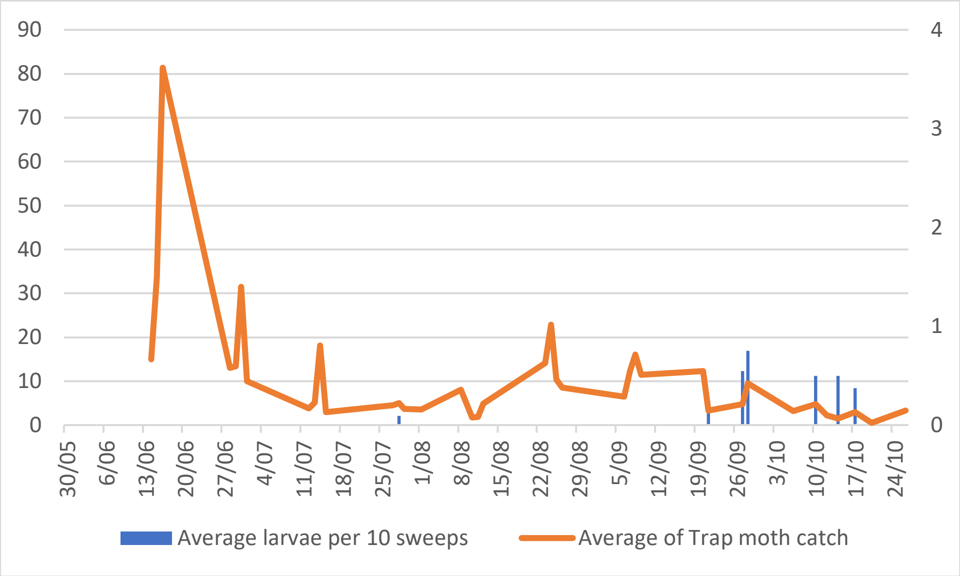



Figure 18. Average moth (left y-axis) and larvae (right y-axis) trapping results across 15 **wheat** crops in the Geraldton port zone of WA during 2022.

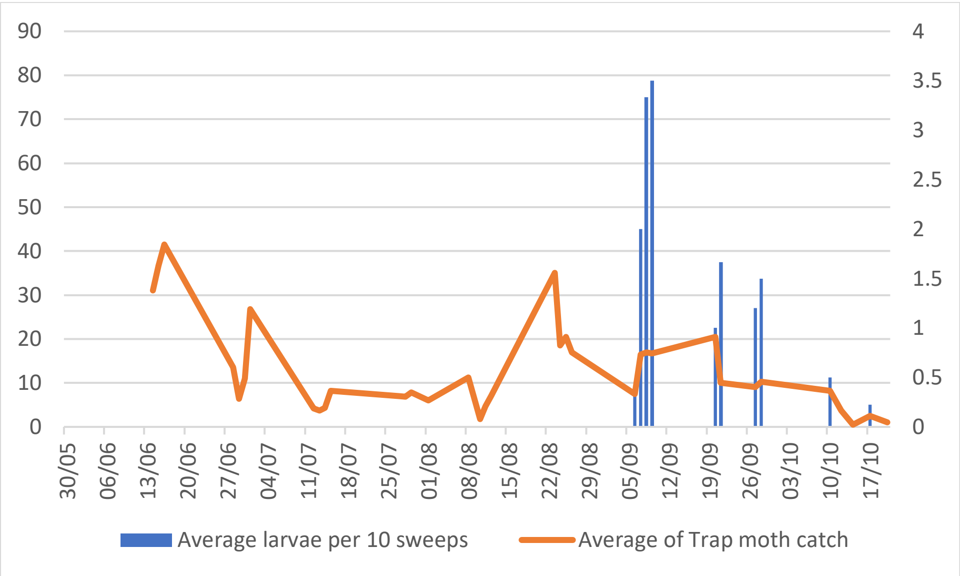



Figure 19. Average moth (left y-axis) and larvae (right y-axis) trapping results across 10 **lupin** crops in the Geraldton port zone of WA during 2022.

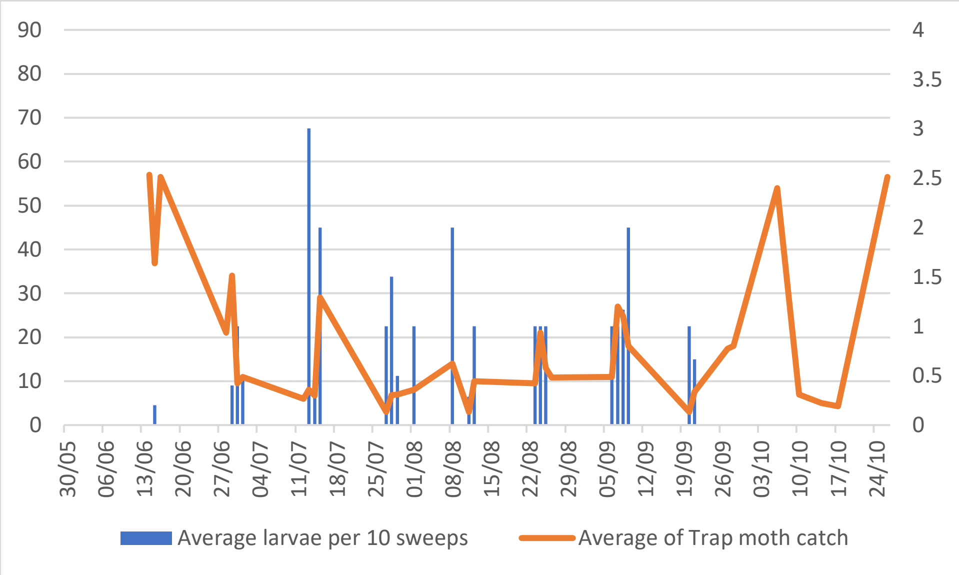



Figure 20. Average moth (left y-axis) and larvae (right y-axis) trapping results across 10 **canola** crops in the Geraldton port zone of WA during 2022.

Average monthly moth numbers per site are presented in Figs. 21, 22, 23 showing ratios of moths in wheat versus moths in paired lupin and/or canola sites.

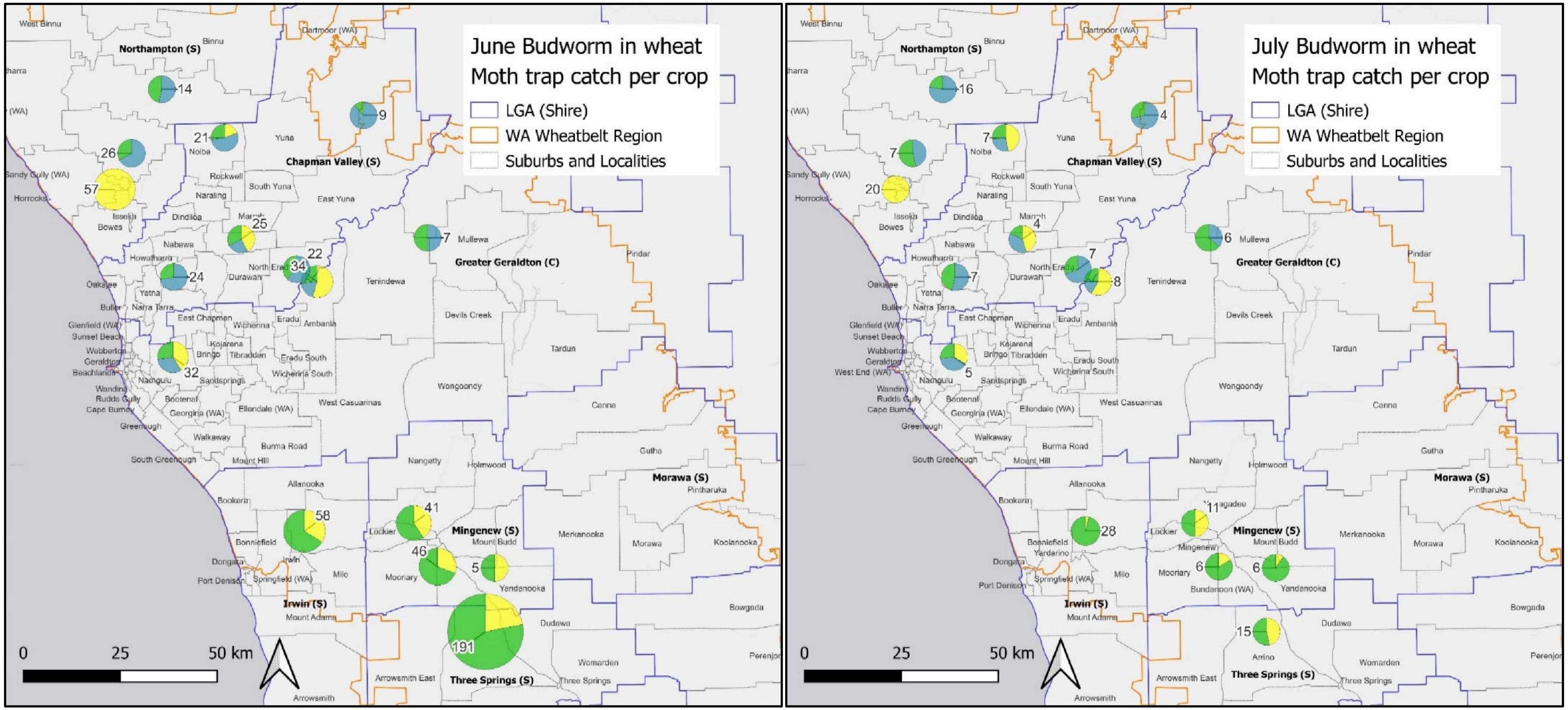



Figure 21. Average monthly budworm moth numbers caught in pheromone traps for each site during June (left) and July (right) 2022 in the Geraldton port zone of WA. Numbers indicate average number of moths across traps at each paired site. Pie charts indicate relative ratio of moth numbers from wheat (green), canola (yellow) and lupin crops (blue).

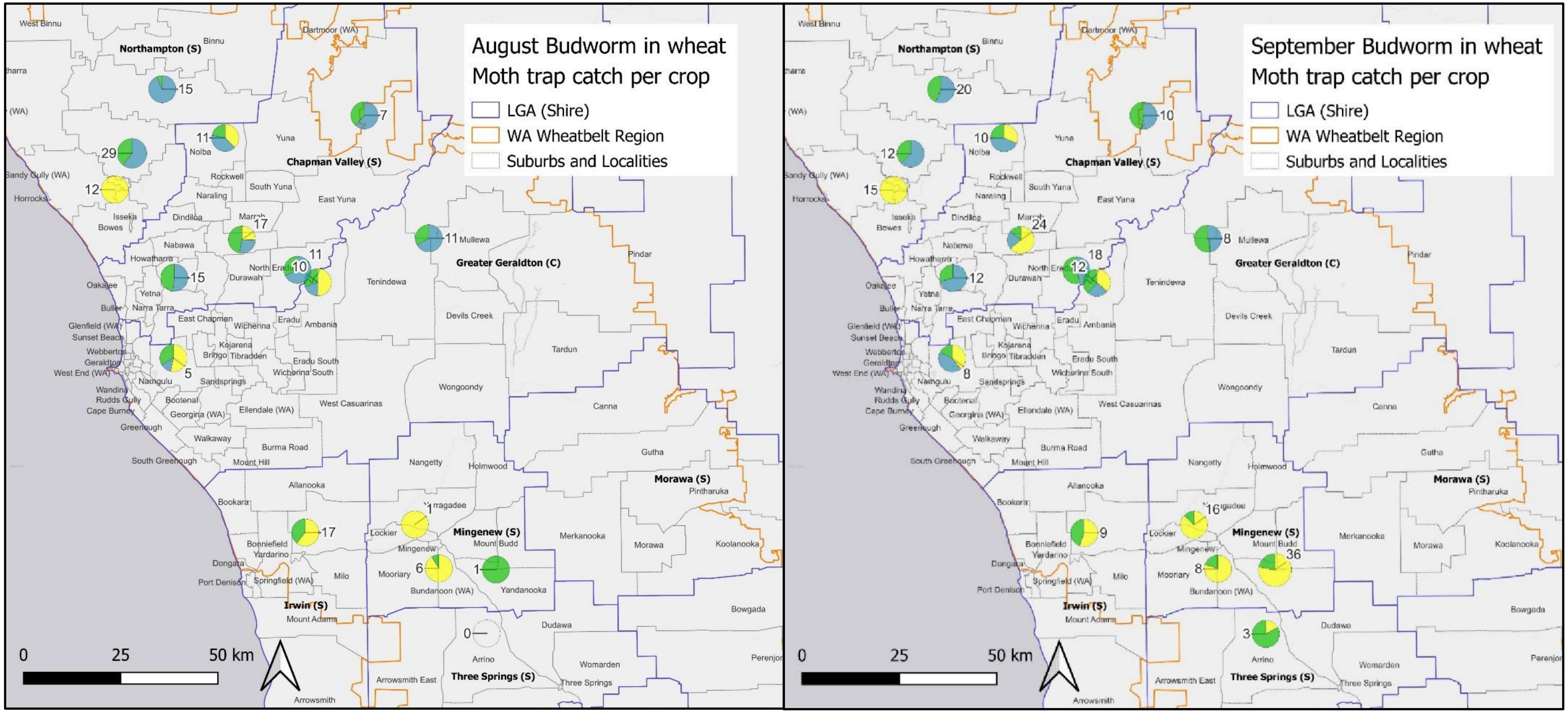



Figure 22. Average monthly budworm moth numbers caught in pheromone traps for each site during August (left) and September (right) 2022 in the Geraldton port zone of WA. Numbers indicate average number of moths across traps at each paired site. Pie charts indicate relative ratio of moth numbers from wheat (green), canola (yellow) and lupin crops (blue).

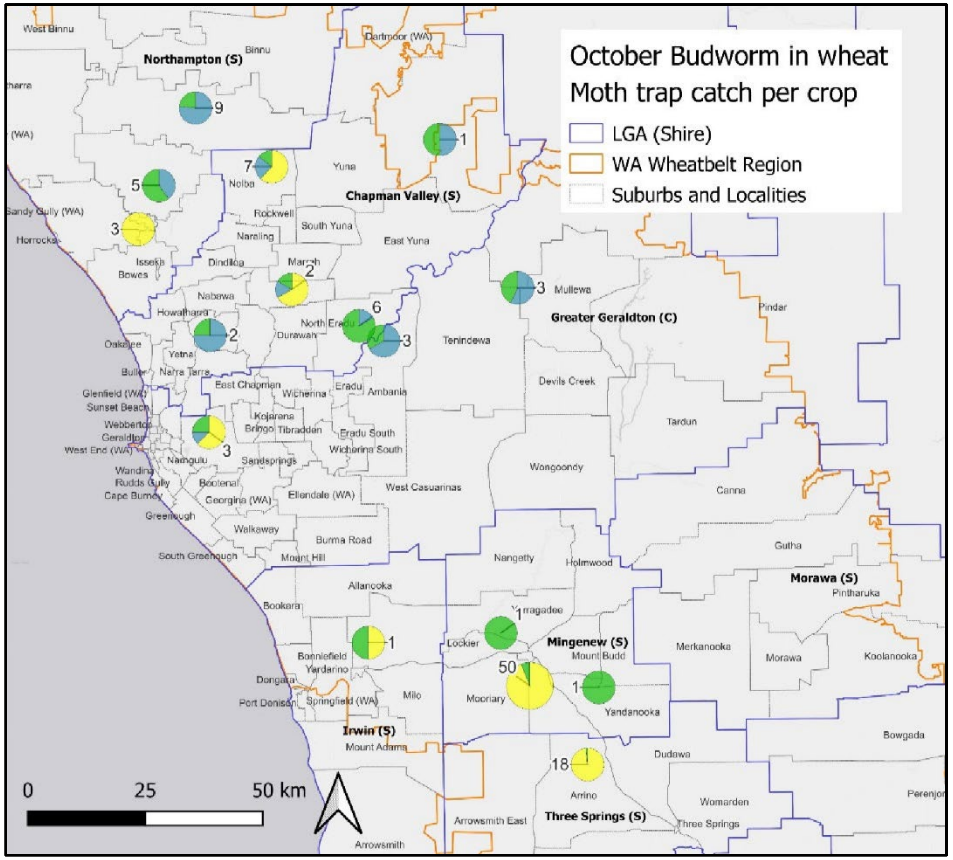



Figure 23. Average monthly budworm moth numbers caught in pheromone traps for each site during October 2022 in the Geraldton port zone of WA. Numbers indicate average number of moths across traps at each paired site. Pie charts indicate relative ratio of moth numbers from wheat (green), canola (yellow) and lupin crops (blue).

### Glasshouse trials

The results of budworm larvae and moth egg laying behaviour when given a choice (or no choice) of the non-traditional host wheat and a known traditional host such as lupin, faba bean or wild radish are summarised in Table 3. Each trial is discussed further below.

Table 3. Summary of results from glasshouse trials using larvae and moths (from pupae) to assess larva and moth egg laying behaviour with and without choice within insect-proof cages.

| No. | Trial | Date | Hosts | Main result | Replicates | Temp range (°C) |
|---|---|---|---|---|---|---|
| 1 | Larva no choice 1 | 29/7/21 to 26/8/21 | wheat, lupins | Damaged both (mostly lupin buds/flowers & wheat heads) | 10 | 16 - 27 |
| 2 | Larva no choice 2 | 10/9/21 to 11/10/21 | wheat, lupins | same as above | 10 | 16 - 27 |
| 3 | Larva choice 1 | 29/9/21 to 18/10/21 | wheat, faba bean | Clear choice of faba bean | 10 | 16 - 27 |
| 6 | Larvae choice 2 | 4/11/21 to 30/11/21 | tillering wheat, wild radish | Clear choice of wild radish | 10 | 16 - 27 |
| 7 | Larvae choice 3 | 24/11/21 to 6/12/21 | early heading wheat, wild radish | Clear choice for early heading wheat | 10 | 16 - 24 |
| 4 | Moth choice 1 | 1/10/21 to 2/11/21 | wheat, faba bean | Lots of eggs on faba bean, almost none on wheat | 9 | 16 - 24 |
| 5 | Moth choice 2 | 15/11/21 to 7/12/21 | wheat, faba bean | same as above | 10 | 16 - 24 |
| 8 | Moth no choice & choice | 25/1/22 to 25/2/22 | Trt 1 = Flowering wheat (Wh-F) + wild Radish (Rd), Trt 2 = Tillering wheat (Wh-T) + Lupin, Trt 3 = Tillering wheat (Wh-T), Trt 4 = Flowering wheat (Wh-F) | No choice: very few eggs on wheat, Choice: lots on wild radish and lupins | 10 | 16 - 24 |
| 9 | Larva no choice | 6/5/22 to 3/6/22 | Barley (tillering), Oats (tillering), Wheat (Heading) | Minimal damage to all cereals | 10 | 16 - 24 |
| 10 | Larva no choice | 2/8/22 to 5/9/22 | Faba bean, Wheat (heading), Barley (Heading), Oats (Heading) | Minimal damage to all cereals, typical damage to faba bean buds & flowers | 10 | 16 - 24 |

**Trials 1-2, larva no-choice, wheat or lupins**

Of the ten larvae per treatment, more larvae died before pupation on wheat plants (6) than lupin plants (3) (Fig. 24a, 24b). The larvae that survived to pupae grew longer in length over the first ten days on lupin than wheat indicating they were feeding and developing better. Pupal weight was significantly lower from wheat plants than lupin plants ($P < 0.01$). Pupal weight means were 0.257 g and 0.329 g for wheat and lupins respectively (LSD = 0.0385) (Fig. 24d).

Although the larva mortality was higher and pupal weights lower in wheat (as measures of fitness), damage to wheat heads ranged from 0 to 21% damage (Fig. 24c). This indicates that budworm larva fitness on wheat plants is reduced but larvae still have the potential for crop damage especially to the flowers and developing seeds within glumes. This is concerning because damage to wheat leaves may not result in yield or quality loss to wheat crops, but direct feeding damage to flowers and developing seeds will depend on the severity (Fig. 25).

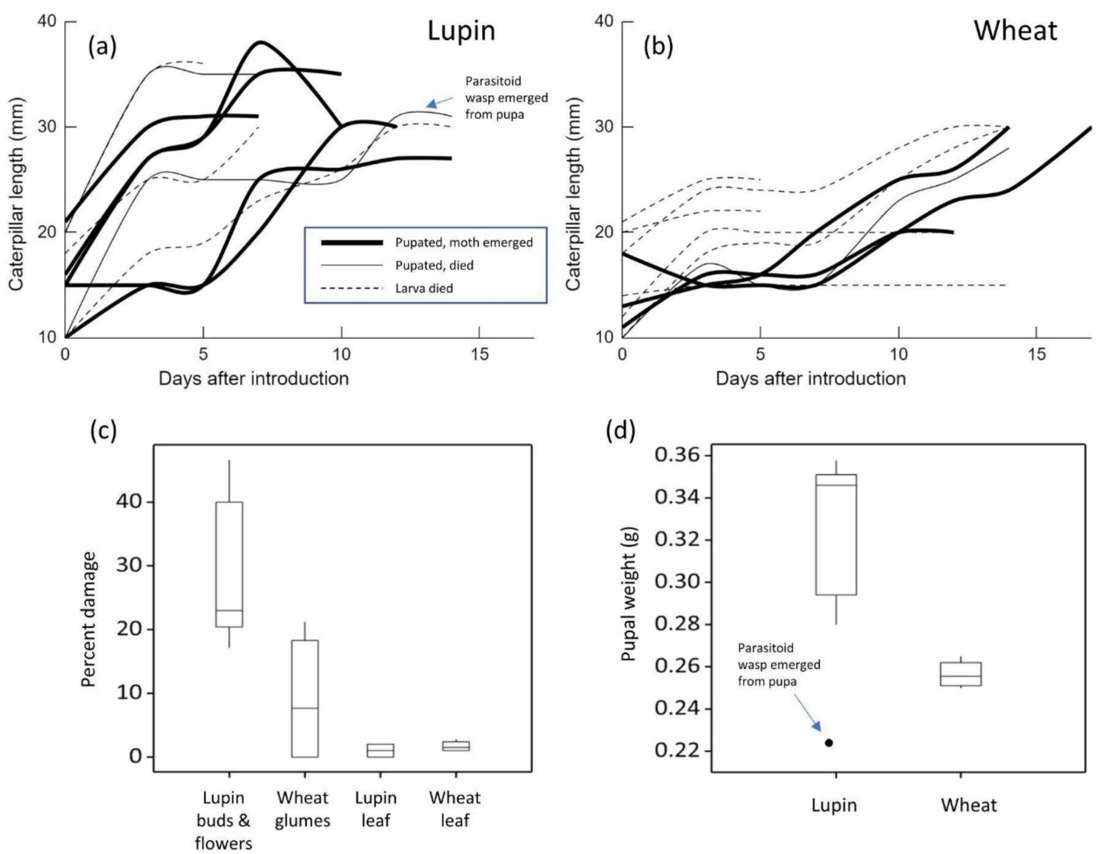



Figure 24. Lupin and wheat with native budworm larvae no-choice trial results for lupin (a) and wheat (b) larvae development over time until either pupated or died, lupin and wheat plant damage (c), and pupal weight (d). N=10.

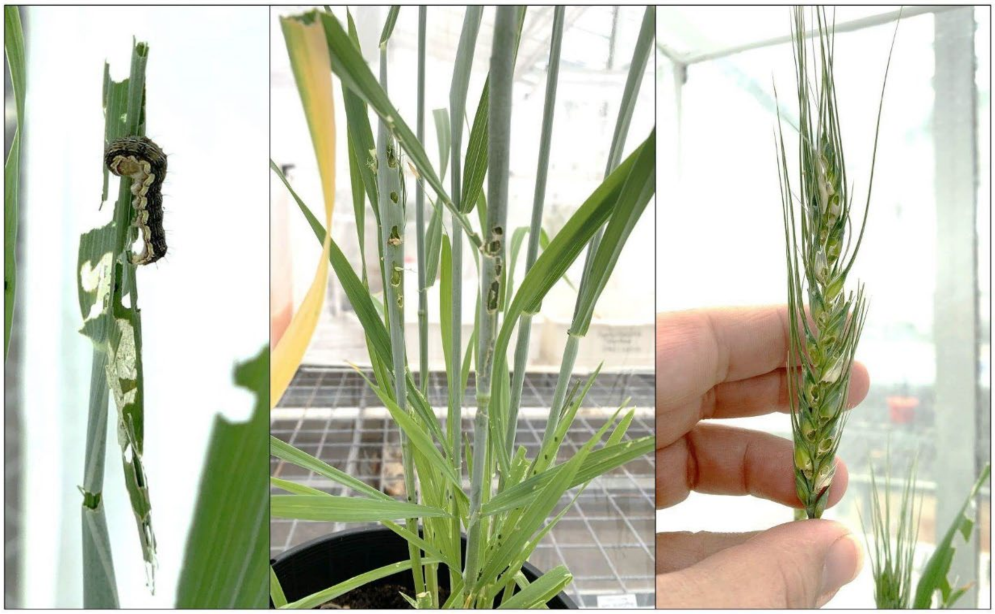


Figure 25. Budworm chewing damage to wheat leaves, boots and glumes in heads by budworm larvae.

**Trial 3, larva choice, wheat or faba beans**

Native budworm larvae showed a clear preference for faba bean plants (Fig. 26). Larvae were rarely observed on three of the ten wheat plants and never observed on the other seven wheat plants.

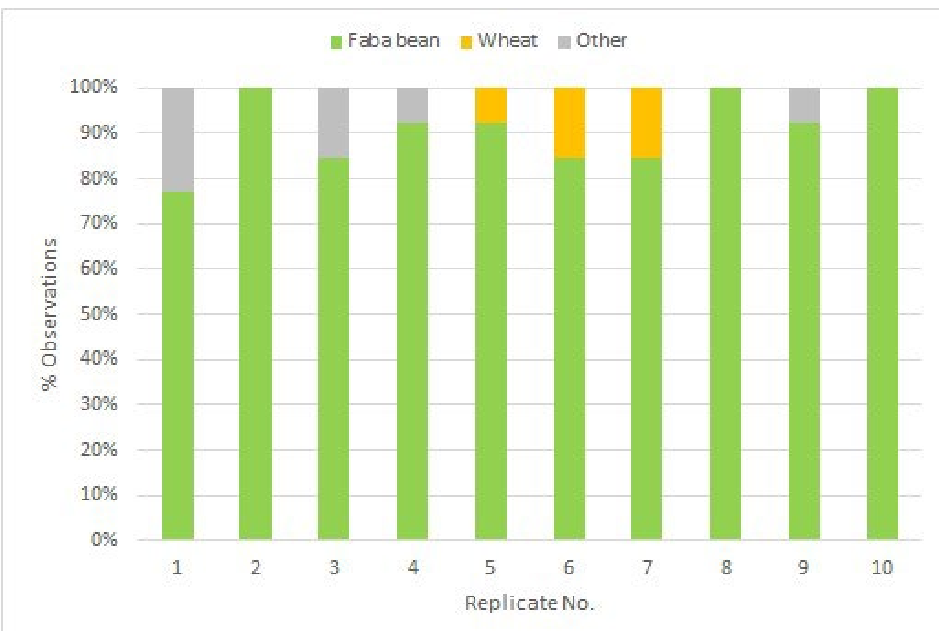



Figure 26. Percentage of total observations of native budworm larva on wheat, faba bean or on other locations such as cage or soil.

Larvae location varied but was predominantly on faba bean plants (Fig. 27). Initially, four of the ten larvae moved onto wheat or did not move onto a plant. After two days these four larvae moved onto and fed exclusively on faba bean until they moved off the plant to begin pupation. Five of the other larvae moved onto and fed exclusively on the faba bean from commencement. Only one larva fed on faba bean initially and later moved to feeding on wheat for the final two days.

Regarding larvae length, all larvae increased in size until they were above 25 mm in length (Fig. 27). Regarding plant damage, budworm larvae caused damage to all faba bean plants and very little damage to only one of the ten wheat plants (Fig. 28). This damage to wheat was caused by one larva that spent two of 14 days on a wheat plant when it was larger than 27 mm.

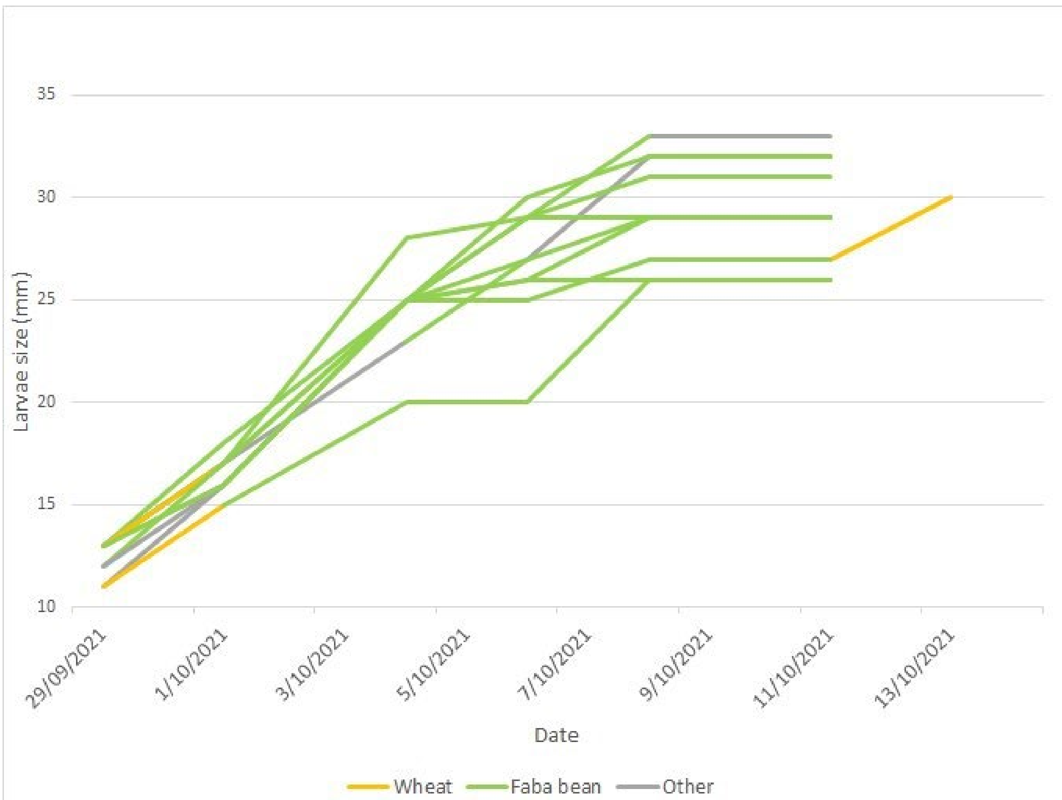



Figure 27. Native budworm larvae growth (mm) and location over time until pupation. In each replicate one larva was provided with one wheat plant and one faba bean plant in an enclosed cage. 'Other' locations are the cage and the soil.

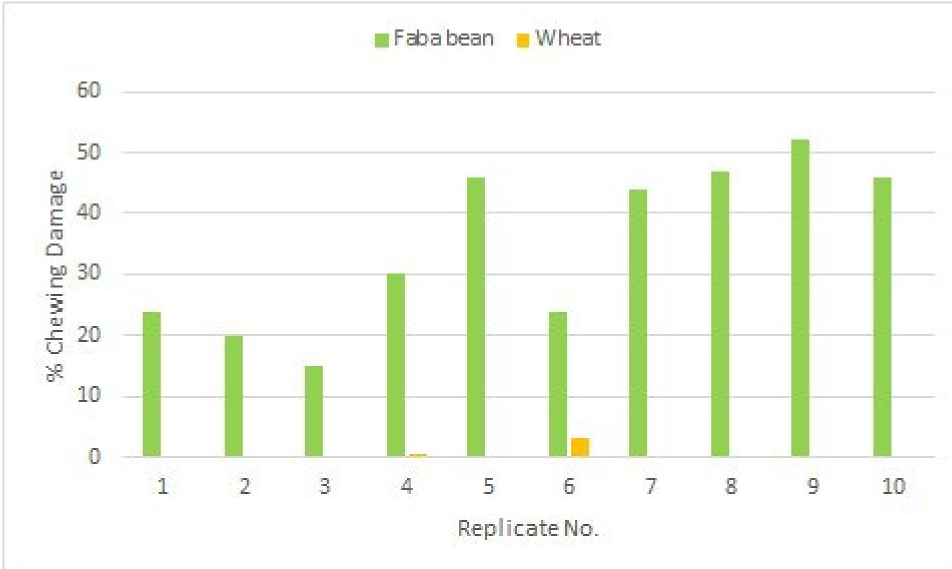



Figure 28. Percentage chewing damage by native budworm larvae to faba bean and wheat plants.

**Trials 4-5, larva choice, wheat or wild radish**

In the first of two wheat/radish trials budworm larvae were intermittently feeding on both the flowering wild radish and wheat at stem elongation in nine of the ten replicates (Fig. 29). This contrasts to the second trial with flowering wild radish and late ear emergence wheat where budworm larvae fed exclusively on wheat. Budworm were only observed on wheat heads and leaves and never on wild radish (no chart presented).

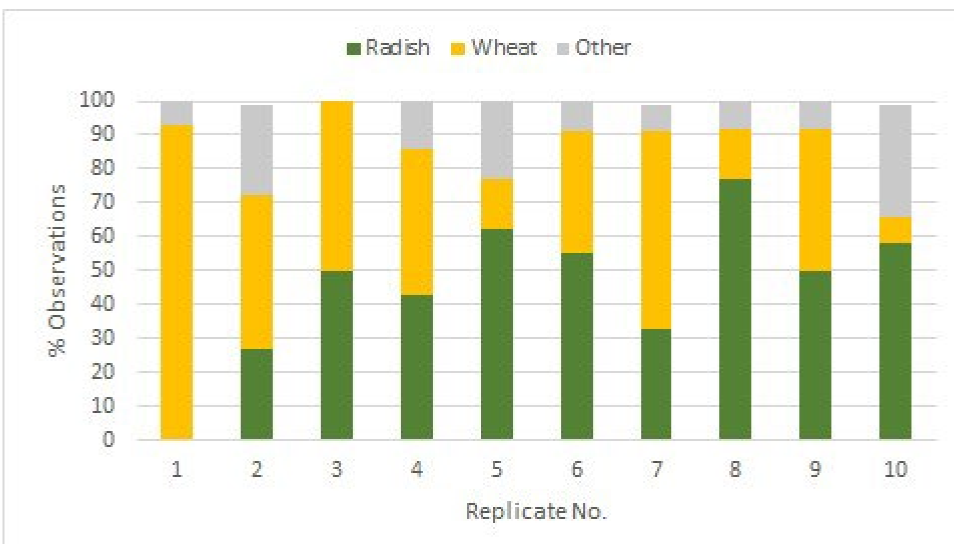



Figure 29. Percentage of total observations of budworm larvae on wheat at stem elongation, early flowering wild radish or on other locations such as cage or soil.

In the first larva choice trial with flowering wild radish and wheat at stem elongation, all except one of the 10 larvae grew to 20mm or greater (Fig. 30). In the second larvae choice trial with flowering wild radish and flowering wheat all larvae grew to 28mm or greater (Fig. 31). Observations of larvae location showed that in the first trial with wheat at stem elongation all larvae moved between feeding on the wheat and wild radish throughout the 20 days of the trial. In the second trial with more advanced wheat at flowering stage, larvae fed exclusively on the wheat and did not move to the wild radish or any other location (Fig. 31).


Figure 30. Budworm larvae growth and location within cages over time until pupation. 'Other' locations are the cage and the soil. Breaks in line indicate larva was unable to be located.

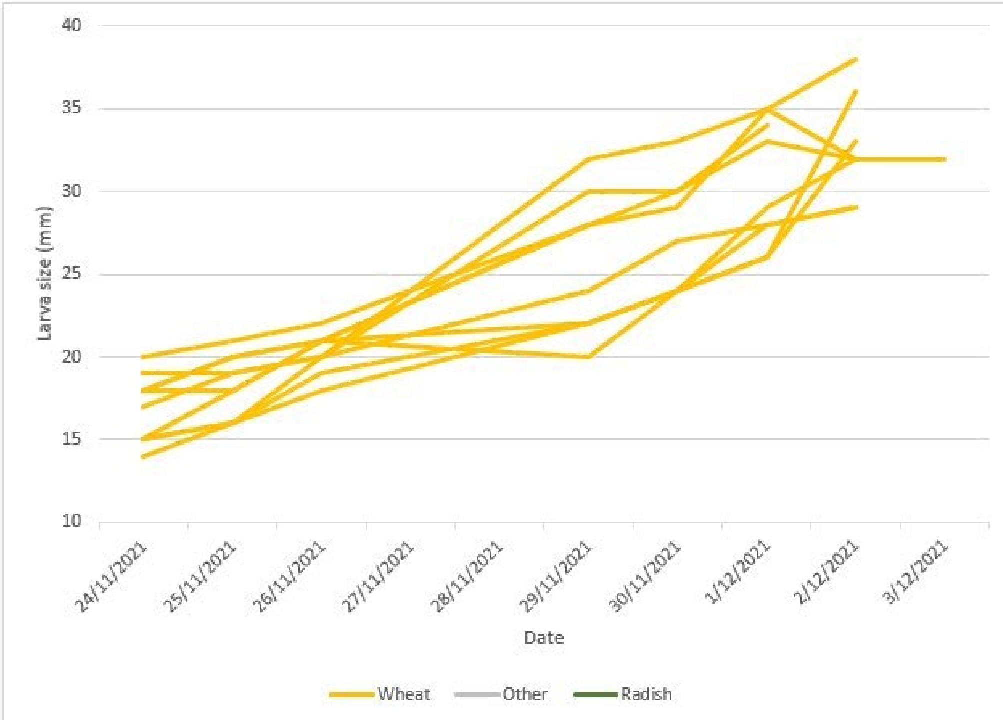



Figure 31. Budworm larvae growth and location within cages over time until pupation. In each of ten replicates one larva was provided with one wheat plant at booting stage and one wild radish plant in an enclosed cage. 'Other' locations are the cage and the soil.

Plant damage assessments show that in the first trial with flowering wild radish and wheat at stem elongation, nine of the ten budworm larvae damaged both wild radish and wheat (Fig. 32). In five of the replicates, the damage was comparable between the wild radish and wheat. Damage assessments for the second trial with flowering wild radish and flowering wheat show that in all cases damage to wild radish was minimal (average of 0.1% chewing damage) and damage to wheat was greater with wheat leaves having a total of 10% chewing damage on average and wheat heads showing a total of 18% chewing damage on average (Fig. 33). Here, damage estimates in wheat were up to 20% of leaf area and up to 31% of glumes chewed.

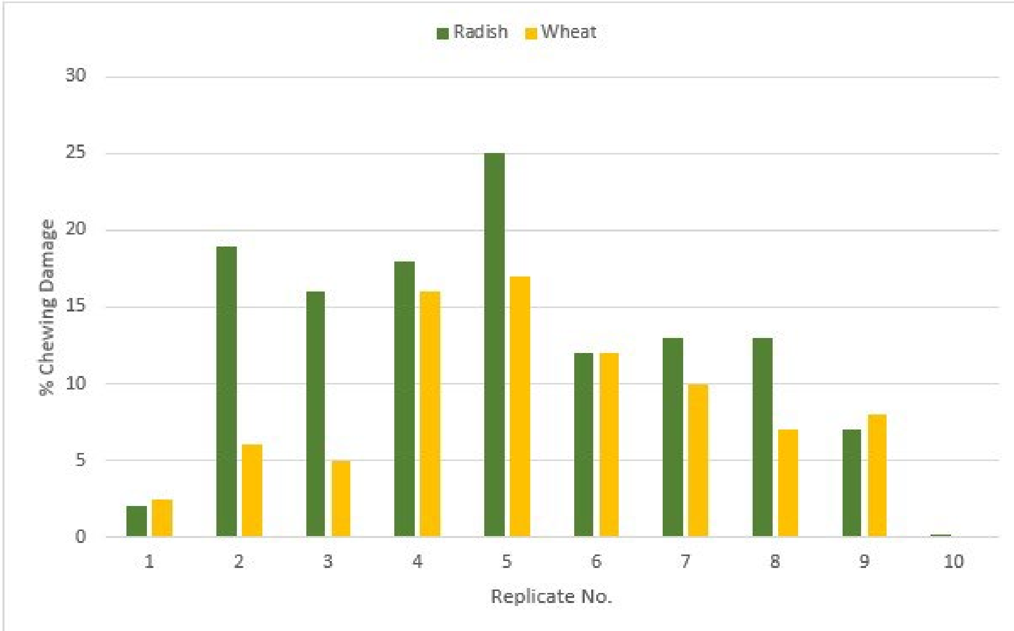



Figure 32. Percent chewing damage by native budworm larvae to vegetative wild radish and tillering wheat when given a choice.

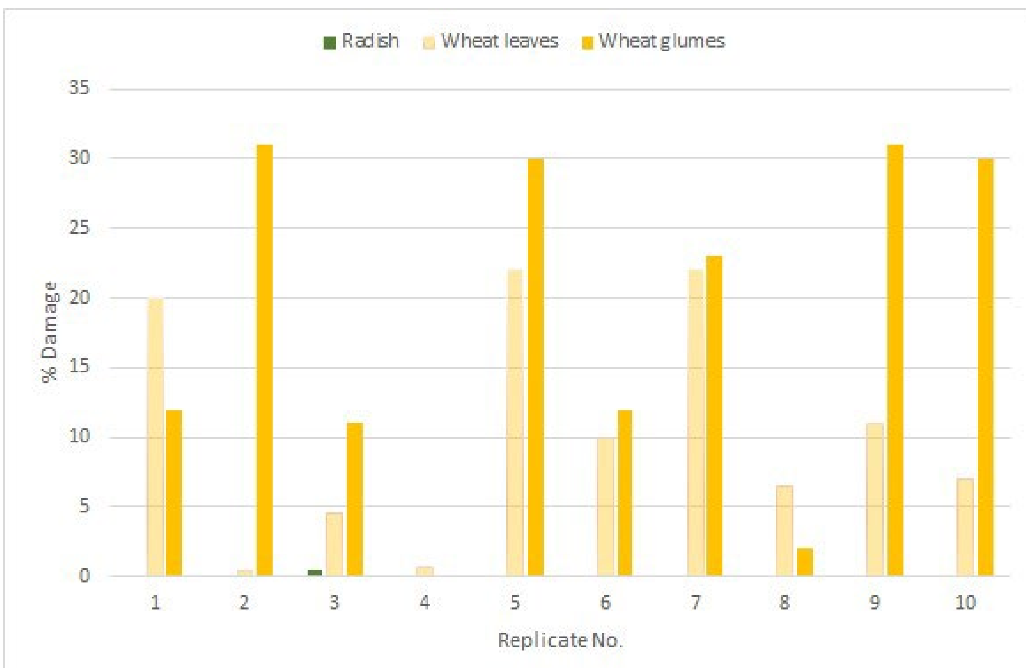



Figure 33. Percent chewing damage by native budworm larvae to early flowering wild radish and wheat leaves and glumes in heads at flowering stage when given a choice.

Overall, radish exhibited more damage (12.5%) than tillering wheat (8.5%). Figure 34 displays how very little damage was seen on flowering wild radish compared to the glumes and leaves of flowering wheat.

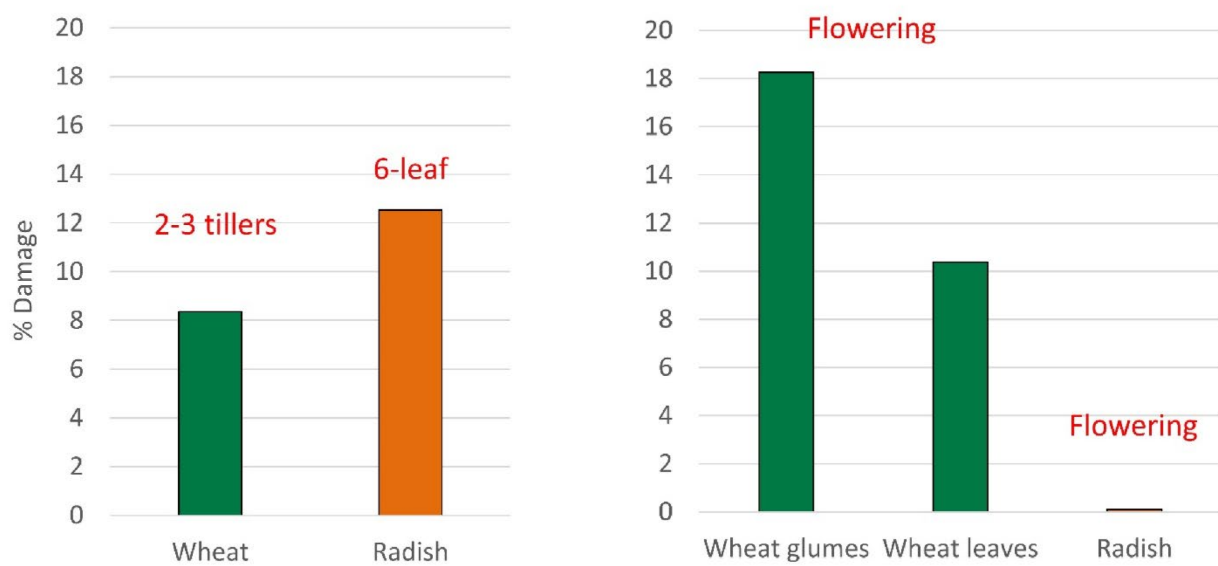



Figure 34. Budworm larvae damage to tillering wheat paired with 6-leaf wild radish versus damage to flowering wheat paired with flowering wild radish. N=10.

**Trials 6-7, moth egg laying choice, wheat or faba bean**

In the first of two-moth egg laying choice trial with faba bean and wheat, seven of the nine female moths laid significantly more eggs on faba bean than wheat. Only one of the moths laid one egg on wheat (Fig. 35). Three of the moths did not lay any eggs on the faba bean or wheat for unknown reasons. However, some eggs were found laid on the internal wall of all cages indicating that the female moths had all mated and were capable of laying eggs.

The second moth egg laying choice trial with faba bean and wheat had a similar result, with female moths laying significantly more eggs on faba bean than wheat in five of the ten replicates (Fig. 36). Eggs were not laid on wheat in three of these five replicates. It should be noted that no eggs were laid on the faba bean or wheat in five replicates due to delayed male budworm moth emergence.

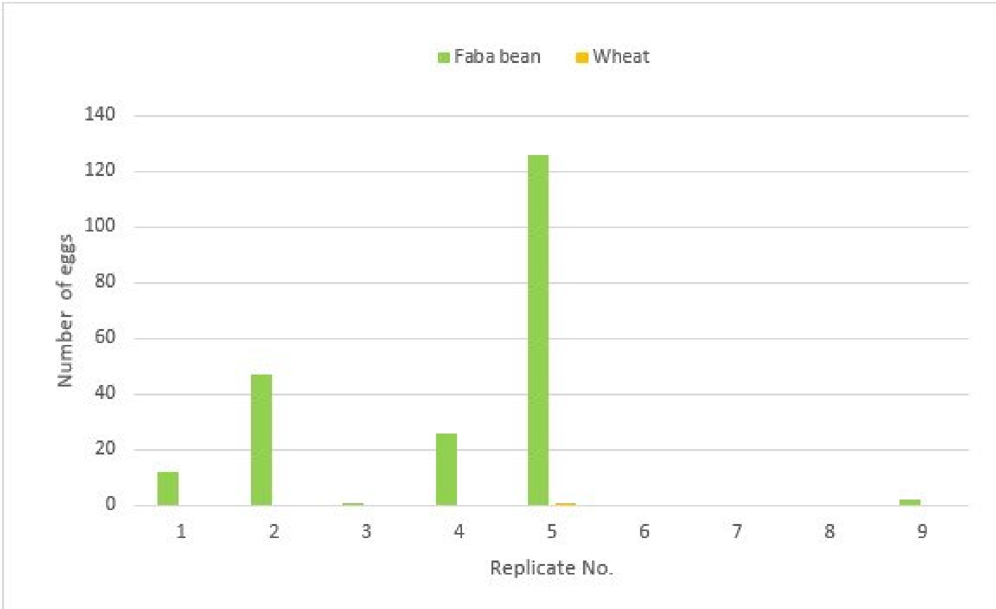



Figure 35. Number of eggs laid by budworm moths on wheat or faba bean plants paired together in cages.

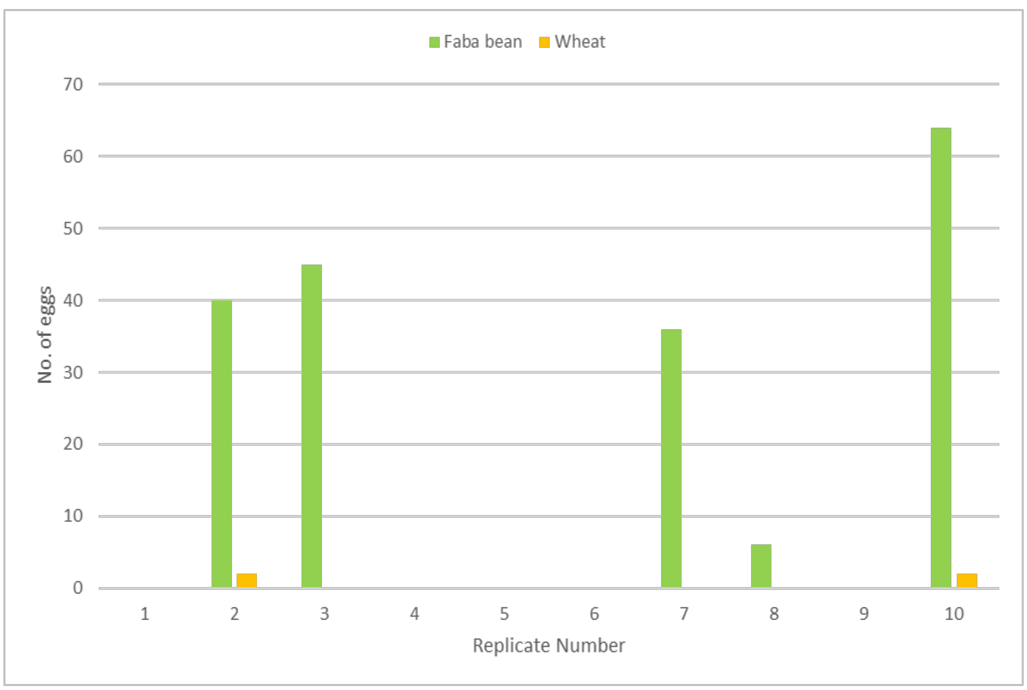



Figure 36. Number of eggs laid by budworm moths on wheat or faba bean plants paired together in cages.

**Trial 8, moth egg laying choice and no-choice, tillering or heading wheat versus lupin or wild radish**

When given the opportunity to lay eggs on wheat or radish, budworm showed a preference for wild radish, laying an average of 42 eggs on radish plants compared to an average of 1.3 eggs on wheat plants. Similarly, budworm preferred to lay eggs on lupins compared to wheat with an average of 22 eggs found on lupin plants compared to 1 on wheat. Egg laying preference between wild radish, lupins and wheat are shown in Figure 37. In both the wheat/wild radish and wheat/lupin treatments, we found an average of less than 1 egg on the pots and walls inside the cage, that is, eggs not laid on plants. When moths were offered only wheat to lay eggs, the number of eggs found on wheat did not increase significantly when compared to the choice treatments. Moths laid an average of 2.6 eggs on flowering wheat plants and 0.8 on tillering wheat plants when offered no choice. There was also a marked increase in the number of eggs found on the non-plant material inside the cages with an average of 3 eggs found on the cages containing only tillering wheat and 4.4 in the cages containing only flowering wheat.

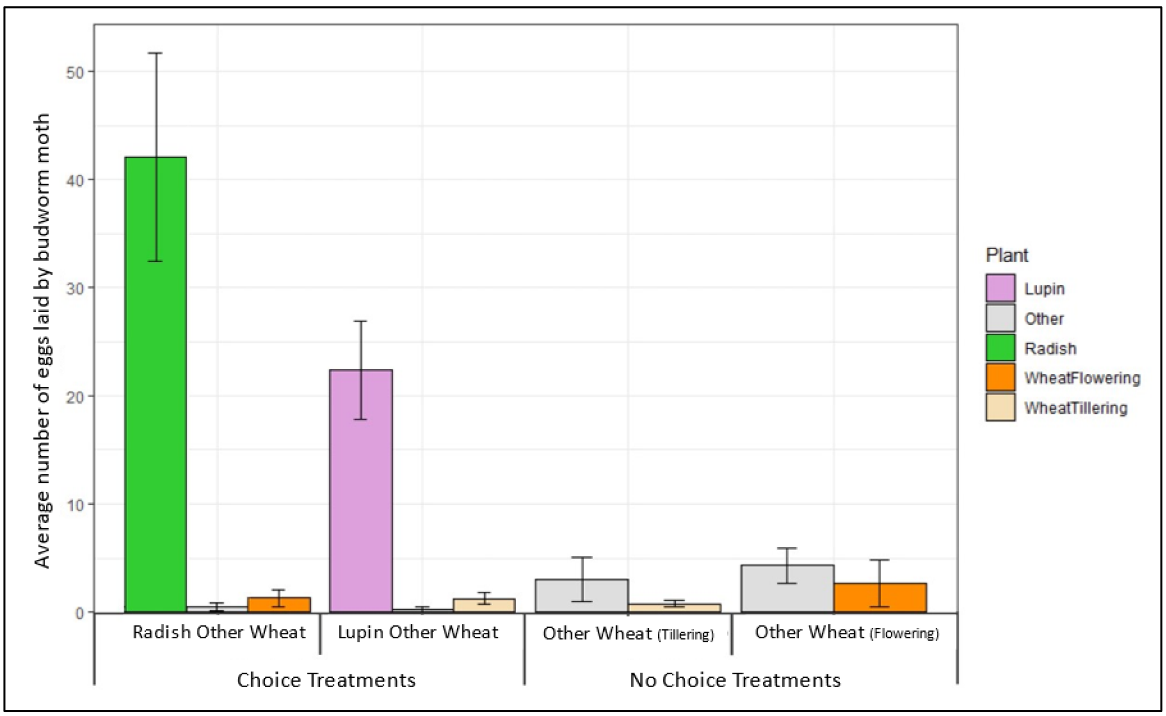



Figure 37. Average number of eggs laid per plant for either tillering or flowering wheat only (no choice) or tillering wheat paired with lupin or flowering wheat paired with radish (choice). N=10. Other, indicates eggs that were laid on areas inside the cage that were not the plant, e.g., soil, plastic or mesh sections of the cage.

The egg laying trial suggests that the budworm moths are more likely to lay eggs on wild radish and lupin if they are in significant numbers in a wheat crop (Figs. 38 and 39). Wheat did not appear to be an attractive host for oviposition, even when there were no other options for budworm when laying eggs.

Figure 38. Budworm eggs on lupin pods in 2022 glasshouse egg laying trial.

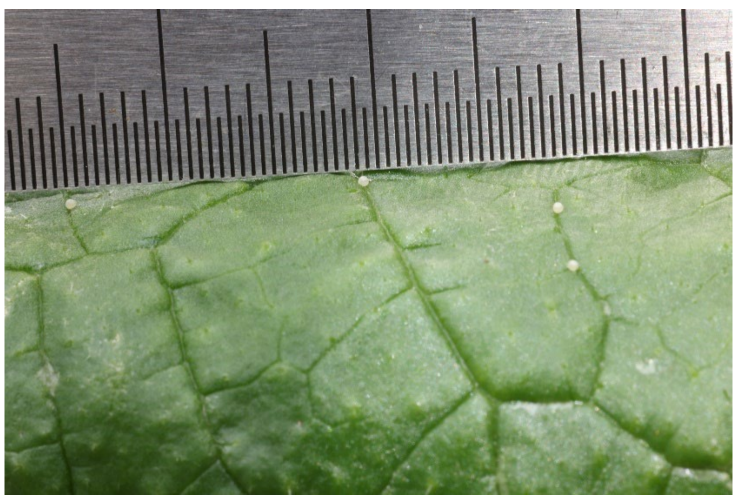


Figure 39. Budworm eggs on wild radish leaves in 2022 glasshouse egg laying trial.

**Trial 9-10, larvae feeding no-choice trial with barley, oats and wheat**

Similar amounts of chewing damage were caused to heads and glumes of wheat, barley and oats with fewer overall heads damaged in barley (Fig. 40). Average damage to heads was 30.1%, 28.7% and 8.0% for wheat, oat and barley, respectively. Average damage to glumes was 9.4%, 8.5% and 6.2% for wheat, oat and barley, respectively. When faba bean treatment was included for comparison, native budworm clearly caused higher levels of damage to buds and flowers of faba bean plants than cereals.

The percentage number of leaves damaged per plant was relatively low for wheat, oat and barley; 3.6%, 6.3% and 1.6% respectively for flag leaves and 0.2%, 6.3% and 1.6% respectively for other leaves (Fig. 41). Regarding overall leaf area removed by larvae feeding, an average of 0.6%, 1.6% and 0.5% was recorded for flag leaves, and an average of 0.7%, 0.3% and 0.1% for other leaves of wheat, oat and barley plants respectively. The weight of pupae was similarly lower than the traditional host faba bean, indicating reduced performance of all three types of cereal plants (Fig. 42).

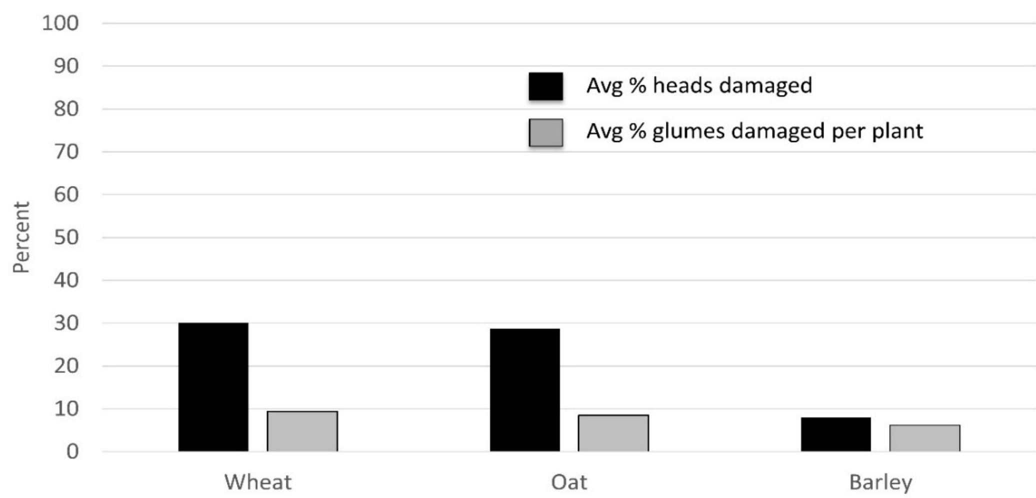



Figure 40. Chewing damage (%) by native budworm larvae to heads and glumes for wheat, barley and oats. N=10.

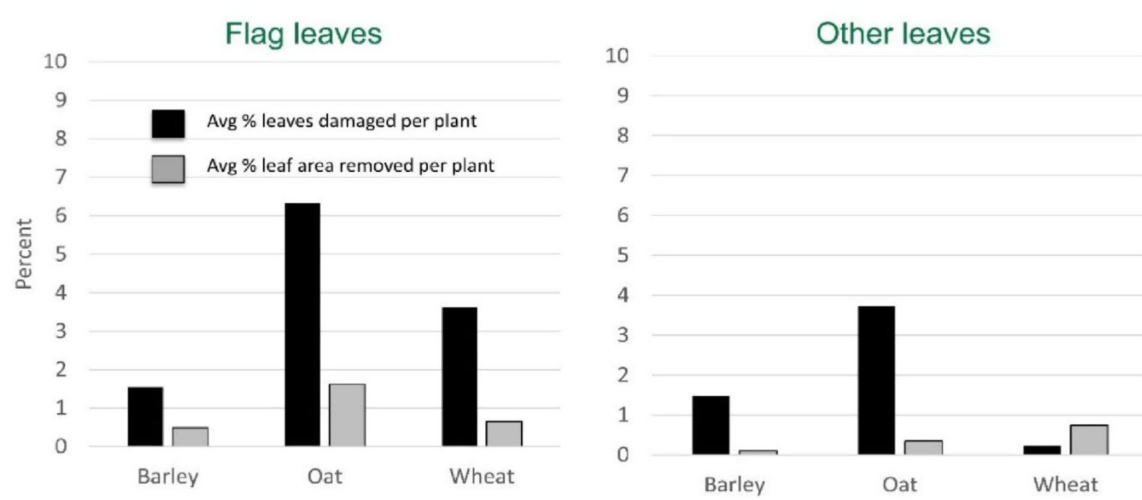



Figure 41. Chewing damage (%) by native budworm larvae to flag and other leaves for wheat, barley and oats. N=10.

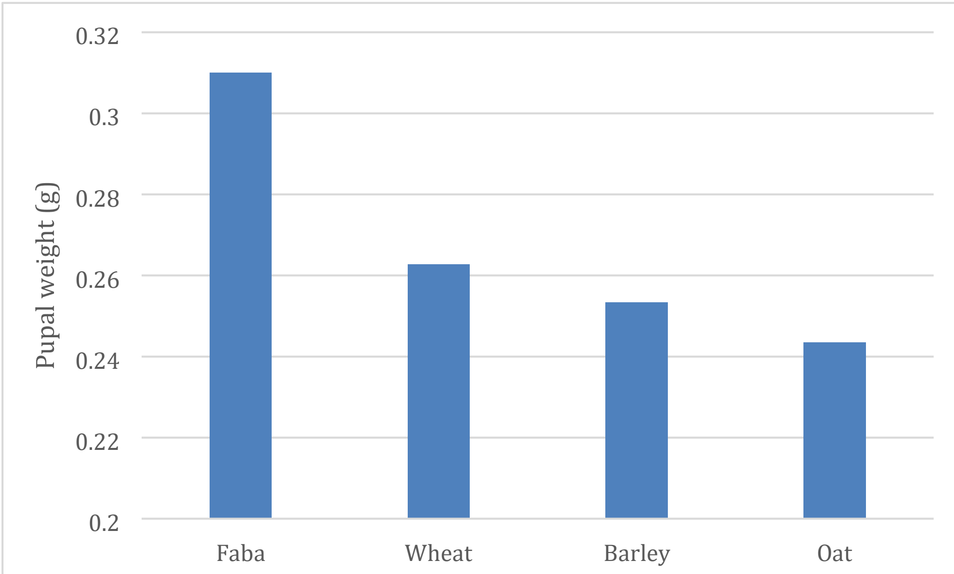



Figure 42. Average mass (g) of native budworm pupae fed on faba bean, wheat, barley and oat plants.

**Native budworm field cage trial, Geraldton WA**

Field cage investigations of native budworm larval chewing damage in advanced stage wheat showed that a larval density of 10 $m^2$ resulted in notably more damage to wheat heads, glumes and flag leaves than a larval density of 5 $m^2$ (Table 4). However, overall damage was relatively low.

**Table 4.** Summary of native budworm chewing damage recorded in advanced stage wheat crops in field cages with 5 larvae per $m^2$ and 10 larvae per $m^2$ treatments. A mean of the five 1m length assessments is presented for each parameter in individual cages.

| Cage no. | No. of larvae in each cage | Mean % heads damaged | Mean % glumes damaged | Mean % flag leaves damaged | Mean % area of flag leaf damage | Mean % other leaves damaged |
|---|---|---|---|---|---|---|
| 1 | 5 | 6.66 | 0.33 | 4.16 | 15.58 | 1.2 |
| 2 | 5 | 5.33 | 0.28 | 3.50 | 21.33 | 0.6 |
| 3 | 5 | 3.68 | 0.17 | 4.00 | 17.67 | 0.6 |
| 4 | 5 | 3.55 | 0.24 | 1.82 | 16.00 | 0.8 |
| 5 | 5 | 3.38 | 0.17 | 2.33 | 17.50 | 0.4 |
| 6 | 10 | 10.23 | 0.48 | 6.11 | 18.50 | 1.2 |
| 7 | 10 | 8.45 | 0.39 | 4.94 | 21.33 | 2.0 |
| 8 | 10 | 8.22 | 0.37 | 5.29 | 22.20 | 1.4 |
| 9 | 10 | 8.35 | 0.34 | 5.21 | 19.89 | 2.4 |
| 10 | 10 | 6.76 | 0.33 | 4.06 | 22.17 | 1.8 |

**Damage to wheat heads and glumes**

Native budworm larvae released into field cages caused damage to wheat heads ranging from 3.38% to 10.23% of wheat heads damaged. Cages with five budworm per $m^2$ (low density) had an average of 4.52% heads damaged, whereas an average of 8.4% of heads were damaged in the cages with ten larvae per $m^2$ (Fig. 44). The glume damage varied from 0.17 % to 0.48% glumes damaged across the entire trial. Comparatively less glume damage (0.24%) was found in the cages that had five larvae, whereas cages with 10 larvae exhibited increased glume damage (0.38%) (Fig. 43).

Figure 44 shows that 5 larvae per square metre equated to approx. 2.5-6.5% heads chewed of which overall glumes chewed into was approx. 0.15-0.35%. Increasing larvae per square metre to 10 increased percent heads chewed to approx. 6.5% which equated to the average total glumes chewed into at approx. 0.3 to 0.5%. Figure 45 shows native budworm larvae feeding on wheat glumes.

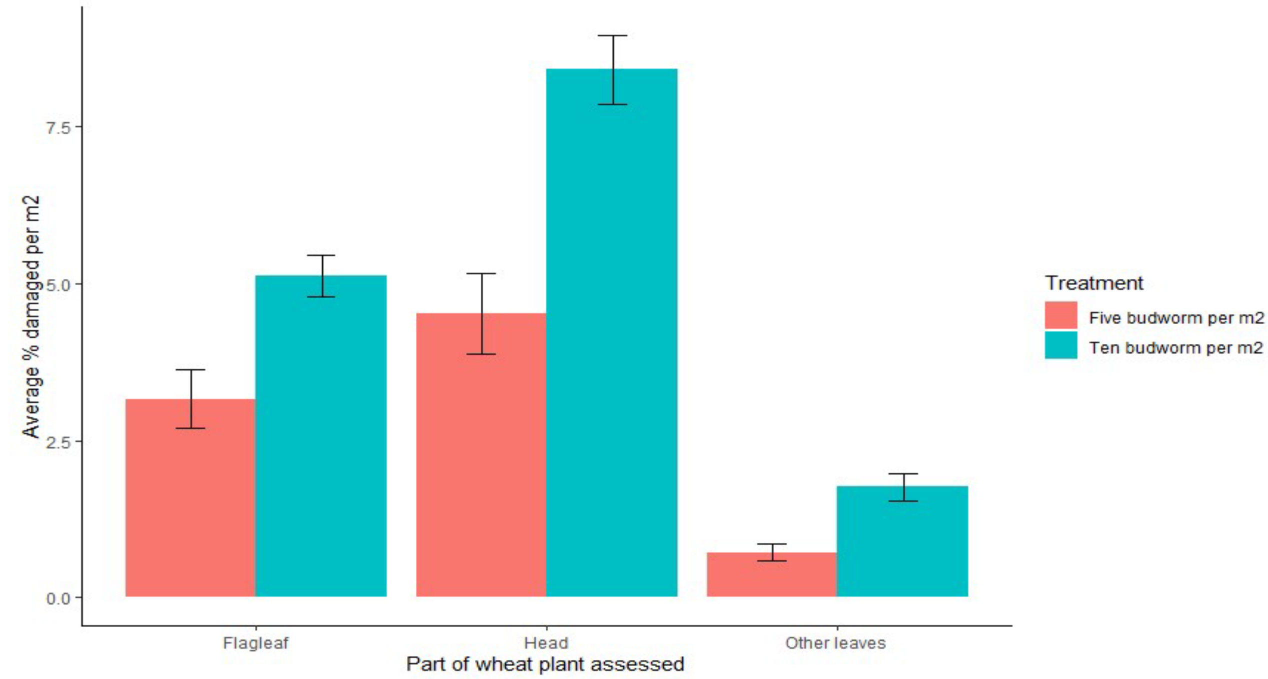



Figure 43. Chewing damage on wheat tissues in field cages with two densities of native budworm. Error bars are standard error of the mean.

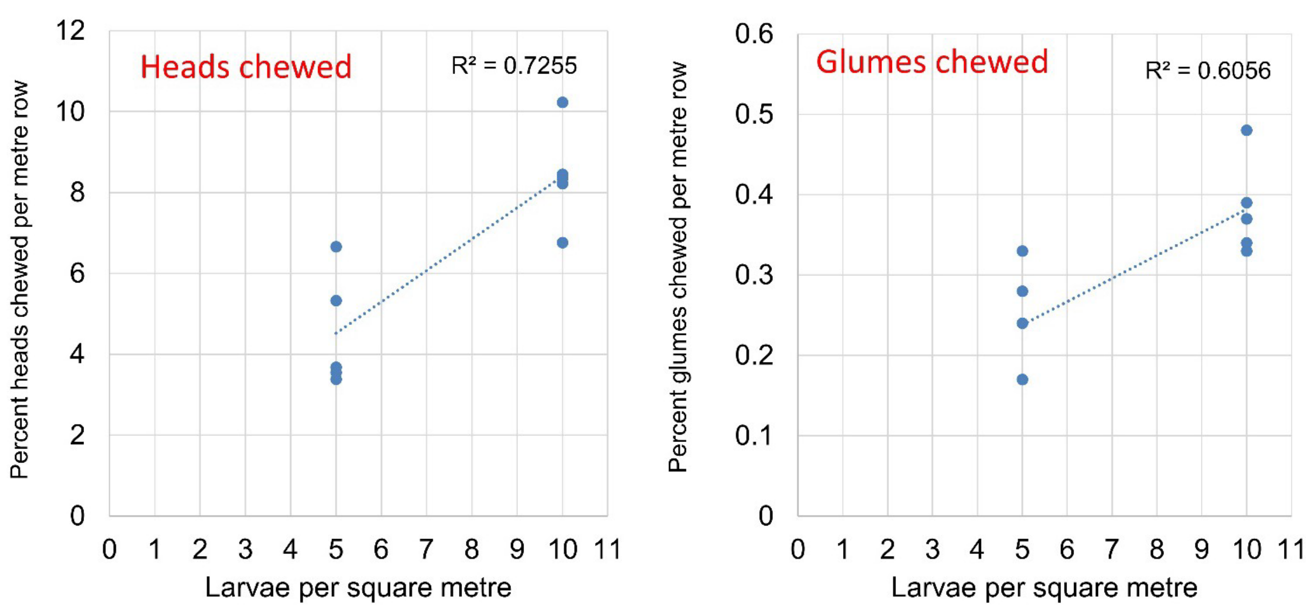



Figure 44. Average percent wheat heads chewed (left) and glumes chewed (right) for 5 and 10 larvae per square metre.

Figure 45. Native budworm larvae feeding on wheat glumes within the emergence cages. Images by Saleh Adnan.

**Damage to flag leaf and other leaves**

For all treatments, the percentage of flag leaves damaged on average ranged from 1.82% to 6.11%. Cages provided with greater numbers of larvae (10 in each cage) experienced a relatively higher proportion of flag leaf damage (5.12%), whereas 3.16% of flag leaf in 1m length wheat were damaged in the cages that housed 5 larvae each. Given that differences found in a proportion of flag leaf damage because of larval numbers, the extent of leaf area damage for the infested flag leaf did not differ notably between the larval density released in the cages. A range of 15.58% to 22.17% leaf area were found damaged in case flag leaves were infested. In addition to flag leaves, we recorded approximately 1 damaged other leaf in 1m length wheat.

### Economic thresholds

Yield loss was calculated according to damage to glumes (i.e. seeds) considering that damage to flag and other leaves was considered very low. According to the field cage trial results of native budworm larvae damage to the wheat glumes, an average of 2.4 and 3.8 kg/ha loss occurred for 5 and 10 larvae per square metre treatments, respectively. Considering that one sweep of an insect sweep net is approximately one square metre of crop canopy area, 5 and 10 larvae per square metre equates to 50 and 100 larvae per 10 sweeps, respectively.

Based on a wheat commodity price of $360/tonne and 2 tonne/ha anticipated yield, the economic losses for 5 and 10 larvae per square metre are $1.71/ha loss at 5 per square metre (50 per 10 sweeps), and $2.75/ha loss at 10 per square metre (100 per 10 sweeps).

Given that no insecticides are registered for native budworm in cereal crops, we here consider the armyworm rate of 240 mL/ha of alphacypermethrin (100 g/L a.i. product) because there is no known insecticide resistance in native budworm and this rate is effective against this pest in traditional crops. This rate of alphacypermethrin is estimated to be $3.10 per hectare without application costs.

Assumptions in this estimated economic threshold include that the yield loss comes from glumes chewed given low damage to leaves overall, that sweeps of an insect sweep net are a proper 180° sweep with good hold of the handle, and that the larvae densities in the crop are comparable to sweep netting the top canopy of the crops.

**Assessment of native budworm presence and chewing damage in wheat focus crops in the Geraldton port zone, October 2022**

Of the focus crops assessed, site 1 in North Eradu had the highest density of budworm larvae, with an average of 1.5 budworm per 10 sweeps (Fig. 46). At this site, there was spatial variation in budworm larvae found per 10 sweeps, with numbers highest at the corner of one paddock. Here, the most larvae found at one location was 12 per 10 sweeps, and on average 6 heads were found chewed per metre squared (Figs. 47 and 48). Larvae numbers were found to be lower further from this point. Three locations at site 1 contained damage of 3-5 heads chewed per metre squared.

The spatial variability of budworm larvae at site 1 coincided with damage assessments albeit relatively low damage up to 4 heads chewed per metre squared.

Figure 49 shows typical feeding damage to wheat leaves by budworm in the field.

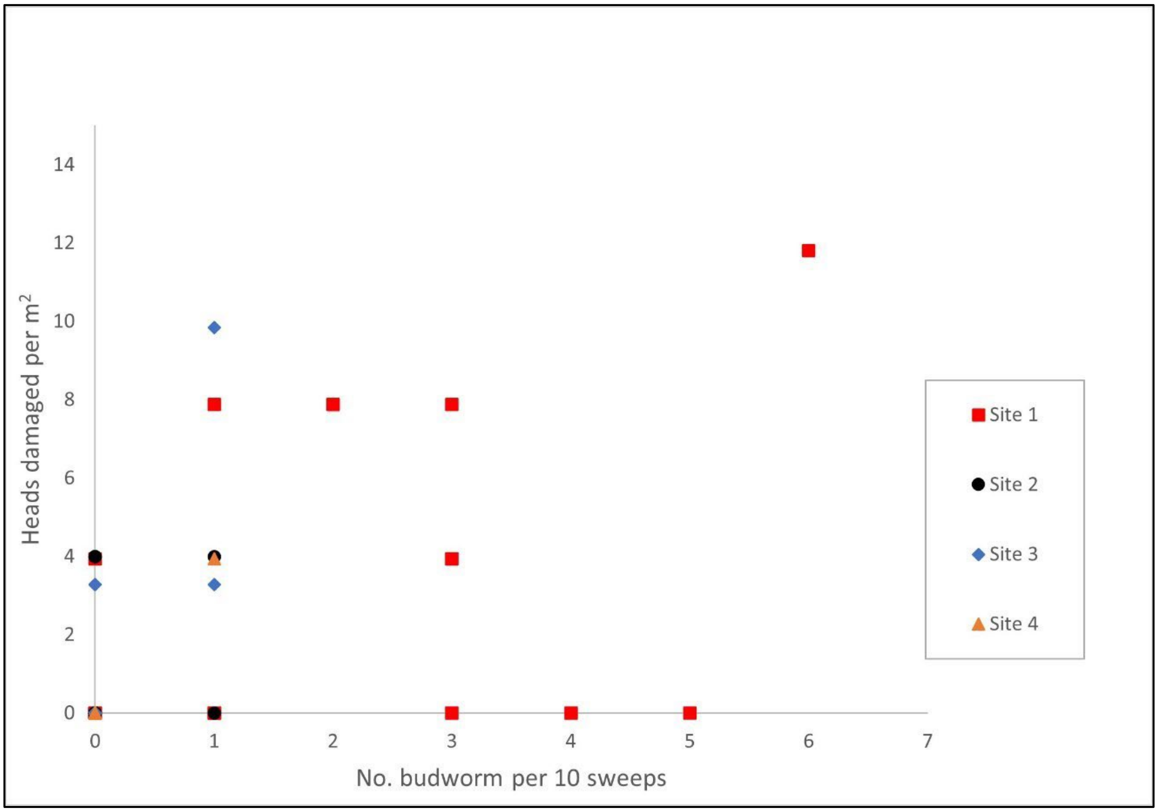



Figure 46. Number of native budworm per 10 sweeps and number of heads damaged per m2 for four wheat paddocks in the Geraldton port zone. Site 1: North Eradu n = 32; Site 2: Wandana n = 30; Site 3: Nanson n = 20 and Site 4 Geraldton RSU n=10.

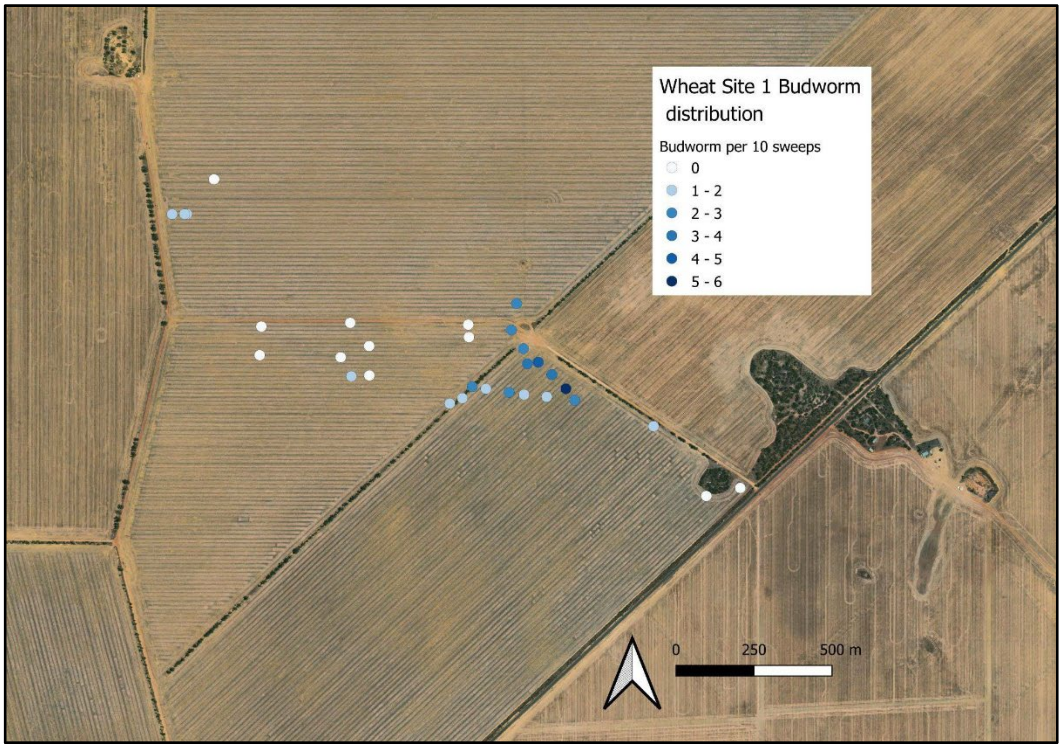



Figure 47. Budworm larvae per 10 sweeps at wheat site 1 in North Eradu.

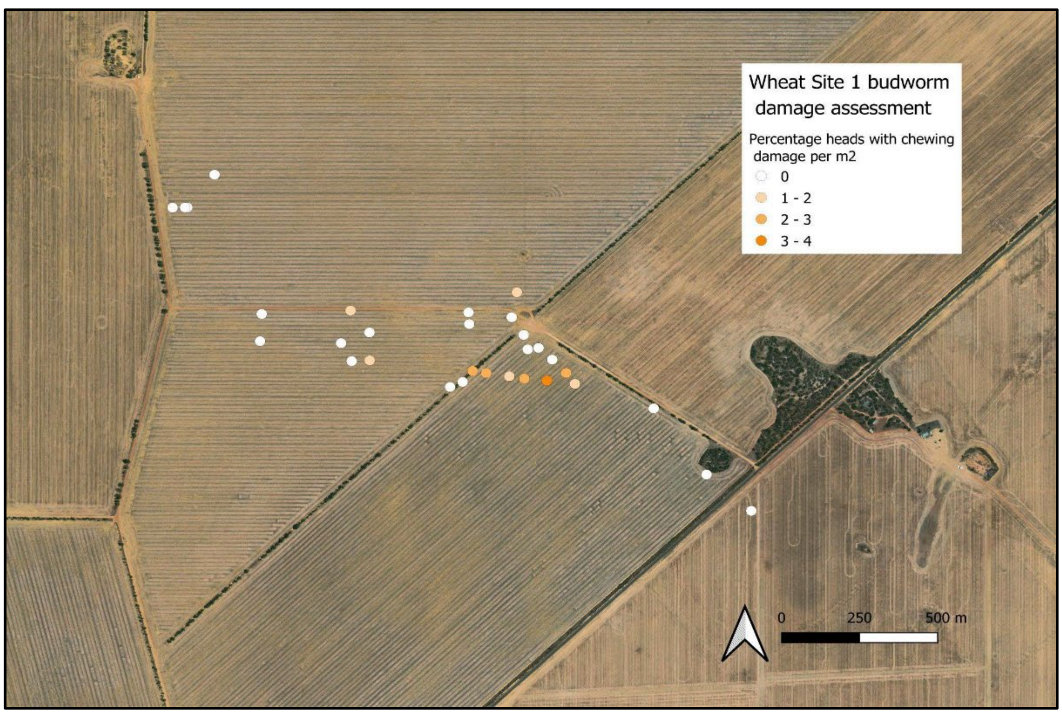



Figure 48. Percent average number of heads with chewing damage at Wheat site 1 in North Eradu.

Figure 49. Wheat leaf damage caused by native budworm at North Eradu WA, 2022. Image courtesy of Amber Balfour-Cunningham (DPIRD).

**Armyworm presence and distribution within Geraldton wheat paddocks**

In addition to native budworm, armyworm larvae were found at all sites, and in higher numbers than native budworm larvae at three of the four sites (Fig. 50). Site 3 in Nanson had the highest number of armyworm on average with 3 per 10 sweeps. Native budworm and armyworm larvae can be misidentified (see Fig. 51) particularly in early instars, so it is important to note that both native budworm and armyworm can be present at the same site. Also, both native budworm and armyworm showed spatial variation in their densities throughout the paddock, with sweep net numbers showing hotspots along paddock edges and localised areas of the crop (Fig. 52 and 53).

The majority of armyworm found in wheat during plant inspections were on the underside of leaves or in leaf litter on the soil surface. In comparison all native budworm found in situ were on wheat heads.

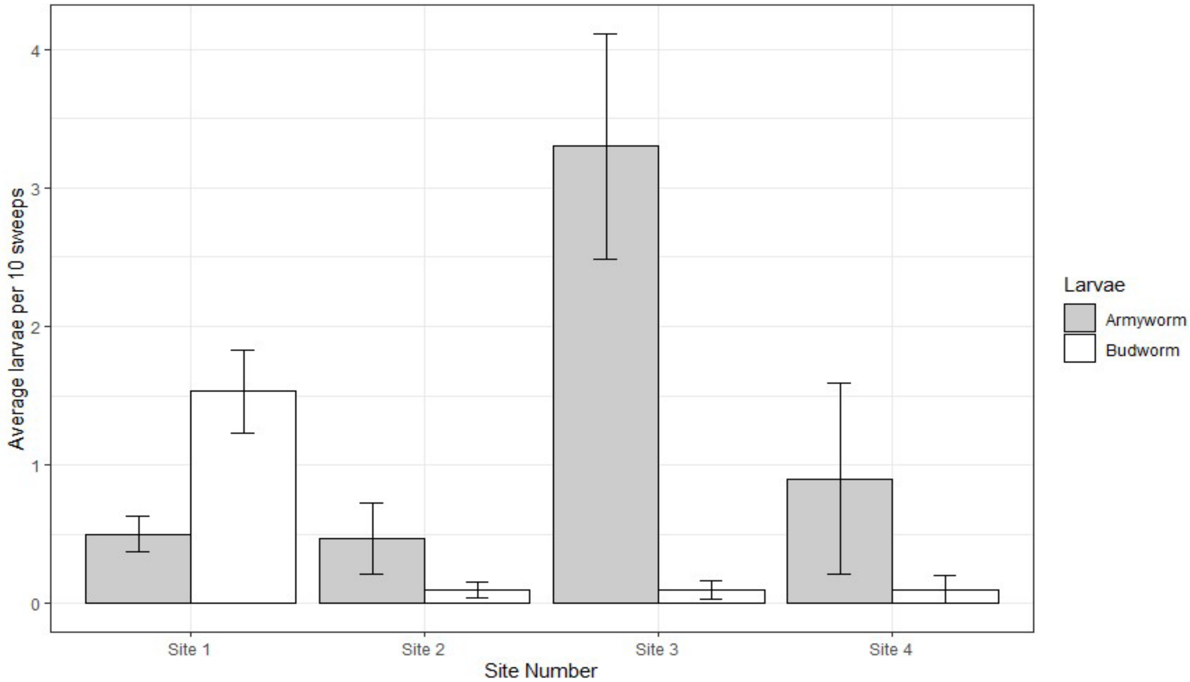



Figure 50. Average budworm and armyworm larvae found per 10 sweeps at four wheat paddocks across the Geraldton port zone. Lots of 10 sweeps per crop is as follows: Site 1: North Eradu n = 32; Site 2: Wandana n = 30; Site 3: Nanson n = 20 and Site 4 Geraldton RSU n: = 10. Error bars indicate standard error of the mean.

Figure 51. Native budworm larvae found in situ chewing on wheat head at North Eradu, WA (left). Armyworm found in situ on wheat head at North Eradu, WA (right). Images courtesy of Amber Balfour-Cunningham (DPIRD).


Figure 52. Number of armyworm per 10 sweeps at each assessment location for wheat Site 3 near Nanson, Geraldton port zone.

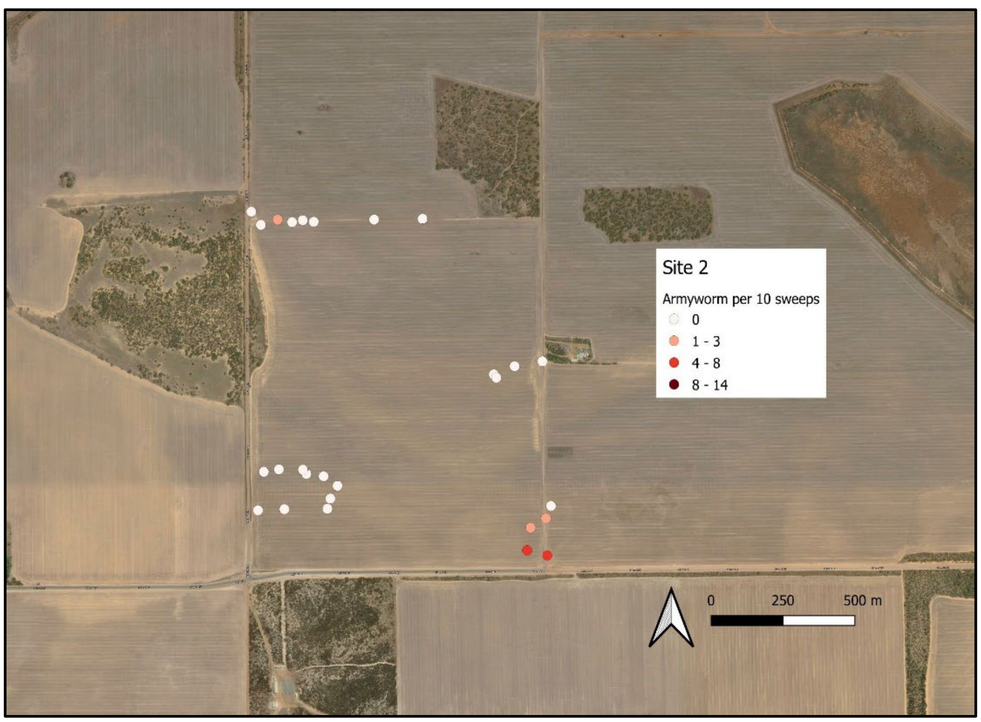



Figure 53. Number of armyworm per 10 sweeps at each assessment location for wheat Site 2 in Wandana, Geraldton port zone.

## Discussion

It was surprising to see native budworm moths trapped in all wheat crops with often similar or higher numbers than in traditional host crops during 2021 and 2022. However, larvae numbers were very low during winter and spring 2021, so field investigations of larvae numbers relative to plant damage were conducted in 2022 only where numbers were >1 per 50 sweeps. The data suggests a possible correlation between moth attraction to lupin crops and increased moth numbers in nearby wheat crops, but this requires further assessment. It was also surprising to see higher numbers of native budworm moths trapped in wheat crops than nearby canola crops considering that canola is a traditional host of native budworm.

As expected, lupin and wheat no-choice trials showed that native budworm larvae preferred to feed on lupin buds and flowers with minimal damage to leaves. When given wheat only, many budworm larvae caused no damage to booting/heading wheat and starved to death. However, some caused damage to leaves (up to approx. 5% leaf area removed) and up to 20% damage to boots and the glumes within heads. Larvae on wheat mostly starved to death without pupating and those that did pupate had significantly lower pupal weights, indicating decreased performance.

Further investigation of moth and larvae preference or deterrence to vegetative and advanced wheat relative to the traditional hosts showed that while very little feeding damage was caused by native budworm larvae to vegetative wheat and many starved to death, once wheat advanced into milky/dough stage, the larvae were attracted to the glumes and caused damage, albeit minimal considering that one larva per plant is a high density.

The larvae choice trials have shown that native budworm greatly prefer feeding on their traditional host faba bean than wheat. However, when provided with a choice between wheat and a known weed host wild radish, larvae alternated between feeding on the wild radish and the wheat if the wheat was at a vegetative growth stage, such as stem elongation. Here budworm larvae caused up to 17% leaf damage to the wheat. When the wheat was at a later growth stage, such as booting/heading, then larvae fed exclusively on the wheat leaves and especially any emerging (boots) and emerged heads. At this later growth stage, budworm larvae caused chewing damage to up to 22% of leaf area and 31% of glumes within heads.

Native budworm moth egg laying trials showed a clear preference by female moths to lay their eggs on their traditional host faba bean, lupin or wild radish rather than on wheat. Moths are deterred from laying eggs on wheat whether paired with a traditional host or isolated with wheat only.

Field cage trials with 5 or 10 larvae per square metre consistently showed relatively minor damage to wheat and economic thresholds were suggested. Based on percent of glumes chewed into as a measure of yield loss, we estimated 2.4 and 3.8 kg/ha loss occurred for 5 and 10 larvae per square metre treatments, respectively. This equated to economic losses of $0.86 per ha given $360 per ton wheat price and 5 larvae per metre square (approx. 50 larvae per 10 sweeps) and $1.38 per ha loss given 10 larvae per square metre (approx. 100 larvae per 10 sweeps).

The cost of insecticide alone (without application) for 240 mL/ha of 100 g/L a.i. (armyworm rate in wheat) is estimated at $3.10 per ha. Therefore, spraying even a cheap broad-spectrum insecticide such as alphacypermethrin is not economically worthwhile at budworm larvae rates exceeding 50 larvae per 10 sweeps, or as high as 10 per square metre, even if adding to the spray tank for other application reasons such as herbicide or fertiliser. However, growers should be diligent about the presence of armyworm in cereal crops as well.

## Conclusions

Since 2018, native budworm caterpillars were confirmed to be feeding on advanced wheat (a non-traditional host) in the Geraldton port zone and to a lesser extent the Kwinana West and East zones, sometimes in numbers exceeding 20 larvae per 10 sweeps. While lesser budworm (*H. punctifera*) and common armyworm (multiple species) have been found causing generally minor damage to wheat crops, native budworm has not been confirmed to be feeding on wheat in the past. Through a series of glasshouse trials, field surveillance, field investigations and a field cage trial, we gained new insight into the host choice behaviour and performance of budworm on wheat plants.

In some years, native budworm moth migrations commence early and in very high numbers in the Geraldton port zone. This high moth pressure increases the chances of native budworm damage to wheat crops, but spraying is likely to be not economically worthwhile even though some visual head damage may seem concerning.

Although results point to agronomic practices such as radish weed control influencing the likelihood of *H. punctigera* larvae presence in wheat crops, we suggest that climate change, especially increased summer rainfall in central Australian migration source areas, is increasing moth pressure onto traditional, and now non-traditional, crops further down the migration pattern. This information is important for ensuring the successful economic production of wheat.

## Recommendations

Budworm prefer to lay eggs on wild radish and (volunteer) lupins in wheat crops so weed control is a critical part of preventing budworm moths laying eggs in crops and larvae transferring onto and feeding on wheat plants in spring.

Although native budworm were significantly deterred from laying eggs onto wheat plants, very low numbers were seen in trials. Therefore, it is likely that in years when native budworm migratory flights are particularly high in number and occur earlier than usual (as we have seen in moth traps in some years), wheat crops may be at risk of increased egg laying regardless of volunteer lupin and wild radish control. Hence sweep netting cereal crops for native budworm may be warranted. However, the economic thresholds suggested are high.

Armyworms were found in some focus wheat crops, so identifying species in the field is important. It is recommended that armyworm be investigated similarly to what was done in this project given their presence in crops and unknown host preferences and performance on cereal crops. Although the common armyworm species in WA are known to cause head lopping in advanced ripening/desiccating barley crops, there are no reliable economic thresholds for armyworm in wheat, oat and barley crops in either vegetative or grain filling stages.

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## Acknowledgements

Many thanks to Bec Severtson for extensive review of this report. Thanks to Mingenew Irwin Group (MIG) who collaboratively conducted the moth trapping and sweep netting surveillance during the two growing seasons. Thanks to the growers who provided access to their properties for moth trapping and crop inspections. Thanks to the DPIRD Geraldton Research Support Unit for providing the paddock of wheat for the field cage trial. This project was a co-investment by the Grains Research and Development Corporation (GRDC) and the WA Department of Primary Industries and Regional Development (DPIRD).