Fall armyworm (Spodoptera frugiperda) population trends in New Zealand 2022-2026

Fall armyworm the first 5 years

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26/06/20026

Report for Foundation for Arable Research

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Contents

1. Executive Summary

- Fall armyworm (FAW), Spodoptera frugiperda Smith & Abbot, 1797 (Lepidoptera: Noctuidae), was first detected in New Zealand in 2022. Since then, populations across New Zealand have been monitored via pheromone trapping and crop scouting.

- The results of field observations to date are consistent with the conclusions of Phillips *et al.* (2024). That is, they predicted that in current climates FAW will occur year-round in the northern third of the North Island and in warmer years may also persist year-round in some coastal parts of the southern North Island and northern South Island.

- The results are also consistent with Phillips *et al.* (2024) prediction that FAW has up to four generations per year in Northern New Zealand and one in more southerly areas. In New Zealand.

- Since pheromone trapping started in 2022 the number of FAW caught each season has increased year by year despite the number of traps in the trapping grid decreasing. The greatest increase in FAW moths trapped has occurred in Northland.

- Significant damage to maize and sweetcorn crops in New Zealand can occur particularly if vulnerable plant growth stages e.g. seedlings and early vegetative plants are present during FAW flight and oviposition activity. Such periods occur from November onwards in the far North of New Zealand and between December and March in more southerly areas.

- Once populations for FAW establish in a crop they tend to increase through the growing season cumulatively damaging the crop. This effect can be pronounced in Northland. However, if early damage isn't too extensive maize silage crops appear relatively unaffected by FAW feeding. Cob damage to maize grain and sweetcorn crops can be extensive and have a major economic impact. It is recommended that these later crops be regularly scouted throughout their productive cycle.

- It is recommended
    - That while the general approach taken by FAR has resulted in a greater understanding of the dynamics between FAW and its hosts, the acquisition of planting date data for maize and sweetcorn crops to incorporate into future analysis of FAW population growth and damage potential would be improve our knowledge.
    - That growers are encouraged to scout vulnerable crops during particularly during risky periods associated with early season FAW flights (November–March).
    - Research that identifies overwintering sites and hosts will be critical for areas such as Northland which may benefit from an integrated approach to FAW control

- To continue monitoring and data gathering to determine whether FAW population densities are continuing to grow in Northland and adjacent areas.
- To compete the analysis of data collected during 2025–26 growing season.

2. Background

2.1. General background information

Fall armyworm (FAW), *Spodoptera frugiperda* Smith & Abbot, 1797 (Lepidoptera: Noctuidae), is a pest of corn/maize and other crops that is native to the Americas and has recently reached Africa, India, China, Japan, SE Asia, Indonesia and Australia (IPPC-Secretariat 2021). It was first detected in New Zealand (NZ) in Tauranga in March 2022 and is now known to be established over widespread areas of the North Island and the Tasman and West Coast regions of the South Island. Due to long range flight behaviour FAW is also commonly observed throughout the late summer in the lower North Island and eastern areas of the upper South Island during late summer and Autumn but is highly unlikely to be overwintering in these regions.

Fall armyworm is a highly polyphagous pest that has been reported as attacking over 350 commercial and non-commercial hosts across 76 plant families. Despite this wide host range FAW shows a distinct preference for r graminaceous plants. The fall armyworm's preference for graminaceous plants makes it a major pest for crops such as corn (Zea mays), sorghum (*Sorghum bicolor*), rice (*Oryza sativa*), wheat (*Triticum aestivum*) and sugar cane (*Saccharum* spp.) (Luginbill 1928, Pashley 1988). It feeds primarily on whorl leaves, and in corn, it may also infest the ears, especially during large infestations (Buntin 2008). Throughout FAW's native and invasive range this feeding causes significant economic losses to crop producers (Overton *et al.* 2021). These losses can be classified into four categories: (1) direct and indirect yield loss, (2) cost of management, (3) quality loss, and (4) impacts on trade arising from phytosanitary measures required by importing countries (Murray *et al.*, 2013; Day *et al.*, 2017).

Maize and sweetcorn are the two crops most likely to be impacted by FAW in New Zealand. In 2025 approximately 80,082 ha (16,801 ha grain crops, 63,281 ha silage crops) of maize (Anon 2024a) and 3300 ha of sweetcorn (Anon 2024b) were grown in New Zealand. If significant FAW infestations occur in these crops during periods of susceptibility, there is potential for significant damage and associated economic losses to occur. Data from other countries in which FAW is present shows that the economic losses to maize and sweetcorn crops caused by the FAW attack can be between 15 and 76% (Guo *et al.* 2018; Hruska and Gould 1997, Marenco et al 1992.). The wide range of reported impacts is due to the complex interactions host crop use e.g. grain verses silage, plant growth stage, FAW ecology and population phenology, and the environmental (Buntin *et al.* 1986).

2.2. Background likely distribution of FAW in New Zealand

The inability of FAW to diapause renders it vulnerable to cold winters, which is why it only persists year-round in regions with tropical/subtropical climates such as central America and southern USA (Luginbill 1928). In spring, it migrates northwards from its year-round range to infest crops as far north as Ontario and Québec in Canada (Rose *et al.* 1975 and Mitchell *et al.* 1991 cited in Westbrook *et al.* (2016)). Phillips *et al.* (2024) reported that in contrast to continental regions, NZ has a temperate oceanic climate with generally much higher minimum temperatures. For example, even parts of Florida in southern USA experience subzero temperatures in some years, whereas northern parts of NZ virtually never do (Chappell 2013). Thus, key questions for NZ include: Are NZ winters sufficiently cold for long enough to kill FAW? If not, where in NZ is it likely to persist? How much will FAW's year-round range in NZ vary with annual climatic fluctuations and climate change? And where in NZ could FAW complete sufficient generations annually to reach pest densities?

Modelling by Phillips *et al.* (2024) suggests that in current New Zealand climates FAW will occur year-round in the northern third of the North Island and in warmer years may also persist year-round in some coastal parts of the southern North Island and northern South Island (Figure 1). As NZ's future climate warms, FAW will occupy marginal areas year-round with increasing frequency and by about 2080 will occupy them year-round practically every year. Concurrently the areas where it occasionally survives winter during warm years will extend further south and further inland. These predictions are in line with early observations (2022-23) of FAW populations in New Zealand by Hardwick *et al.* (2023) which recorded that the greatest activity occurred in the Northland New Zealand with observations decreasing in more southerly regions of the country further south.

Temperature regulates growth in insects. Phillips et al 2024 predicted FAW would have up to 4 generations per year in Northern New Zealand (Figure 2), whereas in Florida, USA, it was estimated to have 5-7 generations (Garcia *et al.* 2018; Garcia *et al.*2019) and in Rio Grande do Sul, Brazil, up to eight (Busato *et al.* 2005). The latter examples are areas that suffer significant damage across maize, sweetcorn and other susceptible crops. The greater the number of generations that FAW can complete within a region the more likely it is to cause significant/economic damage to susceptible crops and migrate to neighbour areas in significant numbers.

In the current report the author will report on FAW pheromone trapping, crop scouting, and damage scoring data from the 2023–24, 2024–25, and 2025–2026 growing seasons. This data will be compared with the predictions of Phillips *et al.* (2024), while giving recommendations for potential monitoring strategies and future research directions.

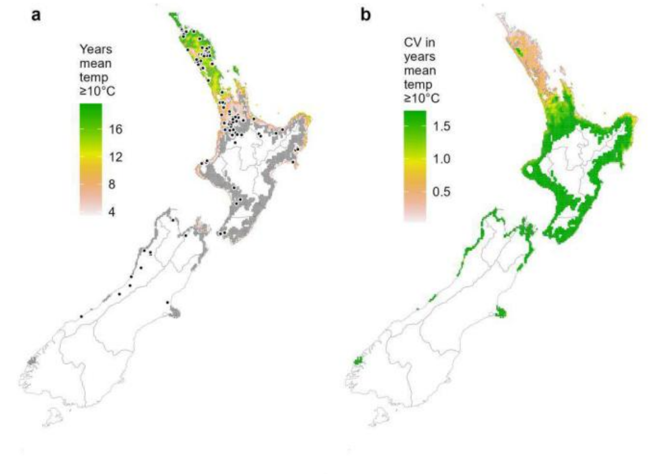

Figure 1: Potential distribution of Fall armyworm in New Zealand (a) Coloured locations had annual mean weekly temperatures ≥10 °C for ≥3.5 years of the 20, and grey shaded locations had annual mean weekly temperatures ≥10 °C for 0 >years < 3.5. Dots indicate locations where FAW was observed in New Zealand between February 2022and March 2023, and lines show regional council boundaries. (b) Coefficient of variation (CV) between climate datasets in years each location was in the isotherm (adapted from Phillips et al 2024).

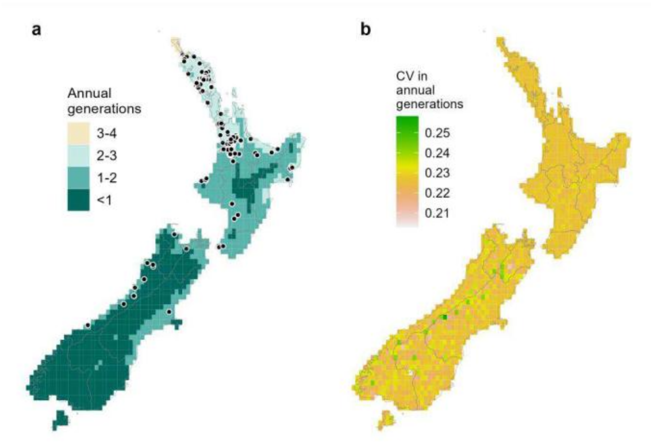

Figure 2: FAW mean annual generations for NZ predicted by the Climex models of Du Plessis *et al.* (2020), Nagoshi *et al.* (2020) and Paudel Timilsena *et al.* (2022) using Climond data for 1975, and (b) between model coefficient of variation in annual generations (adapted from Phillips et al 2024).

3. Method

3.1. Pheromone trapping

Trapping of adult male FAW was undertaken using a mixture of bucket and sticky traps in the latter two seasons a small proportion of traps were monitored using self-reporting cameras that sent images of the trapping surface back to a central server. Traps deployed at a height of 1.5-1.2 meters above the ground, where possible placed on the windward side of the crop and were baited with a Pherocon® controlled release septa containing FAW pheromone. The pheromone catch data for seasons 2023–2024 and 2024–2025 were subjected to analysis and presented in (Appendix 's 1 and 2). Observation inferences for each of the 3 growing seasons are presented below.

3.1.1. 2023–24

Prior to the 2023–24 growing season a trapping network of 51 pheromone traps was established across the major maize (39 crops monitored) and sweetcorn (11 crops monitored) growing areas of New Zealand (See Appendix 1). Regional trap numbers were as follows Northland: 23, Auckland: 2, Waikato: 5, Taranaki: 7, Gisborne: 3, Wellington: 1, Golden Bay/Tasman: 1, Canterbury: 3 and the West Coast: 6. Monitoring started on 1 October 2023 and continued through to the 2 June 2024. Traps were checked and emptied weekly with lure being replace on a 4-6 weekly basis.

3.1.2. 2024–25

Prior to the 2024–25 growing season a trapping network of 36 pheromone traps was established across the major maize (30 crops monitored) and sweetcorn (5 crops monitored) growing areas of New Zealand (See Appendix 2). Regional trap numbers were as follows Northland: 19, Auckland: 1, Waikato: 3, Taranaki: 1, Gisborne: 1, Wellington: 0, Golden Bay/Tasman: 1, Canterbury: 3 and the West Coast: 7. Monitoring started on 15 September 2024 and continued through to the 17 June 2025. Traps were checked and emptied weekly with lure being replace on a 4-6 weekly basis.

3.1.3. 2025–26

Prior to the 2025–26 growing season a trapping network of 35 pheromone traps was established across the major maize (39 crops monitored) and sweetcorn (11 crops monitored) growing areas of New Zealand (See Appendix 1). Regional trap numbers were as follows Northland: 19, Auckland: 0, Waikato: 3, Taranaki: 1, Gisborne: 1, Wellington: 0, Golden Bay/Tasman: 1, Canterbury: 3 and the West Coast: 7. Monitoring started on 15 October 2025 and continued through to the 22 June 2026. Traps were checked and emptied weekly with lure being replace on a 4-6 weekly basis.

3.2. Crop observations

Where possible crops situated next to pheromone traps were scouted while the pheromone traps were checked. Any other serendipitous FAW reports from other crops were also followed and the data. Where possible FAW larvae that were observed were assigned an instar, collected and where possible either preserved for future genetic analysis or reared to determine if they were parasitised. Other details such as crop growth stage and presence of other lepidopteran pests were recorded (Appendix 1 and 2). When possible, the scouting method used is that outlined by the Foundation for Arable Research (https://fallarmyworm.nz/#41). When the appropriate scouting and damage data was recorded it was possible to compare the observations to the appropriate FAW management threshold. The data for seasons 2023–2024 and 2024–2025 were subjected to analysis and presented in Appendix 's 1 and 2). Observation inferences for each of the 3 growing seasons are presented below.

4. Results and Discussion

4.1. Pheromone trapping

4.1.1. Pheromone trapping 2023–24

A total of 442 male FAW adults were captured in pheromone traps over the 2023–24 growing season. The regional breakdown was, Northland: 377 (traps with nil catch=12/23), Auckland: 32 (traps with nil catch=0/1), Waikato: 19 (traps with nil catch=5/5), Taranaki: 0 (traps with nil catch=7/7), Gisborne: 5 (traps with nil catch=1/3), Wellington: 0 ((traps with nil catch=1/1), Golden Bay/Tasman: 0 (traps with nil catch=1/1), Canterbury: 0 ((traps with nil catch=3/3) and the West Coast: 28 (traps with nil catch=2/6). Table 1 outlines the date of first male FAW catch, average number of Male FAW caught per trap and date of final FAW catch for the 2023 season.

Table 1: Regional and seasonal patterns of adult male Fall armyworm catch in pheromone traps deployed across New Zealand between 1 October 2023 and 2 June 2024

Region	Date of first catch	Peak catch	Last catch	Moths per trap[1]
Northland	23 Nov 2023	Mid-Apr–Mid-May 2024	19 May 2024	34.2
Auckland	04 Jan 2024	Mid Feb–Early March 2024	3 March 2024	32.0
Waikato				
Taranaki	-	-	-	-
Gisborne	04 Feb 2024	Eary Feb 2024	3 March 2024	2.5
Wellington	-	-	-	-
Golden Bay/Tasman	-	-	-	-
Canterbury	-	-	-	-
West Coast	10 Dec 2023	Mid-March	5 May	7.2

[1]Total catch per trap per season excluding traps that failed to catch FAW males

4.1.2. Pheromone trapping 2024-25

A total of 1082 male FAW adults were captured in pheromone traps over the 2024–25 growing season. The regional breakdown was, Northland: 833 (traps with nil catch=10/23), Auckland: 32 (traps with nil catch=1/2), Waikato: 19 (traps with nil catch=1/3), Taranaki: 0 (traps with nil catch=7/7), Gisborne: 38 (traps with nil catch=0/1), Golden Bay/Tasman: 41 (traps with nil catch=0/1), Canterbury: 1 ((traps with nil catch=1/2) and the West Coast: 72 (traps with nil catch=0/7). Table 2 outlines the date of first male FAW catch, average number of Male FAW caught per trap and date of final FAW catch for the 2023 season.

Table 2: Regional and seasonal patterns of adult male Fall armyworm catch in pheromone traps deployed across New Zealand between 1 October 2023 and 2 June 2023

Region	Date of first catch	Peak catch	Last catch	Moths per trap[1]
Northland	02 Nov 2023	Mid-Apr–Mid-May 2025	17 May 2025	64
Auckland	03 Mar 2024	Early Mar 2025	3 March 2025	3
Waikato				
Taranaki	30 Jan 2025	Late Jan 2025	30 Jan 2025	10
Gisborne	14 Feb 2025	Mid-Feb–late May 2025	27 May 2025	38
Wellington	-	-	-	-
Golden Bay/Tasman	16 Jan 2025	Late Mar–Late May 2025	20 May 2025	41
Canterbury	29 Mar 2025	29 Mar 2025	29 Mar 2025	1
West Coast	08 Jan 2025	Late Mar–Mid April 2025	5 May 2025	7.0

[1]Total catch per trap per season excluding traps that failed to catch FAW males

4.1.3. Pheromone trapping 2025–26

A total of 2065 male FAW adults were captured in pheromone traps over the 2025–26 growing season (as measured up 2 June 2026). The regional breakdown was, Northland: 1873 (traps with nil catch=9/19), Waikato: 25 (traps with nil catch=2/3), Taranaki: 26 (traps with nil catch=0/1), Gisborne: 40 (traps with nil catch=0/2), Golden Bay/Tasman: 31 (traps with nil catch=0/1), Canterbury: 0 ((traps with nil catch=3/3) and the West Coast: 70 (traps with nil catch=3/7). The results from Northland and the West Coast of the South Island are discussed as these populations exist at the extremes of FAWs northern and southern distribution in New Zealand.

Table 3: Regional and seasonal patterns of adult male Fall armyworm catch in pheromone traps deployed across New Zealand between 1 October 2023 and 2 June 2023

Region	Date of first catch	Peak catch	Last catch	Moths per trap[1]
Northland	01 Nov 2025	Late Apr–Mid-May 2026	14 June 2026	183
Auckland	-	-	-	-
Waikato	23 Jan 2026	Early Mar–Early May 2026	14 May 2026	25
Taranaki	24 Mar 2026	Late Mar–Early Apr 2026	12 May2026	26
Gisborne	26 Dec 2026	Mid–late Mar 2026	20 Mar 2026	20
Wellington	-	-	-	-
Golden Bay/Tasman	17 Dec 2025	Mid-Dec 2025–Mid May 2026	14 May 2026	30
Canterbury	-	-	-	0
West Coast	11 Dec 2025	Early Jan–Mid March 2026	26 April 2025	17

[1]Total catch per trap per season excluding traps that failed to catch FAW males

4.1.4. General observations of FAW flight activity as measured by pheromone trapping.

Since pheromone trapping started in 2022 the number of FAW caught each season has increased year by year despite the size of the trapping grid decreasing (Tables 1–3). This is not an unexpected result as an newly invasive species in New Zealand FAW was still probably in its invasive phase and still reaching an equilibrium. The increase was the largest in Northland (34–184 moths per trap per season). However, it also should be noted that in this region traps that were geographically close to Kaitaia caught more FAW than traps located in southern areas of Northland. Northland will always have a denser FAW population as it predicted to complete 3-4 generations a year in Northland compared to 1-2 in more southerly regions such as Golden Bay, Canterbury and the West Coast of the South Island (Phillips *et al*. 2024). It remains to be seen whether FAW populations and hence trap catch will continue to increase in future years. It therefore may be prudent to maintain a trap network in this region. Fall armyworm fight activity in Northland was observed to start in November compared to December on in the Golden Bay/Tasman and West Coast regions of the South Island. The date of first pheromone trap catch can range between early January and late March (Tables 1–3). Peak pheromone trap catch tends occur earlier in the growing season for the more southerly regions of New Zealand and is a reflection of fewer generations being completed, and hence fewer adult moths on the landscape. Later and longer peaks of flight activity In Northland reflect a greater number of generations of FAW being completed and hence a continued building of the population throughout the growing season.

Seedling maize and sweetcorn are highly susceptible to FAW infestation (Table 4). Any crops that have their planting delayed and are still at the seedling or below knee height growth stages are highly susceptible to FAW infestation. Given the trapping observations in Tables 1–3 planting crops as early as possible should enable growers avoid period of high susceptibility. Crops are still at a susceptible growth stage during potential FAW flight activity should be scouted weekly. The timing of this will vary from region to region. For example, growers of maize or sweetcorn in Northland whose crops are still at the seedling–knee height stage in early November have a high-risk exposure to FAW infestation (Tables 1–3). However, in other regions the exposure period may not occur until mid-December. For Silage maize the risk then drops. However, grain producers will still need to remain vigilant particularly as the season progresses.

Table 4: Current recommended damage threshold for FAW infestation in maize and sweet corn (adopted from https://fallarmyworm.nz/#41).

Current recommendations		
	Crop growth stage	**Threshold**
Maize	Seedling	≥5 % of plants are cut
	Early whorl (knee high)	≥20 % of plants are infested
	Late whorl (shoulder high)	≥40 % of plants are damaged and larvae are present
	Tasselling - early silking	≥20 % of plants are infested
Sweetcorn	Seedling	≥5 % of plants are cut
	Early whorl (knee high)	≥20 % of plants are infested
	Late whorl (shoulder high)	≥40 % of plants are damaged and larvae are present
	Tasselling - early silking	≥5 % of plants are infested

4.2. Crop observations

In this section a synopsis of the crop and FAW data and analysis for the 2023–24 and 2024–25 growing seasons as outlined Appendices 1 and 2 is presented. No results for the 2025–26 cropping season are presented as the data has yet to be analysed.

Sites sampled

During the 2023–24 growing season (11 November 2023–21 May 2024) ninety-one unique sties were sampled at least once with a total of 196 observations being made. These sites were located across the North and South Island (Appendix 1, Figures 1 and 2 and text there in). Of these 190 were from maize crops and 6 were from Sweetcorn. In 2024–25 196 observations, 133 were obtained from the North Island and 63 from the South Island. On the North Island, 110 observations were recorded from maize and 23 from sweetcorn, whereas 58 from maize and 5 from sweetcorn were recorded on the South Island (Appendix 2 Figures 1 and 2 and text there in). Due to limited data from crops from grown in regions outside of Northland and the West coast of the South Island analysis presented in Appendixes 1 and two is limited to Northland and the South Island.

Crop growth stage, FAW life stage and crop damage

Monitoring of maize crops in 2023–24 showed that as maize crops progressed through their development the age of larvae increased (as inferred by instar), populations increased to a maximum at crop maturity and the number of moths associated with crop increased. Observations also showed the cumulative damage to crops also continued to increase throughout the crop maturation process (Appendix 1, Figure 6). In the South Island these trends were more complex (Appendix 1, Figure 7). However, generally after a flush of 5th instar larvae during the early crop growth phases both the larval population and ages of individuals increased as a crop matured to its reproductive stages. However, the damage then dropped off prior harvest (Appendix 1 Figure 7). In 2024–25 the results were less clear. Generally larval age as determined by instar increased with crop age in both the North and South Island (Appendix 2 Figure 8). However, except for a spike in damage to seedling maize crops in the North Island maize damage scores remained static across the growing season in both the North and South Islands (Appendix 2 Figure 8). However, in 2024–25 no consistent population-estimate trends were observed across the North and South Islands, or between maize and sweetcorn (Appendix 2, Figure 9).

The above generally indicates that across both growing seasons that crop damage and larval instar development tended to intensify through the early whorl to tasselling growth stages, most notably around tasselling stage, however population estimates showed more variable patterns across the North and South Islands, seasons and crop types. Further insights and refinements into FAW growth and crop damage patterns might be gained by analysing the relationship between crop planting date and regional FAW fight data as inferred by pheromone trapping.

FAW in Northland 2024–2025

Northland is the region where crops are most at risk to be damaged by FAW. This is because of its subtropical climate which enables FAW to complete up to 4 generations a year (Phillips *et al.*2024). The continued build-up of FAW populations over a growing season has the potential to result in a greater regional over wintering population of FAW which the positively feeds back on population growth through the subsequent season. This means that crops at the seedling stage in November-December are potentially susceptible to FAW damage due to the emergence and dispersal of moths that originate from overwintering larvae.

Monitoring of maize and sweetcorn crops in Northland during the 2024–25 season showed the following. In maize, the mean crop damage scores were 8, 3.0, 3.4, 5.4, 4.4, and 4.0 for seedling, early whorl, late whorl, tasselling, maturing, and harvested stages, respectively (Appendix 2, Figure 12). The mean larval instars were 4.0, 2.7, 3.2, 4.6, 4.3, and 4.0 for seedling, early whorl, late whorl, tasselling, maturing, and harvested stages, respectively (Appendix 2, Figure 12). There were clear increasing trends in both crop damage scores and larval instar, with mean values rising from early whorl stage to tasselling stage, reaching their peak at tasselling stage, and then declining slightly at maturing and harvested stages. This suggests that vulnerable seedlings were exposed to FAW adults and or overwintering larvae moving off non-preferred overwintering hosts. With a second and potential 3 generation completing its development on the crop.

A similar pattern was observed in sweetcorn, where both damage scores and larval instar increased from seedling to maturing stages, peaked at maturing stage, and then declined at harvested stage (Appendix 2 Figure, 12). Notably, the peak differed between the two crops: maize reached its maximum at tasselling stage, whereas sweetcorn peaked at maturing stage. However, the sweetcorn results are based on only 7 observations. This may be due to differences in crop management e.g. the use of insecticides to control FAW, planting date and crop attractiveness at differing life stages.

For maize, mean population estimates peaked at seedling stage (15%; based on only three observations), declined at early whorl (6.4%) and late whorl (3.5%) stages, increased again from late whorl and tasselling (8.6%) stages, slightly decreases from tasselling and maturing (7.4%) stages, and then declined at harvested stage (3%) (Appendix 2, Figure 12). For sweetcorn, population estimates showed an overall increasing trend, with mean values rising from seedling stage (2%) to tasselling stage (25.0%), reaching a highest level at maturing (40.0%) stage, and then declining at harvested stage (10%) (Appendix 2 Figure 12); however, these results are based on only 7 observations.

Two factors which haven't been examined that could help growers better understand the phenology and damage potential of FAW in New Zealand are the impacts of planting date and the identification of overwintering sites and hosts of FAW. Manipulating planting dates has been successful in reducing the exposure of vulnerable crop growth stages e.g. seedlings to flights of FAW (e.g. Ehinomen *et al.* (2026), Shah *et al*. (2026)). It would be useful to identify overwintering hosts as it may be able to remove these from the environment. Recent observations have identified that volunteer maize may be acting as an overwintering bridge for FAW (Hardwick 2026 unpublished data). However, further studies needed to confirm this.

In conclusion FAW populations have been monitored since its establishment in 2022. The results of field observations to date are consistent with the conclusions of Phillips *et al.* (2024). That is they predicted that in current climates FAW will occur year-round in the northern third of the North Island and in warmer years may also persist year-round in some coastal parts of the southern North Island and northern South Island. The results are also consistent with Phillips *et al.* (2024) prediction that FAW has up to 4 generations per year in Northern New Zealand and one in more southerly areas. In New Zealand Significant damage to maize and sweetcorn crops in New Zealand can occur particularly if vulnerable plant growth stages e.g. seedlings and early vegetative plants are present during FAW flight and oviposition activity. Such periods occur from November onwards in the far North of New Zealand and between December and March in more southerly areas. Once populations for FAW establish in a crop they tend to increase through the growing season cumulatively damaging the crop. This effect can be pronounced in Northland. However, if early damage isn't too extensive maize silage crops appear relatively unaffected by FAW feeding. Cob damage to maize grain and sweetcorn crops can be extensive and have a major economic impact. It is recommended that these later crops be regularly scouted throughout their productive cycle.

5. Recommendations

- That while the general approach taken by FAR has resulted in a greater understanding of the dynamics between FAW and its hosts, the acquisition of planting date data for maize and sweetcorn crops to incorporate into future analysis of FAW population growth and damage potential would be improve our knowledge.

- That growers are encouraged to scout vulnerable crops during particularly during risky periods associated with early season FAW flights (November–March).

- Research that identifies overwintering sites and hosts be undertaken as this will be critical for areas such as Northland which may benefit from an integrated approach to FAW control

- To continue monitoring and data gathering to determine whether FAW population densities are continuing to grow in Northland and adjacent areas.

- To compete the analysis of data collected during 2025–26 growing season.

Acknowledgements

We would like to acknowledge all growers, consultants and extension officers for providing records and or access to maize or sweetcorn crops. Thank you also to Jenny Dymock for undertaking the extensive FAW monitoring in Northland.

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Appendices

5.1. Appendix 1 FAR analysed FAW data 2023-24

Client:	Ashley Mills: FAR
Research group:	-
Analyst:	Chanatda Somchit: AgResearch
Statistical software:	R version 4.2.0

Statistical analysis

For FAW Scouting SFFF study, all statistical computations, graphs, and data handling operations were performed using R version 4.2.0 R Core Team (R Core Team, 2022).

The aims of the present survey were

1. to describe and summarise the current situation of crop damage, larvae instar, population estimates, and number of moths in relation to crop growth stage observed in the Northland and South Island from the 2023-24 SFFF survey,
2. to develop preliminary model which can be used to determine the relationship between crop damage scores, larvae instar, crop growth stage, and population estimates using the Northland data (the South Island data were excluded from the analysis due to insufficient data), and
3. to improve data collection tools for the next season of the survey.

Results

1. *Descriptive statistics for crop damage, larvae instar, population estimates, and number of moths*

1.1 Spatial survey-location plots

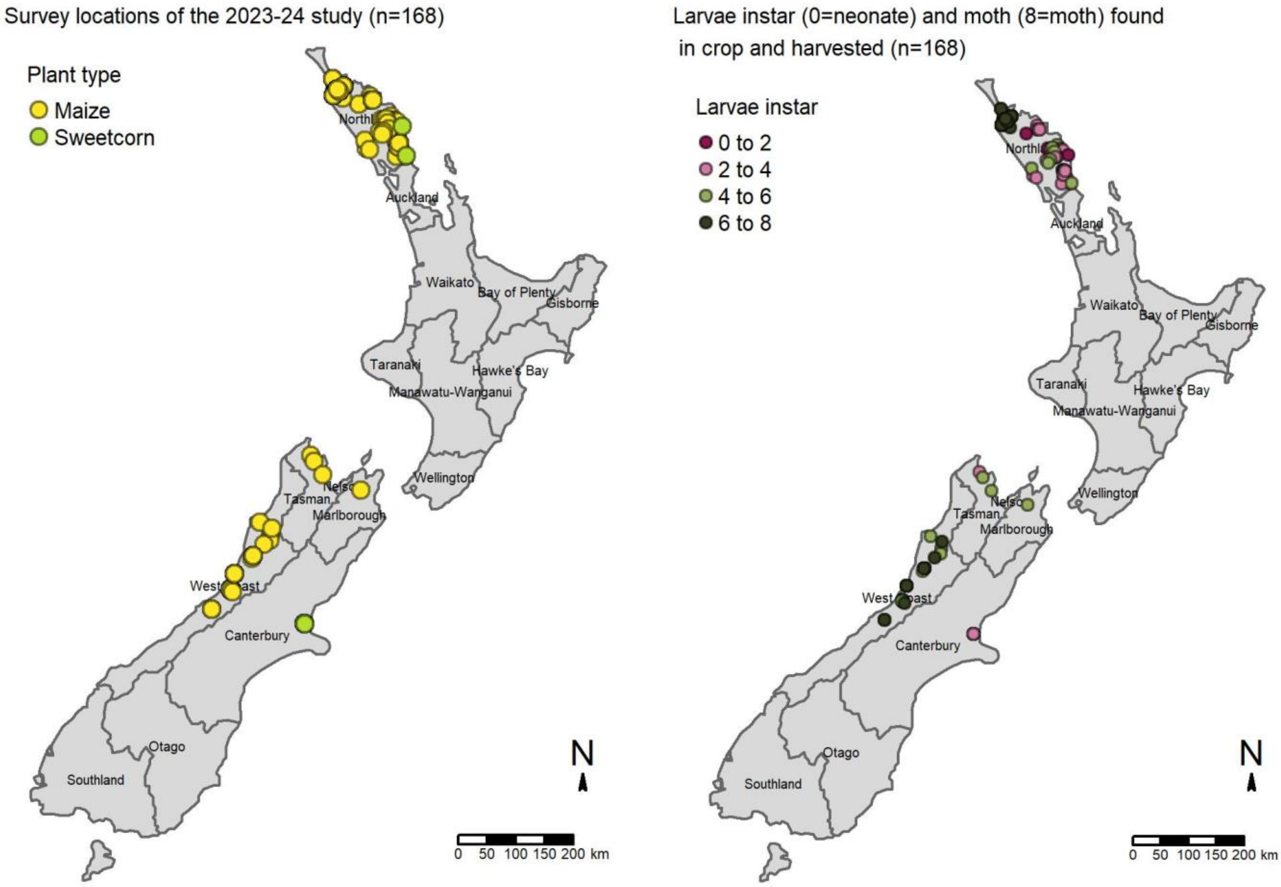


Figure 1 *Map of survey locations with colours refer to plant type (left) and larvae instar (right) observed from Northland and South Island (maize and sweetcorn crop).*

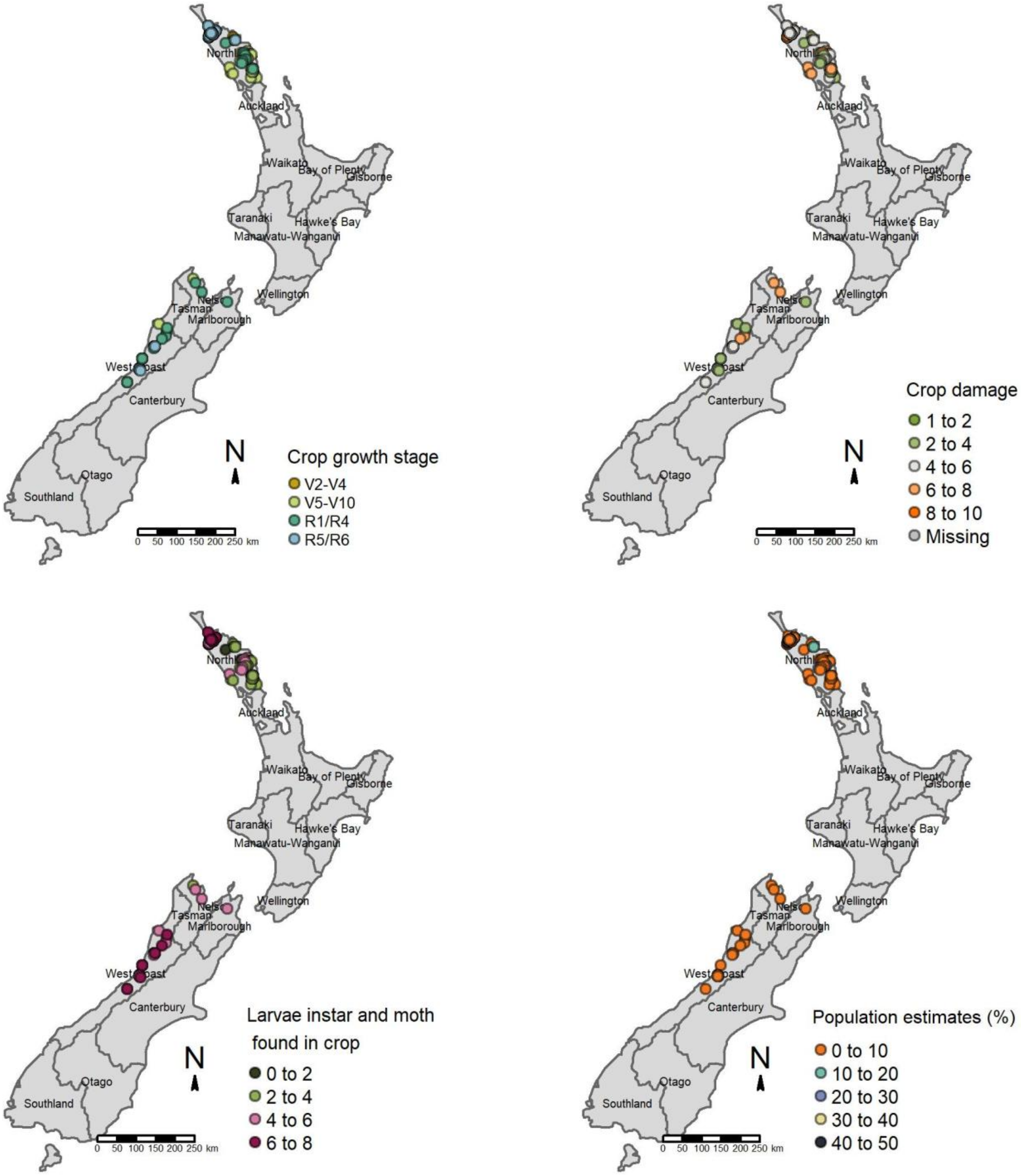


Figure 2 *Map of survey locations with colours refer to crop growth stage (top-left), crop damage (top-right), larvae instar and moths (bottom-left), and population estimate (bottom-right) observed in maize-crop from Northland and South Island.*

1.2 Percentage/ count of the data

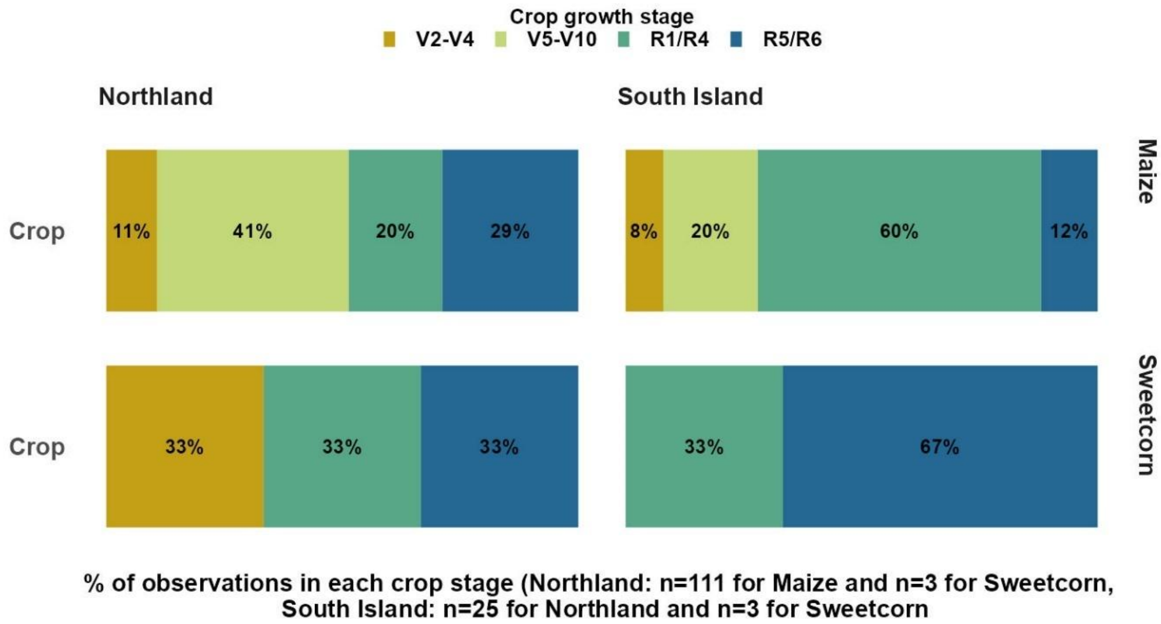


Figure 3 *Percentage of observations observed in each crop stage for maize and sweetcorn for Northland and South Island*

97% of observations were observed from maize crop in Northland, with 11%, 41%, 20% and 29% observed in V2-V4, V5-V10, R1/R4 and R5/R6, respectively, while only 3% were observed from sweetcorn crop (Figure 3). 89% of observations were observed from maize-crop in the South Island, with 8%, 20%, 60% and 12% observed from maize growth stage of V2-V4, V5-V10, R1/R4 and R5/R6, respectively, while 11% were observed from sweetcorn crop (Figure 3).

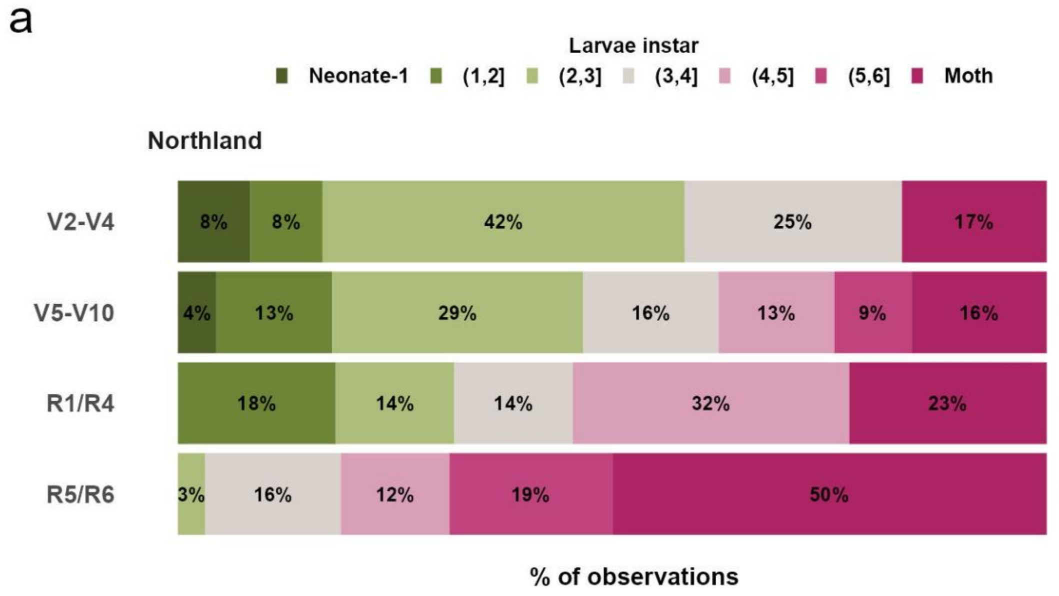


Figure 4 *Percentage of observations observed (a) with each larvae instar and (b) with each crop damage for maize-crop in Northland*

In Northland and crop growth stage of V2-V4, 8%, 8%, 42%, 25% and 17% of observations recorded as larvae instar of neonate-1st instar, >1st instar to 2nd instar, >2nd instar to 3rd instar, >3rd instar to 4th instar, and moth, respectively (Figure 4: a), while larvae instars recorded in V5-V10 were 4%, 13%, 29%, 16%, 13%, 9%, and 16% for neonate-1st instar, >1st instar to 2nd instar, >2nd instar to 3rd instar, >3rd instar to 4th instar, >4th instar to 5th instar, >5th instar to 6th instar, and moth, respectively (Figure 4: a).

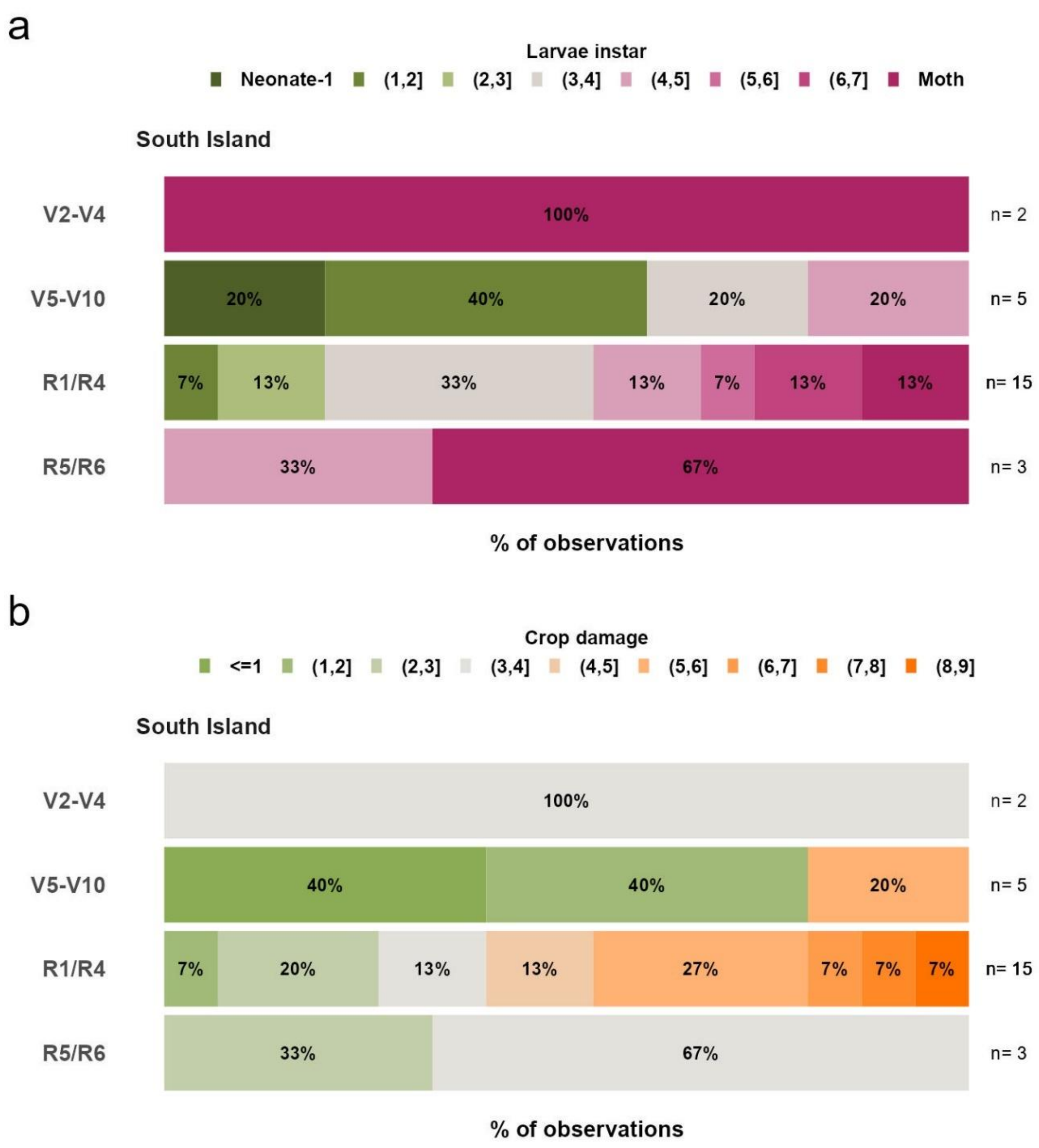


Figure 5 *Percentage of observations observed (a) with each larvae instar and (b) with each crop damage for maize-crop in the South Island*

1.3 Summary statistics for crop growth damage, larvae instar, population estimates, and number of moths observed in Northland and South Island

1.3.1 Northland

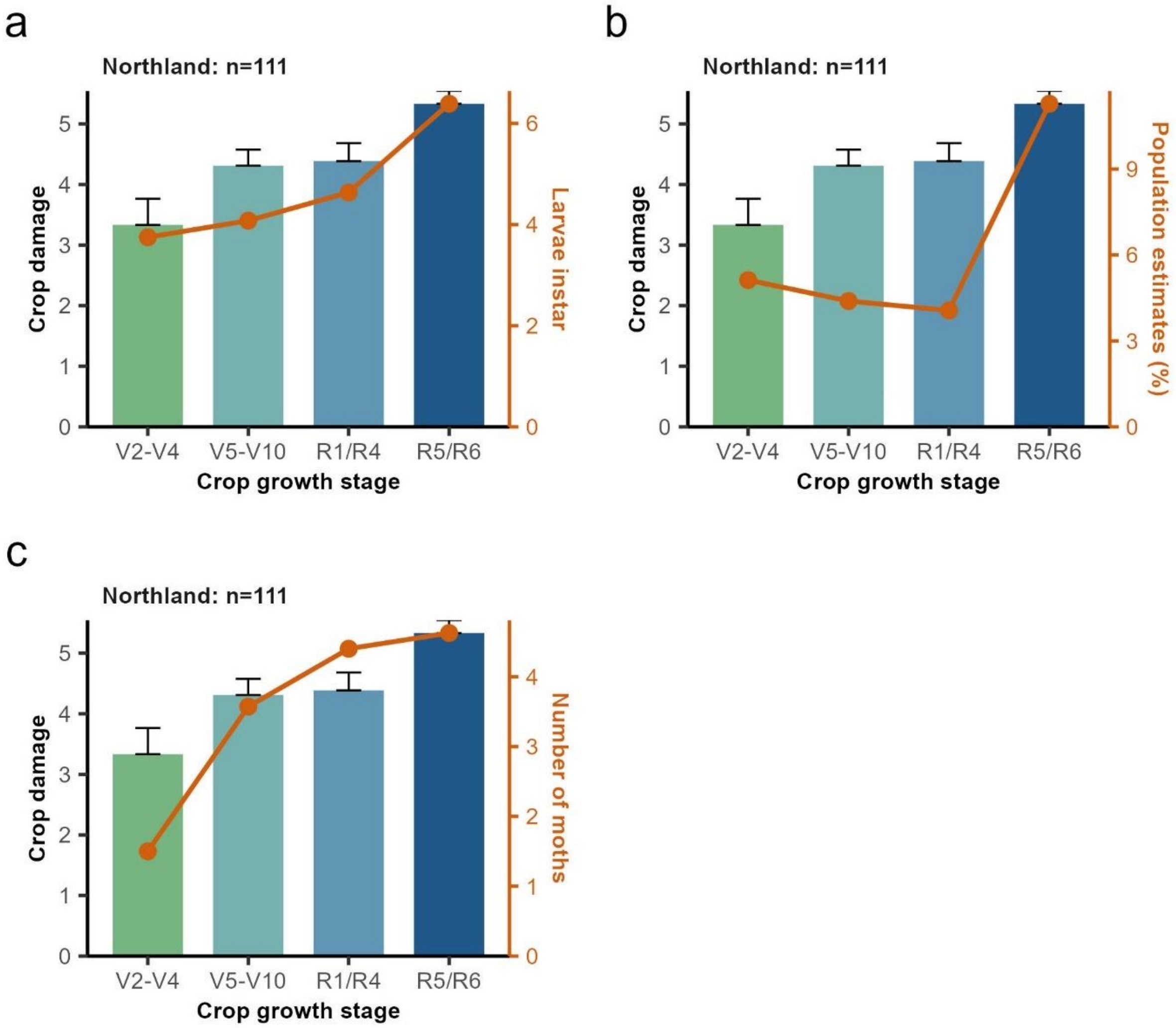


Figure 6 *Mean crop damage score observed in each crop growth stage from maize-crop in Northland. Bars are means ± standard errors SE of crop damage. Orange dots in (a), (b) and (c) represent mean larvae instar, number of moths and population estimates, respectively.*

In the maize-crop observed in Northland, the average of crop damage scores was 3.3, 4.3, 4.4, and 5.3 for V2-V4, V5-V10, R1/R4 and R5/R6, respectively (Figure 6: a). The mean larvae instars were 3.8, 4.1, 4.6, and 6.4 for V2-V4, V5-V10, R1/R4 and R5/R6, respectively (Figure 6: a), while the average number of moths was 1.5, 3.6, 4.4, and 4.6 for V2-V4, V5-V10, R1/R4 and R5/R6, respectively (Figure 6: c). The average percentage of population estimates was 5.1%, 4.4%, 4.0%, and 11.3% for V2-V4, V5-V10, R1/R4 and R5/R6, respectively (Figure 6: b).

Generally, there was an increase in crop damage score, larvae instar, and number of moths between early crop-stage (V2-V4) and late crop-stage (R5/R6) (Figure 6: a and c).

1.3.2 South Island

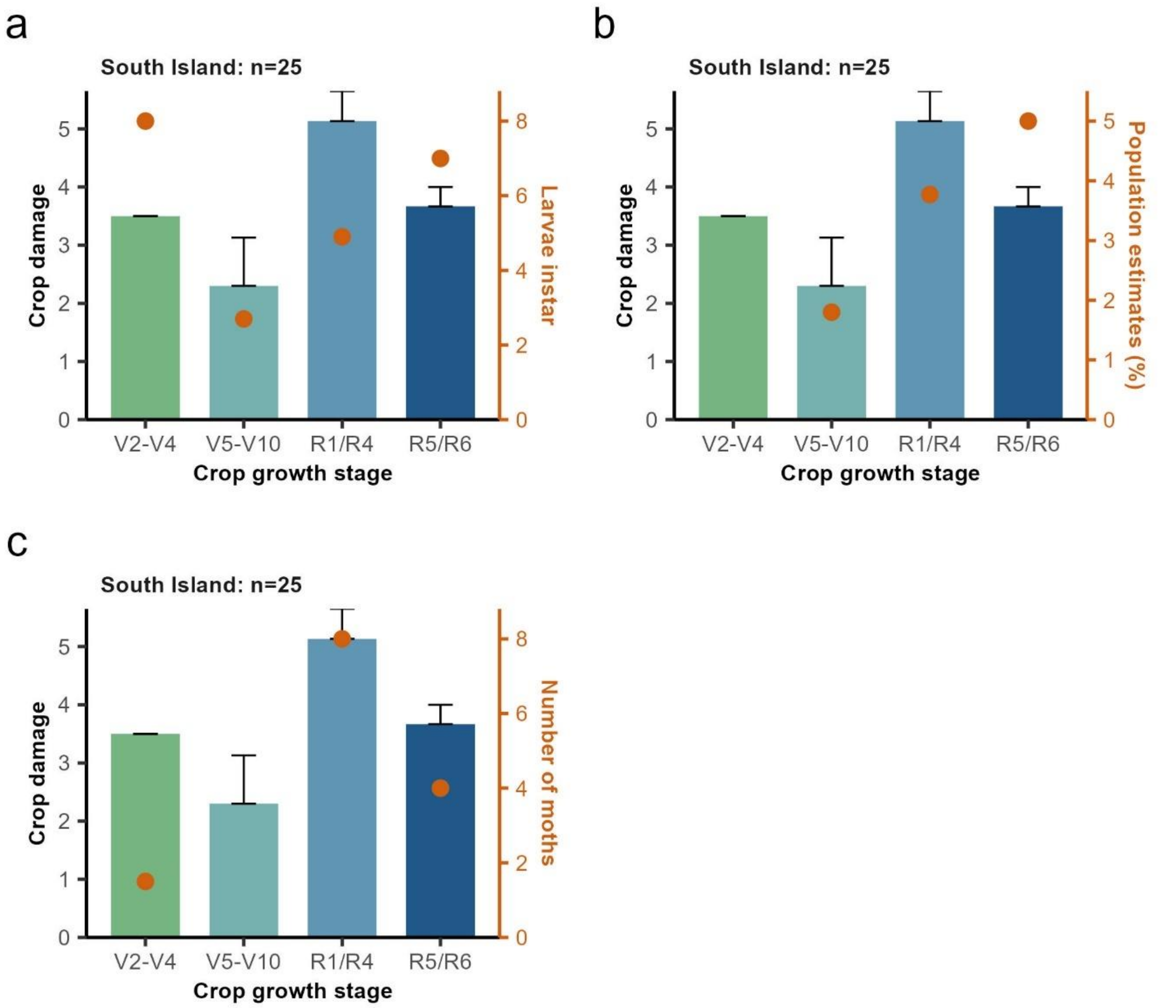


Figure 7 *Mean crop damage score observed in each crop growth stage from maize-crop in the South Island. Bars are means ± standard errors SE of crop damage. Orange dots in (a), (b) and (c) represent mean larvae instar, number of moths and population estimates, respectively.*

In the maize-crop observed in the South Island, the average of crop damage scores was 3.5, 2.3, 5.1, and 3.7 for V2-V4, V5-V10, R1/R4 and R5/R6, respectively (Figure 7: a). The mean larvae instars were 8, 2.7, 4.9, and 7 for V2-V4, V5-V10, R1/R4 and R5/R6, respectively (Figure 7: a), while the average number of moths was 1.5, 8.0, and 4.0 for V2-V4, R1/R4 and R5/R6, respectively (Figure 7: c). The average percentage of population estimates was 1.8%, 3.8%, and 5.0% for V5-V10, R1/R4 and R5/R6, respectively (Figure 7: b).

2. Additive mixed modelling applied on crop damage data (Northland data)

A Generalised additive mixed model (GAMM) was used to analyse non-linear relationships between the crop damage score and three explanatory variables (crop growth stage, larvae instar and population estimates). The GAMM model assumed a Gaussian distribution with 'Location' included as a random effect. The GAMM was conducted using the maize-crop data from the Northland survey (the South Island data were excluded from the analysis due to insufficient data).

The Gaussian GAMMs were fitted by penalised likelihood maximisation implemented in the mgcv package (Wood & Wood, 2015; Wood, 2017). In all cases, thin-plate regression splines were used. The estimated degrees of freedom of the smooth (*edf*) were used to determine whether the response variable was linearly related to the respective variable (*edf* values >1 indicate a nonlinear effect). *t*-statistics and *F*-statistics and their approximate *p*-values for the parametric components and smoothers, respectively, were used to determine the significance level of statistical results. Graphical model validation tools such as plots of residuals against fitted values (linear predictor), standardised residuals versus fitted values, histogram of residuals, and normal quantile–quantile plots were used to assess the underlying model assumptions and suitability of chosen error distributions. The collinearity between three explanatory variables was examined through the variance inflation factor (VIF), and a cut-off value of 3 was used to remove collinearity variables, as recommended by Zuur *et al.* (2009).

The distribution of crop growth stage (Figure 8: a) revealed that most of observations representing crop growth stage of R5/R6 were observed in the northern part of Northland. Therefore, we had insufficient R5/R6-observations to represent the entire population of crop fields in the Northland. Care must be taken in interpreting the results to the entire population of crop fields in the Northland.

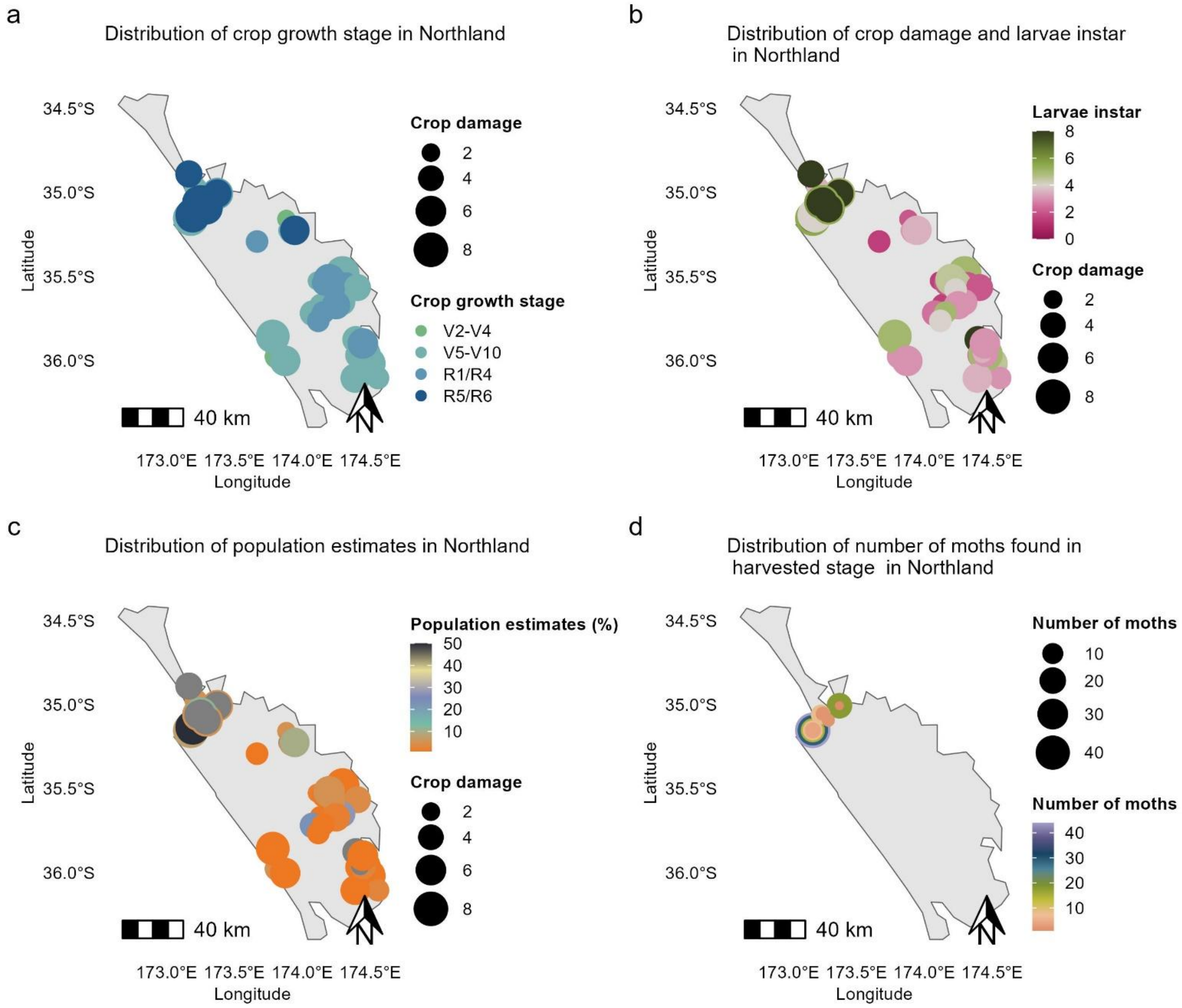


Figure 8 *Spatial distribution of crop growth stage (a), larvae instar (b), population estimates (c), and number of moths observed in harvested stage (d) in Northland.*

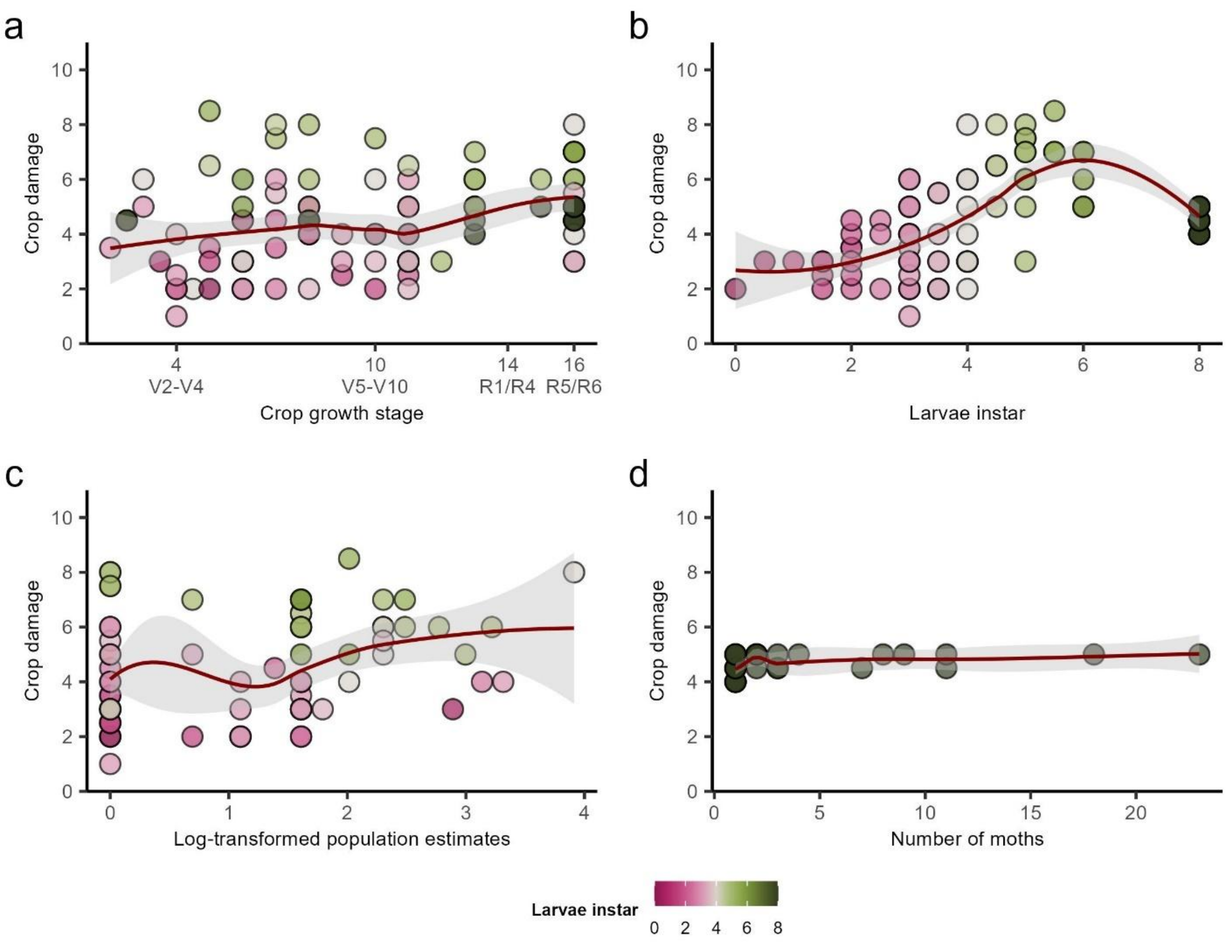


Figure 9 *Scatterplots of crop damage score versus the four explanatory variables: crop growth stage (a), larvae instar (b), log-transformed population estimates (c), and number of moths (d). Smoothing (LOESS) curves and their confidence intervals were added in each panel to visualise trends. The dots were coloured according to values of larvae instar (0=neonate and 8=moth).*

Figure 9: a, b, and c indicate that the crop growth stage, the larvae instar, and the log-transformed population estimates showed nonlinear trends to the crop damage (Figure 9: a, b, and c), while there was a constant trend between the crop damage and number of moths (Figure 9: d). The crop damage scores stayed fairly stable between the crop growth stage of V2 and V10 and then started to increase at crop growth stage of R1 (Figure 9: a). The crop damage scores increased nonlinearly between larvae instar of neonate and 6th instar and then decreased (Figure 9: b).

The optimal model for the crop damage score (the data with moth), according to the GAMM selection approach, contained only larvae instar (F = 20.6, n=109, p <0.001). The estimated crop damage score increased with increasing stages of larvae instars between neonate and 3.5th instar and started to increase sharply with larvae instars between 3.5 and 6 and then decreased when the instar was on moth stage (Figure 11: a). Larvae instar together with variation in location explained 74.1% of the total variation in crop damage score.

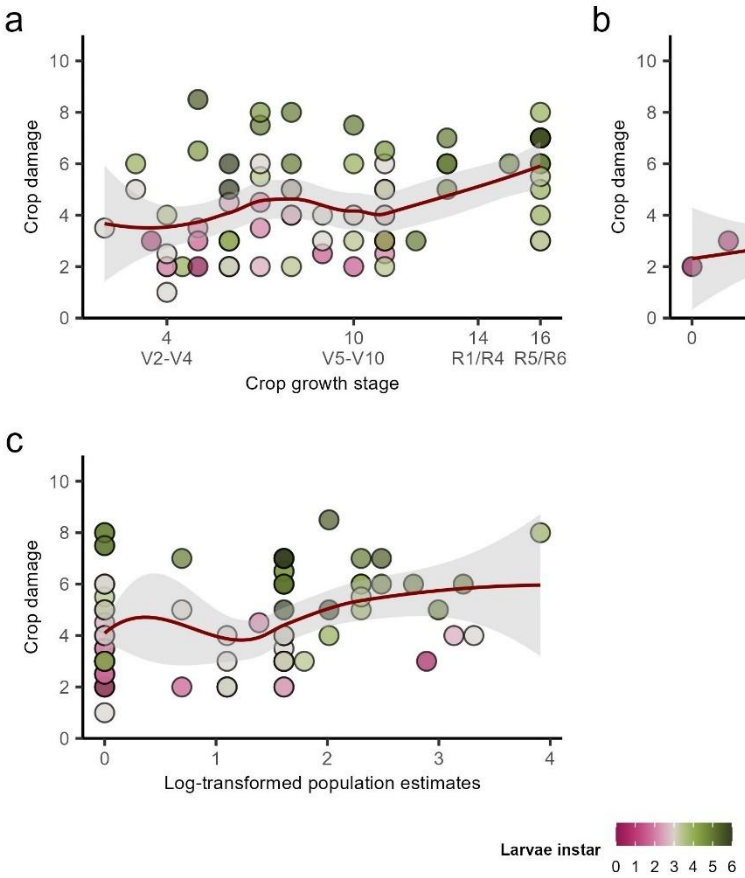


***Figure 10** Scatterplots of crop damage score versus the three explanatory variables: crop growth stage (a), larvae instar (b), and log-transformed population estimates (c) excluding moth data. Smoothing (LOESS) curves and their confidence intervals were added in each panel to visualise trends. The dots were coloured according to values of larvae instar (0=neonate and 6=6th instar).*

With and without moth data, the trends for crop damage scores against the three explanatory variables were very similar (Figures 9 and 10).

The optimal model for the crop damage score excluding moth data, according to the GAMM selection approach, contained only larvae instar (F = 18.3, n=79, p <0.001). Again, the estimated crop damage score increased with increasing stages of larvae instars between neonate and 3.5th instar and started to increase sharply with larvae instars between 3.5 and 6 (Figure 11: b). Larvae instar together with variation in location explained 64.5% of the total variation in crop damage score.

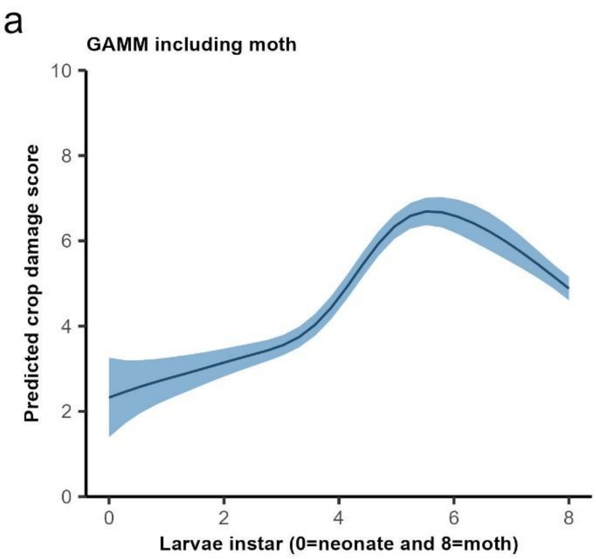


Figure 11 *Predicted crop damage score (1 to 10) over larvae instars of 0 (neonate) – 8 (moth) (a) and 0 (neonate) – 6 (6th instar) (b) with 95% confidence intervals using the Gaussian GAMM.*

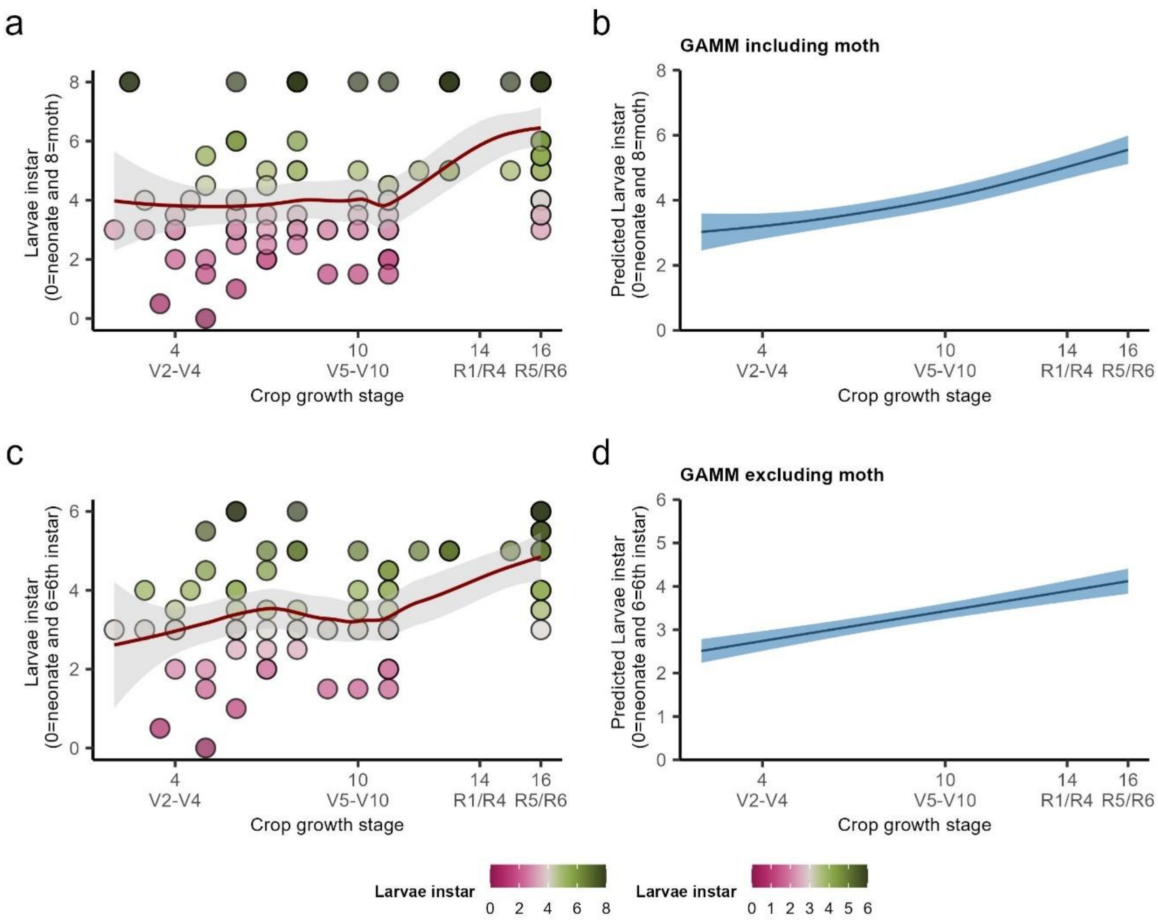
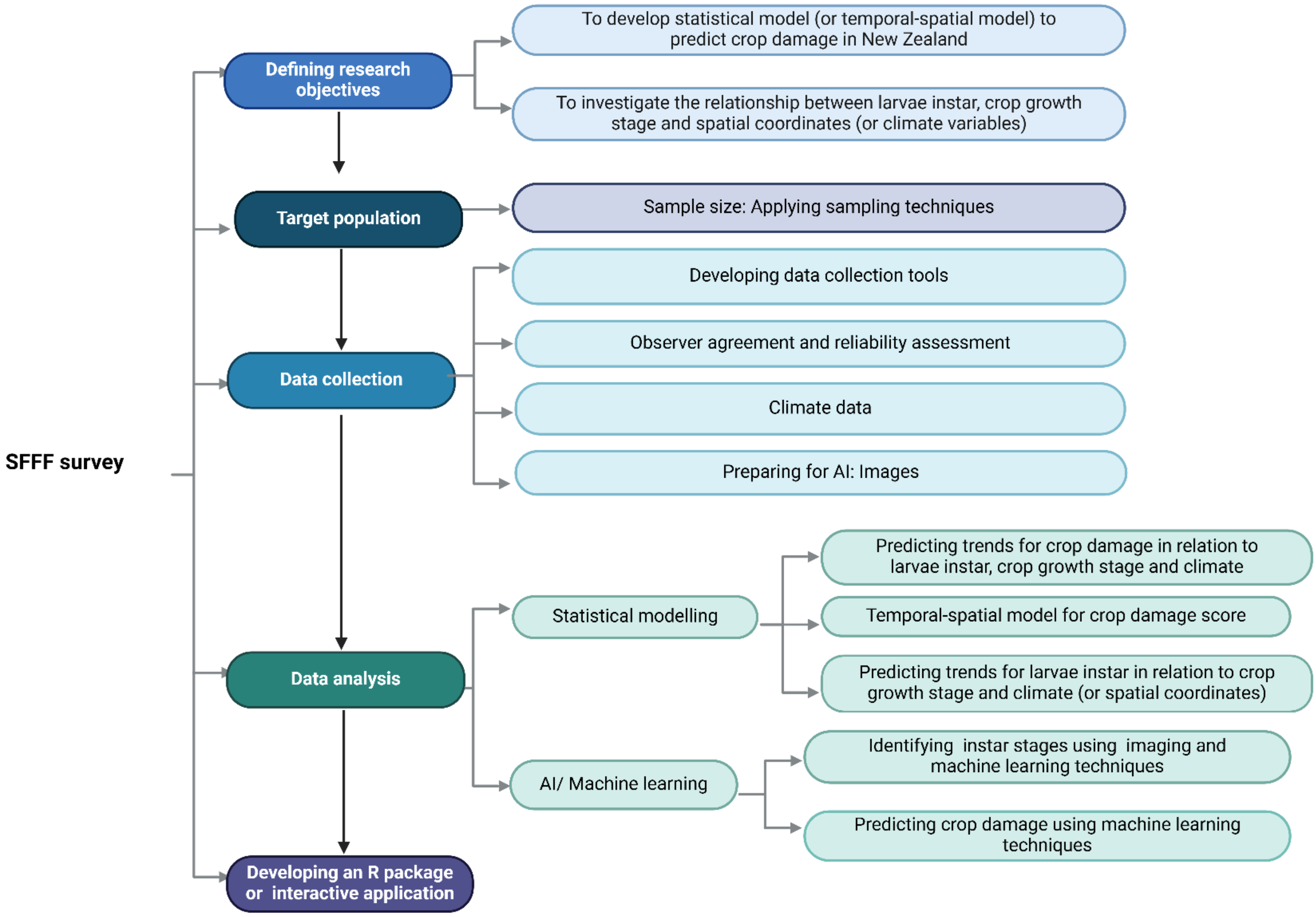


***Figure 12** Scatterplots of larvae instar versus crop growth stage using the data with moth (a) and without moth (c). Smoothing (LOESS) curves and their confidence intervals were added a and b to visualise trends. The dots were coloured according to values of larvae instar. Predicted larvae instar (0=neonate to 8=moth) over the crop growth stage (2=V2 to 16=R6) using the data including moth (b) and without moth (d) with 95% confidence intervals using the Gaussian GAMM.*

To investigate whether the crop growth stage can be used to predict the larvae instar, individual Gaussian generalised additive models (GAMs) were constructed separately for the data with and without moth. For both models, crop growth stage had a significant nonlinear relationship with the larvae instar (F=10.8, n=111, p =0.0001) for the analysis with moth and F=13.5, n=81, p =0.0005 for the analysis without moth). For the data including moth, the estimated larvae instar increased nonlinearly with increasing crop growth stage (Figure 12: b). For the data without moth, the *edf* estimate of crop growth stage supported linearity as its *edf* estimate was equal to 1. As the crop growth stage increased, the larvae instar increased. Crop growth stage together with variation in location explained 45.9% and 55.4% of the total variation in larvae instar for with and without moth, respectively.

3. *Data collection tools and survey charts/guidelines for the next season of the survey*

Modified data collection form and a table of variable description are given in the excel file. To achieve the objectives of the study robustly, I developed the survey chart as given below.



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5.2. Appendix 2 FAR analysed FAW data 2024-25

Client:	Ashley Mills: FAR
Research group:	-
Analyst:	Chanatda Somchit: AgResearch
Statistical software:	R version 4.2.0

Statistical analysis

For FAW Scouting SFFF 2024-25 survey, all statistical analyses, data management, and graphical representations were performed using R version 4.2.0 R Core Team (R Core Team, 2022).

Spatial survey-location plots were used to illustrate distributions of crop damage, larval instars, population estimates (%), and moth abundance across the North and South Islands. The percentage of observations in each crop growth stage, larval instar, and crop damage score for maize and sweetcorn on the North and South Islands was summarised using stacked bar charts. To visualise the relationships between crop growth stages, crop damage scores, larval instars, and population estimates (%), bar plots displaying means and standard errors were used.

Linear and generalised linear mixed models (LMMs and GLMMs) were applied to examine whether crop damage scores, larval instar, population estimates (%), and moth abundance differed across crop growth stages. For the North Island, the analyses were conducted using maize data from the Northland region only, as insufficient data were available from other regions to allow robust modelling. Two crop growth stages: seedling and harvested stages, were excluded from the analysis due to limited observations (only three and two observations, respectively). Population estimates were analysed using LMMs fitted to log-transformed data, whereas moth abundance was analysed using GLMMs assuming a negative binomial distribution with a log link to account for overdispersion. In all models, crop growth stage was included as a fixed effect, while sampling location was specified as a random effect to account for location-specific variation and repeated measures over time.

A Generalised additive mixed model (GAMM) was fitted to predict crop damage score from crop growth stage (converted to a numeric scale), larval instar and population estimates, using maize crop data from the Northland region. The crop damage score was log-transformed prior to analysis to improve normality and stabilise variance. The three continuous predictors were modelled as smooth terms using thin-plate regression splines. Population estimates were log-transformed prior to analysis due to their highly skewed distribution, and 'location' was included as a random effect to account for location-specific variation and repeated measures over time as described above. Collinearity among the three predictors were assessed using variance inflation factor (VIF), with a cut-off value of 3 applied to identify and remove collinear variables, following the recommendations of Zuur *et al.* (2009). All VIF values were below 3, indicating no collinearity among the three predictors; consequently, all were retained in the analysis. GAMMs were fitted using penalised likelihood maximisation as implemented in the mgcv package (Wood & Wood, 2015; Wood, 2017). The estimated degrees of freedom (*edf*) for each smooth term were used to assess whether the relationship between the response variable and each predictor was linear or nonlinear, with *edf* values greater than 1 indicating nonlinearity. Significance was evaluated using *t*-statistics for parametric terms and *F*-statistics for smooth terms, together with their approximate *p*-values.

For all models, plots of Pearson residuals against fitted values, standardized residuals versus fitted values, histogram of residuals, and normal quantile–quantile plots were used to assess the underlying model assumptions and suitability of chosen error distributions. For all LMMs and GLMMs, the significance of fixed effects was assessed using either Type II Wald tests based on a Chi-square statistic for linear mixed-effects models [R package car; Fox and Weisberg (2018)]. The significance of the fixed terms were subsequently examined through multiple comparisons based on estimated marginal mean differences with Tukey adjustment applied to account for multiple testing [R package emmeans (Lenth *et al.*, 2022)].

For the South Island, analyses were also conducted using the maize data only. However, only 58 observations were available for maize from the South Island; therefore, the results should be considered preliminary, intended to observe trends in crop damage, larval instar, and population estimates, rather than to generalise to the entire maize population of the South Island. The mixed-effects models and GAMMs were implemented following the same procedures as described for the analyses of the Northland data.

Results

Part I: Spatial distributions, frequency counts, and summary statistics for the North and South Islands

Figure 1 represents the total 196 survey locations from the 2024-25 study with colours indicating plant types (maize and sweetcorn) in the left panel and crop types in the right panel, across the North and South Islands as observed during 2024-25 survey. The distributions of crop growth stages, crop damage scores, larval instars, and population estimates (%) across the North and South Islands are presented in Figure 2.

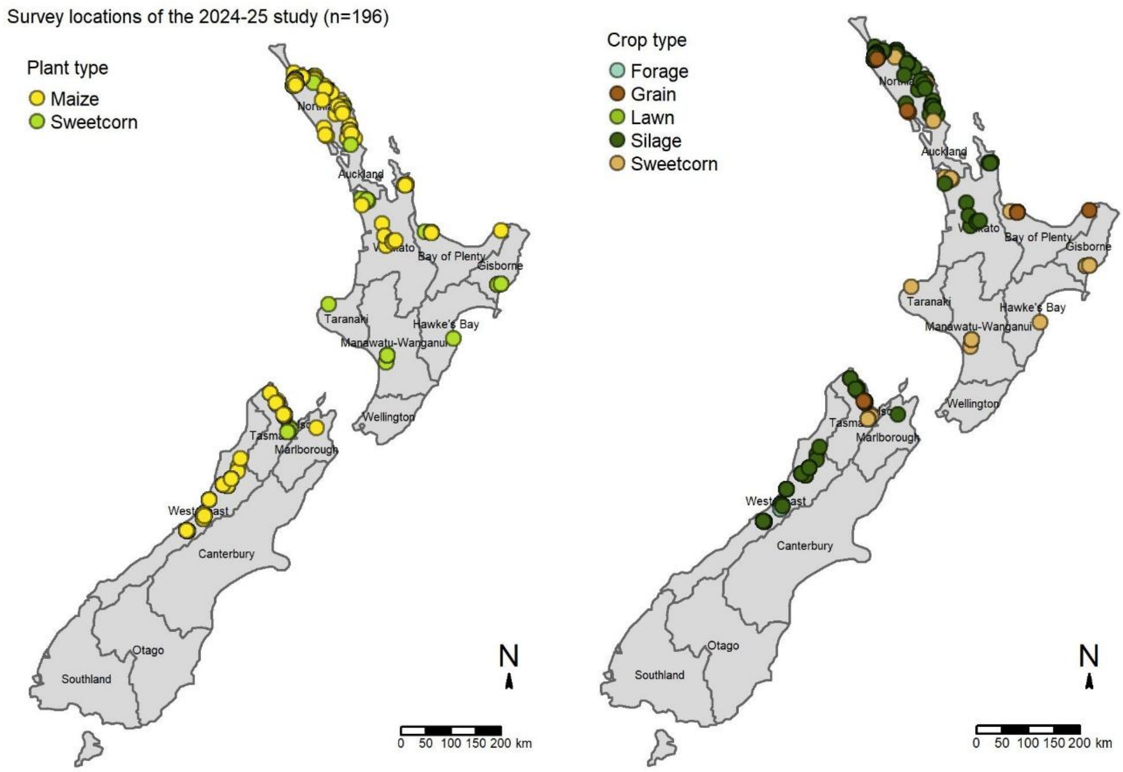


Figure 1. *Spatial distribution of survey locations coloured by plant types: maize and sweetcorn (left) and crop type (right) as observed across the North and South Island during 2024-25 survey.*

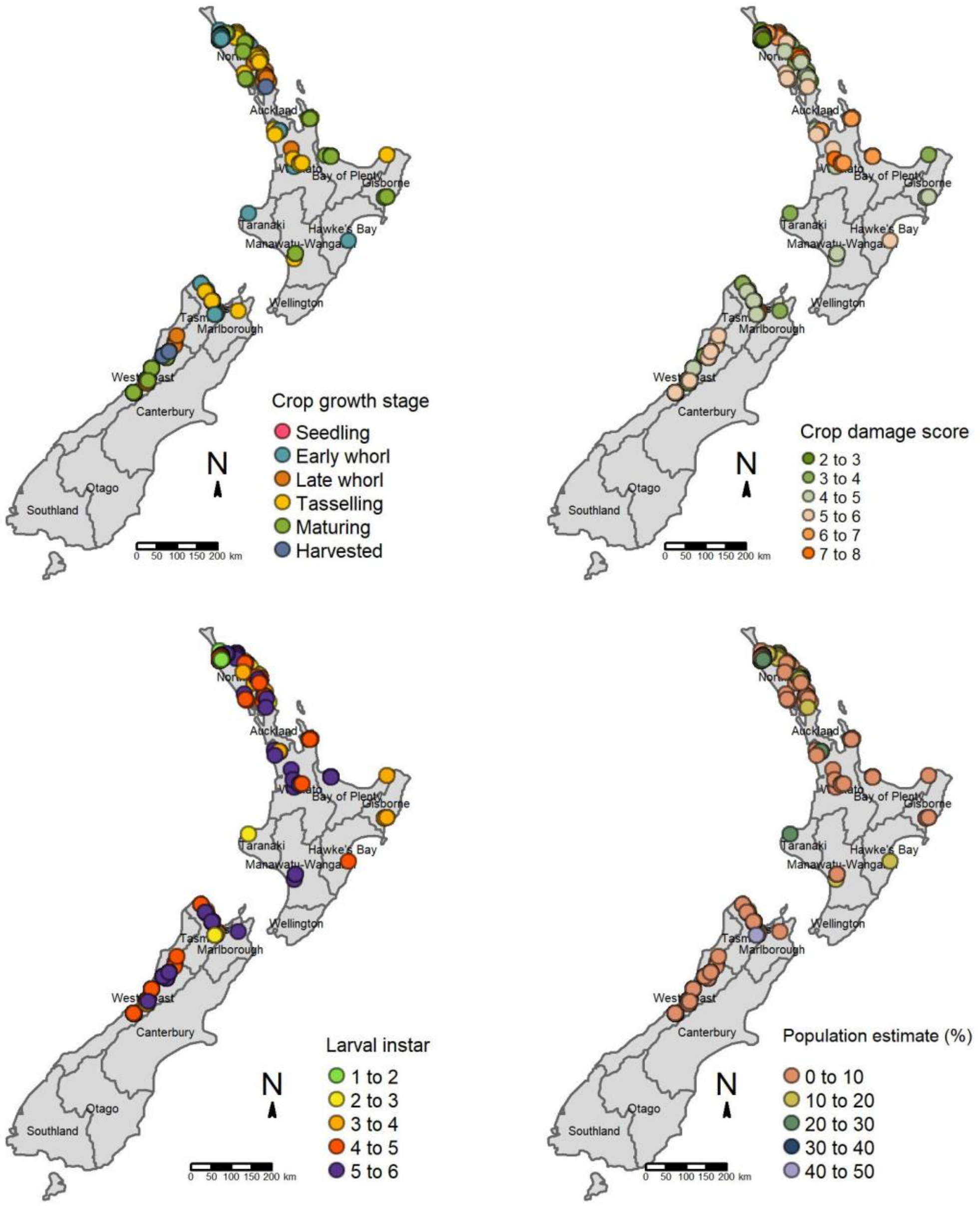


Figure 2. *Spatial distribution of crop growth stages (top left), crop damage scores (top right), larval instars (bottom left), and population estimates (%) (bottom right) observed across the North and South Islands during 2024-25 survey.*

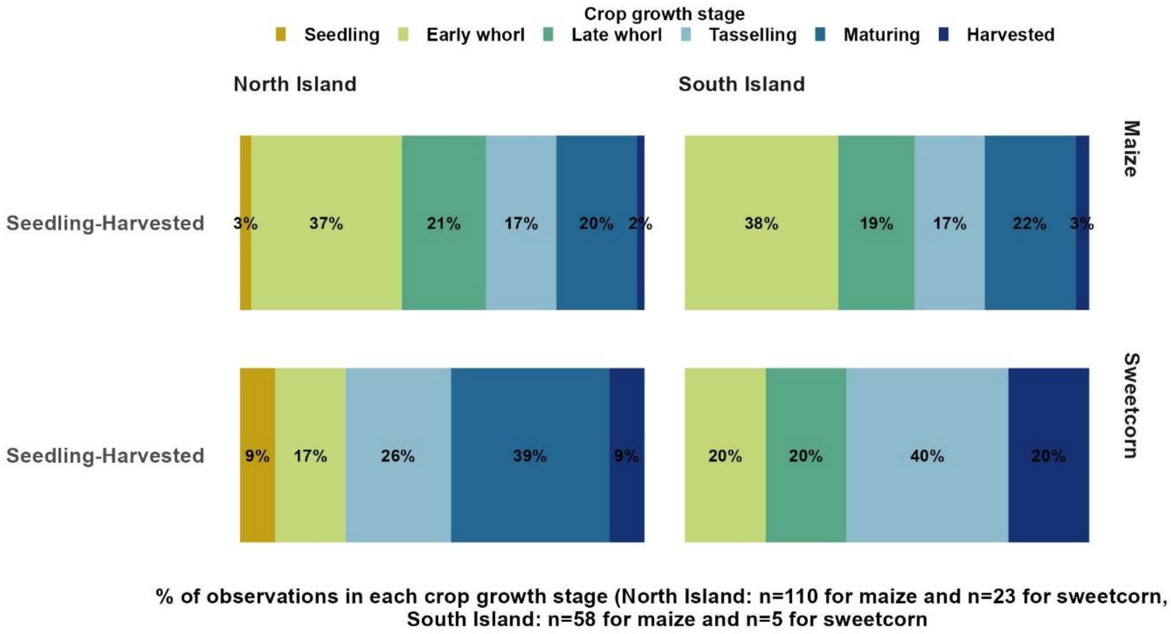


Figure 3. *Percentage of observations recorded at each crop growth stage for maize and sweetcorn across the North and South Islands.*

Of the total 196 observations, 133 were obtained from the North Island and 63 from the South Island. On the North Island, 110 observations were recorded from maize and 23 from sweetcorn, whereas 58 from maize and 5 from sweetcorn were recorded on the South Island.

For the North Island, 37%, 21%, and 20% of total observations from maize crop were observed from early whorl, late whorl, and maturing, respectively (Figure 3). Of the total sweetcorn observations, 39%, 26%, and 17% were observed from maturing, tasselling, and early whorl, respectively.

For the South Island, maize observations were distributed as 38%, 19%, 17%, 22%, and 3% across early whorl, late whorl, tasselling, maturing, and harvested stages, respectively (Figure 3). Twenty, 20%, 40%, and 20% of the total observations from sweetcorn were observed from early whorl, late whorl, tasselling, and harvested stages, respectively (Figure 3)

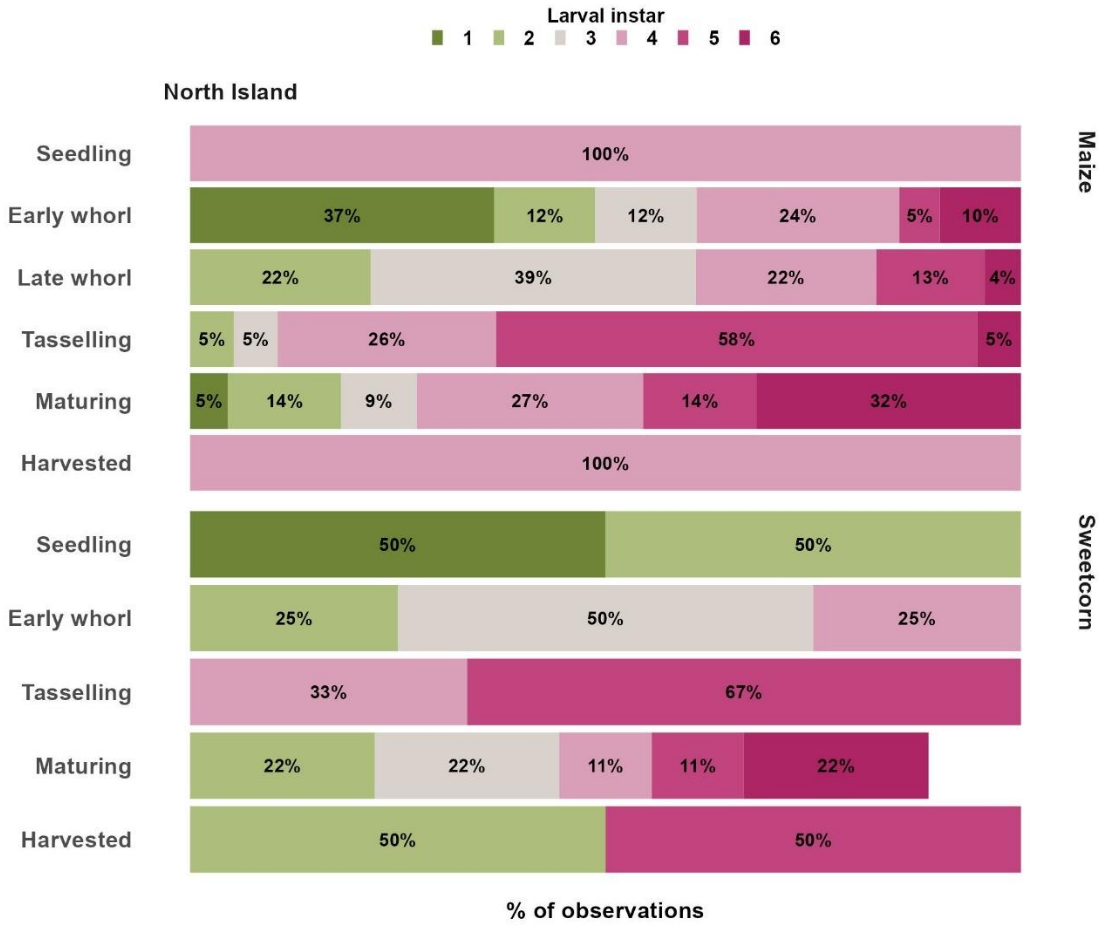


Figure 4. *Percentage of observations at each larval instar within each crop growth stage for maize (n=110) and sweetcorn (n=23) observed from the North Island. Missing cells indicate missing values.*

Percentage of observations at each larval instar within each crop growth stage for maize and sweetcorn on the North Island is shown in Figure 4.

In maize, at the seedling stage, only the fourth instar was observed. At the early whorl stage, the 1st instar accounted for the highest percentage of observations (37%), followed by the 4th, 2nd and 3rd with 24%, 12%, and 12% respectively. At the late whorl stage, the 3rd instar was predominant (39%), followed by the 2nd and 4th with 22% and 22% respectively. At the tasselling stage, the 5th instar accounted for the highest proportion of observations (58%), followed by the 4th with 26%. At the maturing stage, the 6th instar was most frequent (32%), followed by the 4th and 5th instars with 27% and 14% respectively. At the harvested stage, only the 4th instar was found.

In sweetcorn, at the seedling stage, only the first and second instars were observed. At the early whorl stage, the 3rd instar accounted for the majority of observations (50%), followed by the 4th and 2nd with 25% and 25% respectively. No larval instars were observed at the late whorl stage. At the tasselling stage, the 5th instar accounted for the highest proportion of observations (67%), followed by the 4th with 33%. At the maturing stage, the 6th, 2nd, and 3rd instars were most frequent (22%), followed by the 4th and 5th instars with 11% and 11% respectively. At the harvested stage, only the 2nd and 5th instars were observed at equal percentages.

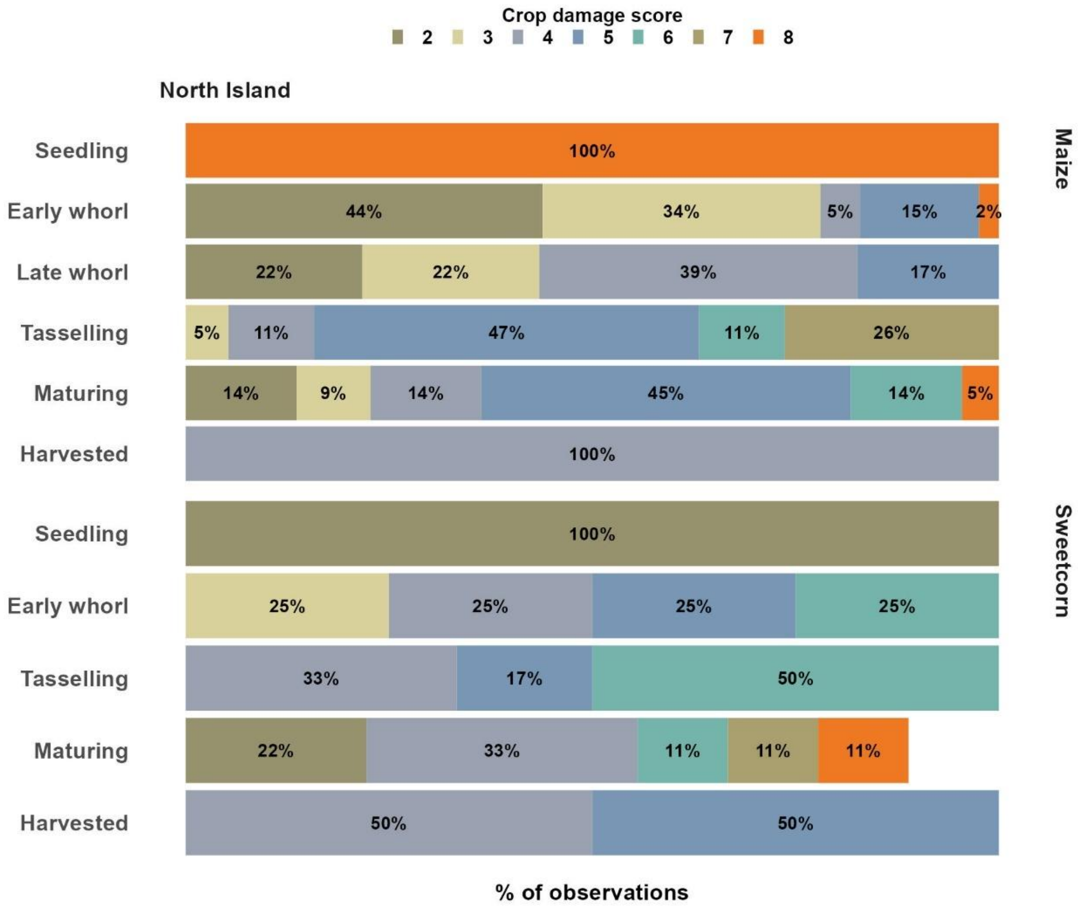


Figure 5. *Percentage of observations at each crop damage score within each crop growth stage for (n=110) and sweetcorn (n=23) observed from the North Island. Missing cells indicate missing values.*

Percentage of observations at each crop damage score within each crop growth stage for maize and sweetcorn on the North Island is presented in Figure 5.

In maize, at the seedling stage, the crop exhibited the highest damage score of 8. At the early whorl stage, most crops were assigned a damage score of 2 (44%), followed by scores 3 and 5 with 34% and 15% respectively. At the late whorl stage, most crops had a damage score of 4 (39%), followed by scores of 2 and 3 with 22% and 22% respectively. At the tasselling and maturing stages, most crops were assigned a score of 5 (47% and 45% respectively). At the harvested stage, all observations (100%) were recorded with a score of 4.

In sweetcorn, at the seedling stage, the crop exhibited the damage score of 2. At the early whorl stage, damage scores of 3-6 were each observed at 25%. At the tasselling stage, most crops had a damage score of 6 (50%), followed by scores of 3 and 4 with 33% and 17% respectively. At the maturing stage, most crops were assigned a score of 4 (33%). At the harvested stage, only damage scores of 4 and 5 were recorded each at equal proportions.

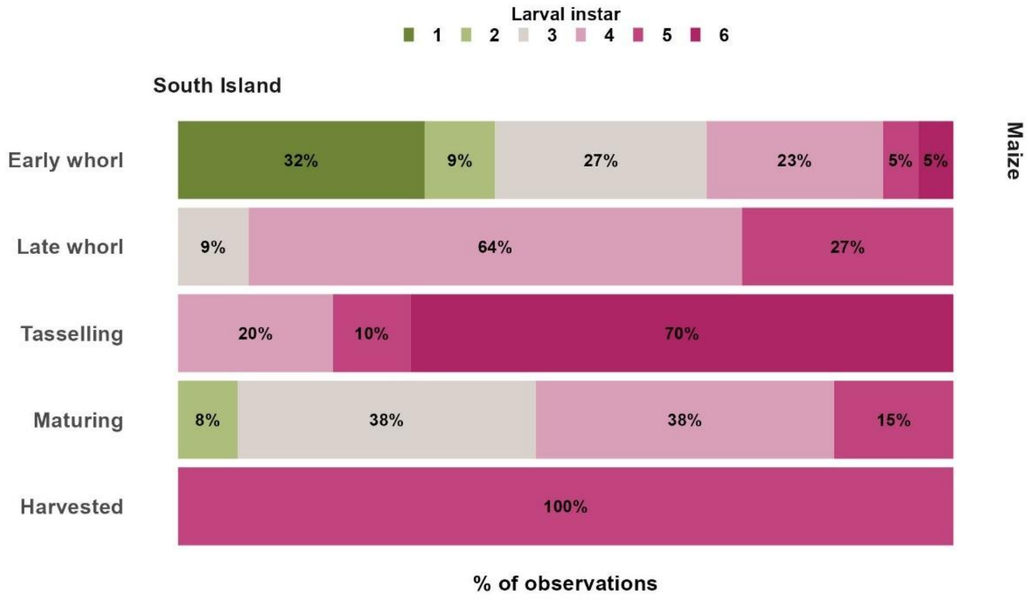


Figure 6. *Percentage of observations at each larval instar within each crop growth stage for maize (n=58) observed from the South Island. Since only five observations were recorded for sweetcorn, the stacked bars for sweetcorn are not presented.*

Percentage of observations at each larval instar within each crop growth stage for maize and sweetcorn on the South Island is shown in Figure 6.

In maize, at the early whorl stage, the 1st instar accounted for the highest percentage of observations (32%), followed by the 3rd and 4th with 27% and 23% respectively. At the late whorl, the 4th instar was predominant (64%), followed by the 5th and 3rd with 27% and 9% respectively. At the tasselling, the 6th instar accounted for the highest proportion of observations (70%), followed by the 4th with 20%. At the maturing, the 3rd and 4th instars were most frequent (38%), followed by the 5th instar with 15%. At the harvested stage, only the 5th instar was found.

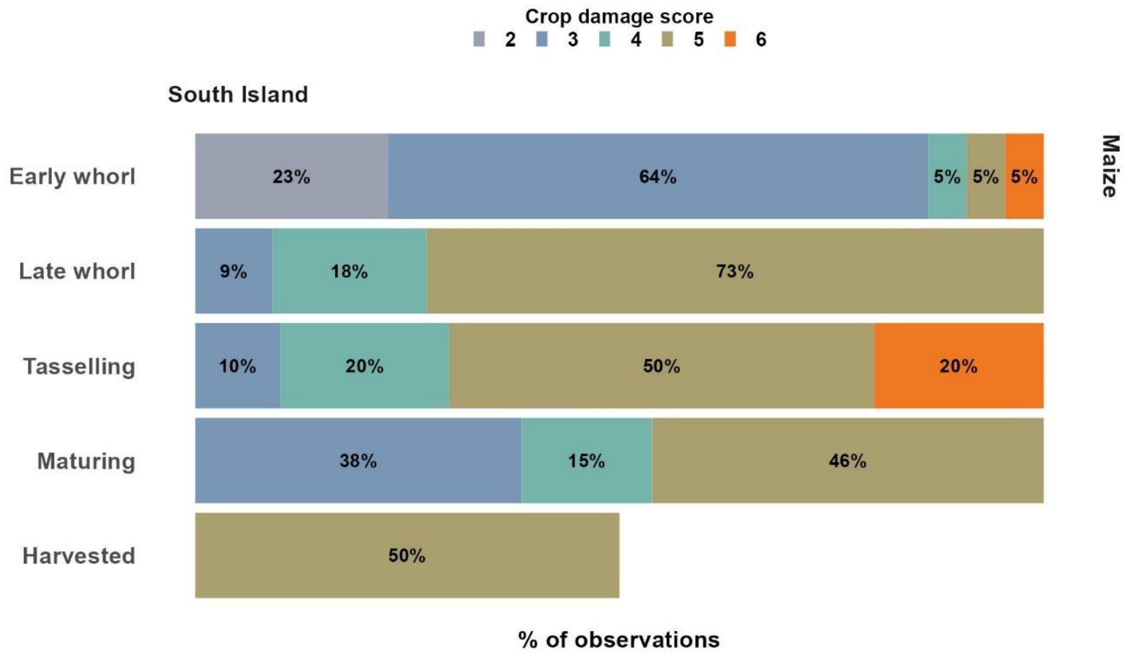


Figure 7. *Percentage of observations at each crop damage score within each crop growth stage for maize (n=58) observed from the South Island. Missing cells indicate missing values. Since only five observations were recorded for sweetcorn, the stacked bars for sweetcorn are not presented.*

Percentage of observations at each crop damage score within each crop growth stage for maize and sweetcorn on the South Island is presented in Figure 5.

In maize, at the early whorl stage, most crops were assigned a damage score of 3 (64%), followed by a score of 2 with 23%. At the late whorl, most crops had a damage score of 5 (73%), followed by scores of 4 and 3 with 18% and 9% respectively. At the tasselling, most crops were assigned a score of 5 (50%), followed by scores of 4, 6 and 3 with 20%, 20%, and 10% respectively. At the maturing, most crops were assigned a score of 5 (46%). At the harvested stage, 50% of observations exhibited a crop damage score of 5.

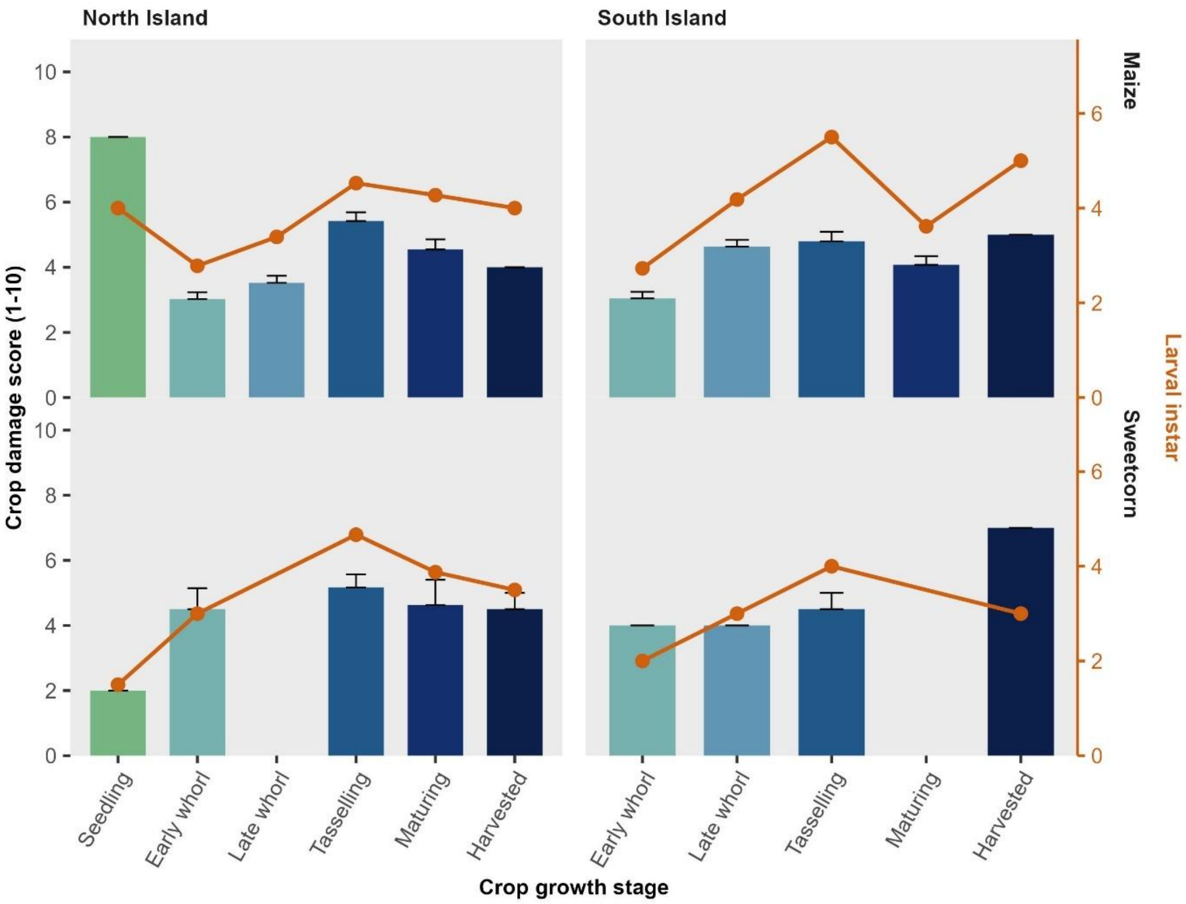


Figure 8. *Mean crop damage scores and mean larval instar observed at each crop growth stage for maize and sweetcorn in the North (n=110 for maize and n=22 for sweetcorn) and South (n=58 for maize and n=5 for sweetcorn) Islands. Bars represent means ± standard errors (SE) of crop damage scores, while orange dots indicate the mean larval instar.*

In maize from the North Island, the mean crop damage scores were 8, 3.0, 3.5, 5.4, 4.6, and 4.0 for seedling, early whorl, late whorl, tasselling, maturing, and harvested stages, respectively (Figure 8: top-left panel). The mean larval instars were 4.0, 2.8, 3.4, 4.5, 4.3, and 4.0 for seedling, early whorl, late whorl, tasselling, maturing, and harvested stages, respectively (Figure 8: top-left panel). There were clear increasing trends in both crop damage scores and larval instar, with mean values rising from early whorl stage to tasselling stage, reaching their peak at tasselling stage, and then declining slightly at maturing and harvested stages. A similar pattern was observed in sweetcorn, where both damage scores and larval instar increased from seedling to tasselling stages, peaked at tasselling stage, and then decreased at maturing and harvested stages (Figure 8: bottom-left panel). These results indicate that the damage scores increased as the crop progressed through the tasselling growth stage, reaching a maximum at tasselling stage before declining thereafter.

In maize from the South Island, the mean crop damage scores were 3.1, 4.6, 4.8, 4.1, and 5.0 for early whorl, late whorl, tasselling, maturing, and harvested stages, respectively (Figure 8: top-right panel). The mean larval instars were 2.7, 4.2, 5.5, 3.6, and 5.0 for early whorl, late whorl, tasselling, maturing, and harvested stages, respectively (Figure 8: top-right panel). A similar pattern observed in the North Island for maize was also evident in the South Island, where both damage scores and larval instar increased from stages early whorl to tasselling and peaked at stage tasselling. However, unlike the trend in the North Island, values declined at maturing stage and then rose slightly again at harvested stage

(Figure 8: top-right panel). Comparable trends observed for maize and sweetcorn in the North Island were also evident for sweetcorn in the South Island (Figure 8: bottom-right panel).

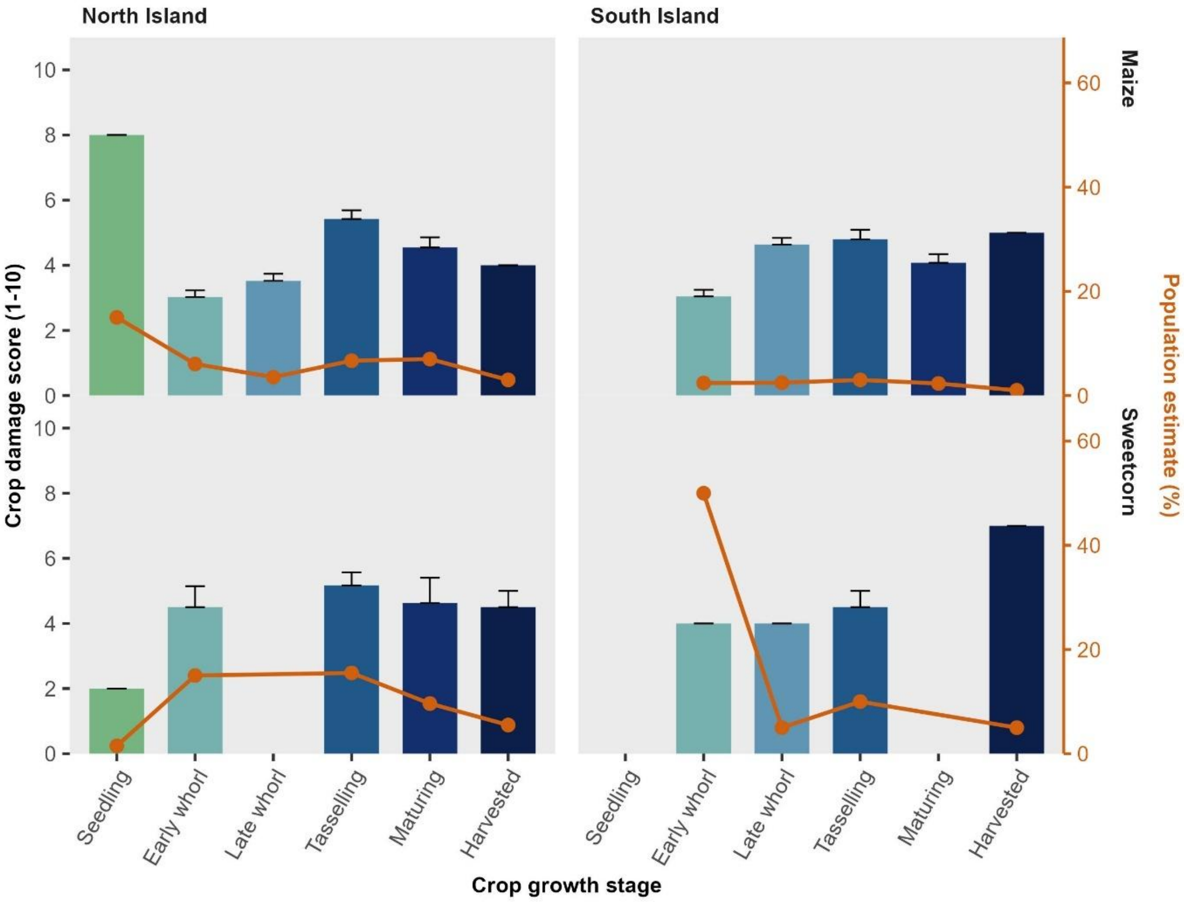


Figure 9. *Mean crop damage scores and mean population estimates (%) observed at each crop growth stage for maize and sweetcorn in the North (n=110 for maize and n=22 for sweetcorn) and South (n=58 for sweetcorn and n=5 for sweetcorn) Islands. Bars represent means ± standard errors (SE) of crop damage scores, while orange dots indicate the mean population estimates.*

In maize from the North Island, the mean population estimates were 15.0%, 6.1%, 3.5%, 6.7%, 7.0%, and 3.0% for seedling, early whorl, late whorl, tasselling, maturing, and harvested stages, respectively (Figure 9: top-left panel). For sweetcorn, mean population estimates increased sharply from seedling (1.5%) to early whorl (15%) stages, remained relatively stable between early whorl and tasselling (15.5%) stages, and then began to decrease at maturing (9.6%) and harvested (5.5%) stages (Figure 9: bottom-left panel).

In maize from the South Island, the mean population estimates were very similar across stages: early whorl, late whorl, tasselling, and maturing, with 2.4%, 2.5%, 3.0%, and 2.3%, respectively, while only 1% was observed at harvested stage (Figure 9: top-right panel).

No consistent population-estimate trends were observed across the North and South Islands, or between maize and sweetcorn (Figure 9).

Figures 8 and 9 indicate that crop damage and larval instar development tended to intensify through the early whorl to tasselling growth stages, most notably around tasselling stage, where population estimates showed more variable patterns across the North and South Islands and crop types.

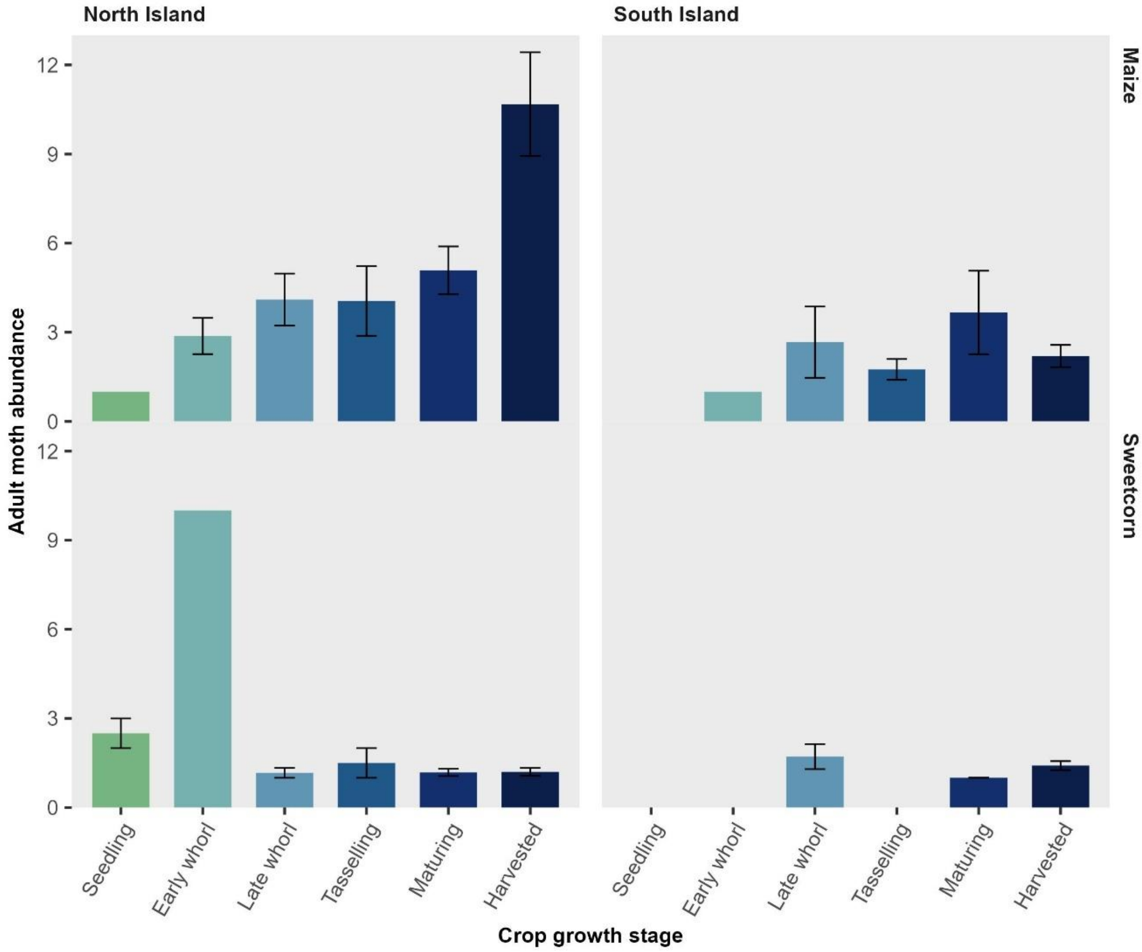


Figure 10. *Mean moth abundance observed at each crop growth stage for maize and sweetcorn in the North (n=142 for maize and n=34 for sweetcorn) and South (n=27 for maize and n=30 for sweetcorn) Islands. Bars represent means ± SE.*

In maize from the North Island, mean moth abundances were 1, 2.9, 4.1, 4.1, 5.1, and 10.7 for seedling, early whorl, late whorl, tasselling, maturing, and harvested stages, respectively (Figure 10: top-left panel). For sweetcorn, mean moth abundances were 2.5, 10, 1.2, 1.5, 1.2, and 1.2 across the same stages (Figure 10: bottom-left panel). These results indicate a non-linear increasing trend in maize, whereas no clear trend was observed for sweetcorn.

In maize from the South Island, mean moth abundances were 1, 2.7, 1.8, 3.7, and 2.2 for early whorl, late whorl, tasselling, maturing, and harvested stages, respectively (Figure 10: top-right panel).

Part II: Spatial distributions, visualisation of data, and summary statistics for the Northland region

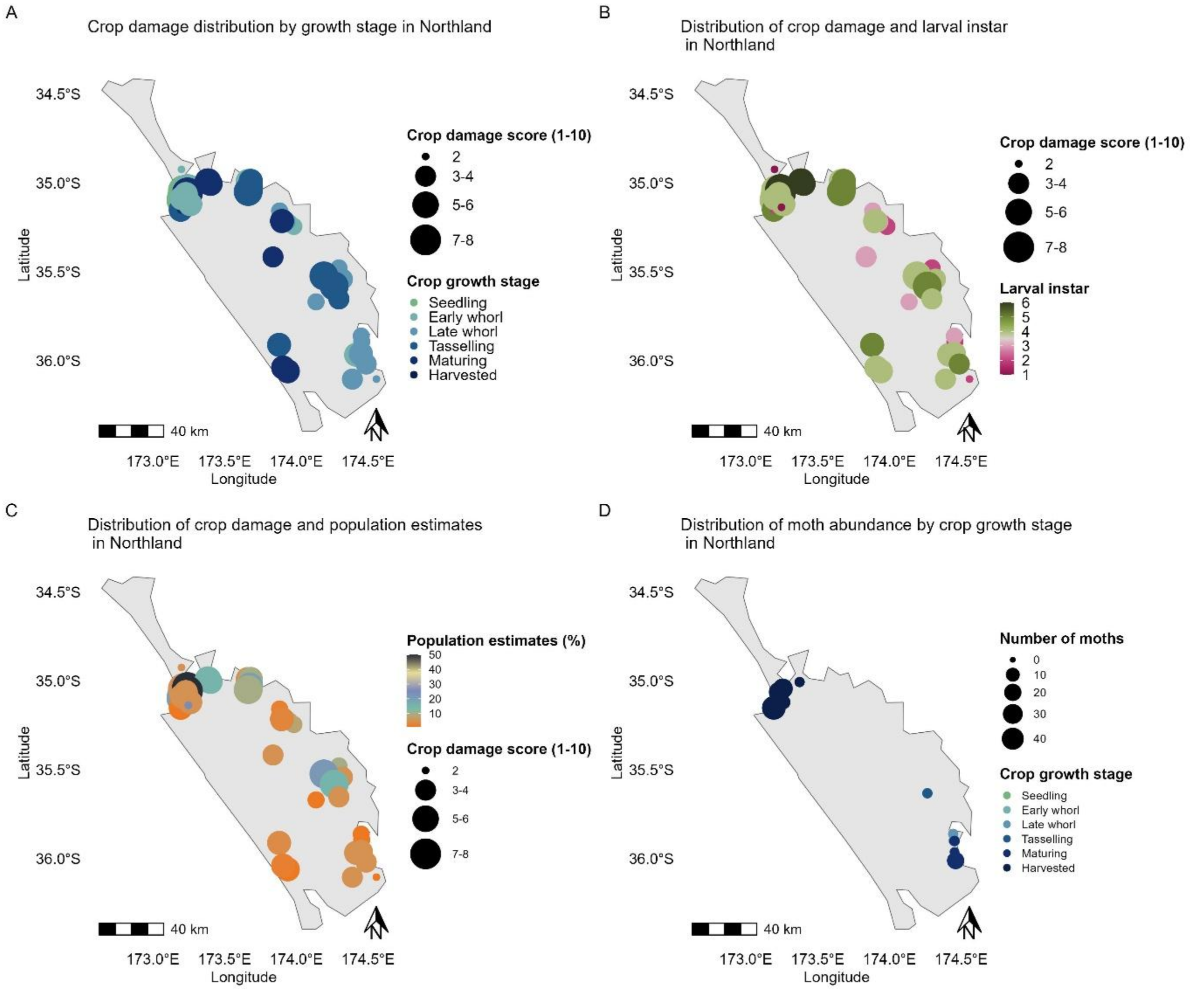


__Figure 11.__ (A) Distribution of crop damage scores by growth stage; (B) Distribution of crop damage scores and larval instar; (C) Distribution of crop damage scores and population estimates; and (D) Distribution of moth abundance by crop growth stage, all for maize in the Northland region.

The spatial distributions of crop damage scores by growth stage, crop damage scores and larval instar, crop damage scores and population estimates, and moth abundance by crop growth stage for the Northland region are presented in Figure 11.

Elevated damage scores were predominantly observed in the northern and lower eastern areas, where the crop had reached a growth stage exceeding late whorl stage, whereas lower damage scores were recorded in the southern area, where crops remained between growth stages early whorl and late whorl (Figure 11: A). A similar pattern of higher crop damage was also evident in the northern and lower eastern areas, where the larval instar had progressed beyond instar 3 (Figure 11: B). In the lower western regions, even though larvae had reached instar 4, crop damage scores did not attend a high score of 7 (Figure 11: B). Regarding population estimates, a comparable pattern of higher crop damage was observed in the northern and south-eastern areas; however, no threshold population estimate corresponded to the occurrence of high damage, as estimates were highly variable, ranging from 1% to

50% (Figure 11: C). Adult moths were predominantly observed in the northern and lower southern areas, where crop growth stages had progressed beyond the late whorl stage (Figure 11: D).

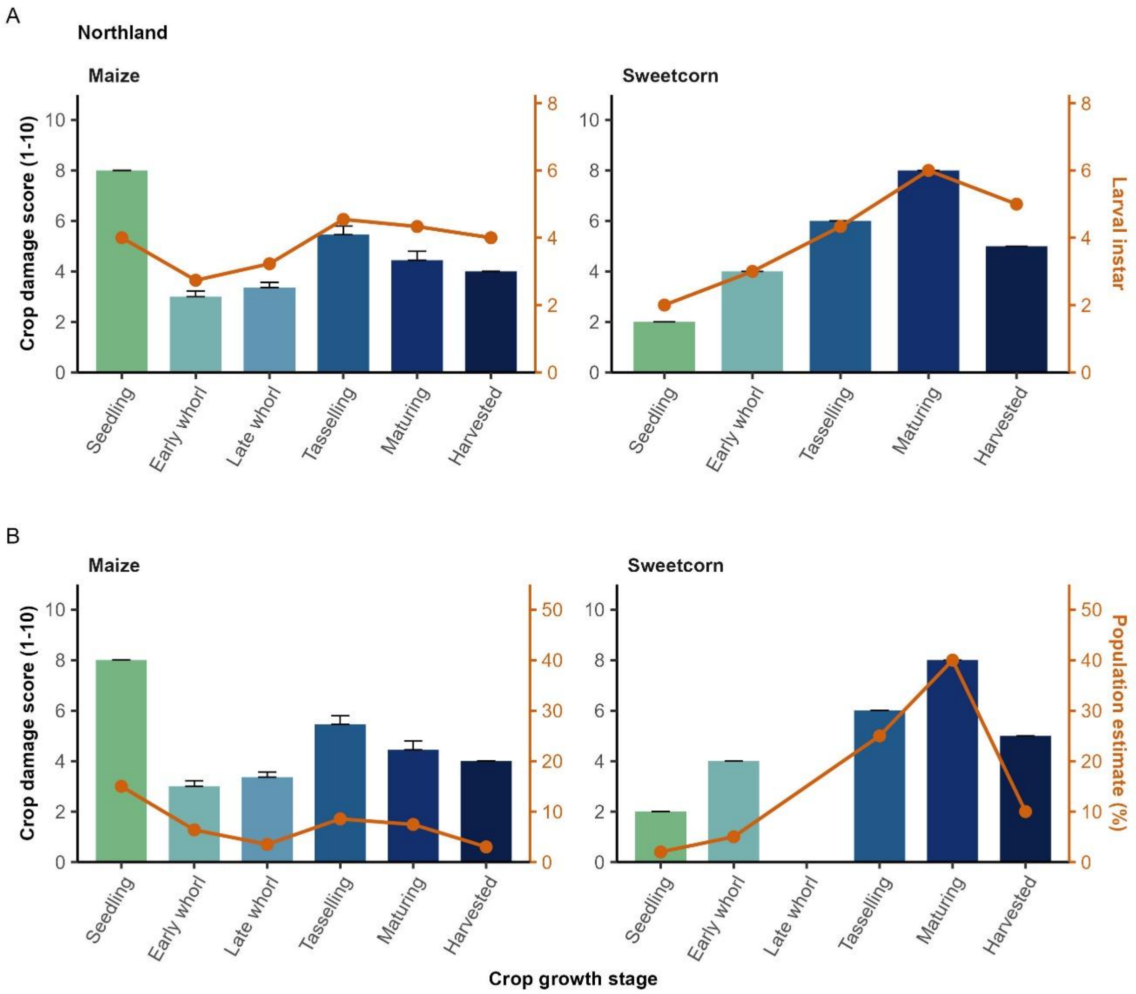


Figure 12. *(A) Mean crop damage scores and larval instar across maize (n=94) and sweetcorn (n=7) growth stages in the Northland. Bars represent means ± SE; orange points indicate larval instar. (B) Mean crop damage scores and population estimates (%) across maize and sweetcorn growth stages in the Northland. Bars show means ± SE; orange points indicate population estimates.*

In maize from the Northland, the mean crop damage scores were 8, 3.0, 3.4, 5.4, 4.4, and 4.0 for seedling, early whorl, late whorl, tasselling, maturing, and harvested stages, respectively (Figure 12: top-left panel). The mean larval instars were 4.0, 2.7, 3.2, 4.6, 4.3, and 4.0 for seedling, early whorl, late whorl, tasselling, maturing, and harvested stages, respectively (Figure 12: A). There were clear increasing trends in both crop damage scores and larval instar, with mean values rising from early whorl stage to tasselling stage, reaching their peak at tasselling stage, and then declining slightly at maturing and harvested stages. A similar pattern was observed in sweetcorn, where both damage scores and larval instar increased from seedling to maturing stages, peaked at maturing stage, and then declined at harvested stage (Figure 12: A). Notably, the peak differed between the two crops: maize reached its maximum at tasselling stage, whereas sweetcorn peaked at maturing stage. However, the sweetcorn results are based on only 7 observations.

For maize, mean population estimates peaked at seedling stage (15%; based on only three observations), declined at early whorl (6.4%) and late whorl (3.5%) stages, increased again from late whorl and tasselling (8.6%) stages, slightly decreases from tasselling and maturing (7.4%) stages, and then declined at harvested stage (3%) (Figure 12: B). For sweetcorn, population estimates showed an overall increasing trend, with mean values rising from seedling stage (2%) to tasselling stage (25.0%), reaching a highest level at maturing (40.0%) stage, and then declining at harvested stage (10%) (Figure 12: B); however, these results are based on only 7 observations.

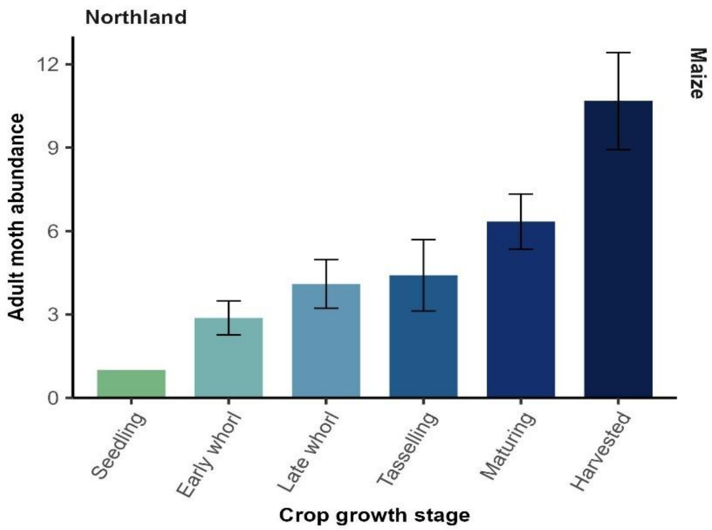


Figure 13. *Mean moth abundance observed at each crop growth stage for maize in the Northland (n=128). Bars represent means ± SE. No moths were observed in sweetcorn.*

In maize from the Northland region, there was a non-linear increasing trend in moth abundance across crop growth stages, with mean moth abundances of 1, 2.9, 4.1, 4.4, 6.3, and 10.7 at seedling, early whorl, late whorl, tasselling, maturing, and harvested, respectively (Figure 13).

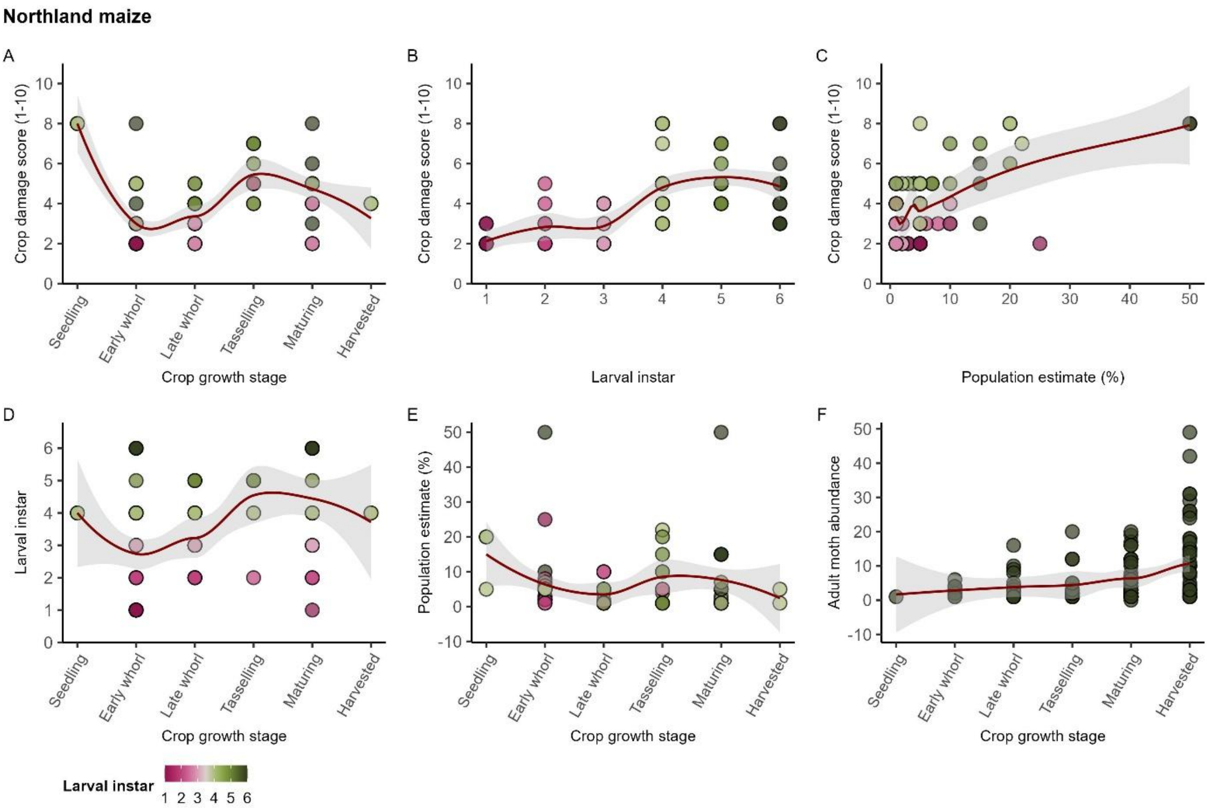
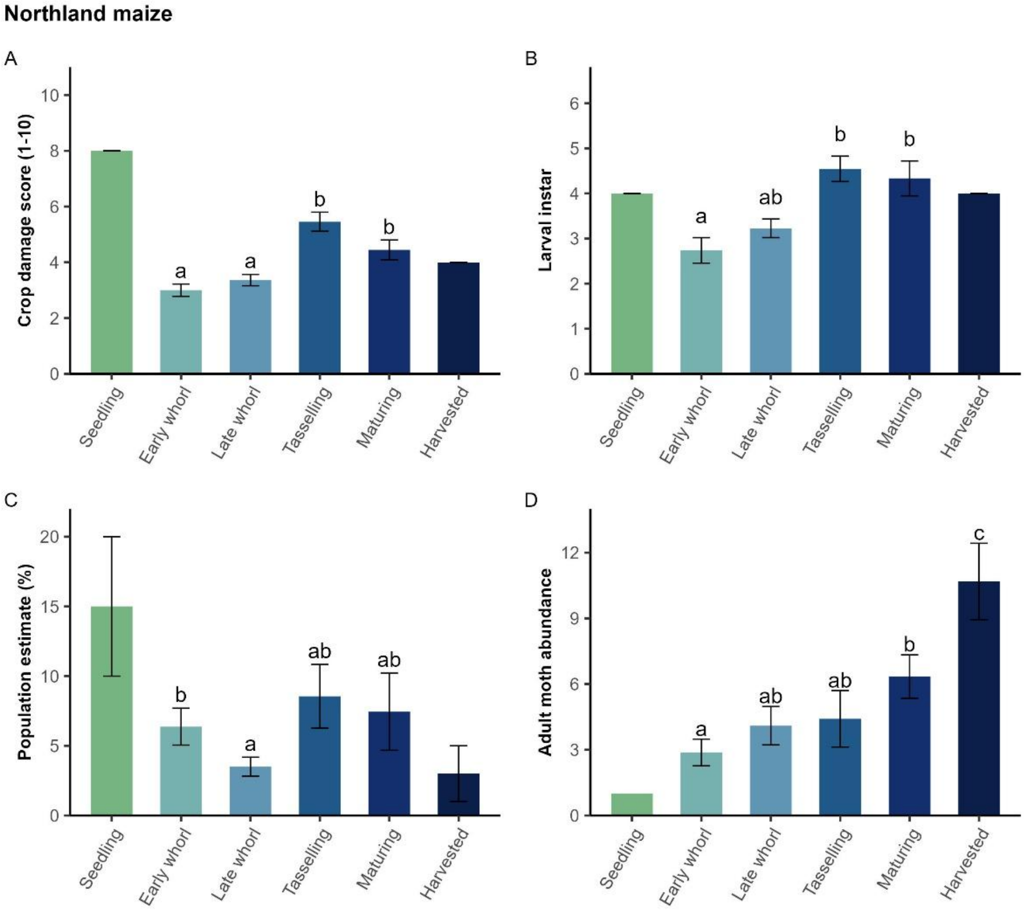


Figure 14. *Scatterplots of crop damage scores against three explanatory variables: crop growth stage (A), larval instar (B), and population estimates (C). (D)-(F) show scatterplots of larval instar, population estimate (%), and adult moth abundance against crop growth stage. All data relate to maize in the Northland region. LOESS smoothing curves with corresponding confidence intervals are included in each panel to illustrate trends. Data points are coloured according to larval instar values.*

Crop damage scores increased from crop growth stage early whorl to tasselling, peaking at the tasselling stage, and then declined slightly at maturing and harvested stages (Figure 14: A). Crop damage scores remained relatively stable when larvae were at instars 1 – 3, increased sharply from instar 3 to 4, and then remained unchanged between instars 4 and 6 (Figure 14: B). A non-linear increasing trend was observed between crop damage scores and population estimates; however, some extreme values were also noted (Figure 14: C). Larval instar stages increased from crop growth stage early to late whorl, rose markedly from late whorl to tasselling, and then declined slightly from tasselling to harvested (Figure 14: D). Population estimates decreased slightly from seedling to late whorl, began to increase from late whorl to tasselling, remained relatively stable between tasselling and maturing, and then declined thereafter (Figure 14: E). Moth abundance was relatively stable between growth stages seedling and tasselling, after which it increased (Figure 14: F).

Part III: Mixed-effects models assessing variation in crop damage scores, larval instar, population



estimates, and moth abundance across crop growth stages in the maize-field Northland region

Figure 15. *Mean crop damage scores (A), larval instar (B), population estimate (%) (C), and adult moth abundance (D) across maize growth stages in the Northland. Bars represent means ± SE. Within each panel, means followed by different letters indicate statistically significant differences between crop growth stages at the 0.05 level (α = 0.05).*

Maize field observations in Northland revealed that crop growth stage significantly influenced crop damage scores, larval instar, population estimates, and moth abundance (all $p < 0.05$). This suggests that the developmental state of the crop is a key determinant of insect presence, population dynamics, and associated damage.

Mean crop damage score was significantly higher at growth stages tasselling and maturing compared with early and late whorl stages, with no significant differences within the early and late whorl or tasselling and maturing pairs. Mean larval instar was significantly greater at tasselling and maturing compared with early whorl but did not differ significantly between early and late whorl stages or among late whorl, tasselling, and maturing stages. Population estimates were significantly higher at early whorl stage than late whorl, with no significant differences among early whorl, tasselling, and maturing stages or among late whorl, tasselling, and maturing stages. Adult moth abundance peaked at the harvested stage, was also significantly higher at maturing stage than early whorl, and showed no significant differences among early whorl, late whorl, and tasselling stages or among late whorl, tasselling, and maturing stages.

Crop damage scores and larval instar increased with crop development, peaked at stages tasselling and maturing, while population estimates were initially higher at early whorl but showed variable patterns across later stages. Adult moth abundance was greatest at harvested stage and elevated at maturing relative to early whorl.

Part IV: Predicting crop damage using generalised additive mixed models of crop growth stage, larval instar, and population estimates in the maize-field Northland region

Crop growth stage, larval instar, and population estimate were significantly nonlinearly associated with crop damage score (all $p < 0.001$; Table 1). The GAMM predicting crop damage score is expressed by the following equation:

$$\log(\text{crop damage})_{ij} = \beta_1 + f_1\left(\text{crop stage}_{ij}\right) + f_2\left(\text{instar}_{ij}\right) + f_3\left(\text{log-transformed population}_{ij}\right) + a_i + \varepsilon_{ij}.$$

Here, β_1 is the intercept, a_i represents the random intercept for ‘location’, assumed to be normally distributed with mean 0 and variance σ_a^2, and ε_{ij} denotes the Gaussian error term.

Estimated crop damage scores rose from early whorl to tasselling, peaking at tasselling, and declined slightly thereafter (Figure 16: A). The estimated crop damage score increased moderately from larval instars 1 to 3, rose sharply between instars 3 and 5 (peaking at 4.5), and declined slightly beyond instar 5 (Figure 16: B). The estimated crop damage increased nonlinearly with population estimates (Figure 16: C). Crop growth stage, larval instar, and population estimate, together with variation among locations explained 80.1% of the total variation in crop damage score.

Table 1. Results from generalised additive mixed models (GAMMs) predicting crop damage score in maize fields on Northland region, using crop growth stage, larval instar, and population estimates. *f*(.) denotes a smooth term; SE = standard error of the estimate; *t* = *t*-statistic; *F* = *F*-statistic; *p* = *p*-value; *edf* = estimated degrees of freedom (*edf* > 1 indicates nonlinearity). Significant levels: $p < 0.05$ = *, $p < 0.01$ = **, $p < 0.001$ = ***.

Component	Term	Estimate	SE	*t*	*p*
Parametric coefficients					
	Intercept	1.25	0.03	41.22	<0.001 ***
Approx. significance of smooth terms			*edf*	*F*	*p*
	f(crop stage)		4.25	6.20	<0.001 ***
	f(instar)		3.86	21.83	<0.001 ***
	f(log-transformed population)		2.28	9.38	<0.001 ***
	f(location)		11.18	0.71	0.009 **
Adjusted R-squared: 0.801					

Northland maize

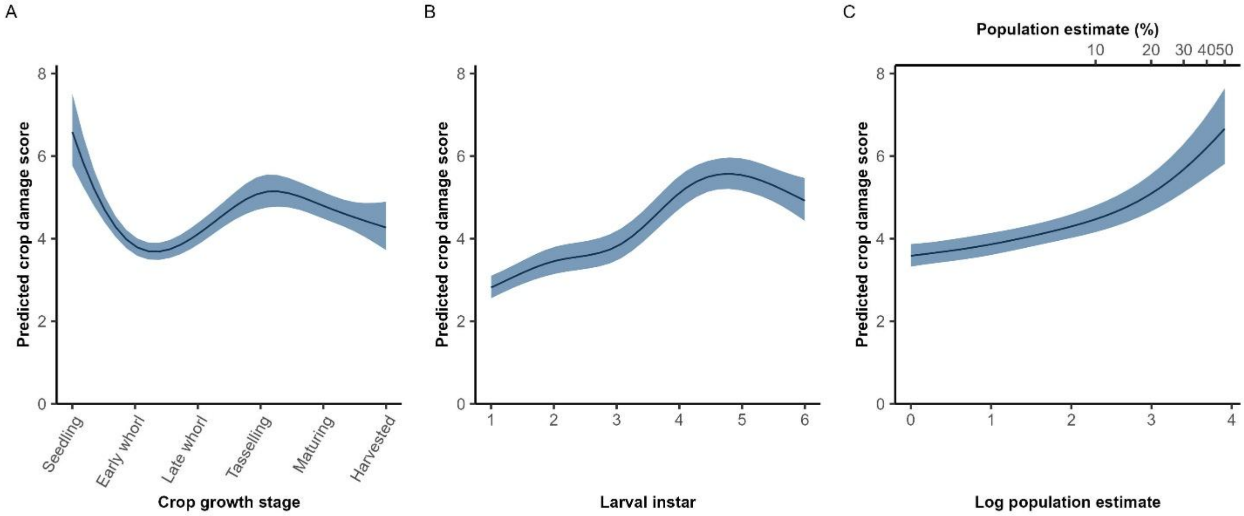


Figure 16. *Predicted crop damage score with 95% confidence intervals, modelled using crop growth stage, larval instars and population estimate in a generalised additive mixed model (GAMM).*

Part V: Mixed-effects models assessing variation in crop damage scores, larval instar, and population estimates across crop growth stages in the maize-field South Island (n = 58)

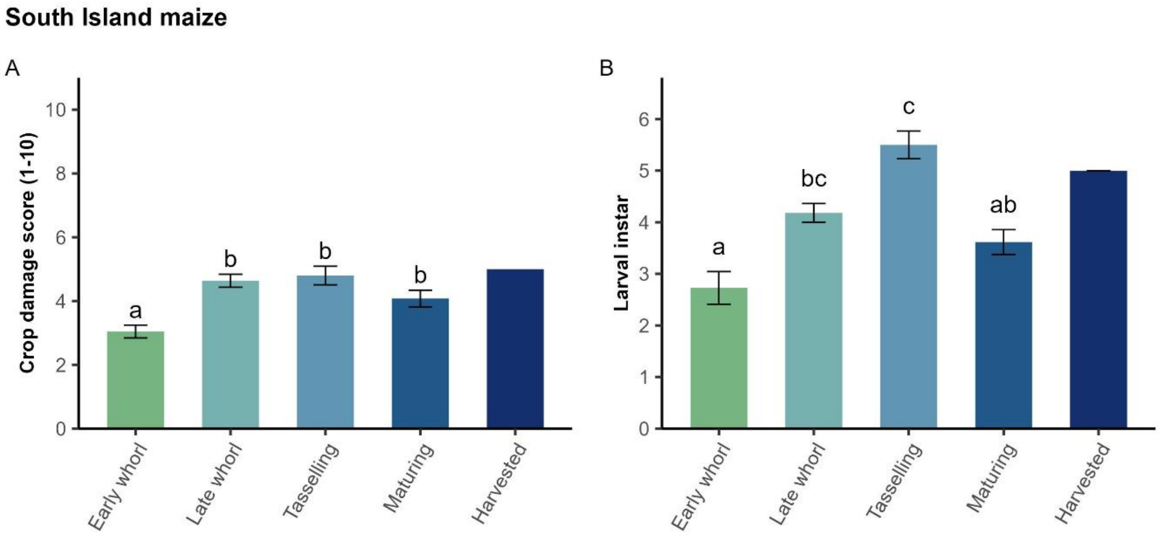


Figure 17. *Mean crop damage scores (A) and larval instar (B) across maize growth stages in the South Island. Bars represent means ± SE. Within each panel, means followed by different letters indicate statistically significant differences between crop growth stages at the 0.05 level (α = 0.05).*

In maize fields on the South Island, both crop damage scores and larval instar increased markedly at later growth stages, and statistical analyses confirmed significant stage-related differences (both $p < 0.001$). Population estimates did not vary with crop growth stage, and no significant association was detected ($p = 0.663$).

Mean crop damage score was significantly higher at late whorl, tasselling and maturing compared with early whorl, with no significant differences among late whorl, tasselling and maturing stages (Figure 17: A). Mean larval instar was significantly greater at tasselling compared with early whorl and maturing stages; however, no significant differences were observed between late whorl and tasselling, late whorl and maturing, or early whorl and maturing (Figure 17: B).

Part VI: Predicting crop damage using generalised additive mixed models of crop growth stage, larval instar, and population estimates in maize-field South Island

Larval instar was significantly and nonlinearly associated with crop damage score ($p < 0.001$; Table 2), whereas crop growth stage and population estimates showed no significant associations. The optimal GAMM predicting crop damage score is expressed by the following equation:

$$\log(\text{crop damage})_{ij} = \beta_1 + f_1(\text{instar}_{ij}) + a_i + \varepsilon_{ij}.$$

Here, β_1 is the intercept, a_i represents the random intercept for 'location', assumed to be normally distributed with mean 0 and variance σ_a^2, and ε_{ij} denotes the Gaussian error term.

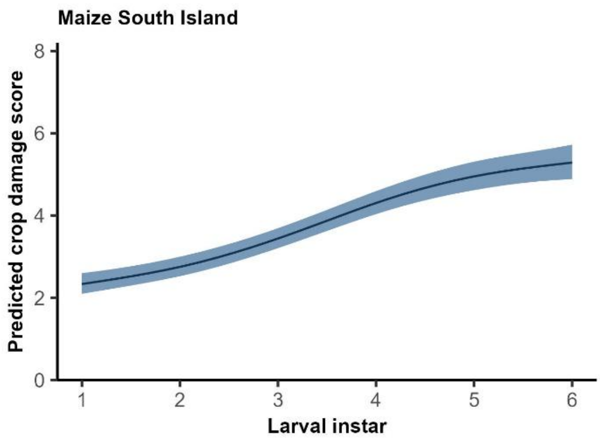


Figure 18. *Predicted crop damage score with 95% confidence intervals, modelled using larval instars in a generalised additive mixed model (GAMM).*

Estimated smoothing curves on the South Island showed a pattern similar to that observed in the Northland region, although no clear turning point was detected. Crop damage scores increased nonlinearly from larval instars 1 to 5, with a slight increase beyond instar 5 (Figure 18). Larval instar along with location effects accounted for 77.1% of total variation in crop damage score.

Table 2. Results from generalised additive mixed models (GAMMs) predicting crop damage score in maize fields on the South Island, using crop growth stage, larval instar, and population estimates from maize field in the South Island. *f*(.) denotes a smooth term; SE = standard error of the estimate; t = t-statistic; F = F-statistic; p = p-value; *edf* = estimated degrees of freedom (*edf* > 1 indicates nonlinearity). Significant levels: $p < 0.05$ = *, $p < 0.01$ = **, $p < 0.001$ = ***.

Component	Term	Estimate	SE	*t*	*p*
Parametric coefficients					
	Intercept	1.30	0.04	30.59	<0.001 ***
Approx. significance of smooth terms			*edf*	*F*	*p*
	f(crop stage)		1.00	0.74	0.394
	f(instar)		2.61	37.42	<0.001 ***
	f(log-transformed population)		1.73	1.41	0.237
	f(location)		7.50	2.06	0.002 **
Adjusted R-squared: 0.771					

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