The challenges of monitoring insect sleeper pests: the example of *Spodoptera litura* (tropical armyworm) in New Zealand

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Highlights
Farmers will face a different suite of insect pests under climate change. Monitoring their population dynamics over time is important for risk assessment and mitigation, but it can be expensive and time-consuming, and published information can be sparse. To highlight this issue, we investigated suitable sources of such information on *Spodoptera litura* (tropical armyworm), a potential sleeper pest in New Zealand. After appropriate quality checks and analyses, data from two online platforms, iNaturalist and the Global Biodiversity Information Facility (GBIF), indicated higher numbers and an extended geographical range for *S. litura* in 2018 and 2022-23. This example suggests that these platforms could be a useful tool for future pest monitoring.

Keywords: citizen science, Global Biodiversity Information Facility, iNaturalist, pasture pests

Introduction
Future agricultural systems will face a novel suite of insect pest species due to factors such as climate change and changing host plant availability (Mansfield et al. 2021). The range and abundance of some current pest species is likely to change, and other species that are not currently considered pests may emerge as such as conditions become more favourable. The latter group, known as 'sleeper pests', can be defined as species that are already present and cause only periodic or geographically restricted damage, but that are predicted to increase their range, and/or outbreak size and frequency, under climate change (Orre-Gordon and Jensen 2025).

Monitoring potential sleeper pest populations, determining their dynamics and delimiting their range can be important in terms of recognizing an emerging threat and responding to that threat. However, with a large number of introduced insects present in New Zealand (Brockerhoff et al. 2010), and limited research resources, most potential sleepers are poorly understood, with few resources directed at intentional monitoring (Mansfield et al. 2021). This is true to the extent that many taxa are likely present but remain undocumented. For those we know something about, information may be restricted to specimens in natural history collections, reports and, increasingly, citizen science data platforms. These sources of data may represent "presence only" data sets and may appear to be haphazard by their nature, and their use and interpretation are challenging (Phillips et al. 2006; Roigé and Phillips 2021). We hypothesise, however, that citizen science platforms such as iNaturalist and the Global Biodiversity Information Facility (GBIF) are likely to be the best available source of data for monitoring an emerging threat like a sleeper pest and that, with appropriate checks and analyses, they have the potential to provide valuable information for understanding and tracking their spread.

Researchers internationally have increasingly turned to citizen science (Cull 2021). Data from platforms, such as iNaturalist and GBIF, have been used to assess phenology (Drury et al. 2019), monitor biodiversity (Alfeus et al. 2025), track invasions (Werenkraut et al. 2020)` and aid in the development of species distribution models (Hochmair et al. 2020). Many authors caution, however, that care must be taken with analysis and interpretation of the data due to the unstructured, opportunistic nature of the sampling and reporting process (Isaac et al. 2014; Di Cecco et al. 2021).

iNaturalist.org is an online platform where anyone, anywhere, can share observations of nature. The platform originated in 2008 as a Master's project at UC Berkely but has since grown and become an independent nonprofit organization in 2023 (iNaturalist.org/pages/about). The New Zealand branch of iNaturalist, iNaturalistNZ - Mātaki Taiao, had its origins in the New Zealand Bio-Recording Network Trust (NZBRN) in 2005. This became 'NatureWatchNZ' in 2012 and finally, in 2018, moved to the inaturalist.nz site. Observers can upload photos and sound files to the iNaturalist site, along with the date and location of the observation and any other relevant information. An artificial intelligence (AI) interface suggests species identification based on location and image analysis. Other users may then either suggest, agree or disagree with the species identification. A 'verifiable'

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observation (*i.e.*, one that has a date, is georeferenced, has either photos or sounds and is neither a captive nor a cultivated organism) becomes 'research grade' when two-thirds of identifiers agree on the identification. Observations that have not reached research grade are classified as 'needs identification (ID)'.

GBIF also provides open access data about all life forms. The network is funded by 'the world's governments', drawing data from diverse sources, including iNaturalist (gbif.org/what-is-gbif). Data are filtered to exclude observations such as those with missing date or location information or, for iNaturalist observations, specimens that are not 'research grade', or are not associated with one of three Creative Commons licenses (CC0, CC BY, CC BY-NC) (Hochmair et al. 2020). Links to a variety of resources are available within GBIF to help gather and interpret data.

Here, we demonstrate the challenges in finding published population data for a potential New Zealand sleeper pest, *Spodoptera litura,* and explore the opportunities and risks of using alternative data-types such as those found on iNaturalist and GBIF.

Tropical armyworm, *Spodoptera litura* (Lepidoptera: Noctuidae), has been identified as a likely sleeper pest of the pasture in New Zealand (Orre-Gordon and Jensen 2025). This noctuid moth species is considered to be one of the most important pests of agricultural crops in the Asian tropics, where the larvae feed on a broad range of economically important plant species and its exposure to pesticides has led to insecticide resistant populations (CABI 2014). The species is highly invasive. The adults are extremely mobile and females typically lay 2,000-2,600 eggs (Zakria et al. 2022). *Spodoptera litura* is currently considered to be a problem only sporadically and mainly in the northern North Island (Kean et al. 2015). However, outbreaks are likely to occur more often and its distribution to move further south as winters become milder and summer and autumn temperatures increase with climate change (Kean et al. 2015). As a pest that is periodic and geographically restricted in New Zealand, studies and publications on the population dynamics of *S. litura* have been sporadic since its initial establishment.

Study approach

As a test case and example of the challenges involved in sleeper pest monitoring in pastoral systems, we searched multiple sources for information on *S. litura* in New Zealand. Online searches were conducted using the citation databases Google Scholar and Scopus® for published information, the search engine Google for mention of *S. litura* in online news articles and industry outputs, and within the social media app, Instagram.

Ministry of Agriculture and Fisheries (MAF) Research Division reports from 1965 to 1986, MAF Agricultural Research in Progress reports from 1981 to 1986 and a selection of MAF Technical Reports held in the AgResearch Ruakura library were inspected.

We conducted an unfiltered search for '*Spodoptera litura'* on the citizen science platform iNaturalistNZ and inspected these over several months in 2024-25. Search results included all life stages (eggs, larvae, adults) and observations with tentative ('needs ID') or corroborated ('research grade') species identification. Monthly totals of the number of observations were obtained from iNaturalistNZ 'History' charts for *S. litura*, Noctuidae (the family that *S. litura* belongs to) and Lepidoptera (all moths and butterflies). Noctuid observation data from 2024 were exported directly from iNaturalist on 18 March 2025 for any life stage and any quality grade ('research grade' and 'needs ID') in New Zealand between 1 January 2024 and 31 December 2024. These data included the proposed species identification and the date and location of each observation.

We downloaded records of *S. litura* in New Zealand from the data aggregator, GBIF, via rgbif in R (https://github.com/ropensci/rgbif) on 12 March 2025 (GBIF Occurrence Download https://doi.org/10.15468/dl.q4kn9r on 2025-03-12, download link https://api.gbif.org/v1/occurence/download/request/0003617-250310093411724.zip).

In addition to visual examination of the number of observations over time, we conducted a simple statistical analysis to account for temporal differences in observer effort. We calculated the proportion of noctuid and Lepidoptera observations each month that were *S. litura* and analysed these separately using Binomial General Linear Models using a logit link (R package glmmTMB; Brooks et al. (2017)). The models contained 'year' representing a long-term trend and 'month' representing a seasonal component. The first 4 years of data were excluded from the final analysis because there were very few *S. litura* observations from 2014 to 2017 and their inclusion resulted in complete separation errors. Post-hoc pairwise comparisons with Bonferroni-adjusted p-values were conducted using R package emmeans (Lenth et al. 2022).

iNaturalist observations are usually accompanied by latitudinal and longitudinal data describing where the specimen was observed. We used these data to examine potential geographical bias in reporting by visually comparing observations of Noctuidae, and the subset of these that were *S. litura*, from mainland New Zealand in 2024. We grouped the observations by location using regions defined in Crosby et al. (1998). These 'Crosby regions' are of approximately equal area and are used for specimens in the New Zealand Arthropod Collection and its associated databases and publications. Maps showing the locations of individual

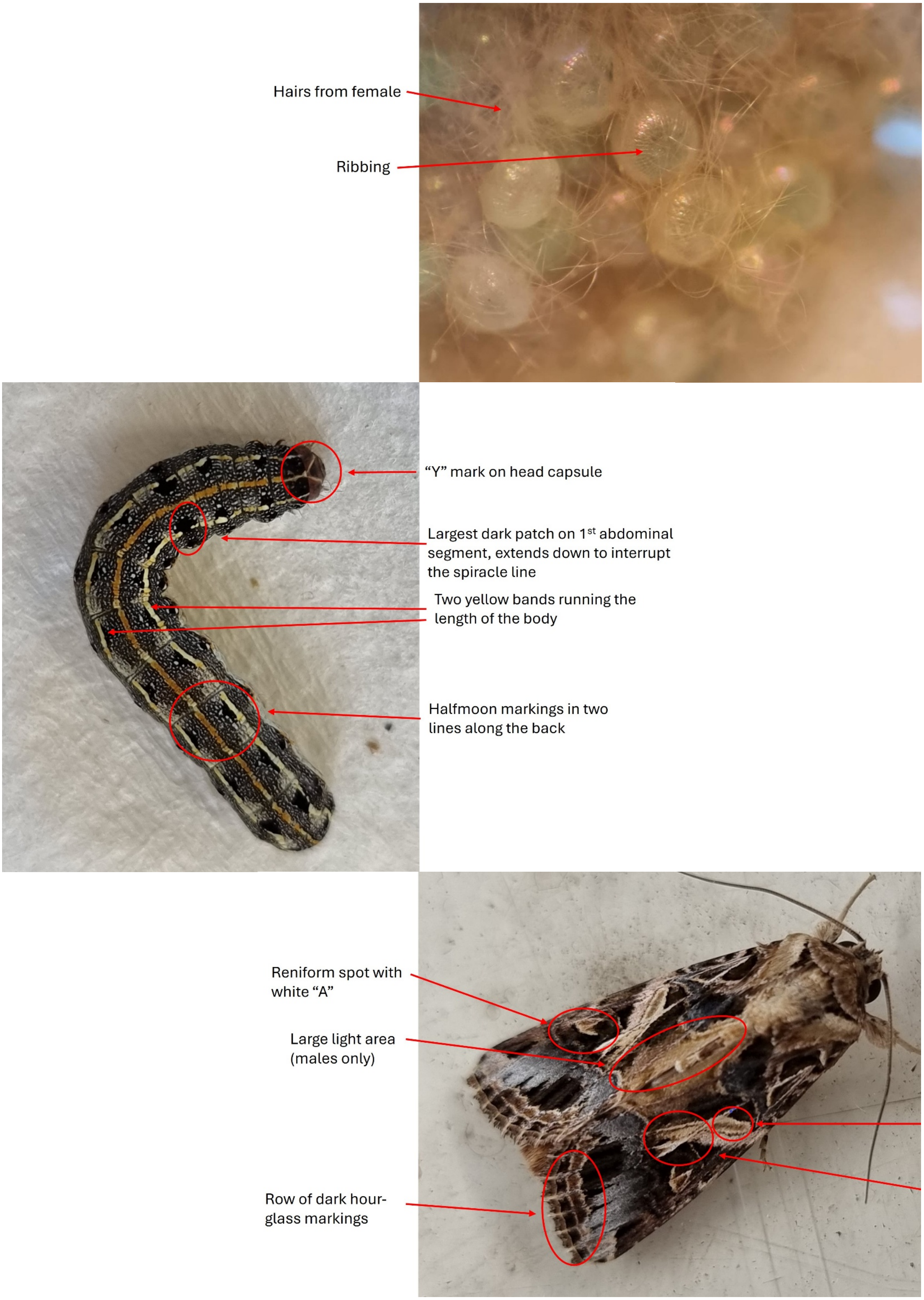

Figure 1 Egg mass, larva and adult *Spodoptera litura* with key characteristics useful for species identification.

S. litura observations reported in iNaturalist each year from 1 January 2015 and 31 December 2024 were examined for evidence of changes in distribution over time.

All images associated with 185 observations from iNaturalistNZ in 2024 with a suggested species identification of *S. litura* were inspected and classified by image quality and certainty of identification by the primary author (J.G. Jensen). Images and descriptions from EPPO (2015) and Brambila (2013) were used to guide species identification. Key morphological characteristics are shown in Figure 1. *Spodoptera litura* eggs can be tentatively identified based on features such as the typical noctuid ribbing and the covering of hairs from the female's abdomen, but molecular methods are required for reliable identification (EPPO 2015). Likewise, very young larvae cannot be accurately identified without molecular methods. Host plant was often not reported or present in the image, so was not included in this study.

Study findings

Published *S. litura* population information

Most of the information published to date on *S. litura* in New Zealand is from before 1980 and comprises brief observations describing the insect's arrival and establishment. The first breeding population of *S. litura* was noted in March 1955 in the Nelson District (Cottier and Gourlay 1955). The population was eradicated by the farmer using 'vigorous measures with DDT' and, for almost the next 20 years, the species was noted only occasionally as a migrant species, with captured adults being assumed to have blown over from Australia (Fox 1973b). An annual series of papers by Dr K.J. Fox in the New Zealand Entomologist described the subsequent establishment of *S. litura* in New Zealand in the mid-1970s. Three specimens (listed under its former genus name, *Prodenia litura*) were recorded in March 1970 from Farewell Spit and Waimangaroa (Fox 1970) and a further two specimens were listed for each of the following 2 years (Fox 1971, 1973a). In 1973, Fox (1973b) noted that 'the tropical army worm and serious pest *Spodoptera litura*, was rather alarmingly common during [mid-March through to early May]', but it was still considered a migrant rather than an established pest. By 1975 *S. litura* was noted to be breeding in the Auckland area (Fox 1975) and in 1976 to be a major pest from Taranaki northwards. Dale et al. (1976) and Boardman (1977) likewise described the species as causing serious damage to pastures, crops such as *Medicago sativa* (lucerne) and *Brassica napus* (rape) and home gardens in Northland and Auckland, and less serious damage in Taranaki and Levin.

Subsequent published reports of *S. litura* in New Zealand are sparse. Gerard et al. (2011) briefly described an outbreak in Bay of Plenty in the autumn of 2011. Widespread, serious damage was observed in *M. sativa* crops and *Trifolium* spp., plantain and *Cichorium intybus* (chicory) in pastures, with larval numbers reaching as high as 100/m^2. A mild and wet winter in 2010 followed by above average spring and summer temperatures and near record summer rainfall were thought to have allowed for the completion of four generations and thus for populations to build up to outbreak levels. The authors noted that they expected these weather patterns to occur more often with climate change.

Unpublished population information

Historical MAF reports contain a wealth of information about the research MAF conducted, together with the challenges faced by the primary industries and their proposed solutions. Reports from 1965 to 1986 were inspected for mention of *S. litura* but none were found. 'Armyworm' infestation areas, damage and control costs were reported in a comprehensive survey of New Zealand pests conducted by MAF in 1979 (Schofield 1979) , but this was probably either *Persectania aversa* (southern armyworm) or *Mythimna* (*Pseudaletia) separata* (northern or common armyworm). The absence of *S. litura* from these reports indicates that it was not causing enough damage to warrant further study at that time.

Anecdotal information about insect pests can occasionally be gleaned from news and social media, personal observations, and conversations with industry partners (e.g. DairyNZ, PGGWrightsons staff), farmers and the general public. Our online search yielded only two news articles (Stuff 2022, 2023) and one Instagram post from May 2022, all describing large numbers of *S. litura* at that time. These reports corroborated observations of *S. litura* in plantain crops at Ōhaupō and *Ipomoea batatas* (kūmara) crops in Ruawai reported to the primary author (J.G. Jensen) in summer-autumn 2023. The author also observed large numbers of larvae in Ruakura, Hamilton pastures that year.

iNaturalist/GBIF data

GBIF data can include observations from multiple sources, but in the case of *S. litura*, only 59 of 721 records from New Zealand until 12 March 2025 were from sources other than iNaturalist. Other sources included the Auckland Museum Entomology Collection, Lepidoptera Observations from New Zealand by Donald Hobern and the New Zealand Arthropod Collection. Only 24 *S. litura* observations were recorded in GBIF and only one in iNaturalist before 2014; therefore, only data from 2014 onwards are shown.

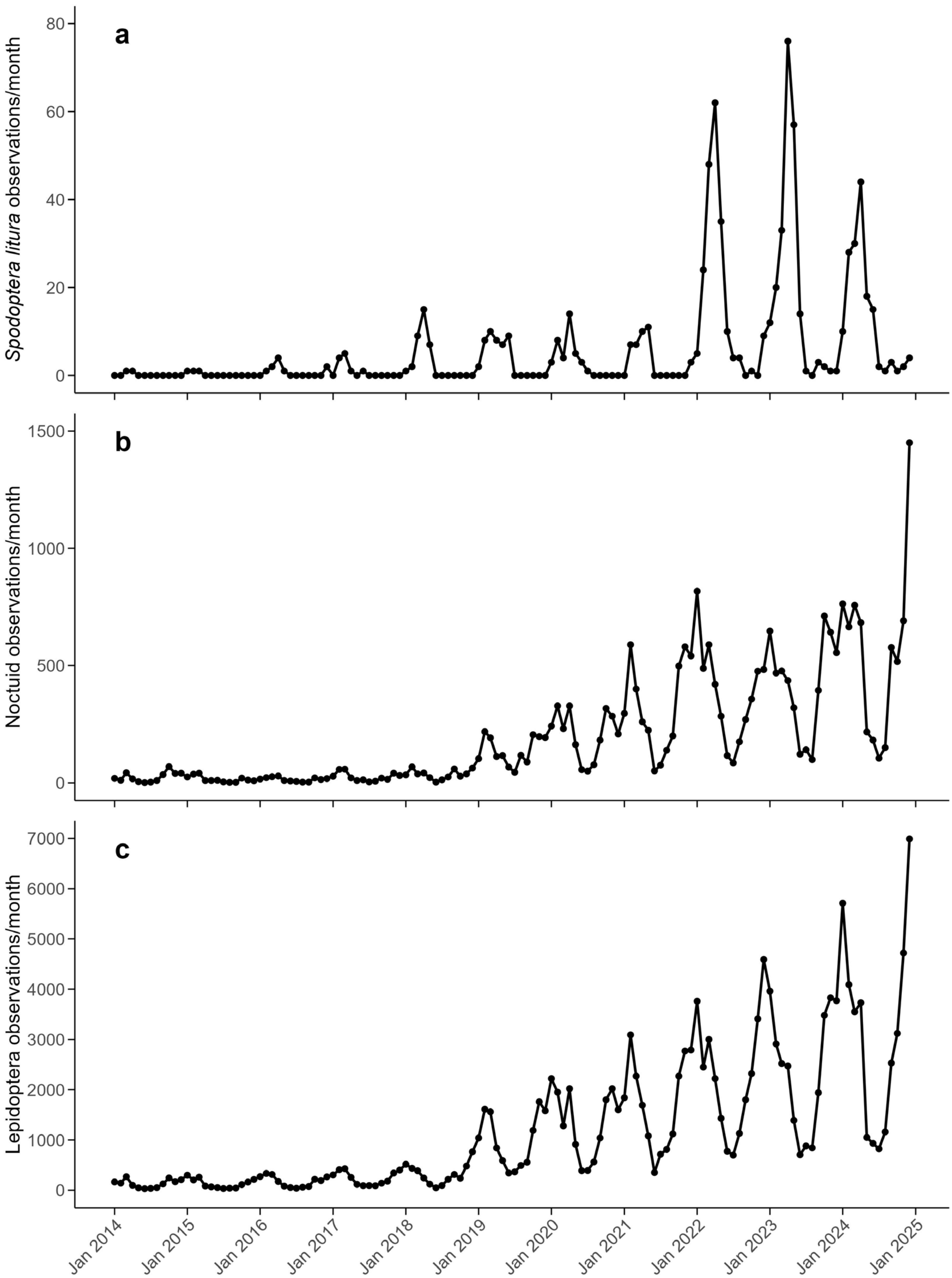

Figure 2 The number of research grade observations reported for New Zealand in iNaturalistNZ each month from January 2014 to December 2024 for (a) *Spodoptera litura*, (b) Noctuidae and (c) Lepidoptera. Observations are research grade when two-thirds of identifiers agree on the species identification.

Spodoptera litura seasonal and annual abundance

Seasonal peaks in observation numbers occurred each year in April (Figure 2a). The annual number of observations appeared to increase in 2018 and again in 2022.

The iNaturalist platform has become more widely known and more popular with time, leading to an increase in the number of users and/or more observations per user. This can be seen from a visual comparison of monthly noctuid and Lepidoptera observations reported on iNaturalistNZ (Figure 2b, c). Both increased over the 2014-2024 period, suggesting an increase in observer 'effort'. The apparent increase in the number of *S. litura* observations (Figure 2a) must therefore be interpreted carefully to account for these differences in overall observer effort. A simple way to do this is to calculate the number of *S. litura* observations in proportion to total number of observations, as iNaturalist does. We refined this calculation slightly by comparing the proportion of *S. litura* observations to observations for the family (Noctuidae) and order (Lepidoptera). Analysis of these proportions showed that there were statistically significant effects of both month and year on the proportion of all Lepidoptera observations that were *S. litura* (χ^2_{11}= 606.7, P<0.001 and χ^2_6= 162.9, P<0.001 for month and year, respectively) and the proportion of all noctuid observations that were *S. litura* (χ^2_{11} = 559.7, P<0.001 and χ^2_6= 167.7, P<0.001 for month and year, respectively). The effect of month on the number of observations is to be expected for a seasonally active insect like *S. litura* as seasonal peaks in population numbers can occur at different times for different lepidopteran species. When considered in relation to the numbers of overall Lepidoptera (Figure 3a) and noctuid (Figure 3b) observations per year, higher proportions of *S. litura* were reported in 2018 and in 2022-23, indicating that these were likely to have been genuine outbreak years in which *S. litura* numbers were higher than in non-outbreak years. Further monitoring is required to determine if there is also an underlying trend upwards that has been masked by the outbreak.

Spodoptera litura geographical range

Most of the *S. litura* observations reported in iNaturalistNZ/GBIF are from the northern North Island – 670 of the 894 iNaturalist observations to the end of 2024 were from Auckland, Northland or the Far North – although there were occasional reports from the South Island, including two adults seen as far south as Doubtful Sound in early 2022. Our simple comparison of *S. litura* and Noctuidae observation locations (Figure 4) showed that, in contrast to *S. litura*, noctuid reports in 2024 were spread reasonably evenly across the country. The potential for bias in user contributions in the iNaturalistNZ data was evident, however, in the large number of observations from Dunedin, which were due mainly to one user who contributed 988 of the 1,787 noctuid observations in that region.

Visual comparison between years of the location of each *S. litura* observation (Figure 5) indicated that higher numbers of observations south of Auckland may have coincided with the 'outbreak years' of 2018 and 2022-23.

Image diagnostic quality

Three of the 185 *S. litura* observations reported for New Zealand in 2024 were of eggs, 74 of larvae (including seven of eggs with newly hatching larvae) and 107 were adults. The remaining specimen could not be identified and may not have been an insect at all. Most (113) of the observations had only one species identification suggestion from a user who was not the original observer – 91 of these were 'research grade'. Through inspection of the images associated with each observation, and looking for identifying features such as those shown in Figure 1, we determined that most of the observations (153) were 'definitely' or 'probably' *S. litura*. Only 34% of the observations were accompanied by 'good' images that clearly showed distinguishing features. We did not consider species identification to be possible for fourteen (8.8%) of the 'research grade' observations. One poor quality 'needs ID' observation suggested by the observer as *S. litura* was most likely *S. frugiperda* so this is not included in Table 1. In iNaturalist, users may add comments when they contribute an identification. Two comments of note that accompanied suggested identifications were 'probably, but hard to be sure without an image of the pattern on its back', and 'I have little idea about identifying larvae' (accompanying a research grade larval observation for an image that this author considered too poor to identify accurately).

Discussion

Our search for published and unpublished work on *S. litura* populations in New Zealand generated sparse information with little detail. The most comprehensive source of data was through the online platforms, iNaturalist and GBIF. Citizen science projects such as iNaturalist offer a continuous, low cost, large scale method for collecting data compared with traditional active surveillance techniques (Cull 2021). These types of data are freely available worldwide, and with new ways of exploring large data sets, their value is clear. Our example of *S. litura* in New Zealand demonstrates the potential usefulness of these data for population monitoring of species for which other sources of data are scarce. It also highlights the need for care to be taken with its analysis and interpretation.

Sampling and reporting in citizen science data is often uneven over time and space (Boakes et al. 2016). More

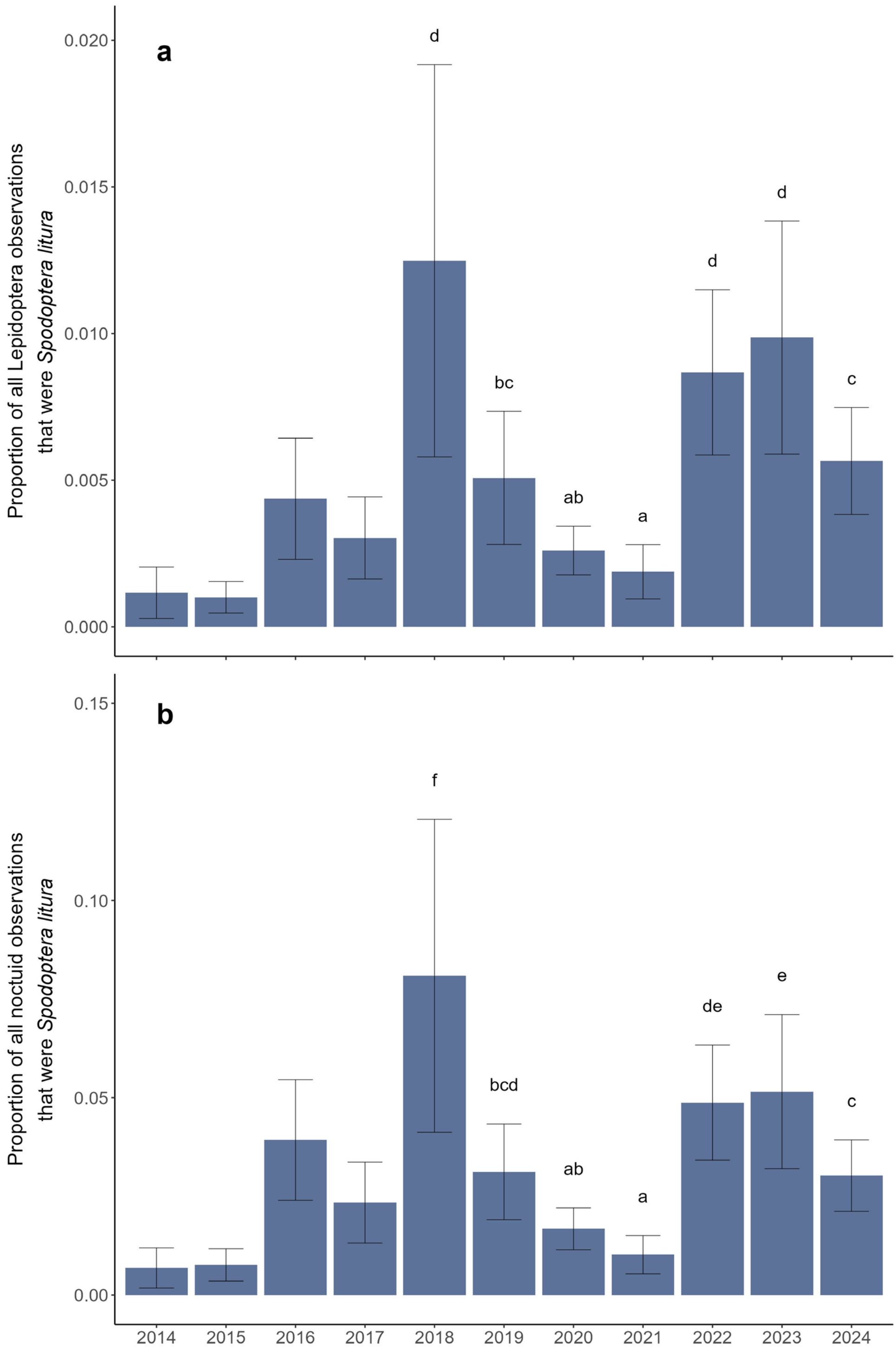

Figure 3 Annual means of research grade *Spodoptera litura* observations reported each month in iNaturalistNZ for mainland New Zealand from January 2014 to December 2024 as a proportion of (a) Lepidoptera and (b) Noctuidae observations. Observations are research grade when two-thirds of identifiers agree on the species identification. Error bars are ± one standard error of the mean. Observations from 2014 to 2017 were omitted from the statistical analysis model due to low observation numbers. Means with different letters are significantly different ($P<0.05$).

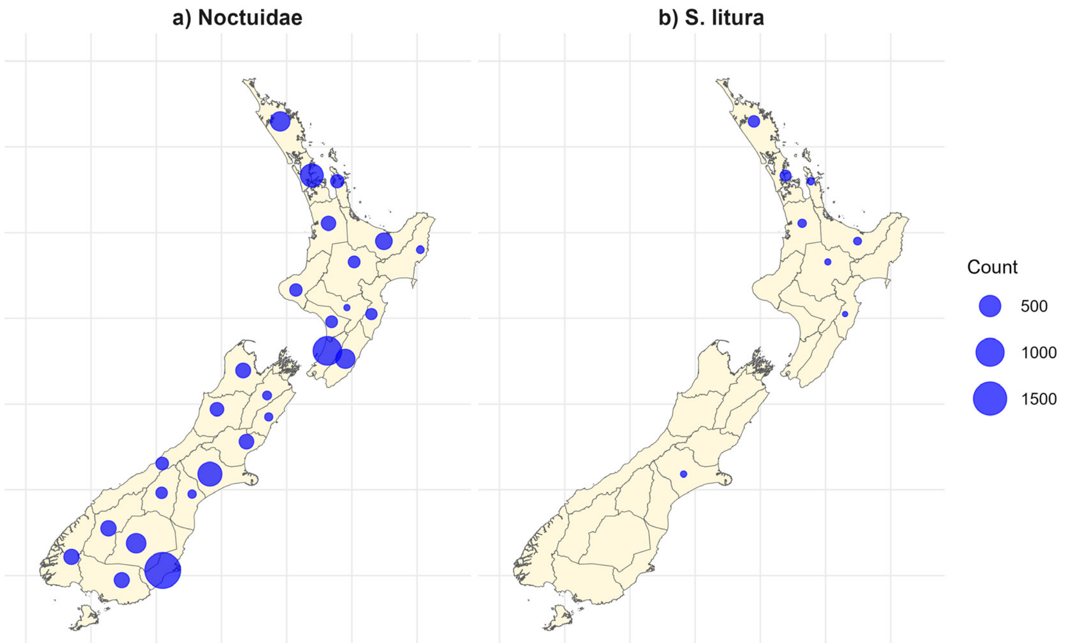

Figure 4 Total number of recorded observations of a) Noctuidae and b) *Spodoptera litura* per 'Crosby region' in iNaturalistNZ in 2024. The size of each point is proportional to the number of observations in that region.

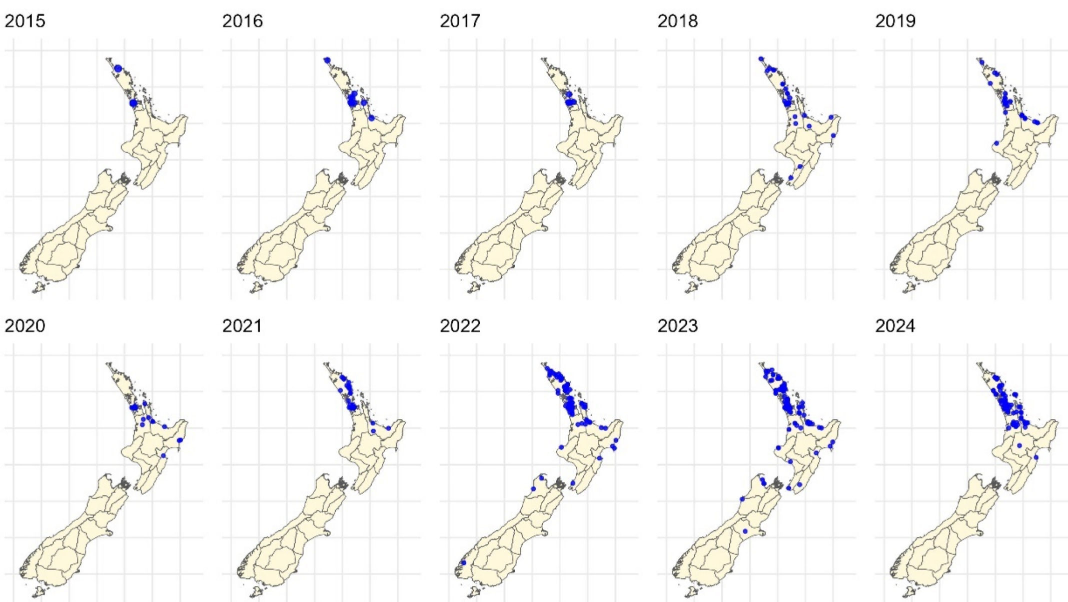

Figure 5 Locations of individual of *Spodoptera litura* observations in iNaturalistNZ per year.

observations may be recorded from densely populated areas, from sites that are easy or enjoyable to access, or from organised survey events such as BioBlitz (https://www.landcareresearch.co.nz/tools-and-resources/education/bioblitz/) or the City Nature Challenge (https://inaturalist.nz/projects/city-nature-challenge-2025-bend). There can also be a wide variation in effort between observers. This was demonstrated by our examination of noctuid data from Dunedin in 2024, where over 55% of the observations were reported

Table 1 Quality rating of images, and certainty of specimen identification, as assessed by J.G. Jensen for all 184 *Spodoptera litura* observations from iNaturalistNZ in 2024.

Image Quality	**iNaturalist Observation Grade**	**Certainty of Identification**			
		Definitely	Probably	Possibly	Can't Identify
Poor	Research	25	13	5	12
	Needs ID	4	5	0	6
Ok	Research	47	1	3	2
	Needs ID	3	3	1	2
Good	Research	49	1	0	0
	Needs ID	2	0	0	0
Total		130	23	9	22
Percentage		70.7%	12.5%	4.9%	12.0%

by a single iNaturalist user. Overall contributions to iNaturalist have grown exponentially over the past decade (Di Cecco et al. 2021) and this temporal trend must be considered when analysing population dynamics. A significant strength of iNaturalist, however, is that observations of any life form can be reported. Statistical models can thus incorporate observation data for other species or higher taxonomic groups to account for uneven sampling. Furthermore, these data can be used to augment data from other sources when multiple sources are integrated to provide a more cohesive picture, such as in Bayesian methods (Gelman et al. 2013). We have used very simple analyses and visual assessments to demonstrate potential observer bias, but for comprehensive studies more in-depth analyses that model the data collection process and appropriately control for biases should be used (e.g. Isaac et al. 2014).

Some species or life stages are easier to find, photograph or identify than others, and some are of more interest to individual observers. This interest may be linked to the 'charisma' or novelty of specific species, or may be increased in response to high profile surveys or media coverage of invasive species (Boakes et al. 2016). Both adult and larval *S. litura* are relatively large and striking, are found in easily accessible locations and the larvae cause significant damage to crops and home gardens. These factors make the species more likely to be noticed and reported on and therefore a good candidate for study through citizen science platforms.

Publicity and industry (e.g., Ministry for Primary Industries, Foundation for Arable Research) responses following the discovery of the related noctuid, *Spodoptera frugiperda* (fall armyworm) in February 2022 may have led to an increase in reported observations of *S. litura*, through an increased public awareness of these pests. Increased reporting can be positive or negative depending on the intended use of the data. Drury et al. (2019) used citizen science data to investigate phenotype variation in three species of damselfly. They were able to improve their outreach through active recruitment strategies, resulting in a larger data set for studying wing pigmentation. In contrast, when looking for differences in population dynamics over time, such as for our sleeper pest study, a change in outreach effort during the study period can lead to a bias in sampling effort that can skew the results and must be accounted for in any analysis.

As with the analysis of species abundance over time, we need to be cautious in our interpretation of a species' geographical distribution from citizen science data. It is important to recognise that a lack of observations does not necessarily mean an absence of the species at that time/location (Gerard et al. 2024). Other site sampling methods like trapping, or mark and recapture, are more definitive, but do not preclude a failure to detect an organism when it is there either. A well-designed study, however, ensures that sampling effort is distributed evenly, and sampling effort can be accurately judged. Geographically widespread reporting of Lepidoptera and Noctuidae in iNaturalistNZ gives us some confidence that users who are likely to be interested and motivated to report *S. litura* are active across all regions of New Zealand. There were 8,519 observers reporting Lepidoptera across New Zealand and 488 of these detected *S. litura*. We can therefore tentatively infer that the species is usually either absent, vagrant or in very low numbers in the South Island rather than simply not being found or reported.

A significant advantage of the iNaturalist platform is the association of each record with an image that allows researchers the opportunity to check the assigned species identification. The species identification of a 'research grade' observation must have the agreement of at least two-thirds of the identifiers. Many identifications are the work of a few very active users. These identifiers have extensive expertise and diagnostic experience, and their contribution is invaluable. However, any user may suggest, agree or disagree with a species identification – no qualifications are required and one of the identifications required for 'research grade' observations may be (and often is) provided by the original poster. In 2017, iNaturalist added computer vision image recognition to aid in species identification. This can be a useful tool but may result in under-qualified identifiers agreeing with incorrect identification suggestions. Thus, although a specimen might be tagged 'research grade', in practice identifications may be unreliable. Photos may be blurry or not show the key identification features required for that species or life stage, and many species cannot be accurately identified based on external morphology alone (a problem for any study or monitoring effort). For small or cryptic species, identification based on hand-held cameras is particularly difficult.

Identification can be based on the appearance of the specimen, where and when it was found and, for herbivorous species, what plant it was associated with. Identifiers will also consider what other similar looking species are known to occur in New Zealand. Before 2022, to a reasonably trained eye, species identification from photographs of *S. litura* in New Zealand seemed relatively easy as there were no known similar looking species in the country. The arrival of the related and similar-looking species, *S. frugiperda,* has made accurate identification more difficult. It is also possible that *S. frugiperda* was present earlier than recognised and was being misidentified as *S. litura* or that other, similar-looking species such as *S. littoralis*, could be present without our knowledge.

The number of *S. litura* observations reported in the citizen science databases iNaturalistNZ and GBIF were higher from 2022 than in previous years. Analysis of these observations in proportion to observations of Lepidoptera and Noctuidae, however, indicated that while the apparent increase in numbers in 2022 and 2023 was probably 'real', it was in part skewed by a temporal increase in observer effort. The analysis also highlighted an earlier potential outbreak year in 2018. We were not able to account for all the potential variation and bias in the data, so these results can only be considered indicative. However, news and social media records from 2022-23, as well as personal observations/ communications appear to corroborate our results for that period. Continued monitoring through tools such as iNaturalist will help us determine if this was a 'real' but temporary increase due to favourable climatic conditions in those years, or part of a trend upwards for a potentially wakening sleeper pest.

Winter temperatures were the 'warmest on record' for the three years from 2020 to 2022 (NIWA 2000–2025), and the 2022-23 summer was exceptionally wet for the North Island. Summer rainfall in 2021-22, however, was below normal for Northland, Auckland and parts of Waikato (NIWA 2000-2025). Gerard et al. (2011) speculated that a mild, wet winter and warm spring and summer led to the *S. litura* outbreak in the Bay of Plenty in 2011, while Kean et al. (2015) and Peacock et al. (2006) considered warmer summer and autumn temperatures to be key, as they allow for additional generations to develop. More accurate presence/ absence data and more sophisticated modelling is needed for proper examination of any correlation with changes in climate for this species.

Increasing public awareness through outreach initiatives, recruitment of observers, education on species identification and increased contributions from subject experts and taxonomists can all help improve engagement with, and accuracy of, citizen science platforms such as iNaturalist (Drury et al. 2019; Hochmair et al. 2020). This should ideally be accompanied by statistically sound validation of the data through carefully designed and conducted studies such as physical survey/s of the species of interest. Unfortunately, for many researchers, this level of effort and cost is out of reach but with careful analysis that accounts for all variation, e.g., the number and location of users and uneven recording intensity, citizen science data can make a valuable contribution to studies such as ours.

Conclusions

In the absence of sufficient resources to conduct population surveys at multiple sites and across multiple years, our study has shown that useful indicators of population size and geographical spread can be inferred from iNaturalist/GBIF data, with the caveat that researchers must conduct quality assessments and care should be taken with the analysis and interpretation. Populations of *S. litura* in New Zealand appear to have been larger during the summer-autumn periods of 2018, 2022 and 2023; however, further monitoring is required to determine if there is an overall trend upwards, and if its distribution is shifting southwards. This information would provide a useful warning tool for farmers under changing climate conditions.

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