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Can 'bad' years for damage by *Prostephanus truncatus* be predicted?

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Abstract

Prostephanus truncatus (Horn) (Coleoptera: Bostrichidae) is a sporadic, but serious pest of maize and cassava in the tropics. Farmers report that some years are far worse for damage than others and it is also known that the numbers of insects dispersing, as measured in pheromone traps, varies between years. Using purpose-built mini-stores it was shown that flight-trap catches of *P. truncatus* were a significant predictor of the risk of stores becoming infested in Ghana but not Tanzania. The estimated relationship between these two variables was, however, similar in both countries, and also matched data subsequently obtained from observations of farmers' stores in Ghana. These findings are an important step towards the development of a warning system to decrease the uncertainty of *P. truncatus* threat to stored maize and cassava.

Keywords: Food-security; Risk-assessment; *Prostephanus truncatus*

1. Introduction

Methods to predict the risk of serious pest attack in agriculture (Nieminen et al., 2000) and forestry (Ravlin, 1991) are gradually being developed. As more is known of pest behaviour and population dynamics, control measures can become increasingly targeted and effective. The goal of research into risk assessment is most commonly to establish the potential range and damage that could be caused by an invading pest, and to predict how the threat might change with time. For example, a decision support system has been developed to enable stakeholders to assess the risk posed to areas of forest from the gypsy moth, an exotic pest. This not only warns of those areas under current threat, but can also be used to predict the likely gypsy moth risk arising from various management options (Potter et al., 2000). In our study, the potential for using changes in the numbers of the beetle *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae) captured in pheromone traps is assessed as a means of predicting seasons of high damage.

Prostephanus truncatus is a particularly destructive pest of stored maize and cassava (Hodges, 1986, 1994; Markham et al., 1991). Its range is expanding in Africa and most recently this pest has been reported in South Africa and Namibia (Roux, 1999; Larsen, 1998). *P. truncatus* poses the greatest threat to small-scale farming communities rather than large-scale stores, where fumigation is a cost-effective control option. Subsistence farmers in sub-Saharan Africa have changed their storage practices in response to the threat of this pest. Farmers have increased their use of insecticides and more have been shelling their maize, even though cobs are the traditional form of storage for many farmers (Golob et al., 1999). *P. truncatus* differs from other common beetle pests in maize storage in the tropics such as *Sitophilus* spp. in that the level of damage is very unevenly distributed between stores (Hodges, 1986), and those farmers who are affected can suffer such extreme losses that a season's harvest can be effectively lost. This uncertainty makes it difficult for farmers to plan their action against this pest. They currently have two options. Either take action every season and perhaps

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use pesticides and other resources unnecessarily, or incur the risk of high food losses.

We suggest that there are two main contributors to this unpredictability of store infestation. First, in any one village at any one time, some stores will be highly infested while others remain undiscovered by the pest. This is because *P. truncatus* does not locate maize or cassava in store by responding to volatiles from the commodity itself; the initial colonisers arrive by chance (Hodges, 1994; Fadamiro et al., 1998; Scholz et al., 1997a). Once even a single male has arrived and releases an aggregation pheromone signal, dispersing adults detect this, and the commodity in store is placed under increased threat (Scholz et al., 1997b; Birkinshaw and Smith, 2000).

Second, farmers from several countries report that there is substantial year to year variation in the number of stores that are damaged. We start with the hypothesis that, for a given length of storage period, year to year variation in damage across a community is determined by annual variation in the numbers of dispersing adults. Since the initial colonisers arrive by chance, then we predict that there should be a good positive correlation between flight activity and the frequency of store colonisation. Obviously the length of a storage season will also be an important determinant of food damage. If, for example, the harvest is poor and stores only contain food for 2–3 months, then the percentage of damage will be much lower than for food stored for 6 months and over (see Holst et al. (2000), for a model of how damage increases with time).

It is possible to sample the dispersing population of *P. truncatus* using flight traps baited with synthetic aggregation-pheromone (Dendy et al., 1989; Richter and Biliwa, 1991; Fandohan et al., 1992; Hodges and Pike, 1995). Samples taken using pheromone-baited traps are not likely to be random samples of the dispersing population, however they are the best practical measure currently available. Four years of trapping data from Ghana showed that the mean trap catches over a year could vary by over threefold. Perhaps more importantly, the peaks of catches that can occur near the beginning of a storage season varied by almost tenfold between years (see data in Birkinshaw and Hodges, 2000). Females caught in traps are mostly inseminated and able to reproduce as soon as they locate a plant host (Scholz et al., 1998; Hodges and Birkinshaw, 1999), although further mating will increase their rate of offspring production (Li, 1988). No large differences in the reproductive potential of insects caught in different seasons were found in a range of habitats (Scholz et al., 1998; Hodges and Birkinshaw, 1999).

To investigate whether the trap catches of *P. truncatus* are a good predictor of store colonisation rates, the current study measured prevailing *P. truncatus* trap catches, and the incidence of colonisation of purpose-built mini-stores. These estimates of how changes in trap catches relate to the risk of stores being colonised were then compared to observations of real farmers' stores at the end of a storage season. This on-farm validation of the risk assessment model used stored dried cassava (*kokonte*) in the Kete Krachi district of the Volta region. Cassava is the main staple crop grown in this area, some is used for family food and some is sold to a trading company for cash. There is one main season for kokonte production normally falling between December and April. The kokonte is then often stored for up to a year until the next harvest.

2. Materials and methods

2.1. 'Mini-stores

Experiments were done in villages in Ghana and Tanzania as shown in Table 1. Two contrasting areas in the Volta Region of Ghana were chosen. First the forest-savannah transition zone of Hohoe/Jasikan district, and second the semi-arid zone of the Nkwanta district. A semi-arid area with high reliance on maize was chosen in Tanzania.

In each village, nine mini-stores were constructed and pheromone traps hung from suitably sited trees in a regular arrangement shown in Fig. 1. Mini-stores were about 150 m apart and traps about 100 m apart depending on the suitability of the terrain. Typically,

Table 1
Summary of the locations, dates and commodities used in mini-store experiments

Location	Dates	Number of stores/village[a]	Total number of hits during experiment
A. Ghana		4 maize	57
5 villages in Hohoe/ Jasikan district	2/4/1998–20/1/1999	4 cassava	17
5 villages in Nkwanta district		1 maize and cassava mix[b]	5
B. Ghana			
5 villages in Hohoe/ Jasikan district	29/3/1999–30/9/1999	9 cassava[c]	163
5 villages in Nkwanta district			
C. Tanzania			
5 villages in Kilosa district	16/8/2000–30/3/2001	9 maize	26

[a] Each village had a total of nine mini-stores so that each district had a total of 45 stores.
[b] Data from mixed commodity stores has been excluded from all analyses.
[c] In this experiment traps were only present for half the time.

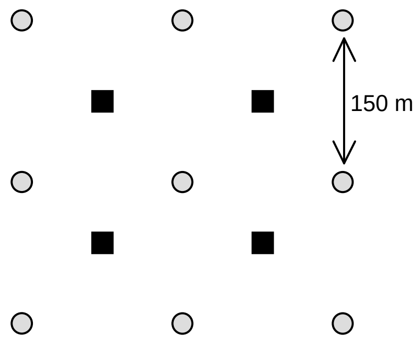

Fig. 1. Plan view of the arrangement of nine mini-stores (□) and four pheromone traps (○) in each village. The exact spacing was limited by the availability of a suitable branch for the traps and by the positioning of households to keep an eye on the stores, however traps and stores were never closer than 100 m from each other.

vegetation and houses stood between traps and mini-stores.

Each mini-store consisted of a chicken wire cage supported by a wooden frame, and protected from the rain by a thatch roof. The design of the stores was slightly different in Ghana and Tanzania, but both held a volume of ~8 l of commodity (60–65 cobs) 1.2–1.5 m above the ground. Local varieties of maize cobs with their sheathing leaves intact were used, and the cassava roots were dried chips about 10–15 cm long and 3–7 cm in diameter. None of the commodity showed any signs of previous infestation by *P. truncatus* and all was fumigated with phosphine for at least 7 days and then maintained in insect-proof plastic bins prior to use. In Ghana, commodity was placed in a cylindrical mesh cage with a diameter of ~60 cm and supported on a single wooden post running up the centre. In Tanzania, the mesh cage was square of sides 60 cm and supported by four legs, one at each corner. In all stores a layer of black polypropylene was fixed directly underneath the mesh cage to allow easy detection of the characteristic dust produced by *P. truncatus* boring activity.

The pheromone-baited traps used to sample the dispersing population of *P. truncatus* were Japanese beetle type supplied by Trécé Inc., Salinas, CA, USA. They consist of a yellow plastic funnel (diameter 15 cm, height 11 cm) with four vertical canes in the form of a cross, extending 10 cm up from the funnel to form a baffle. Incoming beetles hit the baffle and then tumble into the funnel to be collected by a plastic jar attached to its base, containing a Whatman's No. 1 filter paper impregnated with a lethal dose of diluted Actellic Super EC insecticide. Each trap was baited with a standard *P. truncatus* aggregation pheromone lure consisting of a polythene capsule impregnated with 1 mg each of Trunc-call 1 and 2. In each village, four traps were hung 1.5–2 m above the ground on any conveniently located vegetation, often a mango tree branch. The arrangement of traps and stores in the villages is shown in Fig. 1.

Villages were visited every two weeks to collect and count the numbers of *P. truncatus* captured in the traps, to replace the existing pheromone capsule with a fresh one and to examine the mini-stores for signs of infestation. Once infested, the stores were cleared of produce and were refilled with fumigated material after a fallow period of at least two weeks (sometimes longer when commodity was scarce). Store structures were inspected for any signs of infestation and changed if any were found, however such inspection is difficult and may not always have been successful.

During the course of this experiment, the possible influence of the presence of the baited traps in the villages on the colonisation of the mini-stores was tested. This was done by leaving traps unbaited for every other trapping period, i.e. 2 weeks on, 2 weeks off.

Binary logistic regression (Genstat 4.1) was used to determine which out of a number of possible variables significantly contributed to the risk of stores becoming infested. Whether or not a mini-store had been previously colonised was termed, 'hit before'. This variable was included to check whether our disinfestation of stores before re-loading had been successful. The length of time a stored commodity had been exposed to field conditions was termed 'store age'. This was included in the model to determine if other factors that change with time during storage such as moisture content, or the increasing infestation from other pests might influence store colonisation by *P. truncatus.* The logistic regression equation generated by this analysis was used to predict the cumulative number of *P. truncatus* that are associated with a range of probabilities of stores becoming infested. This relationship was estimated using models including only *P. truncatus* trap catch as an explanatory variable. The cumulative trap catch is the number of insects that need to be caught, whilst using any numbers of two-weekly trapping periods, to give a specific probability of stores becoming infested by *P. truncatus*.

For convenience, studies on the infestation of mini-stores in Ghana, in which pheromone-baited traps were present throughout, are referred to as 'Experiment A' and as 'Experiment B' when the traps were left unbaited in alternate two-week periods. The tests in Tanzania are labelled 'Experiment C'.

2.2. Farmers' stores

Krachi district, next to Lake Volta was chosen for the study. The villages in this district are relatively widely spaced and five were selected, spaced ~10 km apart and roughly in a line. Eighty farmers, from the five villages were chosen to participate in the research: Borae (13), Peposu (14), Ankase (21), Ehiamankyene (21), Adomang (11). Borae was the biggest, and is the local administrative capital where there is a lot of trading in agricultural produce. All the other villages were fairly small farming communities and although they all contained several ethnic groups, the Kokomba were predominant. Kokombas mostly store their kokonte in traditional structures called *katchalla*. These were roughly cylindrical in shape and of mean height 130 cm, diameter 215 cm and 40 cm off the ground. Only farmers storing their kokonte (dried cassava chips) in *katchalla* stores were chosen for the study and none treated their kokonte with any protectant against insects. Cassava was usually unloaded from stores gradually in small amounts, initially mostly for sale, then for family food towards the end of the season.

Samples of the stored cassava were collected towards the end of storage period when ~one-tenth of the original quantity of commodity remained. Locally recruited and trained staff were given plastic boxes and asked to collect samples with farmers. Ten cassava pieces were picked at random and later checked by project staff for the presence or absence of *P. truncatus.* The pest initially tends to migrate to the bottom of a store (Hodges and Birkinshaw, 1999) so sampling at this point late in the season maximises the chance of an infestation being detected from such a relatively quick sampling protocol. For each store, the following information was recorded:

- date the store was loaded;
- the dimensions of the store;
- whether the wooden construction of the store was old or new this season;
- date the cassava was sampled;
- whether or not *P. truncatus* was found in the cassava sample.
- The cumulative mean number of *P. truncatus* caught per trap in the village where the store was located, between the date the store was loaded, and the date the store was sampled. Since traps were emptied only every two weeks, the nearest trap catch to the dates of sampling were used.

We were not able to collect information on the presence or absence of any residual *P. truncatus* infestation in wooden component of the *katchalla* since the nature of their construction made inspection difficult. However, such infestation is likely in older stores.

3. Results

3.1. Mini-stores

There was considerable variation in trap catch between different sites and over time (Figs. 2–4). Trap catches were mostly under 1000 beetles per trap per two weeks, but some peaks were in excess of 3000 beetles per trap per two weeks. The mini-stores associated with the traps were colonised by *P. truncatus* or 'hit' to varying degrees (Table 1). The trap catches were found to be a significant determinant of these hits in experiments in Ghana, but not in Tanzania (see Tables 2, 3 and 5). However the estimates of the relationship between trap catch and risk of store colonisation were similar across all sites (Fig. 6). The estimates predict that in a two-week trapping regime (using standard traps and lures), 50% of mini-stores will be infested by the time the cumulative trap catch reaches ~2000–4000 insects.

The commodity type (maize compared to cassava) filling the store was found to influence store colonisation (see Table 2). The regression equations suggest that cassava is more likely than maize to become infested at low beetle density. In general the results suggest that cassava is less sensitive to changes in beetle numbers i.e. increases in beetle density do not result in as much increase in risk as observed in maize-filled stores.

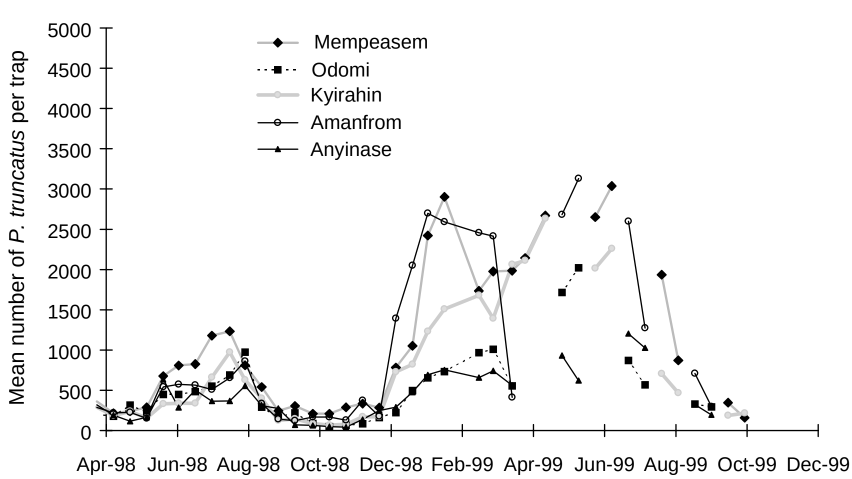

Fig. 2. Mean number of *P. truncatus* caught per flight trap per two-week trapping period in the Hohoe/Jasikan village cluster.

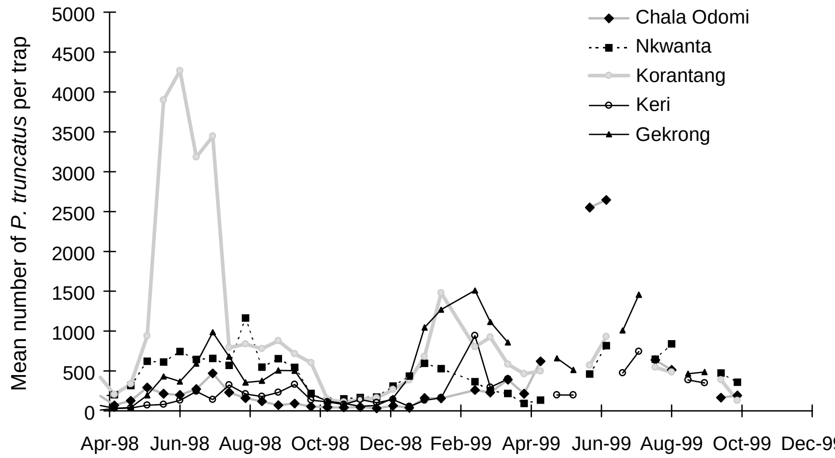

Fig. 3. Mean number of *P. truncatus* caught per flight trap per two-week trapping period in the Nkwanta village cluster.

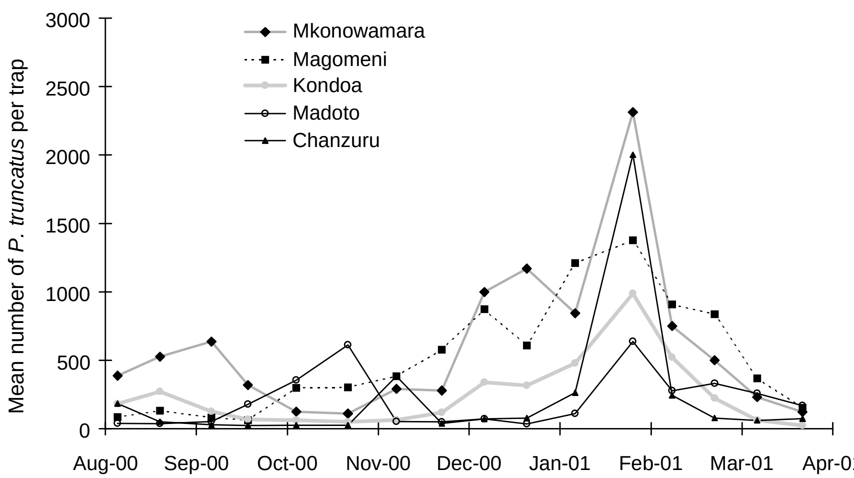

Fig. 4. Mean number of *P. truncatus* caught per flight trap per two-week trapping period in the Kilosa village cluster.

Table 2
Estimates of the influence of factors on the chance of mini-stores in Ghana, holding maize cobs or dried cassava roots, becoming colonised by *P. truncatus* (Experiment A)*

	Estimate	SE	*T*	*p*-Value
Constant	−3.69	0.33	−11.1	<0.001
Maize vs. Cassava	1.29	0.29	4.49	<0.001
Hit before?	−0.213	0.257	−0.83	0.41
Store age	−0.0243	0.0133	−1.82	0.068
P. truncatus trap catch	0.000532	0.000132	4.04	<0.001

*Overall mean deviance = 10.8, $p<0.001$, d.f. = 4.

Table 3
Estimates of the influence of factors on the chance of mini-stores in Ghana, holding dried cassava, becoming colonised by *P. truncatus* when traps were left unbaited with pheromone in alternating two-week periods (Experiment B)*

	Estimate	SE	*T*	*p*-Value
Constant	−2.83	0.29	−9.94	<0.001
Presence of traps	0.308	0.172	1.79	0.073
Hit before?	0.533	0.190	2.81	0.005
Store age	0.0357	0.0148	2.41	0.016
P. truncatus trap catch	0.000351	0.000106	3.31	<0.001

*Overall mean deviance = 4.8, $p<0.001$, d.f. = 4.

There is no overall consistent influence of the presence of traps on the store hit-rate. The stores in Korantang village however, were hit over five times more frequently in the presence of traps than when they were absent (see Table 4).

3.2. Farmers' stores

Again there was variation in the trap catches between villages (Fig. 5). In four of the five villages, predictions

Table 4
Frequency of mini-store colonisation by *P. truncatus* occurring when traps were left unbaited with pheromone in alternating two-week periods (Experiment B)

Village	Traps absent	Traps present	χ^2	*p*-Value
Nkwanta	8	12	0.40	N.S.
Gekrong	5	9	0.57	N.S.
Chala Odomi	12	13	0.02	N.S.
Korantang	4	22	6.23	<0.025
Keri	4	3	0.07	N.S.
Bowiri Ayaniase	2	5	0.64	N.S.
Bowiri amanfrom	4	7	0.41	N.S.
Bowiri Kyriahin	10	6	0.50	N.S.
Akpafu Odomi	12	4	2.00	N.S.
Akpafu Mempeasem	11	10	0.02	N.S.
Total	72	91	1.11	N.S.

(based on the data from the mini-store experiments) of the colonisation rate of stores given their exposure to flying *P. truncatus* were good. However, Borae village was an outlier, where, although trap catches were high, the proportion of stores infested was relatively low (Fig. 6).

Regression analysis on the entire data set indicates that the age of wood used in the construction of the store, was a significant factor in store colonisation. Only about a quarter of stores with new wood (7 of 27) became infested compared to two-third of those with old wood (35 of 53). Thus age of the wood proved to be a significant factor in determining the likelihood of infestation (Table 6). In contrast, store size did not appear to be a significant factor, although there was little variation in the sizes of stores used in the

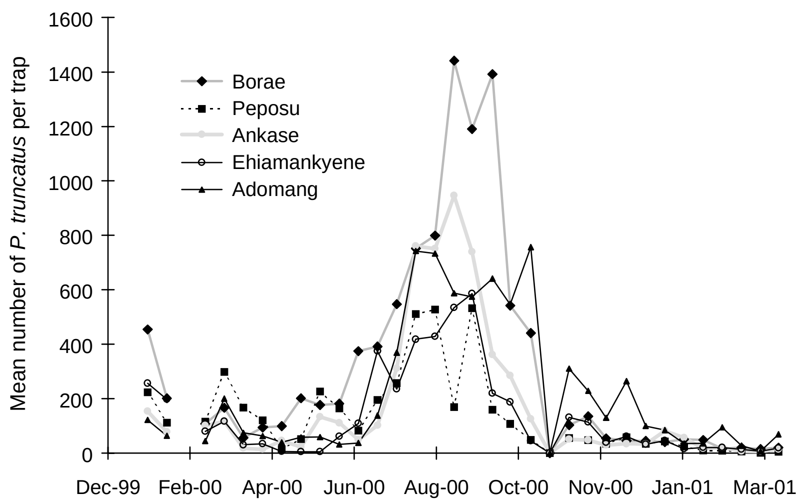

Fig. 5. Mean number of *P. truncatus* caught per flight trap per two-week trapping period in the Kete Krachi village cluster.

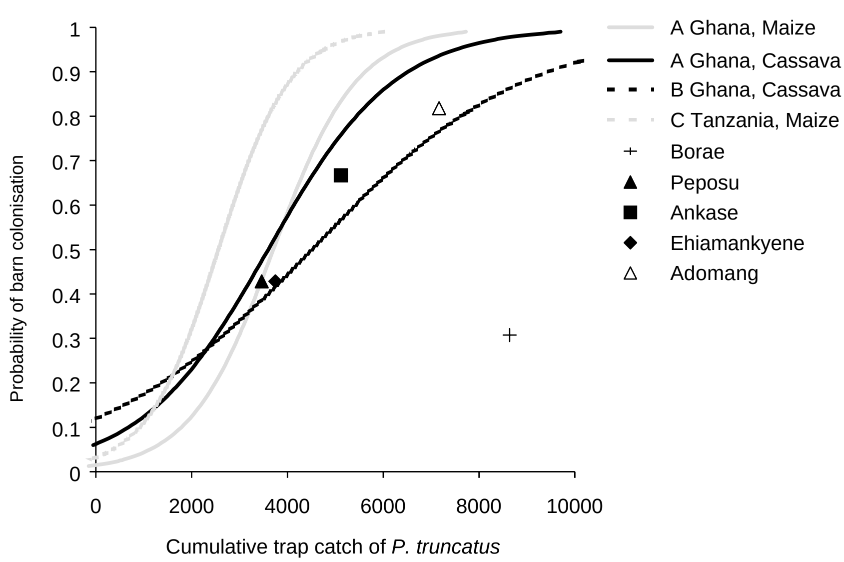

Fig. 6. Estimates of the relationship between cumulative trap catches of *P. truncatus* and probability of store colonisation generated during Experiments A, B and C, and actual data points from observation of farmers' cassava stores in Kete Krachi in Ghana.

Table 5
Estimates of the influence of factors on the chance of mini-stores, holding maize cobs, becoming colonised by *P. truncatus* in Tanzania (Experiment C)*

	Estimate	SE	*T*	*p*-Value
Constant	−4.04	0.46	−8.77	<0.001
Hit before?	0.004	0.563	0.01	>0.99
Store age	0.0512	0.026	1.98	0.048
P. truncatus trap catch	0.000523	0.000421	1.24	0.215

*Overall mean deviance = 2.3, $p = 0.072$, d.f. = 3.

Table 6
Estimates of the influence of factors on the chance of farmers' stores (*katchalla*), holding dried cassava, being colonised by *P. truncatus* at the end of the storage season*

	Estimate	SE	*T*	*t* Probability
Constant	−5.25	2.47	−2.13	0.034
Store wood new?	1.97	0.60	3.30	<0.001
Store size (area in profile)	−0.31	0.56	−0.55	0.58
Time exposed	0.084	0.045	1.89	0.058
P. truncatus trap catch	0.000192	0.000141	1.36	0.17

*Overall mean deviance = 4.39, $p = 0.002$, d.f. = 4.

experiment. The length of time between loading and sampling for *P. truncatus* was a significant determinant of store colonisation by the pest. Obviously time exposed co-varies with the cumulative trap catch of *P. truncatus*.

4. Discussion

Dispersal activity, as measured using flight traps was a significant predictor of mini-store colonisation in most datasets. A cumulative trap catch of about 4000 insects is predicted to be associated with a 50% chance of store colonisation.

Mini-stores loaded with cassava were more likely to become colonised than those loaded with maize cobs at lower beetle dispersal activities. We suggest that this may be a consequence of the relative ease with which *P. truncatus* can bore into cassava compared with the sheath-covered cobs so that the beetle may be more likely to resume flight if landing on cobs than cassava. In the mini-store data there was some evidence that the length of the time the commodity had been in store influenced the chance of *P. truncatus* colonisation during any two-week period. Likewise, the length of time farmers' own stores has been loaded with cassava was also approaching significance as a factor. This suggests that the action of other storage factors such as changes in moisture content or the action of other insects may also make stores increasingly open to *P. truncatus* invasion.

When these predictions were tested on much larger stores used by farmers, the results closely matched the predictions for four out of five villages. There did not appear to be a large increase in the risk of store colonisation from the increase in size of the stores. Such an increase may have been offset by cases where colonisations were not detected with the sampling protocol used. The size and inaccessibility of much of the cassava in the *katchalla* stores precluded any kind of comprehensive sampling plan. Alternatively it may be that *P. truncatus* start to orientate directly to stores over short distances in response to short-range cues. Direct orientation towards stores over short distances (say a few metres) may reduce the significance of store size compared to completely random location. Although long-range attraction has been ruled out, short-range attraction may be possible, especially in the case of cassava (Hodges, 1994; Scholz et al., 1997a).

Farmers' stores have structural timbers the previous use of which had a clear influence on store colonisation. This confirms the importance of earlier observations that *P. truncatus* may survive between storage seasons in wooden storage structures (Kossou, 1992). Farmers, particularly around Ho, reported an increase in their replacement of store wood in response to this threat (Addo, unpublished data).

There is some anecdotal evidence to support our hypothesis that year to year variation in risk of infestation is determined by annual variation in the numbers of dispersing *P. truncatus*. In Tanzania, trap catches were relatively high in Morogoro/Kilosa districts in 1998 and farmers reported this year as being particularly bad for *P. truncatus* damage (Riwa, unpublished data). Likewise, particularly high levels of *P. truncatus* damage were experienced in northern Ghana in 2000/2001, where it was estimated that there was a tenfold increase in reports to the local ministry of agriculture (Andan, personal communication). Although long-term trapping data is not available for this region, traps in place in Tamale were catching over a 1000 beetles per two weeks from September to November 2000 (Andan, unpublished data).

A survey of farmers' experiences since the arrival of *P. truncatus* into the Volta Region of Ghana did not, however, reveal a close link between trap catch data and farmers' experiences of damage (Addo, unpublished data). However, those years with high levels of insect dispersal activity were also years of poor harvest so that the storage seasons were much reduced and with it the opportunity for populations of *P. truncatus* to grow large enough for significant losses to be sustained.

Higher dispersal activity will not only increase the rate at which stores become colonised, it is also likely to influence the immigration rate of insects responding to aggregation-pheromone signals from male colonisers. We do not yet know the significance of higher flight activity on the speed at which stored commodity becomes damaged after its initial invasion. However, it has been suggested that this may be low compared with the rapid rate of reproduction of *P. truncatus* on maize or cassava (Scholz et al., 1997b).

Any warning system, based on the model proposed here, will necessarily need to be fairly general in its predictions since flight activity varies between villages that are geographically quite close and obviously flight activity is not the only influence on store infestation. Examples of other factors that our study has confirmed to be influential are the type of commodity, any *P. truncatus* infestation remaining in store wood and length of storage. However, when trap catches soar into the thousands, particularly if this occurs early in the storage period then we would class this as 'high risk'. The risk system will need to be developed with stakeholders to ensure that information is provided in the most useful and appropriate form. Radio programmes and the extension services were highlighted as two important information providers in the Volta region of Ghana (Addo, unpublished data). More pest control activities are undertaken on maize than cassava, which remains largely, untreated, but this does not mean that cassava farmers could not benefit from risk warning. Farmers may invest more in inspection if a 'bad' year is coming and benefit from more timely selling of their commodity if their store is attacked.

The main constraints to the implementation of such a system are likely to be the sustainability of the measurement of flight activity. Previous risk assessment systems using insect trapping have sometimes faltered because the co-ordination and resources required to maintain the trapping network is too great. Separate studies have given a strong indication that climatic factors can be used to predict trap catches (Hodges, unpublished data). Africa is already well served with meteorological stations and in the future remote methods of sensing climate may prove to be an even more convenient and cost-effective source of climate data.

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References

Birkinshaw, L.A., Hodges, R.J., 2000. Improving IPM approaches for Larger Grain Borer control in Africa. PhAction News 3, ISSN 1595-2304, 13–15.

Birkinshaw, L.A., Smith, R.H., 2000. Function of aggregation pheromone in the Larger Grain Borer *Prostephanus truncatus*: variation in response to individuals as evidence for a role in sexual selection. J. Chem. Ecol. 26, 1325–1339.

Dendy, J., Dobie, P., Saidi, J., Sherman, C., 1989. The design of traps for monitoring the presence of *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae) in maize fields. J. Stored Prod. Res. 25, 187–191.

Fadamiro, H.Y., Gudrups, I., Hodges, R.J., 1998. Upwind flight of *Prostephanus truncatus* is mediated by aggregation pheromone but not food volatiles. J. Stored Prod. Res. 34, 151–158.

Fandohan, P., Langner, B., Mutulu, P., 1992. Distribution, récherche et contrôle du grand capucin du maïs *Prostephanus truncatus* (Horn) au Benin. In: Boeye, J., Wright, M.A.P., Laborious, G.A. (Eds.), Implementation of and further Research on Biological Control of the Larger Grain Borer. Proceedings of an FAO/GTZ Co-ordination Committee Meeting, Lomé, Togo, pp. 8–28.

Golob, P., Marsland, N., Nyambo, B., Mutambuki, K., Moshy, A., Kasalile, E.C., Birkinshaw, L., Day, R., 1999. Coping strategies employed by farmers against the larger grain borer in East Africa: Preliminary observation. In: Zuxin, J., Quan, L., Yongsheng, L., Xianchang, T., Lianghua, G. (Eds.), Stored Product Protection. Proceedings of the Seventh International Working Conference on Stored-Product Protection, 14–19 October 1998, Beijing, China, 2, pp. 1772–1781.

Hodges, R.J., 1986. The biology and control of *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae)—a destructive pest with an increasing range. J. Stored Prod. Res. 22, 1–14.

Hodges, R.J., 1994. Recent advances in the biology and control of *Prostephanus truncatus* (Coleoptera: Bostrichidae). In: Highley, E., Wright, E.J., Banks, H.J., Champ, B.R. (Eds.), Stored Product Protection. Proceedings of the 6th International Working Conference on Stored Product Protection, 17–23 April 1994, Canberra, Australia, CAB International, Wallingford, UK, pp. 929–934.

Hodges, R.J., Birkinshaw, L.A., 1999. Risk warning to farmers of Larger Grain Borer infestation and reduced pesticide treatment in farm maize stores. Final Technical Report, R6684, pp. 1–84, Natural Resources Institute, Chatham Maritime, Central Ave., Chatham, Kent, ME4 4TB, UK.

Hodges, R.J., Pike, V., 1995. How to use pheromone traps to monitor the Larger Grain Borer (*Prostephanus truncatus*). Natural Resources Institute, Central Ave., Chatham Maritime, Kent ME4 4TB, UK, pp 16.

Holst, N., Meikle, W.G., Markham, R.H., 2000. Grain injury models for *Prostephanus truncatus* (Coleoptera: Bostrichidae) and *Sitophilus zeamais* (Coleoptera: Curculionidae) in rural maize stores in West Africa. J. Econ. Entomol. 93, 1338–1346.

Kossou, D.K., 1992. Susceptibility of wood for constructing traditional granaries to infestation by *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae). Ins. Sci. Appl. 13, 435–439.

Larsen, A., 1998. Nambian crop pests, http://hjem.get2net.dk/arne_larsen/74lgb.html.

Li, L., 1988. Behavioural ecology and life history evolution in the Larger Grain Borer, *Prostephanus truncatus* (Horn). Ph.D. thesis, University of Reading.

Markham, R.H., Wright, V.F., Rios Ibarra, R.M., 1991. A selective review of research on *Prostephanus truncatus* (Coleoptera: Bostrichidae) with an annotated and updated bibliography. Ceiba 32, 1–90.

Nieminen, M., Leskinen, M., Helenius, J., 2000. Doppler radar detection of exceptional mass-migration of aphids into Finland. Int. J. Biometeorol. 44, 172–181.

Potter, W.D., Deng, X., Li, J., Xu, M., Wei, Y., Lappas, I., Twery, M.J., Bennett, D.J., 2000. A web-based expert system for gypsy moth risk assessment. Comput. Electron. Agric. 27, 95–105.

Ravlin, F.W., 1991. Development of monitoring and decision-support systems for integrated pest-management of forest defoliators in North America. Forest Ecol. Manage. 39, 3–13.

Richter, J., Biliwa, A., 1991. A countrywide survey for the presence of *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae) in Togo using pheromone traps. Anz. Schädlingsk. Pflanz. Unweltschutz 64, 89–92.

Roux, P.W.J., 1999. Larger grain borer: further developments. Plant protection news (South Africa). Plant Prot. Res. Inst. 55, 3–4.

Scholz, D., Tchabi, A., Borgemeister, C., Markham, R.H., Poehling, H.M., Lawson, A., 1997a. Host-finding behaviour of *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae): Primary attraction or random attack? J. Appl. Entomol. 121, 261–269.

Scholz, D., Borgemeister, C., Meikle, W.G., Markham, R.H., Poehling, H.M., 1997b. Infestation of maize by *Prostephanus truncatus* initiated by male-produced pheromone. Entomol. Exp. Appl. 83, 53–61.

Scholz, D., Borgemeister, C., Markham, R.H., Poehling, H.M., 1998. Flight initiation and flight activity in *Prostephanus truncatus* (Coleoptera: Bostrichidae). Bull. Entomol. Res. 88, 545–552.