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Aggregation Pattern, Sampling Plan and Intervention Threshold for *Pezothrips kellyanus* in Citrus Groves

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Abstract

Pezothrips kellyanus (Bagnall) (Thysanoptera: Thripidae) has recently emerged as an international pest of citrus. It causes severe scarring of the fruit surface and commercial downgrading of fresh fruit production. The goals of this paper were to determine the aggregation patterns of *P. kellyanus* on citrus, to establish an efficient sampling plan to assess their population density, and to develop an environmental economic injury level. The study was conducted in 14 citrus groves in Valencia (Spain) during 2008 and in eight citrus groves during 2009. On each grove, population densities of thrips were monitored weekly on citrus flowers and fruitlets during the flowering and fruit setting period. Final damage was determined on developed fruits. *Pezothrips kellyanus* was the most abundant thrips species, with 73.5% of adults and 92.1% of larvae present, followed by *Frankliniella occidentalis* (Pergande) (Thysanoptera: Thripidae), with 18.2% and 3.5%, respectively. First description of first and second larvae of *P. kellyanus* is provided. Our results prove that thrips show clumped population distributions, with no differences in aggregation parameters between flowers and fruitlets, thrips species, larval stages or sex of adults. Immature thrips showed a higher aggregation (Taylor's value of $b = 1.40 \pm 0.06$) than adults ($b = 1.19 \pm 0.04$). Fruit damage by *P. kellyanus* on developed fruits was strongly correlated (r = 0.8968; n = 22) with number of fruitlets with immature *P. kellyanus*. Based on the percentage of fruitlets occupied by immature thrips the economic injury levels (EIL) and environmental economic injury levels (EEIL) were calculated (using chlorpyrifos as insecticide) obtaining values of 7% and 12%, respectively. Insecticide treatments will be necessary if more than 12% of fruitlets are infested by thrips larvae. Constant precision (D = 0.25) sampling plans developed show that 200 sample units should be observed in enumerative sampling, and 310 in binomial presence-absence sampling, at population levels of immatures on fruitlets around the EEIL.

Introduction

Thrips (Thysanoptera: Thripidae) are common insects that feed on a wide variety of plants and are frequently found associated with citrus (Quayle, 1941; Lewis, 1997). A great number of thrips species have been recorded on citrus trees, but only relatively few species are serious crop pests (Bodenheimer, 1951; Childers & Nakahara, 2006; Costa et al., 2006).

Kelly's Citrus Thrips (*Pezothrips kellyanus* (Bagnall), thereafter KCT) became a serious pest of citrus fruits during the last decade in southern Australia, New Zealand and several countries of the Mediterranean Basin namely Italy, Greece, Portugal, Turkey, Cyprus and Spain (Blank & Gill, 1997; Marullo, 1998; Mound & Jackman, 1998; Orphanides, 1998; Conti et al., 2001; Varikou et al., 2002; Franco et al., 2006; Vassiliou, 2007; Navarro et al., 2008). KCT is a flower-living species and its abundance in citrus groves peaks in spring during the main flowering period (Baker et al., 2002). Adults need to establish on flowers for breeding purposes (Blank & Gill, 1997). KCT causes a ring of scar tissue around the calyx and rind blemish on young and mature fruit (Blank & Gill, 1997; Baker, 2006). Most of the rind damage to fruitlets is apparently caused by larvae (Blank & Gill, 1997; Navarro-Campos et al., 2011). In cases of serious damage, the scarring can cover the entire fruit (Vassiliou, 2010). The period of greatest risk of injury occurs during the first four to five weeks after petal fall (Baker et al., 2002). The feeding activities of these arthropods cause no substantial degradation of the tissues consumed by humans (Hare, 1993), but have a major economic impact on fresh fruit production, as they downgrade the external appearance of the fruit, reducing or eliminating its market value (Gilbert & Bedford, 1998).

At the moment, the basic problem remains on how to control KCT (as well as other citrus thrips) effectively without destroying the very important natural enemy complex of scale insects, mealybugs, mites and other citrus pests (Gilbert & Bedford, 1998). In that context, integrated pest management (IPM) is based on the idea that chemical control should only be used as a last resort. The decision to apply chemical insecticides is taken only when the population exceeds the economic injury levels (EIL). The EIL is defined as the lowest population density that will cause economic damage. Economic damage begins to occur when the cost (in terms of money) of suppressing insect-caused injury is equal to the potential monetary loss from a pest population (Stern et al., 1959; Pedigo, 1999). The EIL indicates when the management of a pest is economically justified, but does not provide users with information of choosing the least environmentally hazardous pesticide when a pesticide must be used. Another intervention threshold, the environmental EIL (EEIL), incorporates both economic criteria and environmental risk criteria for IPM decision making (Higley & Winstersteen, 1996).

Thus, it is necessary to develop a methodology for sampling KCT populations and to obtain an EIL in order to facilitate decision-making regarding the management of this pest. Sampling programs are dependent on knowledge of the spatial distribution of the population being sampled (Kuno, 1991). Up to date, there is limited information available about the above aspects for KCT due to its recent appearance as an international pest (Vassiliou, 2010). Intervention thresholds have been established for other species of citrus thrips like *Scirtothrips citri* Moulton and *Scirtothrips aurantii* Faure. Flint et al. (1991) recommended a threshold level of 5-10% of fruits with presence of *S. citri* larvae. Regarding *S. aurantii*, treatment threshold was determined for using yellow traps as monitoring system (Samways et al., 1986; Grout & Richards, 1990). Subsequently, Grout and Stephen (2000) and Moore et al. (2008) refered a fruit infestation of 2% on oranges by *S. aurantii* larvae as an intervention threshold during the first 4 weeks after petal fall. In the case of KCT, direct fruit counting seems to be the best method for management decision-making (Conti et al., 2003; Baker, 2006; Perrotta & Conti, 2008). Monitoring of 100 fruits has been recommended in several technical documents (Baker, 2006; Jackman et al., 2011) and chemical treatment is recommended if more than 5-10% of fruits are occupied by thrips larvae (Perrotta et al., 2004; Baker, 2006). Nevertheless, these recommendations were not based on statistical data analysis.

Consequently, the goals of this paper were to determine the aggregation pattern of KCT on citrus trees, to develop an efficient and statistically accurate sampling plan to assess population changes, to relate thrips population density and economic damage and to establish an EEIL for KCT in order to reduce crop vulnerability to this pest.

Materials and methods

Sampling Groves. The study was conducted in 14 groves in 2008 and eight groves in 2009. All of the groves were commercial citrus plantations situated in an extensive citrus monoculture region in the south of the city of Valencia, Spain. The eight groves sampled in 2009 included four groves sampled the year 2008 and four new groves. The groves were located in areas where high damage by KCT was observed the previous year. Groves were selected trying to cover different environmental characteristics, as sampling plans should be developed from robust data sets covering the geographic area of the taxa and encompassing the range of environmental conditions likely to be encountered for particular species in specific environments (Naranjo & Hutchison, 1997). The groves were of sweet orange (*Citrus sinensis* (L.) Osbeck) (including the varieties Valencia late (four groves) Navel Lane late (six groves) and Navelina (two groves)), Clementine mandarin (*Citrus reticulata* Blanco) (two groves) and the hybrid Ortanique (*C.*

sinensis (L.) x *C. reticulata*) (four groves). All the groves had normally developed 11 to 15-yr-old trees in full production. Their surface area ranged from 0.5 ha to 2 ha. The groves had not been treated with pesticides for at least six months before sampling and were not treated during the sampling period.

Sampling procedure. On each grove, fifty open fresh citrus flowers or fruitlets, (five per tree from 10 trees), were haphazardly collected around the tree canopy. This sampling was repeated weekly from late March until the end of June during the two years of the study. Each flower or fruitlet sampled was immediately placed individually inside a plastic recipient containing 10ml of 70% ethanol. In the laboratory, flowers and fruitlets were carefully searched and all postembrional development stages of thrips were extracted and counted under a stereomicroscope. In total, 259 samples of 50 sample units per sample were collected: 107 samples of flowers and 152 samples of fruitlets.

Thrips identification. Adults and larvae were identified on the basis of the descriptions of Mound & Walker (1982) and Milne et al. (1997). Only a brief description of second-instar larvae of KCT is published by Kirk (1987), thus larvae of this species were identified by using our own keys based on progeny reared from KCT adults. Recently, during the redaction of this manuscript, a new key of second instar larvae of the Thripidae, with *P. kellyanus* included, has been published by Veirbergen et al. (2010). Nevertheless, first instar larvae were not included. According to our keys, first larvae (L1) of KCT was characterized by having the abdominal segment IX dorsally with a sclerotised band from the posterior margin to at least the insertion of setal pairs 1 and 2, which are knobbed. This abdominal segment presents several rows (from 4 to 5) in addition to the posterior comb. The abdominal segment X of L1 presents a sclerotised band extending from the posterior margin to at least the insertions of setal pairs 1 and 2. Finally, presence of minute microtriquia is other characteristic of this segment. Second larvae (L2) weres characterized by having one dorsal pair and two ventral pairs of large teeth laterally in the comb on the posterior margin of abdominal segment IX. Both abdominal segments, IX and X, are similar than segments of L1 in having sclerotised bands but different in the absence of rows of microtriquia (see Navarro et al. (2009) for images of the abdominal segments).

Dispersion Pattern. Aggregation indices were calculated using Taylor's power law (Taylor, 1961) and Iwao's patchiness regression (Iwao, 1968). Taylor's power law relates mean density to variance by the equation: $s^2 = a\, m^b$, where s^2 is the sample variance, m is the sample mean density, and a and b are Taylor's coefficients. The coefficient a is a scaling factor related to sample size and b is the Taylor's index of aggregation. A simple regression after log-log transformation ($\log s^2 = \log a + b \log m$) is used to estimate the coefficients. Iwao's patchiness regression, $m^* = \alpha + \beta$, m is based on the relationship of Lloyd's index of mean crowding (m^*) to mean density (m): $m^* = m + [(s^2/m) -1]$ (Lloyd, 1967). The intercept (α) is an index of basic contagion and the slope (β) has the same meaning as b in the Taylor's power law. The goodness-of-fit of the linear model was evaluated by the estimation of r^2. Two-tailed t-tests (df = $n - 2$, α = 0.05) were used to determine if the slopes of regression lines were significantly different from 1.0. Values of b over groves, years of sampling, thrips life stages and sample units were compared using 95% confidence interval.

Taylor's and Iwao's coefficients were calculated separately for each thrips life stage sampled (L1, L2, adult males and adult females) and thrips species (KCT and *Frankliniella occidentalis* (Pergande) (Western Flower Thrips, thereafter, WFT)). KCT indices were calculated separately in flowers and fruitlets, whereas in the case of WFT we calculated only indices in flowers because this species was almost absent from fruitlets.

Economic injury levels. The EIL was calculated according to the formula of Norton (1976) modified by Pedigo et al. (1986): $EIL = C/VIDK$, where C = cost of KCT control (€/ha), V = price of the fruit on origin (€/ha), I = injury units per insect per production unit [proportion fruits scarred/(insect/ha)], D = damage per unit injury [(Kg reduction/ha)/proportion fruits scarred] and K= reduction of damage with treatment (i.e. efficacy of the product, $0 < K < 1$). $I*D$ (yield loss per unit of pest) was obtained from the slope b of the damage function: $y = a + bx$, where y is the percentage of damaged fruits at harvest and x is the percentage of sample units (flowers or fruitlets) infested by thrips; therefore: $EIL = C/VIDK = C/VbK$.

To obtain the damage function we calculated the correlation coefficients between fruit injury at each grove and the percentage of flowers and fruitlets occupied by adult and immature KCT in the previous flowering and fruit setting period, using Statgraphics 5.1 program (Statgraphics, 1994). The injury at each grove was obtained directly from the average percentage of fruits with severe rind damage. We considered severe rind damage when the fruit had scars consisting in a complete ring around the calyx or a substantial partial ring with other lineal scars on the fruit surface. These fruits were considered totally lost from a commercial point of view. On each grove, a random sample of 10 fruits per tree from 10 trees was taken weekly along the summer (from July to September). During this period the damage remains constant as it is produced earlier, in late spring. The relative abundance of KCT larvae and adults on each grove was calculated as the maximum percentage of sample units infested by KCT.

Enumerative Sampling. The calculation of the minimum sample size (n) required to estimate density with a fixed coefficient of variation D was based in the Green's method (Green, 1970), which establishes the precision of the sample considering the standard error as a fixed proportion

(D) of the sample mean. The variance was substituted by its expression according to Taylor's indices:

$$n = a\, m^{(b-2)} / D^{2}$$

We used the value of D which is usually applied for extensive studies of insects populations ($D = 0.25$) (Southwood & Henderson, 2000).

Binomial Sampling. A binomial sampling plan was developed with the aim of estimating the thrips density by counting the number of sample units infested. This method can only be applied if we know the relationship between the proportion of sample units infested with KCT and the mean number of thrips per unit. We checked the fit of our data to the Wilson & Room's model (1983):

$$p = 1- \exp\left(- m \ln \left(a\, m^{(b-1)}\right) / \left(a\, m^{(b-1)} -1\right)\right),$$

where p is the proportion of infested sample units, m is the thrips mean density and a and b are Taylor's coefficients.

The sample size (n) required to estimate the thrips mean density (m) for a fixed relative precision (D) in the presence-absence sampling was calculated using the expression of the variance proposed by Kuno (1986):

$$n = D^{-2} (1 - p_{\mathrm{o}})\, p_{\mathrm{o}}^{-(2/k)-1} \left[k \left(p_{\mathrm{o}}^{-1/k} - 1\right)\right]^{-2},$$

where p_o is the proportion of non infested sample units and k was calculated from the mean and the Taylor's indices by the equation:

$$k = m^2 / (a\, m^b - m).$$

Results and discussion

A total of 5,123 adult thrips were obtained from individually collected flowers and fruitlets of the 18 citrus groves sampled during the years 2008 and 2009. The most abundant species was *Pezothrips kellyanus* (Bagnall) (KCT) (73.5% of the specimens), followed by *Frankliniella occidentalis* (Pergande) (WFT) (18.5%), *Thrips tabaci* (Lindeman) (5.3 %) and *Thrips major* Uzel (2.1%). Similarly, out of a total of 4,037 thrips larvae, the species proportions found were KCT (92.1%), WFT (3.5%), *T. tabaci* (2.7%) and *T. major* (1.2%). Similar proportions were found when considering the groves and years of sampling separately. In every one of the 18 groves sampled and on each of the two years KCT was the most abundant thrips species, followed by WFT.

Aggregation Indices. The two most abundant species, KCT and WFT, include 92% of the adults sampled and 95.6% of the larvae. Although KCT is considered more important pest, WFT is often found in citrus flowers. For that reason we determined initially the aggregation indices separately for the two species. Correlation coefficients of Taylor's power law were higher and less variable than values for Iwao's regression for all development stages, species of thrips and units sampled. The coefficient of determination (r^2) of Taylor indices ranged from 0.88 to 0.98 for KCT and from 0.70 to 0.97 for WFT. For Iwao's patchiness regression, values of r^2 ranged from 0.28 to 0.65 in KCT and from to 0.01 to 0.75 for WFT. Thus, Taylor's power law provided a consistently better fit for the relationship between the variance and the mean of thrips samples (Table 1). Therefore, only Taylor's power law parameters were used in the development of the sampling plan.

The values of the coefficient *b* of Taylor were almost always significantly > 1 ($P < 0.01$, two-tailed *t* tests, see Table 1) (except for L1 of WFT in flowers, due probably to the low number of samples), indicating an aggregated population distribution. For each thrips species, no significant differences in the value of *b* ($P > 0.05$) were found neither between sexes nor between the two larval stages (see Table 1). Consequently we calculated common *b* values for both sexes in adults and for both immature stages in larvae. Similarly, no significant differences of the value *b* were obtained between flowers and fruitlets ($P > 0.05$) and between the two thrips species, KCT and WFT ($P > 0.05$). Therefore, common values were added to Table 1.

When considering separately development stages, plant sample units and thrips species, the immature stages of thrips showed always higher *b* values than the adults. Values of *b* ranged from 1.31 to 1.47 for immature (L1 or L2) (excluding L1 of WFT, see above), whereas in adults (females or males) they ranged from 1.12 to 1.27 (Table 1). Similarly, when all adults or all larvae were grouped together, *b* values were always numerically greater for larvae than for adults. The final result of the Taylor aggregation index *b* for KCT in flowers and fruitlets together shows a value of 1.40 for larvae, significantly higher than the value of 1.19 for adults (Table 1; Figure 1).

Similar results were found by Rhodes & Morse (1989) in *Scirtothrips citri* Moult in Navel oranges. They found, as in our experience, a higher value of the Taylor index *b* for larvae ($b = 1.31$) than for adults ($b = 1.13$). Lower dispersal activity of larvae compared to that expected by winged adults is the probable cause cited by those authors for this difference. On host plants other than citrus, several studies have analyzed the dispersion pattern of WFT populations, which change with the host plant considered. However, as in our results, when comparing immature and adult stages on the same host plant, populations of immature thrips are always more clumped than populations of adults (Steiner, 1990; Salguero-Navas et al., 1994; Wang & Shipp, 2001; Park et al., 2009). The *b* value of WFT in citrus flowers found in our study is considerably lower than the *b* value observed for the same thrips species in tomato and cucumber flowers by other authors. The *b* value of WFT is common to the *b* value of KCT in our study and similar to the *b* value for *Scirtothrips citri* on citrus fruitlets (Rhodes & Morse, 1989). Thus, probably the pattern of aggregation on citrus is similar on other phytophagous thrips species as well.

It is remarkable that WFT was present in flowers but was almost absent from fruitlets. Moreover, WFT does not reproduce adequately in citrus orchards, as only 3.5% of all thrips larvae found were of WFT, whereas 18.5% of all adults identified belonged to this species. Thus, adults of WFT visit citrus flowers for feeding on pollen, but rarely reproduce on the flowers and are not attracted by the developing fruits. According to Teksam & Tunç (2009) the only thrips that damage citrus fruit are those that feed on the developing fruits, just as, or soon after, the petals fall, not those that feed on pollen and floral tissues in the flowers. WFT is not considered a pest of citrus in Italy (Marullo 2001), Cyprus (Vassiliou 2007) or Spain (Lacasa & Llorens 1996). It was reported as a pest in Japan (Tsuchiya et al. 1995), but its damage consisted in young fruit rot as a result of fungal infection caused by WFT infesting flowers at the end of the flowering period, not in scarring of the fruit.

Enumerative Sampling Plan. The required number of sample units (sample size) to monitor KCT was calculated using Green's sequential sampling plan at a precision level of $D = 0.25$ (Figure 2). The sample size was calculated separately for adults and larvae as they show significantly different aggregation patterns. The results are equally applicable to flowers and fruitlets because it was generated from a common Taylor's power law regression.

Binomial Sampling Plan. The determination of the relationship between insect density per sample unit and percentage of infested sample units can reduce the time of sampling as it allows estimating density without counting all insects present on each sampling unit. The model by Wilson & Room's (1983) fits adequately the above relationship for both adult and immature KCT in flowers and fruitlets (Figure 3). The equation describes our field data well, with $r^2 = 0.96$

for adults and $r^2 = 0.91$ for immatures. The number of required units to be sampled in order to obtain the precision level of 0.25 (SEM/mean) when using a binomial sampling plan is showed in Figure 4.

Economic injury levels. The relationships between the percentage of damage on developed fruit and the percentage of flowers or fruitlets infested by immature or adult KCT are showed in Table 2. We included in these correlations all citrus species or varieties sampled in this work, as they showed similar trends in all cases. Higher correlation coefficients are associated with immatures and the highest value corresponds to immatures on fruitlets. Other authors had previously observed that KCT damage is produced mostly by larvae feeding on fruitlets (Blank & Gill, 1997; Navarro-Campos et al., 2011). Consequently, EIL's were developed for the percentage of fruitlets infested by immature KCT.

To calculate an EIL as percentage of citrus fruitlets occupied by immature KCT we used the formula: $EIL = C/VIDK = C/VbK$. The cost of control C (285 €/ha) was composed by cost of the product (135 €/ha) and cost of the application (150 €/ha). Monetary values were taken from published assays with chlorpyrifos (96 g/liter of water) as treatment for KCT (Collof et al., 2003; Tena et al., 2009). The price of the crop was fixed at:

$$V = 0.22 \text{ €/kg} * 30{,}000 \text{ kg/ha} = 6{,}600 \text{ €/ha}$$

according to official national statistics about prices on origin for navel oranges (MARM, 2011). The efficacy (K) of the product chlorpyrifos in controlling KCT in oranges groves was taken as K = 0.68, an average among values obtained from two different authors (Vassiliou, 2007; Tena et al., 2009). The slope b of the correlation between the maximum percentage of fruitlets infested by immature KCT and the average damage on fruits at harvest was taken from the equation on table 2.

EIL = $C/VIDK$ = C/VbK = 285 €/ha / (6,600 €/ha*0.8968*0.68) = 7.1 (percentage of fruitlets infested by immature KCT).

The EEIL using chlorpyrifos as insecticide can be approximated as 1.7*EIL according to Higley & Wintersteen (1996). Therefore: EEIL = 12% of fruits occupied by immature KCT. This percentage corresponds to a population density of 0.20 immature thrips per fruit (see Figure 3). Since economic and dynamic biological parameters determined the EIL, few studies have concentrated on the development of EIL in perennial crops after its first theoretical definition (Damos & Savopoulou-Soultani, 2010). The IPM guidelines of the University of California recommended a threshold for treatment with sabadilla for *Scirtothrips citri* in Valencia oranges, of 10% infestation by immature thrips without predaceous mites, and 20% if predaceous mites are present. For navel oranges, a 5% infestation of immatures without predaceous mites may warrant treatment and 10% when predaceous mites are present above a threshold of 0.2 predaceous mites per leaf (Flint et al., 1991).

Sample size. The estimated sample size depends on the population density of the species. According to our results, the EEIL of 12% corresponds to a population density of 0.20 immature thrips per fruit. Thus, when the population density is 0.20 thrips per sample unit, the number of units to be sampled, according to the enumerative sampling plan, would be 125 for adult thrips and 200 for immature thrips (see Figure 2). This is the minimum number of units to be sampled if we wish to attain the desired precision level of = 0.25 at population densities around the EEIL. On the other hand, according to the binomial sampling plan, the number of units to be sampled when the population density is 0.20 thrips per unit would be 160 for adult thrips and 310 for immature thrips (see Figure 4). These sample sizes are considerably larger than earlier recommendations (Baker, 2006; Jackman et al., 2011).

At higher population densities, fewer sample units are required. For instance, to estimate a mean density of 0.6 thrips per unit, 50 sample units are required for adults and 100 for larvae (see Figure 2).

In summary, after the study of dispersion parameters of KCT and WFT, we have shown that these phytophagous thrips have patterns of aggregation similar between species and between citrus unit sampled, flowers or fruitlets, but differing between immatures and adults. Sample sizes needed to estimate population densities for KCT and WFT in citrus flowers or fruitlets with preestablished precision levels were developed. The curves that relate sample size with thrips population, either for enumerative or presence-absence sampling, will be useful to estimate population densities of KCT or WFT from citrus flowers/fruitlets. From these results, and considering that binomial or presence-absence sampling (counting plant sample units with thrips present) is considerably easier and less time-consuming that counting all thrips on each unit, a binomial sampling plan is recommended for monitoring KCT in IPM programs to determine if the pest reaches the EEIL. Not less than 300 fruitlets should be monitored weekly from petal fall until the fruits reach 4 cm in diameter. Fruits 4 cm or larger in diameter are rarely scarred by citrus thrips (Flint et al., 1991; Blank & Gill, 1997). Insecticide treatment will only be necessary if more than 12% of fruitlets are occupied by larvae.

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Figure legends

Fig.1. Taylor’s power law regression for adult and immature Kelly’s Citrus Thrips (KCT) *Pezothrips kellyanus* on citrus flowers or fruitlets individually collected (50 units/sample); Combined data from 18 groves sampled during 2008 and 2009. Broken line represents expected immature KCT and solid line represents expected adult KCT.

Fig.2. Number of sample units required for sampling Kelly’s Citrus Thrips (KCT) *Pezothrips kellyanus* populations in citrus, based on the number of thrips per flower or fruitlet, to achieve a fixed precision level of 0.25. The number of real samples encountered at each population density is shown in a secondary axis.

Fig.3. Relationship between the proportion of sample units infested with adult (A) and immature (B) Kelly’s Citrus Thrips (KCT) *Pezothrips kellyanus* and the mean number of thrips per sample units. X-axis truncated at 1 (approximately 95% of samples have a mean number of thrips per unit < 1).

Fig. 4. Number of sample units required for sampling Kelly’s Citrus Thrips (KCT) *Pezothrips kellyanus* populations in citrus, based on the percentage of flowers or fruitlets infested, to achieve a fixed precision level of 0.25. The number of real samples encountered at each population density is shown in a secondary axis.

Figures

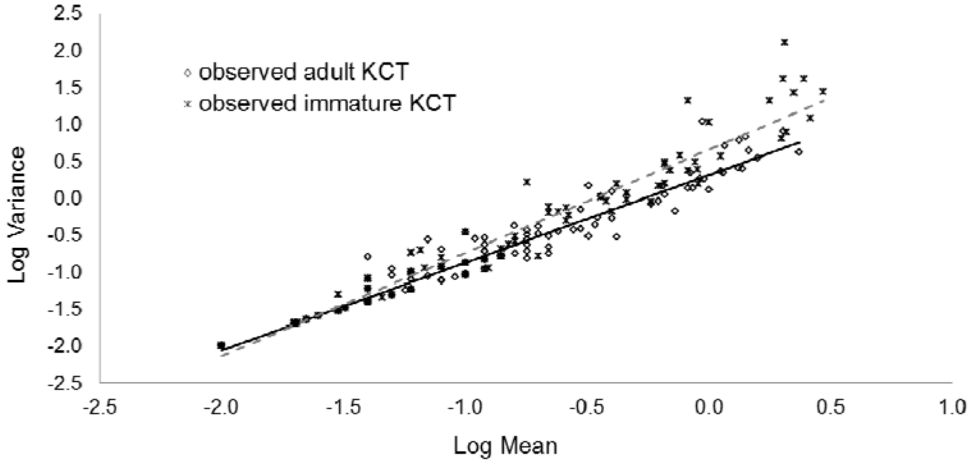
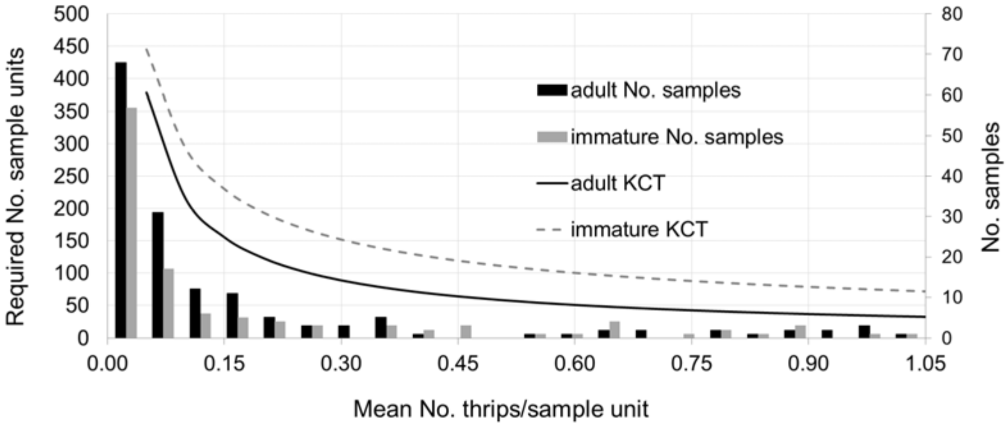


Fig. 1



500
450
400
350
300
250
200
150
100
50
0
Required No. sample units
80
70
60
50
40
30
20
10
0
No. samples
adult No. samples
immature No. samples
adult KCT
immature KCT
0.00
0.15
0.30
0.45
0.60
0.75
0.90
1.05
Mean No. thrips/sample unit

Fig. 2

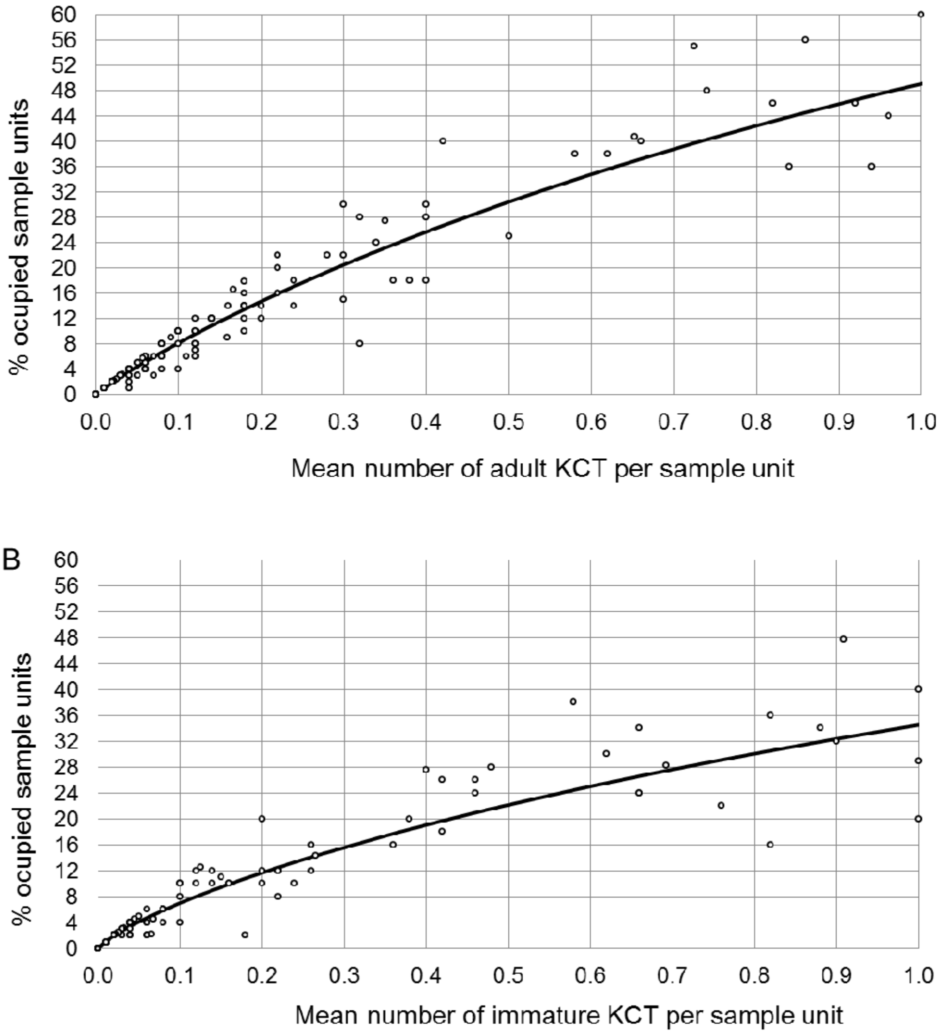

% ocupied sample units
60
56
52
48
44
40
36
32
28
24
20
16
12
8
4
0
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
Mean number of adult KCT per sample unit
B
% ocupied sample units
60
56
52
48
44
40
36
32
28
24
20
16
12
8
4
0
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
Mean number of immature KCT per sample unit

Fig. 3

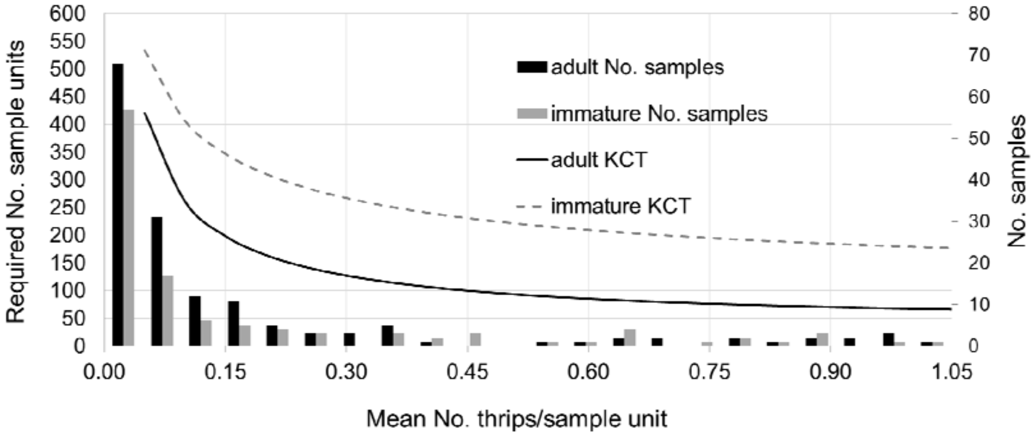

Required No. sample units
600
550
500
450
400
350
300
250
200
150
100
50
0
No. samples
80
70
60
50
40
30
20
10
0
adult No. samples
immature No. samples
adult KCT
immature KCT
0.00
0.15
0.30
0.45
0.60
0.75
0.90
1.05
Mean No. thrips/sample unit

Fig. 4

Tables

Table1. Regression statistics generated by Taylor’s power law for the relationship between the variance and mean of Kelly’s Citrus Thrips (KCT) *Pezothrips kellyanus* and Western Flower Thrips (WFT) *Frankliniella occidentalis* sampled on citrus flowers and fruitlets.

Species	**Sample unit**	**Lifestage**	***n***	***a***	***b***	r^2	***t*-value for slope = 1**	**Confidence interval (*b*)**
KCT	flower	Female	61	1.69	1.15	0.962	5.04	1.09 - 1.21
KCT	flower	Male	50	2.90	1.27	0.968	8.06	1.20 - 1.34
KCT	flower	L1	41	4.25	1.38	0.946	7.12	1.27 - 1.48
KCT	flower	L2	44	6.12	1.47	0.943	8.49	1.36 - 1.59
KCT	fruitlet	Female	81	2.44	1.22	0.891	4.65	1.13 - 1.32
KCT	fruitlet	Male	49	1.63	1.12	0.976	4.61	1.07 - 1.17
KCT	fruitlet	L1	18	4.05	1.36	0.880	2.84	1.09 - 1.62
KCT	fruitlet	L2	59	3.30	1.31	0.947	7.53	1.23 - 1.39
WFT	flower	Female	52	1.62	1.14	0.971	4.88	1.08 - 1.19
WFT	flower	Male	25	1.69	1.16	0.957	3.08	1.05 - 1.26
WFT	flower	L1	13	1.78	1.13	0.699	0.57[1]	0.64 - 1.61
WFT	flower	L2	19	4.01	1.37	0.887	3.11[1]	1.12 - 1.61
KCT	flower	Adult[2]	69	2.12	1.21	0.968	7.83	1.16 - 1.26
KCT	flower	Immature[2]	56	5.41	1.44	0.950	9.81	1.35 - 1.53
KCT	fruitlet	Adult	91	2.05	1.18	0.924	4.92	1.11 - 1.25
KCT	fruitlet	Immature	63	3.36	1.31	0.949	8.01	1.23 - 1.39
WFT	flower	Adult	55	1.76	1.16	0.976	6.48	1.11 - 1.21
WFT	flower	Immature	26	3.98	1.38	0.867	3.42	1.15 - 1.60
KCT	flower+fruitlet	Adult	160	2.09	1.19	0.956	9.31	1.15 - 1.23
KCT	flower+fruitlet	Immature	119	4.61	1.40	0.952	13.74	1.34 - 1.46

[1] Indicates t-value for slope = 1 ($P > 0.01$)

[2] Adults = combined analysis for males + females; Immatures = data for L1 + L2

Table 2. Equations relating, on each grove, the percentage of developed citrus fruits with severe scarring by Kelly's Citrus Thrips (KCT) *Pezothrips kellyanus* (*y*) with the maximum percentage of flowers or fruitlets infested by adults or immature KCT (*x*). Data obtained from 14 groves in 2008 and eight groves in 2009.

Sample unit	**KCT Life stage**	**Equation**[1]	**r^2**	**n**	**P-value**
flower	**adult**	$y = 0.3544x$	0.64	22	$P < 0.0001$
flower	**immature**	$y = 0.5461x$	0.81	22	$P < 0.0001$
fruitlet	**adult**	$y = 0.6594x$	0.51	22	$P < 0.001$
fruitlet	**immature**	$y = 0.8968x$	0.92	22	$P < 0.0001$

[1] The intercepts are no significantly different to zero ($P > 0.05$).