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Peer-reviewed author version

DANIELS, Silvie; WITTERS, Nele; Beliën, Tim; VRANCKEN, Kristof; VANGRONSVELD, Jaco & VAN PASSEL, Steven (2017) Monetary Valuation of Natural Predators for Biological Pest Control in Pear Production. In: Ecological economics, 134, p. 160-173.

DOI: 10.1016/j.ecolecon.2016.12.029
Handle: http://hdl.handle.net/1942/23061

Monetary valuation of natural predators for biological pest control in pear production

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Abstract

In spite of global actions, biodiversity is declining at an alarming rate. Despite the need for objectively comparable monetary standards to include biodiversity arguments in policymaking, research on the relationship between species diversity and its valuation from a societal perspective is still scarce.

In this paper, a methodological framework for the valuation of natural predators based on their ecological role in the agroecosystem is introduced. The framework integrates a dynamic ecological model simulating interactions between species with an economic model, thereby quantifying the effect of reduced numbers of natural predators on the net farm income. The model attributes an objective monetary value to increased species diversity through the changes in the provisioning of a marketable good.

Results indicate that the loss of three predators could decrease net farm income with 88.86 €ha^{-1} to 2186.5 €ha^{-1}. For the pear production sector in Flanders in 2011, this constitutes to an indirect use value of 0,68 million € for one predator and 16.63 million € for the presence of three predators. The aim is to provide a justification for the argument for biodiversity conservation, based on the ecological function of species, through the delivery of comparable monetary standards.

Keywords: monetary valuation, ecological function, biodiversity loss, biological pest control, ecological-economic modeling

1. Introduction

In spite of global actions, biodiversity is declining at an alarming rate (Butchart et al., 2010). The transformation of natural landscapes to agricultural systems, the abandonment of farmland with high natural values, and the intensification and changing scale of agricultural operations are the key processes driving low ecosystem quality and biodiversity losses in agro-ecosystems (Liu et al., 2013; Reidsma et al., 2006; Smith et al., 2013). Available evidence strongly indicates the importance of agro-ecosystem restoration for environmental benefits and acknowledges the potential to simultaneously minimize biodiversity harm at the local level and increase farm yields (Barral et al., 2015; Cunningham et al., 2013).

Although measurements of biodiversity have often been investigated, analyses at the farm scale and specific studies providing insights into factors driving agro-ecosystem community structure are scarce (Birrer et al., 2014; Farnsworth et al., 2015; Turtureanu et al., 2014). Furthermore, habitat and increased numbers of natural predators facilitate the provisioning of important ecosystem services such as maintaining agricultural pest control, and may increase efficiency in controlling pests. However, the relationship between natural predators and pest reduction potential is not well established (Chaplin-Kramer et al., 2013; Letourneau et al., 2015). More specifically, the control of pests and diseases by biological control agents contributes positively to the provisioning of agricultural products of a better quality or in higher quantities, however the relationship between the presence of natural predators and pear production in particular has not been investigated yet. Mathematical models for biological pest control have proposed the use of linear feedback control strategies to indicate how natural enemies should be introduced into the environment (Rafikov and de Holanda Limeira, 2011).

Farmers are in need of supporting evidence of biodiversity benefits outweighing the opportunity costs incurred in order to strengthen the argument for biodiversity conservation at the farm level. Moreover, without economic valuation of the environment, policy decisions that contradict economic rationality could be supported. In spite of the need for objectively comparable monetary standards, empirical literature investigating the relationship between species diversity and its valuation from a farmer's perspective is still scarce (Finger and Buchmann, 2015). The elicitation of values for biodiversity with the aid of stated preference methods suffers from the generally low level of awareness and understanding of what biodiversity means on the part of the general public (Bräuer, 2003; Christie et al., 2006). Furthermore, the willingness-to-pay (WTP) for species that are unfamiliar or undesired by the general public could yield extremely low values despite the fact that these species could be performing indispensible ecological services and thereby contribute indirectly to the farmers' income. This, combined with the complexity of biodiversity (Feest et al., 2010), might just overstretch the capacity of the usual stated preference valuation techniques for the valuation of biodiversity (Bartkowski et al., 2015). Revealed preference techniques have the advantage that they rely on the observation of peoples' actions in markets. However, the majority of species do not have a market price. Letourneau et al. (2015) value the changes in natural enemy diversity by studying changes in producer and consumer surplus. They estimate that losses in natural enemy species richness in squash and cucumber fields in Georgia and South Carolina could cost society between \$1.5 and \$12 million in social surplus every year.

In this paper we provide a complementary approach and overcome some of the limitations mentioned by Letourneau et al. (2015) by (i) including an ecological model that allows for spatial and temporal variation in the ecosystem service potential of natural enemies, their interactions with pests and the effect of those interactions on pest control cost savings, (ii) providing an alternative approach when the relationship between natural enemies and crop damage is not known, as is true for the majority of cases, (iii) confirming the results of Letourneau et al. (2015) that values are case specific and providing these values for a different crop in a different climatic zone, with a different pest insect and natural enemies and (iv) including the comparison of realistic alternative scenarios of species richness and measure economically meaningful data in a field setting that comes close to the conditions that prevail on actual farms.

This paper values the biological pest control provided by three natural predators of pear psylla (*Cacopsylla pyri L.*) (Homoptera: Psyllidae) in organic pear orchards in Flanders (Belgium). Three main research hypotheses are investigated:

H_1: a decrease in natural predators' species richness causes a decrease in pest suppression

H_2: a reduction in species richness of natural predators reduces marketable agricultural production, thereby decreasing farm revenues

H_3: an alternative valuation method for natural predators based on their ecological function in the ecosystem can be identified

The first hypothesis is quantified through the development of an ecological simulation model; the second hypothesis is supported by the use of production functions and a direct market valuation technique and the third hypothesis integrates all three research tools: an ecological simulation model with a production function approach and a direct market valuation technique.

The approach results in a monetary value for marginal changes of biodiversity losses (here: reduced number of natural predators) whereby the functional role of the species in the ecosystem (here: pest control) is the key mechanism for affecting the provisioning of a marketable good (here: agricultural production). The aim is to provide support for the decision making process so that not only the costs of biodiversity conservation can be taken into account but also the monetary benefits.

2. Case study description: biological pest control of pear psylla

Apple and pear production in Flanders accounted for 13764 hectares in 2011 and increased to 14285 ha in 2013, comprising 3% of all farmland. Since 2005, pear production comprised just over half the hectarage with 7607 ha in 2011 and 7995 ha in 2013. The province of Limburg accounts for 85% of the total apple and pear production in Flanders. In 2011, an average farm possessed 12,0 hectares of pear plantations and 14,4 hectares in 2013. Organic production accounts for only a small fraction but production areas increased by 224% over the period 2002 – 2012 from 25,09 ha to 58,07 ha. Average yields were 36031 kg per ha in 2011 and 38681 kg per ha in 2013, with a maximum of 44751 kg per ha in 2014 (Van der Straeten, 2016). Yearly sales volumes of pears amounted to almost 340 million kg in 2014 (NIS, 2015). Annual sales revenues ranged between 15133 €ha^{-1} in 2011 and 20114 €ha^{-1} in 2013 (Van der Straeten, 2016). Yearly average selling prices for the period 2009-2013 were 0.57 €kg^{-1} for first-class pears, 0.39 €kg^{-1} for second-class pears and 0.88 €kg^{-1} for organic pears (personal communication Regional Auction Borgloon). Assuming that annual sales volumes would consist of second class pears only, 55.68% of gross revenues would be lost since if harvests consisted of only second class pears and gross revenues would amount to 11736 €ha^{-1} as compared to 26481 €ha^{-1} for harvests consisting of only first class pears (Van der Straeten, 2016). The sector is characterized by a decrease in the number of farms and an increase in the average size. Sales volumes and revenues remain extremely volatile due to changing environmental and market conditions (Platteau et al., 2014).

A major threat for the pear production industry is pear psylla (*Cacopsylla pyri*). The adults cause damage both directly by extracting nutrients from the meristem tissue, and indirectly by causing russet and roughness on pear skin. Pear psylla's status as a major pest is based on its damage potential and its ability to develop resistance to insecticides. Through the production of honeydew, the growth of black, sooty fungi, causing so-called “black pears” is facilitated. It russets the pear skin and causes the fruit to be downgraded, thereby decreasing its market value (Erler, 2004). Literature quantifying the relationship between pest insect density levels and the occurrence of fruit russet is however scarce (Brouwer, 2008). Research revealed the failure of conventional chemical control agents against the pear tree psyllid, stressing the need for alternative strategies such as enhancing natural arthropod enemies (Daugherty et al., 2007; Erler, 2004; Rieux et al., 1999). Pear psylla are commonly attacked by several different natural enemies (e.g. *Anthocoris nemoralis* (Heteroptera: Anthocoridae), *Allothrombidium fuliginosum* (Acari: Trombidiidae) and *Heterotoma planicornis* (Hemiptera: Miridae)), of which *A. nemoralis* is the most common predator. Data collection is comprised of two independently executed field tests. The first field test comprises field data collected on 7 plots in organic *Conférence* pear orchards in Hesbaye (Belgium) for two years from 2013 until 2014. Each field test sampled pear psylla eggs and nymphs on multiple days with an interval of 2-3 weeks (See ANNEX A.1 for data sampling method and pooled results). The second dataset was obtained from field tests performed every two weeks for the period 2010-2011 on 7 different organic plots in Hageland (Belgium) and Gelderland and Limburg (NL). The same techniques were used to assess mean egg numbers and larvae numbers (visual scouting and the beating tray method) (see ANNEX A.3).

Counts for the presence of beneficial insects were performed between February and October of 2013 and 2014 in organic *conférence* pear orchards (see ANNEX A.2 for data sampling methods and pooled counts).

3. Methodology

3.1 Ecological model construction

The ecological model simulates predator-prey dynamics between the pest insect and three of its main natural enemies to analyze the effect on pear psylla (Pp) abundance in case of a reduction in species diversity and abundance of natural predators. The main criterion for selection of the natural enemies is the importance of a species as main pear psylla antagonist and has been verified through expert opinion and literature review. With the use of STELLA 10.0.6 (Stella; available at http://www.iseesystems.com) (Costanza and Gottlieb, 1998; Costanza and Voinov, 2001), the biodemographics of a pest insect *Cacopsylla pyri* (Pp) and the interaction with (i) *Anthocoris nemoralis* (An), (ii) *Allothrombidium fuliginosum* (Af) and (iii) *Heterotoma planicornis* (Hp) (Erler, 2004) are simulated over a period of one year whereby:

$$dn_{Pp}/dt = f(\, n_{An}, n_{Af}, n_{Hp}, n_{other}) \qquad \text{(eq. 1)}$$

with n the species abundance and n_{other} the effects of other predators not explicitly included in the model.

Initial model parameter values are allowed to vary on a daily basis and can be found in ANNEX B. The food fractions (the fraction that Pp makes up in a daily diet of a natural predator) were set at 0.8 for specialists (An) and 0.2 for generalists (Af and Hp) (Piechnik et al., 2008). The number of Ppe (eggs) and Ppn (nymphs) preyed upon per day are variable and depend on prey density according to a logistic dependency. The higher the density of Pp, the more Pp will be subject to predation as opposed to a linear dependency approach. Natural mortalities for all species are represented as a time-dependent variable longevity. Both Oviposition and longevity are non-constant parameters, depending on the time of the year and the adult generation cycle. The carrying capacity for Pp has been determined by excluding predation under the assumption that resource use did not pose constraints. The growth function is modeled as a logistic growth curve, followed by a decline of the population.

In the model, the effects of omitted species in the agro-ecosystem have been taken into account in various ways:

(i) An, Af and Hp are themselves subjected to predation from omitted species at higher trophic levels and this effect has been taken into account by the inclusion of a predation fraction for An, Af and Hp of 0.6. All natural predators are continuously exposed to this predation fraction, on top of the longevity variable. The natural predators, as well as the pest insect, therefore disappear from the model either by natural death or due to predation by omitted species.

(ii) An, Af and Hp have multiple food sources besides Pp which is represented in the model by varying the An, Af and Hp food fractions between 0 and 1. The predation fractions therefore allow the predation of omitted species.

Other predators besides the three natural predators included in the model prey on Cacopsylla pyri. This effect is not included in the model, since the main aim of the model is to assess the specific effect of the loss of three specific natural predators on pest insect dynamics.

Despite the potential for beneficial effects for other natural predators upon removal of one natural predator, no such interspecies competition has been taken into account due to various reasons:

(i) different pest stages are attacked by different predators. Each species is modelled throughout their different life stages (egg, nymph, adult) and it is only that specific stage which is under predation from that natural predator.

(ii) there is an overlap in timing of occurrence for the three natural predators but their peak times differ considerably, thereby reducing the potential for competitive effects.

(iii)they differ in their nature (generalists/specialists) and generalists have the ability to switch to other food sources.

(iv) the pest insect is abundant and there is no lack of food resources for all predators.

Biodiversity loss is then quantified by the loss in species richness of natural predators which is defined as the loss in the total number of species present, and assessed for its effect on the species abundance of the pest insect, both expressed in absolute numbers per hectare. A total of eight model scenarios (S1 – S8) were developed with S1 containing all species, S2 - S4 extinction of one natural predator, S5 - S7 extinction of two predators and S8 no natural predators.

Predator species	**Scenarios**							
	S1	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**
PREDATOR 1: *Anthocoris nemoralis* (An)	x	x	0	x	0	x	0	0
PREDATOR 2: *Allothrombidium fuliginosum* (Af)	x	x	x	0	x	0	0	0
PREDATOR 3: *Heterotoma planicornis* (Hp)	x	0	x	x	0	0	x	0

Table 1: Schematic overview of the eight predator loss scenarios developed, indicating the presence (x) or absence (0) of a natural predator for 8 scenarios (S1-S8). Scenario 1 (S1) contains the pest insect and three natural predators, scenario 2 to 4 (S2 - S4) contains the pest insect and two predators, scenario 5 to 7 (S5 - S7) contains the pest insect and one natural predator and scenario S8 represents the scenario without predators.

The effect of a loss of species richness of natural predators is modeled for a one-year period whereby the effect on pest suppression results in the absolute biological pest control loss BPC_{loss} composed as the sum of (i) an increase in pest insect abundance (Pp_I) and (ii) a decrease in predation (C_{loss}) with

$$BPC_{loss} = \sum(C_{loss}, Pp_I) > 0 \qquad \text{(eq.2)}$$

with $Pp_I = \sum(Ppe(S1) + Ppn(S1)) - \sum(Ppe(Sx) + Ppn(Sx)) < 0$ (eq.3)

and $C_{loss} = C(S1) - C(Sx) > 0$ (eq.4)

Since eggs and nymphs are the main target for predation by predators, Pp_I calculates the difference between S1 and each of the other scenarios (Sx) for the sum of all eggs Ppe and nymphs Ppn appearing per year.

The relative loss in biological pest control $RBPC_{loss}$ for S2-S8 compared to S1 is then

$$\frac{BPC_{loss(Sx)}}{BPC_{loss\,(S1)}} \qquad \text{(eq.5)}$$

As eggs and nymphs are the main target for predation by predators, $RBPC_{loss}$ is described in terms of numbers for pest insect eggs and nymphs. These losses result in exponential increases of numbers of adults over multiple generations per year. The latter numbers are then linked to the occurrence of black pears through the identification of an ecological-economic linking function.

3.2 Identification of ecological-economic linking function

Linking biological pest control losses, which result from the ecological simulation model, with the economic model (section 3.3) is established by identifying a damage threshold function that links the maximum pest density level ∂_{Ppa} (adults $ha^{-1}y^{-1}$) over all eight scenarios with the yield quality decrease (black pear occurrence) γ (%). It is assumed that the maximum ∂_{Ppa} at any given time throughout the growing season will affect fruit russeting. Experimental fruit research institutions recommend action to avoid 'detectable damage' when monitoring reveals pest insect densities ∂_{Ppa} > 1000 adults per 10 beatings ($\partial_{ETL} = 386*10^6$ adults ha^{-1})[1]. They then define the Economic Treshold Level (ETL) as the percentage of black pears that is encountered at ∂_{ETL}.

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[1] ∂_{Ppa}>1000 (adults per 3 shoots)*20 (assume 5% caught)*40 (shoots per tree)* 1450 (trees per ha) = $386*10^6$ (adults per ha)

Since the shape of the damage threshold function is not known, two sets of four hypothesized relationships are constructed to simulate the correlation between Pp_a density levels δ_{Ppa} ($ha^{-1}y^{-1}$) and black pear occurrence γ (%) for the two assumptions made:

(i) Linear: $\gamma_{lin} = \alpha\, \partial_{Ppa}$ (eq. 6)

(ii) Logistic: $\gamma_S = \frac{k}{(1+(k-\partial_0/\partial_0)} * exp^{r\partial_{Ppa}}$ (eq. 7)

(iii) Logarithm: $\gamma_{log} = 1 - exp^{-\partial_{Ppa}}$ (eq. 8)

(iv) Exponential: $\gamma_{exp} = exp^{\partial_{Ppa}}$ (eq. 9)

For the two sets of relationships, this results in a lower (γ_l) and upper (γ_u) percentage of black pears for each scenario S1-S8 with:

$\gamma_l = \min(\gamma_{lin}, \gamma_s, \gamma_{log}, \gamma_{exp})$ and $\gamma_u = \max(\gamma_{lin}, \gamma_s, \gamma_{log}, \gamma_{exp})$ (eq. 10)

The first set of four hypothesized relationships assumes that the maximum ∂_{Ppa} in the no-predator scenario (S8) results in 100% black pears. This results in an ETL of 0,28% and 32,02% black pears (figure 1 left vertical axis).

The second set of four hypothesized relationships assumes that the ETL for ∂_{Ppa} equal to $386*10^6$ adults ha^{-1} equals 1% of black pears. This results in a potential maximum amount of black pears of 12.90% at maximum ∂_{Ppa} [2] (figure 1 right vertical axis).

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[2] It is assumed that 'detectable damage' for the farmer equals 1% black pears.

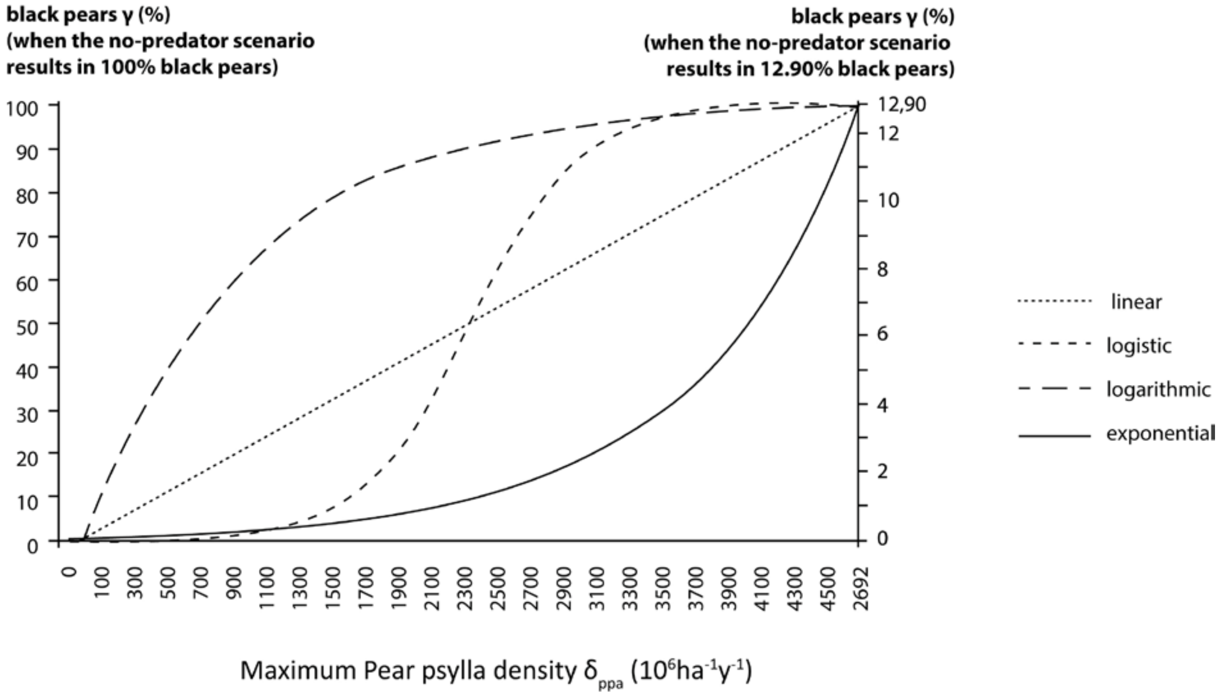

Figure 1: shows the four hypothesized relationships γ_{lin}, γ_S, γ_{log}, γ_{exp} that can exist between the maximum pest density level δ_{ppa} (10^6ha^{-1}y^{-1}) and the occurrence of black pears γ (%). For each scenario, changing natural predator species results in changing pest density levels. The damage threshold function then assesses the lower (γ_l) and upper (γ_u) percentage of black pears encountered at the maximum pest density level δ_{ppa} (10^6ha^{-1}y^{-1}). For the first set of hypothesized relationships (left vertical axis), the maximum ∂_{Ppa} in the no-predator scenario (S8) results in 100% black pears (and therefore the ETL ranges between 0,28% and 32,02% black pears). The second set of hypothesized relationships (right vertical axis) assumes that the ETL equals 1% of black pears, resulting in a maximum potential percentage of black pears of 12.90%.

3.3 Economic model construction

The economic model assesses the costs of a decrease in abundance and richness of natural predators by analyzing the effects on yield quality decreases at farm scale calculating the impact on (i) gross revenue and (ii) net income.

The gross revenue I_G for each scenario is defined as $I_G = \sum(I_b, I_f)$ with b black pears and f first class pears where I_b(respectively I_f) represents the gross revenue with $I_b = P_b * Q_b$ (respectively $I_f = P_f * Q_f$), with P_b (respectively P_f) the price and Q_b (respectively Q_f) the quantity. The farm net income for each scenario is defined as $I_F = I_G - TC$ with TC the total costs, C_v the sum of all variable costs and C_f the sum of all fixed costs.

Annual accounting data on yields (kg ha^{-1}), revenues (€ ha^{-1}), variable costs (€ ha^{-}1) and fixed costs (€) for organic production and non-organic production (ANNEX C) were used from the Agricultural Monitoring Network (LMN) data (Van der Straeten, 2016), which are conform FADN[3] data collection procedures. The LMN dataset contains 53 non-organic pear farmers (accounting for 662 hectares) and provides annual accounting data for the period 2009-2014 (Van der Straeten, 2016). Some numbers needed adjustment to represent organic production taking into account the following assumptions: (1) yields (kgha^{-1}) are 80% of non-organic production with μ = 30092,27 kgha^{-1} and s = 3652,28[4], (2) organic management requires 30 % more full-time equivalents (FTEs) with μ = 4118,33 €ha^{-1} and s = 352,15 for non-organic production and μ = 5353,83 €ha^{-1} and s = 457,79 for organic production (EC, 2013).

The parameters for which differences exist between organic and non-organic production are discussed here, for all other parameters we refer to ANNEX C. The yearly average selling price for 2009-2013 for all pear classes was μ = 0.57 €kg^{-1} (s = 0,16) (Van der Straeten, 2016) (with μ = 0.55 €kg^{-1} and s = 0,16 for first class non-organic pears, μ = 0.88 €kg^{-1} (s = 0,17) for organic pears and μ = 0.39 €kg^{-1} (s = 0,12) for black pears (personal communication Regional Auction Borgloon)).”

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[3] Farm Accounting Data Network

[4] With μ the average and s the standard deviation

The Department of Agriculture and Fisheries[5] states that organic farmers receive 50% higher subsidies (μ = 140 €ha^{-1} (***s*** = 55) for non-organic and μ = 210 €ha^{-1} (***s*** = 55) for organic production). Costs for crop protection account for 1579,83 €ha^{-1} (***s*** = 100,12) for non-organic production and no costs are taken into account for organic production (Van der Straeten, 2016).

Yields of black pears for each scenario were calculated based on the percentages of black pears encountered in the two sets of hypothesized relationships (section 3.2) and hence differ for all scenarios under analysis. For reasons of simplicity, other production factors (*e.g.* conservation costs, maintenance, packaging) are assumed equal for non-organic and organic production. The accounting data are imported into the risk analysis tool Aramis (@risk) and all economic parameters are stochastic variables to calculate a confidence interval for the gross revenues and the farm net income for each scenario S1-S8. Results from the risk analysis show the difference in gross revenues and the farm net income for a 95% confidence intervals for S1 to S7 for the two sets of relationships and are linked to yield quality decreases (black pear increases) that result directly from species richness losses.

3.4 Model calibration

We calibrated the dynamic simulation model for pest suppression in organic agriculture based on field data from one year for which most data points were available (2010). The units of field measurements (mean eggs/10 shoots) were transformed to yield model parameter units (absolute egg numbers per hectare), based on 33,84 shoots/tree on average, 5% of the eggs captured and 1714 trees per hectare (Van der Straeten, 2016). The reference model (S1) predicts both the peak density as well as the timing of the peaks relatively well (see ANNEX D).

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[5] http://lv.vlaanderen.be/nl/bio/subsidies/hectaresteun-biologische-productiemethode-pdpo-iii (last visited: 08-08-2016)

4. Results

4.1 Losses of natural predators result in significant decreases for biological pest control $RBPC_{loss}$

The effect of a loss of species richness of natural predators on pest insect suppression revealed an increase in pest insect abundance (Pp_I) (see eq.3) with decreasing predator numbers depending on the generalist/specialist nature of predation. For the reference scenario (S1), containing the 3 natural predators under investigation, the peak density of the sum of pest insect eggs and nymphs equaled 1237*10^6ha^{-1}. S7 simulated the absence of An and Af revealing an increase to maximum peak density of 23888 (10^6ha^{-1}) or an increase rate of 19.31. S2 (respectively S3; S4; S5; S6) simulates the absence of Hp (respectively An; Af; An & Hp; Af & Hp; An & Af) resulting in a peak density increase rate of 6.57 (respectively 10.21; 8.82; 12.94; 19.31) revealing increases in eggs and nymphs absolute numbers to 2551 (respectively 12633; 8130; 10905; 16005) (10^6ha^{-1}).

Furthermore, for S1, 133 (10^6ha^{-1}) of the total eggs and nymphs (see section 4.1) are consumed in absolute terms (eq. 4). For S2 (respectively S4; S5; S6; S7) predation decreased to 113 (respectively 88; 78; 27; 4) (10^6ha^{-1}) equal to a reduction of 14.45 % (respectively 33.71%; 96.98%; 79.61%; 41.43%) compared to predation in S1. For S3 an increase in predation to 290 (10^6ha^{-1}) was observed. This can be explained by the sharp increase in absolute numbers but when comparing relative numbers predation decreased from 10.72% in S1 to 2.30% for S3.

Summing the (i) increase in pest insects density and (ii) the decrease in predation resulted in an estimate for the biological pest control provided by differing combinations of natural predators (eq. 2). For S1, 10.72% of the total eggs and nymphs are consumed. For S2 to S7 the relative biological pest control $RBPC_{loss}$ reduced gradually to 4.45%, 2.30%, 1.08%, 0.71%, 0.17% and 0.02%.

Predator losses resulted in exponential increases of numbers of pest insect adults over multiple generations per year, and the maximum peak densities for pest insect adults δ_{ppa} (10^6ha^{-1}y^{-1}) increased from 146.92 for S1 to 379.77 (respectively 386.00; 1331.68; 1815.20; 2134.83; 2714.97; 4036.55) for S2 (respectively S3; S4; S5; S6; S7). The no predator scenario (S8) resulted in adult pear psylla densities of 4692.23 10^6ha^{-1}y^{-1}. Biological pest control losses of eggs and nymphs therefore induced adult pest insect increases as compared to S1 of 258% for S2, 263% for S3, 1236% for S4, 1453% for S5, 1847% for S6, 2747% for S7 and 3193% for S8, thereby strongly supporting Hypothesis 1.

Next, the decrease in biological pest control, particularly the increase in adult pest insect densities, was investigated for its potential to decrease pear quality in terms of % black pears observed.

4.2 Correlation between maximum pest insect density δ_{ppa} and black pear occurrence γ

For each scenario, the maximum pest density δ_{ppa} (10^6ha^{-1}y^{-1}) resulting in a lower (γ_l) and upper (γ_u) percentage of black pears for the two sets of four hypothesized relationships γ_{lin}, γ_S, γ_{log}, γ_{exp} was obtained. The results are presented in table 2.

(1)	(2)	(3)	(4)	(5)	(6)
Scenario	Max pest insect density δ_{ppa} (10^6ha^{-1}y^{-1})	Loss of three predators causes 100% black pears		Loss of three predators causes 12.90% black pears	
		Lower % black pears (γ_l)	Upper % black pears (γ_u)	Lower % black pears (γ_l)	Upper % black pears (γ_u)
S1	146.92	0.14	13.66	0.01	1.08
S2	379.77	0.27	31.60	0.03	2.25
S3	1331.68	3.79	73.60	0.31	6.32
S4	1815.20	6.14	83.72	1.01	7.75
S5	2134.83	8.46	88.17	2.08	8.53
S6	2714.97	15.10	93.38	4.39	9.66
S7	4036.55	56.63	99.38	9.02	11.28
S8	4692.23	100.00	100.00	12.90	12.90

Table 2: the lower (γ_l) and upper (γ_u) percentage of black pears that can be encountered for the scenarios under investigation (S1-S8). Column (2) represents the maximum adult pest insect densities δ_{ppa} that are expected for each scenario. Column (3) and (4) represent the lower (γ_l) and upper (γ_u) percentage of black pears under the assumption that the overall maximum ∂_{Ppa} in the no-predator scenario S8 results in 100% black pears. Column (5) and (6) represent the lower (γ_l) and upper (γ_u) percentage of black pears under the assumption that the ETL equals 1% of black pears, corresponding to a potential maximum of black pears of 12.90%.

4.3 Economic impact of natural predator losses

The economic impact of a loss of natural predators is first discussed for the first set of hypothesized relationships, which assumed that the loss of three predators could result in 100% black pears.

The gross revenues for S1 ranged between 12856 €ha^{-1} and 23835 €ha^{-1} with a mean of 18261 €ha^{-1}. The reduction in mean gross revenues for S2 (respectively S3-S8) constituted 2.9% (respectively 18.41%, 27.49%, 33.69%, 45.10%, 79,34% and 86.98%) resulting in an average I_G of 217731€ha^{-1} (respectively 14899 €ha^{-1}, 13241 €ha^{-1}, 12109 €ha^{-1}, 10026 €ha^{-1}, 3773 €ha^{-1} and 2377 €ha^{-1}). Hence, for the loss of the three predators, the average gross revenues decreased from 18261 €ha^{-1} for S1 to 2377 €ha^{-1} for S8. The net farm income (figure 2) also reveals large losses under the assumption that the loss of three predators can yield 100% black pears. The mean farm income I_F for S1 with three natural predators (n) was 11921 €ha^{-1} and decreased to -3962 €ha^{-1} for S8 with the loss of three predators (n-3).

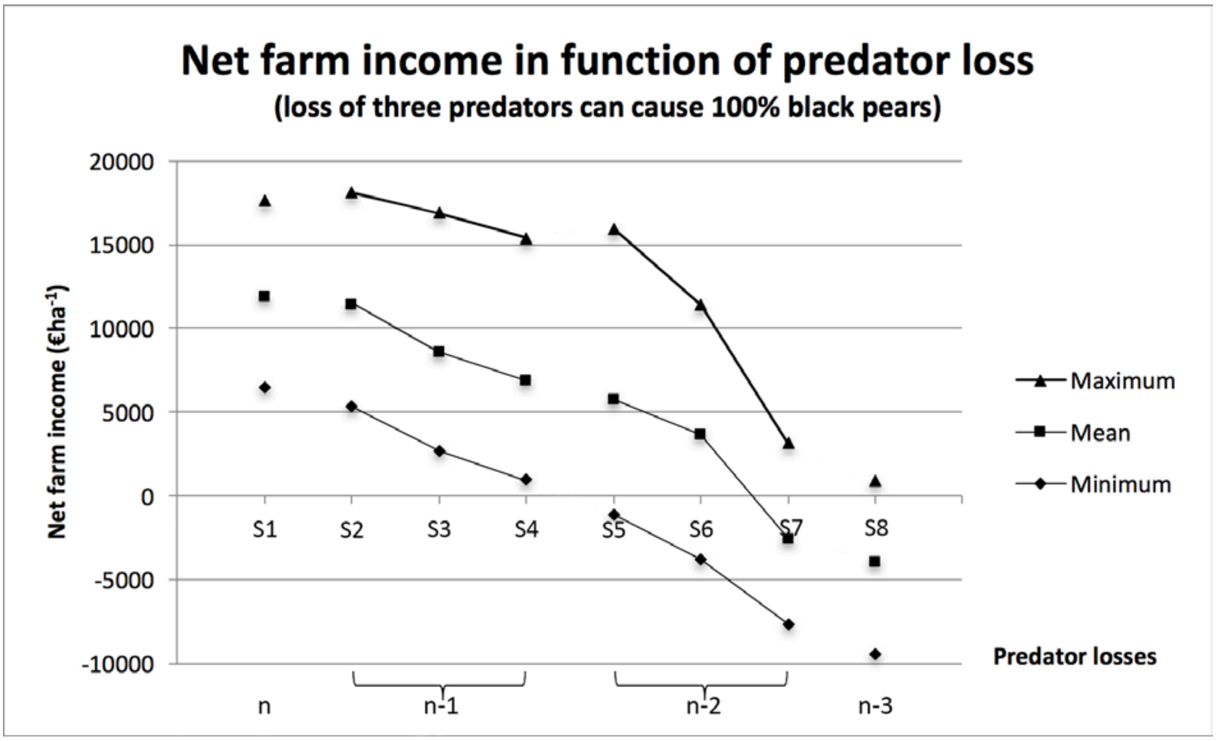

Figure 2 represents the effect of a loss of one or more natural predator on the net farm income I_F (€ha^{-1}) under the assumption that the loss of all three predators can result in 100% black pears (with n all predators present for S1; n-1 the loss of one predator for S2, S3 and S4; n-2 the loss of two predators for S5, S6 and S7; and n-3 the loss of all three predators for S8). The 95% confidence intervals are represented as the minimum and the maximum and are plotted together with the mean for each scenario. The graph shows that for the loss of all three predators, the mean net farm income for S1 reduces from 11921 €ha^{-1} to -3962 €ha^{-1} for S8.

Next, the economic impact of a loss of natural predators is discussed for the second set of hypothesized relationships, which assumed that the loss of three predators could result in an overall maximum of 12.90% black pears.

Under this assumption, the mean gross revenues I_G for S1 reduce from 18500 €ha^{-1} to 16313 €ha^{-1} for S8, constituting a loss of 2187 €ha^{-1} or 11,82 % for the loss of all three predators. The mean net farm income I_F (figure 3) reduces from 12161 €ha^{-1} for S1 to 9974 €ha^{-1} for S8, also constituting a loss of 2187 or 17,98 % for the loss of all three predators. The losses on a per hectare basis vary between 1941 €ha^{-1} and 2531 €ha^{-1} for S1 compared to S8. All the results for the gross revenues and the net farm income are presented in table 3.

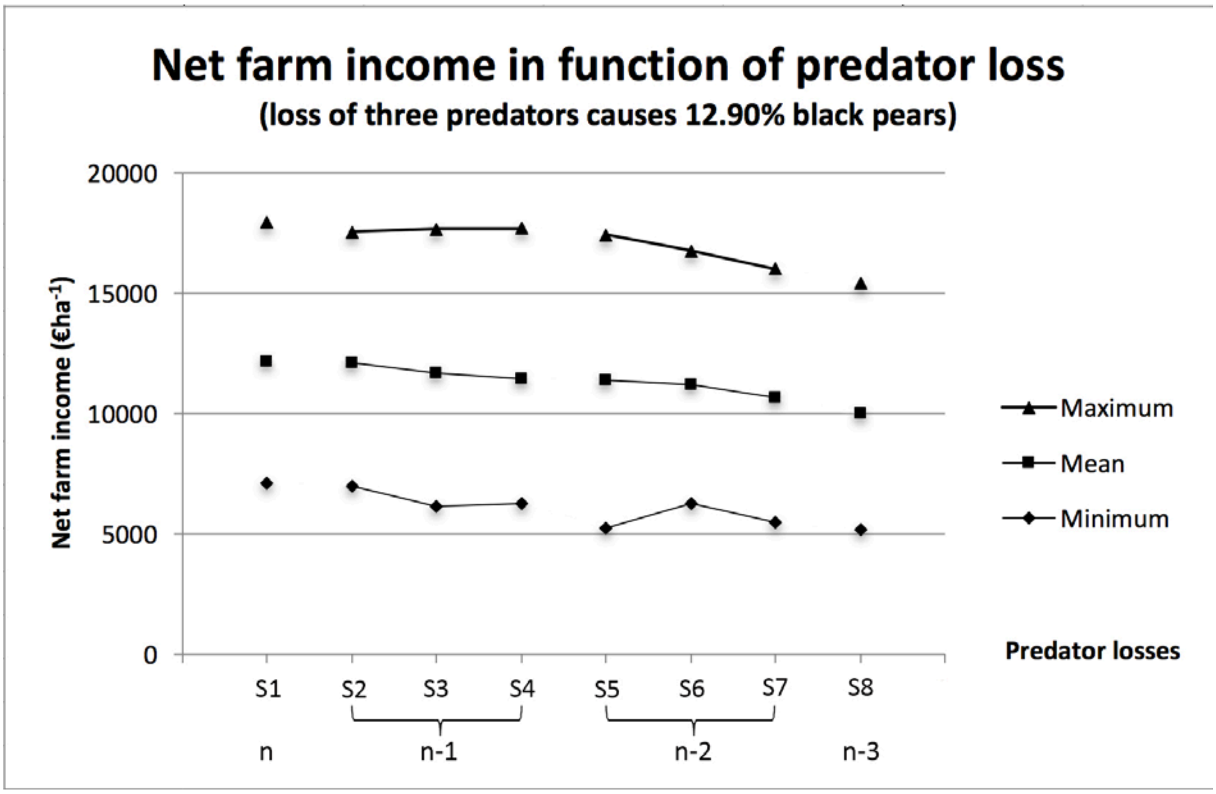

Figure 3 represents the effect of a loss of one or more natural predator on the net farm income I_F (€ha^{-1}) under the assumption that the ETL equals 1% black pears (with n all predators present for S1; n-1 the loss of one predator for S2, S3 and S4; n-2 the loss of two predators for S5, S6 and S7; and n-3 the loss of all three predators for S8). The 95% confidence intervals are represented as the minimum and the maximum and are plotted together with the mean for each scenario. The graph shows that for the loss of all three predators, the mean net farm income for S1 reduces from 12161 €ha^{-1} for S1 to 9974 €ha^{-1} for S8.

Scenario	Loss of three predators causes 100% black pears				Loss of three predators causes 12.90% black pears			
	min	max	mean	stdev	min	max	mean	stdev
	GROSS REVENUES (€ha^{-1})							
S1	12856,3	23834,94	18260,68	1944,92	13227,04	24280,28	18499,78	2028,19
S2	11739,73	24203,07	17730,51	2043,76	13207,21	23877,41	18410,92	1997,01
S3	9234,34	23200,83	14898,57	2329,98	12476,74	24158,11	18040,56	1921,93

S4	7410,81	21788,05	13241,45	2487,25	12788,47	23938,64	17789,06	1963,86
S5	5075,61	22270,21	12108,94	2512,07	11812,83	23620,97	17735,32	1960,43
S6	2692,53	17836,26	10025,62	2565,14	12567,21	22959,54	17516,96	1910,06
S7	-1095,99	9653,07	3773,27	1749,26	11806,73	22142,97	16994,41	1868,49
S8	-3128,91	7227,23	2377,36	1778,3	11591	21634,32	16313,27	1840,14
	NET FARM INCOME (€ha^{-1})							
S1	6440,26	17621,08	11921,49	1956,64	7082,07	17908,47	12160,6	2032,66
S2	5384,04	18080,43	11391,35	2053,67	6957,19	17537,69	12071,74	2001,95
S3	2688,18	16904,73	8559,41	2332,45	6120,66	17660,34	11701,39	1935,03
S4	945,09	15384,3	6902,27	2487,09	6272,24	17685,12	11449,9	1977,06
S5	-1096,02	15937,79	5769,77	2505,61	5250,49	17396,57	11396,15	1971,96
S6	-3753,8	11385,11	3686,44	2567,32	6247,29	16741,57	11177,8	1912,34
S7	-7651,83	3138,49	-2565,92	1751,27	5460,22	15988,82	10665,26	1868,96
S8	-9443,79	878,18	-3961,8	1784,15	5141,26	15377,25	9974,1	1836,61

Table 3: shows the minimum, maximum, mean and standard deviation for the gross revenues (€ha^{-1}) and the net farm income (€ha^{-1}) for scenario S1 to S8 under the assumption that the loss of three predators causes 100% of black pears, and under the assumption that the loss of three predators causes a maximum of 12.90% of black pears.

For both sets of hypothesized relationships, the net farm income reduces when natural predators are lost, thereby supporting Hypothesis 2.

4.4 An indirect use value for the presence of natural predators

The losses with respect to the gross revenue show results very similar to the losses with respect to the net farm income but differ greatly between the two sets of hypothesized relationships. Under the assumption that the overall maximum ∂_{Ppa} in the no-predator scenario S8 results in 100% black pears, gross revenue for the removal of one predator indicate a loss of I_G between 530.17 €ha^{-1} and 5019.23 €ha^{-1}. A loss of two natural predators would result in I_G losses between 6151.74 €ha^{-1} and 14487.41 €ha^{-1} and the removal of all predators caused a loss of 15883.32 €ha^{-1}. With regards to the net farm income I_F, results are in the same order of magnitude with the loss of one natural predator resulting in a loss of I_F between 530.14 and 5019.22 (€ha^{-1}). A loss of two natural predators would result in I_F losses between 6151.72 €ha^{-1} and 14487.41 €ha^{-1} and the removal of all predators caused a loss of 15883.29 €ha^{-1}.

Under the assumption that the loss of natural predators can cause a maximum of 12.90% black pears, gross revenue reductions for the removal of one predator indicate a loss of I_G between 88.86 €ha^{-1} and 710.72 €ha^{-1}. A loss of two natural predators would result in I_G losses between 764.46 €ha^{-1} and 1505.37 €ha^{-1} and the removal of all predators caused a loss of 2186.51 €ha^{-1}. With regards to the farm income I_F, results are again in the same order of magnitude with the loss of one natural predator resulting in a loss of I_F between 88.86 €ha^{-1} and 710.70 €ha^{-1}. A loss of two natural predators would result in I_F losses between 764.46 €ha^{-1} and 1495.34 €ha^{-1} and the removal of all predators caused a loss of 2186.50 €ha^{-1}. The net farm income losses for both hypotheses are presented in table 4.

Scenario	Loss of three predators causes 100% black pears	Loss of three predators causes 12.90% black pears
	Net farm income losses (€ha^{-1})	Net farm income losses (€ha^{-1})
S2	530.14	88.86
S3	3362.08	459.21
S4	5019.22	710.70
S5	6151.72	764.45
S6	8235.05	982.80
S7	14487.41	1495.34
S8	15883.29	2186.50

Table 4: shows the losses to the net farm income (€ha^{-1}) for all scenarios S1 – S8 under the assumption that a loss of three predators can cause 100% black pears and under the assumption that the loss of three predators causes 12.90% black pears.

5. Discussion

The results support Hypothesis 1 that a decrease in natural predators causes a significant decrease in the provisioning of the ecosystem service biological pest control from 10.72% for S1 to a minimum of 1.08% for the loss of one predator, further reducing to 0.02% for the loss of three predators, or equal to a total potential reduction with a factor 536 for the loss of two species. Also, the analysis showed that a reduction in natural predators could considerably reduce the quality of marketable agricultural production and that this depends highly on the hypotheses used. The first set of hypothesized relationships assumed that the total yield could consist of black pears only if all three predators would no longer occur in the agro-ecosystem. The second set of hypothesized relationships assumed that the Economic Threshold Level (ETL) equaled 1% of black pears, fixing the maximum potential of black pears upon losing the three predators at 12.90%. The economic results for the first set revealed losses of up to 15883 €ha^{-1} for the loss of three predators, making pear production financially unviable. The results for the second set reveal losses of up to 2186 €ha^{-1} when losing all three predators. Considering the fact that pear psylla has other natural predators (e.g. *Theridion spp*., *Philodromus spp*., members of the Araneidae and the seven-spot ladybird) (Erler, 2004)), it seems likely that the combined effect of all predators keeps pest densities within economic threshold levels, thereby supporting Hypothesis 2 that the three predators under analysis could induce a maximum of 12.90% of lower quality pears. On a per hectare basis, the occurrence of lower quality yields could therefore decrease gross revenues or net farm income with 88.86 € to 2186.5 €. For the pear production sector in Flanders in 2011, this would mean an indirect use value of 0,68 million € for one predator and 16.63 million euros for three predators. Considering that the gross revenues for the sector totaled on average 163 million euros for the period 2009-2013, the contribution of the predators accounts for 0,41% to 10.2% of the sectors’ gross revenues.

By employing the ecological role of species through the development of an ecological simulation model, combined with a production function technique and a direct market valuation approach, we believe that economic values of non-marketable species could be estimated more realistically as compared to employing WTP estimates. This is largely due to the fact that the importance of lesser-known species to perform valuable ecological services is not known by the general public, and therefore this might impact the valuation of these species. Therefore, according to Hypothesis 3, we are convinced that the methodology applied here could contribute to the introduction of alternative methods for the valuation of biodiversity based on the ecological role of species. Research from Boerema et al. (2016) supports this hypothesis since: (i) their results show that, up until now, there was no paper on biological control examining the whole ES 'cascade', (ii) it is stated that '*measures of ecosystem functions are stronger as they give a better idea of ES supply and how this fluctuates spatiotemporally*' as compared to '*simple measures or indicators of biodiversity and population size*', (iii) they recommend that net value, defined as "*the market price corrected for production costs…*", "*is a more appropriate measure to determine the added value*" and last, (iv) "*To quantify the sustainable supply of an ES, it is necessary to quantify the properties and functions of an ecosystem (ecological side of the cascade), whereas to quantify the importance to society it is necessary to understand and quantify the benefit to society (socio-economic side). Many researchers are only considering one side of this cascade and therefore are not succeeding in understanding the whole picture.(Boerema et al., 2016)*"

The results of applying a functional role-based approach, shows that losses of natural predators for pear production could significantly reduce a farmer's income. The results of this analysis need to be viewed within a wider framework of (1) the partitioning of biodiversity effects on function into species richness, species composition and abundance effects and (2) functional redundancy.

First, in this analysis the number of predators was reduced, which also reduced total predator biomass. The resulting effects on net farm income can therefore not solely be attributed to a decline in species richness. In Winfree et al. (2015) biodiversity effects on function were split into five additive components according to the Price equation: species richness losses (RICH-L), species richness gains (RICH-G), species composition effects that capture any non-randomness with respect to function of the species that were lost (COMP-L) and of the species that were gained (COMP-G) and changes in abundance of species that are always present (ABUN) (Fox, 2006; Fox&Harpole, 2008; Fox & Kerr, 2012). Winfree et al. (2015) stated that "*abundance fluctuations of dominant species in real world conditions drives ecosystem service delivery, whereas richness changes were relatively unimportant because they primarily involved rare species that contributed little to function.*" Also, Winfree et al. (2015) revealed that "*…random loss of species has (or would have) large functional effects, and that the identity of the species that are lost is also important*". Although we cannot be sure on the nature of the losses and how much each component contributes to the effects on net farm income, this does not undermine the overall effect that a reduction in the number of predators and their biomass can potentially have on farm income.

Second, the indirect use value for the presence of natural predators depends highly on the functional redundancy of these species. The concept of functional redundancy is based on the principle that some species perform similar roles in ecosystems and might therefore be substitutable with little impact on ecosystem processes (Lawton and Brown, 1993). Therefore the effect of species loss depends on (i) the range of functions and the diversity of species within a functional group, (ii) the relative partitioning of variance in functional space between and within functional groups, and (iii) the potential for functional compensation of the species (Rosenfeld, 2002). Whilst *Anthocoris nemoralis, Allothrombidium fuliginosum* and *Heterotoma planicornis* are all natural predators of *Cacopsylla pyri,* one might assume that they are functionally redundant and that the impact of the loss of one natural predator does not significantly alter the impact on biological pest control. However, it is argued here that although providing the same function they are not functionally redundant due to (i) exertion of ecological function occurring on different time scales: species that occur on critical timings *e.g.* when high pest density levels are expected, can be considered of higher functional importance, (ii) differences in duration of ecological function, (iii) differences in degree of specialization: whilst some species thrive in a wide variety of environmental conditions, some require specific conditions for survival, rendering them less resilient to external shocks (iv) differing impacts on other species in the ecosystem due to predation preferences: generalists versus specialists, (v) attacking different pest stages and (vi) the absolute numbers of predators. The relationship between functional redundancy and economic value of species can be represented as an exponential decline whereby the marginal value of the loss of the first species is small and the loss of the last species is infinite. Therefore, the economic values represented in this analysis do not reflect values on either of the extreme ends of the marginal value curve. It is argued here that although species perform the same function, they are not functionally redundant, that the loss of one species or abundance of the species can significantly alter the provisioning of ecological functions and that attributing an indirect use value to the loss of one species is justified. Furthermore, our simulation model does effectively take into account differences in timing, duration and prey preference. The indirect use value therefore reflects the functional differences and effectively takes into account the importance of the different species for the biological pest control of *Cacopsylla pyri*.

Finally, of equal importance in this analysis is the fact that the economic valuation of biodiversity is regarded as just one of the aspects that could strengthen the argument in favor of biodiversity conservation and hence needs to be viewed within a wider framework of biodiversity valuation. Biodiversity is by nature a multidimensional concept and expressing the importance of biodiversity in economic terms does by no means exclude the presence of an intrinsic value (Feest et al., 2010). It is our opinion that choosing the most effective valuation methodology depends both on the context as well as on the species involved. When it considers species with a high socio-cultural value, economic valuation may not be needed and its socio-cultural value alone may be sufficient to ensure protection. However, when it concerns species that do not possess such an explicit socio-cultural value (as it in our case with insects or natural predators) additional arguments such as economic valuation may strengthen the argument in favor of conservation. Within this wider framework of valuation, it is our belief that *if* an economic argument for biodiversity conservation is needed, an ecological function approach may reveal more objective values than the application of stated preference techniques, due to the complex nature of the biodiversity and ecosystem services concept on behalf of the general public.

4 Conclusion

It is the aim of this paper to emphasize the importance of healthy agro-ecosystems, not only for the purpose of food production but also for the contribution to the farmer's income. It is stressed here that effective valuation of biodiversity can include both intrinsic as well as economic arguments but that, in order to take into account the effect of biodiversity losses in economic arguments, it is imperative that the ecological function is taken into account. This implies some challenges. First, modeling real systems is rarely simple and the reality shows a great variability both in ecological as well as in economic parameters. The analysis provided here therefore provides an indication of the effect of the loss of species on the provisioning of biological pest control and on the decrease of quality. Furthermore, the authors point out the limitations of the use of stated preference techniques when valuing complex concepts such as biodiversity and ecosystem functioning. Willingness To Pay may not reflect the true ecological service that is provided by beneficial insects, since only a part of the general public has limited knowledge of the concept. Our analysis therefore provides an alternative methodology for the valuation of biodiversity, taking into account the ecological function of species in the ecosystem, hereby revealing values linked to marketable agricultural outputs.

Using an ecological function based approach, values for the presence of species diversity could be considered more objective compared to stated preference methods. These values could be supplied to inform policy makers about the importance of including biodiversity effects and providing a justification for the opportunity costs encountered.

Acknowledgments

The research was made possible with the financial aid from a BOF grant of the Centre for Environmental Sciences (CMK, Hasselt University). Nele Witters is funded by Research Foundation- Flanders (FWO). The authors would like to thank Ellen Elias from Symbio for providing relevant data and insights into the complex interplay between pest insects, natural predators and human impacts from fertilizers and pesticide use.

ANNEX A

Each field test sampled pear psylla eggs and nymphs on multiple days. The first dataset comprises a total number of 111 field tests in *conférence* pear orchards (7 in organic production and 104 in IPM (Integrated Pest Management)) on 15 different plots (8 in IPM and 7 in organic production) performed in Haspengouw (Belgium) for consecutive years of measurement (2004-2014). Data obtained from the plots under organic management were sampled in 2013 and 2014. Using the beating-tray method (3 beatings x 3 branches x 10 trees plot^{-1}), the nymph stages N1 to N5 are collected in a beating tray and counted (for a review of sampling methods see Jenser et al., 2010). A visual count is performed on newly developed shoot tips to assess the presence of eggs (visual counts are performed for 2 shoots per tree for 4-10 trees per plot segment with 4 plot segments per plot). Adult counts were performed sporadically with the beating-tray method but have not been included in the data due to its susceptibility to bias caused by adult mobility and the dependency on weather conditions. The mean counts of eggs per ten shoots are pooled for all consecutive years and plotted in figure A.1. For the years of measurement, it can be observed that counts in IPM orchards are considerably higher than counts in organic orchards.

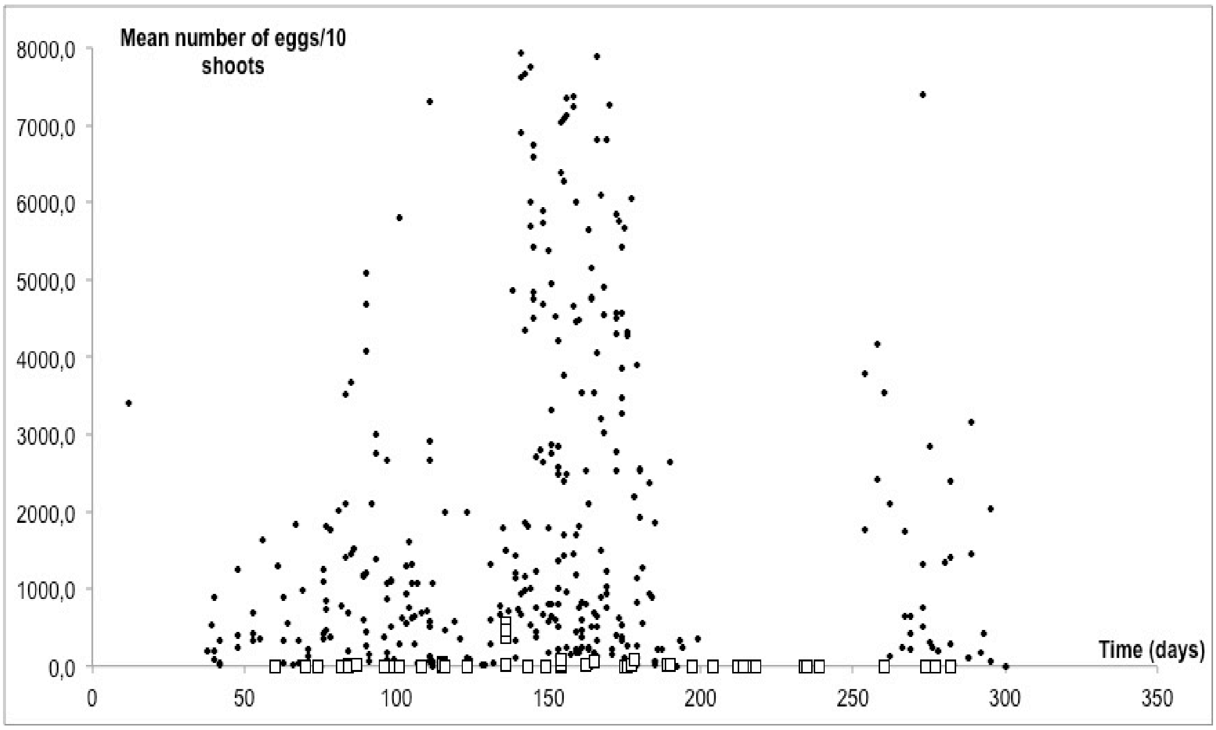

Figure A.1: pooled sample of mean numbers of pear psylla eggs per ten shoots collected between 2004 and 2014 (♦IPM; ☐ organic).

In 2013 and 2014, counts for the presence of beneficial insects were been performed between February and October in IPM and organic *conference* pear orchards. Linear transects of three pitfall traps (r=0.2m) per 50m per pear row for three rows per plot were filled with water and detergent and left standing for 7 days. Emptying of the containers produced members of the order of the Aranea, Acari, Coleoptera, Hemiptera and Neuroptera. Figure 2 represents the pooled counts for a selection of the species in the samples collected based on the importance of their functional role as natural predators of pear psylla *Cacopsylla pyri* (Homoptera: psyliidae): *Anthocoris nemoralis* (Heteroptera: anthocoridae), *Allothrombidium fuliginosum* (Acari: trombidiidae) and *Heterotoma planicornis* (Hemiptera: miridae).

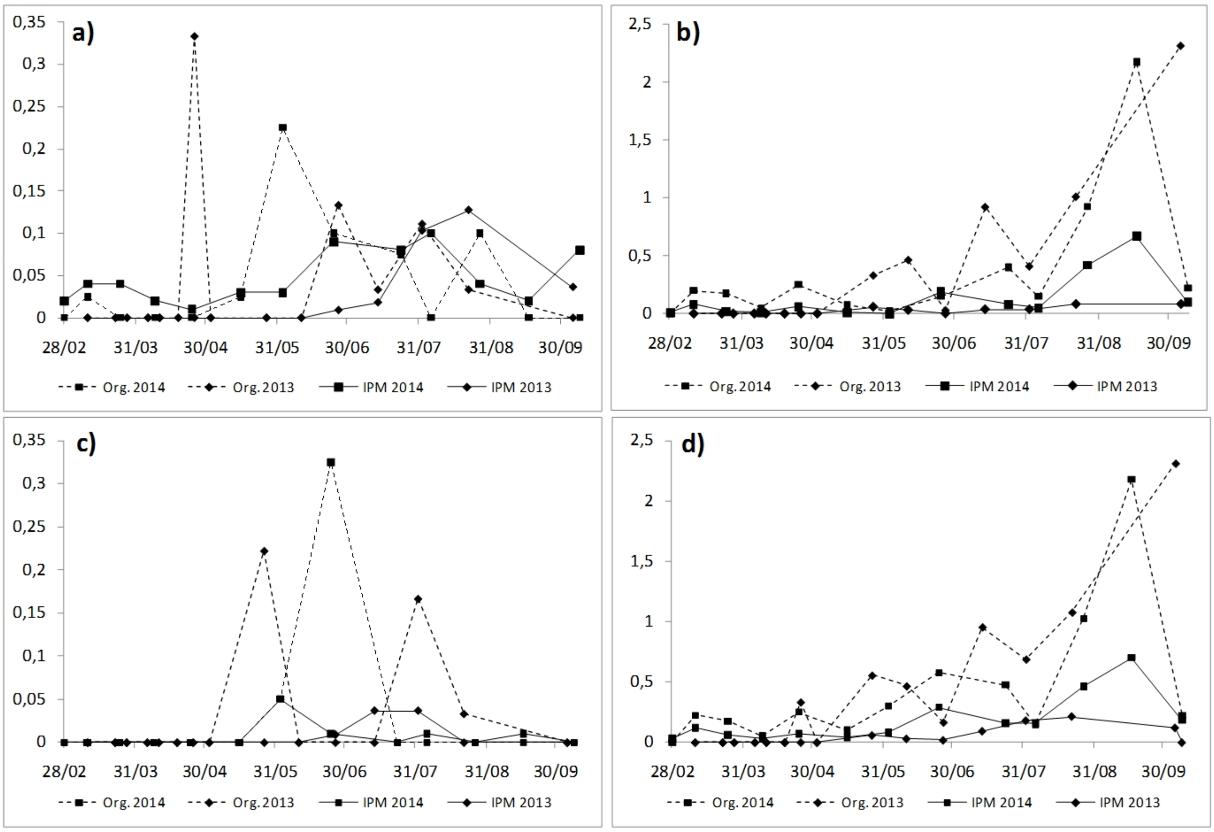

Figure A.2: absolute number of individuals per sample for a) *Anthocoris nemoralis, b) Allothrombidium fuliginosum*, c) *Heterotoma planicornis* and d) sum of the absolute numbers of a, b and c.

Figure A.2 shows (i) the difference in abundance levels of the three natural predators and (ii) the timing of occurrence. These two factors combined with their generalist/specialist nature determine the importance as natural pest controllers. Whilst *Allothrombium fuliginosum* (b) may be abundant, it is not a specialist and it preys on other insects than *Cacopsylla pyri*. *Anthocoris nemoralis* (a) is less abundant but is a specialist and therefore qualifies as a rare but highly effective pest controller. Last, *Heterotoma planicornis* (c) is both rare and a generalist and therefore differs from the two other predators.

Whilst the predators differ in terms of their generalist/specialist nature and their levels of abundance, they also differ in the timing of occurrence. Whilst *Anthocoris nemoralis* (a) is mainly encountered during the first half of the year, *Hetertoma planicornis* (c) is mainly found in the middle of the year whilst *Allothrombium fuliginosum* (b) is the main predator at the end of the year. So even when *Anthocoris nemoralis* (a) can be considered a rare species, they are highly effective and important given their ability to suppress the build-up of the pest population in the beginning of the season. The removal of one individual in the beginning of the year has an exponential effect on the pest insect density later that year, making the presence of predators in the beginning essential for controlling pest outbreaks. Equally so, *Allothrombium fuliginosum* (b) is an abundant species occurring at the end of the season, suppressing the population before the build-up in the new season.

The second dataset was obtained from field test performed every two weeks for the period 2010-2011 on 14 plots (7 in organic production and 7 in IPM) in Hageland (BE) and Gelderland and Limburg (NL). The same techniques were used to assess mean egg numbers and larvae numbers (visual scouting and beating tray method).

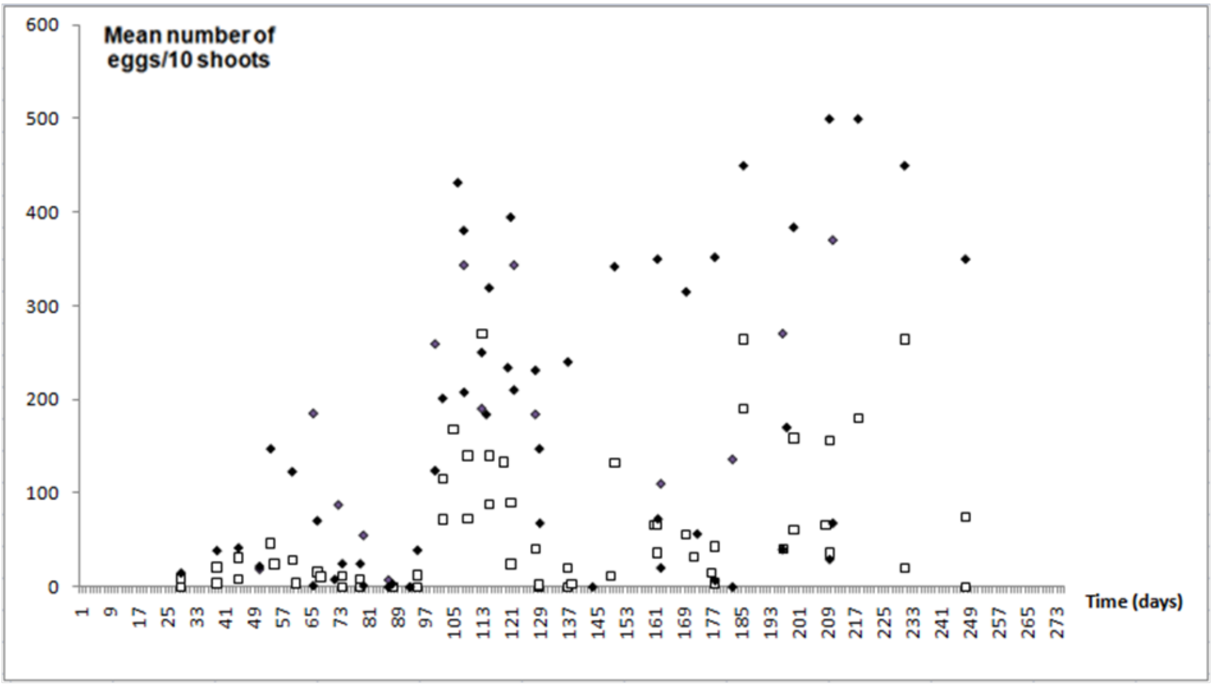

Figure A.3: Pooled sample of mean numbers of pear psylla eggs per ten shoots (♦IPM; □ organic).

Data obtained from the plots under organic management were sampled in 2013 and 2014. Using the beating-tray method (3 beatings x 3 branches x 10 trees plot^{-1}), the nymph stages N1 to N5 are collected in a beating tray and counted (for a review of sampling methods see Jenser et al., 2010). A visual count is performed on newly developed shoot tips to assess the presence of eggs (visual counts are performed for 2 shoots per tree for 4-10 trees per plot segment with 4 plot segments per plot). Adult counts were performed sporadically with the beating-tray method but have not been included in the data due to its susceptibility to bias caused by adult mobility and the dependency on weather conditions. The mean counts of eggs per ten shoots were pooled for all consecutive years and plotted.

ANNEX B

	Parameter	Model component	Initial value
(1)	Initialization adults	Ppa, Ana, Afa	$1.8 * 10^6$; 29520; $0.41*10^6$
(2)	Initialisation eggs	Hpe	$0.15 * 10^6$
(3)	Female fraction	Ppa, Ana, Afa, Hpa	0.5
(4)	Loss fraction (eggs)	Ppe, Ane, Afe, Hpe	0.3; 0.4; 0.65; 0.6
(5)	Pp Food fraction	Ann, Afn, Hpn, Ana, Afa, Hpa	0.8;0.8;0.2;0.2;0.2;0.2
(6)	Predation fraction	Ann, Afn, Hpn, Ana, Afa, Hpa	0.6

Table b presents initial parameter values for Pp, An, Af, Hp for eggs (e), nymps (n) and adults (a)

ANNEX C

NON-ORGANIC PRODUCTION

	Mean	stdev	95% confidence interval	
Total yield (kgha^{-1})	37615,33	4565,36	33962,29	41268,38
Selling price all pears(€kg^{-1})	0,57	0,16	0,44	0,70
Selling price 1st class pears(€kg^{-1})	0,55	0,16	0,42	0,68
Selling price black pears(€kg^{-1})	0,39	0,12	0,29	0,49
GROSS REVENUES (€ha^{-1})				
Main products	20247,67	3654,52	17323,44	23171,89
Plantation growth	207,00	34,05	179,75	234,25
Other products	96,83	127,62	-5,28	198,95
Subsidies	140,00	55,00	95,99	184,01
VARIABLE COSTS (€ha^{-1})				
Fertilizers	362,33	39,51	330,72	393,94
Crop protection	1579,83	100,12	1499,72	1659,94
Seasonal wages and labour	4118,33	352,15	3836,56	4400,11
Maintenance, packaging and preservation	1329,33	62,64	1279,21	1379,46
Energy	799,33	85,55	730,88	867,79
Other variable costs	260,50	23,68	241,55	279,45
FIXED COSTS (€)				
Lease/rent	463,00	76,87	401,49	524,51
Amortization fixed equipment	1274,17	35,72	1245,59	1302,75
Amortization buildings	1033,50	85,93	964,74	1102,26
Amortizations plantations	392,83	8,77	385,81	399,85
Interests	1450,00	31,25	1424,99	1475,01
General corporate costs	1692,67	275,62	1472,13	1913,21

ORGANIC PRODUCTION

	Mean	stdev	95% confidence interval	
Total yield (kgha^{-1})	30092,27	3652,28	27169,83	33014,70
Selling price all pears(€kg^{-1})	0,57	0,16	0,44	0,70
Selling price 1st class pears(€kg^{-1})	0,88	0,17	0,74	1,02
Selling price black pears(€kg^{-1})	0,39	0,12	0,29	0,49
GROSS REVENUES (€ha^{-1})				
Main products				
Plantation growth	207,00	34,05	179,75	234,25
Other products	96,83	127,62	-5,28	198,95
Subsidies	210,00	105,00	125,98	294,02
VARIABLE COSTS (€ha^{-1})				
Fertilizers	362,33	39,51	330,72	393,94
Crop protection	0,00	0,00	0,00	0,00
Seasonal wages and labour	5353,83	457,79	3836,56	5635,61

Maintenance, packaging and preservation	1329,33	62,64	1279,21	1379,46
Energy	799,33	85,55	730,88	867,79
Other variable costs	260,50	23,68	241,55	279,45
FIXED COSTS (€)				
Lease/rent	463,00	76,87	401,49	524,51
Amortization fixed equipment	1274,17	35,72	1245,59	1302,75
Amortization buildings	1033,50	85,93	964,74	1102,26
Amortizations plantations	392,83	8,77	385,81	399,85
Interests	1450,00	31,25	1424,99	1475,01
General corporate costs	1692,67	275,62	1472,13	1913,21

(Van der Straeten, 2016; Personal communication from Regional Auction Borgloon)

Table C presents annual accounting data on yields (kg ha^{-1}), revenues (€ ha^{-1}), variable costs (€ ha^{-}1) and fixed costs (€) for non-organic production and organic production from the Agricultural Monitoring Network (LMN) data (Van der Straeten, 2016), which are conform FADN[6] data collection procedures. The LMN dataset contains 53 non-organic pear farmers (accounting for 662 hectares) and provides means, standard deviations and the 95% confidence interval based on annual accounting data for the period 2009-2014 (Van der Straeten, 2016). Some numbers were adjusted to represent organic production taking into account the following assumptions: (1) yields (kgha^{-1}) are 80% of non-organic production with μ = 30092,27 kgha^{-1} and s = 3652,28[7], (2) organic management requires 30 % more full-time equivalents (FTEs) with μ = 4118,33 €ha^{-1} and s = 352,15 for non-organic production and μ = 5353,83 €ha^{-1} and s = 457,79 for organic production (EC, 2013).

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[6] Farm Accounting Data Network

[7] With μ the average and s the standard deviation

ANNEX D

Model calibration for organic production based on field data from 2010, comparing the pooled field sample (eggs/ten shoots) with the organic model results (eggs ha^{-1}).

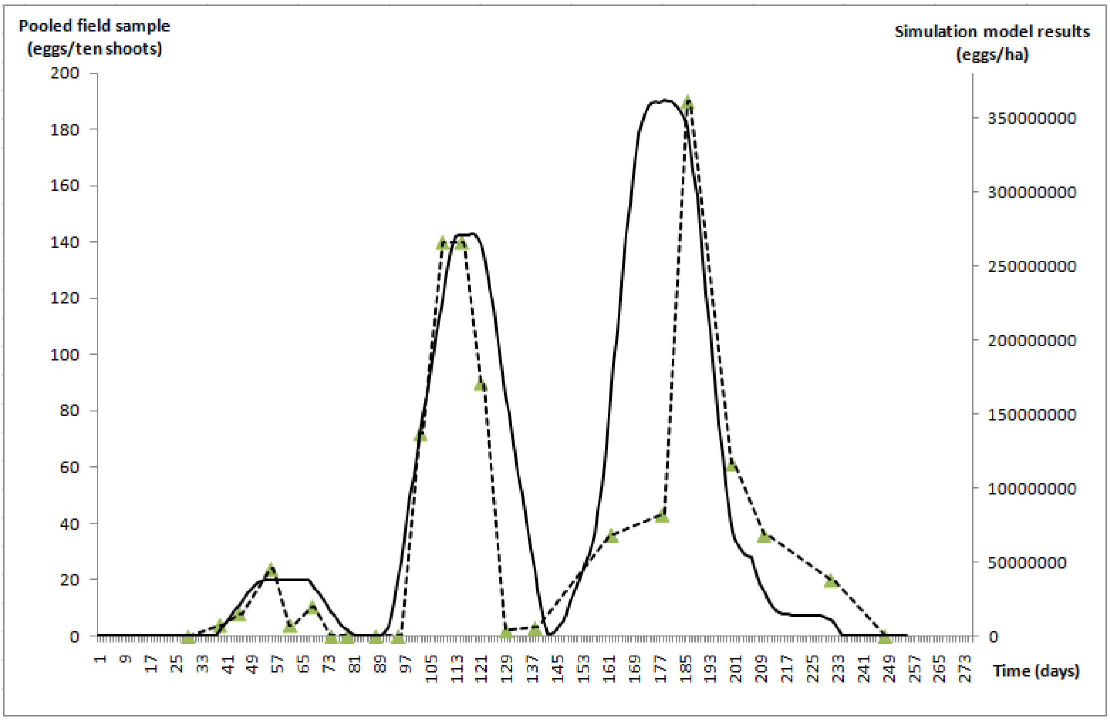

Figure D: Model calibration for organic production based on field data from 2010, comparing the pooled field sample (eggs/ten shoots) with the organic model results (eggs ha^{-1}) (- simulation model, -- field sample data). The units of field measurements (mean eggs/10 shoots) were transformed to yield model parameter units (absolute egg numbers per hectare), based on 33,84 shoots/tree on average, 5% of the eggs captured and 1714 trees per hectare (Van der Straeten, 2016).

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