Validation of the RIMpro Decision Support System for Apple Sawfly (*Hoplocampa testudinea*) with field observations in The Netherlands, Belgium, Denmark and Austria 2010-2015

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Abstract

Apple sawfly is a key pest in organic and low-input apple production systems in Europe. Many organic orchards need an annual pesticide application to control the apple sawfly population at an economic level. The botanical larvicides used for this have to be applied at, or just before, the start of egg hatch. Consultants estimate the start of egg hatch by extrapolating the results of field observations on the embryonal development of the egg population. These microscopic observations are time consuming and have an unavoidable margin of error. We examined if the output of the RIMpro-Hoplocampa DSS is accurate enough to replace these field observations.

The application dates as had been recommended tot fruitgrowers in The Netherlands, Belgium, Denmark and Austria between 2010 and 2015 were compared to the application dates as calculated by the simulation model for 123 orchards.

Though treatments are aimed at first egg hatch, the bulk of the sawfly eggs hatch several days later. A foreseen long stretched period of egg hatch can force to the decision to postpone the first treatment, use a split-up treatment, of repeat the treatment. To examine if the variation in egg development observed in the field samples is explained by the model, the average development stage of the egg-population in each of 238 samples was compared to the average development as simulated by the model for that same date and location.

In 86 % of the 123 cases the DSS advised date was close enough to the human expert advised date to expect the same level of efficacy (between 2 days before, and 1 day after). In cases were the difference was more important, this could be due to incompleteness of the simulation model, incorrect noted biofix date, unreliability of the on-farm weather station data, as well as inaccuracy of the human expert's estimation.

The distribution in the egg development as simulated by the model matched the observed variation in development stages close enough to allow advanced decisions on timing of control measures. (Correlation coefficients for the years examined range from 0.88 to 0.65).

We concluded that the RIMpro-Hoplocampa DSS is a valuable tool for optimizing the management of apple sawfly populations. The model can reduce the field observations to a final check on the day before the DSS recommends the pesticide treatment, or even completely substitute the field observations.

Keywords: Apple sawfly, RIMpro, Decision Support System, model validation

Introduction

Apple sawfly is a key pest in organic and low-input apple production systems in Europe. In mid- and north Europe 50-80 % crop loss occurs frequently in unmanaged orchard situations, and many organic orchards have to be treated every year to control the apple sawfly population on an economic level.

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Botanical and synthetic non-systemic larvicides are only effective on apple sawfly larvae between egg hatch and the moment the larvae start mining the fruitlet. For individual larvae this window is less than one day. As the total period of egg hatch of the population stretches over 7 to 14 days, residual efficacy of the insecticide covering that period is required. The first and main treatment is aimed at, or just before the start of egg hatch. When a prolonged period of egg hatch is foreseen the application maybe split-up or repeated.

Consultants and experienced fruit growers try to estimate the start of egg hatch by observing the embryonal development of the egg population. This microscopic work is however time consuming, and it is hardly possible to establish the exact date the first eggs hatch for each orchard and apple variety. The moment chosen for the pesticide application is the expert's best estimation based on extrapolation of the observation results. The RIMpro-*Hoplocampa* DSS is developed to replace these labour intensive field observations and recommends the treatment the day 2 % of the eggs is expected to hatch (Trapman, 2016). The research question is if simulations by the RIMpro-*Hoplocampa* model are accurate enough to substitute the microscopic observations that are currently still necessary to find the optimal application date.

Material and Methods

As part of the consultancy work for organic fruit growers in The Netherlands, Belgium, Austria and Denmark between 2010 and 2015 microscopic observations were made on the egg development of apple sawfly to enable local recommendations on the optimal application date. For each orchard and main apple variety 30 to 70 flower clusters were picked from the older wood, and examined for apple sawfly eggs. The individual eggs were examined under microscope and the development stage of each egg was noted according to the scale published by Keunen in 1951. This scale together with some additional notes to distinguish the individual development stages are provided in table 1. To allow numerical processing the Keunen stages A to F are renamed 1 to 7 where 7 are the eggs that have hatched. The distribution of the egg population over the seven development stages in a sample at a given date provides information on the average development stage of the population on this date, and allows an extrapolation to the day the first eggs are expected to hatch. Rule of thumb in this extrapolation is that the later development takes about two days per stage. Often these observations were repeated for the same location to improve the prognoses. The application was recommended on the early morning of the day the first eggs were expected to hatch.

<u>Start of egg hatch</u>

The application date as had been recommended tot the individual fruit growers 2010-2015 was compared to the application date as calculated by the simulation model. The default setting in the DSS is to recommend the application on the day 2 % egg hatch is reached before 23:30 that day. The simulation model needs the date of start of flowering (BBCH 60) as local and variety specific biofix, and weather data representative for the orchard at 30 to 60 minute interval, starting before March 15. Most fruit growers did note the start date of bloom of their main apple varieties. Were these notes were missing, the biofix date was interpolated from data from nearby orchards. The weather data used to process the observations were taken form 'on-farm' weather stations in, or near, the orchards were the observations were made. (Station types: 'iMetos' Pessl Instruments-Austria, 'Davis vantage Pro2' Davis Instruments-USA, 'Mety' Bodata-The Netherlands).

The weather stations were not specially serviced or calibrated. These stations are not scientific instruments but represent the data quality a practical DSS has to work with.

Distribution of egg hatch

When interpreted according the Keunen scale most samples contain eggs in three to five development stages, representing a variation in development of more than one week. Cold weather during bloom stretches the egg deposition and delays egg development, leading to a prolonged period of egg hatch. The simulation model includes effects of weather on the female flight, egg deposition and development. To examine if the distribution of egg development stages observed in the field samples is explained by the model, for each sample the average development stage of the egg-population was compared to the average development stage simulated by the model for that same date and location. The data were analysed by linear regression analysis.

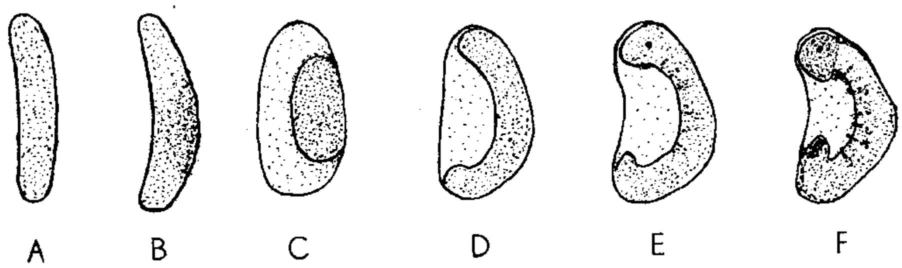

Figure 1: Stages in the embryonal development of an Apple Sawfly egg. From: Keunen 1951.

Table 1: Stages in the embryonal development of an apple sawfly egg.

Stage	Details
A (=1)	Only in freshly opened flowers. The cut is fresh and green. The egg is like a small sausage: long and slender, slightly curved, opaque white.
B (=2)	The position of the egg is only recognizable from the cut in the outside of the flower, not yet visible on the inside of the flower. The egg is slightly curved, but wider than in the drawing. The content of the egg is completely opaque white, there is no structure in it visible. The surface and shape of the egg is irregular, sometimes with brownish spots. Some eggs don’t look healthy and don’t develop further.
C (=3)	The egg gets wider. Inside the flower the flowerbottom gets slightlylightly swollen at the place where the egg is underneath the hypanthium. In the eggs content separation between a clear and whitish part starts from the tip of the egg, but in the whitish structure there is no larva recognizable.
D (=4)	The hypanthium rips. The egg is completely transparent and the whitish larva is recognizable. No eye visible yet.
E (=5)	The hypanthium is ripped and the edges of the wound tissue turn brown. The egg is visible inside. The egg is swollen, the larvae inside well differentiated. The eye is visible as a small black point. The body is still completely whitish. When touched, the larva does not move inside the egg.
F (=6)	Due to further swelling, the egg lies almost free on the flower bottom in the wound in the hypanthium. The larvae inside the egg looks ready to hatch. The head capsule gets little darker, the eyes are red. When touched, the larvae moves inside the egg.
7	At first it is difficult to see whether the egg is just hatching, or crushed during dissecting. The head is little greyer than the whitish/transparent body. The larva is moving between the remainders of the egg. Soon after hatching the larvae starts tunnelling down, just under the skin of the young fruit, at the place where it left its egg.

Results and discussion

Table 2 shows an example of the result of the successive samples for one location. On each sampling date eggs in up to five different development stages were found. The average development stage of the egg population increases in time. First eggs hatched between April 23 and May 30. Based on the observation on April 23, the pesticide application was recommended for April 26. Nine days later on May 5 still 17 % of the eggs had to hatch.

Table 2: Distribution of development stages found on four successive sample dates in the same orchard. Elstar, Zeewolde, The Netherlands 2011.

Sample date	**% eggs in the development stages:**							**AVG stage**
	1	**2**	**3**	**4**	**5**	**6**	**Hatched**	
April 20	55	45						1.5
April 23	7	50	33	7	3			2.5
April 30				6	23	37	35	6.0
May 5						17	83	6.8

Table 3 shows the effect of the start date of flowering on the egg deposition and development. The three apple varieties in the same orchard start flowering two days after each other, resulting in a shift in the apple sawfly development. The egg populations in the tree apple varieties differ one stage in their average development and three apple varieties would require different application dates for optimal sawfly management

Table 3: Distribution of development stages found in samples taken on the same date (May 21) from and early-, mid- and late flowering apple variety in the same orchard. Bandholm, Denmark 2015.

Apple variety	**Start of bloom**	**% eggs in the development stages on May 21:**							**AVG stage**
		1	**2**	**3**	**4**	**5**	**6**	**Hatched**	
Discovery	May 4			6	29	48	16		4.7
Bellida	May 6		13	30	30	25	3		3.8
Elstar	May 8		33	52	14				2.8

Observations on apple sawfly eggs are normally concentrated on flowers on the older wood as these flowers open early and are most important for the apple production. Flowers on the one year old wood open several days later and accordingly receive ‘their’ sawfly eggs later, just like the later flowering apple varieties in table 3. Apple sawfly’s can continue to deposit eggs on late opening flowers as in the example in Table 4. On May 9 the eggs on the one-year-old wood are on average 2.5 stages (or ca. 5 days) later in development than the eggs on the older wood.

Table 4: Distribution of development stages found in samples taken on the older wood (=early flowering) and young wood (=late flowering) on the same variety. Elstar, Ewijk, The Netherlands 2015.

Apple variety	Sample date	% eggs in the development stages:							AVG stage
		1	2	3	4	5	6	Hatched	
Old wood	May 1	15	69	15					2.0
	May 7			38	56	6			3.7
	May 9				36	28	36		5.0
Young wood	May 7		38	46	15				2.8
	May 9	6	48	29	16				2.5

Start of egg hatch

For a total of 123 field cases the application date that had been recommended by the human expert, could be compared to the date the simulation model recommended the treatment. Table 5 and Figure 2 summarize the results. The average number of days between start of bloom (BBCH 60) and the application date recommended by the human expert was 16.0 days (STD 3.3 days), with a minimum of 7 days (South Steiermark 2015), and a maximum of 24 days (Odense Demark 2015).

On average the simulated moment of 2 % egg hatch was 0.69 day before the human expert advised day for treatment. Figure 2 visualizes the difference between the simulation and the advised application date for all cases examined. There are a few odd cases (were the model predicts egg hatch 4 or 5 days earlier-, or more than 1 day later than the expert estimation.

Table 5: The difference in days between the human expert advised application date and the day the DSS simulation reached 2 % egg hatch. (Orchards in The Netherlands, Belgium, Austria and Denmark 2010-2015)

Year	Orchards	DSS advice earlier or later than expert advice (days):										AVG
		-5	-4	-3	-2	-1	0	1	2	3	4	
2010	6				1		2	1	2			0.50
2011	15			2	3	1	8	1				-0.80
2012	13		1		2	5	4	1				-0.92
2013	19	1	2	1	4	4	7					-1.47
2014	26				4	5	9	8				-0.19
2015	44	1	1	4	11	11	12	2	1			-1.23
												-0.69

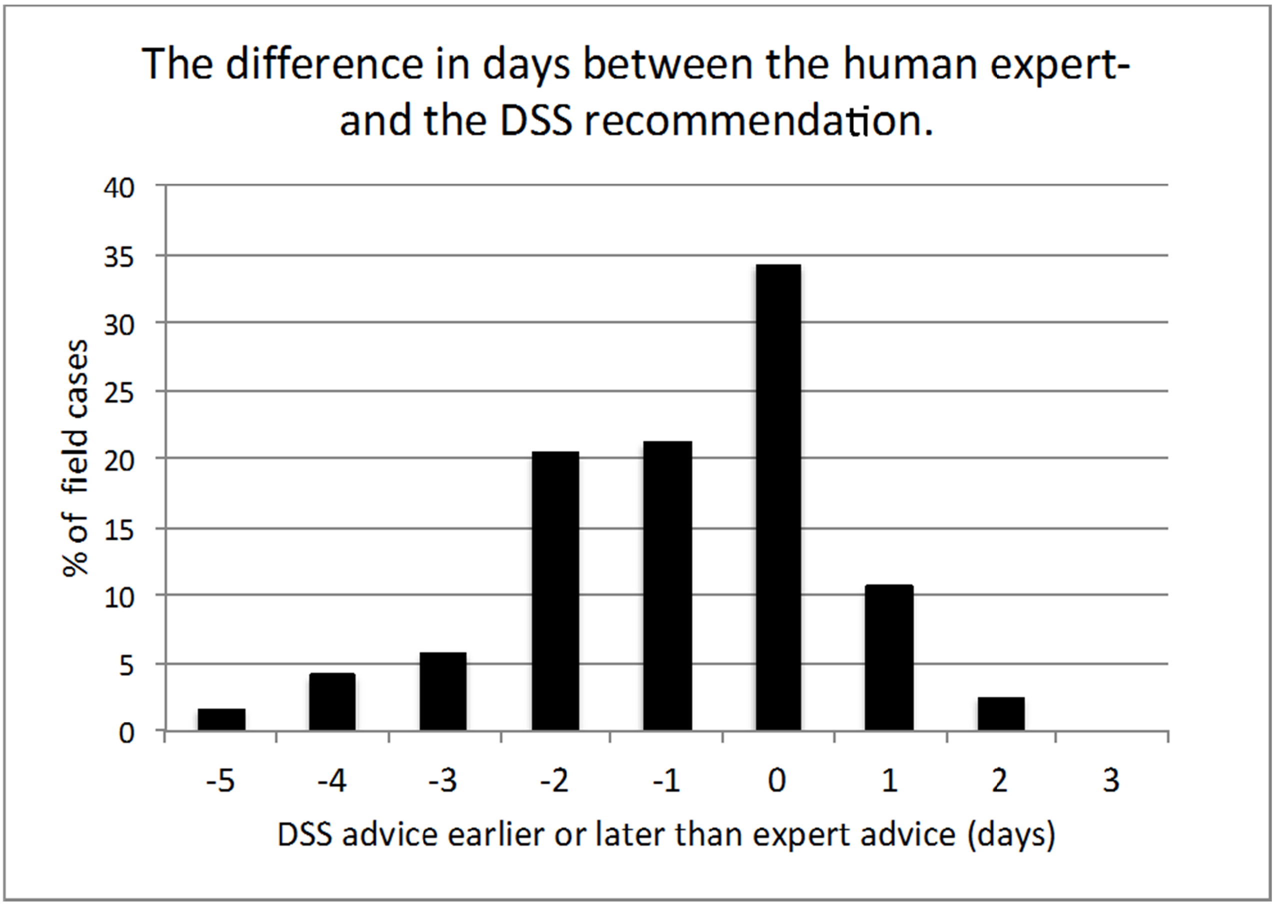

Figure 2: The difference in days between the human-expert recommended application date and the day the DSS simulation reached 2 % egg hatch. (123 orchard cases in The Netherlands, Belgium, Austria and Denmark 2010-2015).

Distribution of egg hatch

In total 238 observation results could be compared to simulated distributions of development stages in egg populations. Figure 3 shows the correlation between the observed and simulated average development stage of the egg population for each available sample. The dotted 'Expected' line marks the situation were observation and simulation are equal. In most years the simulated values closely match the expected development. The correlation coefficients are 0.82, 0.88, 0.88, 0.75, 0.75 and 0.66 for the years 2010 till 2015.

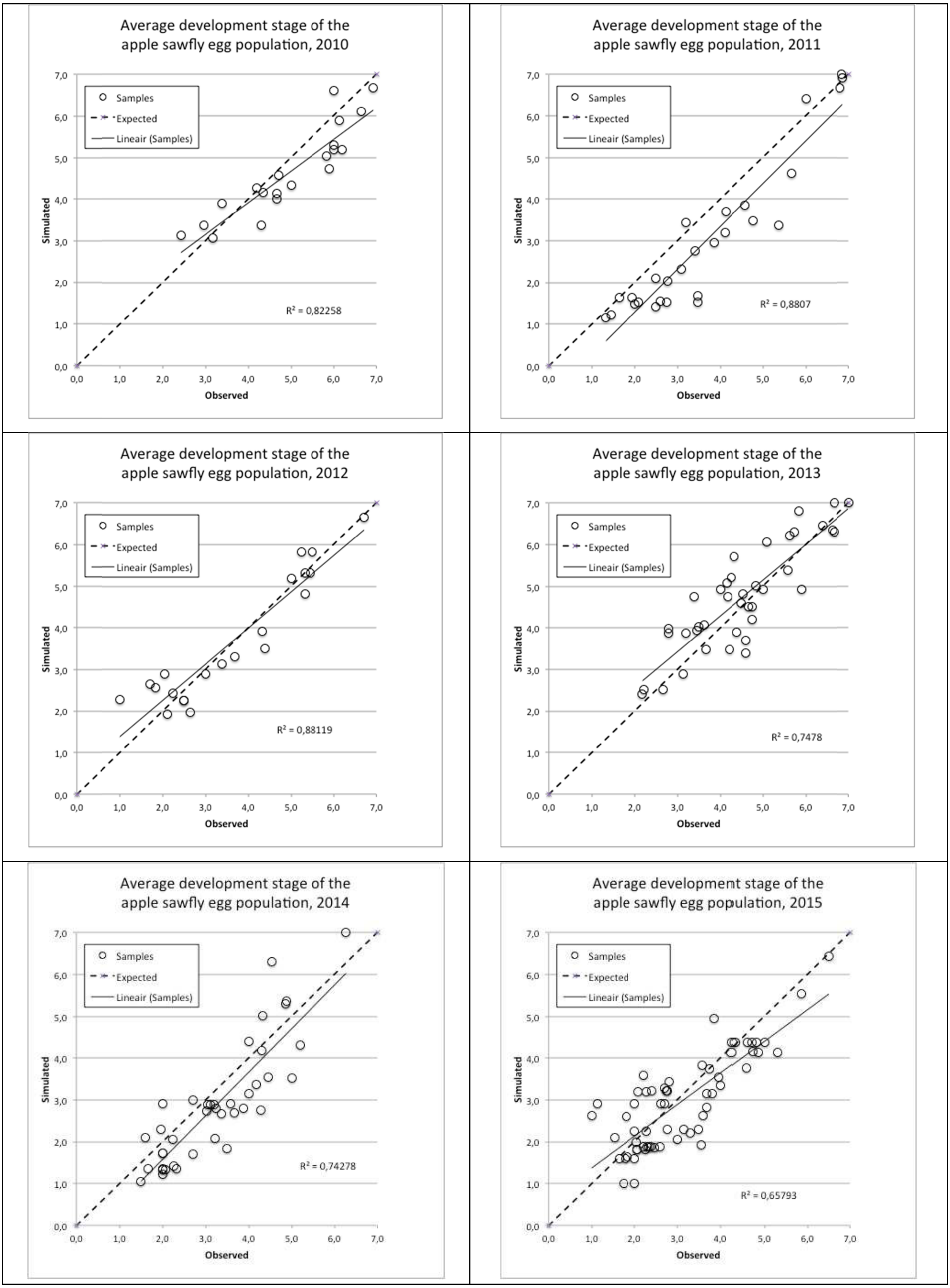

Figure 3: Correlations between the observed and simulated average development stage of the apple sawfly egg population for each sample. Samples taken in The Netherlands, Belgium, and Denmark 2010-2015.

Discussion and conclusion

Recommend application date

The human expert recommended the pesticide application in the morning of day 0 in table 2 and figure 2. The DSS advised dates for both day-1 and day 0 are within 24 hours of this advised moment of treatment and can be regarded as exact match. Applying the pesticide one day earlier (day-2) would result in one days less residual activity, which will not lead to remarkable differences in efficacy under practical conditions. Making the treatment more than one day after start of egg hatch allows 5-10 % of the larvae to hatch and escape the treatment. This will be recognizable in the efficacy of the treatment and should be avoided.

In 86 % of the cases the DSS advised date is close enough to the human expert advised date to expect the same level of efficacy (Day -2 to +1). Cases where the difference is more days, this can be due to several sources of variation. It could be incompleteness of the simulation model, incorrect BBCH60 biofix date, unreliability of the on-farm weather station data, as well as inaccuracy of the human expert estimation to witch the simulation results are always compared. The human expert advice is based on observations and experience but does not by defenition indicate the exact date of start of egg hatch.

Duration of egg hatch

Though treatments are aimed at first egg hatch, the bulk of the sawfly eggs hatches several days later. (Table 2,3,4) For effective control of the apple sawfly population residual activity of the applied pesticides should cover the complete period of egg hatch.

The distribution in the egg development as simulated by the model matches the observed variation in development stages close enough to allow advanced decisions on timing of control measures. A model-forecasted long stretched egg hatch period could lead to the decision to postpone the first treatment, apply a 'split-up' treatment, of repeat the treatment. Optimal dates for these treatments could be derived from the model output.

Taken into account the accepted margins of error in practical consultancy work, and the extensive dataset used for the validation of this model covering multiple years and production regions, we conclude that the RIMpro-*Hoplocampa* DSS is a valuable tool for optimizing the management of apple sawfly populations. The model can reduce the field observations to a final check on the day before the DSS recommends the pesticide treatment, or even completely substitute the field observations.

References

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