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A simple approach for a spatial terrestrial exposure assessment of the insecticide fenoxycarb based on a high resolution landscape analysis

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1. LOCATION OF THE REGIONS OF INTEREST IN GERMANY

The exact location of the three Regions of Interest (ROI) in the south-western of Germany is shown in Figure S 1.

Figure S 1: Location of Regions of interest (ROI) in Germany: Rhine-Hesse (Ingelheim), Middle Rhine Valley (Koblenz) and Lake Constance (Friedrichshafen)\textsuperscript{1,2}
2. ERROR ANALYSIS FOR THE OBJECT CLASSIFICATION BASED ON AERIAL IMAGES (BY GROUND TRUTHING)

The area of the relevant objects, where an incorrect classification would have influenced the results of the exposure analysis, takes up 243 ha of the 736 ha area which had been randomly selected for ground truthing from 6236 ha in the Area Under Investigation (AUI) Rhine-Hesse (Table S 1). Ground truthing showed that 12.3 ha out of the 243 ha had been classified incorrectly.

This figure corresponds to an error rate of 5.1 % in total. 94.9 % of the areas were classified correctly. The greatest error occurred in the capture (i.e., classification) of vineyards as orchard areas. 46 objects with a total area of 7.49 ha were classified incorrectly and off-target drift of fenoxycarb was assumed to occur from this area in the exposure analysis whereas, in reality, this fenoxycarb drift would not have occurred. This error can be explained by the pergola-like construction of the vines with a wide distance between the rows which, in the aerial image only differs with regard to the context of the object, but not with regard to the appearance of espalier fruit. Orchards were never classified incorrectly as vineyards.

The second largest error involves the incorrect classification of orchard areas as biotopes (0.74 ha in total, 0.31 % of the proportion of the area of the relevant objects). This error occurred because it is sometimes difficult to differentiate between these two categories in aerial images. For commercial reasons, many orchard areas are no longer farmed by the fruit-growers, and are in a state of transition. Figure S 2 shows different orchards types (single trees, high trees and low trees plantations).

The error rates in AUI Middle Rhine valley and Lake Constance were 0.7% and 2.1%.

Neither of the errors are systematic but are due to peculiarities regarding the landscape structure. The error rates are reasonably small and effects on the result of the exposure analysis from aerial images were deemed to be of low practical significance so that no further evaluations of classification errors were conducted.
Table S 1: Error analysis for the object classification based on aerial images using ground truthing in Rhine-Hesse

| Classification based on ground truthing | Classification based on aerial images | Error Code | Number of objects (n) | Area (ha) | Proportion of total checked area (%) | Proportion of the area of the relevant objects (%) |
|----------------------------------------|--------------------------------------|------------|-----------------------|----------|-------------------------------------|-------------------------------------------------|
| Orchard                                | Vineyard                             | 1          | 0                     | 0        | 0                                   | 0                                               |
| Vineyard                               | Orchard                              | 2          | 46                    | 7.49     | 1.02                                | 3.08                                            |
| Orchard                                | Biotope                              | 3          | 28                    | 0.74     | 0.10                                | 0.31                                            |
| Biotope                                | Orchard                              | 4          | 11                    | 0.18     | 0.02                                | 0.07                                            |
| Single tree / clump of trees           | Other biotope category               | 5          | 1                     | 0.02     | 0.00                                | 0.01                                            |
| Other biotope category                 |                                      |            |                       |          |                                     |                                                 |
| Other                                  | Single tree / clump of trees          | 6          | 0                     | 0        | 0                                   | 0                                               |
| Other                                  |                                      | 0          | 24                    | 3.89     | 0.53                                | 1.60                                            |

Total of incorrectly classified areas 110 12.32 1.67 5.06

Total area of relevant objects - 243.29 33.07 100.00

Total area of irrelevant objects - 492.43 66.93 -

Total checked area (relevant + irrelevant) - 735.72 100.00 -

Figure S 2 shows the results of the landscape classification and analysis for a small patch within the AUI Rhine-Hesse (underlying a DigitalOrthoPhoto (DOP) with 0.25 m x 0.25 m pixel size). Different orchard types are presented (single trees, (espalier) plantations). The 20 m buffer zone around the orchards (OBZ), the biotopes (non agricultural habitats) completely within the OBZ, the theoretical maximum PDIA (step 2, when wind would blow from all sides simultaneously during application), and the PDIA in the worst case wind direction NE (Step 3) are shown. Step 1 analyses for biotopias which are fully in the OBZ but also for those which are only partially located in the OBZ and from which recolonization from outside into the OBZ may take place.
Figure S 2: Directional exposure analysis in the AUI Rhine-Hesse. The Potentially Drift Impacted Area (PDIA) is shown.

Coordinate System: German Gauss-Krueger Zone 3
3. BASIC DRIFT VALUES AND REGRESSION FUNCTION PARAMETERS
PUBLISHED BY JULIUS KÜHN INSTITUT, BRAUNSCHWEIG, GERMANY (JKI) AND USED FOR ESTIMATING THE PDIA EXTENSION IN THE REFINED APPROACH

The basic drift value function \( f(x) = a \cdot x^b \) with parameters shown in Table S 2 was used to calculate the dispersion of drift from the treated orchards into the vicinity in the Refined Approach, where

\[
f(x): \text{deposition rate [as a percentage of the application rate]},
\]
\[
x: \text{distance from the edge of the field [m]},
\]
\[
a, b: \text{regression parameters}
\]

Table S 2: Median (= 50th percentile) of the regulatory spray drift values and associated functions for the scenario “orchard early” by JKI\(^3\)

| Distance (m) | Basic spray drift value (%) | Basic wind drift value = a \cdot distance \(^b\) |
|--------------|-----------------------------|-------------------------------------------------|
| 3            | 18.96                       | \(a = \text{factor close (≤ 10 m)}\) 53.645      |
| 5            | 11.69                       | \(b = \text{exponent close (≤ 10 m)}\) -0.9466   |
| 10           | 6.07                        | \(a = \text{factor far (≥ 15 m)}\) 5688.1       |
| 15           | 3.02                        | \(b = \text{exponent far (≥ 15 m)}\) -2.7844    |
| 20           | 1.36                        | Point of interception (hinge point) of the functions at 12.65 m |
| 30           | 0.44                        |                                                 |
| 40           | 0.20                        |                                                 |
| 50           | 0.11                        |                                                 |

3.1 Calculation of the filtering effect of high growing biotope vegetation

Data to estimate the effect of interception in the biotopes were taken from drift experiments conducted by Gove\(^4\) and Koch et al.\(^5\). In these studies, however, different experimental designs and methods for the calculation of deposits had been applied. Therefore, the individual measured data of Gove\(^4\) and Koch et al.\(^5\) were normalised to the same basis of reference by the following steps:
• The residue concentrations measured in the treated target areas were set to 100 %. A hypothetical hedge located directly adjacent to the target area would therefore also have received 100 % deposition on the outer leaves (on the edge of the treated area).

• Measured deposition on two-dimensional structures was transformed by means of an extrapolation factor of 5 to deposition on three-dimensional structures. The factor of 5 was chosen according to ESCORT 2.6 This transformation was necessary for the Gove4 study because different measuring methods had been used in the orchard and in the hedge. The reference system used by Koch et al.5, (normalising residues in the treated area to 1 g/ha) was adapted to the actual deposition measurements in the hedge.

• The deposition values measured for individual distances were grouped into distance classes (cf. Table S 3).

• 50th and 90th percentile deposition values were calculated and referred to the results of the upper (conservative) tail of the distance class.

The experiments by Gove4 and Koch et al.5 were mostly conducted with hedges in full foliage. Very early applications of fenoxycarb may be made when hedges are not yet in full foliage. To avoid an over-estimate of the filtering capacity of hedges at this time of the year, the 90th percentile of the measured deposition was multiplied by a factor of 1.6. This factor of 1.6 was derived from the ratio of deposition between the scenarios ‘orchards early’ and ‘orchards late’ in the FOCUS7 interception data compilation. The resulting 90th percentile “early” filtering function was used for all calculations throughout this study although, for applications at the full foliage stages, this may be overly conservative. The normalised data points derived and used for curve fitting, as well as the resulting functions, are shown in Table S 3.

For future exposure assessments at the landscape level, it would be helpful to have more data available on the filtering effect of hedges and other high growing 3D-structures, as well as on their occurrence in the landscape. Lazzaro et al.8 used an exponential function for fitting the deposits measured after interception of the drift in hedgerows at three different vegetation stages. Currently, however, such data are still scarce and there is some variability in the results for measured depositions. On
the other hand, failure to use the available information and thus neglecting the filtering effect of the 3D-structures (which unequivocally exists) would have made the overall risk assessment less precise and/or realistic. Therefore, the higher tier exposure assessment presented here, that makes use of high resolution geodata and integrates drift and drift interception, should be understood as a “straw-man” proposal on how refinements could be applied to risk assessments of pesticide use in an agricultural landscape.

Table S 3: Deposition in hedges as function of distance from treated areas. (calculated from data published by Gove\textsuperscript{4} and Koch et al.\textsuperscript{5})

| Class for distance (upper limit taken as reference value, x-axis) (m) | Deposition in Hedge (%, y-axis) | Average (% | 50\textsuperscript{th} Percentile (%) | 90\textsuperscript{th} Percentile late (full) foliage (%) | 90\textsuperscript{th} Percentile early (first) foliage (%) |
|---|---|---|---|---|---|
| 0 | 100.00 | 100.00\textsuperscript{a} | 100.00 | 100\textsuperscript{a} |
| 0.1 - 1.0 | 16.09 | 10.00 | 38.50 | 61.60 |
| 1.1 - 2.0 | 10.22 | 6.25 | 21.70 | 34.72 |
| 2.1 - 3.0 | 7.71 | 6.65 | 13.50 | 21.60 |
| 3.1 - 4.0 | 5.74 | 3.75 | 10.50 | 16.80 |
| 4.1 - 6.0 | 3.22 | 2.43 | 6.70 | 10.72 |
| 6.1 - 8.0 | 1.74 | 1.25 | 3.64 | 5.82 |
| 8.1 - 10.0 | 1.07 | 0.56 | 2.07 | 3.31 |
| 10.1 - 12.0 | 0.29 | 0.29 | 0.48 | 0.77 |

\textsuperscript{a} The treated area and also the exposed face of the hedge were assumed to receive 100\% deposition, for the purpose of this evaluation the hedge was considered to begin directly adjacent to the treated orchard area (deposition on hedges in ≥ 0.1 m distance is not affected).

The function with the general equation:

\[ y = m_0 \left( \frac{x}{b} + 1 \right)^{-a} \]  

(1)
was fitted to the deposition values, which should represent hedges in early leaf stage (as shown in Table S 3). A single first order multi-compartment function obtained from ModelManager (Cherwell Scientific Ltd, Oxford, UK) software was used for the curve fitting procedure.

The fit resulted in the following parameters and equations:

\[
m_0 = 100 \quad a = 3.9215 \quad b = 6.8603,
\]

\[
y = 100 \cdot \left( \frac{x}{6.860} + 1 \right)^{-3.922}
\]

Deposition (2)

\[
x = 6.860 \cdot \left( \frac{y}{100} \right)^{-\frac{1}{3.922}} - 1
\]

and Distance (3)

with \( y \) = deposition (in percent) and \( x \) = distance (in metre) and \( R^2 = 0.99 \)

The above equations were then used to calculate the distance necessary to ensure residues would decline to the regulatory acceptable deposition concentration. Table S 4 shows the fitted values for various percentiles of deposition as a function of distance from treated areas.
### Table S 4: Fitted values for various percentiles of deposition in hedges

| Distance (upper limit of class taken as reference value) (m) | Function for various percentiles of deposition in Hedges | Rautmann drift (90th Perc. for comparison) |
|---------------------------------------------------------------|-------------------------------------------------------|------------------------------------------|
|                                                               | Average Fitted (%) | 50th Percentile (%) | 90th Percentile late (full) foliage (%) | 90th Percentile early (first) foliage (%) | Orchards late (%) | Orchards early (%) |
| 0                                                             | 99.99                | 100.00              | 99.96                          | 100.00                          | 100                | 100                |
| 1                                                             | 16.88                | 10.60               | 38.87                          | 58.65                          | -                  | -                  |
| 2                                                             | 9.34                 | 6.14                | 21.37                          | 36.67                          | -                  | -                  |
| 3                                                             | 6.48                 | 4.43                | 13.78                          | 24.11                          | 15.73              | 29.20              |
| 4                                                             | 4.97                 | 3.51                | 9.74                           | 16.50                          | -                  | -                  |
| 5                                                             | 4.04                 | 2.93                | 7.31                           | 11.68                          | 8.41               | 19.89              |
| 6                                                             | 3.40                 | 2.52                | 5.73                           | 8.51                           | -                  | -                  |
| 8                                                             | 2.59                 | 1.99                | 3.83                           | 4.83                           | -                  | -                  |
| 10                                                            | 2.10                 | 1.66                | 2.78                           | 2.94                           | 3.60               | 11.81              |
| 12                                                            | 1.76                 | 1.43                | 1.89                           | 2.12                           | -                  | -                  |
| 15                                                            | 1.42                 | 1.19                | 1.51                           | 1.06                           | 1.81               | 5.55               |

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**Example calculation**

The regulatory acceptable deposition of fenoxycarb in Germany was set to 0.0975 g/ha.

An example calculation, showing how wide a biotope would have to be for the exposure level to reach or fall below this regulatory acceptable level, is shown below.

The example calculation below is based on the assumption that the biotope begins at a distance of 3 m from the treated orchard, which is the default regulatory worst case. Deposition at the outer edge of this biotope (i.e. the edge facing the orchard) would be equivalent to 0.876 g/ha of fenoxycarb. This value results from assuming an application of 150 g/ha, worst-case drift dispersal according to the basic drift values (29.2 % as 90th percentile for the scenario “orchards early”3, the use of 90 % drift reduction application equipment, and a Vegetation Distribution Factor of 5 (accounting for the 3-dimensional structure of the hedge, according to Candolfi et al.6)).
The regulatory acceptable deposition of 0.0975 g/ha is equivalent to 11% of this default deposition at the outer edge of the “example biotope”. As shown in equation (4) below, the drift would need to pass through a further 5.15 m of the “example biotope” in order to drop to 11% of the level at the outer edge, i.e. in order to drop to a regulatory acceptable level. In other words: The outer 5.15 m of the “example biotope” could still be impacted by drift and would be part of the PDIA.

\[
\text{Depth of the PDIA} = \frac{6.860 \cdot \left( \frac{11\%}{100} \right)^{-1/3.022} - 1}{1} = 5.15 \, m
\]  

(4)

Biotopes further than 3 m from the treated orchard would receive lower drift deposits (than the above value of 0.876 g/ha fenoxycarb) at their outer edge. Consequently, the PDIA in these biotopes would be less than 5.15 m wide.

The individual width of the PDIA for all biotopes in the landscape was calculated using the individual deposition at the outer edge of the biotope as a function of distance and basic drift values, and then the further decrease of drift within the biotope was estimated according to formula (2) above.

As this step of the GIS landscape analysis required extensive computing resources, it was only conducted once (for the Default Approach in the AUI Rhine-Hesse). The resulting filtering factor for Rhine Hesse (a reduction of the PDIA by a factor of 1.75 from Step 3 to Step 4) was then used to extrapolate the Step 4 PDIA in the Refined Approach.
4. WEIGHTING OF THE MAXIMUM STEP 3 PDIA FROM THE DEFAULT SCENARIO WITH THE WIND DIRECTION DISTRIBUTION

The worst case PDIA from Step 3 (i.e. the largest PDIA for the 8 cardinal wind directions) is a conservative estimate, because it is based on the unrealistic assumption that the wind is always blowing towards the potentially vulnerable areas at high speed. In reality, the frequency of the wind direction determines the probability with which a biotope might be affected by drift. A more realistic estimate of the PDIA can therefore be achieved by weighting the calculated 8 PDIs with the probability of the wind blowing in that direction. Statistics on the distribution of the winds with speeds < 5 m/s (i.e. according to good agricultural practice) for Rhine-Hesse in the months of March to May (when Fenoxycarb is being applied), provided by the DWD (German Weather Service), are listed in Table S 5.

Table S 5: Frequency of the cardinal wind directions calculated for the Ingelheim area for the months of March to May and for wind speeds below 5 m/s (provided by Grosch⁹)

| Cardinal wind direction (direction the blowing wind comes from) | Frequency | Resulting direction of the impacted biotope (Compass direction “opposite” wind direction) | Step 3 PDIA (ha) | Wind direction weighted Step 3 PDIA (ha) |
|---------------------------------------------------------------|-----------|------------------------------------------------------------------------------------------|-----------------|-----------------------------------------|
| NE                                                           | 24%       | 225°                                                                                    | 88.43           | 21.22                                   |
| E                                                            | 10%       | 270°                                                                                    | 87.96           | 8.80                                     |
| SE                                                           | 5%        | 315°                                                                                    | 85.17           | 4.26                                     |
| S                                                            | 13%       | 360°                                                                                    | 78.42           | 10.19                                   |
| SW                                                           | 21%       | 45°                                                                                     | 83.89           | 17.62                                   |
| W                                                            | 7%        | 90°                                                                                     | 83.95           | 5.88                                     |
| NW                                                           | 8%        | 135°                                                                                    | 80.67           | 6.45                                     |
| N                                                            | 11%       | 180°                                                                                    | 80.17           | 8.82                                     |
| Regulatory relevant PDIA                                     |           |                                                                                         | 88.43           | 83.24                                   |

(worst case from 8 wind directions) (sum of wind direction weighted PDIs)
4.1 Worked example: Calculation of the maximum impacted area for 2 applications for Rhine-Hesse in the Refined Approach

For step 3, the PDIA was first determined separately for each of the eight cardinal wind directions. The resulting values, taking into account the refinement steps described above, are listed in Table S 6.

Table S 6: Potentially drift-impacted area (PDIA) dependent on wind direction

| Direction a (degrees) | PDIA in Rhine-Hesse (ha) |
|-----------------------|--------------------------|
| 45                    | 33.82                    |
| 90                    | 33.97                    |
| 135                   | 32.45                    |
| 180                   | 30.89                    |
| 225                   | 32.99                    |
| 270                   | 32.75                    |
| 315                   | 32.25                    |
| 360                   | 31.42                    |

* direction = location of the drift-impacted biotope section, as seen from the treated area, i.e. at a direction of e.g. 45°, the drift-impacted biotope section is located to the northeast of the treated area

The worst case direction for Rhine-Hesse (Refined Approach), with a PDIA of 33.97 ha, is 90 degrees, i.e. the maximum PDIA is located east of the treated area.

If the wind blows from different directions during two consecutive treatments of the same orchard area, it is clear that the total PDIA becomes larger than in the case of identical wind directions. However, it is not possible to simply add the areas for the two wind directions because the drift plumes of the two applications overlap to a greater or lesser extent, depending on the landscape structure and the precise direction of the wind (Figure S 3). Even in the case of opposite wind directions, the potential for overlap cannot be completely excluded, e.g. when a narrow hedge is situated between two neighbouring orchards.
For this reason, the areas that were predicted to potentially receive spray drift from two possible source areas (i.e. overlapping) during the two drift events were first calculated for the eight cardinal wind directions. The values for Rhine-Hesse are shown in Table S 7.

If, for instance, the product is applied on the first spray date with a southwest wind in Rhine-Hesse (affected biotope area at a direction of 45 degrees) while, on the next application day, there is a west wind (affected biotope at a direction of 90 degrees), then a total of 21.02 ha of the biotope area is potentially drift-impacted by the two applications.

Figure S 3: Schematic portrayal for the calculation of the potentially drift-impacted biotope area with two applications and different wind directions
Table S 7: Overlapping drift-impacted areas (in ha) after two treatments

| Direction °  | 45    | 90    | 135   | 180   | 225   | 270   | 315   | 360   |
|--------------|-------|-------|-------|-------|-------|-------|-------|-------|
| (degrees)    |       |       |       |       |       |       |       |       |
| 45           | 33.82 | 21.02 | 12.72 | 6.51  | 5.62  | 7.23  | 10.40 | 17.85 |
| 90           | 21.02 | 33.97 | 19.27 | 10.27 | 7.58  | 5.90  | 6.31  | 11.12 |
| 135          | 12.72 | 19.27 | 32.45 | 18.12 | 10.63 | 6.32  | 6.12  | 8.44  |
| 180          | 6.51  | 10.27 | 18.12 | 30.89 | 17.64 | 10.78 | 8.44  | 6.26  |
| 225          | 5.62  | 7.58  | 10.63 | 17.64 | 32.99 | 20.37 | 12.65 | 6.11  |
| 270          | 7.23  | 5.90  | 6.32  | 10.78 | 20.37 | 32.75 | 18.93 | 9.85  |
| 315          | 10.40 | 6.31  | 6.12  | 8.44  | 12.65 | 18.93 | 32.25 | 18.00 |
| 360          | 17.85 | 11.12 | 8.44  | 6.26  | 6.11  | 9.85  | 18.00 | 31.42 |

* direction = location of the drift-impacted biotope section, as seen from the treated area, i.e. at a direction of e.g. 45°, the drift-impacted biotope section is located to the northeast of the treated area

Since the fenoxycarb residues on the leaves available to Non-Target Arthropods decline quickly (DT₅₀ = 1.4 days) relative to the interval between applications, it is irrelevant in terms of the maximum exposure level whether a certain proportion of the area receives drift from only one or both applications. The important aspect is the total maximum area that can be affected by drift following the two applications. This area is estimated by summing the two individual areas for the respective direction (see Table S 6) and then subtracting the area of overlap (Table S 7).

As an example, if the wind was blowing towards the 45° direction during one application and towards 90° during the other application, a total area of 46.77 ha (i.e. 33.82 + 33.97 – 21.02 = 46.77) could be impacted by drift.

The total maximum potentially drift-impacted biotope area, under the assumption of two applications to all of the cultivated areas for the approved crops, amounts to 61.19 ha (9.5 % of 645 ha BIO in AUI) in Rhine-Hesse (45/225 degrees). The average potentially impacted area would be 51.05 ha (arithmetic mean of all figures in Table S 8).
Table S 8: Total area (in ha) affected at least once by spray drift after two treatments

| Direction ° (degrees) | 45   | 90   | 135  | 180  | 225  | 270  | 315  | 360  |
|----------------------|------|------|------|------|------|------|------|------|
| 45                   | 33.82| 46.77| 53.55| 58.20| 61.19| 59.34| 55.67| 47.39|
| 90                   | 46.77| 33.97| 47.15| 54.59| 59.38| 60.82| 59.91| 54.27|
| 135                  | 53.55| 47.15| 32.45| 45.22| 54.81| 58.88| 58.58| 55.43|
| 180                  | 58.20| 54.59| 45.22| 30.89| 46.24| 52.86| 54.70| 56.05|
| 225                  | 61.19| 59.38| 54.81| 46.24| 32.99| 45.37| 52.59| 58.30|
| 270                  | 59.34| 60.82| 58.88| 52.86| 45.37| 32.75| 46.07| 54.32|
| 315                  | 55.67| 59.91| 58.58| 54.70| 52.59| 46.07| 32.25| 45.67|
| 360                  | 47.39| 54.27| 55.43| 56.05| 58.30| 54.32| 45.67| 31.42|

* direction = location of the drift-impacted biotope section, seen from the treated area, i.e. at a direction of e.g. 45°, the drift-impacted biotope section is located to the northeast of the treated area

4.2 Worked example: Influence of the wind directional distribution for Rhine-Hesse in the Refined Approach

Long term statistical data on the directional distribution of winds with speeds < 5 m/s (i.e. for applications according to good agricultural practice) for Rhine-Hesse in the months of March to May (when fenoxycarb is being applied), provided by the DWD (German Weather Service), are listed in Table S 5.

The prevailing wind direction was North-East, with 24 % of the recordings being from this direction. Wind direction matrices that reflect the frequency (probability) of the occurrence of combinations of wind directions can be generated from the wind direction distributions for Rhine-Hesse (Table S 9).

The figures in Table S 8 describe the areas potentially impacted by drift with the occurrence of the respective combination of wind directions. The values in the above wind direction matrices (Table S 9) describe the probability or frequency of the occurrence of such combinations of wind directions. Multiplying the data from the respective tables provides a realistic measure for how much biotope area can potentially be impacted under the wind conditions typically prevalent during the application season of fenoxycarb.

The results, obtained by weighting the PDIAs shown in Table S 8 with the probability for the respective wind combination from Table S 9, are shown in Table S 10, below.
The sum of all of the 64 individual areas defines the potentially drift-impacted biotope area under the wind conditions typical for the respective region.

Table S 9: Occurrence of the different combinations of wind direction (in percent)

| Direction a (degrees) | 45  | 90  | 135 | 180 | 225 | 270 | 315 | 360 |
|-----------------------|-----|-----|-----|-----|-----|-----|-----|-----|
| 45                    | 4.5%| 1.5%| 1.7%| 2.4%| 5.1%| 2.1%| 1.1%| 2.8%|
| 90                    | 1.5%| 0.5%| 0.6%| 0.8%| 1.7%| 0.7%| 0.4%| 0.9%|
| 135                   | 1.7%| 0.6%| 0.7%| 0.9%| 2.0%| 0.8%| 0.4%| 1.1%|
| 180                   | 2.4%| 0.8%| 0.9%| 1.2%| 2.7%| 1.1%| 0.6%| 1.5%|
| 225                   | 5.1%| 1.7%| 2.0%| 2.7%| 5.9%| 2.4%| 1.2%| 3.2%|
| 270                   | 2.1%| 0.7%| 0.8%| 1.1%| 2.4%| 1.0%| 0.5%| 1.3%|
| 315                   | 1.1%| 0.4%| 0.4%| 0.6%| 1.2%| 0.5%| 0.3%| 0.7%|
| 360                   | 2.8%| 0.9%| 1.1%| 1.5%| 3.2%| 1.3%| 0.7%| 1.7%|

*a direction = direction in which the wind flows off from the orchard in the direction of the biotope.

Table S 10: Biotope areas (in ha) in Rhine-Hesse, weighted by the probability of the occurrence of certain combinations of wind directions, that can be maximally drift-impacted for these combinations of wind directions (2 applications)

The sum of all of the individual areas amounts to 50.81 ha

| Direction a (degrees) | 45  | 90  | 135 | 180 | 225 | 270 | 315 | 360 |
|-----------------------|-----|-----|-----|-----|-----|-----|-----|-----|
| 45                    | 1.52| 0.70| 0.92| 1.37| 3.15| 1.27| 0.60| 1.32|
| 90                    | 0.70| 0.17| 0.27| 0.43| 1.02| 0.43| 0.21| 0.50|
| 135                   | 0.92| 0.27| 0.21| 0.41| 1.07| 0.48| 0.24| 0.59|
| 180                   | 1.37| 0.43| 0.41| 0.38| 1.25| 0.59| 0.31| 0.82|
| 225                   | 3.15| 1.02| 1.07| 1.25| 1.94| 1.11| 0.64| 1.86|
| 270                   | 1.27| 0.43| 0.48| 0.59| 1.11| 0.33| 0.24| 0.72|
| 315                   | 0.60| 0.21| 0.24| 0.31| 0.64| 0.24| 0.08| 0.30|
| 360                   | 1.32| 0.50| 0.59| 0.82| 1.86| 0.72| 0.30| 0.54|

*a direction = direction in which the wind flows off from the orchard in the direction of the biotope = location of the biotope section coated by drift, seen from the treated area
After two applications of fenoxycarb (each at 100 g/ha) to those orchard crops where fenoxycarb use is authorised, assuming median (50th percentile) drift conditions (justified by the multitude of applications) and considering the typical wind distribution for the region, the PDIA is 50.81 ha (sum of individual areas shown in Table S 10).
5. RESULTS FOR THE LAKE CONSTANCE AND MIDDLE RHINE VALLEY AREAS

Table S 11 shows the comparison of results from the Default Approach with the refined landscape analysis for the AUI Lake Constance. Table S 12 presents the corresponding results for the AUI Middle Rhine Valley.

Table S 11: Lake Constance: Comparison of the results of the Default Approach with the refined landscape analysis. Refinement based on an average use rate of 100 g/ha fenoxycarb, 13 m buffer, and 1 application (typical use pattern for Lake Constance)

| Description                                                                 | Results of Default Approach | Results of Refined Approach |
|----------------------------------------------------------------------------|------------------------------|----------------------------|
|                                                                            | Area (absolute)              | Area (absolute)             |
|                                                                            | Biotope area to be protected (%) | Biotope area to be protected (%) |
| Area under investigation (AUI)                                              | 56 km²                       | 56 km²                      |
| Orchard areas (all orchards) within the AUI (100% of all plantations)      | 1330 ha                      | 1330 ha                     |
| Orchard areas (fenoxycarb orchards) within the AUI (100% of all plantations) |                              |                             |
| Biotopes within the AUI                                                     |                              |                             |
| with whole forest area                                                      | 1181.0 ha 100.0              | 480.1 ha 100.0              |
| only with forest fringe (20 m)                                              |                              |                             |
| Biotope area fully within the OBZ (Step 2)                                  | 112.0 ha 3.3                 | 75.1 ha 15.6                |
| PDIA without interception (Step 3)                                         |                              |                             |
| in worst-case direction, after one treatment                                | 39.3 ha 3.3                  | 24.0 ha 5.0                 |
| maximum (worst-case directions)                                            |                              |                             |
| after two treatments n.r. n.r.                                              |                             |
| wind distribution weighted after two treatments n.r. n.r.                   |                             |

PDIA: Potentially drift-impacted area (without estimating the effect of interception)

n.r.: not relevant because only one treatment is applied per season at Lake Constance according to information from the official advisory expert service

biotopes: non agricultural habitats as defined by regulatory regulations for plant protection products in Germany
Table S 12: Middle Rhine Valley: Comparison of the results of the Default Approach with the refined landscape analysis. Refinement based on an average use rate of 100 g/ha fenoxycarb, 13 m buffer, and 2 applications

| Description                                                                 | Results of Default Approach | Results of Refined Approach |
|                                                                            | Area (absolute) | Biotope area to be protected (%) | Area (absolute) | Biotope area to be protected (%) |
| Area under investigation (AUI)                                             | 40 km²          | 291 ha                          | 40 km²          | 112 ha                          |
| Orchard areas (all orchards) within the AUI (100% of all plantations)     |                |                                |                |                                |
| Orchard areas (fenoxycarb orchards) within the AUI (38% of all plantations)|                |                                |                |                                |
| Biotopes within the AUI                                                   |                |                                |                |                                |
| with whole forest area                                                    | 928.9 ha       | 100.0                          | 563.6 ha       | 100.0                          |
| only with forest fringe (20 m)                                            |                |                                |                |                                |
| Biotope area fully within the OBZ (Step 2)                                | 85.5 ha        | 9.2                            | 25.8 ha        | 4.6                            |
| PDIA without interception (Step 3)                                        |                |                                |                |                                |
| in worst-case direction, after one treatment                              | 33.1 ha        | 3.6                            | 8.2 ha         | 1.5                            |
| maximum (worst-case directions) after two treatments                      |                |                                | 14.9 ha        | 2.6                            |
| wind distribution weighted after two treatments                            |                |                                | 11.4 ha        | 2.0                            |

PDIA: Potentially drift-impacted area (without estimating the effect of interception)
biotopes: non agricultural habitats as defined by regulatory regulations for plant protection products in Germany
6. **RESULTS FOR THE AUI RHINE-HESSE ASSUMING A USE RATE OF 150 G/HA FENOXYCARB**

150 g/ha is the use rate foreseen for large trees with a tree top height of 3 m. In commercial plantations, tree height rarely exceeds 2 m, in order to facilitate maintenance measures and harvest. Table S 13 contains the comparison of the results of the basic approach with the refined landscape analysis.

Table S 13:  Rhine-Hesse: Comparison of the results of the basic approach with the results of the refined landscape analysis. Refinement based on an average use rate of 150 g/ha fenoxycarb, 15 m buffer, 2 applications

| Description | Results of Default Approach | Results of Refined Approach |
|-------------|----------------------------|----------------------------|
|             | Area (absolute) | Biotope area to be protected (%) | Area (absolute) | Biotope area to be protected (%) |
| Area under investigation (AUI) | 80 km² | 80 km² |
| Orchard areas (all orchards) within the AUI (100% of all plantations) | 1400 ha | 863 ha |
| Orchard areas (fenoxycarb orchards) within the AUI (62% of all plantations) | 766.8 ha | 644.6 ha |
| Biotope area within the AUI with whole forest area | 100.0 |
| only with forest fringe (20 m) | 265.9 ha | 136.6 ha |
| Biotope area fully within the OBZ (Step 2) | 34.7 |
| PDIA without interception (Step 3) in worst-case direction, after one treatment | 88.4 ha | 11.5 |
| maximum (worst-case directions) after two treatments (fenoxycarb orchards) | 70.5 | 10.9 |
| wind distribution weighted max. after one treatment (all orchards) | 84.0 ha | 11.0 |
| wind distribution weighted max. after two treatments (fenoxycarb orchards) | 58.6 | 9.1 |
| PDIA with interception (Step 4) | 50.4 ha | 33.4 \(^a\) |

\(^a\) Extrapolated from the wind distribution-weighted PDIA under consideration of the area ratio of [Step 3] to [Step 4] of the standard approach for Rhine-Hesse of 1.753.

PDIA:  Potentially drift-impacted area

biotopes: non agricultural habitats as defined by regulatory regulations for plant protection products in Germany
7. **SOME DETAILS ON STEP 3: DIRECTIONAL EXPOSURE ANALYSIS**

The objective of Step 3 was to expand the omni-directional analysis from Step 2 by determining the potentially impacted biotope area for each of the eight cardinal wind directions (following the approach of Hendley et al.\textsuperscript{10}).

In the default approach, dispersion of drift in the eight cardinal wind directions was modelled using the basic spray drift values (scenario ‘orchard early’), i.e. interception by the dense vegetation of hedges or bushes was not taken into consideration (this was part of the Step 4 analysis). The following individual actions were taken to determine the potentially drift-impacted area (PDIA):

1. Segmentation of the outer boundary of the orchard areas at 2 m intervals and calculation of sample points in the centre of each segment

2. Calculation of intersection lines with a length of 20 m, starting from the sample points, in the eight cardinal wind directions (starting from 0°, at 45° intervals) and identification of the points of intersection of the lines with the biotope areas

3. Calculation of the length of the intersection lines between the sample points on the orchard boundary and the biotope boundary. This length (distance) yields the potential penetration depth of the intersection lines into the biotope (penetration depth = 20 m minus the distance between the boundaries).

4. Calculation of the potentially drift-impacted area (PDIA) of a biotope by buffering the penetration depth. The lines are converted to areas by buffering each line with 1 m in all directions. The PDIA in Step 2 resulted from the intersection of this buffered area with the biotopes. NB: This approach slightly over-estimates the PDIA, because a semi-circle with a radius of 1 m is added at the end of each intersection line.

5. Calculation of the PDIA$s$ for all wind directions and selection of the worst-case direction, (i.e. direction with the largest PDIA) for further analyses

The result of the directional exposure assessment is exemplified for two wind directions in Figure S4. The intersection lines in the northeast and northwest directions and the potentially impacted area for these two directions are shown. In this example,
the northwest direction would be the worst-case direction. The higher level of accuracy compared to Step 2 can also be seen here: the 20 m buffer zone from Step 2 (Step 2 PDIA in Figure S 4) is omni-directional; it is formed by spanning a radius of 20 m for every point on the perimeter of the orchard area. The exposure area from Step 3 is directional, meaning that, at the corresponding angle between the wind direction and perimeter of the orchard area, it does not penetrate as deeply into the biotope as the omni-directional buffer from Step 2.
Figure S 4: Directional exposure analysis (step 1 - step 3), example for two selected wind directions (NW = North-West, NE = North-East)
REFERENCES

1 Enzian S, Gutsche V, GIS - gestützte Berechnung der Ausstattung von Agrarräumen mit naturnahen terrestrischen Biotopen auf der Basis der Gemeinden – 2. Ausgabe des Verzeichnisses der regionalisierten Kleinstrukturanteile. Nachrichtenb. Deut. Pflanzenschutzd. 52(12): 299 – 308 (2004).

2 Gutsche V, Enzian S, Quantifizierung der Ausstattung einer Landschaft mit naturbetonten terrestrischen Biotopen auf der Basis digitaler topographischer Daten. Nachrichtenb. Deut. Pflanzenschutzd. 54(4): 92-101 (2002).

3 Julius Kühn Institut (JKI): Guideline for the testing of plant protection equipment. 2-2.1 Procedure for the registration of plant protection equipment in the section “drift-reduction” of the register of loss reducing equipment of the descriptive list. Julius Kühn Institut (JKI), Braunschweig, Germany (2013). Available online at: http://www.jki.bund.de/fileadmin/dam_uploads/_AT/pr%C3%BCfverfahren/rilis/ge raetepruefung_en/2-2.1%20Procedure%20for%20Registration%20of%20DRT_en.pdf (accessed: 02.12.2015)

4 Gove B, The impacts of pesticide spray drift and fertiliser over-spread on the ground flora of ancient woodland: Full report on woodland survey and spray drift analysis. Ph.D. thesis, Imperial College London, Silwood Park campus, Ascot, Berkshire, United Kingdom (2004). Available online at: http://publications.naturalengland.org.uk/publication/117001

5 Koch H, Weißer P, Landfried M, Effect of drift potential on drift exposure in terrestrial habitats. Nachrichtenbl. Deut. Pflanzenschutzd. 55(9): 181-188 (2003).

6 Candolfi MP, Barrett KL, Campbell PJ, Forster R, Grandy N, Huet MC, Lewis G, Oomen PA, Schmuck R and Vogt H (eds), Guidance document on regulatory testing and risk assessment procedures for plant protection products with non-target arthropods. From the ESCORT 2 workshop. SETAC, Pensacola, 46 p (2001).

7 FOCUS, Generic guidance for FOCUS groundwater scenarios, version 1.1., April 2002. Available online at: http://esdac.jrc.ec.europa.eu/public_path/projects_data/focus/gw/docs/Generic_guidance_forV1_1.pdf (accessed 02.02.2016)
8 Lazzaro L, Otto S, Zanin G, Role of hedgerows in intercepting spray drift: Evaluation and modelling of the effects. *Agric. Ecosyst. Environ.* 123: 317-327 (2008).

9 Grosch L, Windrichtungsverteilung für den Raum Ingelheim. (Frequency of the cardinal wind directions for the Ingelheim area). Letters from 19 September & 24 October 2006. Deutscher Wetterdienst (DWD; German National Meteorological Service), Abteilung Klima- und Umweltberatung, Mainz, 3p. (2006).

10 Hendley P, Holmes C, Kay S, Maund S, Travis K, Zhang M, Probabilistic risk assessment of cotton pyrethroids: III. A spatial analysis of the Mississippi, USA, cotton landscape. *Environ. Toxicol. Chem.* 20(3): 669-678 (2001).