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APPROPRIATE EXPOSURE ESTIMATES FOR WILDLIFE RISK ASSESSMENTS OF CROP PROTECTION PRODUCTS BASED ON CONTINUOUS RADIO TELEMETRY: A CASE STUDY WITH WOODPIGEONS

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Abstract: The registration of pesticides follows guidance published by the European Food Safety Authority (EFSA). As a default, the EFSA guidance document on risk assessment for birds and mammals assumes that animals feed exclusively on pesticide-treated fields. However, the guidance document suggests refining the risk via the proportion of food animals obtain from a treated field or specific crop (expressed via the portion of diet obtained from a treated area [PT value]). The EFSA guidance equalizes the portion of food taken from a treated area per day with the portion of time spent potentially foraging over the course of a day within this area. Therefore, radiotracking is commonly used to gather species-, crop-, and season-specific PT data, and radio telemetry of continuously tracked farmland species can deliver individual PT values for a given day, crop, and species. In the present study the authors introduce a way of calculating long-term PT values based on empirically recorded data via telemetry field studies for the most appropriate use in wildlife risk assessment of pesticides. The novel aspect of the proposal is that the authors follow the prerequisite given by EFSA to cover the long-term risk by introducing 21-d PT values that aim to cover both intra- and inter-individual variability of foraging focal farmland species in cropped habitats. Currently, the intra-individual variability is not taken into account for PT calculations. The authors demonstrate this approach and discuss EFSA guidance input requirements for PT values recorded in field studies, based on a PT field study conducted with woodpigeons (*Columba palumbus*) radiotracked in an agricultural landscape in the United Kingdom. The results indicate that a 21-d PT value considering intra-individual variability gives a more appropriate PT value for long-term risk assessments. *Environ Toxicol Chem* 2017;36:1270–1277. © 2016 SETAC

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INTRODUCTION

Registration of the active substances of plant protection products needs to be assessed by the European Food Safety Authority (EFSA) and EU Member State Regulatory Authorities for possible approval of active substances at a community level by Member States and the EU Commission. Plant protection products, using approved active substances, are then authorized at the Member State level.

Within this complex process, applicant companies have to submit a data package covering a wide range of safety and efficacy topics, including environmental assessments of the risk to wildlife [1]. The term wildlife as used in the present study refers to terrestrial vertebrates and is represented by nontarget, free-ranging birds and mammals for which acceptable levels of risk have to be demonstrated. The process by which the risk to birds can be assessed and refined in a stepwise fashion has been explained in detail by Ludwigs et al. [2].

Birds and mammals may be exposed to residues of plant protection products by feeding on food items containing residues after the pesticide has been applied to the field. In conservative initial screening and tier 1 assessments, it is assumed that all food consumed by a given bird or mammal is taken from the treated area (i.e., a treated field), expressed by a default PT value of 1.0 to be used in a toxicity-to-exposure ratio calculation. The PT is defined as the portion of diet obtained from a treated area and can range from 0 (portion = 0%) to 1 (portion = 100%).

The recommended method to gather more realistic species-, crop-, and time-related PT values is radiotracking, and respective field studies should be conducted according to EFSA recommendations [1] as continuous full-day telemetry sessions per tracked individual ("Ideally, radio-tracking of an individual should encompass the activity period of a single day" [1]), with a number of different individuals at crop growth stages [3] corresponding to intended pesticide application timings.

However, at present, the PT values used and evaluated in birds and mammals risk assessments often do not fulfill these criteria, and it is necessary to distinguish between telemetry data collected differently (i.e., continuously or not; full day or part day; within a crop of concern or in general farmland, etc.). The use of such PT values based on different study designs, sample sizes, applied methodologies, and so forth, and PT data derived from publicly available literature resulted in the following evaluation principle used by Member State Regulatory Authorities in Europe as well as the EFSA: to retain PT = 1, or to use a single maximum value of a given PT dataset, if the sample size is small (below 10 [4]).

However, most Regulatory Authorities in the EU recommend that the 90th percentile of the PT data be used, irrespective

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of sampling methodology. The EFSA Guidance Document [1] states: "... if the PT of 1 was replaced by a median or mean then this would suggest, (...) that the estimation of risk would be protective for only half the target population," and hence if mean or median values from empirical PT datasets are used in wildlife risk assessments, these values are commonly rejected by many Member State Regulatory Authorities because they are uncertain whether the protection goal of the EFSA [1] has been addressed appropriately: that "no long-term repercussions on abundance and diversity will occur" and that "mortality or reproductive effects are unlikely."

For long-term risk assessment, the EFSA guidance recommends generation of realistic species-, time-, and crop-related PT values as a higher tier refinement option. According to the EFSA [1], an exposure period of 21 d is appropriate for long-term risk assessment, assuming no long-term effects from short-term exposure. Therefore, appropriate PT values for use in long-term risk assessments should be based on multiday trackings of single individuals. This would take into account the inter- and intra-individual differences in foraging and feeding behavior over time (i.e., a realistic long-term PT value of 21 d for different individuals; see also Van Moorter et al. [5]). Publicly available PT data show, not surprisingly, that PT values differ between individuals [6], but also on a day-to-day basis for the same individual [7,8]. If daily PT data were available for a single individual over a suitably long time period, the average of these values would represent a realistic and appropriate long-term PT value for this individual (i.e., 21 d [1]) that can be used for long-term risk assessments. However, for logistical reasons, such resource-intensive long-term studies covering several individuals of the same species are normally not conducted.

It is the aim of the present study to present a statistical approach that can be used to obtain an appropriate PT value to refine the long-term risk assessment for birds and mammals, and advise on how to use PT data of different quality and quantity for long-term risk assessments. The approach takes both the intra- and inter-individual variability of the PT into account. The main basis of the present study is a PT field study on woodpigeons (*Columba palumbus*), carried out in the United Kingdom with several individuals that were radiotracked over multiple days.

METHODS

We evaluated the empirical PT values of woodpigeons trapped and tagged in a UK agricultural landscape. The telemetry study was conducted by Bayer CropScience from 18 September to 12 November 2003 in an area of arable farmland situated approximately 20 km to the north of York. The study area was known to hold a high abundance of woodpigeons. To gain empirical, full-day PT values, 20 individuals were caught, fitted with radio transmitters, and tracked for 3 consecutive d during the whole daylight (i.e., activity) period. After these tracking sessions, 6 of the 20 woodpigeons were tracked for a second time for 3 consecutive days (for more details on tracking sessions of each woodpigeon, see the Supplemental Data, Table S1).

Wood pigeon data

To equip woodpigeons with radio tags (Biotrack), individuals were captured by means of mist netting. Radio tags were attached to the back of the pigeons with a harness made of a Teflon band. The aim of the tracking was to monitor the activity of individual birds in all habitats used (i.e., to generate individual and daily PT values). For the purposes of the present study, we focused on the portion of time woodpigeons spent foraging (i.e., being active) on crop stubble fields, the most preferred habitat of the woodpigeons under study, which is in line with other studies (see also Shrubb [9], Wilson et al. [10], and Baker et al. [11]).

Birds were followed continuously, mostly by car—in some cases by foot—and every change of behavior or change of habitat (exact positions according to a map) was recorded on a laptop computer (map software ArcView GIS Ver 3.1 with electronic map [Ordnance Survey, 1:10 000 Scale Raster] and database software Microsoft Access 97). In addition, whenever possible, the behavior of tracked individuals was observed with spotting scopes and recorded. If no visual contact was possible, the behavior of the tracked individual was identified via the radio tag signal (stable signal = inactive behavior; fluctuating signal = active behavior). A minimum convex polygon was used as the home range estimator for each pigeon (cf. Kenward [12]). The total area of all home ranges of all woodpigeons was mapped regularly during the present study, to assign a certain habitat type to each location of each woodpigeon tracked in the study.

Because woodpigeons are diurnal [13,14], pigeons were considered inactive at night, and at the beginning of each tracking session (always during darkness before pigeons start to get active), their behavior fell in the same category as the end of the tracking period. (Pigeons were always followed to their night roost until they became inactive.) The behavior "inactive (night)" specified the behavior from midnight until the start of the first activity and from the end of the last activity until midnight for each empirically and continuously recorded 24-h telemetry session. The category "inactive (day)" specified the summarized duration of inactivity between the first and the last activity of the day. From this dataset we used the time (as proportion of the total active time) each woodpigeon was potentially foraging (verified and potential feeding/being active) on stubble fields per day as the single "daily PT value" of a given woodpigeon. Overall, we evaluated 78 continuous full-day telemetry sessions of 20 different individuals over a total of approximately 8 wk.

Monte Carlo simulations with empirical PT values

Empirical PT values of individual woodpigeons in the present study differed between different days of tracking and between different individuals (Table 1). If such empirical multiday data were available, the average of these values of a single individual would represent a realistic long-term PT value for that specific individual, because the average would reflect its long-term behavior (according to the EFSA [1]).

The EFSA protection goal for assessing the risk from pesticide use to birds and mammals is the protection of the "population" [1,15], or, as quoted from the EFSA Guidance [1], making "... any reproductive effects unlikely. At higher tiers, assessments may be directed either at the surrogate protection goal or at the actual protection goal of clearly establishing that there will be no visible mortality and no long-term repercussions for abundance and diversity." Studies using PT values usually include a limited number of individuals (20 or fewer), mainly because of budget and logistical constraints. However, to create more population-relevant data, Monte Carlo simulations [16] (cf. also Wang [17]) are a promising tool because they provide a comprehensive and realistic dataset on the basis of empirical recorded data. The Monte Carlo simulations demonstrate the probability of how such rather small datasets would look for higher sample sizes. Repeated calculations via a probabilistic computing approach are conducted using multiple input values. This results in multiple output values, which then reflect the

Table 1. Full-day empirical PT values obtained for the habitat stubble field from 20 individual woodpigeons radiotracked continuously for 1 daylight period in autumn in the United Kingdom[a]

Woodpigeon individual	PT value, for stubble field of tracking session number (full-day radiotracking)					
	1	2	3	4	5	6
1	0.546	0.355	1.000			
2	0.054	0.465	0.110	0.211	0.000	0.000
3	0.335	0.603	0.254	0.000	0.000	0.000
4	0.486	0.626	0.217			
5	0.000	0.000	0.119	0.000	0.000	0.000
6	0.374	0.052	0.584	0.719	0.158	0.541
7	0.175	0.263	0.479			
8	1.000	0.526	0.967	0.444	0.429	0.435
9	0.933	0.459	0.113			
10	0.478	0.114	0.140			
11	0.497	0.794	0.530			
12	0.513	1.000	0.708			
13	0.118	0.314	0.233			
14	0.452	0.000	0.102			
15	0.447	1.000	0.923	0.438	0.542	0.487
16	0.140	0.000	0.000			
17	0.150	0.000	0.171			
18	0.399	0.691	0.924			
19	0.778	0.878	0.572			
20	0.366	0.000	0.069			

[a]Where PT = 1.0 means all active/foraging time spent in stubble and 0 = no active/foraging time spent in stubble.
PT = portion of diet obtained from a treated area.

variability of all input values. Translated to the problem at hand, this means that large numbers of individuals are simulated, each represented by multiple PT values. Therefore, it is critical for obtaining a realistic approximation of an actual long-term PT of an individual, how the single measurements of these PT values are selected for each of the Monte Carlo simulated individuals (hereafter called Monte Carlo individuals). The Monte Carlo simulations were conducted on 1000 Monte Carlo individuals, that is, 1000 horizontal lines in the data matrix, each comprising 21 single daily PT values, resulting in a long-term 21-d mean PT of 1 single Monte Carlo individual per horizontal line. Each PT value in the Monte Carlo data matrix represents an empirically measured PT value from the radiotracking data; then all such values are randomly combined to draw 21-d single PT values for all Monte Carlo individuals. Because it is assumed that a time period of 21 d (the common default period used in long-term risk assessments) covers the long-term behavior of an individual, the arithmetic mean over the 21-d period is calculated for each of these Monte Carlo individuals. Finally, to obtain a realistic worst-case PT value to be used in risk assessments, which protects 90% of the population, the 90th percentile is calculated from these mean values for the population (see an example of such a data matrix in Table 2).

Although such a general approach is straightforward, several constraints are common when conducting this approach using telemetry field data. As mentioned in the *Introduction*, there are never enough field data (daily PT sessions) to fill each cell of such a matrix with data from different real individuals tracked in the field (frequently 10–20 individuals are investigated and tracked once or twice). Therefore, multiple empirical PT values on a single individual should be used whenever available. Thus, the optimum case would be a dataset comprising empirical PT values for multiple individuals, in which each individual is tracked over a period of 21 d. In this case, and also for each simulated single Monte Carlo individual PT value, data from real individuals from the field could be used. However, no datasets are known in which empirical PT values on single individuals are available over a time period that comes close to the 21 d commonly used in long-term assessments. To overcome this problem, it is possible to combine individual data from tracked individuals. From these combined intra- and inter-individual data, one can draw 21 data points to simulate individuals with 21 hypothetical PT values based on empirical data (following the bootstrapping technique) or by fitting a probability distribution to the empirical PT values and deriving random values from this distribution.

Importantly, when empirical daily PT values are combined, an approach should be used confirming the adequate usage of data from multiple individuals but at the same time, taking into account behavioral differences between individuals. This is because each individual behaves differently, as is confirmed by the variability of empirical PT values in different individuals. Consequently, combining data into a common dataset could minimize differences between individuals. Therefore, having too few individuals tracked in parallel at least once (for inter-individual differences) and multiple times (for intra-individual differences) might lead to a reduction in the potential individual variability (for more details, see Table 3). Thus the approach proposed in the present study includes the comparison of variability of multiple empirical daily PT values that were obtained from a single individual versus the variability of multiple empirical daily PT values of a single day obtained from different individuals. The comparability of these variabilities is tested to determine whether combining these 2 datasets is statistically appropriate.

Inter- and intra-individual variability of empirical PT values

Single empirical PT values may only be used to fill the data matrix of a Monte Carlo individual if their variability is comparable to the individual variability for individuals of the same species from a comparable environment (i.e., preferably from the same field study). Otherwise the variability of individual behavior, resulting in temporally varying PT values, would be ignored (Table 3). To determine whether such

Table 2. Data matrix for Monte Carlo (MC) approach[a]

Individual	PT Day 1	PT Day 2	PT Day 3	PT Day 4	PT Day 5	. . .	PT Day 21	Mean PT for "MC Individual"
"MC Individual" 1	0.34	0.28	0.45	0.73	0.64		0.34	0.45
"MC Individual" 2	0.22	0.43	0.21	0.44	0.32		0.46	0.23
. . .								
"MC Individual" 1000	0.62	0.55	0.12	0.35	0.33		0.11	0.21
								90th percentile of all mean PT values of all MC individuals

[a]Example data matrix showing concept of Monte Carlo approach listing MC individuals, and resulting in the 90th percentile of 1000 mean portion of diet obtained from a treated area (PT) values (rightmost column) consisting of 21 mean daily PT values each.

Table 3. Problems of combining data[a]

	PT Session	PT Session	PT Session	PT Session	PT Session	Mean PT
Individual 1	0.18*	0.23*	0.28*	0.17*	0.21*	0.22*
Individual 2	0.61**	0.52**	0.56**	0.62**	0.53**	0.56**
"MC Individual" X	0.18*	0.52**	0.28*	0.62**	0.21*	0.41
"MC Individual" Y	0.61**	0.23*	0.56**	0.17*	0.53**	0.37

[a]When averaging over multiple days, differences between different days and individuals can disappear, which may have effects on the results (if there are marked differences between individuals). As row no. 1 and 2 in Table 3 shows, the mean of individual 1 (*) based on empirical portion of diet obtained from a treated area (PT) values is 0.22 and the mean of individual 2 (**) is 0.56. If these data are pooled as basis for simulating Monte Carlo (MC) individuals, the differences of these individuals are minimized (mean of 0.41 and 0.37), as can be seen for rows no. 3 and 4 of "pooled" MC individuals X and Y.

variabilities within intra- and inter-individual empirical PT values are comparable, the distributions of both samples are tested with the Kolmogorov–Smirnov test. This test does not assume any specific distribution of the tested data. However, for small sample sizes, differences between 2 distributions cannot be detected, leading to type II errors (the failure to reject the false hypothesis that both samples were drawn from the same distribution). To overcome this problem, it has to be determined if the sample sizes are sufficient for the Kolmogorov–Smirnov test to yield reliable results. However, whether the sample size is sufficient or not depends on the distribution of empirical data at hand (for details and examples, see Table 4).

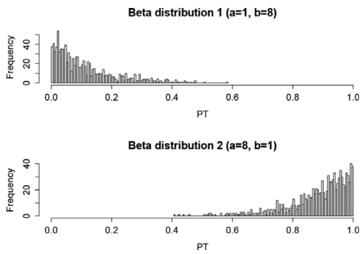
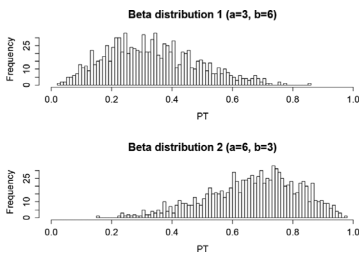
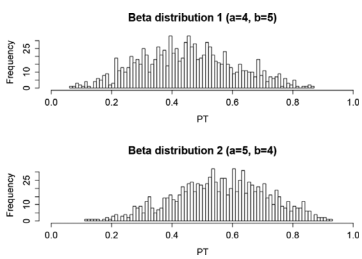
Set of empirical PT values used

Calculations were conducted using the PT dataset from a field study comprising empirical daily PT values of 20 individual woodpigeons, covering up to 6 full-day PT measurements per individual (Table 1).

Subdatasets for inter- and intra-individual variability check

First, individuals were identified from the dataset for which the highest number of measured values was available (woodpigeons 2, 3, 5, 6, 8, and 15). These data can be used directly to obtain single daily PT values, but they can also be

Table 4. Sensitivity of Kolmogorov-Smirnov Test[a]

Probability Distribution	Size of sample 1	Size of sample 2	Kolmogorov-Smirnov test result
	50	50	Yes ($p < 0.01$)
	25	25	Yes ($p < 0.01$)
	10	10	Yes ($p < 0.01$)
	10	5	Yes ($p < 0.01$)
	5	5	Yes ($p < 0.01$)
	10	3	Yes ($p < 0.01$)
	9	3	Yes ($p < 0.01$)
	50	50	Yes ($p < 0.01$)
	25	25	Yes ($p < 0.01$)
	10	10	Yes ($p < 0.01$)
	10	5	Yes ($p < 0.01$)
	5	5	Yes ($p < 0.01$)
	10	3	Yes ($p < 0.05$)
	9	3	Yes ($p < 0.05$)
	50	50	Yes ($p < 0.01$)
	25	25	Yes ($p < 0.01$)
	10	10	No ($p = 0.4175$)
	10	5	No ($p = 0.9191$)
	5	5	No ($p = 1$)

[a]The sample that is required to detect differences between 2 distributions using the Kolmogorov-Smirnov test depends on the actual distributions of the recorded empirical portion of diet obtained from a treated area (PT) values. Therefore, no universally valid numbers can be given. Thus, we conducted several test assessments using different beta distributions in a range-finding approach to examine the sensitivity of the Kolmogorov-Smirnov test to sample size in dependence of the similarity of the distributions. We used 3 different pairs of probability distributions (left column). For resulting threshold sample sizes see sample size columns.

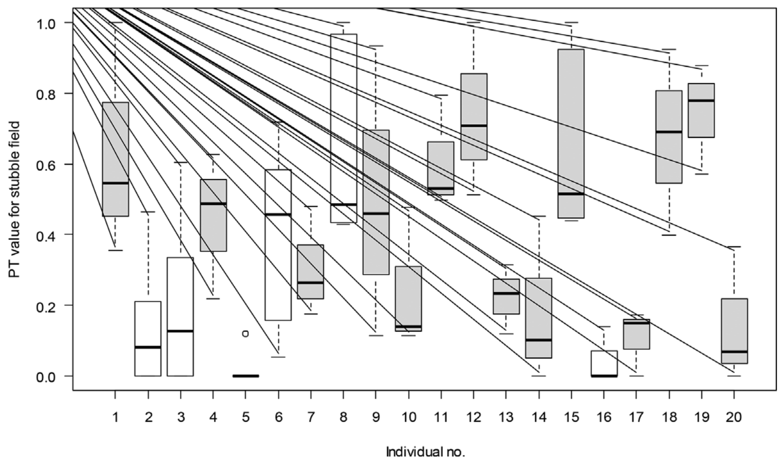


Figure 1. Distribution of portion of diet obtained from a treated area (PT) values of 20 woodpigeons in stubble fields (cf. Table 1). Boxes enclose 25% and 75% quartiles of the individual's PT values. Bar = median of the data; circles = outliers; error bars = minimum and maximum of the data. Gray boxes are based on sample size $n = 3$, and white boxes $n = 6$. Individual no. 5: sample size $n = 6$.

combined with other data if their inter-individual variability is comparable. In contrast, sample sizes of intra-individual empirical PT values of the remaining individuals (woodpigeons 1, 4, 7, 9–14, and 16–20) were too small ($n = 3$) to be used directly for sampling values for the present approach. This sample size is not sufficient for bootstrapping, nor could a reasonable probability distribution be fitted to the data. However, these empirical PT values are used to represent inter-individual variability. In most applications, to calculate a representative 21-d PT value from an empirical database, a proportion of data (i.e., columns or lines of empirical PT values, as shown in Table 1 for the study investigated) might be suitable to be added to the pool, whereas the data of some individuals might not be comparable and should thus not be added to the pool. Therefore the following combined procedure is suggested to derive samples from individual and empirical PT datasets. For each Monte Carlo individual a random number is drawn according to the number of individuals in the original dataset (i.e., a number between 1 and 20; see Table 1). If the random number corresponds to the number of an individual for which data should not be combined (see the *Inter- and intra-individual variability of empirical PT values* section above), then PT values only from this individual are drawn for the respective Monte Carlo individual. If a different random number is drawn, then PT values can be drawn from the pooled data. This leads to the correct proportion of individual data and combined data in the resulting data matrix for 21 daily values of 1000 individuals.

RESULTS

The data are taken from a PT field study containing 78 full-day telemetry sessions of 20 individual woodpigeons utilizing stubble fields in autumn in the United Kingdom. The PT values of all birds are shown in Table 1 and Figure 1.

To represent variability of empirical PT values over time for a single individual, the woodpigeons with 6 tracking sessions were used, that is, woodpigeons 2, 3, 5, 6, 8, and 15 (Table 5). Single daily and empirical PT values of session 1 that did not belong to 1 of these individuals (Table 5) were combined into a dataset representing inter-individual variability.

The results of the tests for all 6 individual datasets (individuals 2, 3, 5, 6, 8, and 15), tested against the inter-individual sample (Table 5), show that the variabilities of individuals 2 and particularly 5 are not comparable to the variability of the inter-individual sample, as indicated by a p value < 0.05 (Table 6). Therefore, data of the inter-individual sample (session 1) are pooled with the data of individuals 3, 6, 8, and 15 only. The excluded individuals are treated separately (see section *Subdatasets for inter- and intra-individual variability check*).

The data for individuals from the present study as well as the pooled data were fitted to different probability distributions (beta, gamma, normal, and log-normal distributions); however, none of these resulted in appropriate fits to the data for this dataset. Therefore the approach was not conducted using fitted distributions, and instead bootstrapping was applied in this example.

Table 5. Example datasets for comparison of inter- and intra-individual variability

Woodpigeon individual	PT value for stubble field of tracking session (full-day radiotracking) number					
	1	2	3	4	5	6
1	0.546*	—	—	—	—	—
2	0.054**	0.465**	0.110**	0.211**	0.000**	0.000**
3	0.335**	0.603**	0.254**	0.000**	0.000**	0.000**
4	0.486*	—	—	—	—	—
5	0.000**	0.000**	0.119**	0.000**	0.000**	0.000**
6	0.374**	0.052**	0.584**	0.719**	0.158**	0.541**
7	0.175*	—	—	—	—	—
8	1.000**	0.526**	0.967**	0.444**	0.429**	0.435**
9	0.933*	—	—	—	—	—
10	0.478*	—	—	—	—	—
11	0.497*	—	—	—	—	—
12	0.513*	—	—	—	—	—
13	0.118*	—	—	—	—	—
14	0.452*	—	—	—	—	—
15	0.447**	1.000**	0.923**	0.438**	0.542**	0.487**
16	0.140*	—	—	—	—	—
17	0.150*	—	—	—	—	—
18	0.399*	—	—	—	—	—
19	0.778*	—	—	—	—	—
20	0.366*	—	—	—	—	—

*Dataset representing inter-individual variability.
**Dataset for intra-individual variability.
PT = portion of diet obtained from a treated area.

Table 6. Results of Kolmogorov–Smirnov tests for comparability of inter- and intra-individual empirical PT values

Woodpigeons with 6 individual empirical PT values	*p* value of Kolmogorov-Smirnov test
2	0.048*
3	0.161
5	0.001*
6	0.883
8	0.423
15	0.423

*Significant at $p < 0.05$.
PT = portion of diet obtained from a treated area.

As a result of the Monte Carlo simulations, a long-term 90th percentile (of mean and simulated 21-d PT values per individual) of 0.53 was determined when bootstrapping was used to draw values from the field data. In contrast, the 90th percentile of the observed 1-d PT values only is 0.89.

If we had conducted unconditional pooling of data (Table 3), the results after bootstrapping the combined data would be as shown in Figure 2.

The results of the Monte Carlo approach using unconditional pooling show that the differences between the individuals are reduced by combining them in a common dataset. In contrast, by discrimination of the dataset by a priori testing of variability, the resulting distribution shows a slightly different (bimodal) distribution.

DISCUSSION

The EFSA birds and mammals Guidance [1] gives a default exposure period of 21 d to be considered for potential long-term effects (where there is no indication of long-term effects from short-term exposure). Even though this period is arbitrarily chosen, an appropriate PT value to be applied in long-term risk assessments should in this situation cover 21 d.

With regard to PT telemetry data, the EFSA [1] proposes that "ideally, radio-tracking of an individual should encompass the activity period of a single day," and the continuous tracking of birds from dawn till dusk ensures this parameter in the present study. This single-day period is not generally part of the data considered by Finch et al. [6], the only publicly and commonly used available collection of statistical PT value estimates. The data presented by Finch et al. [6] are based on partly shorter tracking periods (i.e., a few hours) and then are distributed over several days, sometimes still not covering a full activity period of a whole day. Data for individuals radiotracked continuously for a full day, as in the present study, are not often available, particularly not over 21 d, because this is very time and cost intensive. Therefore, another option to derive appropriate 21-d long-term PT values is to model PT values of a population based on empirically recorded full-day PT data. Such an example is shown in the present study based on a dataset of 3 to 6 full-day PT values for 20 woodpigeons potentially foraging on crop stubble fields.

This is an exceptional database compared with most other and more typical PT field studies providing PT values for risk assessment calculations (cf. Finch et al. [6] and Ludwigs [8]). By applying a Kolmogorov–Smirnov test to check comparability of inter- with intra-individual variability for woodpigeons' PT values for optimal combination of data to conduct Monte Carlo simulations as depicted in Figure 3, we calculated a long-term 21-d 90th percentile PT value of 0.53 (Figure 4), which is significantly lower than the 90th percentile daily PT value of 0.89 calculated exclusively from observed and daily PT data (as listed in Table 1). If the inter- to intra-individual empirical PT values had not been carefully tested and selected before combining observed PT values for the Monte Carlo simulations, this would have resulted in a slightly different PT value (Figure 2). However, both values are significantly lower than the 90th percentile of daily empirical PT data. It should be noted that the 90th percentile daily PT value of the empirical data does not consider the long-term aspect actually intended by the EFSA [1]. Such 90th percentile daily PT values are mainly influenced by the maximum of a single individual on only a single day, and intra-individual variation is not appropriately reflected. Such single-day PT values reflect the time spent in treated areas of the single tracking sessions with the highest 10% PT values. A change in behavior (i.e., use of the treated area) over time would therefore only affect this value if the PT contributes to the highest 10% PT values. In contrast, a change

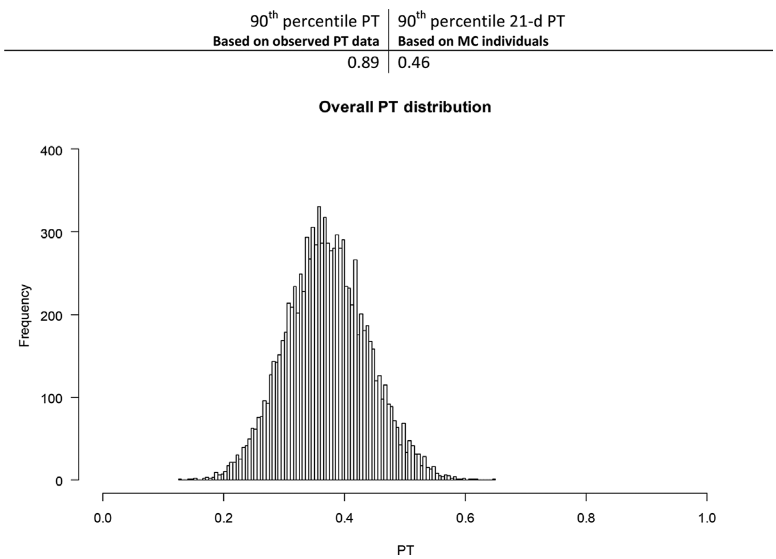


Figure 2. Histogram of all Monte Carlo (MC) individuals as the basis for the long-term 90th percentile 21-d portion of diet obtained from a treated area (PT) value following unconditional pooling of empirical PT values (i.e., extreme values/individuals are missing).

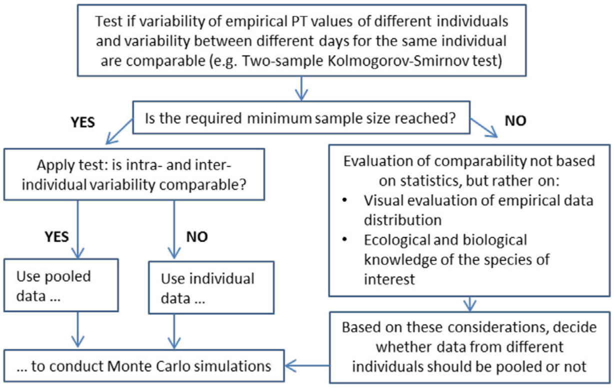


Figure 3. Scheme of how to prepare intra- and inter-individual empirical portion of diet obtained from a treated area (PT) values to be used for Monte Carlo simulations as basis to reveal realistic 21-d PT estimates for pesticide wildlife risk assessments.

in spatial use of the agricultural field or landscape would always be reflected in the arithmetic mean, because this measure depends on all values. The present case study demonstrates that the main reason for this difference is that a 90th percentile PT value based on observed daily PT data does not consider changing PT values over time for the same individual.

There is 1 published woodpigeon study supporting our results that appropriate long-term PT values are much smaller than 1.0 for woodpigeons for any kind of habitat, including highly preferred habitats like stubble fields. Haynes et al. [18] showed a shift in daily woodpigeon home ranges, with a mean of 254 ha for adults and 294 ha for fledged young in summer, and even 628 ha and 1283 ha, respectively, in winter months. These sizes of daily activity ranges suggest that a PT value of 1 (meaning that 100% of the diet from a local population within 21 d is taken from 1 or some treated fields within the animals' activity ranges) overestimates the risk and results in an unrealistic PT value estimate for pesticide risk assessments according to the EFSA protection goal. Woodpigeons utilize multiple habitats, as expressed by rather large home ranges, which results in the use of a large variation in specific habitats (see Haynes et al. [18], and can be seen from the entire data of the present study evaluated here for stubble fields only).

Woodpigeons vary their use of a given area like stubble fields by adjusting the duration of their visit or the frequency of revisits. Thus, in spatially heterogeneous environments (farmland during harvest time and drilling of winter cereals), woodpigeons can exploit such known, high-quality resource areas by increasing their foraging time or decreasing their time to return to stubble fields over time, but would always use different fields/crops/habitats for foraging over 21 d.

Daily activity ranges of woodpigeons in the present study were on average approximately 270 ha (data not shown). Like the data from Haynes et al. [18], this finding reveals that woodpigeons utilize more than 1 field, and also other habitats within their daily activity range for foraging. Birds such as woodpigeons use the landscape on larger scales than individual fields or even some farms in current agricultural landscapes (cf. Fuller [19]). In addition, based on their nutritional needs, which vary over the course of a year and also within much shorter time spans, woodpigeons rely on different foraging habitats [13,14]. Based on what is known about the dietary needs of woodpigeons (see review in Holland et al. [20]), which cannot be fulfilled completely by treated crop fields over the long term, for example, a PT value of or close to 1.0 for any crop, habitat or stubble fields in autumn, as the present study shows, seems to be highly unrealistic. Furthermore, predator vigilance and response to predators, which influences habitat choice of farmland birds [21], as well as diet accessibility over time at the same place, may render a specific treated crop field unattractive over the long term (cf. Butler and Gillings [22]).

It should be noted that Monte Carlo simulations can be done without conducting 2-sample Kolmogorov–Smirnov tests (i.e., with smaller sample sizes or no/less intra-individual data). Comparing 90th percentile PT values based on 1) observed daily PT data, or 2) the simulated 21-d long-term dataset will also result in lower long-term PT values for other farmland bird species (e.g., for skylark, see Wang [17]). On the basis of the findings from the present study, we propose to transfer this concept of simulated 21-d PT value calculations to other available empirical PT datasets and farmland wildlife species to gain more appropriate PT values (ecologically and exposure-

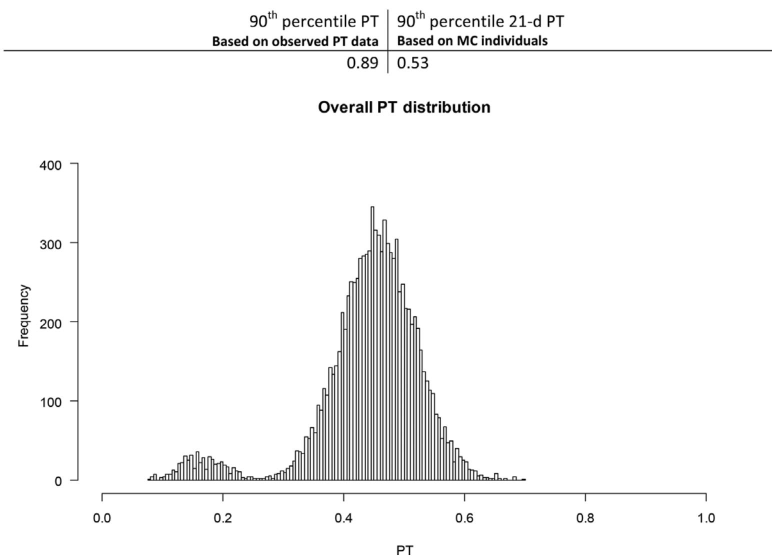


Figure 4. Histogram of all Monte Carlo (MC) individuals that are the basis for the long-term 90th percentile 21-d portion of diet obtained from a treated area (PT) value.

related) for pesticide risk assessment according to the EFSA [1]. The results of the present case study with woodpigeons radiotracked for up to 6 d continuously from dawn until dusk indicate that more research should be conducted into the applicability of the 21-d 90th percentile PT concept for other species and other sets of radiotracking data covering fewer individuals and sessions per individual tracked. Furthermore, when new radiotracking studies for birds are planned with regard to determining PT for wildlife risk assessment, inclusion of more repeated tracking of the same individual should be considered.

Supplemental Data—The Supplemental Data are available on the Wiley Online Library at DOI: 10.1002/etc.3656.

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Data Availability—The original data are available from the corresponding author (jan-dieter.ludwigs@rifcon.de).

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