Received: 10 May 2021 | Revised: 30 August 2021 | Accepted: 2 September 2021

DOI: 10.1111/csp2.551

Conservation Science and Practice Open Access
A journal of the Society for Conservation Biology

WILEY

CONTRIBUTED PAPER

The value of increased spatial resolution of pesticide usage data for assessing risk to endangered species

Erin L. Murphy[1,2] | Steffen Eikenberry[1,3] | Gwenllian Iacona[1,2,4] | Greg Watson[5] | Leah R. Gerber[1,2]

[1]Center for Biodiversity Outcomes, Arizona State University, Tempe, Arizona, USA

[2]School of Life Sciences, Arizona State University, Tempe, Arizona, USA

[3]School of Mathematical and Statistical Sciences, Arizona State University, Tempe, Arizona, USA

[4]Resources for the Future, Washington, DC, USA

[5]Regulatory Scientific Affairs, Bayer U.S. – Crop Science, Chesterfield, Missouri, USA

Correspondence
Erin L. Murphy, Center for Biodiversity Outcomes, Arizona State University, Tempe, AZ 85281, USA.
Email: elmurph1@asu.edu

Funding information
Bayer CropScience, Grant/Award Number: FP00016353

Abstract

Decision makers often cite data quality as a limitation in environmental management. Value of information approaches evaluate the benefit of new data collection for management outcomes. Pesticide exposure risk assessment for endangered species is one context where data limitations may affect decisions and a value of information type approach could be useful for identifying optimal data quality and resolution. Under the U.S. Federal Insecticide, Fungicide and Rodenticide Act, the U.S. Environmental Protection Agency (EPA) is responsible for registering pesticides before they can be sold and regularly reviewing pesticides. Section 7 of the Endangered Species Act requires that the EPA consider potential impacts of pesticides to listed endangered species and critical habitats in this process, and for the Services—U.S. Fish and Wildlife Service and National Marine Fisheries Service—to complete a formal Section 7 consultation if the EPA deems it necessary. The current process is time-intensive, lacks transparency and confidence among stakeholders, and leaves hundreds of unreviewed pesticides on the market. Increasing the resolution of pesticide usage data could address these concerns by improving estimated overlaps between species ranges and pesticide usage. Thus, we evaluated the relative importance of different resolutions of pesticide usage data for assessing expected carbaryl exposure to endangered plant species endemic to California. We found that spatially explicit, township resolution usage data (~36 mile^2) excluded 33% of terrestrial plants (55/168) and 51% their critical habitats (27/53) from requiring a Section 7 consultation, while coarser resolution data excluded none. In contrast, the EPA's biological evaluation for carbaryl only excludes 4% of terrestrial plants (nationally) from requiring formal Section 7 consultation. This suggests high-resolution data could increase pesticide review efficiency and decrease the amount of time pesticides remain on the market without a formal evaluation.

KEYWORDS
conservation, critical habitat, decision theory, endangered species conservation planning, environmental policy, value of information

1 | INTRODUCTION

Environmental management requires decision makers to determine the potentially negative impacts of human activities and regulate those actions. Assessing impacts often requires extensive knowledge of both the natural environment and human–nature interactions (Spash, 2000). Therefore, data quality and resolution play an important role in the efficacy of environmental risk management, and stakeholder confidence in decisions made (Brain et al., 2015). This has driven decision makers and stakeholders to advocate for more strategic data collection (Bottrill, Hockings, & Possingham, 2011; Ferraro & Pattanayak, 2006).

Data collection comes with a cost—obtaining new data is resource-intensive and it is often unclear which information will improve management efforts (Bennett et al., 2018). In some instances, improved information will not change management decisions, or the return-on-investment from the updated decision may not justify the costs of information collection (Maxwell et al., 2015). When new data collection does not improve management efforts, the time and resources used represent resources and time lost toward achieving the management goal (Martin et al., 2012). Value of information (VOI) theory provides an approach to assess the benefit of new data, with regards to decision making, before resources are used to collect it (Canessa et al., 2015).

The U.S. Environmental Protection Agency (U.S. EPA) is one of the primary environmental regulators in the United States. Under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA), the EPA—through their Office of Pesticide Programs—is responsible for registering all pesticides before they can be placed on the market and regularly reviewing registered pesticides to ensure they will have limited effects on the environment and human health (U.S. EPA, 2021a). Under the Endangered Species Act (ESA), the EPA has additional obligations to work with the Services—U.S. Fish and Wildlife Service (USFWS) and National Marine Fisheries Service (NMFS)—to determine potential impacts of a pesticide to all approximately 1,800 endangered species and almost 800 critical habitats (USFWS, n.d.; U.S. EPA, 2021b). Specifically, the EPA is responsible for determining a pesticide's potential for adverse effects on listed species. For those where the EPA determines adverse effects are likely, the Services then evaluate whether pesticide use may jeopardize the continued existence of the species (USFWS, n.d.; U.S. EPA, 2021b).

To address concerns about this process, the Agriculture Improvement Act of 2018 established an Interagency Working Group to review the EPA's methods. In their report to congress, the Working Group determined that the initial processes for determining adverse effects were opaque and time-intensive (U.S. EPA, 2019). In response, the EPA released the *Revised Method for National Level Listed Species Biological Evaluations of Conventional Pesticides* in March 2020 (U.S. EPA, 2020a). This *Revised Method* has been used for six draft biological evaluations of pesticides that are currently on the market. Though EPA did address many comments between their initial and final versions of the *Revised Method*, improvements in efficiency, transparency, and confidence in this process are still needed (U.S. EPA, 2020b; U.S. EPA, 2021c). For instance, most species are still determined to be likely to be adversely affected by the pesticides through the EPA biological evaluation process. The EPA is liable for determinations they make, so they are implicitly incentivized to be precautionary; however, this determination triggers a full Section 7 consultation by the Services, a resource-intensive process (U.S. EPA, 2021d). Additionally, the time intensity of registration reviews has hindered progress in their completion. Currently, the EPA is supposed to review at least 744 pesticides that are already on the market by 2025 (Brain et al., 2015). As a result, pesticides that have not had a formal registration review remain on the market, and industry is unable to proactively adapt to federal regulations.

The spatial analyses included in the *Revised Method* evaluate the potential and actual exposure of endangered species and critical habitats to a given pesticide, which is an important first step in understanding the potential for adverse effects. These analyses require three types of data: pesticide use data (i.e., locations where pesticides may legally be applied, or potentially used, defined as the "action area"), pesticide usage data (i.e., locations where pesticides are applied), and species range or critical habitat data. Species range and critical habitat maps are being updated by the Services and other organizations (Giger, 2019; USFWS, 2019). However, due to limited data availability, pesticide use and usage data remain coarse, and pesticide usage data is rarely spatially explicit. Some stakeholders believe that accurate, high-resolution pesticide usage data may increase the efficiency, transparency, and confidence in evaluations of risks for species and critical habitats (U.S. EPA, 2019). Despite these claims, there has not yet been a formal evaluation of how usage data resolution affects the efficiency of the EPA pesticide regulation process.

In this paper, we evaluate the extent to which the resolution and precision of pesticide usage data affect the ability of the decision maker (the EPA) to determine the potential exposure of a listed endangered species to a pesticide. Using terrestrial plants endemic to California and their critical habitats as a case study, we evaluate the extent to which three different spatial resolutions of pesticide usage data influence expected exposure to carbaryl—a pesticide approved for a broad range of uses that has received a final biological evaluation using the EPA's *Revised Method*. We used California data for this analysis because it has spatially explicit, township resolution pesticide usage data unavailable in the rest of the United States.

Our analysis is a modified version of the EPA's *Revised Method* screening process to determine whether the pesticide is likely to adversely affect the species. The EPA first determines if a pesticide "may affect" a species, and if so, two possible procedures follow. If the EPA determines that a species may be affected but is "Not Likely to be Adversely Affected" (NLAA) by pesticide usage, the Services review the assessment to determine whether they concur. However, if the EPA determines that a species is "Likely to be Adversely Affected" (LAA) then the Services must perform a formal Section 7 consultation. Currently, very few species receive an NLAA determination through the spatial analyses in the EPA's *Revised Method* (U.S. EPA, 2020a).

We hypothesized that using spatially explicit, township resolution pesticide usage data would increase the number of species designated as NLAA compared with the number of species receiving this designation using crop reporting district (most similar to the EPA *Revised Method*) or county resolution pesticide usage data. If NLAA determination is found to be sensitive to higher-resolution usage data, this would support current calls for improving data quality. Alternatively, if NLAA determination is found to be insensitive to changes in data, this may suggest that updating data used in spatial analyses is not the most efficient strategy for improving biological evaluations.

2 | METHODS

To identify a species' or habitat's likelihood of exposure, the EPA's *Revised Method* considers the percent overlap between pesticide usage and species range or critical habitat. If a species range or critical habitat has less than 1% overlap with the range of pesticide usage (i.e., the area where pesticides are applied), or less than one individual is expected to be affected, then the EPA will issue a designation of NLAA. If the overlap area is greater than 1% and/or more than one individual will be exposed, then the EPA will give a designation of LAA (U.S. EPA, 2020a, 2020b).

We evaluated the extent to which the overlap areas between species range or critical habitat and carbaryl usage changed with increasing resolution of carbaryl usage maps. We used carbaryl for our analysis because it is one of only six pesticides that the EPA has evaluated using their *Revised Method*. Carbaryl is labeled for a broad range of agricultural and non-agricultural uses, including a wide variety of terrestrial food and feed crops, turf management, ornamental production, rangeland, commercial shrimp production in Texas, and residential settings.

We performed our analysis in the state of California because the California Department of Pesticide Regulation's Pesticide Use Reporting Program (CDPR PUR) collects pesticide usage data at the township scale resolution, which is the highest level of resolution available in the country, and it is the only census of pesticide usage—most usage data is based on surveys that do not give a complete picture of pesticide usage (CDPR, 2021). Additionally, California is home to more than 100 endemic, endangered terrestrial plants, which allowed us to ensure the entire species range and associated critical habitats could be evaluated with high-resolution pesticide usage data. Our analysis focused on terrestrial plants to simplify spatial analyses because they are immobile and require no aquatic modeling or prey species for consideration.

2.1 | Species ranges and critical habitats for evaluation

Our analysis included 168 listed terrestrial plants native to California and 53 of their critical habitats. To identify terrestrial plants endemic to California, we used the list of terrestrial plants in the continental United States from the EPA's *Final National Level Listed Species Biological Evaluation for Carbaryl* (U.S. EPA, 2021d). We then checked the range for every species in the USFWS Environmental Conservation Online System (USFWS, n.d.). If a species' United States range was limited to California, we downloaded the range map from the ESA database (all range maps were downloaded between September 2020 and January 2021). Of these species, 53 also had designated critical habitats in ECOS (maps downloaded in January 2021).

2.2 | Carbaryl usage maps

To evaluate the influence of carbaryl usage resolution on expected pesticide usage overlap with ESA species ranges and critical habitats, we used three resolutions for usage data: crop reporting district (CRD), county, and survey township scale (generally 36 $mile^2$ resolution). We developed these maps using data from the CDPR PUR program (CDPR, 2021). The PUR program requires end users to report all agricultural pesticide usage to County Agricultural Commissioner's monthly and most data are presented at township resolution (CDPR, 2021). The PUR data are checked for errors by the County Agriculture Commissioners offices during data entry, and by the Department of Pesticide Regulation before they are recorded in the PUR database. Error rates for reported data are low, varying between 0.46 and 5.10% from 1999 to 2016. Underreporting rates are expected to be higher, ranging from 10 to 20%; however, no extensive analysis of underreporting has been completed (Wilhoit, 2018).

To develop usage maps, we obtained carbaryl usage data for 2013–2017 from the CDPR PUR program website, obtained September 16, 2020 (CDPR, 2021). We chose these years to match the temporal range used in the EPA's spatial analysis. We aggregated 2013–2017 usage data at each resolution to create our analysis usage maps. For each base polygon at the different resolutions (i.e., CRD, county, or township), we assigned the maximum annual carbaryl usage reported between 2013 and 2017, to provide the most conservative estimates of possible pesticide usage (see Data S1). This was a binary assessment of pesticide usage (i.e., pesticides were present or absent). Therefore, if a base polygon had any carbaryl usage, no matter how small, it was included in the usage footprint. Though carbaryl usage is thought to be underreported by up to 20% (Wilhoit, 2018), we assumed that all pesticide usage was reported and accurate for this assessment. With no analysis of underreporting, it is not known where underreporting occurs, or how actual usage maps would differ from usage maps created with reported data. To reduce errors of omission, we pooled the maximum values of carbaryl usage for every year from 2013 to 2017 (see Data S1); however, if EPA were to use this data for determinations it would be beneficial to evaluate and address rates of underreporting.

The vast majority of carbaryl usage in the PUR is reported at the township resolution (nearly 99% in terms of mass applied). However, in the years 2013 through 2017, between 0.95 and 2.11% of total carbaryl applied was only reported at county resolution; on average 1.2% of carbaryl application was not assigned a township. We exclude any application that does not report the township (see Data S1 for more detail on development of township maps), because assuming equal usage across a county for applications where township resolution was not available significantly reduced our ability to evaluate the value of township resolution data. By excluding applications without an assigned township for our primary analysis, we slightly underestimate pesticide usage at the township level, and may incorrectly mark some townships as having received no carbaryl. We acknowledge this would not be appropriate in a formal EPA Biological Evaluation. However, given that a very small fraction of carbaryl applications are excluded in any given year, and the fact that we use the maximum carbaryl usage across our 5 years of interest, we consider this a reasonable choice in order to better evaluate the in-principle utility of high spatial usage resolution on risk evaluation.

2.3 | Calculating the percent overlap at each resolution

At each spatial resolution (CRD, county, and township), we determined the fraction of each species' range that overlapped with any carbaryl usage. We considered a polygon (e.g., county) as treated with carbaryl if there was any usage in the polygon. Then, the sum of intersecting area between treated polygons and species range was determined and divided by the total species range area to give the usage overlap percentage (Figure 1). We performed this analysis for all species ranges and critical habitats. All analyses were performed using Python (version 3.7.7) (All code and data needed to perform this analysis are in Data S1 and in the repository provided).

2.4 | Calculating characteristics of species ranges with no or minimal usage overlap under township resolution

We also calculated the mean range and critical habitat areas for species with <1 and >1% overlap with township resolution pesticide usage. We used a Mann–Whitney test to test for significant differences between range size and critical habitat area for these two groups.

3 | RESULTS

3.1 | Carbaryl usage and range/habitat overlap at different usage resolutions

The 168 endangered species and 53 critical habitats used in our analysis varied appreciably in the size of their range and in the region of California they covered. Species' ranges varied from 0.776 to 58,357 $mile^2$, with a

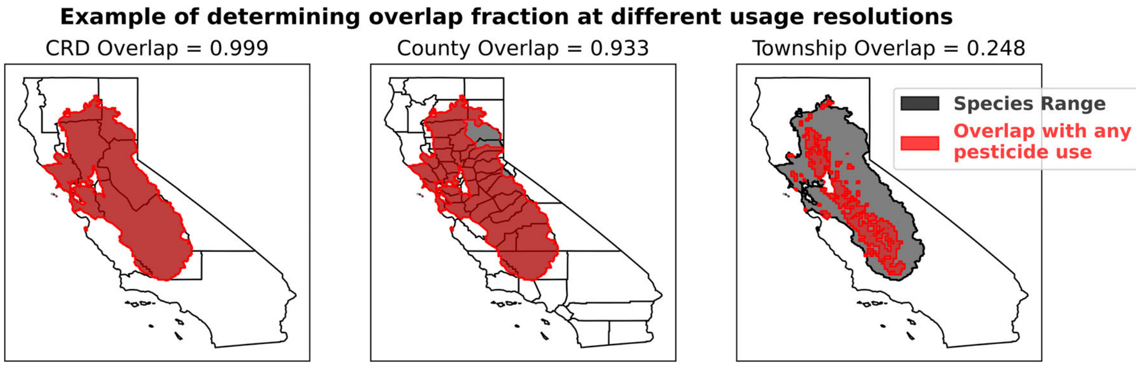

FIGURE 1 Example of calculating overlap between species range (*Cupressa goveniana* ssp. goveniana) and any usage at different usage resolutions (from left to right: CRD, county, and township). At each resolution, overlap with carbaryl usage is outlined with red while the black outline is the overall species' range. The fraction of the range that overlaps with any usage is the "overlap" in the subfigure titles

mean of 2,449 (see Data S1 for more detailed information on species' ranges and critical habitats). At both the CRD and county resolution, no species had less than 1% overlap with carbaryl usage. However, we found that increasing resolution to township scale dramatically shifted the overlap distributions and resulted in 52 species having 0% overlap with pesticide usage and an additional three (for a total of 55 species) having less than 1% overlap (Figure 2).

A similar pattern emerged for critical habitats (Figure 3). At both the CRD and county resolution no critical habitats had less than 1% overlap with species range. However, at the township resolution 26 critical habitats (49%) had no overlap and one additional critical habitat (for a total of 27) had less than 1% overlap (51%).

3.2 | Characteristics of species ranges with no or minimal usage overlap under township resolution

Our results suggest that species with <1% range/usage overlap at the township level are geographically concentrated in the southern portion of the state and their range sizes are significantly smaller than those with more than >1% overlap. Mean area for species ranges that have <1% overlap is 206.2 mile^2 (*SD* 342.7), compared with 3,179.6 mile^2 (*SD* 9015.7) for those with >1% overlap (sets significantly differ under Mann–Whitney *U* test, $p < .001$, 95% CI: 273.21–534.58).

We observed a similar size pattern for critical habitats. The mean area for habitats with <1% usage overlap is 4.3 mile^2 (*SD* 5.3), compared with 52.6 mile^2 (*SD* 84.2) when overlap is >1% (sets significantly different under Mann–Whitney *U* test, $p = .001$, 95% CI: 1.29–16.78).

3.3 | Species range and critical habitat overlap alignment

For the 53 species with designated critical habitats, 27 of these critical habitats had less than 1% overlap with any carbaryl usage at the township resolution. We investigated the concordance between species range and critical habitat overlaps. Sixteen species had <1% overlap with carbaryl usage for both their range and critical habitat. Two species had <1% overlap with their range, but >1% overlap with their critical habitat, and 11 species had <1% overlap between their critical habitat and carbaryl usage, but >1% overlap between their range and usage (Figure 4). This is expected, given that ranges tend to cover a larger area than critical habitats.

4 | DISCUSSION

4.1 | Value of pesticide usage data resolution

In this paper, we evaluated how the use of spatially explicit pesticide usage data at three resolutions—CRD, county, and township—would affect the number of endangered species and critical habitats that could be designated as NLAA, and subsequently excluded from Section 7 consultation requirements, using a <1% overlap criteria, following the classifications used in the EPA's *Revised Method*. We found that no species were excluded using CRD or county resolution data; however, with township resolution data 33% of evaluated species and 50% of critical habitats would be eligible for the NLAA designation.

Our results suggest that the use of high-resolution, spatially explicit pesticide usage data could increase both the

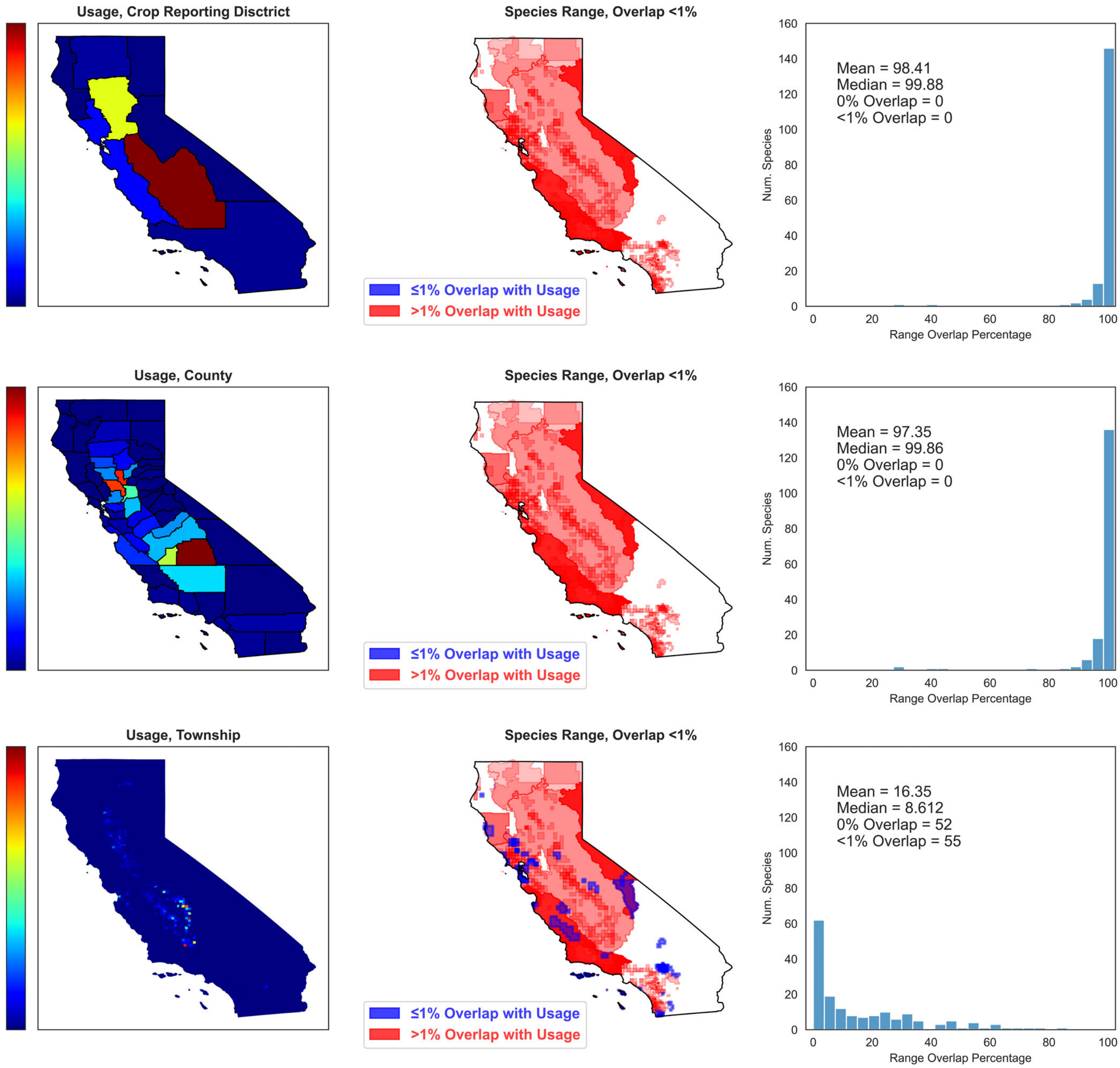

FIGURE 2 Species range overlap with carbaryl usage at (a) CRD, (b) county and (c) township resolution. The left panels show carbaryl usage (color bar provides relative usage intensity). In the center panels, species ranges are mapped and color-coded based upon their overlap with any carbaryl usage. Red signifies a more than 1% overlap, while blue represents less than 1% overlap. The histograms in the right panels provide the range and usage percent overlap distributions. The text in the histograms summarize the distributions, including the number of species with 0 and <1% overlap

efficiency of the pesticide registration and review process and confidence in the findings. As previously stated, the EPA is required to review at least 744 pesticides by 2025 (Brain et al., 2015). Since releasing their *Revised Method* in March 2020, the EPA has released draft biological evaluations for six pesticides, including carbaryl. In their nationwide analysis of carbaryl, 0.17% of species' determinations were "No Effect" and only 9% were NLAA (U.S. EPA, 2021d). Therefore, 91% of all listed species determinations were LAA, and the rate for terrestrial plants was even higher at 96%. This leaves the Services with 1640 full Section 7 consultations to complete for the carbaryl review process alone (U.S. EPA, 2021d).

The formal consultation process for FIFRA/ESA pesticide registration review is both expensive and time-intensive. An analysis of all consultations completed by USFWS

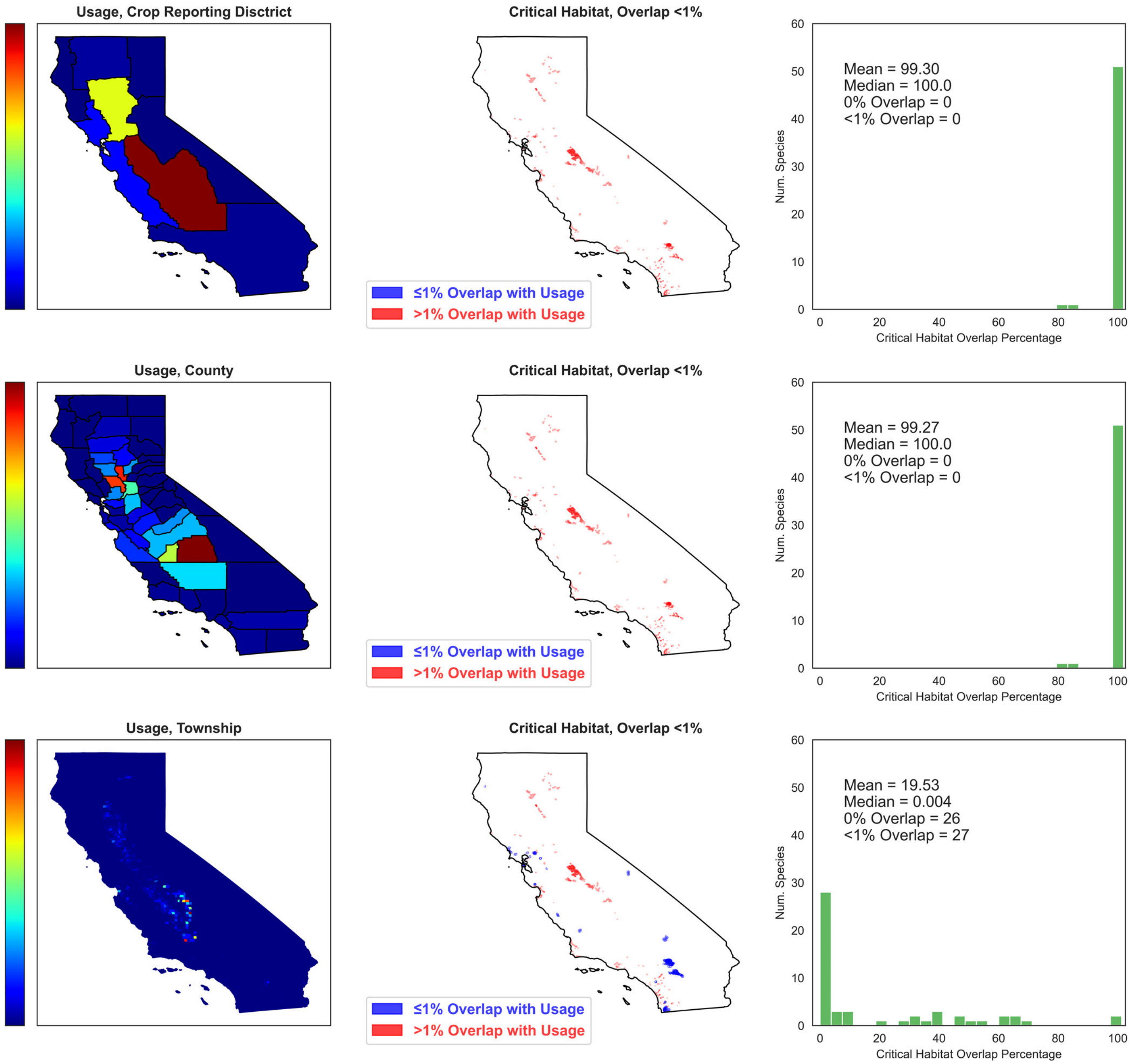

FIGURE 3 Critical habitat overlap with carbaryl usage at (a) CRD, (b) county, and (c) township resolution. The left panels show carbaryl usage (color bar provides relative usage intensity). In the center panels, critical habitats are mapped and color-coded based upon their overlap with any carbaryl usage. Red signifies a more than 1% overlap, while blue represents less than 1% overlap. The histograms in the right panels provide the critical habitat and usage percent overlap distributions. The text in the histograms summarize the distributions, including the number of species with 0 and <1% overlap

nationally found formal consultation takes a median of 62 days to complete compared to 13 days for an informal consultation (Malcom & Li, 2015). Moreover, a study specific to the pesticide registration review process found formal consultations, required by LAA determinations, cost roughly $350,000 more than informal consultations required by NLAA determinations (Summit, 2013). Excluding the 52 species (5.5% of listed terrestrial plants or 3% of species) identified in this analysis from the Section 7 consultation requirement already could save the Services years of person hours of work, but this increase in efficiency could be even higher if spatially explicit, township resolution data or estimates were available for the analysis of all species. Improvements to species' range and critical habitat maps would further increase efficiency.

Confidence in these findings could also be greater relative to the EPA's current process due to the spatially explicit nature of the California PUR data. Most of the

FIGURE 4 Comparisons of <1% overlap determinations for species' ranges and their critical habitats. The left panel shows the ranges and critical habitats for species where both maps had <1% overlap with any carbaryl usage. The center panel shows the first type of disagreement, where <1% of the range map overlaps with any carbaryl usage, but >1% of the critical habitat overlaps. The right panel shows where >1% of the range map overlaps with any carbaryl usage while <1% of the critical habitat overlaps

usage datasets the EPA uses are based on surveys, meaning they do not census everywhere pesticides are applied. Therefore, the EPA must use quasi-spatial estimations of where pesticide usage occurred, developing three different scenarios—minimum, mean, and maximum—for possible usage. Although the EPA uses a precautionary approach, there is still greater uncertainty in the resulting estimates of where pesticide usage and species ranges overlap using this approach, and our results suggest this increases the type 1 error rate (i.e., species wrongly receiving LAA determinations in the biological evaluation).

Pesticide usage also varies from year to year. Considering this temporal variation, some stakeholders believe pesticide usage data should not be used at all for endangered species risk assessments, and instead EPA should only consider the action area (i.e., everywhere the pesticide can be used legally) in the spatial analysis (U.S. EPA, 2020b). EPA aims to address this concern by combining usage data from 2013 to 2017 to create an aggregate usage map. To build confidence in the conservativeness of our analysis, we followed this approach from the *Revised Method*. Additionally, we used the maximum annual value of pesticide usage, between 2013 and 2017, in each base polygon to ensure our map represented the most conservative pesticide usage map possible. When we tested the sensitivity of this assumption by rerunning this analysis five times, for every year independently, between 67 and 74 species' ranges had zero overlap with carbaryl usage and between 70 and 82 species had <1% overlap (95 unique species). This is notably less conservative than the 52 species' ranges with zero overlap and 55 species' ranges with <1% overlap identified in our final analysis (see Data S1 for complete analysis). Therefore, aggregating data in a similar fashion over multiple years is likely essential to avoiding false negatives and increasing confidence in results if reported usage, and not action areas, are used in screening processes.

4.2 | Implications for decision making

Our results offer practical insights on ways to improve efficiency in pesticide risk assessment in the U.S. First, where spatially explicit and high-resolution pesticide usage data already exists, such as California, the EPA should use them. In fact, Section 7(a)(2) of the ESA requires that the EPA use the "best scientific and commercial data available" (USFWS, 2020). Currently, they apply the same methods across the entire continental United States; however, our findings suggest using existing data would meaningfully reduce the number of species requiring a Section 7 consultation, without any additional investment in data collection. Although the findings for terrestrial plants endemic to California may not be generalizable, California is home to more than 250 endangered species. If species other than plants were to be excluded at the same rate as in our study, this alone would qualify approximately 94 species as NLAA, and meaningfully reduce the number of Section 7 consultations the Services would be required to complete. Therefore, though EPA currently employs a blanket approach, it may be appropriate for them to include an exception that utilizes higher-resolution analyses when data is available.

Second, while our results suggests that spatially explicit, township resolution usage data could improve the pesticide registration and registration review process, collecting spatially explicit township resolution data at the national scale would be difficult for many reasons. We recommend the EPA take a targeted approach and first identify the regions where high-resolution data would be most valuable. For instance, new high-resolution data would likely be most valuable in states or ecoregions with many endangered species and heterogeneous land cover. Florida, for example, has 134 listed endangered species, 18 commodity crop types and only 23% of the state is agricultural land. Carbaryl is applied in 97% of its counties—accounting for 3.4% of national usage (USGS, 2017). These characteristics are similar to California, making it a location where this type of data could be valuable (USFWS, n.d.; USDA, 2021). Alternatively, high-resolution pesticide usage data may not be cost-effective in states with few endangered species and homogenous land cover that is predominantly agricultural. Nebraska, for example, only contains 14 endangered species and only one is endemic (USFWS, n.d.). Additionally, 92% of its land is agricultural, with carbaryl only applied in 71% of counties (1.8% of carbaryl usage nationally) (USDA, 2021; USGS, 2017). Though data collection costs may be lower due to less carbaryl usage in fewer counties, few species would be excluded through a high-resolution spatial analysis and the cost of data collection may still outweigh the benefit for decision making. The value of high-resolution pesticide usage data in a state or ecoregion may also depend on a pesticide's labeled use. For instance, broader collection of high-resolution data may be more cost effective where registered uses are restricted, limited to uses with small production areas, or for perennial crops (e.g., pome fruit, citrus, stone fruit) that are in the same sites for multiple years. Considering these patterns of variation could enable the EPA to identify where data collection is valuable and ensure they do not waste resources changing protocols or collecting data where the value of information is low.

Third, the responsibility and costs of data collection should be shared across stakeholder groups. Registrants, operators, state governments, farmers, and other stakeholders all benefit from the efficient, transparent, and accurate evaluation of pesticides undergoing registration and registration review. Therefore, we hope our results will motivate a broad group of stakeholders to contribute to data collection and validation and encourage collaboration between them.

Finally, there remains uncertainty in species range maps and critical habitats (U.S. EPA, 2019). The Services and other organizations are currently updating these maps (U.S. EPA, 2019). However, our findings suggest that focusing on species with certain characteristics may result in greater efficiencies in the EPA's biological evaluation. For instance, we found that species and habitats excluded by higher-resolution usage maps had significantly smaller ranges than those not excluded. Almost 83% of all listed critical habitats and 35% of listed endangered species ranges fall below the mean area of critical habitats (52.6 mile^2) and species ranges (206.2 mile^2) found for those that had <1% overlap with township usage data (Data S2 provides a complete list of species range and critical habitat areas). Additionally, species with temporal variation in their ranges (e.g., migratory, or hibernating species) may not overlap with carbaryl usage based on temporal differences in species occurrence and pesticide application. Updating these species ranges and critical habitats first or focusing on states with more of these species may be beneficial.

4.3 | Broader implications

Uncertainty is an ongoing challenge in environmental risk management and decision makers often express the need for high-quality, high-resolution data to address this uncertainty. However, data collection is resource-intensive, requiring time and money (Canessa et al., 2015). VOI offers a practical approach to evaluate how much decision making will be improved by collecting data. Such analyses can help decision makers identify when more data is better and when the costs of data collection outweigh the benefits (Bennett et al., 2018). Our study provides a salient example of the potential role of VOI in streamlining the ESA pesticide risk assessment process. Although this is not a traditional VOI analysis because we do not estimate the cost of data collection or the benefit it would provide for management (Bennett et al., 2018), some general conclusions can be drawn from our findings. First, the added value of increased data resolution may not be linear. Data at CRD scale, though spatially explicit, did not remove any species from LAA designation. Similarly, increasing resolution to the county level did not decrease the number of species considered LAA. However, when township resolution data was used, a third of the species and half of the habitats we evaluated were excluded from the LAA category. Traditionally, VOIs consider two binary options for data collection (existing data vs. a new data scenario); however, this indicates that decision makers should evaluate the value added across a range of possible improvements to data availability to optimize the cost–benefit of data collection for decision making.

Our study also suggests that the optimal data resolution and quality may not be homogeneous across a decision context. As we described above, endangered species and critical habitats are not evenly distributed across the United States.

Thus, increasing data resolution in some regions may add more value to decision making than in others.

4.4 | Limitations

There are limitations to both the methods and scope of our study. First, our methods differed somewhat from the EPA *Revised Method*. The EPA uses a two-step approach for their spatial analysis, where they develop a spatially explicit use footprint (i.e., area of land where carbaryl can legally be applied) and then use nonspatial usage data to estimate three possible percent overlaps—minimum, mean, maximum—between pesticide usage and species range or critical habitat. Our analysis did not include a pesticide use footprint and leverages the spatially explicit nature of the CA PUR data (Data S1 provides a summary of differences in methods). Due to these differences, we cannot say with certainty the true value of higher-resolution usage data for the existing the EPA *Revised Method* and it is probable that the EPA would have to modify their spatial analysis methods to benefit fully from township resolution usage data.

The scope of our study is also limited. We only considered the risks of carbaryl to terrestrial plants endemic to California. Terrestrial plants do not require the inclusion of predator and prey species ranges or hydrological modeling. As a result, our findings may not be generalizable for all species. In addition, the value of township pesticide usage data may not be as high in other states. California has many ecosystems, diverse agriculture, and more endangered species than any other state besides Hawai'i (USFWS, n.d.; USDA, 2021). These traits make the value of high-resolution data high, because many species have smaller ranges and pesticide usage is highly variable between crops. Therefore, the value of township resolution data in California is likely greater than in other states. Finally, carbaryl is a general use pesticide applied in both agriculture and nonagriculture settings. Township resolution usage data may not have the same value for all pesticides, such as restricted use pesticides or conversely for pesticides that are utilized only in row crops like maize or soybean which occupy a large portion of agricultural lands in the United States. Therefore, it is important that similar analyses are done for other taxa, regions, and pesticides to better understand in what contexts the value of information warrants more data collection.

4.5 | Next steps

Future studies should address the limitations in our study's scope and consider the value of high-resolution data for other taxa, states, and pesticides. They could also consider temporal variation in pesticide usage and species range, which may influence species likelihood of exposure. The CA PUR program captures temporal variation in pesticide usage, but species range maps do not capture temporal variation (e.g., migration). Including seasonal ranges of species may influence species likelihood of exposure, particularly if a seasonal range does not overlap with periods of pesticide usage. Additionally, to test the sensitivity of our findings to minor errors in species or habitat maps and usage data, it would be beneficial to replicate this analysis with varying buffer sizes around both the range maps and usage maps to identify the level of error that would be necessary to flip a species from NLAA to LAA. Finally, incorporating existing conservation practices in the agricultural system that benefit listed species and their habitat may also add value to use of high-resolution data.

It would also be interesting to formally evaluate the conditions under which high-resolution data is most useful. We found species range and habitat size were highly correlated with their likelihood of receiving an NLAA determination when using township usage data. A deeper analysis of the characteristics that impact the likelihood of the NLAA determination could be used to develop a predictive model that would help identify species and regions where high-resolution data would be most important. The value of spatially explicit township resolution usage data seems high in this analysis. However, a formal VOI analysis should be completed to identify the true costs and benefits of data collection of this caliber for the decision maker.

Finally, for instances where collecting higher-resolution usage data does not appear to be an appropriate solution, more attention should be given to improving the methods for modeling the likelihood of exposure based on existing data.

5 | CONCLUSION

In the EPA's draft biological evaluation for carbaryl, the agency determined that more than 90% of species and critical habitats—1,600 species and 700 critical habitats—required a full Section 7 consultation by the Services. High-resolution pesticide usage data could significantly reduce the number of species requiring a Section 7 consultation for carbaryl, ultimately increasing the efficiency of the pesticide registration and review process while maintaining, and even building, stakeholder confidence in the conclusions. Moving forward, the EPA should consider using existing high-resolution data, supporting data collection efforts and developing methods to estimate high-quality data of this nature. More broadly, our results underscore the potential efficiencies to be gained by assessing the value of information before investing in data collection efforts.

ACKNOWLEDGMENTS

We would like to acknowledge Bayer for funding this work. We would also like to thank R. Forvargue for helping develop the research question, while in her postdoctoral position in the Center for Biodiversity Outcomes. Finally, we would like to thank staff members of FWS and EPA for early discussions that helped shape the project, and Y. W. Li, from the Environmental Policy Innovation Center, and A. Frank and L. Duzy, from Compliance Services International, for their invaluable knowledge and feedback throughout the completion of this research.

CONFLICT OF INTEREST

Greg Watson is an employee of Bayer, the funder of this work.

AUTHOR CONTRIBUTIONS

Erin Murphy: Project development; review of EPA methods; data collection and analysis; writing. **Steffen Eikenberry:** Data collection and analysis, including all coding necessary for spatial analyses; review of EPA methods; writing. **Gwen Iacona:** Project development; data analysis; writing. **Greg Watson:** Conceptualization; writing. **Leah Gerber:** Conceptualization; writing.

DATA AVAILABILITY STATEMENT

All data are available here: doi:10.5061/dryad.5hqbzkh6q.

ORCID

Erin L. Murphy https://orcid.org/0000-0003-4910-4903
Steffen Eikenberry https://orcid.org/0000-0002-8874-9600
Gwenllian Iacona https://orcid.org/0000-0002-7408-3895
Greg Watson https://orcid.org/0000-0002-4053-9428
Leah R. Gerber https://orcid.org/0000-0002-6763-6842

REFERENCES

Bennett, J. R., Maxwell, S. L., Martin, A. E., Chadès, I., Fahrig, L., & Gilbert, B. (2018). When to monitor and when to act: Value of information theory for multiple management units and limited budgets. *Journal of Applied Ecology*, *55*(5), 2102–2113.

Bottrill, M. C., Hockings, M., & Possingham, H. P. (2011). In pursuit of knowledge: Addressing barriers to effective conservation evaluation. *Ecology and Society*, *16*(2), 14.

Brain, R. A., Teed, R. S., Bang, J., Thorbek, P., Perine, J., Peranginangin, N., … Moore, D. R. (2015). Risk assessment considerations with regard to the potential impacts of pesticides on endangered species. *Integrated Environmental Assessment and Management*, *11*(1), 102–117.

California Department of Pesticide Regulation. (2021). *Pesticide use reporting (PUR)*. Retrieved from https://www.cdpr.ca.gov/docs/pur/purmain.htm

Canessa, S., Guillera-Arroita, G., Lahoz-Monfort, J. J., Southwell, D. M., Armstrong, D. P., Chadès, I., … Converse, S. J. (2015). When do we need more data? A primer on calculating the value of information for applied ecologists. *Methods in Ecology and Evolution*, *6*(10), 1219–1228.

Ferraro, P. J., & Pattanayak, S. K. (2006). Money for nothing? A call for empirical evaluation of biodiversity conservation investments. *PLoS Biology*, *4*(4), e105.

Giger, G. (2019). *Mapping conservation success*. Washington, D.C.: Defenders of Wildlife. Retrieved from https://defenders.org/blog/2019/11/mapping-conservation-success

Malcom, J. W., & Li, Y. W. (2015). Data contradict common perceptions about a controversial provision of the US Endangered Species Act. *Proceedings of the National Academy of Sciences of the United States of America*, *112*(52), 15844–15849.

Martin, T. G., Nally, S., Burbidge, A. A., Arnall, S., Garnett, S. T., Hayward, M. W., … Possingham, H. P. (2012). Acting fast helps avoid extinction. *Conservation Letters*, *5*(4), 274–280.

Maxwell, S. L., Rhodes, J. R., Runge, M. C., Possingham, H. P., Ng, C. F., & McDonald-Madden, E. (2015). How much is new information worth? Evaluating the financial benefit of resolving management uncertainty. *Journal of Applied Ecology*, *52*(1), 12–20.

Spash, C. L. (2000). Reviewed work(s): handbook of environmental risk assessment and management by peter calow. *Environmental Values*, *9*(1), 109–111. Retrieved from https://www.jstor.org/stable/30302239

Summit (2013). Analysis of cost estimates and additional resources required for timely FIFRA/ESA pesticide registration review.

U.S. Department of Agriculture (2021). National agricultural statistics services quick stats. Retrieved from https://www.nass.usda.gov/Statistics_by_State/index.php

U.S. Environmental Protection Agency. (2020a). *Revised method for national level listed species biological evaluations of conventional pesticides*. Retrieved from https://www3.epa.gov/pesticides/nas/revised/revised-method-march2020.pdf

U.S. Environmental Protection Agency. (2020b). *Response to public comments received on proposed revised method for national level endangered species risk assessments for biological evaluations of conventional pesticides*. Retrieved from https://www3.epa.gov/pesticides/nas/revised/response-to-public-comments.pdf

U.S. Environmental Protection Agency. (2021a). *Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) and Federal Facilities*. Retrieved from https://www.epa.gov/enforcement/federal-insecticide-fungicide-and-rodenticide-act-fifra-and-federal-facilities

U.S. Environmental Protection Agency. (2021b). *Assessing Pesticides under the Endangered Species Act*. Retrieved from https://www.epa.gov/endangered-species/assessing-pesticides-under-endangered-species-act#responsibilities

U.S. Environmental Protection Agency. (2021c). *Response to public comments received on draft biological evaluations for carbaryl and methomyl*. Retrieved from https://www3.epa.gov/pesticides/nas/carbaryl/response-to-draft-bes.pdf

U.S. Environmental Protection Agency. (2021d). *Final national level listed species biological evaluation for carbaryl*. Retrieved from https://www.epa.gov/endangered-species/final-national-level-listed-species-biological-evaluation-carbaryl

U.S. Environmental Protection Agency, U.S. Fish and Wildlife Services, National Marine Fisheries Service, U.S. Department of Agriculture and Council on Environmental Quality. (2019). *Improving the consultation process required under Section 7 of the endangered species act for pesticide registration and registration review* (Report to Congress).

U.S. Fish & Wildlife Service (2019). *USFWS refined range maps for threatened and endangered species*. Retrieved from https://ecos.fws.gov/docs/SR_SOP/SDM_SOP_Final_14Nov2019.pdf

U.S. Fish & Wildlife Service. (2020). *Endangered Species Act: Section 7*. Retrieved from https://www.fws.gov/endangered/laws-policies/section-7.html

U.S. Fish & Wildlife Service (n.d.). *Environmental conservation online system*. Retrieved from https://ecos.fws.gov/ecp/

U.S. Geological Survey (2017). *Pesticide national synthesis project*. Retrieved from https://water.usgs.gov/nawqa/pnsp/usage/maps/about.php

Wilhoit, L. (2018). Data quality assessment within the pesticide use database. In *Managing and analyzing pesticide use data for pest management, environmental monitoring, public health, and public policy* (pp. 31–75). Washington, D.C: American Chemical Society. Retrieved from https://pubs.acs.org/doi/pdf/10.1021/bk-2018-1283.ch003

SUPPORTING INFORMATION

Additional supporting information may be found in the online version of the article at the publisher's website.

How to cite this article: Murphy, E. L., Eikenberry, S., Iacona, G., Watson, G., & Gerber, L. R. (2021). The value of increased spatial resolution of pesticide usage data for assessing risk to endangered species. *Conservation Science and Practice*, e551. https://doi.org/10.1111/csp2.551