

Developing an Outcome-Based Biodiversity Metric in Support of the Field to Market Project: Final Report

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**Developing an Outcome-Based Biodiversity Metric
in Support of the Field to Market Project:
Final Report**

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1. INTRODUCTION

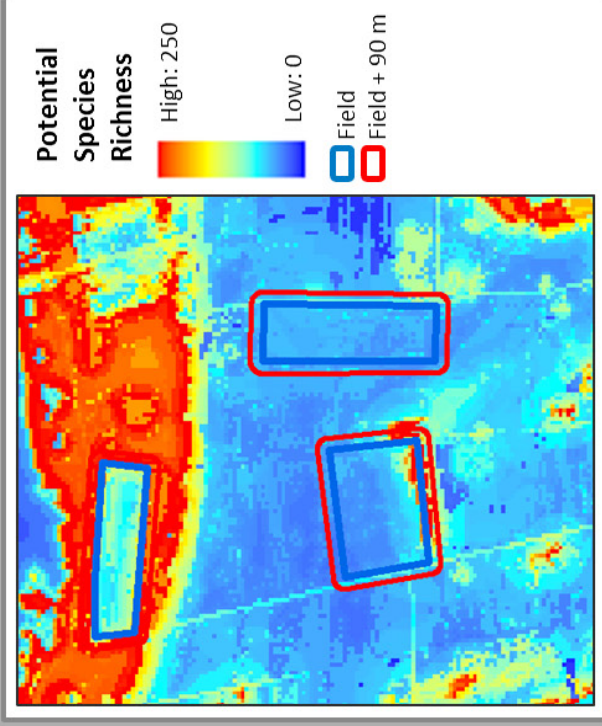
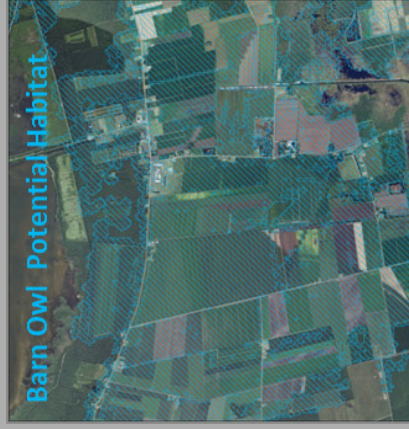
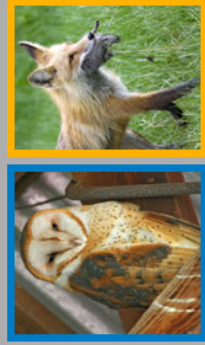
Our objective was to create a metric that would calculate the relative impact of common commercial agricultural practices on terrestrial vertebrate richness. We sought to define impacts in fields (including field borders) of the southeastern region's commercial production of corn, wheat, soy, and cotton. The metric is intended to serve as an educational tool, allowing producers to see how operational decisions made at the field level impact overall vertebrate species richness and to explore decision impacts to targeted species groups (e.g. game, pest, or beneficial species).

Agricultural landscapes are often mistakenly thought to be unsuitable habitat for most species. However, as demonstrated by results reported here, even large-scale, conventional agricultural producers are potentially important partners in biodiversity conservation. Many vertebrate species do inhabit agricultural landscapes, benefitting from the provision of water, food, or shelter within cultivated fields and their immediate borders (e.g., Holland et al. 2012). In the Southeastern US, of the 613 terrestrial vertebrate species modeled by the Southeast Gap Analysis Program (SEGAP) (<http://www.basinc.ncsu.edu/segap/index.html>), 263 utilize row crop and associated agricultural land cover classes as potential habitat (Box 1). While some species may be sensitive to certain operational practices (e.g., tillage, pest management, or field border management practices), others are generally tolerant, and some may benefit either directly or indirectly. For example, field margins and ditches often serve as semi-natural habitats providing foraging resources and shelter for vertebrates and are shown to positively influence species richness and abundance (Billeter et al. 2007; Herzon & Helenius 2008; Marshall & Moonen 2002; Shore et al. 2005; Weibull et al. 2003; Wuczyńska et al. 2011). Biodiversity responses are, therefore, complex, as an individual species' responses to agricultural production practices depends on that animal's resource specialization, mobility, and life history strategies (Jeanneret et al. 2003a, b; Jennings & Pocock 2009).

The knowledge necessary to define the biodiversity contribution of agricultural lands is specialized, dispersed, and nuanced, and thus not readily accessible. Given access to clearly defined biodiversity tradeoffs between alternative agricultural practices, landowners, land managers and farm operators could collectively enhance the conservation and economic value of agricultural landscapes. Therefore, Field to Market: The Keystone Alliance for Sustainable Agriculture and The Nature Conservancy jointly funded a pilot project to develop a biodiversity metric to integrate into Field to Market's existing sustainability calculator, The Fieldprint Calculator (<http://www.fieldtomarket.org/>). Field to Market: The Keystone Alliance for Sustainable Agriculture is an alliance among producers, agribusinesses, food companies, and conservation organizations seeking to create sustainable outcomes for agriculture. The Fieldprint Calculator supports the Keystone Alliance's vision to achieve safe, accessible, and nutritious food, fiber and fuel in thriving ecosystems to meet the needs of 9 billion people in 2050. In support of this same vision, our project provides proof-of-concept for an outcome-based biodiversity metric for Field to Market to quantify biodiversity impacts of commercial row crop production on terrestrial vertebrate richness.

Little research exists examining the impacts of alternative commercial agricultural practices on overall terrestrial biodiversity (McLaughlin & Mineau 1995). Instead, most studies compare organic versus conventional practices (e.g. Freemark & Kirk 2001; Wickramasinghe et al. 2004), and most studies focus on flora, avian, or invertebrate communities (Jeanneret et al. 2003a; Maes et al. 2008; Pollard & Relton 1970).

Two common species in agricultural landscapes are the barn owl (*Tyto alba*) and the red fox (*Vulpes vulpes*).



SEGAP has modeled the potential habitat of these and 613 other vertebrate species based on habitat availability, configuration, and context. The set of species modeled in and around a given field provide a baseline of potential species richness.

Box 1. Agricultural fields differ in their species richness and composition. The Southeast Gap Analysis Program maps terrestrial vertebrate species Potential Habitat based on habitat area, connectivity, and context. These data provide a foundation for our biodiversity analysis. The box illustrates how two species' (Barn Owl, blue; Red Fox, gold) shelter locations and foraging movements differ (left). The landscape scale habitat requirements of these species are captured in SEGAP's distribution models (center). Each field and field margin in the study region will have a unique species composition based on data extracted from the SEGAP distribution models (right).

Therefore, we used an expert-knowledge-based approach to develop a metric that predicts expected impacts to shelter and forage resources, individual species, and overall biodiversity (species richness). This approach is modeled after an ecosystems services concept (WRI 2005), except that we examine services (i.e., resources) provided to vertebrate wildlife rather than service provided to the human population. SEGAP predicts species that are potentially present in an area given landscape-scale habitat availability, configuration, and context (e.g., patch size, proximity to resources, connectivity, potential for disturbance). Based on the prediction of species that may be potentially present, the impacts of management decisions within fields and around their borders can be analyzed based on the impact of those practices to the availability of species' resources. The final metric provides an index of a producer's relative impact, but perhaps even more importantly, the underlying database allows producers to explore details such as which species are most impacted or how alternative decisions would impact their score.

2. METHODS

We used an expert-knowledge-based approach to develop a metric that predicts expected impacts to shelter and forage resources, individual species, and overall biodiversity (species richness) (Box 2). The resource impact predictions are prior probabilities, with credible intervals, defined within a Bayesian mixed-model logistic regression model. Producer decisions were linked directly to resource impacts and indirectly to species impacts through relational databases populated by regional experts (producers and biologists).

2.1 Study Region and Focal Crops

This pilot study focused on commercial-scale production of corn, cotton, soy, and wheat in Virginia, North Carolina, and South Carolina (Figure 1). In 2010, these crops accounted for 7.5% of the total land cover and 36.7% of the agricultural land cover in these states (NASS Cropscape 2011).

2.2 Design Workshop

The design workshop elicited qualitative expert knowledge from producers, conservation land managers, and scientists knowledgeable of the commercial row crop agriculture in the south-east and/or vertebrate wildlife and their habitats in southeastern agricultural landscapes (Appendix 1). The primary workshop objectives were to (1) introduce and clarify the scope of work (e.g., spatial, temporal, and thematic), (2) produce a list of operational decisions that likely impact the biodiversity value of a field and field borders, and (3) identify suites of characteristics that distinguish sensitive from insensitive species. These decisions and characteristics were then used to query taxa specialists' quantitative expectations for each vertebrate species' response to a given set of decisions (probability of a positive, neutral, or negative response). Based on the elicited probability estimates, we then constructed prior probability distributions (O'Leary et al. 2009, Method C) regarding how operational decisions impact biodiversity outcomes in agricultural landscapes. The secondary objectives of the design workshop related to the design of the elicitation script that would be used to elicit quantitative responses from species experts. These objectives were to (1) identify potential language conflicts (e.g., variance in terminology use among experts' fields of



Box 2. Illustration of the two sets of biological knowledge elicited once agricultural production decisions had been defined. We constructed a relational database to link expert-defined impacts to forage and shelter resources (left) and species local shelter and forage preferences (right).

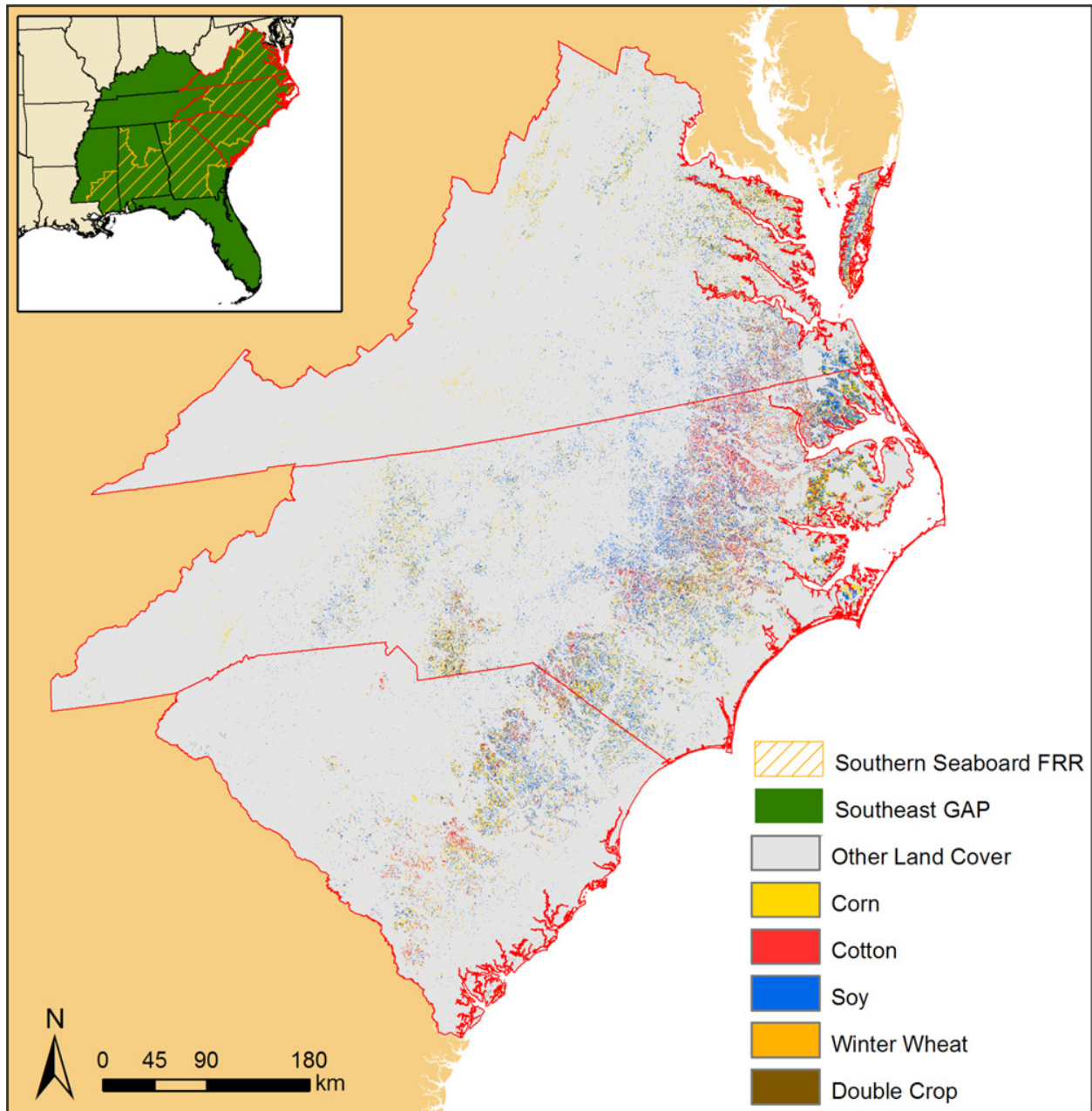


Figure 1: The pilot study focused on corn, wheat, cotton, and soy crops in portions of three states (red outline: Virginia, North Carolina, and South Carolina, main map). These states fall within both the Southeast Gap Analysis Program modeling region (green, inset map) and the Southern Seaboard Farm Resource Region (gold hashed, inset map).

specialization) and (2) to assess the level of knowledge available to ascertain the best methods to elicit and statistically model biodiversity outcomes. While the design workshop sought consensus outcomes, the elicitation methods were designed to maximize the opportunity to capture the full breadth of knowledge, including dissenting opinions. Group discussions were documented by the primary facilitator (A. Drew) via summary notes on the whiteboard (preserved by photograph) and via detailed notes scribed by a secondary facilitator (L. Alexander-Vaughn).

Following initial presentations to introduce the Field to Market project and the biodiversity pilot project, all experts participated in a series of individual, small group, and large group activities. The first set of activities focused on the list of operational decisions (Appendix 1), organized under the following headings: Crop Choice; Tillage Practices; Fertilizer Practices; Crop Protectant Practices; Irrigation Practices; Harvest Practices; Rotational Practices; Field Border and Swale Practices. An initial list of practices had been gathered from the existing Field to Market tool (Version 1), the National Handbook of Conservation Practices (USDA-NRCS 2011), and a variety of Best Management Practices review documents (e.g., McLaughlin and Mineau 1995, Allen 2005, Dabney et al. 2006). After first reviewing the material together as a group to address questions about methods and content, experts individually reviewed the list voting “Yes,” “No,” or “No Knowledge” to indicate whether they thought the decision would impact vertebrate wildlife use of the field and immediate field border. They also indicated if the decision was relevant to all or only a subset of the targeted row crops (corn, soy, cotton, and wheat). Next, three small groups were formed, each with at least one wildlife biology representative, one agro-technology representative, one sustainability/conservation representative, and one producer representative. Given the diverse background of the participants, some individuals represented multiple perspectives. The small groups focused on refining the list of operational decisions, removing, editing, or adding decisions as necessary to develop a list of practices that potentially impact one or more vertebrate species residing in agricultural landscapes. We placed one restriction on experts’ lists: to be included a practice must be common (>5% of producers would use the practice in a given year). Each group shared their individual lists and decision processes back to the larger group. A final consensus list was reached through large-group debate and discussion.

It would be unwieldy to ask experts to quantify responses of ~250 species in four row crops under 36 sets of decisions. A pragmatic alternative is to ask experts to predict positive, neutral, or negative responses for certain common traits shared by numerous species. The literature predicting biodiversity impacts of climate change often refers to species’ vulnerability traits (e.g., Foden & Collen 2007). These are characteristics common to multiple species (e.g., dispersal distances, reproductive strategies, habitat preferences) that, in the case of climate change, make populations more or less vulnerable to extinction. Our work here focuses on a finer-scale process, predicting individual habitat selection given local habitat resources rather than population extinction given landscape change, but similar logic applies. In general, given access, species are most likely to occur where suitable, high-quality resources are available. As we are focused on both positive and negative changes in species probability of occurrence in fields, we choose to refer to species traits in our models with the more neutral term “sensitivity traits.” Diet provides an example of a sensitivity trait for bird species, such that each species could be generally described as an insect-eater, seed-eater, or omnivore. Avian experts would then be asked to predict the responses of insect and seed forage resources to a suite of operational decisions (three interview questions), rather than describing the response of individual species (100+ interview questions). A significant assumption of this approach is that species responses mirror changes in availability and quality of their forage and shelter resources. Assessment of species responses to agricultural practices based on such traits has successful precedence in the ecological literature for birds (e.g., Ondine et al. 2009; Pocock 2010), but to our knowledge has not previously been applied to other species groups.

The second set of activities focused on the list of species (Appendix 1), organized into taxa groups as: Amphibians, Reptiles, Migratory Birds, Resident Birds, Waterfowl & Waterbirds, Small

Mammals, Large Mammals, and Bats. Experts were asked to focus not on the specific species named in the lists but rather on ecological or behavioral traits (e.g., insect-eater vs. seed-eater, nocturnal vs. diurnal) of species within or among taxa groups that might make them more or less sensitive to the various operational practices previously discussed. As guidance to illustrate the appropriate level of detail for this discussion, we highlighted the Cornell (2003) All About Birds project, which has assigned each bird species generalized character traits to describe the species forage, shelter, and behavioral habits. Following the orientation, the same small groups gathered, with each group focusing on a different set of taxa based on the group biologists' primary expertise: Mammals, Birds, or Reptiles & Amphibians. The small groups then shared their sensitivity traits for discussion within the larger group. The larger group debated and reached consensus regarding what traits influence species sensitivity to operational practices and which traits apply to all versus a subset of the taxa groups.

The third set of activities addressed the structure of the biodiversity metric (Appendix 1). Experts reviewed a series of alternative methods to break down vertebrate biodiversity into more informative subcategories. As a large group, experts discussed the positive and negative aspects of assessing biodiversity as the richness of different taxonomic groups, species guilds, or socio-cultural categories.

2.3 Quantitative Expert Elicitations

The design workshop resulted in lists of species traits and operational decisions. We defined the forage and shelter resources based on the summary of diet and microhabitat traits, respectively. To relate the operational decisions to impacts on resources and to associate each species with their preferred resources, we conducted a series of individual, quantitative expert elicitations (Appendix 2). Although some elicitations were conducted in a group setting, each expert independently quantified their expectations based on their personal experience and insights. We conducted a trial run of these elicitations with a volunteer from the Southeastern Bat Diversity Network (M. Frazer, NC Dept. of Transportation) to improve the quality of the orientation materials and elicitation structure and to clarify terminology in the elicitation. Each participating expert (1) provided scores for impacts of operational decisions on randomly assigned forage and shelter resources, (2) assigned primary forage and shelter resource categories to all species within their specialty taxa group, and (3) indicated their confidence in each of their responses.

Participants from the design workshops provided an initial list of potential experts with knowledge in terrestrial vertebrates. We expanded this list by performing an internet search of professors and researchers whose research included a focus in wildlife biology and/or were associated with Cooperative Fish and Wildlife Research Units. Specifically, we included staff from the University of Virginia, the College of William and Mary, Virginia Tech University, North Carolina State University, and Clemson University. We also searched various state and federal government agency websites and interest groups in order to identify staff whose expertise included knowledge of terrestrial vertebrates. These agencies included state natural resource departments, the Natural Resources Conservation Service, the NC Wildlife Resource Commission, state natural heritage programs, the Virginia Department of Game and Inland Fisheries, and natural science museums. We also included staff from The Nature Conservancy as potential experts. We spent approximately three weeks researching and contacting potential experts to participate in elicitations. We sent

all potential experts an introductory email describing the project objectives and general methods. Potential experts were then contacted via phone and formally invited to participate.

2.3.1 Score Operational Decisions

Experts used their best professional judgment to predict if and how alternative operational decisions regarding commercial row crop production and field margin management would influence the availability and quality of resources for wildlife. For each randomly assigned forage or shelter resource, experts indicated whether they expected a given agricultural practice to have a positive, negative, or neutral impact on the availability or quality of that resource. We presented operational decisions as either categorical (e.g., till versus no-till) or continuous (e.g. frequency of mowing borders) variables (Appendix 2). Both types of variables were scored by the same rubric (Table 1) on a scale of +2 to -2, but with slightly different wording of the questions. These scores were later simplified to a three-level system (negative, neutral, or positive impact) to facilitate analysis (O’Leary 2011).

Table 1. The scoring system used by experts to define the expected response of forage and shelter resources to operational decisions.

Example question for decisions among <i>categorical</i> variables:	
Compared to the baseline choice (e.g., no till), I would expect this choice (e.g., mulch till) to produce a _____ impact on the availability or quality of this resource in the field and field margin.	
Example question for decisions on <i>continuous</i> variables:	
As the decision value increases (e.g., frequency of mowing), I would expect a _____ impact on the availability or quality of this resource in the field and field margin.	
Score	Definition
+2	Strong increase
+1	Weak increase
0	Neutral
-1	Weak decrease
-2	Strong decrease

2.3.2 Assign Resource Categories to Species

We assigned each expert one taxon group (mammals, reptiles, amphibians, birds) and two of three resource types (day shelter, night shelter, forage). For each species by resource type combination, experts identified one primary resource for that species (Table 2). For this project, we defined primary resources based on total time spent utilizing a resource in a given year. Most species utilize diverse resources, and many exhibit seasonality in their resource preferences (e.g., diet may differ between breeding and non-breeding seasons). This diversity could be captured by extending the elicitations but was outside the scope of the pilot project and was not necessary to test the basic feasibility of our approach.

2.3.3 Document Uncertainty

The breadth of knowledge elicited from each expert was extensive, covering many species and many operational decisions across a broad geographic region. In addition, experts differed in their professional background and expertise. We expected expertise to vary among experts and among responses from a single expert. It was important that we distinguish expert responses provided with high versus low confidence. Therefore each time an expert scored an expected impact

of an agricultural practice or assigned a primary resource to a species, they also indicated the reliability (i.e., confidence) of their response with a numeric score (Table 3). Reliability scores ranged from one to seven, but only scores of four to seven were reasonable in the context of this elicitation (i.e., we did not allow experts to bet against themselves).

We elicited impact and reliability scores for operational decisions to construct logistic regressions predicting the presence/absence of each resource within a field's cropped and margin areas. The elicitation methods we used were originally developed to elicit signs of coefficients in regression models predicting the abundance of bird species in the presence of cattle grazing (Martin et al. 2005). O'Leary (2011) extended the model to allow multiple categorical and continuous covariates and to incorporate a measure of expert confidence. The major advantages of this method were the simple spreadsheet design and its suitability for combining knowledge from one or more experts. The method is specifically designed to allow for experts that are unfamiliar with statistical probability theory. The elicited responses are combined to calculate a single probability distribution for each coefficient in the logistic regression (e.g., one per decision by resource combination). These distributions are intended to serve as prior probabilities in Bayesian logistic regression when

Table 2. Forage and shelter resource categories.

Forage Resources	Shelter Resources (Day, Night)
Omnivore	Herbaceous vegetation
Aerial invertebrates	Shrub, vine, thicket vegetation
Tree/shrub invertebrates	Living tree canopy, bark, or cavity
Soil invertebrates	Aquatic vegetation
Herbaceous invertebrates	Freshwater
Aquatic small invertebrates	Marine (water and beach)
Tree/shrub foliage, seeds, & fruits	Standing dead tree (snag)
Herbaceous foliage, seeds, & fruits	Fallen logs, leaf litter, & detritus
Aquatic plant foliage, seeds, & fruit	Bare ground surface or burrow
Pollen/Nectar	Ground burrow (dense veg & roots)
Terrestrial vertebrates	Rocky outcrops
Aquatic vertebrates and large invertebrates	Caves, mines, & wells
Marine prey	Buildings, bridges, & towers
Detritus, fungi, & decaying material	

Table 3. Reliability scores that experts used to define the uncertainty associated with their professional judgements regarding decision impacts and species resource preferences. For this project, we did not allow experts to bet against their own judgement (e.g., we disallowed scores of 1-3).

Score	Text Definition	Odds Ratio Definition	Probability
7	Fully confident this is true	All odds on	1.00
6	Very confident this is true	Better than 10-1 or 20-1 odds on	0.93
5	Somewhat confident this is true	Better than 2-1 or 3-1 odds on	0.71
4	I could be right or wrong	50-50 odds of being right	0.50
3	It's possible I'm right, but unlikely	No worse than 1-3 odds against	0.29
2	It's not impossible I'm right	No worse than 1-20 odds against	0.07
1	Not confident at all	All odds against	0.00

empirical data are available. In the absence of such data, the distributions serve as quantitative expert hypotheses regarding agricultural impacts on wildlife resources.

2.4 Statistically Encode Expert Knowledge and Calculate Resource Impacts

To generate probability distributions from experts' scores, we used the equations presented in O'Leary (2011: Chapter 6). Simply, when an expert selected an impact score and a reliability score, the latter was used to allocate probability among the three possible impacts (negative, neutral, or positive). For example, if an expert assigned a negative impact score with a confidence score of five (i.e. 0.71 probability of being correct), we assumed this implied a 0.29 probability that the true impact could be neutral or positive. Three distributions were generated, one for each possible impact score, and then merged to create a single probability density function defining the expected beta coefficient value for that decision's resource impact in a logistic regression (Figure 2).

In some cases, multiple experts provided independent impact and confidence estimates for a given decision-resource combination. To combine responses from multiple experts, we first calculated each expert's distribution for the coefficient and then merged the distributions, assigning equal weight to each expert. Had one expert exceeded the others in expertise (e.g., years of experience, relevant research publications) we could have assigned unequal weights, but this was not the case during the pilot project.

For this pilot project, we interviewed one producer to generate two hypothetical but realistic decision sets for fields within the study region. We then calculated the probability distributions (e.g., probability of resource presence) for each category within the day shelter, night shelter, and forage resource types. To infer species impacts from these resource impacts, we used the relational database to match each potential species to their three primary resources and calculated the average of the three probabilities. By averaging, we assumed that the absence of any one resource would reduce the overall probability of species presence but not reduce the probability to zero.

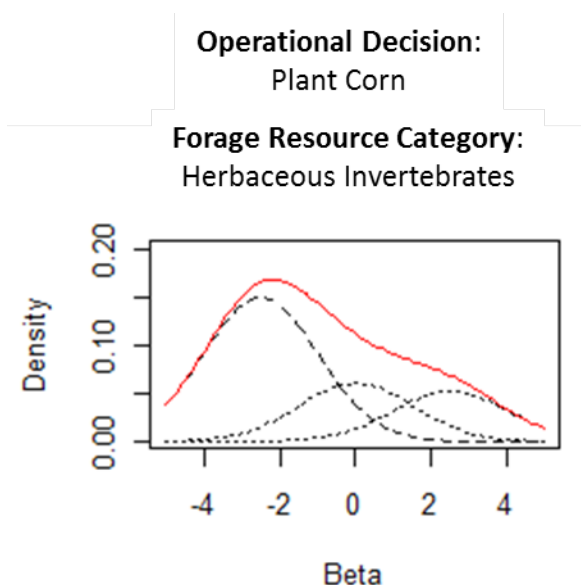


Figure 2. We used logistic equations to predict the presence/absence of resources given a suite of operational decisions. We elicited expert knowledge to estimate the beta coefficients for each decision-resource response. This probability density function illustrates how one expert's judgement is translated to an estimate of beta. An expert expected the decision to plant corn (versus allow the field to lie fallow) to have a negative impact on the availability or quality of herbaceous invertebrates as a forage resource (long-dash black line peaking over -2.5). However, based on their reliability score, we note that they acknowledge there is a small possibility that the response could also be neutral or positive (short-dash black lines peaking over 0 and 2.5, respectively). The distributions of this expert's expectation among the negative, neutral, and positive outcomes are merged to produce the single red line, which represents the expert's hypothesis (the prior probability for beta in a Bayesian logistic model). Based on this expert's responses, beta could be any value from -5 to +5, but a value near -2 is most likely.

2.5 Summarize Impacts and Calculate the Biodiversity Metric

We used three methods to summarize the impacts of operational decisions on terrestrial vertebrate wildlife (Box 3). All metrics are standardized in relation to the total number of species potentially present in the field and field margin, as modeled by SEGAP. When a farmer identifies their field within a geographic information system (e.g., digital map), we extract the list of species for which the field and the surrounding habitat (to 90 m from the field edge) have been identified as potential habitat. Within the relational database the species are matched to their primary resources, and these impacts are calculated based on the producer decisions.

The first metric simply calculates the percentage of potential species for which one or more of the three primary resources are provisioned within the field or field margins. A resource is considered “provisioned” when it is predicted to be present with a probability greater than or equal to 0.5. This metric does not account for any increased benefit that species might gain from having more than one resource present. This metric allocates resource (and species) responses to one of two categories: positive or negative. The possibility of a neutral impact is excluded.

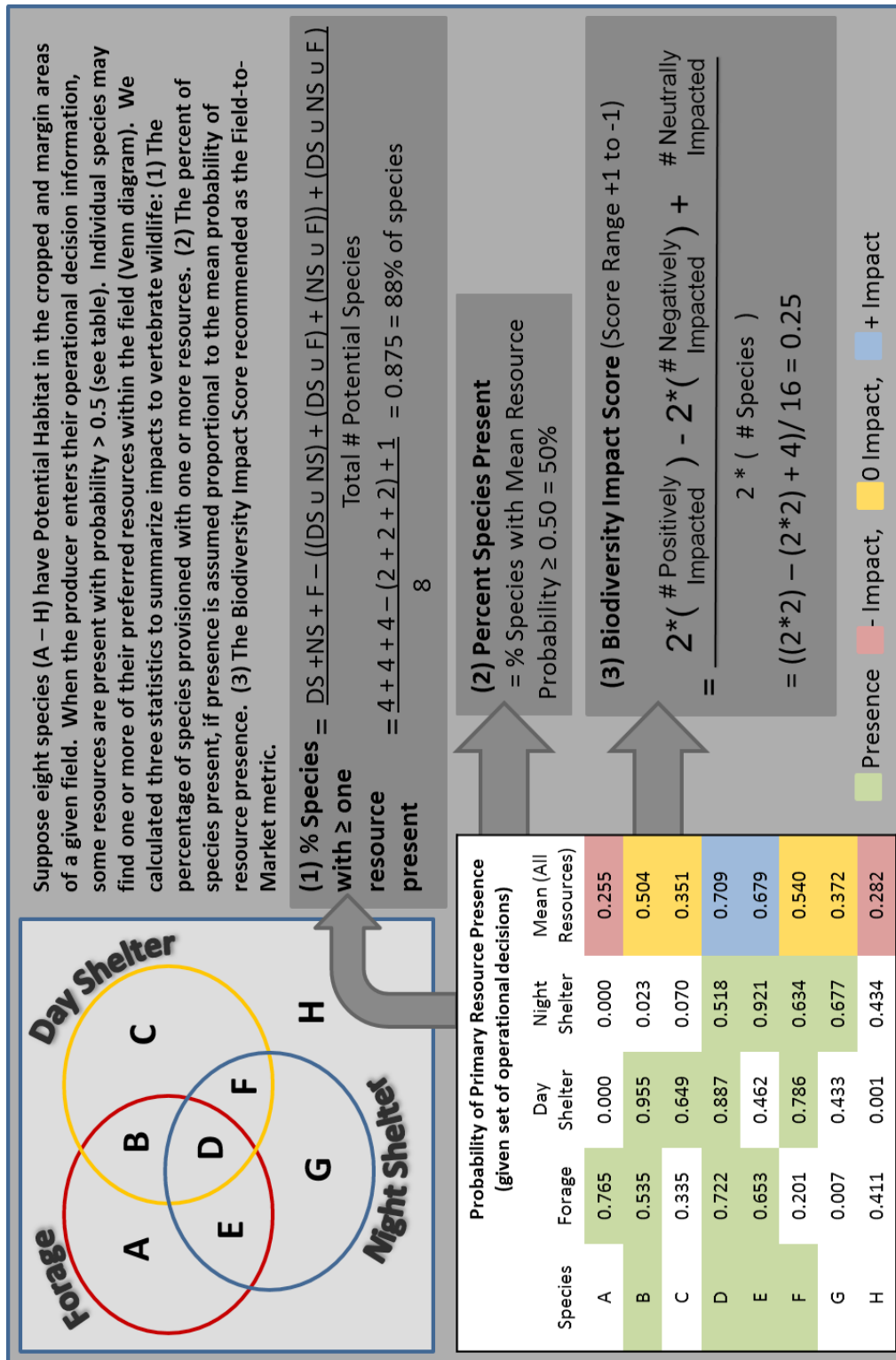
The second metric calculates the percentage of potential species expected to occur within the field and field margins. For each species, we calculated the mean of the three resource probabilities and scored the species as present when the average probability was equal to or greater than 0.5. This metric is more conservative than the first, as species provisioned with two or three resources will be more likely to occur in the field or field margin than species provisioned with just one resource.

The third metric is the metric we propose as the Biodiversity Metric for the Field to Market project. This metric calculates the relative value of fields to vertebrate wildlife where the highest value fields are those where the production practices positively or neutrally impact the majority of species present in that landscape. As in the second metric, we first calculate the mean probability of resource presence. However, we then divide the probability scale into three equal interval impact bins (Negative = 0 to 0.333; Neutral = 0.334 to 0.666; Positive = 0.667 to 1.0). Negative and positive impacts are inversely proportional. Unique to this method, decision sets that result in neutral impacts are also scored as a benefit to wildlife (receiving half the value of a positive impact). The final metric, standardized to the number of potential species, ranges from +1 to -1.

3. RESULTS

3.1 Qualitative Expert Knowledge

The Vertebrate Biodiversity in Row Crop Agricultural Landscapes Workshop was held the 13th and 14th of July, 2011, in Raleigh, North Carolina, at North Carolina State University. The 14 participants (Appendix 1) represented state (NCWRC [2]) and federal (NRCS [3]) government agencies, agro-technology businesses (DuPont [1], Bayer [1]), academic institutions (NCSU [2], UoA [1]), agro-production and resource management consortiums (Delta F.A.R.M [1], Keystone Center [1]), a commodity consultant (Shaver Consulting [1]), and a conservation organization (TNC [1]). Seven experts, in the course of their careers, had direct experience managing farm resources both as producers and as researchers or regulators. The knowledge elicited and debated



Box 3. We used three methods to summarize the expected impacts of operational decisions. The first method reports the percentage of species expected to encounter one or more of their primary resources within the field or field margin given the decision set entered by the producer. This method is illustrated by the Venn diagram. The second and third methods are based on the average of the modal (most likely) probabilities for the three resources (one average calculated per species) as calculated by the logistic regressions. The second method simply uses the standard 0.5 probability threshold to count the number of species predicted to be present (versus absent), if species occur in fields in proportion to the availability and quality of their preferred resources. The third method defines three equal interval ranges for the average probability scores (Negative, Neutral, and Positive) and applies a formula that credits producers not only for decisions that have a positive impact, but also for those that have a neutral impact (though to a lesser degree).

in the workshop resulted in: (1) a list of operational decisions relevant to predicting relative biodiversity outcomes and (2) descriptions of species dietary and microhabitat traits. We also obtained descriptions of species life history traits that could be used to design an elicitation to temporally link impacts to periods of the crop production cycle, if the pilot project is extended.

Two major themes that emerged throughout workshop discussions were the amount and quality of vegetation on the landscape throughout the year and the timing of potential disturbance relative to species biological cycles. Vegetation was important to some species as shelter and to others as forage (either directly for herbivores or indirectly for species whose diets consisted of insects and animals sheltering in the foliage). Disturbance could be the passage of farm equipment or side effects of agrochemical products applied to the field. Soil management and water management practices, acknowledged as critically important to aquatic species, received less emphasis in relation to terrestrial vertebrates. However, amphibians, some reptiles, and waterbirds could be sensitive to the amount, quality, and seasonality of water available on the farm landscape as well as vegetation management along the edge of any open water or wet area. Practices aimed at maintaining healthy soils would benefit vertebrates consuming soil invertebrates but depending on when the soil is tilled or turned, could result in harm to fossorial (i.e., ground burrowing) species. Experts acknowledged that few (if any) operational decisions would have positive or negative outcomes for all species, and thus predicting the expected biodiversity outcome from a suite of operational decisions is complex.

Based on the workshop discussions and later review, the proposed diet and microhabitat traits were organized into two resource groups: forage and shelter. Later, in review of the list and test quantitative elicitations, shelter was further subdivided into day shelter and night shelter. Each small group also offered proposed amendments to the species list, although changes to the SEGAP models were beyond the scope of the pilot project.

The workshop participants debated the relative utility of biological (e.g., birds, mammals) and socio-cultural (e.g., game species, pest species, endangered species) species groupings as a means to refine the overall biodiversity metric. Participants generally expressed the opinion that the value of the metric as an educational tool should be emphasized over its value as a biological tool. That is, the axes labels should be meaningful to producers, ideally allowing them to draw connections between their operational decisions and species they would recognize. However, the vast majority of the species potentially present and impacted by producers' decisions would likely be unknown to them. Ultimately, participants concluded that the pilot project should focus on completing the overall biodiversity metric. Once the metric was created, the potential value of alternative summary statistics for individual species or species groups could be explored.

3.2 Quantitative Expert Knowledge

Of the 116 queries sent to 69 potential experts, we received responses from 44 individuals (64%), while 25 individuals (36%) did not respond to either emails or phone calls (Appendix 2). Of those that responded, 18% declined, 45% were interested but unable to participate, and 36% participated. The majority of respondents who declined to participate did so because they described themselves as not having knowledge or expertise suitable for elicitations. Similarly, the majority of respondents who were interested but unable to participate could not attend the scheduled

Table 4. Distribution of experts (denoted by initials) among taxa and resource types. Font color of initials indicates experts' state (purple: VA; red: NC; blue: SC).

Taxa Group	Forage	Day Shelter	Night Shelter
Amphibians	JH, SB	JH	JH
Birds	DL, CL, MP, JS, CP	DL, BD, JS, CP	MP, JS
Mammals	MF, LG, NL, RR, JB	MKC, LG, JB	JF, NL, RR
Reptiles	SB	JB, SB	JB

Table 5. Experts (denoted by initials) were randomly assigned one to three resource categories for which to evaluate operational decision impacts. Font color of initials indicates experts' state (purple: VA; red: NC; blue: SC). Five resource categories were not scored by experts (**).

Forage Resources	Experts
Omnivore	CL
Aerial invertebrates	JH, KD, NL
Tree/shrub invertebrates	KD, NL
Soil invertebrates	DL, MP
Herbaceous invertebrates	RR
Aquatic small invertebrates	JH
Tree/shrub foliage, seeds, & fruits	MKC
Herbaceous foliage, seeds, & fruits	DL
Aquatic plant foliage, seeds, & fruit	JH, KD, MP
Pollen/Nectar	DL
Terrestrial vertebrates	BD
Aquatic vertebrates and large invertebrates	**
Marine prey	JB
Detritus, fungi, & decaying material	CL
Shelter Resources	
Herbaceous vegetation	CP, MF
Shrub, vine, thicket vegetation	RR
Living tree canopy, bark, or cavity	MF
Aquatic vegetation	JH
Freshwater	CP
Marine (water and beach)	**
Standing dead tree (snag)	MKC
Fallen logs, leaf litter, & detritus	LG, BD
Bare ground surface or burrow	JH, KD
Ground burrow (dense veg & roots)	KD, JB
Rocky outcrops	**
Caves, mines, & wells	**
Buildings, bridges, & towers	**

elicitations because of a conflict in scheduling. We hosted three one-day meetings to elicit the quantitative expert knowledge, one in each state. From these meetings, we obtained at least one expert's input for most resource by species combinations (Table 4) and most decision by resource combinations (Table 5). Where no expert input could be obtained, we assumed a neutral response with a reliability score of 5 (the lowest possible score). In some cases, we obtained multiple experts' input for a particular combination. For resource-by-decision combinations, we calculated the unweighted average of multiple expert judgments (O'Leary 2011). For species-by-resource combinations, for simplicity in the pilot, we selected the response with the highest reliability score. Where two different responses had the same reliability score, we randomly selected one of the two responses. In future iterations of the model, species could be assigned multiple resources.

3.2.1 Probability of Resource Presence

With 97 defined decisions (based on responses to 33 questions) and 29 defined resources, we calculated beta estimates for 2813 decision by resource combinations. The modal estimates of the calculated beta values were 21% positive, 52% neutral, and 26% negative (Digital Appendix 1)

To demonstrate the variance in resource impacts, we describe two hypothetical example fields with contrasting crop and field margin management decisions (Table 6). Field One is planted in cotton and generally managed to maximize soil conservation and reduce agrochemical inputs. However, the field margins are frequently and intensively managed to keep back vegetation. Field Two is planted in corn. In this field, the producer is more dependent on agrochemical products to control pests. Neighboring ditches frequently hold water, and the field margins include a mix of self-established herbaceous and shrubby vegetation. Each field received 29 probability scores on the logit scale, one for each resource category listed for the three resource types (Table 7). Of the two decision sets, the decisions applied to Field Two resulted in a higher probability of resource presence for all resources but not necessarily for all species (see below).

3.2.2 Probability of Species Presence

The two example fields existed in different landscape contexts and thus differed in the number and composition of species potentially present (Table 8). Based on the SEGAP species distribution models, Field One contained 22% more Potential Species than Field Two. The primary resources of the species associated with each field also varied (Table 9). After applying the decision sets to their matching field, we calculated the probability of each resource being present, matched these to the appropriate species, and then for each species calculated the mean of the three resource probabilities (Table 10). Considering all species in a given field, the decisions applied to Field Two had a higher probability of provisioning the species potentially present than did the decisions applied to Field One (Table 10).

If species occur in direct proportion to the probability of resource provisioning, then the median probability of species presence given operational decisions was 0.002 in Field One and 0.645 in Field Two.

Table 6. All operational decisions considered in the pilot project. Questions and possible answers describe decisions in the cropped field area, any wet field margin areas, and any dry field margin areas. Responses for two hypothetical fields are provided to illustrate data collection from producers.

FIELD	All Possible Answers	Producer Answers	
		Field 1	Field 2
What crop did you plant?	Fallow, No cover crop	0	0
	Corn	0	1
	Wheat	0	0
	Cotton	1	0
	Soy	0	0
Area planted	<i>acres</i>	200	200
Frequency of forage/fallow crop rotation	<i>years</i>	1	1
Frequency of sub-soil or deep-rip practice	<i>years</i>	4	3
What tillage methods did you use to prepare this field?	None or Strip-till	1	0
	Reduced or Mulch-till	0	0
	Conventional-till	0	1
What soil conservation practices do you use?	None	0	1
	Cover crop	0	0
	Strip cropping	0	0
	Vegetation filter strips	1	0
What GMO products do you use?	None	0	0
	Pest Resistant	0	0
	Herbicide Resistant	1	0
	Stacked	0	1
What type of herbicide did you apply?	None	0	0
	Selective	0	1
	Non-Selective	1	0
How did you apply the herbicide?	Post-emergent ground	0	1
	Pre-emergent	1	0
	Post-emergent aerial	0	0
	Not Applicable	0	0
Total amount of herbicide applied	<i>wgt/acre</i>	1.75	2
What type of pesticide did you apply?	None	0	1
	Selective	1	0
	Non-Selective	0	0
How did you apply the pesticide?	Post-emergent ground	0	0
	Seed	0	0
	Pre-emergent	0	0
	Post-emergent aerial	1	0
	Not Applicable	0	1
Total amount of pesticide applied (wgt/acre)	<i>wgt/acre</i>	1.5	0
Total amount of fertilizer applied	<i>wgt/acre</i>	120	300
Do you seasonally flood this field?	No	1	1
	Yes	0	0
Do you irrigate from surface water neighboring this field?	No	1	1
	Yes	0	0
Area of open water associated with irrigation	<i>acres</i>	0	0
Is there surface water available year-round neighboring this field?	No	0	1
	Yes	1	0
What accommodations do you make to allow wildlife to escape during harvest?	None	0	0
	Flushing bar	0	0
	Delayed harvest	0	0
	Reduce speed	0	1
	No night harvest	1	1
	Alter harvest pattern	0	0
What accommodations do you make to allow some forage/shelter value for wildlife?	None	1	0
	Leave residue	0	1
	Leave some rows	0	1
Amount of residue cover	<i>percent</i>	0	18

Table6, continued.

FIELD MARGIN (WET)	All Possible Answers	Field 1	Field 2
Size of the drainage/wet margin area	<i>acres</i>	1	0
How frequently does the drainage/wet area contain standing water?	Never	0	1
	Seasonally	0	0
	Monthly	1	0
	Always	0	0
What is the dominant vegetation in the drainage/wet area?	Naturally self established	0	1
	Planted exotic grasses	1	0
	Planted native grasses	0	0
	Planted native grasses & forbes	0	0
	Planted shrubs	0	0
	Planted trees	0	0
Frequency of vegetation management in drainage/wet area	<i>months</i>	3	0
How do you manage the vegetation in the drainage/wet area areas?	No Management Action	0	1
	Mow	1	0
	Fire	0	0
	Disc	0	0
	Selective Herbicide	0	0
	Non-Selective Herbicide	1	0
When did you manage the vegetation in the drainage/wet area?	Winter	1	0
	Spring	1	0
	Summer	1	0
	Fall	1	0
	Not Applicable	0	1
FIELD MARGIN (DRY)	All Possible Answers	Field 1	Field 2
Size of the dry edge/margin area	<i>acres</i>	1	3
Width of the non-crop edge/margin area	<i>meters</i>	12	30
What is the dominant vegetation in the edge/margin area?	Naturally self established	1	1
	Planted exotic grasses	0	0
	Planted native grasses	0	0
	Planted native grasses & forbes	0	0
	Planted shrubs	0	0
	Planted trees	0	1
Frequency of vegetation management in dry edge/margin area	<i>months</i>	3	24
How do you manage the vegetation in the dry edge/margin area areas?	No Management Action	0	0
	Mow	1	1
	Fire	0	1
	Disc	0	0
	Selective Herbicide	0	0
	Non-Selective Herbicide	1	0
When do you manage the vegetation in the edge/margin area?	Winter	1	1
	Spring	1	0
	Summer	1	0
	Fall	1	0
	Not Applicable	0	0

Table 7. Resource impacts calculated for each field (based on responses in Table 6). Values represent the probability that a resource is present.

Resource	Field 1	Field 2
FORAGE		
Aerial invertebrates	0.001	0.994
Aquatic plant foliage, seeds, & fruit	0.000	0.059
Aquatic small invertebrates	0.000	0.006
Aquatic vertebrates and large invertebrates	0.500	0.500
Herbaceous foliage, seeds, & fruits	0.000	0.899
Herbaceous invertebrates	0.000	0.303
Marine prey	0.500	0.500
Omnivore	0.000	0.007
Pollen/Nectar	0.000	0.899
Soil invertebrates	0.000	0.043
Terrestrial vertebrates	0.000	0.630
Tree/shrub foliage, seeds, & fruits	0.004	0.993
Tree/shrub invertebrates	0.612	0.995
Undefined forage	0.500	0.500
SHELTER		
Aquatic vegetation	0.000	0.863
Bare ground surface or burrow	0.002	0.072
Buildings, bridges, & towers	0.500	0.500
Caves, mines, & wells	0.500	0.500
Detritus, fungi, & decaying material	0.000	0.086
Fallen logs, leaf litter, & detritus	0.000	0.928
Freshwater	0.547	0.744
Ground burrow (dense veg & roots)	0.003	0.432
Herbaceous vegetation	0.000	0.064
Living tree canopy, bark, or cavity	0.000	0.961
Marine (water and beach)	0.500	0.500
Rocky outcrops	0.500	0.500
Shrub, vine, thicket vegetation	0.000	0.973
Standing dead tree (snag)	0.702	0.783
Undefined shelter	0.500	0.500

Table 8. The number of terrestrial vertebrate species that could potentially occur in the vicinity of each field given landscape-scale habitat characteristics, prior to knowledge of fine-scale land management decisions.

Taxa	Field 1	Field 2
AMPHIBIANS	27	6
BIRDS	107	108
MAMMALS	44	36
REPTILES	43	36
<i>Total Species</i>	221	186

Table 9. Amphibian species identified in SEGAP as potentially present with their associated primary resource categories for the three resource types. Note that “potential presence” merely indicates that the landscape-scale habitat characteristics are suitable, but not necessarily that all species are, or could be, present at any given time. The number of species present at any given time would be shorter based on (1) local habitat resources (modeled in this project) and (2) species interactions (e.g., competition, predation, etc.; not modeled).

AMPHIBIAN SPECIES			POTENTIAL PRESENCE		PRIMARY RESOURCES		
Common Name	Scientific Name	Field 1	Field 2	Forage	Day Shelter	Night Shelter	
Southern Cricket Frog	Acris gryllus	X		Soil invertebrates	Aquatic vegetation	Aquatic vegetation	
Mabee's Salamander	Ambystoma mabeei	X		Soil invertebrates	Ground burrow (dense veg & roots)	Ground burrow (dense veg & roots)	
Marbled Salamander	Ambystoma opacum	X		Soil invertebrates	Ground burrow (dense veg & roots)	Ground burrow (dense veg & roots)	
Two-toed Amphiuma	Amphiuma means	X		Aquatic small invertebrates	Freshwater	Freshwater	
Fowler's Toad	Anaxyrus fowleri	X		Soil invertebrates	Fallen logs, leaf litter, & detritus	Fallen logs, leaf litter, & detritus	
Southern Toad	Anaxyrus terrestris	X		Soil invertebrates	Fallen logs, leaf litter, & detritus	Fallen logs, leaf litter, & detritus	
Southern Dusky Salamander	Desmognathus auriculatus	X		Aquatic small invertebrates	Fallen logs, leaf litter, & detritus	Fallen logs, leaf litter, & detritus	
Southern Two-lined Salamander	Eurycea cirrigera	X		Aquatic small invertebrates	Fallen logs, leaf litter, & detritus	Fallen logs, leaf litter, & detritus	
Eastern Narrow-mouthed Toad	Gastrophryne carolinensis	X	X	Soil invertebrates	Fallen logs, leaf litter, & detritus	Fallen logs, leaf litter, & detritus	
Green Treefrog	Hyla cinerea	X	X	Soil invertebrates	Shrub, vine, thicket vegetation	Shrub, vine, thicket vegetation	
Pine Woods Treefrog	Hyla femoralis	X		Tree/shrub invertebrates	Living tree canopy, bark, or cavity	Living tree canopy, bark, or cavity	
Barking Treefrog	Hyla gratiosa	X		Tree/shrub invertebrates	Living tree canopy, bark, or cavity	Living tree canopy, bark, or cavity	
Squirrel Treefrog	Hyla squirella	X		Tree/shrub invertebrates	Shrub, vine, thicket vegetation	Shrub, vine, thicket vegetation	
American Bullfrog	Lithobates catesbeianus	X		Soil invertebrates	Freshwater	Freshwater	
Green Frog	Lithobates clamitans	X	X	Aquatic vertebrates and large invertebrates	Freshwater	Freshwater	
Pickrel Frog	Lithobates palustris	X		Aquatic vertebrates and large invertebrates	Freshwater	Freshwater	
Southern Leopard Frog	Lithobates sphenocephalus	X	X	Soil invertebrates	Freshwater	Freshwater	
Carpenter Frog	Lithobates virgatipes	X		Aquatic vertebrates and large invertebrates	Freshwater	Freshwater	
Dwarf Waterdog	Necturus punctatus	X		Aquatic small invertebrates	Freshwater	Freshwater	
Eastern Newt	Notophthalmus viridescens	X		Aquatic small invertebrates	Fallen logs, leaf litter, & detritus	Fallen logs, leaf litter, & detritus	
Atlantic Coast Slimy Salamander	Plethodon chlorobryonis	X	X	Soil invertebrates	Ground burrow (dense veg & roots)	Fallen logs, leaf litter, & detritus	
Northern Slimy Salamander	Plethodon glutinosus	X	X	Soil invertebrates	Ground burrow (dense veg & roots)	Fallen logs, leaf litter, & detritus	
Brimley's Chorus Frog	Pseudacris brimleyi	X		Soil invertebrates	Herbaceous vegetation	Herbaceous vegetation	
Spring Peeper	Pseudacris crucifer	X		Tree/shrub invertebrates	Herbaceous vegetation	Herbaceous vegetation	
Little Grass Frog	Pseudacris ocularis	X		Soil invertebrates	Herbaceous vegetation	Herbaceous vegetation	
Mud Salamander	Pseudotriton montanus	X		Aquatic small invertebrates	Fallen logs, leaf litter, & detritus	Fallen logs, leaf litter, & detritus	
Greater Siren	Siren lacertina	X		Aquatic vertebrates and large invertebrates	Freshwater	Freshwater	

Table 10. Amphibian species listed with the probabilities for presence of each of their respective primary resources and the combined mean of all resources. The two example fields are those illustrated in Table 6, and the primary resource values are those listed in Table 7.

AMPHIBIAN SPECIES			FIELD ONE			FIELD TWO		
Common Name	Scientific Name	P(Forage)	P(Day Shelter)	P(Night Shelter)	Mean	P(Forage)	P(Day Shelter)	P(Night Shelter)
Southern Cricket Frog	Acris gryllus	0.0000	0.0001	0.0001	0.0001	*	*	*
Mabee's Salamander	Ambystoma mabeei	0.0000	0.0028	0.0028	0.0019	*	*	*
Marbled Salamander	Ambystoma opacum	0.0000	0.0028	0.0028	0.0019	*	*	*
Two-toed Amphiuma	Amphiuma means	0.0004	0.5470	0.5470	0.3648	*	*	*
Fowler's Toad	Anaxyrus fowleri	0.0000	0.0001	0.0001	0.0001	*	*	*
Southern Toad	Anaxyrus terrestris	0.0000	0.0001	0.0001	0.0001	*	*	*
Southern Dusky Salamander	Desmognathus auriculatus	0.0004	0.0001	0.0001	0.0002	*	*	*
Southern Two-lined Salamander	Eurycea cirrigera	0.0004	0.0001	0.0001	0.0002	*	*	*
Eastern Narrow-mouthed Toad	Gastrophryne carolinensis	0.0000	0.0001	0.0001	0.0001	0.0425	0.9281	0.9281
Green Treefrog	Hyla cinerea	0.0000	0.0003	0.0003	0.0002	0.0425	0.9726	0.9726
Pine Woods Treefrog	Hyla femoralis	0.6125	0.0000	0.0000	0.2042	*	*	*
Barking Treefrog	Hyla gratiosa	0.6125	0.0000	0.0000	0.2042	*	*	*
Squirrel Treefrog	Hyla squirella	0.6125	0.0003	0.0003	0.2044	*	*	*
American Bullfrog	Lithobates catesbeianus	0.0000	0.5470	0.5470	0.3647	*	*	*
Green Frog	Lithobates clamitans	0.5000	0.5470	0.5470	0.5313	0.0425	0.7443	0.7443
Pickrel Frog	Lithobates palustris	0.5000	0.5470	0.5470	0.5313	*	*	*
Southern Leopard Frog	Lithobates sphenocephalus	0.0000	0.5470	0.5470	0.3647	0.5000	0.7443	0.7443
Carpenter Frog	Lithobates virgatipes	0.5000	0.5470	0.5470	0.5313	*	*	*
Dwarf Waterdog	Necturus punctatus	0.0004	0.5470	0.5470	0.3648	*	*	*
Eastern Newt	Notophthalmus viridescens	0.0004	0.0001	0.0001	0.0002	*	*	*
Atlantic Coast Slimy Salamander	Plethodon chlorobryonis	0.0000	0.0028	0.0001	0.0010	0.0425	0.4320	0.9281
Northern Slimy Salamander	Plethodon glutinosus	0.0000	0.0028	0.0001	0.0010	0.0425	0.4320	0.9281
Brimley's Chorus Frog	Pseudacris brimleyi	0.0000	0.0003	0.0003	0.0002	*	*	*
Spring Peeper	Pseudacris crucifer	0.6125	0.0003	0.0003	0.2044	*	*	*
Little Grass Frog	Pseudacris ocularis	0.0000	0.0003	0.0003	0.0002	*	*	*
Mud Salamander	Pseudotriton montanus	0.0004	0.0001	0.0001	0.0002	*	*	*
Greater Siren	Siren lacertina	0.5000	0.5470	0.5470	0.5313	*	*	*

3.3 Field-level Biodiversity Calculation & Exploration

Based on these species level predictions, we explored and summarized the biodiversity outcomes (for example, compare Table 10 to the table in Box 3) expected for the cropped and margin areas of our example fields. Given the operational decisions made in each field, 37% of the potential species associated with Field One and 92% in Field Two had a greater than 0.5 probability of finding one or more of their preferred resources in the field or field margins (Table 11). Seven percent of the species in Field One and 76% in Field Two had a mean probability of resource provisioning greater than 0.5 (Table 11). Application of the biodiversity metric calculation, which scales the number of species impacted by the number of species Potentially Present, resulted in Field Two scoring much higher biodiversity value overall (Table 11). Mammals were most negatively impacted by decisions in Field One. A few birds and mammals were negatively impacted by decisions in Field Two, while the majority of species (58%) were neutrally impacted.

4. DISCUSSION

Agricultural landscapes have the potential to host diverse vertebrate wildlife communities. Species-habitat models, such as the Southeast Gap Analysis Project, include row crop and other agricultural land cover classes as primary or secondary habitat for many species. Empirical research shows that operational decisions made throughout the crop production cycle impact the species composition of wildlife communities in and around row crop fields. Our project linked field-level operational decisions with the SEGAP species-habitat models to predict relative impact of these decisions on individual species and overall biodiversity. We proposed and met three criteria for the presented biodiversity metric: it is (a) based on theory and methods that are scientifically valid, (b) reproducible over time, and (c) scalable to the landscape, regional, and national levels. In addition,

Table 11. Summary of different methods to evaluate expected species richness and the final biodiversity metric, the Biodiversity Index.

		Species with One or More Resources	Counts Based on Logistic Probability Values				
	SEGAP Species	Present # (%)	Present (X > 0.05)	Negative (X < 0.334)	Neutral (0.334 < X < 0.666)	Positive (X > 0.666)	Biodiversity Index
Field 1							
Total	224	83 (37)	16	181	39	1	-0.72
Amphibian	27	12 (44)	4	19	8	0	-0.56
Bird	107	52 (49)	5	89	17	1	-0.74
Mammal	44	4 (9)	0	44	0	0	-1.00
Reptile	43	15 (35)	7	29	14	0	-0.51
Field 2							
Total	184	170 (92)	139	5	107	72	0.65
Amphibian	6	6 (100)	4	0	6	0	0.50
Bird	108	96 (89)	85	3	53	52	0.70
Mammal	36	34 (94)	26	2	20	14	0.61
Reptile	34	34 (100)	24	0	28	6	0.59

we designed the metric to be transparent with component parts easily accessible in support of the stated educational objectives.

4.1 Review of Pilot Project Outcomes

4.1.1 Theoretical Foundations

Biodiversity patterns in agricultural landscapes are complex, especially at the scale impacted by an individual producer's decisions. Like most predictive biodiversity models, ours rests on assumptions founded upon ecological theories of habitat selection. Specifically, we make assumptions about resource provisioning as a driving factor behind biodiversity (richness) at a field-scale. Habitat selection is a hierarchical process; populations respond to landscape scale patterns, while individuals respond to locally available resources (Rettie & Messier 2000; Jones 2001), among other factors (e.g., disturbance, competition; Jones 2001). The SEGAP data represent distribution patterns of vertebrate populations based on landscape-scale habitat characteristics. Then, when a given field falls within a population's available potential habitat, we must determine if an individual of that species is likely to actually use the field and its margins (Jones 2001). This is akin to predicting third-order selection (*sensu* Johnson 1980), which is the selection of habitat within home ranges. Fields may offer forage and shelter resources, but few, if any, vertebrate species would locate their entire territory within a single field. Thus, species are likely moving among multiple fields and the intervening landscape as resource availability or quality varies spatially and temporally. A limiting aspect of our approach is that we cannot know the relative availability and quality of alternative forage or shelter resources present within the home range but outside the field and field margin area. In effect, we assume that in the absence of any decision, the field and the neighboring available habitat are equally likely to be used. Then, while decisions of the producer change the field and field margin in a manner that increases or decreases the probability of use by each species, the neighboring habitat remains static.

We also constructed our models around the assumption that species would not respond uniformly to any single decision. Under a given production decision, one species may gain improved forage opportunities but lose shelter opportunities. Or, decisions during planting and growing seasons may benefit a species, while the same species is deterred by decisions made during the harvest season. Thus, two alternative decisions might benefit and deter an equal proportion of the species potentially present but result in a very different wildlife community. This complexity drove our decision to focus on the ecosystem services of fields and field margins to wildlife (i.e. the provisioning of shelter and forage resources) and to then indirectly predict a biodiversity impact as the cumulative response of individual species dependent upon these resources. By this design, our approach acknowledges and facilitates testing of two distinct potential sources of uncertainty: error predicting changes in the availability or quality of resources given a decision, and error predicting species responses to changes in resource quality or availability at the field-scale.

4.1.2 Expert-based Bayesian Methods

As most empirical research has focused on comparisons of organic versus conventional production systems, there are insufficient data to inductively model variance in species or biodiversity

response to alternative suites of conventional operational decisions. Our biodiversity metric therefore depends on deductive models constructed through an intensive series of expert knowledge elicitations. We used a rigorous approach to statistically encode experts' hypotheses and confidence as Bayesian prior probabilities (O'Leary 2011), based on the synthesis of their personal experience (i.e., observations, education, and reflection; per Perera et al. 2011). The expert-elicited hypotheses at the core of our model are untested but designed to be updated as new knowledge or data become available. By storing and analyzing expert knowledge and producer decisions within a semi-automated relational database, the models are easily updated with knowledge from additional experts or expanded to incorporate additional operational decisions or crops. This database could be further developed to present an interactive data-entry form for producers to enter their decisions. The database could also be linked to Geographic Information System software where, when producers identify their field, the associated species data could be directly downloaded into the database.

4.1.3 Transferability and Scalability of Methods

A major advantage of our approach is the ease with which it can be applied to new crops or new geographies. The Gap Analysis Project is a national project, so the species distribution data underlying our metric are (or will soon be) available throughout the country. If new crop species are added, additional expert elicitations will be required to first confirm the relevance of the defined operational decision, and then to identify if additional decisions should be added or deleted to characterize impacts of the new crop. If new geographic regions are incorporated, additional expert elicitations will be required to assign primary resource categories to any new species.

To develop the biodiversity metric, we down-scaled the GAP species-habitat models by adjusting predictions of potential presence based on an individual producer's actions in a single field. Scaling these field-level predictions back up to predict landscape-level biodiversity conservation risk and opportunity ideally would draw upon spatially explicit data representing the full suite of actions implemented in every field in a given year. Such data do not exist. However, we believe we could scale the concept to generate landscape-scale decision-value scores, if we used probabilistic simulations, expert elicitation, and regional agricultural statistics to define sets of actions that are most likely and least likely. For actions monitored by the USDA National Agricultural Statistics Service (NASS, <http://www.nass.usda.gov/index.asp>), county-level statistics could define the probability of alternative decisions within a decision set (e.g., probability of a field being planted in corn, wheat, cotton, soy, or other). Actions not monitored by the USDA (e.g., frequency of standing water in field ditches, type of vegetation in field margin), would require landowner surveys. The most likely decision landscapes could be simulated using the Tool for Exploratory Landscape Scenario Analyses (TELSA, <http://essa.com/tools/telsa/>), and the biodiversity metric then applied to generate maps of biodiversity scores and associated credible intervals (i.e., uncertainty). These maps could offer great value to conservation planners because the final spatial data layers would indicate potential conservation opportunities in present day agricultural landscapes. These maps would address the question: Do certain regions offer higher (or lower) biodiversity scores and therefore suggest different methods to tackle partnership with landowners? Such county-level biodiversity information could complement the work presented in this report but could not replace it,

if the goal is to create an interactive, educational tool that evaluates outcomes from an individual producer's decisions.

4.1.4 Educational Value

Our approach was designed to serve an educational role that would integrate with and complement the Field to Market Fieldprint Calculator. The relational database underlying the metric would allow producers (or conservation managers) to request standard biodiversity reports or to pose custom queries. For example, they could query the relative biodiversity impact of alternative decisions in a given field or similar decisions in two different fields. Users could also query which species or species groups benefit more (or less) under a given set of decisions or query which individual decisions are most beneficial (or detrimental). Thus our project not only provides a biodiversity metric for the Fieldprint Calculator but also supports the creation of highly customizable tools to educate producers about their biodiversity impacts. Furthermore, the versatility of the model to formulate individual queries facilitates empirical testing of the metric and the underlying theory.

4.2 Considerations to Advance Beyond the Pilot Project

Our pilot project demonstrates the feasibility and utility of a field-scale, resource-driven, species-based approach to calculate biodiversity impacts of individual producers' actions. Should the pilot concept be adopted by the Field to Market, we would recommend some immediate modifications to improve the metric, review by ecologists to judge the underlying assumptions, and interactive testing by producers to improve functional utility and educational value. Here we describe these modifications and then address some possible optional extensions.

4.2.1 Recommended Modifications

Time constraints did not allow us to incorporate seasonality in the pilot project, but we strongly recommend that the intersection of impact and species seasonality be added to future versions of the models. Seasonality could be incorporated most easily by categorizing species according to their seasonal presence (e.g., present during spring/fall migration, summer breeding, or winter seasons) and then limiting impacts to only occur when there is a joint occurrence of decisions and species. For example, species present only during the breeding season would not be affected by resource impacts occurring due to production decisions made in fall and winter. More intensive, but also valuable, would be to include seasonality in species primary resource preferences. A pre-screening elicitation to identify species with year-round presence, but significant seasonal shifts in diet or resource preferences, could reduce the elicitation effort necessary to collect this information.

For the pilot, for simplicity, we limited each species to one primary resource category of each resource type. When two or more experts offered conflicting judgments, we chose one representative response. However, the data we collected and the structure of the relational database are such that we could allow species resource preferences to also be represented as uncertain, probabilistic values.

4.2.2 Review, Testing, and Modification

Our models exist as a proof-of-concept, but have been neither rigorously peer-reviewed nor empirically tested. Should Field to Market choose to continue developing the metric for inclusion in the Fieldprint Calculator, we recommend the next step be an external peer review of the overall methodology. Ideally, partnerships could be formed to also empirically test the decision-resource-species-biodiversity linkages. We intend to actively pursue testing the biodiversity predictions and the underlying assumptions through state, federal, and other partnerships.

The Fieldprint Calculator has developed markedly over the course of our project. We therefore anticipate the opportunity to adjust some of our operational decision questions to better align with data already collected for other metrics within the tool. The structure of our elicitation database facilitates adjustment, removal, or addition of operational decisions. Significant adjustment or addition of new decisions would necessitate additional elicitation to quantify impact probabilities.

5. CONCLUSIONS

In 2011, Field to Market: Keystone Alliance for Sustainable Agriculture and The Nature Conservancy contracted us to pilot the development of a biodiversity metric that would allow producers to compare the expected impacts of alternative practices (e.g., crop choice, tillage methods, field margin management, etc.) on vertebrate species within and around commercial agricultural fields. Now complete, the pilot biodiversity metric uses a producer's inputs about their field-level practices to calculate a biodiversity score for individual fields of commercially grown corn, wheat, cotton, and soy crops in the Coastal Plain and Piedmont of VA, NC, and SC.

Although the majority of agriculture products are grown by conventional practices at large commercial scales, except for a few species the relative impacts of alternative conventional agricultural practices are poorly known. Despite this lack of empirical data, our project provides the first concrete example of a means to measure and incorporate biodiversity impacts into the Field to Market Fieldprint Calculator. Our results demonstrate that even large-scale conventional agricultural producers are potentially important partners in biodiversity conservation. The metric offers a means to educate both producers and conservation managers about the potential value of agricultural practices in sustaining diverse vertebrate wildlife communities.

The metric is an indirect additive index that combines landscape-level species-habitat distribution data and expert knowledge of species site-level forage and shelter resource preferences. It is indirect, in that producers' actions are linked to species-level responses via site-level impacts on forage and shelter resources. Southeast Gap Analysis Program (GAP, <http://www.basinc.ncsu.edu/segap/index.html>) data predict species potentially present based on landscape characteristics such as habitat type and the spatial context of that habitat. Once a producer identifies a field of interest, we use geographic information systems (GIS) to extract a list of the local GAP species, and relational databases match these species to their preferred forage and shelter resources. Then, as the producer enters information about their field and field margin management practices, the same relational database matches each action to resource impacts and then, finally, to species-level impacts. The metric is additive, in that these species-level predicted responses are then aggregated to produce a single quantitative measure of biodiversity. In the pilot, this metric places equal value on all vertebrate species, and it is scaled to score fields in relation to the maximum number of species

potentially present in the landscape (i.e., the score measures producers' impacts after accounting for variability in species richness). These aspects of the biodiversity metric calculation could be changed depending on the specific educational objectives to be set by Field to Market.

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