Bright spots in agricultural landscapes: Identifying areas exceeding expectations for multifunctionality and biodiversity

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Abstract
1. Agriculture's influence on humanity is a dichotomy of promise and peril. Research on the food-environment dilemma has highlighted the environmental consequences of food production, yet the identification of management solutions is an ongoing challenge.
2. We suggest “bright spots” as a promising tool to identify levers of change by finding areas that exceed expectations for goals, such as agricultural landscape multifunctionality and biodiversity.
3. We identified bright, dark and average spots within a complex agricultural landscape and explored the associated socioeconomic patterns. We found that areas exceeding expectations for biodiversity and landscape multifunctionality were neither spatially congruent nor in conflict. It was more common for areas to underperform (dark spots) for both biodiversity and multifunctionality than over perform for both (bright spots).
4. While dark spots for multifunctionality were alike in their ecosystem service composition, bright spots were bright in multiple, diverse ways. The socioeconomic attributes that characterize bright and darks spots included both farm characteristics as well as farming practices, suggesting that both have potential to be levers of change.
5. Synthesis and applications. Our results suggest that while biodiversity and landscape multifunctionality show similar spatial patterns due to underlying biophysical drivers, managing for biodiversity or landscape multifunctionality alone will not implicitly achieve the other in this system. Bright spots (areas exceeding expectations) in multifunctionality were associated with many different combinations of ecosystem services, but dark spots were uniquely agricultural intensive areas devoted to maximizing crop production at the expense of all other services. From a management perspective, specific farm characteristics and farming practices may impact the potential for multifunctionality: increased mechanization, increased agricultural inputs and larger farm size and capital were associated with dark spots, while smaller farms with potentially greater space for innovation were associated with bright spots.

Keywords
agricultural landscapes, agriculture, biodiversity, bright spots, conservation, ecosystem services, multifunctionality, social-ecological systems
1 | INTRODUCTION

Covering more than a third of the terrestrial, ice-free surface of the planet (Ranakutty, Evan, Monfreda, & Foley, 2008), agricultural landscapes are one of the principal interfaces between people and the environment. These landscapes are often areas of intense pressure and promise, supporting dense human populations, but also capable of supporting rich and diverse communities of other species (Wright, Lake, & Dolman, 2012). In addition to food, agricultural landscapes also provide other ecosystem services vital to human well-being, such as fresh water, clean air, carbon storage and places for outdoor recreation (Power, 2010). Agriculture economically supports nearly half the global human population as farmers, labourers and agribusiness workers, and contributes c. 6% to the global gross domestic product (Sandhu et al., 2016; Wratten, Sandhu, Cullen, & Costanza, 2013). But agricultural practices can also cause critical, and at times irreversible, environmental damage (Gerstner, Dormann, Stein, Manceur, & Seppelt, 2014; Newbold et al., 2015). Agriculture’s environmental footprint is pushing humanity to, or even past, the peak-rate year for multiple global nonrenewable resources such as cropland and irrigated area (Seppelt, Manceur, Liu, Fenichel, & Klotz, 2014). Thus, a critical societal challenge is to understand how to best manage our agricultural landscapes.

Multifunctionality has been an oft-prescribed goal of agroecological science. Its goals of achieving both commodity and noncommodity outputs (e.g. human residence, wildlife habitat and recreational activities; Anderson, Vejre, Dalgard, & Brandt, 2013) was introduced more than a decade ago to meet the challenge of balancing food production and environmental conservation, but its adoption has been slow (Jordan & Warner, 2010). To date, work on multifunctional agriculture has focused primarily on farm-scale approaches, namely farm characteristics and activities (Anderson et al., 2013). Landscape multifunctionality scales up to encompass both agricultural and other land use types (e.g. hedgerows, woodlots, wetlands, etc.) that provide a diverse range of ecosystem functions, services and beneficiaries (DeClerck, Estrada-Carmona, Garbach, & Martinez-Salinas, 2015; Fischer, Abson, Bergsten, Collier, et al., 2017; Garbach et al., 2017; Mastrangelo et al., 2014). Landscape multifunctionality and biodiversity are intrinsically linked, with research broadly suggesting that biodiversity begets ecosystem multifunctionality (Gamfeldt, Hillebrand, & Jonsson, 2008; Gamfeldt & Roger, 2017; Hector & Bagchi, 2007; Lefcheck et al., 2015). As a result, ecosystem multifunctionality has been incorporated in conservation policies such as the European Union’s Biodiversity Strategy and Japan’s National Strategy for Biological Diversity (Fischer, Meacham, & Queiroz, 2017).

To date a majority of research investigating the food-environment dilemma typically focuses on two outcomes: the delivery of food production and its impact on biodiversity (e.g. land sparing/sharing, sustainable intensification, ecological intensification, diversified farming systems and closing the yield gap; Bommarco, Kleijn, & Potts, 2013; Kremen, Iles, & Bacon, 2012; Perfecto & Vandermeer, 2010; Phalan, Green, & Balmford, 2014; Phalan, Onial, Balmford, & Green, 2011; Tilman, Balzer, Hill, & Befort, 2011). These discussions have prompted ecological research on the effect of food production on biodiversity and the environment, and introspection into the sustainability of ensuring long-term food availability (Seppelt et al., 2016; Wittman et al., 2017); however, they have largely neglected the complex multifunctionality of agricultural landscapes (Wittman et al., 2017). Some research on agricultural landscapes as complex systems has employed a social-ecological lens (Lescourret et al., 2015), which recognizes that the food-environment dilemma is shaped by key drivers with complex dynamics and feedbacks, and may differ or interact across spatiotemporal scales (Fischer et al., 2015; Fischer, Abson, Bergsten, French Collier, et al., 2017; Wittman et al., 2017). While such social-ecological perspectives have been lauded as the panacea to the shortcomings of the oversimplified food production-oriented frameworks, they themselves have many challenges, including the difficulty of capturing the complexity of multifaceted variables such as food security (Seppelt, Beckmann, & Václavík, 2017), and understanding the relationship between agricultural production and the surrounding environment (Saunders, Peisley, Rader, & Luck, 2016).

There is an urgent need to pursue solutions about how to achieve preferred outcomes for multiple goals and stakeholders in agricultural landscapes (Fischer, Abson, Bergsten, Collier, et al., 2017). One way to do so is to focus on those areas and landscapes that are already achieving multiple positive outcomes. Places that are performing substantially better than expected or “bright spots” (Cinner et al., 2016) can highlight proven local solutions to complex societal problems (Levinson, Barney, Bassett, & Schultink, 2007). Exploring bright spots is an approach that has been used with great success in medicine and social sciences (Spreitzer & Sonenshein, 2004; Subbiah & Subbiah, 2015), but remains in its infancy in ecological research. The bright spot analysis first accounts for variation via a preliminary (null) model (e.g. using biophysical variables that humans have little influence over) followed by further pattern exploration of a second set of variables (e.g. social-economic variables governed by human action), which renders this framework ideally suited for the inherent challenges of complex social-ecological systems (Cinner et al., 2016). While there are many other frameworks currently employed in ecosystem service research that elucidate the spatial patterns of ecosystem services or their interactions (Table 1), the bright spot approach is unique in its ability to account for deviations from expected given the expected constraints on the system as detailed in the preliminary null model.

Ecosystem services represent the critical interface between ecosystems and people; it captures both the desired diversity of ecosystem functions, as well as human actions and management methods. The concept of ecosystem services, broadly defined as a process or function of an ecosystem that provides benefits to humans (Mace, Norris, & Fitter, 2012), was first introduced in the early 1980s as a pedagogical tool to raise awareness of the benefits provided by ecosystems, and hence to argue for their protection (Ehrlich & Mooney, 1983). Managing agricultural landscapes using an ecosystem service framework means guiding agricultural management towards improving and conserving multiple services, such as carbon storage,
TABLE 1 Overview of concepts used in ecosystem service research

<table>
<thead>
<tr>
<th>Concept</th>
<th>Concept description</th>
<th>Concept use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bundles</td>
<td>Identifies spatially co-occurring ecosystem services (e.g. Raudsepp-Hearne et al., 2010)</td>
<td>Exploring ecosystem service spatial relationships</td>
</tr>
<tr>
<td>Trade-offs/synergies</td>
<td>Identifies relationships between multiple ecosystem services (e.g. Bennett, Peterson, &amp; Gordon, 2009)</td>
<td>Exploring ecosystem service mechanistic relationships</td>
</tr>
<tr>
<td>Hot/cold spots</td>
<td>Identifies spatial locations of highest/lowest ecosystem service total value(s) (e.g. Reyers et al., 2009)</td>
<td>Exploring best areas for producing ecosystem services</td>
</tr>
<tr>
<td>Win-win/lose-lose</td>
<td>Identifies spatially co-occurring optimal or unwanted locations for multiple ecosystem services (e.g. Qiu &amp; Turner, 2013)</td>
<td>Exploring desirable or degraded areas for multiple ecosystem services</td>
</tr>
<tr>
<td>Spatial prioritization</td>
<td>Identifies priority areas for ecosystem services and conservation via valuable synergies (e.g. Anderson et al., 2009)</td>
<td>Integrating ecosystem services in conservation planning</td>
</tr>
<tr>
<td>Bright/dark spots</td>
<td>Identifies spatial locations where ecosystem services deviate from expected (from a null model of known or expected drivers)</td>
<td>Exploring deviations from expected for ecosystem services</td>
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water quality, soil fertility, food production and outdoor recreation (DeClerck et al., 2015).

Biodiversity links to the concept of ecosystem services on many levels: it supports key ecosystem processes; it may directly affect the delivery of services; and it may itself even be considered a type of service (Mace et al., 2012). Despite these links, the relationship between biodiversity conservation and the management of ecosystem services is complex (Mace et al., 2012), and focusing solely on one or the other does not ensure reciprocal benefits (MacFadyen, Cunningham, Costamagna, & Schellhorn, 2012). Managing agricultural landscapes for a diverse set of ecosystem services or multifunctionality, as well as for biodiversity, will intrinsically benefit a broader range of beneficiaries (Fischer, Meacham, et al., 2017).

We suggest that searching for and investigating real-world solutions using bright spots is a promising, interdisciplinary approach to highlight feasible solutions and their drivers in agroecological research. As agricultural landscapes are inherently multifaceted and multifunctional (Bennett, 2017), managing them as such should conserve a diversity of ecosystem functions and species (Gamfeldt et al., 2008; Hector & Bagchi, 2007), all while providing a broader set of services to local beneficiaries, who in turn are likely involved in management of the landscape from which they benefit (Fischer, Meacham, et al., 2017). In this study, we applied the bright spots approach to first identify bright and dark spots of biodiversity and landscape multifunctionality in an agricultural region of Canada, and explored socio-economic patterns associated with bright and dark spots to help elucidate possible management and policy strategies that help achieve landscape multifunctionality.

2 | MATERIALS AND METHODS

2.1 | Applying the bright spot approach in a diverse agricultural landscape

We used existing data from the Montérégie region of Québec, Canada (Renard, Rhemtulla, & Bennett, 2015a) to quantify multifunctionality using nine ecosystem services, by integrating the quantity of each service as well as its presence using the multiple ecosystem service landscape index (MESLI; Rodríguez-Loinaz, Alday, & Onaindia, 2014) for each municipality (n = 131), where a higher MESLI score means a greater provision of multiple ecosystem services. We also quantified biodiversity to compare the location and drivers of multifunctionality vs. biodiversity. We assessed avian biodiversity using distributional data for individual bird species from the second Breeding Bird Atlas of Québec (Atlas of the breeding birds of Québec 2017; accessible online at https://birdscanada.org/birdmon) by calculating the Shannon diversity index using the vegan package of R version 3.4.2 for each municipality. To control for biophysical drivers of landscape multifunctionality and avian biodiversity, we developed generalized additive models with Gaussian distributions to generate expectations of how landscape multifunctionality and avian biodiversity were related to known abiotic environmental drivers such as soil and weather (Gaston, 2000; Mouchet et al., 2017). We used six variables in the multifunctionality GAM model, including: (a) the mean number of days during the growing season, (b) the mean precipitation, (c) the mean temperature, (d) the dominant soil class in each municipality based on soil potential and limitations for agriculture, (e) the maximum elevation, and (f) the area of the municipality. The biodiversity GAM model had the same six variables, with the addition of the average observer effort in hours (logged) of the atlas volunteers, for a total of seven variables. Further descriptions of the data and analysis used can be found in the supplementary information.

2.2 | Identifying bright and dark spots

We identified bright and dark spots as those municipalities that deviated by one or more standard deviation (SD) in landscape multifunctionality (as measured by MESLI scores; Rodríguez-Loinaz et al., 2014) or avian biodiversity (as measured by Shannon diversity scores) from the expected relationship determined by the null biophysical models (Figure 1a,b). It is important to note that not all bright spots were those with the highest measured multifunctionality.
**FIGURE 1** (a) & (c) The predicted Shannon diversity index values from the biophysical generalized additive model vs. the actual Shannon diversity index values for avian species, (b) & (d) the predicted multiple ecosystem service landscape index (MESLI; Rodríguez-Loinaz et al., 2014) from the biophysical generalized additive model vs. the actual MESLI, on the municipality scale in the Montérégie region of Québec, Canada. The data points represent municipalities: in (a) & (b) those within 1 standard deviation (SD) from the black linear regression lines as “average spots” in grey, those ≥1 SD as “bright spots” in orange and those ≤−1 SD as “dark spots” in blue; in (c) & (d) points are coloured according to the Shannon diversity index values and actual MESLI respectively [Colour figure can be viewed at wileyonlinelibrary.com]
or biodiversity (i.e. hot spots), and similarly the dark spots were not all those with the lowest measured values (i.e. cold spots); instead bright/dark spots were areas that strongly deviated from expected given their biophysical conditions (Figure 1c,d). This emphasis on deviation from expected is what makes bright spot analysis unique from several other analytical frameworks such as ecosystem service bundles, trade-offs or hot spots (Table 1). We used 1 SD in this example, as having multiple outliers helps test the general validity outlier analysis (Post & Geldmann, 2017). As a sensitivity analysis, we also tested bright and dark spots derived from less (0.5 SD) and greater (1.5 SD) deviation in our exploration of social-economic variables. We found that although the details may differ, the general patterns we described in our results was similar across the different SD thresholds, with the 1 SD threshold providing the best proportion of bright/dark spots for our sample size. We examined the relationship between overall avian biodiversity and landscape multifunctionality, as well as between the deviations from expected (based on the biophysical models) of avian biodiversity and landscape multifunctionality, using generalized additive models with the mgcv package of R version 3.4.2.

### 2.3 Ecosystem service bundles in bright and dark spots

To explore the variation in the composition of the ecosystem services across bright, dark and average spots, we quantified the average of each of the nine ecosystem services in bright spots and dark spots. To compare how bright and dark spot ecosystem services bundles related to ecosystem service spatial patterns inherent in the study area, we identified ecosystem service bundles (i.e. mix of positively spatially correlated ecosystem services; Raudsepp-Hearne, Peterson, & Bennett, 2010; Renard et al., 2015a) using K-means clustering analysis in R using the stats package across all 131 municipalities. We predetermined the number of partitioning to be for three cluster groups, which was both supported by the "elbow method" to determine the optimal number of clusters for K-means clustering and matched the number of the groups from the bright spot analysis (i.e. bright, dark, average).

### 2.4 Socio-economic patterns in bright, dark and average spots

We used Bray–Curtis based nonmetric multidimensional scaling ordinations (NMDS) to explore the composition of ecosystem services of the bright, dark and average spots, and their relationship with socio-economic variables in R using the vegan package. NMDS is an indirect gradient analysis approach, which produces an ordination where objects that are more similar to one another are ordinated closer together. We chose the NMDS method as our goal was to explore, not explain, the relationship between the socio-economic variables and the grouping of the sites, and because the NMDS handles nonlinear and nonnormal response variables. We used 22 socio-economic variables available from the 2011 Canadian Agricultural Census (available online via Statistics Canada https://www.statcan.gc.ca/eng/ca2011/index and the 2006 Canadian Census of Population (available online via Statistics Canada https://www12.statcan.gc.ca/census-recensement/2006/index-eng.cfm), as well as the distance from a major centre as described by Renard et al. (2015a) (Table 2). We chose those variables that were available on the municipality scale that reflected a suite of farm characteristics (size, capital, ownership) and farm management practices (agricultural inputs, organic farming), as well as factors that may influence demand and accessibility of ecosystem services (population density and distance from major centre), all of which we hypothesized could be drivers of the production of ecosystem services across an agricultural landscape. We used the nine ES (ranked from 0 to 1 according to the minimum/maximum reported values in the dataset) from the MESLI as the community component, with the municipalities as the sites and the 22 socio-economic variables as potential drivers. We ran the NMDS for all municipalities (n = 131), as well as for just the bright and dark spots (n = 39).

### 3 RESULTS

Our analysis designated 21 out of 131 municipalities as dark spots for landscape multifunctionality and 18 as bright spots; 17 out of 131 municipalities designated as dark spots for biodiversity and 17 as bright spots (Figure 2). Overall, five municipalities, or 7% of all bright or dark spots (n = 67) were congruent for multifunctionality and biodiversity targets, with four municipalities as dark spots, and one municipality as a bright spot, for both landscape multifunctionality and biodiversity concurrently (Figure 2). There was only one municipality as a conflicting bright/dark spot for multifunctionality and biodiversity; this municipality (Ange-Gardien) was a bright spot for landscape multifunctionality, but a dark spot for biodiversity (Figure 2). These findings suggest that there are few municipalities that both deviate from expected for both multifunctionality and biodiversity, and in those that do the most common outcome (4/6) were congruent dark spots for both multifunctionality and biodiversity.

We found that avian biodiversity was a significant predictor of landscape multifunctionality (F-value = 6.58, p = 0.0001); this relationship was curvilinear, with an increasing Shannon diversity index related to higher MESLI until the mean Shannon diversity index reached c. 3.5, at which higher biodiversity was related to declines in multifunctionality (Figure 3a). When comparing the outliers of avian biodiversity and landscapes multifunctionality, as measured by the deviance of the actual value from the predicted value from the biophysical models, outliers of biodiversity were weak, nonsignificant predictors of outliers of multifunctionality (F-value = 1.53, p = 0.17). The relationship between the outliers was similar to that of the total values, but with only a slight decline in multifunctionality at higher values of biodiversity outliers (Figure 3b). This suggests that while avian biodiversity significantly predicts landscape multifunctionality, this relationship is weakened and nonsignificant once the effects of biophysical conditions have been accounted for.
We found that dark spots were characterized by fewer ecosystem services, primarily crop production with smaller contribution from cattle production and carbon sequestration (Figure 4a). Comparatively bright spots, while still having strong contributions from crop and cattle production, included a wider variety of ecosystem services (Figure 4a). We describe the three cluster groups from the K-means clustering (Figure 4b) as such: (a) the Recreation-dominated bundle (n = 27 or 21% of municipalities) characterized by carbon sequestration and hunting, with secondary contributions of flood regulation and cattle production; (b) the Agriculture-dominated bundle (n = 92 or 70% of municipalities) characterized by crop and cattle production; and lastly (c) the Recreation agriculture bundle (n = 12 or 9% of municipalities) characterized by other outdoor recreation and crop production, with secondary contributions of carbon sequestration and cattle production. All 21 dark spot municipalities were clustered in the Agriculture-dominated bundle (Table 3). In comparison, the bright spots clustered across all three bundles, including Recreation forest (4/27 or 15%), Agriculture-dominated (10/92 or 11%) and Recreation agriculture (4/12 or 33%). While the Agriculture-dominated bundle had the most municipalities overall, and the most bright spots (10/18), it had the lowest percentage of bright spots of the cluster types. Comparatively, the least numerous cluster type, the Recreation agriculture bundle, had the highest percentage of bright spots for landscape multifunctionality.

The NMDS plot for all municipalities (k = 3, final stress = 0.137) showed that ecosystem services composition was most similar among dark spots (tightest clustering), intermediate for bright spots and broadest for average spots (Figure 5a). Dark spots were closely associated with only three ecosystem services (cattle production, crop production, camping). The NMDS plot for bright and dark spots only (k = 3, final stress = 0.113) had nine socio-economic attributes that significantly influenced the distribution of the municipalities in ordinal space (i.e. influenced the composition of the ecosystem services). This included medium capital (p = 0.008; R² = 0.41), large capital (p = 0.003; R² = 0.52), tractors per farm (p = 0.009; R² = 0.42), tractor value per farm (p = 0.005; R² = 0.47), small farm size (p = 0.005; R² = 0.43), medium farm size (p = 0.004; R² = 0.43), insecticides (p = 0.048; R² = 0.41), inorganic fertilizers (p = 0.001; R² = 0.71) and green manure (p = 0.025; R² = 0.31; Figure 4). While there was overlap between the bright and dark spot clusters, the two were divided along the first axis, with insecticides, green manure, tractors per farm and tractor value per farm being associated with dark spots, and small farm size and medium capital being associated with bright spots (Figure 5b).

<table>
<thead>
<tr>
<th>Variables</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sole proprietor</td>
<td>Percentage of farms with the operating arrangement described as sole proprietor</td>
</tr>
<tr>
<td>Family corporation</td>
<td>Percentage of farms with the operating arrangement described as family corporation</td>
</tr>
<tr>
<td>Non-family corporation</td>
<td>Percentage of farms with the operating arrangement described as non-family corporation</td>
</tr>
<tr>
<td>Computer use</td>
<td>Percentage of farms using computers for the farm business</td>
</tr>
<tr>
<td>Organic production</td>
<td>Percentage of farms reporting organic products for sale</td>
</tr>
<tr>
<td>#Tractors per farm</td>
<td>Average number of tractors per farm</td>
</tr>
<tr>
<td>Tractor value per farm</td>
<td>Average capital value of all tractors per farm</td>
</tr>
<tr>
<td>Small farm</td>
<td>Percentage of farms under 10 acres to 179 acres in size</td>
</tr>
<tr>
<td>Medium farm</td>
<td>Percentage of farms 180 to 1119 acres in size</td>
</tr>
<tr>
<td>Large farm</td>
<td>Percentage of farms 1120 to 3520 acres in size</td>
</tr>
<tr>
<td>Small capital</td>
<td>Percentage of farms with total farm capital of $349,999 and less</td>
</tr>
<tr>
<td>Medium capital</td>
<td>Percentage of farms with total farm capital between $350,000 and $999,999</td>
</tr>
<tr>
<td>Large capital</td>
<td>Percentage of farms with total farm capital between $1,000,000 and $3,500,000 and over</td>
</tr>
<tr>
<td>Population density</td>
<td>Number of inhabitants per square kilometre</td>
</tr>
<tr>
<td>Distance to major centre</td>
<td>Distance between the geometric centre of each municipality and the city of Montréal, Québec, Canada</td>
</tr>
<tr>
<td>Rotational grazing</td>
<td>Percentage of farms reporting rotational grazing</td>
</tr>
<tr>
<td>Green manure</td>
<td>Percentage of farms reporting the ploughing down of green crops</td>
</tr>
<tr>
<td>Winter cover</td>
<td>Percentage of farms reporting the planting of winter cover crops</td>
</tr>
<tr>
<td>Windbreaks</td>
<td>Percentage of farms reporting natural or planted windbreaks or shelterbelts</td>
</tr>
<tr>
<td>Herbicides</td>
<td>Herbicide application reported as the percentage of total municipality area</td>
</tr>
<tr>
<td>Insecticides</td>
<td>Insecticide application reported as the percentage of total municipality area</td>
</tr>
<tr>
<td>Fertilizer</td>
<td>Insecticide application reported as the percentage of total municipality area</td>
</tr>
</tbody>
</table>

We found that dark spots were characterized by fewer ecosystem services, primarily crop production with smaller contribution from cattle production and carbon sequestration (Figure 4a).
neither spatially congruent nor in conflict. This finding mirrors similar findings on the global (Naidoo et al., 2008) as well as the local scale (Cimon-Morin, Darveau, & Poulin, 2013) between biodiversity and ecosystem services. In most cases in our study area of the Montérégie, managing for either multifunctionality or biodiversity alone will not indirectly achieve the other target. While in this study we were limited by small sample size, further research into bright spots congruent for both multifunctionality and biodiversity would be particularly useful to guide conservation investment and policy planning.

Second, our findings suggest that it is more common for areas to underperform for both biodiversity and multifunctionality than to overperform for both. Differences in valuation, interpretation, responses to particular management actions, and linkages for biodiversity and ecosystem services makes comanagement for both complex (Mace et al., 2012). We suggest that a more comprehensive understanding to what farm and land management practices associated with congruent dark spots or those municipalities that are negatively deviated from the expected for both multifunctionality and biodiversity may help avoid creation or expansion of such areas in agricultural landscapes.

We found that while dark spots for landscape multifunctionality are almost all alike in the composition of ecosystem service they provide, bright spots can achieve increased multifunctionality through the provision of many different sets of services. The composition of ecosystem services in dark spot appears to be a trade-off of higher crop production at the expense of most other services. Conversely, composition of ecosystem services at bright spots suggests that when trade-offs are balanced this leads to a more multifunctional landscape. Bright spots for landscape multifunctionality did include municipalities in the Agriculture-dominated bundle, thought this was the least common bright spot of the cluster types. These municipalities had the lowest mean carbon sequestration compared to bright spots in the other two bundle types, suggesting that inherent trade-offs may be unavoidable even in bright spots.

Finally, preliminary explorations demonstrate that the socioeconomic attributes that characterize bright and dark spots in agricultural landscapes include both farm characteristics such as farm size and capital, as well as farming practices, such as insecticide use, suggesting the potential for different levers of change. Broadly speaking, it appears that increased mechanization (number and value of tractors), increased agricultural inputs (inorganic fertilizer and insecticides), and larger farm size and capital was related to dark spots for multifunctionality, and smaller farms with medium capital related to bright spots of multifunctionality. We can only speculate to the relationship underlying these patterns, such as a greater space for innovation in smaller farms (e.g. on-site farm tourism activities), leading to greater multifunctionality than predicted solely by the area’s biophysical characteristics and larger, more mechanized farms maximizing intensively cropped land area for profits to meet the increased costs of machinery, land purchases and agricultural inputs, leading to a monofunctional landscape specialized in crop production.

Our goal in applying the bright spot approach in research of agricultural landscapes is to gain introspective on the processes and management practices enabling or hindering multifunctionality and
biodiversity conservation in these landscapes, in a practical, generalizable way so that the findings may be applicable in the real world across regions and scales. Despite its promising use, this approach comes with several inherent challenges. For robust, meaningful identification of bright spots in agricultural landscapes, we caution future research to carefully consider the following six challenges:

1. **Accounting for biophysical drivers of bright spots**—The identification of bright spots depends on a strong preliminary null model (e.g. our biophysical model). In the case of agricultural bright spots, we thus need to ensure that positive deviations are not, for example simply an artefact of intrinsically more productive regions. As such we needed a strong model (i.e. one of reasonably good fit) that controls for background biophysical drivers of agroecosystem performance to identify cases of exceptionism that may be driven by human management.

2. **Independent data**—Another general challenge of bright spot analysis is the need for a wide range of ecological, social and economic data at similar spatial and temporal resolutions. An important caveat to this challenge is the need for independent data. Datasets on ecosystem services or on management characteristics may be derived from modelling processes and as such may be based on other indirect variables (e.g. water quality as modelled from fertilizer data or greenhouse gas emissions are modelled from livestock populations). Using interdependent datasets to identify outliers and their commonalities may build circularity into the analysis and predefine relationships, and therefore should be avoided. For example, we used biophysical variables (temperature, elevation, soil) in our null model to identify outliers of landscape multifunctionality and avian biodiversity, and then used an independent dataset of socio-economic variables to explore commonalities.

3. **Multicriteria of ecosystem function**—The representation of a full spectrum of ecosystem services to include in multifunctionality indices, and the choice of indicators used, are key considerations for a robust and thoughtful analysis of ecosystem multifunctionality (Stürck & Verburg, 2017). Ecosystem service research is a (relatively) young field of research and its inherent complexity means that careful thought must be given in how it is applied. For example, the capacity of an ecosystem to produce a service (capacity) and societal demand for the service (demand) are interlinked yet independent components of ES delivery (Villamagna, Angermeier, & Bennett, 2013), both of which determine the use of the service (flow). The methodological decision to consider one or all
components of service delivery in the delineation of bright spots may lead to the variation in the presence or locations of bright spots.

4. Scale—Ecosystem services operate, and are managed at multiple scales making scalar research imperative (Bennett et al., 2015) and the choice of scale will likely influence the outcomes of a

**FIGURE 4** (a) Ecosystem service bundles for bright and dark spot of landscape multifunctionality and (b) ecosystem services bundles for three clusters types determined by K-means clustering. Each petal in the bundle is associated with an ecosystem service that was used in quantifying landscape multifunctionality. To facilitate comparison between services, all ecosystem service values were standardized from 0 to 1 for the minimum and maximum ecosystem service value across all 131 municipalities, as such petals are comparable across bundles [Colour figure can be viewed at wileyonlinelibrary.com]

**TABLE 3** Overview of the relationship between the ecosystem service composition of different municipality classes from the bright spot analyses (bright, dark and average), and the K-means partitioned clusters

<table>
<thead>
<tr>
<th>Class/Cluster</th>
<th>Recreational forest</th>
<th>Agriculture-dominated</th>
<th>Recreational agriculture</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average spot</td>
<td>23 (85%)</td>
<td>61 (66%)</td>
<td>8 (66%)</td>
<td>92</td>
</tr>
<tr>
<td>Bright spot</td>
<td>4 (15%)</td>
<td>10 (11%)</td>
<td>4 (33%)</td>
<td>18</td>
</tr>
<tr>
<td>Dark spot</td>
<td>0</td>
<td>21 (22%)</td>
<td>0</td>
<td>21</td>
</tr>
<tr>
<td>Total</td>
<td>27 (100%)</td>
<td>92 (100%)</td>
<td>12 (100%)</td>
<td></td>
</tr>
</tbody>
</table>
bright spots analysis. The most appropriate spatial scale for a bright spot analysis may vary with the scale at which management and policy actions take place—which may differ from the scale of the available data. As such, multiscale research is the ideal. Opportunities presented by multiscalar research may include determining drivers or commonalities that are present at multiple scales, or identifying bright spots at a finer scale within dark or average locations thus allowing the prioritization of actions at the appropriate scale.

5. Landscape structure—Landscape structure is known to affect the production and delivery of ecosystem services (Eigenbrod, 2016). And while we are beginning to understand the effects of landscape structure on ecosystem services (Mitchell et al., 2015), more research is critically needed. For the sake of brevity we did not include landscape composition or structure as a potential drivers in identifying commonalities of bright spots in our study, but we suggest this should be a key future consideration, given the importance of landscape composition and
structure in agricultural landscapes for biodiversity (Fahrig et al., 2011), for ecosystem services in general (Power, 2010), and for the provisioning of multiple ecosystem services (Mouchet et al., 2017).

6. Spatial autocorrelation—Bright spot analyses inherently make use of highly spatial data, and as such these data are likely subject to spatial autocorrelation. In our analyses, we purposely did not account for spatial autocorrelation in our preliminary null biophysical models for two reasons: (a) our goal was not statistical inference, but rather the creation of a null model, and (b) we did not wish to blindly account for the spatial autocorrelation in the dataset when identifying the bright/dark spots, as our ultimate goal was to explore the commonalities and variations among and between bright/dark spots, including the very factors that may be driving the spatial autocorrelation (e.g. social-economic conditions). Yet, as the field of bright spots research matures, future research on the influence of spatial autocorrelation on bright spots identification is certainly warranted.

5 | CONCLUSIONS

Despite a growing understanding of the perils and promise of agricultural landscapes, identification of the levers to facilitate desirable change in these landscapes is an ongoing challenge. We suggest bright spots as an innovative and promising tool in ecological research to identify and understand levers of change and feasible management recommendations in complex social-ecological systems. Such “learning from positive examples” is well suited to help build common ground among various stakeholders, build participatory approaches, and present feasible solutions to local challenges while guiding global actions. Our findings highlight the socio-economic factors associated with bright spots of landscape multifunctionality that may promote or encourage more multifunctionality in our agricultural landscapes. We also suggest that managing for multifunctionality or biodiversity alone will not implicitly achieve the other, and that the inherent trade-off between crop production and other ecosystem services may mean that to achieve multifunctionality it necessitates a decrease in crop production. Future research on bright spots of multifunctionality in agricultural landscapes ultimately depends on the knowledge gaps being addressed, but may include: contacting stakeholders within bright, dark, and average spots for a more explicit understanding of local management and policy patterns, identifying areas of conservation or improvement priority, or as a foundation for scenario building to envision a future where bright (or dark) spot conditions were applied broadly. We believe using bright spots has the compelling potential to ensure that agricultural research asks the critical questions required to build solution-oriented pathways that will lead to a brighter and multifunctional future for agricultural landscapes.

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AUTHORS’ CONTRIBUTIONS

B.F. and E.M.B initially conceived the study, with all authors contributing to designing the conceptual framework. B.F. and D.R. compiled the data; B.F. conducted the analysis; B.F. and E.M.B led the writing of the manuscript. All authors contributed critically to the drafts and gave final approval for the publication.

DATA ACCESSIBILITY


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REFERENCES


