Group-based Crop Change Planning: Application of SmartScape™ Spatial Decision Support System for Resolving Conflicts

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Abstract

Agricultural changes are complex and managing an appropriate type of crop change to satisfy stakeholders with various interests is challenging. Decisions regarding a crop change need to be debated among multiple stakeholders with various conflicting viewpoints. Two kinds of conflicts might occur as a result of crop change in an agricultural landscape: 1) conflicts among multiple ecosystem services i.e., internal conflicts and 2) conflicts among multiple stakeholders i.e., external conflicts. While a spatial decision support system (SDSS) can provide answers concerning multifaceted problems, there are currently a few SDSSs that indicate the trade-offs among multiple ecosystem services as a result of crop change and also enable stakeholders with diverse preferences to arrive at group-based decisions. In this study, we held a series of meetings with stakeholders, who were experts in economics, energy, soil erosion, greenhouse gas emission, surface water, and biodiversity, to develop two crop change scenarios by replacing perennial energy crops with annual energy crops and vice versa. We then used an online SDSS, SmartScapeTM, and applied it to Dane county, Wisconsin, U.S. to 1) run the two aforementioned crop change scenarios separately in order to assess how effectively SmartScapeTM enables decision makers to resolve internal conflicts while considering the relative values of multiple ecosystem services, and 2) run the two crop change scenarios jointly to show how well SmartScapeTM enables decision makers to resolve external conflicts in a group while taking into account the diverse goals of stakeholders. The outcomes of this study can inform policy-makers about both internal conflicts within a crop change scenario and external conflicts among stakeholders and provide a unique framework to resolve both types of conflict in an effective way. Obtaining acceptable crop change solutions among stakeholders with conflicting interests

can lead us in moving from individual decision-making to group-based decision-making so that we can enhance sustainability in agricultural landscapes.

Keywords: SmartScapeTM, Internal and external conflicts, Crop change scenario, Ecosystem services trade-off, Group-based decision-making.

1. Introduction

Agricultural ecosystems play a significant role in the life cycle by providing a variety of valuable services to humans, including food, bioenergy, fibre, and animal feeds (Turner *et al.*, 2016; Fisher *et al.*, 2009; Song *et al.*, 2015a). The science of ecosystem services has received a lot of attention since the Millennium Ecosystem Assessment (MA, 2003 and 2005) scheme was set up. Despite a variety of studies on ecosystem services in agricultural landscapes, linking the ecosystem services concepts to decision-making at the landscape scale still remains as a key challenge (Fisher *et al.*, 2009). This challenge at the landscape scale is how to determine location and required management practices in agricultural landscapes. Ecosystem services are vital in policy-making since decision makers are always confronted with demands for land changes from a wide range of stakeholders with diverse interests (Hein *et al.*, 2006).

Decisions about land use change are sufficiently complex and require debate of conflicting viewpoints (Feick and Hall, 2001). Seeking a balance among conflicting viewpoints is also challenged by other factors such as land suitability, slope, distance to river, and competition among different land uses (Zhang *et al.*, 2012; Arsanjani *et al.*, 2016a and 2016b). Since there are always conflicting interests among groups of stakeholders (Tayyebi and Pijanowski, 2014), any strategic land use change requires discussions among groups of stakeholders with different interests in the planning strategy (Koontz, 2005). Crop change in an

agricultural landscape is a great example of this as it is affected by multiple parties, such as farmers, economists, environmental specialists and stakeholders (Tayyebi *et al.*, 2016a and 2016b). Policy-makers are currently involved in the challenge of understanding the conflicts among multiple parties and identifying the trade-offs among multiple ecosystem services to achieve sustainability in agriculture landscapes (Meehan *et al.*, 2013).

Two kinds of conflicts can be identified as a result of crop change: 1) internal conflict, and 2) external conflict. The first type of conflict exists among various ecosystem services when crop change occurs in agriculture landscapes. Thus, landscape configuration and limitations on natural resources can cause internal conflicts (Le Billon, 2001). The existing studies on ecosystem services have emphasised that more than 50% of ecosystem services decreased within the last ten years (MA, 2003 and 2005; Song *et al.*, 2005a), and that this will have a negative impact on human wellbeing. Thus, it is vital to understand how the benefits of one ecosystem service can have negative consequences on the other ecosystem services (Dubois *et al.*, 2015). To remove such conflicts in agriculture landscapes, a crop change policy promoting bioenergy crop production, for example, should be compatible with multiple ecosystem services, such as climate regulation (Searchinger *et al.*, 2008; Tayyebi and Jenerette, 2016), water quality regulation (Tayyebi *et al.*, 2015), biodiversity support (Groom *et al.*, 2008), as well as pollinator abundance (Kennedy *et al.*, 2013; Azari *et al.*, 2016) in order to provide sustainability in an agriculture landscape. This type of integrative assessment is a novel challenge due to its multidisciplinary nature.

The second conflict arises among crop change scenarios that benefit multiple stakeholders, which we earlier called external conflict. This is due to the fact that stakeholders usually have different goals in relation to crop change, which might conflict with those of other

69 stakeholders (Koontz, 2005). For example, farmers are interested in growing crops close to rivers
70 while environmental experts encourage farmers to form a buffer around rivers to reduce the
71 amount of nutrients (e.g., phosphorus) leaching into rivers as a result of crop production. Policy-
72 makers currently face the challenge of understanding the views of multiple stakeholders and
73 come up with the best decisions for them as a group (Sheppard and Meitner, 2005). Considerable
74 efforts are required to increase stakeholders' confidence in defining crop change policy and to
75 build policy-maker support for the necessary investments. Incorporating stakeholder
76 commitment to the process of crop change policy will encourage community acceptance of the
77 subsequent policy decisions (Tayyebi *et al.*, 2016a).

78 Crop change scenarios have been commonly used to assess the future consequences of
79 crop change with respect to environmental implications (Song *et al.*, 2015b). Alternative crop
80 change scenarios illustrate the impact of different crop change scenarios on multiple ecosystem
81 services (Tan and Shibasaki, 2003). The outcomes of crop change scenarios are useful for policy-
82 makers in order to implement appropriate crop change policies that better contribute to the goal
83 of sustainability in agricultural landscapes (LaBeau *et al.*, 2014). However, the right way of
84 evaluating this information by users is a key challenge as each scenario usually has both gains
85 and losses and it is complicated to find one optimum scenario that satisfies the varying concerns
86 of policy-makers (Bormann *et al.*, 2007). Thus, it is necessary to resolve both internal and
87 external conflicts using various sustainability metrics and competing criteria (Diakoulaki and
88 Karangelis, 2007).

89 Sustainable agriculture calls for the balancing of diverse social, economic, and ecological
90 values across space and time in the form of multiple criteria (Lichtfouse *et al.*, 2009). SDSSs
91 have been utilized as promising tools to consider multiple criteria in the course of decision-

making (Tayyebi *et al.*, 2010). They have been used to provide unique solutions for managerial problems such as allocating wind farms (Mari *et al.*, 2011), the planning of urban infrastructures (Coutinho-Rodrigues *et al.*, 2011), managing and planning the USDA's Conservation Reserve Program (Rao *et al.*, 2007), and watershed management (Choi *et al.*, 2005). SDSSs have shown that they can achieve a balance among multiple ecosystem services if they can incorporate spatial and temporal data as well as environmental models (Pijanowski *et al.*, 2009 and 2014). For example, an agricultural production systems simulator (APSIM) was invented to simulate the ecological and economical outcomes of crop change in farming systems (Keating *et al.*, 2003). Apollo SDSS was developed to manage SDSS for Agrotechnology Transfer (SDSSAT; Jones *et al.*, 2003) and to analyze land management (Thorp *et al.*, 2008). CropSyst (crop systems simulation model) was developed to study the consequences of climate, management practices, and soils on cropping systems and the environment (Stöckle *et al.*, 2003).

Despite a variety of studies on ecosystem services, the existing SDSSs, which have all been developed for crop change analysis, are limited to showing the trade-offs among multiple ecosystem services (i.e., internal conflicts) as a consequence of crop change (Tayyebi *et al.*, 2016a). Furthermore, the capability of existing SDSSs is limited by its single-user perspective thus ignoring the involvement of stakeholders with varying interests in group decision-making (i.e., external conflict; Zhang *et al.*, 2012). What is lacking, therefore, is an SDSS that can illustrate how stakeholders can overcome internal and external conflicts among multiple parties by achieving a balance between different viewpoints to provide sustainability in agricultural landscapes. Tayyebi *et al.*, (2016a and 2016b) recently developed an online SDSS called SmartScapeTM that allows planners to assess the effects of changes in bioenergy crops within a spatially explicit environment. Tayyebi *et al.*, (2016a) discussed the technical aspects of

SmartScapeTM development and then explored how stakeholders can define crop change scenarios using SmartScapeTM (see Tayyebi *et al.*, 2016b); however, neither of these recent studies detailed how stakeholders can take advantage of SmartScapeTM to resolve internal and external conflicts.

To fill this gap in the literature, this study aims to go one step further and illustrate how policy-makers can take advantage of SmartScapeTM to: 1) resolve the internal conflicts by monitoring the trade-offs among multiple ecosystem services and 2) resolve the external conflicts among stakeholders so that effective crop change decisions can be achieved. We applied SmartScapeTM in the mid-west of the U.S., an area that has experienced considerable changes due to extensive bioenergy crop production. We worked closely with a team of stakeholders with expertise in economics, energy, soil erosion, greenhouse gas emission, surface water, and biodiversity through a series of public meetings to define two crop change scenarios (replacing perennial energy crops with annual energy crops and vice versa).

2. Materials and Methods

2.1 Study Area

The study area is Dane county in Wisconsin, which is dominated by a high number of agricultural fields. It is located in the southern part of Wisconsin state next to the counties of Iowa and Columbia. Dane County is dominated by agricultural lands 61%, urban areas 24% and has more than 60 cities, towns, and villages as shown in Figure 1. A combination of vector and raster data is used for display on the client side; however, the data on the server side to run various models is in raster format. The datasets were projected to the Spherical Mercator Projection Coordinate System (EPSG: 3857). Cropland Data Layer (CDL) and Soil Survey

Geographic Database (SSURGO) were used to extract crop/soil and elevation data, respectively at 30m×30m size. SmartScape™ includes the combination of perennial energy crops (grass and alfalfa) and annual energy crops (corn and soy).

Figure 1: The study area is located in a) Dane county of b) Wisconsin, c) U.S.

2.2 SmartScape™

SmartScape™ has an interactive, web-based environment for strategic crop change planning, which allows users to build and evaluate a crop change scenario (Available at <http://gratton.entomology.wisc.edu/smartscape>). SmartScape™ consists of three major components (Figure 2): 1) a land selection panel that enables users to select parts of the landscape using a set of spatial criteria (Figure 2, Item 1), 2) a scenario panel that enables

stakeholders to make a hypothetical crop change and run multiple environmental models (Figure 2, Item 2). This panel also enables stakeholders to interact with each other in order to define multiple crop change scenarios in a group. Lastly, 3) there is a scenario comparison panel that enables users to compare the outcome of crop change scenarios on various ecosystem services using various visual analytics and to highlight the trade-offs among multiple ecosystem services (Figure 2, Item 3).

SmartScape™ includes eleven ecosystem services, which are summarized as follows.

- The yield model estimates crop yields based on the soil and topographic characteristics as recommended by Meehan *et al.*, (2013).
- The biofuel production model estimates the amount of liquid biofuel generated from the crop yield model (Hill *et al.*, 2006), which describes the volume of liquid fuel that can be attained from a mass of feedstock.
- Net income is calculated as the gross return minus production costs using the estimated yield from the crop yield model, current crop prices, and crop production costs (Meehan *et al.*, 2013).
- Net energy is estimated as the gross energy of ethanol and co-products minus the gross life-cycle energy requirements for production (Meehan *et al.*, 2013), using the estimated yield from the crop yield model, conversion ratios that convert feedstock to liquid fuel and liquid fuel to units of energy.
- The Revised Universal Soil Loss Equation (RUSLE) estimates the annual soil loss using various factors such as annual rainfall, soil erodibility, runoff erosivity, slope steepness, slope length, management, and conservation practices (Khanal *et al.*, 2013).

- 171 - The phosphorus model estimates the amount of phosphorus loading using the
172 Environmental Policy Integrated Climate (EPIC) agro-ecosystem model (Zhang *et al.*,
173 2010) that is further modified based on the distance of a location from the nearest stream
174 and the type of land cover.
- 175 - The nitrous oxide model estimates the nitrous oxide emission using environmental and
176 management-related factors such as soil organic carbon content, climate, drainage, soil
177 texture, nitrogen rate per fertilizer type, soil pH and type of crop (Bouwman *et al.*, 2002).
- 178 - Below-ground, sequestered carbon is calculated using a baseline soil carbon and
179 empirical rates of soil carbon change that depend upon baseline soil carbon and land use
180 (West *et al.*, 2008).
- 181 - The pollination model estimates an index of flower visitation by bees using the
182 proportions of grassland and forest within a 1 km radius (Bennett and Issacs, 2014).
- 183 - The bio-control model estimates an index of crop-pest removal by arthropod natural
184 enemies using the proportion of grassland within a 1 km radius (Skevas *et al.*, 2014).
- 185 - The grassland bird habitat model estimates an index using the amount of grassland and
186 row crops within a 400-metre radius (Meehan *et al.*, 2013).

Figure 2: User interface of SmartScape™ with the following panels: item (1) Land selection panel enables users to select parts of the landscape using a set of spatial criteria; item (2) Build scenario panel enables users to make hypothetical crop change and run multiple economic and environmental models; and item (3) Scenario comparison panel enables users to compare crop change scenarios with each other using a variety of visual output

2.3 Using SmartScape™ to resolve conflicts

2.3.1 Internal Conflicts among Multiple Ecosystem Services

Before public meetings with stakeholders, we sent out a questionnaire (Supplementary 1) and asked stakeholders to fill it out before attending each meeting. Both crop change scenarios are supposed to represent stakeholders' interests in economy, energy, soil erosion, greenhouse gas emission, surface water, and biodiversity (Table 1). Previous studies suggest that replacing perennial energy crops with annual energy crops results in a rise of income (Meehan *et al.*, 2013) and a higher energy balance (Farrell *et al.*, 2006). For first crop change scenario (Table 1; Figure 3a), we investigated the replacement of perennial energy crops with annual energy crops (called perennial replacement scenario (PRS)). For the PRS, areas under grass production that were located on high quality soil (Cropland I) and a flat slope (≤ 2.4 degree) were selected and converted to corn.

Table 1. The details of two crop change scenarios as a result of interaction with stakeholders

Crop Change Scenarios	Initial Land Cover	Slope (Degree)	Distance to River (m)	Land Capability Class	New Land Cover	Percentage
PRS	Grass	≤ 2.4	All ranges	Cropland I	Corn	0.30%
ARS	Corn and soy	≥ 10	≤ 100	All ranges	Grass	0.30%

a) Perennial replacement scenario

b) Annual replacement scenario

c) Perennial-annual replacement scenario

202 Figure 3: User framework of SmartScape™ for running crop change scenarios individually
 203 (Items a and b) as well as in a group (Item c)
 204

205 Previous studies demonstrated that perennial energy crops degraded considerably less soil
 206 (Khanal *et al.*, 2013), emitted less nitrous oxide (Bouwman *et al.*, 2002), could hold more carbon
 207 in the soil (West *et al.*, 2008), load less phosphorus to the surface water (Zhang *et al.* 2010) and
 208 provide higher biodiversity than annual energy crops (Meehan, 2012; Bennett and Isaacs, 2014).
 209 For the second crop change scenario (Table 1; Figure 3b), we investigated the replacement of
 210 annual energy crops with perennial energy crops (called annual replacement scenario (ARS)).

For the ARS, areas under corn and soy production that were located on a high slope (≥ 10 degree) and within a 100 m (330 feet) buffer of streams were selected and converted to grass.

SmartScapeTM has an option for accommodating the interests of stakeholders and resolve the internal conflicts among multiple ecosystem services. This module specifically provides an interactive environment for users to satisfy their interests as well as keeping a balance between multiple ecosystem services. Stakeholders can create and explore an entirely separate scenario and come up with their own crop change scenario. To achieve this, users must select a part of the landscape utilizing spatial criteria to maximize their benefits. Users then change the current crop to the hypothetical future crop to meet their goals in the future. SmartScapeTM then enables users to assess the trade-off among multiple ecosystem services by comparing current and future landscapes. The trade-off analysis allows users to know a) how much they succeed/fail to satisfy their goals, and b) how they can either modify land selection or change the crop change scenario to satisfy their goals and resolve internal conflicts among multiple ecosystem services through iterative runs. We compared the outcomes of the two crop change scenarios (PRS and ARS) to analyze what the main goal of both scenarios was and how SmartScapeTM was able to monitor and resolve internal conflicts among multiple ecosystems services.

2.3.2 External Conflicts among Stakeholders

Conflicts arise among stakeholders when they strongly favour different outcomes (Connelly and Richardson, 2004). Resolving conflicts in a group context is more challenging than a single decision-making process as participants in a group are more likely to have varying objectives (Koontz, 2005). Designing crop change policy options in a participatory context will increase the likelihood of stakeholder acceptance and the probability of attaining sustainable bioenergy systems. This section describes how SmartScapeTM can integrate multiple crop change

scenarios and shows the conflicts among multiple participants while providing more details about the current options that are available in SmartScapeTM for resolving the conflicts and balancing conflicting viewpoints.

Within the SmartScapeTM, stakeholders can stack multiple crop transformation scenarios for accommodating the interests of multiple stakeholders (Tayyebi and Pijanowski, 2014). This module enables stakeholders to integrate various perspectives in order to come up with a better crop change scenario that satisfies the needs of most stakeholders. First, stakeholders are required to interact with each other to determine the desired outcomes and then rank the various crop transformations. Through this process, conflicts among various stakeholders can be debated. Crop transformations that are more likely to satisfy stakeholder goals are manually placed higher in the crop transformation list while others are placed lower on the list. Thus, crop transformations at the top and bottom of the list have higher and lower ranks, respectively (Figure 3c). SmartScapeTM then runs the crop transformation with a higher rank first, and runs lower ranking crop transformations in sequence, resulting in progressively fewer untransformed raster cells. This is a method for allowing multiple crop change scenarios to be enacted at the same time for the same area. This approach quantifies the trade-offs between multiple ecosystem services and has a formal procedure for balancing these trade-offs in a mutually agreeable manner.

We also held a series of meetings with stakeholders to integrate two crop change scenarios, harmonise the desired outcomes of stakeholders and resolve the conflicts among them. To demonstrate how stakeholders can proceed from single decision-making processes to making decisions in a group, we stacked two crop change scenarios generated in the previous section (internal conflict section) and ran both of them together using SmartScapeTM. The first crop

change scenario includes the replacement of perennial energy crops with annual energy crops while the second crop change scenario consists of the replacement of annual energy crops with perennial energy crops (Table 1; called perennial-annual replacement scenario (PARS)). To keep the balance between two crop change scenarios and arrive at unbiased group decision-making, we asked stakeholders to choose the same amount of landscape in both crop change scenarios.

3. Results

3.1 Internal Conflicts among Multiple Ecosystem Services

Around 7572 Ha (0.30%) of the whole study area was selected in each crop change scenario. SmartScapeTM shows the internal conflicts among multiple ecosystem services using the spider graph and table. For each metric in the spider graph, the scenario with the higher outcome value is set to a value of 100%, and the lower value from the other scenario is divided by the maximum value and expressed as a value of 100% or lower (Figure 4). The net income and gross biofuel generated from PRS for current and future landscapes were 57.96% and 75.41%, respectively (Figure 4a); however, the net income and gross biofuel generated from ARS for future projections were 23.03% and 82.23% of the current landscape (Figure 4b). These figures highlight the difference between the price of corn and grass and the fact that corn and soy are more suitable for gross biofuel production compared to grass (Tables 2 and 3). In contrast, the net energy produced from PRS in the future was 59.25% of the current landscape (Figure 4a) while the net energy produced from ARS currently was 49.88% of the future landscape (Figure 4b). The difference was due to the fact that net energy production from corn is less than from grass (Tables 2 and 3).

Table 2. Summary of perennial replacement scenario for the current landscape, the transformed landscape, and the difference between both scenarios in absolute values

Models	Current Scenario	Transform Scenario	Delta
Net-Income (\$Million)	2.73	4.71	1.98
Gross Biofuel (Gal)	7,456,989	9,887,953	2,430,964
Net-Energy (MBtu)	560,832	332,299	-228,533
Phosphorous Loading (lb)	96.71	4188.30	4091.58
Soil Loss (ton)	18,712	280,683	261,971
Soil Carbon Sequestration (ton)	845,290	845,287	-3
Nitrous Oxide Emission (ton)	13.91	74.35	60.44
Pollinator Index	0.22	0.17	-0.04
Biocontrol Index	0.65	0.40	-0.25
Bird Habitat Index	0.24	0.09	-0.14

Table 3. Summary of annual replacement scenario for the current landscape, the transformed landscape, and the difference between both scenarios in absolute values

Models	Current Scenario	Transform Scenario	Delta
Net-Income (\$Million)	4.61	1.06	-3.54
Gross Biofuel (Gal)	7,027,527	5,779,331	-1,248,196
Net-Energy (MBtu)	210,849	422,686	211,837
Phosphorous Loading (lb)	102,797	1494.60	-101,302.40
Soil Loss (ton)	1,733,078	127,001	-1,606,077
Soil Carbon Sequestration (ton)	729,410	738,565	9155
Nitrous Oxide Emission (ton)	59.5070	11.3240	-48.18
Pollinator Index	0.34	0.37	0.02
Biocontrol Index	0.45	0.68	0.22
Bird Habitat Index	0.11	0.21	0.10

a) PRS

b) ARS

c) PARS

Figure 4: Comparison of the current and crop land change scenarios including a) PRS, b) ARS and c) PARS using spider graph.

The phosphorus loading and soil loss of PRS for the current landscape were 2.30% and 6.66% of the future landscape (Figure 4a). In contrast, the phosphorus loading and soil loss of ARS for the future landscape was 1.45% and 7.32% of the current landscape (Figure 4b). This highlights the fact that the rate of phosphorus loading and soil loss is much smaller for grass compared to corn and soy (Tables 2 and 3). The soil carbon slightly decreased and increased under PRS and ARS, respectively (Figure 4a and 4b). The nitrous oxide emission for the current landscape was 18.71% of the future landscape under PRS (Figure 4a) while nitrous oxide emission in the future was 19.02% of the current landscape under ARS (Figure 4b). This highlights that perennial energy crops (e.g., grass and alfalfa) emit less nitrous oxide than annual energy crops (e.g., corn and soy). The pollinator abundance, bio-control and bird habitat index for the future were respectively 77.92%, 61.31%, and 39.59% of the current landscape for PRS

(Figure 4a). In contrast, the pollinator abundance, bio-control and bird habitat index for the current landscape were respectively 92.43%, 67.40%, and 52.51% of the future landscape for ARS (Figure 4b). This highlights the fact that grass provides better beneficial insect activity and biodiversity than corn and soy.

3.2 External Conflicts and Group-based Decision-making

The change in net income was negative under PARS (Table 4) as losing net income under ARS was higher than the gaining net income under PRS (Tables 2 and 3). The net income under PARS in the future was 78.67% of the current landscape (Figure 4c). In contrast, gross biofuel production had positive changes under PARS (Table 4), as decreasing gross biofuel production under ARS was lower than increasing gross biofuel under PRS (Tables 2 and 3). The gross biofuel generated under PARS in the future was 92.45% of the current landscape (Figure 4c). The net energy changes were negative under PARS (Table 4) as the negative changes of net energy generation for PRS were higher than the positive changes of net energy generation for ARS (Tables 2 and 3). The net energy from PARS in the future was 97.83% of the current landscape (Figure 4c).

Table 4. Summary of perennial-annual replacement scenario for the current landscape, the transformed landscape, and the difference between both scenarios in absolute values

Models	Current Scenario	Transform Scenario	Delta
Net-Income (\$Million)	7.34	5.77	-1.56
Gross Biofuel (Gal)	14,484,516	15,667,284	1,182,768
Net-Energy (MBtu)	771,682	754,985	-16,697
Phosphorous Loading (lb)	102,894	5682.80	-97,211.20
Soil Loss (ton)	1,751,791	407,685	-1,344,106
Soil Carbon Sequestration (ton)	1,574,700	1,591,236	16,536
Nitrous Oxide Emission (ton)	73.41	85.67	12.25
Pollinator Index	0.26	0.25	-0.01
Biocontrol Index	0.55	0.54	-0.02
Bird Habitat Index	0.18	0.15	-0.02

Further analysis showed that changes of phosphorus loading and soil loss were negative under PARS between current and future landscapes (Table 4) as the negative changes in phosphorus loading and soil loss under ARS were higher than the positive changes under PRS. The phosphorus loading and soil loss under PARS in the future were 5.52% and 23.27% of the current landscape (Figure 4c). The soil carbon slightly increased under PARS (Figure 4c; Table 4). The difference in nitrous oxide emissions between current and future landscapes was positive under PARS (Table 4) as losing perennial crops under PRS was more effective than losing annual crops under ARS in increasing nitrous oxide emission (Tables 2 and 3). Nitrous oxide emission under PARS for the current landscape was 85.69% of the future landscape (Figure 4c). The difference of pollinator abundance, bio-control and bird habitat index between current and future landscapes were negative under PARS (Table 4) as the effect of losing perennial crops under PRS was higher than losing annual crops under ARS on beneficial insect activity (Tables 2 and 3). Pollinator abundance, bio-control and bird habitat index under PARS in the future were respectively 97.36%, 97.12% and 97.77% of the current landscape (Figure 4c). The lower difference between current and future landscapes under PARS emphasises the fact that our group decision-making was more successful in moving toward sustainability than running each of these crop change scenarios separately.

4. Discussion

Considering crop change in a group is more challenging as participants in a group usually have differing objectives and conceptualisations of these issues are likely to be in conflict (Koontz, 2005). Considerable efforts are required to support the confidence of stakeholders in being able to develop an efficient crop change policy. SmartScapeTM links ecosystem services to

trade-off assessment methods and opens up discussions among stakeholders with varying interests to better understand eventual conflicts while providing mechanisms for exploring compromises among group preferences (Tayyebi *et al.*, 2016a and 2016b). SmartScapeTM: 1) explore spatial attributes and geographical data for improving communication in a group and providing a unique framework to achieve common goals, 2) provide mechanisms for testing crop change alternatives based on group preferences, and 3) facilitate underlying group decisions and satisfying the demand created by stakeholders with various beneficial interests.

The replacement of perennial with annual crops in Midwest of U.S. (PRS) is as a result of 1) economy condition caused primarily by technological development (Rounsevell *et al.*, 2005) and 2) mandated the corn grain production (15 billion gallons per year) under Energy Independence and Security Act (Tyner, 2008). While the replacement of annual with perennial crops in Midwest of U.S. (ARS) is as a result of 1) Conservation Reserve Program in order to protect water resources, soil and habitat by taking land out of cultivation (Lovell and Sullivan, 2006), 2) crop rotations which influence soil health that impacts long-run productivity and environmental outcomes (Stanger and Lauer, 2008) and 3) using appropriate management practices to reduce agriculture intensification (Tscharntke *et al.*, 2012).

Stakeholders are required to estimate the impact of crop change on multiple ecological dimensions in order to trace and resolve internal conflicts among multiple ecosystem services. This study showed the internal conflicts among multiple ecosystem services for PRS and ARS act against each other. For PRS, net energy, phosphorus loading, soil loss, nitrous oxide emission, biodiversity, pollinator abundance and bio-control were negatively affected while the remaining provisioning services were enhanced. On the other hand, net income and gross biofuel were negatively affected by ARS while the remaining regulatory services were enhanced. These

findings are in line with the existing literature (Bouwman *et al.*, 2002; Hill *et al.*, 2006; Farrell *et al.*, 2006; West *et al.*, 2008; Khanal *et al.*, 2013).

There are always conflicting interests among groups of experts. Thus, conflicting ecological, hydrological, climatic, economy, environmental, and social aspects of planning should be involved in the trade-offs (Koontz, 2005; Feick and Hall, 2001). The term sustainability in agriculture landscapes generally refers to the ability to change crops in a manner that promotes multiple ecosystem services, rather than only focusing on one specific ecosystem service (Mendas and Delali, 2012). This study proved that decision-making in a group (integrating PRS and ARS) successfully moved toward better sustainability as compared to running each of these crop change scenarios separately. For most of the ecosystem services the current and future landscapes had very similar ecosystem values.

The current study has some limitations. First, SmartScapeTM resolves conflicts among stakeholders to achieve the ultimate objectives of the stakeholders. However, crop transformations with higher rank may dominate the crop transformations with lower rank, if higher rank crop transformations select more areas in the landscape. The future direction is to find a better approach to tackle this challenge. Second, management practices play a key role in supporting various ecosystem services. While we incorporated more conventional management practices in both crop change scenarios, it is necessary to involve more complex management practices in the future, which can provide better and more reliable outcomes for decision-making. Finally, three scenarios reported in this study (PRS, ARS and PARS) have various level of uncertainties due to the uncertainties associated with models and management practices (Tayyebi *et al.*, 2014a and 2014b). It is vital in future work to communicate with end-users about the level of uncertainty within each scenario.

5. Conclusions

SmartScapeTM is particularly helpful in strategic planning for sustainable development and provides answers concerning the effects and costs of possible crop changes. A group of stakeholders was involved in evaluating two crop change scenarios in Dane County of WI, in the U.S. The evaluation of SmartScapeTM showed that various crop change scenarios have various impacts on ecosystem services depending on the type and location of the crop change. We conclude that SmartScapeTM can provide a unique framework for policy-makers with regard to internal conflicts within a crop change scenario and external conflicts among stakeholders. SmartScapeTM can be used to obtain acceptable crop change solutions and help policy-makers to move from individual decision-making to group-based decision-making. This study shows the critical advantage of SmartScapeTM in ease of solving internal and external conflicts within crop change scenarios compared to other existing SDSSs (e.g., InVEST, CommunityVizTM and EPIC). SmartScapeTM can be used by potential users with various levels of expertise and backgrounds to define a crop change scenario together. Of course, the evaluation of trade-offs and the ability to resolve conflicts among stakeholders with differing visions and values requires significant skill and experience.

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References

- Arsanjani, J. J., See, L., & Tayyebi, A. (2016a). Assessing the suitability of GlobeLand30 for mapping land cover in Germany. *International Journal of Digital Earth*, 1-19.
- Arsanjani, J. J., Tayyebi, A., & Vaz, E. (2016b). GlobeLand30 as an alternative fine-scale global land cover map: Challenges, possibilities, and implications for developing countries. *Habitat International*.
- Azari, M., Tayyebi, A., Helbich, M., & Reveshty, M. A. (2016). Integrating Cellular Automata, Artificial Neural Network and Fuzzy Set Theory to Simulate Threatened Orchards: Application to Maragheh, Iran. *GIScience & Remote Sensing*, 53(2), 183-205.
- Bennett, A. B., & Isaacs, R. (2014). Landscape composition influences pollinators and pollination services in perennial biofuel plantings. *Agriculture, Ecosystems & Environment*, 193, 1-8.
- Bormann, H., Breuer, L., Gräff, T., & Huisman, J. A. (2007). Analysing the effects of soil properties changes associated with land use changes on the simulated water balance: A comparison of three hydrological catchment models for scenario analysis. *Ecological modelling*, 209(1), 29-40.
- Bouwman, A. F., Boumans, L. J. M., & Batjes, N. H. (2002). Modeling global annual N₂O and NO emissions from fertilized fields. *Global Biogeochemical Cycles*, 16(4), 28-1.
- Choi, J., Engel, B., & Farnsworth, R. (2005). Web-based GIS and spatial decision support system for watershed management. *Journal of Hydroinformatics*, 7, 165-174.
- Connelly, S., & Richardson, T. (2004). Exclusion: the necessary difference between ideal and practical consensus. *Journal of Environmental Planning and Management*, 47(1), 3-17.
- Coutinho-Rodrigues, J., Simão, A., & Antunes, C. H. (2011). A GIS-based multicriteria spatial decision support system for planning urban infrastructures. *Decision Support Systems*, 51(3), 720-726.
- Diakoulaki, D., & Karangelis, F. (2007). Multi-criteria decision analysis and cost-benefit analysis of alternative scenarios for the power generation sector in Greece. *Renewable and Sustainable Energy Reviews*, 11(4), 716-727.
- Dubois, L., Mathieu, J., & Loeuille, N. (2015). The manager dilemma: Optimal management of an ecosystem service in heterogeneous exploited landscapes. *Ecological Modelling*, 301, 78-89.
- Feick, R. D., & Hall, G. B. (2001). Balancing consensus and conflict with a GIS-based multi-participant, multi-criteria decision support tool. *GeoJournal*, 53(4), 391-406.
- Fisher, B., Turner, K. R., Morling, P., (2009). Defining and classifying ecosystem services for decision making. *Ecol. Econ.* 68 (3), 643–653.
- Fisher, B., Turner, R. K., & Morling, P. (2009). Defining and classifying ecosystem services for decision making. *Ecological economics*, 68(3), 643-653.
- Farrell, A. E., Plevin, R. J., Turner, B. T., Jones, A. D., O'Hare, M., & Kammen, D. M. (2006). Ethanol can contribute to energy and environmental goals. *Science*, 311(5760), 506-508.
- Groom, M. J., Gray, E. M., & Townsend, P. A. (2008). Biofuels and biodiversity: principles for creating better policies for biofuel production. *Conservation biology*, 22(3), 602-609.
- Hein, L., (2006). Cost-efficient eutrophication control in a shallow lake ecosystem subject to two steady states. *Ecol. Econ.* 59, 429–439.

- Hill, J., Nelson, E., Tilman, D., Polasky, S., & Tiffany, D. (2006). Environmental, economic, and energetic costs and benefits of biodiesel and ethanol biofuels. *Proceedings of the National Academy of Sciences*, 103(30), 11206-11210.
- Jones, J. W., Hoogenboom, G., Porter, C. H., Boote, K. J., Batchelor, W. D., Hunt, L. A., ... & Ritchie, J. T. (2003). The DSSAT cropping system model. *European journal of agronomy*, 18(3), 235-265.
- Keating, B. A., Carberry, P. S., Hammer, G. L., Probert, M. E., Robertson, M. J., Holzworth, D., ... & Smith, C. J. (2003). An overview of APSIM, a model designed for farming systems simulation. *European journal of agronomy*, 18(3), 267-288.
- Kennedy, C. M., Lonsdorf, E., Neel, M. C., Williams, N. M., Ricketts, T. H., Winfree, R., ... & Kremen, C. (2013). A global quantitative synthesis of local and landscape effects on wild bee pollinators in agroecosystems. *Ecology letters*, 16(5), 584-599.
- Khanal, S., Anex, R. P., Anderson, C. J., Herzmann, D. E., & Jha, M. K. (2013). Implications of biofuel policy-driven land cover change for rainfall erosivity and soil erosion in the United States. *GCB Bioenergy*, 5(6), 713-722.
- Koontz, T. M. (2005). We finished the plan, so now what? Impacts of collaborative stakeholder participation on land use policy. *Policy Studies Journal*, 33(3), 459-481.
- LaBeau, M. B., Robertson, D. M., Mayer, A. S., Pijanowski, B. C., & Saad, D. A. (2014). Effects of future urban and biofuel crop expansions on the riverine export of phosphorus to the Laurentian Great Lakes. *Ecological Modelling*, 277, 27-37.
- Le Billon, P. (2001). The political ecology of war: natural resources and armed conflicts. *Political geography*, 20(5), 561-584.
- Lichtfouse, E., Navarrete, M., Debaeke, P., Souchère, V., Alberola, C., & Menassieu, J. (2009). Agronomy for sustainable agriculture: a review. In *Sustainable Agriculture* (pp. 1-7). Springer Netherlands.
- Lovell, S. T., & Sullivan, W. C. (2006). Environmental benefits of conservation buffers in the United States: evidence, promise, and open questions. *Agriculture, ecosystems & environment*, 112(4), 249-260.
- MA, (2003). *Ecosystems and Human Well-being: A Framework for Assessment*. Island Press, Washington.
- MA, (2005). *Ecosystems and Human Well-Being: Current State and Trends*. Island Press, Washington, DC.
- Mari, R., Bottai, L., Busillo, C., Calastrini, F., Gozzini, B., & Gualtieri, G. (2011). A GIS-based interactive web decision support system for planning wind farms in Tuscany (Italy). *Renewable energy*, 36(2), 754-763.
- Meehan, T. D., Werling, B. P., Landis, D. A., & Gratton, C. (2012). Pest-suppression potential of midwestern landscapes under contrasting bioenergy scenarios. *PLoS ONE*, 7(7), e41728.
- Meehan, T. D., Gratton, C., Diehl, E., Hunt, N. D., Mooney, D. F., Ventura, S. J., ... & Jackson, R. D. (2013). Ecosystem-Service Tradeoffs Associated with Switching from Annual to Perennial Energy Crops in Riparian Zones of the US Midwest. *PLoS ONE*, 8(11), e80093.
- Mendas, A., & Delali, A. (2012). Integration of MultiCriteria Decision Analysis in GIS to develop land suitability for agriculture: Application to durum wheat cultivation in the region of Mleta in Algeria. *Computers and electronics in agriculture*, 83, 117-126.

- Pijanowski, B. C., Tayyebi, A., Delavar, M. R., and Yazdanpanah, M. J. (2009). Urban expansion simulation using geographic information systems and artificial neural networks. *International Journal of Environmental Research*, 3(4), 493-502.
- Pijanowski, B. C., Tayyebi, A., J. Doucette, B. K. Pekin., D. Braun and J. Plourde, 2014. A big data urban growth simulation at a national scale: configuring the GIS and neural network based Land Transformation Model to run in a high performance computing environment. *Environmental modeling and software*. 51, 250–268.
- Rao, M., Fan, G., Thomas, J., Cherian, G., Chudiwale, V., & Awawdeh, M. (2007). A web-based GIS Decision Support System for managing and planning USDA's Conservation Reserve Program (CRP). *Environmental Modelling & Software*, 22(9), 1270-1280.
- Risse, L. M., Nearing, M. A., Laflen, J. M., & Nicks, A. D. (1993). Error assessment in the universal soil loss equation. *Soil Science Society of America Journal*, 57(3), 825-833.
- Rounsevell, M. D. A., Annetts, J. E., Audsley, E., Mayr, T., & Reginster, I. (2003). Modelling the spatial distribution of agricultural land use at the regional scale. *Agriculture, Ecosystems & Environment*, 95(2), 465-479.
- Searchinger, T., Heimlich, R., Houghton, R. A., Dong, F., Elobeid, A., Fabiosa, J. and Yu, T. H. (2008). Use of US croplands for biofuels increases greenhouse gases through emissions from land-use change. *Science*, 319(5867), 1238-1240.
- Sheppard, S. R., & Meitner, M. (2005). Using multi-criteria analysis and visualisation for sustainable forest management planning with stakeholder groups. *Forest ecology and management*, 207(1), 171-187.
- Skevas, T., Swinton, S. M., Meehan, T. D., Kim, T. N., Gratton, C., & Egbendewe-Mondzozo, A. (2014). Integrating agricultural pest biocontrol into forecasts of energy biomass production. *Ecological Economics*, 106, 195-203.
- Song, W., Deng, X., Yuan, Y., Wang, Z., & Li, Z. (2015a). Impacts of land-use change on valued ecosystem service in rapidly urbanized North China Plain. *Ecological Modelling*.
- Song, W., Pijanowski, B. C., & Tayyebi, A. (2015b). Urban expansion and its consumption of high-quality farmland in Beijing, China. *Ecological Indicators*, 54, 60-70.
- Soranno, P. A., Hubler, S. L., Carpenter, S. R., & Lathrop, R. C. (1996). Phosphorus loads to surface waters: a simple model to account for spatial pattern of land use. *Ecological Applications*, 6(3), 865-878.
- Stanger, T. F., & Lauer, J. G. (2008). Corn grain yield response to crop rotation and nitrogen over 35 years. *Agronomy journal*, 100(3), 643-650.
- Stöckle, C. O., Donatelli, M., & Nelson, R. (2003). CropSyst, a cropping systems simulation model. *European journal of agronomy*, 18(3), 289-307.
- Tan, G., & Shibasaki, R. (2003). Global estimation of crop productivity and the impacts of global warming by GIS and EPIC integration. *Ecological Modelling*, 168(3), 357-370.
- Tayyebi, A., Pijanowski, B. C., & Tayyebi, A. H. (2011). An urban growth boundary model using neural networks, GIS and radial parameterization: An application to Tehran, Iran. *Landscape and Urban Planning*, 100(1), 35-44.
- Tayyebi, A., & Pijanowski, B. C. (2014). Modeling multiple land use changes using ANN, CART and MARS: Comparing tradeoffs in goodness of fit and explanatory power of data mining tools. *International Journal of Applied Earth Observation and Geoinformation*, 28, 102-116.

- Tayyebi, A., Pijanowski, B. C., Linderman, M., & Gratton, C. (2014a). Comparing three global parametric and local non-parametric models to simulate land use change in diverse areas of the world. *Environmental Modelling & Software*, 59, 202-221.
- Tayyebi, A. H., Tayyebi, A., & Khanna, N. (2014b). Assessing uncertainty dimensions in land-use change models: using swap and multiplicative error models for injecting attribute and positional errors in spatial data. *International Journal of Remote Sensing*, 35(1), 149-170.
- Tayyebi, A., Pijanowski, B. C., & Pekin, B. K. (2015). Land use legacies of the Ohio River Basin: Using a spatially explicit land use change model to assess past and future impacts on aquatic resources. *Applied Geography*, 57, 100-111.
- Tayyebi, A., & Jenerette, G. D. (2016). Increases in the climate change adaption effectiveness and availability of vegetation across a coastal to desert climate gradient in metropolitan Los Angeles, CA, USA. *Science of The Total Environment*, 548, 60-71.
- Tayyebi, A., Meehan, T. D., Dischler, J., Radloff, G., Ferris, M., & Gratton, C. (2016a). SmartScape™: A web-based decision support system for assessing the tradeoffs among multiple ecosystem services under crop-change scenarios. *Computers and Electronics in Agriculture*, 121, 108-121.
- Tayyebi, A., Tayyebi, A., Vaz, E., Arsanjani, J. J., & Helbich, M. (2016b). Analyzing crop change scenario with the SmartScape™ spatial decision support system. *Land Use Policy*, 51, 41-53.
- Thorp, K. R., DeJonge, K. C., Kaleita, A. L., Batchelor, W. D., & Paz, J. O. (2008). Methodology for the use of DSSAT models for precision agriculture decision support. *Computers and electronics in agriculture*, 64(2), 276-285.
- Tscharntke, T., Clough, Y., Wanger, T. C., Jackson, L., Motzke, I., Perfecto, I., ... & Whitbread, A. (2012). Global food security, biodiversity conservation and the future of agricultural intensification. *Biological conservation*, 151(1), 53-59.
- Turner, K. G., Anderson, S., Gonzales-Chang, M., Costanza, R., Courville, S., Dalgaard, T., ... & Ratna, N. (2016). A review of methods, data, and models to assess changes in the value of ecosystem services from land degradation and restoration. *Ecological Modelling*, 319, 190-207.
- Tyner, W. E. (2008). The US ethanol and biofuels boom: Its origins, current status, and future prospects. *BioScience*, 58(7), 646-653.
- West, T. O., Brandt, C. C., Wilson, B. S., Hellwinckel, C. M., Tyler, D. D., Marland, G., ... & Nelson, R. G. (2008). Estimating regional changes in soil carbon with high spatial resolution. *Soil Science Society of America Journal*, 72(2), 285-294.
- Zhang, X., Izaurralde, R. C., Manowitz, D., West, T. O., Post, W. M., Thomson, A. M., ... & Williams, J. R. (2010). An integrative modeling framework to evaluate the productivity and sustainability of biofuel crop production systems. *GCB Bioenergy*, 2(5), 258-277.
- Zhang, Y. J., Li, A. J., & Fung, T. (2012). Using GIS and multi-criteria decision analysis for conflict resolution in land use planning. *Procedia Environmental Sciences*, 13, 2264-2273.