DISSERTATION

A SOCIO-CULTURAL ASSESSMENT OF ECOSYSTEM SERVICES FOR COMMUNITY PLANNING AND SUSTAINABILITY

Submitted by

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Graduate Degree Program in Ecology

In partial fulfillment of the requirements

For the Degree of Doctor of Philosophy

Colorado State University

Fort Collins, Colorado

Fall 2018

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ABSTRACT

A SOCIO-CULTURAL ASSESSMENT OF ECOSYSTEM SERVICES FOR COMMUNITY PLANNING AND SUSTAINABILITY

Ecosystem service (ES) mapping is a useful mechanism for measuring and communicating ES values spatially; however, most ES mapping is conducted at coarse resolutions over large spatial scales, which calls into question their practicality for local decision-making. Since policy is implemented and managed locally, mapping efforts in Europe, Australia, and the United States have shifted towards local-scale, stakeholder-driven assessments over the past several years. Despite this shift, it is unclear whether similar efforts have been undertaken in Africa, where resource management has direct impacts on impoverished, marginalized communities. The following three chapters in this dissertation represent a novel effort to assess socio-cultural ES in rural South Africa.

(Chapter 1) In the first chapter, we conduct a systematic literature review of ES mapping in Africa to identify gaps and trends in research. The intent of this analysis is to: (1) identify where ES maps exist and where coverage gaps remain in ES mapping across the continent; (2) pinpoint which mapping approaches have been used to map ES in Africa and understand whether valuation methods are being integrated in maps; (3) determine whether or not trends in ES mapping in Africa follow recommendations for more localized and inclusive approaches (e.g. socio-cultural & participatory); and (4) assess the appropriateness of management recommendations stemming from these mapping analyses with support from the literature. We identified 25 ES mapping studies, most of which occur in East and South Africa. Additionally,

large-scale biophysical approaches are overwhelmingly represented. The results of this review demonstrate that ES mapping research in Africa has not shifted towards local-scale, participatory approaches and that few maps represent local values for ES. Furthermore, 72% of these studies make recommendations for ES management, despite the potential scalar misalignments and lack of community participation in the mapping and valuation of ES. New local-scale ES mapping evaluations are needed to revise our understanding of the potential impacts of decision-making on vulnerable communities.

(Chapter 2) In the second chapter, we implement a socio-cultural valuation approach intended to understand how services are valued by people living in rural-urban landscapes. Specifically, we ask: (1) what ecosystem services do communities value; (2) where are these services located on the landscape (parcels vs. communal lands); (3) how do these services relate to land cover; and (4) what are the social and spatial characteristics of households that determine values/demand for services? We implement our study in Bushbuckridge, South Africa using 26 walking interviews and 105 household surveys. We find that communities value an assortment of ecosystem services on both parcels and in communal lands, and roughly 80% of all ecosystem services are associated with tree cover; however, parcels provide a more diverse and sustainable array of services to individuals than communal lands. Additionally, ecosystem service values are at least partially related to how isolated communities are from more urbanized townships. This narrative is counter to previous studies and management plans that emphasize the value of communal lands at the expense of more developed areas. Furthermore, these types of participatory socio-cultural valuations are potentially more representative of community needs, making policy and management strategies based on their results more likely to succeed (or be less harmful).

(Chapter 3) In the third and final chapter, our goal is to utilize stakeholder input to map community-identified, socio-cultural ES related to tree cover in urbanizing South Africa at a high spatial resolution. Our specific objectives are to: (1) quantify the probabilities that trees will be used to secure ES benefits both within villages and in communal lands; and (2) map and assess these probabilities to compare villages sampled along a gradient of urbanization. We ask whether or not differences in tree ES values among villages can be captured with high-resolution, local-scale mapping? To achieve these objectives, we link information collected from walking-interviews and social surveys to a high-spatial resolution ($1m^2$) land-cover classification in two rural villages in the Bushbuckridge Local Municipality, South Africa. We apply an advanced HUFF model to calculate and map tree ES use probabilities among these communities within parcels and communal lands. We then compare these probability distributions using violin and boxplots to determine whether or not differences in ES use/benefits among these communities are adequately captured. We find that there are subtle differences among tree ES use probabilities in communal lands among these communities, and more substantial differences among use of ES on parcels, which are determined by community specific ES priorities. These results have important implications for community planning in this and similar regions throughout sub-Saharan Africa.

ACKNOWLEDGEMENTS

This dissertation would not have been possible without the help of my community. I would like to thank my fellow graduate students and friends for all of their support. In particular, Shawn Dayson Shifflett, Derek van Berkel, Sarah Wiener, Devon Gaydos, Monica Dorning, and Whalen Dillon have been abundantly generous with their time, advice, and friendship. I thank my family, especially my parents, who supported and encouraged me to pursue my PhD, and talked me out of quitting numerous times. I thank my committee for their various contributions: to Dr. Kelly Jones for your profound knowledge of Ecosystem Services, and for your thoughtful advice, comments and insights on these manuscripts; To Dr. Jeni Cross for helping me understand the importance of participatory research; and to Dr. Mike Falkowski for guiding my mapping efforts. Additionally, I would like to thank Dr. Louie Rivers III for helping me with my methodological approaches (and for being such a positive influence), and Dr. Wayne Twine for teaching me about South African culture. None of this work would have been possible without the incredible support of the Bushbuckridge communities and my dynamic translator, Debra Mnisi. I am thankful for the institutional support I received from the Graduate Degree Program in Ecology and the Department of Ecosystem Science & Sustainability at Colorado State University. I also received support from the Center for Geospatial Analytics at NC State University, for which I am eternally grateful. I owe an immeasurable debt of gratitude to Dr. David Bunn, who has been a never-ending source of clarity, encouragement, friendship, and laughter. Finally, I would like to thank my mentor, Dr. Melissa McHale, who saw something in me despite my lack of qualifications, believed in me despite my lack of confidence, gave me the tools I needed to succeed, and walked me across the finish line. I hope I made you proud.

DEDICATION

To my parents, who gave me life. To my brothers, who showed me the way. To Erica, who saved my life. And to Osi and Ella, who brought it joy.

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CHAPTER 1 – A REVIEW OF ECOSYSTEM SERVICE MAPPING IN AFRICA

1.1 Introduction:

Since the concept of ecosystem services (ES) was first popularized (Daily 1997; Costanza et al. 1997), and later refined (MEA 2005), the usefulness of ES assessments for decision-making has been met with a substantial amount of criticism (Kosoy and Corbera 2010). In response, the scientific community has invested a lot of energy in developing mapping tools (e.g. Daily et al. 2009; Tallis and Polasky 2009) and valuation methodologies/frameworks (e.g. De Groot, Wilson, and Boumans 2002; Farber, Costanza, and Wilson 2002) intended to standardize ES assessments. For instance, the current International Platform on Biodiversity and Ecosystem Services (IPBES) framework focuses on linking humans and the environment through pluralistic ES valuations that promote a "good quality of life" for people (Díaz et al. 2015; Pascual et al. 2017). This framework draws distinctions between individual ES valuation approaches, and combined approaches that lead to value pluralism (Pascual et al. 2017).

Within the context of mapping, distinctions are made between values and benefits, where benefits are the ES that support human life and values are the economic or socio-cultural standards assigned to ES by people (Verhagen et al. 2015). ES mapping can spatially identify, inventory, and measure these biophysical benefits, or economic or social values, produced by nature that improve quality of life for people (Costanza et al. 1997; Pascual et al. 2017). Therefore, mapping has been emphasized as a promising mechanism for communicating these ES values and benefits spatially (e.g. Naidoo et al. 2008; Crossman, Burkhard, and Nedkov 2012), and are viewed as useful policy inputs (Malinga et al. 2015). However, there are several issues associated with the current practice of ES mapping that call into question its relevance for decision-making (Willcock, Phillips, et al. 2016).

A noteworthy critique of ES mapping is that it typically relies on mapping proxies, like land cover or land use, to represent ES spatially (Egoh et al. 2012). For example, Eigenbrod et al. (2010) found that proxies are not illustrative of primary data for identifying hotspots of single or multiple ES. Additionally, ES mapping approaches and results are highly variable, often not validated, and are frequently conducted at inappropriate extents for local decision-making (e.g. Global, National, Regional) (Cowling et al. 2008; Martínez-Harms and Balvanera 2012). Despite these issues, mapping remains a popular engagement tactic for ES assessment.

There are three primary approaches for assessing ES (Pascual et al. 2017). Economic approaches are used to express the value of nature in monetary terms, and are commonly applied at local to global extents (e.g. Costanza et al. 1997; Costanza et al. 2014). Biophysical approaches, which emerged in response to difficulties associated with applying monetary values to biophysical benefits, like carbon sequestration (e.g. Egoh et al. 2009). Finally, socio-cultural approaches, which have recently been promoted as a mechanism to elicit the social and cultural values of landscapes through participatory stakeholder engagement (e.g. Scholte, van Teeffelen, and Verburg 2015).

Traditionally, biophysical and economic ES mapping approaches have been favored for measuring regulating, provisioning, and supporting services (Egoh et al. 2012); however, a substantial amount of recent effort has been allocated towards the incorporation of cultural values into mapping evaluations (e.g. Chan et al. 2012; Van Berkel & Verburg 2014; Pereira et al. 2017). This push towards the measurement of cultural values is driven by the recognition that expert assessments of ES are not necessarily representative of the shared needs of stakeholders (Chan et al. 2012; Chan et al. 2012; Willcock et al. 2016; Irvine et al. 2016). Furthermore, the emergence of the socio-cultural ES paradigm has shifted cultural ES assessments away from traditional approaches, like economic valuations of tourism, towards shared and plural stakeholder value systems across service classes (Scholte et al. 2015; Pascual et al. 2017). The emergence of the socio-cultural ES valuation approach follows calls for stakeholder inclusivity in science and decision-making (Cowling et al. 2008; Sherrouse, Clement, and Semmens 2011; McHale et al. 2018). Until recently, most ES mapping has been a highly technocratic activity, where experts make judgements about the importance of ES, map them using land-use proxies, and tout their usefulness for conservation planning (e.g. Egoh et al. 2008; Anderson, Ankor, and Sutton 2017). Stakeholders are rarely consulted during this process, which threatens the credibility of scientific products (Clark et al. 2016). Additionally, biophysical and economic assessments are typically unable to account for cultural ES and values, which are important characteristics of landscapes (Chan et al. 2012).

Conversely, socio-cultural and participatory ES mapping approaches are inherently focused on spatially inventorying the benefits people derive from the natural environment based on their unique values and require some level of stakeholder engagement to identify and characterize tangible and non-tangible services (Chan et al. 2012; Scholte et al. 2015). In Africa, these services support livelihoods directly within the places in which people live (McHale et al. 2018; Beck et al. in prep). For instance, Scholte et al. (2015) presents a framework for integrating socio-cultural perspectives into ES valuation that hinges on the characteristics and perceptions of beneficiaries and their interactions with the natural environment. In terms of mapping, studies that incorporate stakeholder input are often able to identify differences in ES that are important to people at local extents, which makes them more relevant to decision-making (Cowling et al. 2008). In one example, Garcia-Nieto et al. (2015) used a participatory mapping approach that found distinct variations in ES value patterns between high and low influence stakeholders in Southern Spain. Similarly, Bryan et al. (2010) used participatory mapping methods to measure the social values of common ecological/biodiversity indices in a localized region of southern Australia. Socio-cultural ES studies like these, and others (e.g. Raymond et al. 2009; Plieninger et al. 2013), arguably produce more useful, equitable and credible information for decision-making since they spatially inventory the shared and individual values of landscapes that are most important for the people living in, and managing, these places.

The potential usefulness of socio-cultural ES mapping for decision-making is particularly appealing in Africa, where impoverished communities are reliant on shared natural resources to sustain their livelihoods (Kirkland, Hunter, and Twine 2007; Madubansi and Shackleton 2007; Shackleton et al. 2008; B. N. Egoh et al. 2012). However, most of the aforementioned studies that employ socio-cultural mapping approaches were conducted in Europe, Australia, and the United States. Indeed, ES mapping in sub-Saharan Africa appears to generally be lagging behind the rest of the world. For instance, of the 67 studies included in a global review of ES mapping, only 14 were conducted in Africa (Egoh et al. 2012). This is surprising given the very tangible relationship that African communities have with the natural environment. In another more recent review of ES studies in Africa, Wangai, Burkhard, and Müller (2016) indicated that of the 14 mapping analyses reviewed by Egoh et al. (2012), only two were conducted at local extents. Again, this is surprising given the recognition that to be useful for management and decision-making, ES assessments need to be inclusive of stakeholders and completed locally (Cowling et al. 2008; Wangai et al. 2016).

Although these reviews highlight some essential points about the state of ES mapping in Africa, they do not comprehensively address or compare the approaches or methods used to measure and value ES (e.g. economic, biophysical, socio-cultural, and mixed). Furthermore, they do not fully report any management recommendations stemming from these studies, or comment on their appropriateness for local decision-making based on analysis extent or spatial resolution. Additionally, the most recent mapping studies included in these reviews were conducted in 2014 using reference data from 2008 and 2011, respectively (Cavan et al. 2014; Petz, Glenday, and Alkemade 2014).

With the recent emergence of socio-cultural ES valuation approaches, and the push towards localized actionable science, a new review of ES mapping in Africa is needed to identify any evolving trends and/or gaps in research that might influence decision-making. Our overarching research focus is to determine whether ES mapping approaches in Africa shifting away from large-scale, non-participatory assessments towards more local-scale, participatory assessments. Our specific objectives are to: (1) conduct an updated systematic literature review of ES mapping in Africa; (2) identify whether economic or socio-cultural ES valuation approaches are being integrated into ES mapping; and (3) compare management suggestions across valuation approaches and analysis extents. Achieving these objectives will allow us to: (1) identify coverage gaps in ES mapping across the continent; (2) pinpoint the valuation methods that have been used in ES maps in Africa and understand how frequently they are applied; (3) determine whether or not trends in ES mapping in Africa follow recommendations for more localized and inclusive approaches (e.g. socio-cultural & participatory valuation); and (4) assess the appropriateness of management recommendations stemming from these analyses with support from the literature. We discuss the consequences of our findings for management and decision-making. The results of this review have important implications for the high-stakes future of actionable and sustainable management of ES at local-scales in predominantly resource-reliant communities across Africa.

1.2. Methods:

1.2.1. Systematic Literature Review:

To conduct an updated literature review of ES mapping in Africa, we applied standard methods used in systematic literature reviews (Pullin and Stewart 2006; Booth, Sutton and Papaioannou 2016). Systematic reviews consist of explicit, rigorous, and transparent methods (Greenhalgh et al. 2005; Booth, Sutton and Papaioannou 2016) that are typically applied in three stages (Pullen and Stewart 2006). These stages include review planning (e.g. question formulation, review protocol), conducting the review (e.g. data search, data selection, data extraction and synthesis), and reporting and dissemination of results (Gates 2002; Pullin and Stewart 2006). Ultimately, the research question under review will determine the nature of the protocol, and data search, selection, extraction and synthesis.

For this review, we formulated our question of interest to identify trends in ES mapping in sub-Saharan Africa to determine whether or not research is following recommendations for more local-scale, socio-cultural approaches. Before conducting the review, we designed a review protocol that focused on answering this question by identifying potentially relevant studies through the application of a series of queries within the Web of Science/ ISI Web of Knowledge database. Our query approach was specifically designed to be broad in order to cast a wide net, and then was refined to reduce the number of returns. We set the initial limitations of the search to select papers published from 1990-2018 in peer reviewed journals within relevant fields (e.g. ecology, geography, forestry, anthropology, etc.).

When conducting the finalized review, we included search terms for titles, topics, and locations that used the keywords “ecosystem services”, “mapping”, “maps”, and “Africa”. This query returned 84 results that were included for further quality assessment. During this quality assessment process we identified several additional potentially relevant studies through reference analysis and abstract screening, where ES mapping was a primary focus of studies that were missed in our initial search. These studies were added to our database, bringing the total number of potentially relevant papers to 111. For a study to be included in our comprehensive analysis, we created the following selection criteria: (1) it must specifically deal with ES, which means that the authors of the study are intending to contribute to the overall body of ES literature; (2) it must be conducted in sub-Saharan Africa; and (3) it must be an empirical study that uses primary data to map ES. These selection criteria limit the range of studies to those that provide empirical evidence that could support decision-making in Africa.

1.2.2. Definitions and Analysis:

To identify gaps and trends in mapping approaches and link management suggestions to analysis extent and spatial resolution, we carefully reviewed each study that met our search criteria using abstract and full text screening, and analyzed content to extract data relevant to our research questions. These data were then numerically coded into a database for use in our analysis, and to generate summary statistics. Specifically, we extracted data to generate seven variables for use in our analysis: (1) country where the study was conducted; (2) the extent (e.g. local, regional, national) at which the study was conducted; (3) the spatial resolution at which the mapping was applied; (4) the valuation approach (e.g. economic, biophysical, socio-cultural, mixed) used to assess ES; (5) whether or not participatory methods (e.g. stakeholder engagement, participatory mapping) were used in the ES valuation and/or mapping process; (6) whether or not management suggestions were offered based on the results of the study; and (7) the number of ES that were assessed and mapped by each study. Additionally, we listed the specific ES that were mapped in each study.

Although the 'country' variable that was extracted from the selected studies is self-explanatory, we offer more precise definitions for the extent, spatial resolution, valuation approach, participatory, management suggestion, and ES list variables for clarity. Extent refers to the area range of analysis. Local extents refer to villages, towns, or cities. Regional extents cover a much larger area and likely encompass many villages, towns, or cities depending on the study location. National extents are analyses or studies that cover the entirety of a country. Continental and global extents are the largest areas of analysis.

Spatial resolution refers to the size of the ground pixel offered by a given sensor, where higher, or finer, spatial resolution images have more pixels and can more easily distinguish between image objects. Valuation approach is defined as the specific method used to determine the ES values that were ultimately mapped. Valuation approaches can be economic, biophysical, socio-cultural, or mixed. The participatory variable describes whether a study used any participatory or stakeholder inclusive methods to identify or assign values to ES. The management suggestions variable determines whether a given study offered suggestions for management or decision-making based on the results of the study. Finally, the ES list variable identifies the specific ES that are assessed in each study.

These analysis variables were ultimately used to generate summary statistics that allow us to: (1) determine the number of studies conducted by country; (2) quantify and compare the number of ES mapping and valuation approaches used; (3) identify trends in scales of analysis and the use of participatory methods; and (4) link these trends to any management recommendations highlighted by these studies. These statistics are reported in tables and bar charts. Additionally, all study selection by text screening, and coding, was completed by the first author (Beck).

1.2.3. Limitations:

This study follows guidelines and best practices for conducting systematic literature reviews; however, there are two discrepancies with our methods that could be considered weaknesses. The first potential issue is that we only applied our search criteria within one database, the ISI Web of Knowledge. Pullen and Stewart (2006) suggest that multiple databases should be searched to ensure that potentially relevant data are not missed. The second potential issue is that we excluded grey literature from our search criteria. Grey literature typically consists of governmental or technical society documents, like technical reports, that are scientifically rigorous assessments of important phenomena.

Although these issues might be considered weaknesses in our methodological approach, we feel that the search strategy employed sufficiently meet the goals of our study and the nature of our research questions. Since our goal was to build upon and update previous reviews that assess ES mapping in sub-Saharan Africa (Egoh et al. 2012; Wangai, Burkhard, and Müller 2016) to determine if new ES mapping assessments are shifting towards socio-cultural valuation approaches, we used these previous reviews as a baseline for our own study. Because neither of these reviews include grey literature, we also chose to focus on studies appearing in peer-reviewed scientific journals. Additionally, the advanced search features offered to researchers by the ISI Web of Knowledge database allowed us to cast a broad net given our relatively specific search criteria.

1.3. Results:

1.3.1. Objective 1: Systematic Literature Review

We found 25 studies that met our three inclusion criteria and map ES in sub-Saharan Africa (Table 1.1). This includes eight more papers than the 17 reported by Wangai (et al. 2016);

although our study excludes three studies included in Wangai et al. (2016) that did not meet our criteria of specifically mapping ES using data (e.g. van Jaarsveld et al. 2005; Batjes 2008; Chisholm 2010). Van Jaarsveld (et al. 2005) could have been included as it does present several maps of ecosystem services; however, we chose to exclude this particular study since it is essentially a meta-analysis of quantified ES in southern Africa, and is presented as a supplemental regional report to the Millennium Ecosystem Assessment (2005). Although it maps soil carbon stocks in Central Africa, which we acknowledge to be an ecosystem service, Batjes (2008) was not included because it makes no mention of "ecosystem services" anywhere in the text of the paper, nor does it adhere to any known ES framework. Therefore, it is unknown whether this study was intended to contribute to the overall body of ES knowledge, which is part of our exclusionary criteria. Conversely, Chisholm (2010) explicitly measures tradeoffs in water and carbon ES in South Africa, but it does not map these ES or tradeoffs, and therefore does not meet our third exclusionary criteria.

1.3.2. Objective 2: Analysis of Gaps and Trends

Specifically, this analysis allowed us to determine the extent of ES mapping coverage across Africa, to understand the spatial scales, resolutions, and frequencies of specific valuation approaches that have been applied to map ES, and to determine if existing trends follow recent calls for more inclusive and localized approaches to ES mapping and valuation. These results reveal that 80% of ES mapping studies have been conducted in East and South Africa, with South Africa serving as the largest single contributor of ES assessments (40%) (Figure 1.1). Within East Africa, Tanzania and Kenya are strongly represented and account for 32% of all ES mapping studies in Africa. Central and West Africa are woefully underrepresented, accounting

Table 1.1: Citations of Applicable ES Mapping Studies in Africa by Year Published

Citation	Year	Country(s)	Extent	Spatial Resolution (m)	Valuation Approach	Participatory	Management Suggestions
Egoh et al.	2008	South Africa	National	700000	Biophysical	No	Yes
Egoh et al.	2009	South Africa	National	700000	Biophysical	No	Yes
Reyers et al.	2009	South Africa	Regional	10000	Biophysical	Yes	Yes
Egoh et al.	2010	South Africa	Regional	1000	Economic	No	Yes
O'Farrell et al.	2010	South Africa	Regional	1000	Biophysical	Yes	Yes
Rogers et al.	2010	Madagascar	National	Vector	Biophysical	No	No
Egoh et al.	2011	South Africa	Regional	700000	Biophysical	No	Yes
Fisher et al.	2011	Tanzania	Regional	Not Reported	Economic	No	Yes
Simonit et al.	2011	Kenya	Local	Not Reported	Economic	No	Yes
Swetnam, et al.	2011	Tanzania	Regional	100	Biophysical	No	Yes
Ericksen et al.	2012	Kenya	Regional	Vector	Economic	No	Yes
Fagerholm et al.	2012	Tanzania	Local	600	Socio-Cultural	Yes	Yes
Heubes et al.	2012	Benin	Local	10000	Economic	Yes	No
O'Ferrell et al.	2012	South Africa	Local	25000	Mixed	No	Yes
Silvestri et al.	2013	Kenya	Regional	10000	Economic	No	Yes
Willemen et al.	2013	DRC	National	30	Biophysical	No	Yes
Cavan et al.	2014	Ethiopia & Tanzania	Local	1000	Biophysical	No	No
Pet et al.	2014	South Africa	Regional	Not Reported	Mixed	Yes	Yes
Baker et al.	2015	Ethiopia	Regional	30	Mixed	Yes	No
Duku et al.	2015	Benin	Regional	30	Biophysical	No	Yes
Hamann et al.	2015	South Africa	National	Vector	Biophysical	No	Yes
Vrebos et al.	2015	Uganda	Regional	30	Biophysical	No	Yes
Leh et al.	2016	Ghana & Cote d'Ivoire	National	300	Biophysical	No	No
Winowiecki et al.	2016	Tanzania	National	500	Biophysical	No	No
Turpie et al.	2017	South Africa	National	25000	Economic	No	No

for just 4% and 15% of all ES mapping studies, respectively. Furthermore, although South Africa is the largest contributor of ES mapping research in Africa, no other Southern African countries are represented in this review.

In terms of spatial extents and resolutions, ES mapping in Africa has primarily occurred at regional (48%) and national (32%) levels (Table 1.1). Only five studies (20%) have applied ES mapping at locally. Of these local assessments, two are economic, one is socio-cultural, one is mixed-method, and one is biophysical. Furthermore, perhaps due to the large number of regional and national evaluations, ES mapping in Africa is typically conducted at coarse spatial resolutions (Table 1.1). 30 m is the highest spatial resolution at which ES have been mapped in Africa. Eleven (44%) studies map ES at 1 km or greater resolution, while only seven (28%) map ES at 30 m spatial resolution. Three studies use vector polygons to map ES and three more do not report the resolution at which ES mapping was applied (Table 1.1). All other studies fall somewhere between 30 m and 1 km spatial resolution, and there are currently no identifiable trends in analysis extents or spatial resolutions of ES mapping.

Regarding ES valuation methods or proxies for ES benefits, biophysical approaches are most frequently applied (52%), while economic approaches are also well represented (28%) (Figure 1.2). Socio-cultural approaches are nearly non-existent, as only one study uses these methods (Fagerholm et al. 2012). More recently, there has been an increase in mixed-method approaches that apply social-ecological thinking to ES mapping (16%). Mixed method approaches are those that use multiple valuation or proxy methods to measure and map ES. For example, Reyers et al. (2009) recognized that ES are best viewed in the context of social-ecological systems, where the social and environmental systems of a place are inextricably linked. Thus, they sought stakeholder input to determine which ES would be most important to

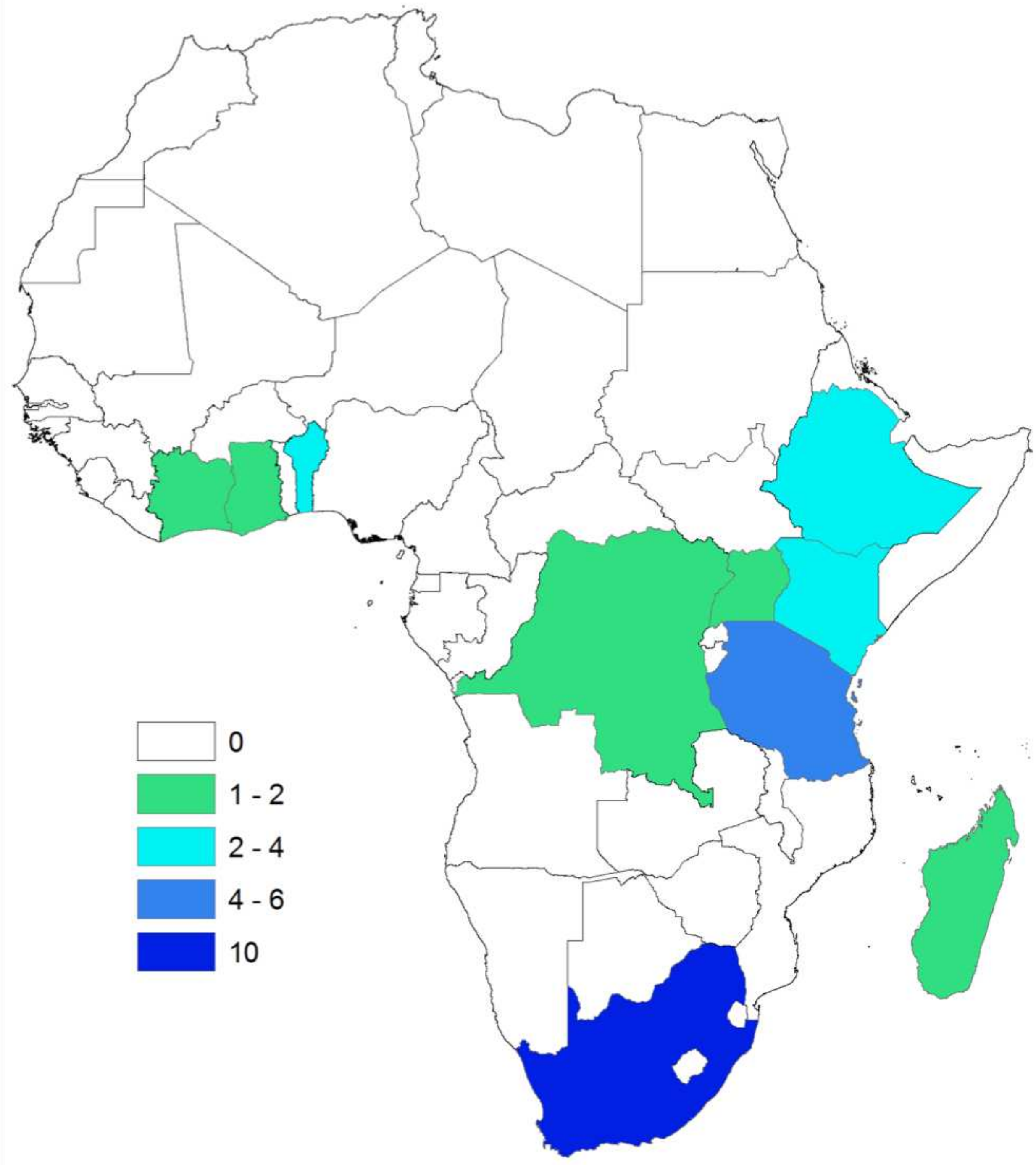

Figure 1.1: Number of Ecosystem Service Mapping Studies by Country

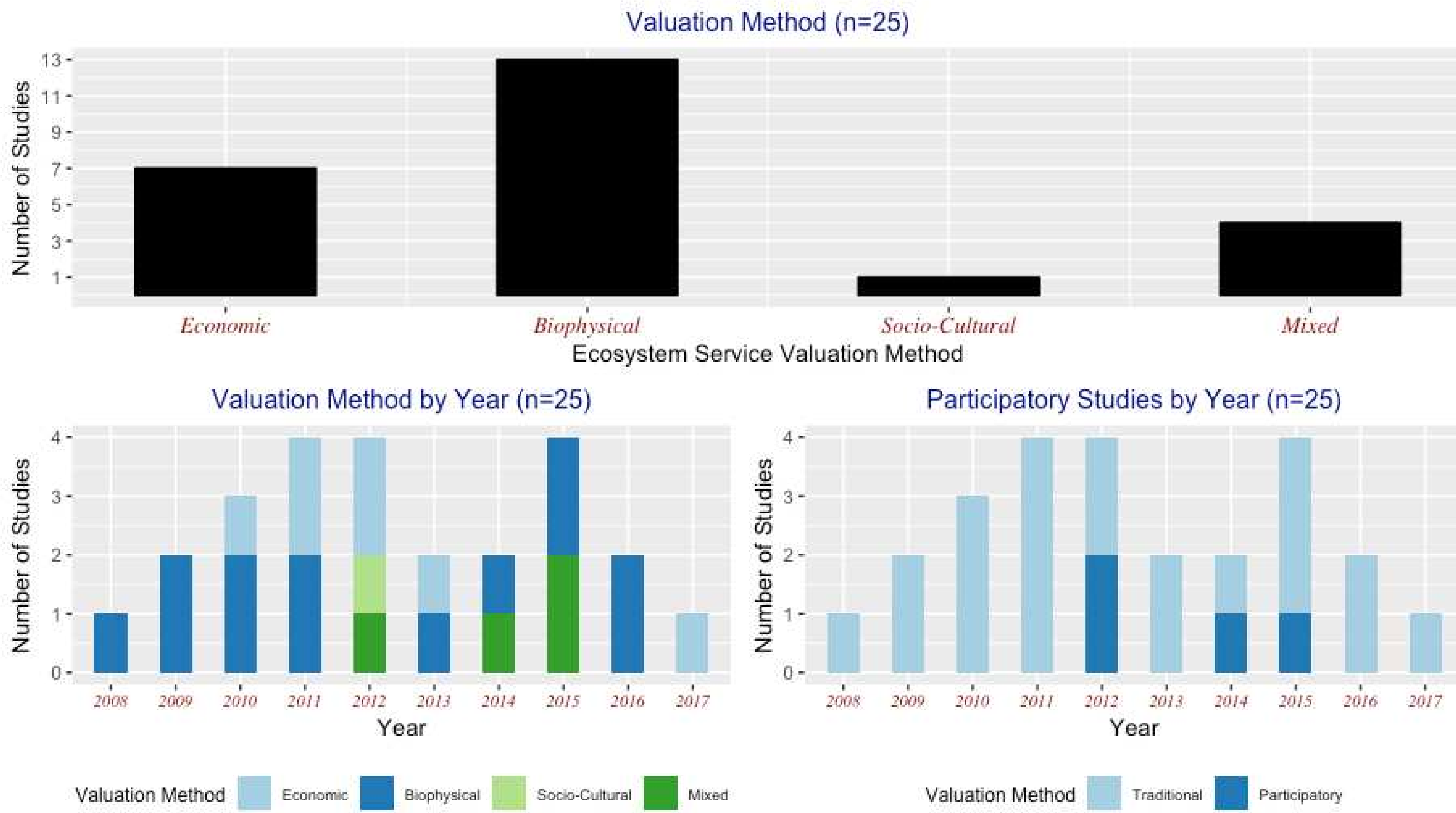

Figure 1.2: Summary of Ecosystem Service Valuation Methods, Including Participatory Methods, Used for Mapping in Africa

map based on the benefits they offer, and used this input to map biophysical proxies for these benefits (Reyers et al. 2009).

Despite, the recent use of mixed approaches, there are no real identifiable trends that suggest a shift towards these types of ES valuations in Africa (Figure 1.2). Perhaps unsurprisingly, given the sparse frequency with which socio-cultural methods have been applied to map ES in Africa, of the 25 studies discussed in this review, only six (24%) have used even basic levels of stakeholder engagement to identify or value ES for mapping (Figure 1.2). The results of this oversight mean that most of the ES that have been mapped in Africa are biophysical proxies or economic values of these benefits.

In total, the studies included in our analysis mapped 128 ES, with roughly 38 unique services across all valuation approaches (Table 1.2). Unsurprisingly, provisioning services (42%) and regulating services (31.5%) were most frequently mapped, while cultural (23.6%) services were less of a focus. The only supporting service that was mapped is biodiversity as a proxy for habitat services. Of the regulating services that were chosen for mapping, carbon storage was mapped in 13 studies, soil retention/accumulation was mapped in 11 studies, and water supply was mapped 10 studies (Table 1.2). In terms of provisioning services, forage production / non-timber forest products were mapped in eight studies, while tourism represents the most frequently mapped cultural service (seven studies).

The ways in which these unique ES were mapped are quite variable. For instance, economic, biophysical, and mixed valuation approaches were all used to map carbon storage; however, the spatial resolution at which carbon storage was mapped ranges from 30 m (Willemen et al. 2013) to 700 km (Egoh et al. 2008; Egoh et al. 2009). This variation in spatial

Table 1.2: Citation & Valuation Approach with number of ES mapped

Citation	Year	Valuation Approach	Tot ES	Participation	Service List
Egoh et al.	2008	Biophysical	5	No	Surface Water Supply; Water Flow Regulation; Carbon Storage; Soil Accumulation; Soil Retention
Egoh et al.	2009	Biophysical	5	No	Surface Water Supply; Water Flow Regulation; Carbon Storage; Soil Accumulation; Soil Retention
Reyers et al.	2009	Mixed	5	Yes	Production of Forage for Domestic Livestock; Carbon Storage, Erosion Control; Freshwater Flow Regulation; Tourism
Egoh et al.	2010	Economic	3	No	Carbon Storage; Fodder Provision; Water Recharge
O'Farrell et al.	2010	Biophysical	4	Yes	Surface Water Supply; Groundwater Recharge; Grazing Provision; Tourism
Rogers et al.	2010	Biophysical	1	No	Relative Hydrological Importance
Egoh et al.	2011	Biophysical	5	No	Water Supply; Water Flow; Carbon Storage; Soil Retention; Soil Accumulation
Fisher et al.	2011	Economic	1	No	Carbon Storage
Simonit et al.	2011	Economic	1	No	Water Quality
Swetnam, et al.	2011	Biophysical	1	No	Carbon Storage
Ericksen et al.	2012	Economic	7	No	Forest Conservation; Forest Production; Irrigated Crop Production; Livestock Production Mixed-Crop Livestock Production; Livestock-Wildlife Production; Wildlife Conservation
Fagerholm et al.	2012	Socio-Cultural	19	Yes	Cultivation; Livestock Keeping; Wild Fruit Harvesting; Fishing & Seafood Catching; Beekeeping; Tree Planting; Construction Materials; Handicraft; Coral Rock Extraction : Sand and Soil Extraction; Firewood Collection; Wood For Charcoal; Medicinal Species in Nature; Decorative Aesthetic Material; Aesthetically Valuable Places; Free Time & Social Interaction; Religious or Sacred Places; Value for Local Culture; Value of Nature
Heubes et al.	2012	Economic	2	Yes	Crop Production; Non-Timber Forest Products
O'Ferrell et al.	2012	Mixed	13	No	Land Capability; Grazing Provision; Soil Retention; Critical Infiltration; Flood Mitigation Zone; Coastal Protection Zone; Ground Water Recharge; Ground Water Yield; Ground Water Quality; Remnant Agriculture Association; Remnant Culture Association; Remnant Tourism Association; Remnant Schools Association;
Silvestri et al.	2013	Economic	4	No	Livestock Assets; Livestock Products; Crops; Tourism
Willemen et al.	2013	Biophysical	5	No	Agricultural Fields; Carbon Stocks; Timber Production; Fuelwood Collection; Tourism Attraction
Cavan et al.	2014	Biophysical	1	No	Temp Regulating Services
Petz et al.	2014	Mixed	7	Yes	Forage Production; Fuelwood Provision; Water Supply; Erosion Prevention; Carbon Sequestration; Ecotourism; Biodiversity (Habitat Service)
Baker et al.	2015	Mixed	1	Yes	Stream Flow
Duku et al.	2015	Biophysical	4	No	Crop Water Supply; Household Water Supply; Water Purification; Soil Erosion Control
Hamann et al.	2015	Biophysical	6	No	Wood for Heating; Wood for Cooking; Crop Production; Animal Production; Freshwater; Building Materials
Vrebos et al.	2015	Biophysical	15	No	Water Supply; Fuelwood; Capture & Collection; Crops; Fodder; Water Quality; Water Flow; Soil Maintenance; Erosion Control; Carbon Storage; Habitat; Biodiversity Maintenance; Ecotourism; Cultural Significance
Leh et al.	2016	Biophysical	4	No	Sediment Retention; Nutrient Retention; Water Yield; Carbon Storage
Winowiecki et al.	2016	Biophysical	1	No	Soil Organic Carbon
Turpie et al.	2017	Economic	9	No	Fodder Production; Provision of Harvested Resources; Tourism; Property Premium; Carbon Storage; Agricultural & Fisheries Support; Sediment Retention; Flow Regulation; Water Quality Amelioration

resolution is common among all mapped ES, regardless of valuation approach. Generally, economic and biophysical valuation approaches are most frequently used to measure regulating and provisioning services. Conversely, cultural services (tourism) represent just 4% of mapped ES using an economic valuation approach, and 8% of mapped ES using a biophysical approach. Mixed valuation approaches (19%) and socio-cultural valuation approaches (37%) do a better job of capturing important cultural ES.

1.3.3. Objective 3: Analysis of Management Suggestions

With support from the literature, this breakdown will allow us to provide commentary about the usefulness of management recommendations for decision-making. Our results show that 18 (72%) studies offer some sort of management suggestions based on their mapping results (Figure 1.3). Of these 18 studies, nine are biophysical (50%), five are economic (28%), one is socio-cultural (5%), and three are mixed-method (17%). Additionally, only four (~22%) of these studies use some sort of participatory or stakeholder inclusive method to identify or value ES for mapping (Figure 1.3). Regarding analysis scales, four of eight (50%) studies that were conducted at national scales, 11 of 12 (91.6%) that were conducted at regional scales, and three of five (60%) that were conducted at local scales offer suggestions for management based on their findings. A full accounting of these studies, and their subsequent suggestions for management, is available in Table 1.3.

1.4. Discussion:

Overall, this review suggests that despite the need for local-scale and participatory assessments of ES, the practice of ES mapping in Africa remains limited to economic and biophysical evaluations at coarse resolutions. As a result, local-scale decision-making will likely continue to be informed by studies that might not support community values. In this section we draw on our results with support from the literature to discuss: (1) current ES mapping practices and their usefulness for local-scale decision-making; (2) gaps and limitations in current-ES mapping and their implications for local communities; and (3) suggestions for how we might move forward to advance ES science for local-scale decision-making. In advance of this discussion we would like to clarify that we are not commenting on the quality or necessity of any single mapping study included in this review, only the general implications of current mapping approaches and trends for local-scale decision-making.

1.4.1. Current ES Mapping Practices and Decision-Making in Africa

A fundamental argument for more localized and participatory approaches to ES mapping is that large-scale, technocratic assessments are not representative of community or individual values and needs (Chan, Satterfield, and Goldstein 2012; Chan et al. 2012; Willcock, Phillips, et al. 2016; Irvine et al. 2016; McHale et al. 2018). This fact has been deliberated since the concept of ES was reviewed for the Millennium Ecosystem Assessment (MEA 2005; van Jaarsveld et al. 2005). Additionally, many of the early ES mapping studies conducted in Africa explicitly call for more direct local-scale stakeholder engagement (e.g. Egoh et al. 2009; Reyers et al. 2009; O'Farrell et al. 2010). For example, although it was conducted at the regional landscape-scale in South Africa, Reyers (et al. 2009) unambiguously states that doing science to build sustainable futures requires active and dynamic stakeholder participation in the process. Furthermore, in their comprehensive southern African supplement to the MEA, van Jaarsveld (et al. 2005) concluded that "incorporating and validating informal local knowledge" in ES assessments can improve the overall credibility of the science.

Table 1.3: Citation with Valuation Approach, Participation, and Management Suggestions

Citation	Year	Valuation Approach	Participation	MGNT	Suggestions
Egoh et al.	2008	Biophysical	No	Yes	Biodiversity is not a perfect predictor of multiple ES, so ES/Biodiversity hotspots should not be used for management in lieu of all available data
Egoh et al.	2009	Biophysical	No	Yes	There is some spatial congruence of Biodiversity & ES, so an integrated approach to ES management is needed so that management of one ES is not depleted by management of another ES
Reyers et al.	2009	Biophysical	Yes	Yes	The scale and importance of biodiversity in Little Karoo is necessitates extending beyond the conservation sector. PES Schemes can potentially help. To build a sustainable future science need active partnerships with stakeholders.
Egoh et al.	2010	Economic	No	Yes	Conservation plans can be more efficient in selecting areas for both biodiversity and ES at no or minimal additional costs, and can help assess tradeoffs
O'Farrell et al.	2010	Biophysical	Yes	Yes	No single management tool can account for all services and flows, so a multi-pronged assessment that accounts for stakeholder and local knowledge are needed
Rogers et al.	2010	Biophysical	No	No	NA
Egoh et al.	2011	Biophysical	No	Yes	maximization of conservation benefits through matching biodiversity priorities with overlapped ecosystem services provided by grasslands using PES to encourage sustainable land use
Fisher et al.	2011	Economic	No	Yes	using maps like this with multiple layers of information to evaluate tradeoffs and make decisions about impacts of land management
Simonit et al.	2011	Economic	No	Yes	Type of PES scheme that will boost value of regulating water services
Swetnam, et al.	2011	Biophysical	No	Yes	Scenario planning for Sustainable Development
Ericksen et al.	2012	Economic	No	Yes	Locate areas with high service value to maximize benefits to people. Changing use will alter values of services provided.
Fagerholm et al.	2012	Socio-Cultural	Yes	Yes	local scale assessments of values of services elicit better recommendations for management
Heubes et al.	2012	Economic	Yes	No	NA
O'Ferrell et al.	2012	Mixed	No	Yes	Rapid assessment tool for identifying priority conservation areas.
Silvestri et al.	2013	Economic	No	Yes	planning requires stakeholder responses for successful management
Willemen et al.	2013	Biophysical	No	Yes	exploration of PES schemes
Cavan et al.	2014	Biophysical	No	No	No specific recommendations
Petz et al.	2014	Mixed	Yes	Yes	Scenarios are for planning to meet conservation targets…
Baker et al.	2015	Mixed	Yes	No	NA
Duku et al.	2015	Biophysical	No	Yes	no specific recommendations
Hamann et al.	2015	Biophysical	No	Yes	Mapping ES according to use and classifying the data can identify green and red loop dynamics and places in transition, which should be managed differently for sustainability
Vrebos et al.	2015	Biophysical	No	Yes	Using methods for evaluating scenarios of within the context of Integrated Natural Resource Management.
Leh et al.	2016	Biophysical	No	No	NA
Winowiecki et al.	2016	Biophysical	No	No	NA
Turpie et al.	2017	Economic	No	No	NA

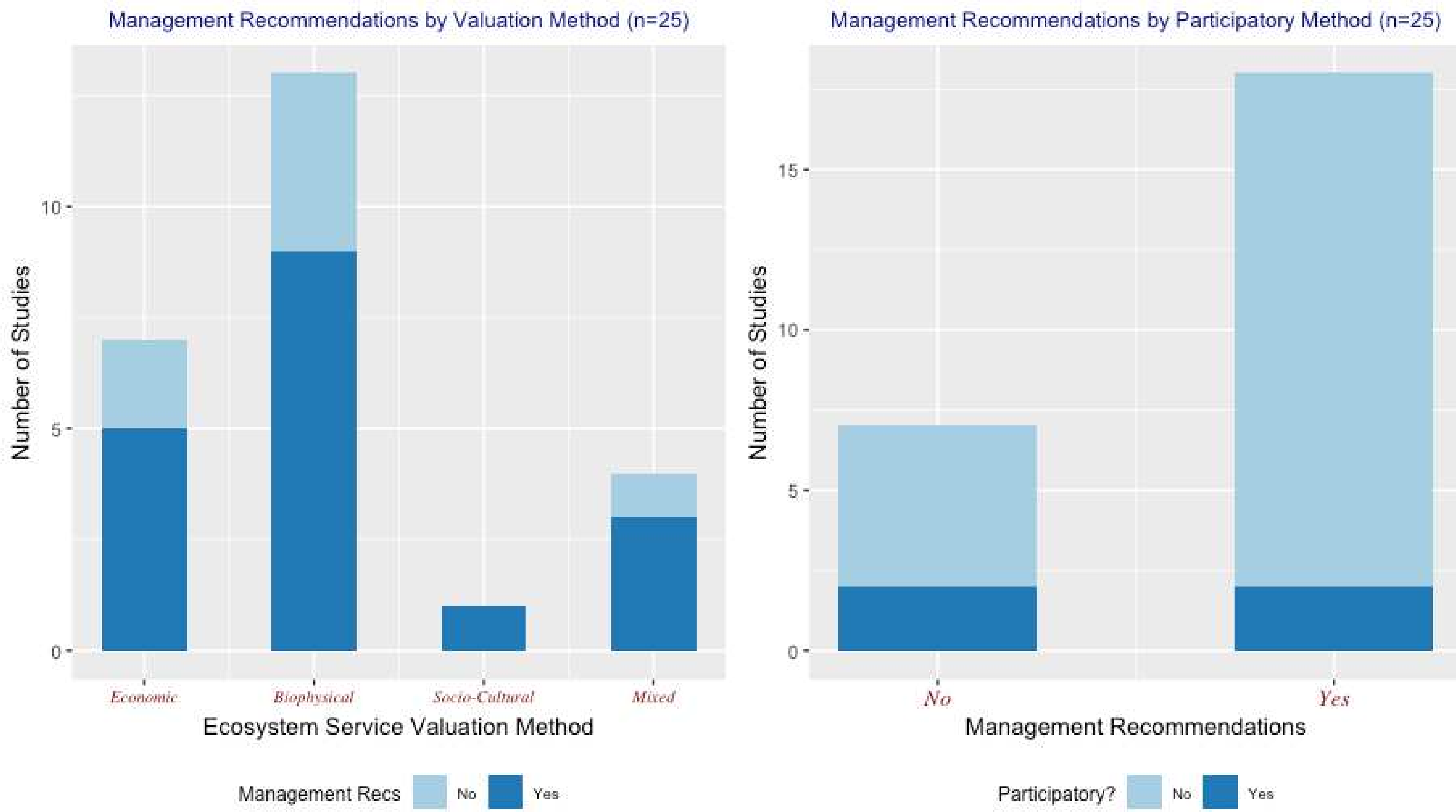

Figure 1.3: Summary of African Mapping Studies that Offer Management Recommendations by ES Valuation and Participatory Methods

Although it appears like these early lessons were meant to lay the groundwork for future studies attempting to assess and map ES for decision-making in Africa, local-scale, stakeholder-driven mapping approaches have still not taken root. These results confirm assertions made by Wagnai (et al. 2016), who, despite not commenting on stakeholder involvement, proposes that significant progress needs to be made regarding local-scale ES mapping. While any remarks as to why local-scale, stakeholder driven mapping has not become more established would be speculation, van Jaarsveld (et al. 2005) does describe the difficulties associated with incorporating local knowledge into expert assessments. These difficulties, at least in part, could be used to rationalize perpetuating the status quo; however, the contemporary acceptance and use of participatory GIS and mapping methods in other parts of the world suggest that ES mapping in Africa is simply lagging behind (Egoh et al. 2012). Decision-making based on current mapping products in Africa that are intended to conserve or promote local ES could have unintended consequences for communities due to issues of scale, spatial-resolution, and ES valuation approach.

1.4.2. Gaps and Limitations in ES Mapping, and Implications for Local-Scale Decision-Making

Scale is one of the fundamental issues in ecology (Levin 1992), and challenges associated with scale in ES mapping are evident. For example, if decision-making ultimately takes place at local-scales (Reyers et al. 2009), then conservation policies based on research conducted at regional or national scales are likely to produce misalignments (Cowling et al. 2008). Indeed, 80% of the studies included in this review were conducted at national or regional scales, which leaves a gaping hole in our collective understanding of ES in local systems. Additionally, although national and regional scale mapping are helpful for characterizing big-picture ES, the lack of local-scale assessments makes it difficult to evaluate potential tradeoffs or issues that could arise from scaler misalignments related to ES planning.

In addition to concerns associated with mapping scale, the spatial resolution (pixel size) of mapping presents another significant barrier to effective/equitable decision-making. The common use of proxies to value and map ES, compounded by other issues associated with proxies (Eigenbrod et al. 2010), means that the spatial resolution of ES mapping products are likely to be variable in different locations. Although 30 m resolution land cover data are ubiquitous in the United States (e.g. NLCD) , they are relatively spotty in Africa (Crompvoets and Bregt 2003). This lack of reliable data means that classifications are often created using freely available coarse spatial resolution satellite products (e.g. MODIS).

Our analysis shows that the spatial resolution of ES mapping studies in sub-Saharan Africa are highly variable, ranging from 30 m to 700 km. Although these more coarse resolution products are useful for identifying trends and characterizing ES at larger spatial extents (e.g. national and regional), they are likely not as useful for local-scale planning (Cadenasso, Pickett, and Schwarz 2007; Pickett et al. 2016). Surprisingly, none of the five local-scale assessments in this review mapped ES at spatial resolutions higher than 600 m, though one (Simonit and Perrings 2011) did not report a mapping resolution.

This issue of spatial resolution in ES mapping products in Africa has serious implications for local-scale decision-making. Several studies have demonstrated that characterizing social and biophysical phenomena in heterogeneous human landscapes requires the use of high spatial resolution data (1 m) that have been disaggregated into basic “true ground” components (Ridd 1995; Cadenasso et al. 1997; Pickett et al. 2016). For example, a 30 m resolution pixel classified as “urban” (e.g. NLCD) cannot be used to accurately quantify any tree cover occurring within that pixel. Since coarse resolution data products do not capture the fine spatial detail characteristic of human influenced landscapes, their application could negatively impact community access to vital ES resources when applied at local scales.

The valuation approach used to map ES is also a potential challenge for local-scale decision-making. While biophysical ES mapping approaches tend to focus on measuring the benefits associated with extensive services like carbon sequestration and water regulation, socio-cultural approaches assign values to localized ES based on the preferences of individuals and communities though stakeholder processes (Fagerholm et al. 2012; Scholte et al. 2015; McHale et al. 2018). For example, the one socio-cultural mapping assessment in this review (Fagerholm et al. 2012) measures local values for benefits identified by the community in which the research was conducted (Table 1.2).

Although economic ES approaches can be local-scale and participatory, and also measure ES values, they are still typically mapped at coarse resolutions and are not necessarily representative of community ES values. While biophysical and economic assessments are useful for mapping services like carbon sequestration, water regulation, fodder provision and timber harvesting, these studies don’t capture the social values of these services for local decision-makers. Socio-cultural ES mapping examples, like Fagerholm (et al. 2012), tend to map the ES benefits valued by communities, like bee keeping, charcoal production, seafood harvesting, and religious/sacred places (Table 1.2).

1.4.3. The Science-Policy Interface: A Way Forward?

Moving forward to fill these gaps in ES mapping in sub-Saharan Africa will require a significant investment from researchers, communities, and decision-makers. Although revealing the localized socio-cultural dynamics of a given place is a promising mechanism for crafting equitable management strategies, there are serious issues that need to be considered when translating ES science for policy. Generally, there has been a failure of communication between scientists, decision-makers, and stakeholders, which leads to a "loading dock" approach to information dissemination (Beier et al. 2017). Despite our best attempts, this failure to include stakeholders and decision-makers in the ES mapping process (80% of studies in our review) fits the familiar "loading dock" pattern, where scientists produce a potentially valuable product, but it does not span the policy boundary by filling the needs or knowledge system of decision-makers (Beier et al. 2017).

The co-production of knowledge is one avenue for ES researchers to create science that is useful for decision-makers (Díaz et al. 2015; Fish, Church, and Winter 2016). Knowledge co-production has 3 guiding principles: (1) identifying a decision that needs to be made (2) prioritizing the co-production process and outcomes over the production of individual products; and (3) emphasizing building connections across disciplines. Within the context of ES mapping, this means that researchers need to have an understanding of how decision-makers use information (Posner, McKenzie, and Ricketts 2016). The information produced by ES researchers must be: (1) salient, meaning relevant to the needs of decision-makers, (2) credible, meaning scientifically rigorous, and (3) legitimate, meaning that products are sensitive to the divergent values of stakeholders (Cash et al. 2003).

Clearly, some concrete actions in the form of "best practices" are needed in order to ensure that ES research effectively bridges the science-policy interface. One such action involves the use of "boundary organizations", or organizations that specialize in spanning the boundaries between science and practice (Cook et al. 2013), to facilitate knowledge co-production. To bridge the science-policy interface, "boundary organizations" could be employed by ES researchers to facilitate these processes. Additional actions for spanning these knowledge boundaries include: (1) Embedding research scientists in resource agencies; (2) establishing links between researchers and decision-makers where embeddedness is impossible, and (3) incorporating knowledge-action boundary spanning into the training of conservation professionals (Cook et al. 2013). Although theoretically these actions could facilitate more appropriate ES mapping in Africa, we still have a long way to go towards understanding how local systems function. Therefore, efforts to incorporate local knowledge systems through participatory socio-cultural ES mapping approaches should be emphasized moving forward.

1.5. Conclusions:

This paper provides an updated systematic review of ES mapping studies in Africa with the goal of identifying whether ES mapping efforts are keeping pace with global trends that call for more local-scale, and stakeholder driven, approaches that quantify socio-cultural ecosystem benefits. We identified 25 studies that map ES in Africa, and only one is a local-scale, socio-cultural assessment. In general, ES mapping has been disproportionately conducted in East and South Africa. Furthermore, there are no identifiable trends that suggest ES mapping in Africa is moving towards local-scale participatory evaluations, and it appears that researchers have not begun to move beyond quantifying large-scale biophysical and economic services. Although management is implemented at local-scales, local-scale ES assessments are exceedingly rare. Additionally, when ES mapping studies are conducted at local-scales, they rely on inappropriate land-cover proxy data that is too coarse resolution to be useful for planning or decision-making. In order to fill these gaps, more investment is needed in conducting local-scale, participatory socio-cultural ES mapping assessments. The inclusion of decision-makers in these mapping processes could also potentially aid in the development of more equitable policy solutions.

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CHAPTER 2 – SOCIO-CULTURAL DEMAND FOR ECOSYSTEM SERVICES

2.1. Introduction:

Since Costanza et al. (1997) first estimated the value of the world's ecosystems and the services they provide to humans, the concept of ecosystem services has generated considerable excitement and criticism in the scientific community (Scholte et al. 2015; Wei et al. 2017; Costanza et al. 2017). Although the debate among scientists has cascaded in numerous directions, there have been two main trajectories for ecosystem services assessments (Cowling et al. 2008; Chan et al. 2012; Scholte et al. 2015). There are those who apply methods to assess nature's contribution to humans in economic terms (Costanza et al. 1997; De Groot et al. 2002; Howarth & Farber 2002), and others who support more biophysical assessment methods to include services that are difficult to measure economically (Brauman et al. 2007; Sherrouse et al. 2010). However, an emerging paradigm that focuses on the socio-cultural valuation of ecosystem services is gaining traction (Martin-Lopez et al. 2012; Sholte et al. 2015; Costanza et al. 2017). With the surge of competing research frameworks seeking to clarify and broaden these diverging valuation pathways, it is unsurprising that interdisciplinary scientists and managers have yet to agree on a clear path towards advancing the science.

Despite the overwhelming array of studies and recommendations, some recent critiques have highlighted the broader need for participatory evaluations in science and policy (Cowling et al. 2008; Sherrouse et al. 2011; Carpenter et al. 2006; MEA 2005). For instance, how can management decisions based on ecosystem service assessments be effective if practitioners have no understanding of how communities value and use those services? Although levels of stakeholder participation can vary (Arnstein 1969), in practice it has proven to be a mechanism for eliciting the socio-cultural values of landscapes (Scholte et al. 2015) – even at the most basic participatory levels. Since humans are major drivers of ecosystem change (Vitousek et al. 1997; Alberti et al. 2003), stakeholder participation in ecosystem service evaluations is not only a clear path forward but is necessary to strengthen outcomes and balance decision-making (Argwal & Gibson 1999; Rayers et al. 2009; Menzel & Teng 2010).

For instance, meticulous attention has been paid to the valuation of cultural ecosystem services since they are often the most difficult to gauge, but highly important to communities (Daniel et al. 2012; Milcu et al. 2013; van Berkel & Verburg 2014); however, most of these studies are non-inclusive of local stakeholders, and it is questionable whether or not resulting maps and models are representative of their needs (Willcock et al. 2016). Although lacking, ecosystem service evaluations that promote localized stakeholder involvement, even in a limited fashion, have offered insights into some of the critical questions facing planning and decision-making at local scales. Specifically, evaluations of the supply and social demand potential of ecosystems are receiving increased positive recognition since they balance an ecosystems ability to provide services with social demand for those services (Wei et al. 2017).

For example, several recent studies have highlighted socio-cultural values to elicit social demand for ecosystem services, which has significant implications for resource management. In one study, Castro (et al. 2016) identifies conservation tradeoffs based on community ecosystem service values to improve water management in the Kiamichi River watershed in the United States. To prioritize services for targeted management in a region of southern Australia, Bryan (et al. 2010) applies an asset mapping strategy, where stakeholders use maps to highlight surrounding areas of importance. Additionally, Plieninger (et al. 2013) conducts a series of interviews and surveys, coupled with GIS techniques, to model and map the demand for cultural ecosystem services among five villages in southeastern Germany. These studies, among others

(Andersson et al. 2007; Raymond et al. 2009; Barthel et al. 2010; Wei et al. 2017), tap into highly personal sense-of-place narratives that communities' experience, which make policies informed by their design more likely to succeed than those using less participatory methods (Stringer et al. 2006).

While this progress is encouraging, these studies focus exclusively on regions in the Global North. Community/stakeholder-based ecosystem service assessments are particularly scarce in the Global South (Rayers et al. 2009; Milcu et al. 2013). For example, in a recent review of cultural ecosystem services studies, Milcu (et al. 2013) did not identify a single case study outside of United States, Europe, or Australia. This is surprising given the tangible relationships that most impoverished people in the Global South have with the natural environment (Ellis 1998; Shackleton et al. 2008). In 2010 it was estimated that roughly 80 percent of people living in sub-Saharan Africa rely on biomass harvesting to supplement their energy needs and sustain their livelihoods (IEA 2010; Wessels et al. 2013). Yet policies centered on the provisioning and use of ecosystem services continue to be implemented from the top-down and at inappropriate scales for local management (e.g. BBR IDP 2015).

In addition to these challenges, the acceleration in urban migration patterns throughout sub-Saharan Africa (Ahrandas et al. 2010; Angel et al. 2012) further complicates rural livelihoods and ecosystem service provisioning. Urbanization in South Africa exemplifies these complications, where the most noteworthy increases in urban land cover are due to remittance-driven development from temporary urban migrants, and subsequent reclassification of rural to urban landscapes (McHale et al. 2013). Rural regions are experiencing amplified parcelization and development that contributes to the loss of communal resources (Ahrands et al. 2010). Communal resource loss is likely to imperil already vulnerable populations. Although comparative work in the field of urban ecology has revealed distinctions in social preferences between parcels and shared spaces in the US (Grove et al. 2006; Troy et al. 2007; Cho et al. 2010; Cook et al. 2012), similar trends have not been explored in Africa. In Africa, far more attention is paid to the use and management of communal resource lands (Cousins 1999; Shackleton & Shackleton 2000; Hoffman & Todd 2000; Cousins 2007; Twine 2013). As growth continues to escalate communal resource loss, it is imperative that future management strategies incorporate distinctive socio-cultural values of communal *and* parcel scale ecosystem services.

In this study, our goal is to reveal the heterogeneous social and spatial characteristics of households that contribute to the use and valuation of community-identified ecosystem services in a rapidly urbanizing region of South Africa. To achieve this overarching goal, we employ social and geospatial methodologies to address the following key research objectives: (1) work with communities to identify and prioritize the ecosystem services that they value; (2) determine where these services are located on the landscape (parcels vs. communal lands); (3) link these services to land cover; and (4) use this information to statistically model the social and spatial characteristics of households that determine values/demand for services on parcels and communal lands. In addressing these objectives, we expected to find that the way in which households use and value parcel versus communal ES is dependent on the location of the villages in which they reside based on proximity to, or isolation from, urbanized townships. Additionally, we expect that any variation in ES use and values among the study villages is a function of household wealth and parcel morphology (e.g. parcel size, parcel age). For example, poorer households are likely more highly value tangible provisioning ES from parcels and communal lands because they are more reliant on them for survival. Finally, we aimed to inform the discussion on how management strategies influence access to services. An improved understanding of the socio-cultural demand for ecosystem services will ultimately lead to better management initiatives, a more inclusive planning process centered on community buy-in, and less detrimental conservation and development practices.

2.2. Methods:

2.2.1. Study Site:

The Bushbuckridge Local Municipality is an approximately 10250 km^2 third tier administrative unit situated in Mpumalanga Province, in Rural South Africa (Figure 2.1). It has a population of roughly 550,000 people (Census 2011). There are 135 individual settlements spread among nine traditional authorities that act as informal governmental organizations headed by “Indunas” (or chiefs). Despite the presence of a centralized municipal government, the traditional authorities are highly influential organizations that govern the development of villages and conservation of communal lands. For instance, although the municipality claims authority over growth in the region, the tribal governments collect annual fees and taxes from individuals, set parcel size limits, and ultimately allocate parcels within settlements.

The ecology of the region is dominated by arid woodland savannah. It is highly biodiverse and the surrounding private and public conservation reserves, including the Kruger National Park to the east, make it one of the most visited regions in the country (SANParks Annual Report 2016). In addition, the area covers a significant portion of the UNESCO Kruger to Canyons biosphere reserve, which extends from the interior of the Kruger National Park to the Blyde River Canyon and Drakensberg Escarpment.

To capitalize on the region’s proximity to such significant biodiversity, the municipal government conducted a Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis and presented the results in the 2016 Bushbuckridge Integrated Development Plan (BBR IDP

2016). The region's strengths and opportunities focus on establishing new eco-tourism development. Its weaknesses and threats are best summarized as poor infrastructural and economic development, a lack of skilled labor, the growing HIV/AIDS pandemic, uncoordinated

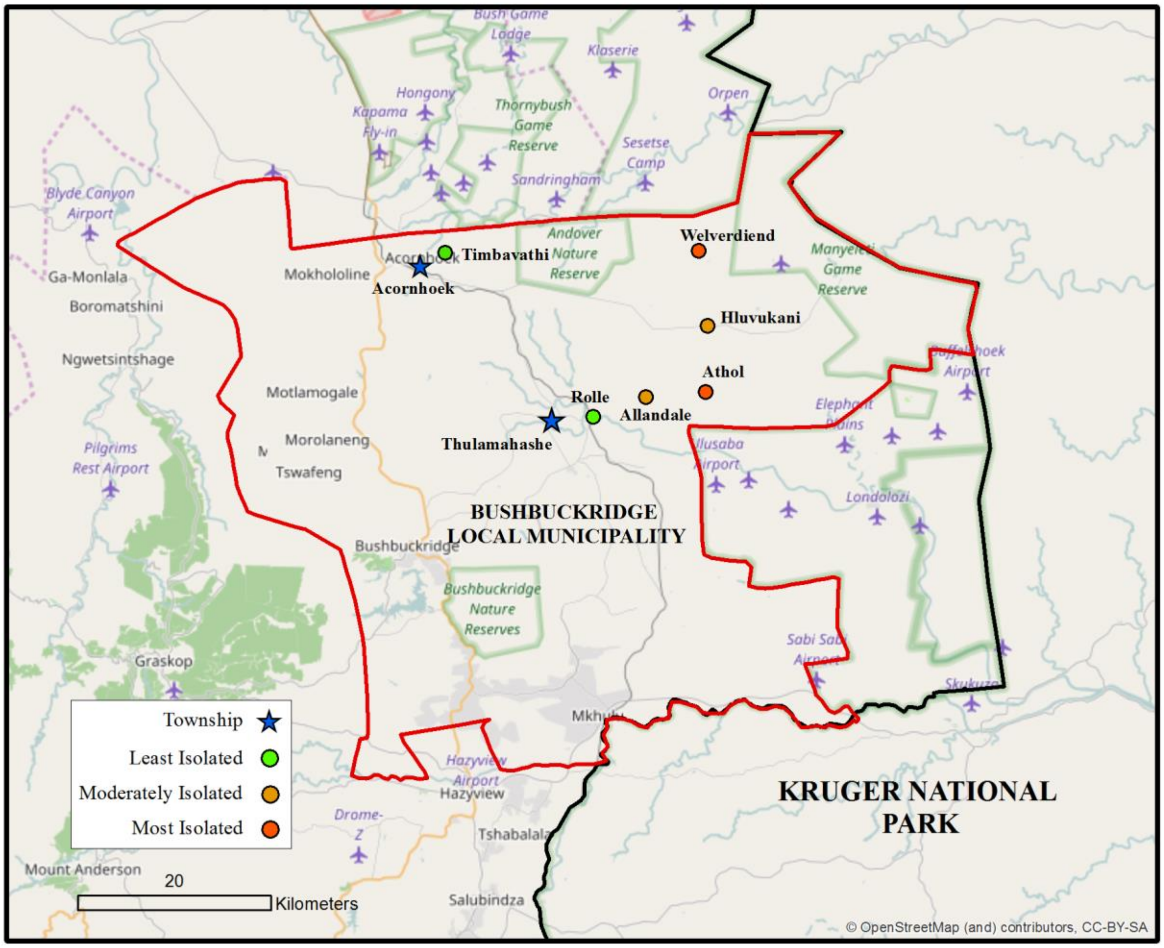

Figure 2.4: Map of Bushbuckridge Local Municipality and Sample Villages along an Isolation Gradient from Townships

land use, immigration, and poverty. Although some would argue that tourism can be used to alleviate poverty in the region, there is conflicting evidence that tourism and community goals are aligned and beneficial to all stakeholders in the region. Since ecosystem services have been used in planning to assess these potentially contrasting goals, the Bushbuckridge Local Municipality is an ideal location to explore the dynamics of socio-cultural demand for ecosystem services.

2.2.2. Social & Spatial Methods:

Our first and second objectives were to work with communities to identify the ecosystem services they value, and to determine where these services are located on the landscape. To achieve these objectives, we devised a stakeholder inclusive mixed-method approach (NCSU IRB #7994). First, we conducted 26 walking interviews in three communities sampled along an urbanization gradient from major townships – where low isolation villages are immediately adjacent and high isolation villages are far away and cut off from major transportation routes – to identify their ecosystem services.

Walking interviews have been used extensively in the social sciences as a means of eliciting situationally appropriate responses from interviewees (Jones et al. 2008; Evans & Jones 2011). In this case, respondents were asked to "lead us on a tour" of their parcel and to "teach us about the places and natural things" from which they benefit. As the tours progressed, respondents were asked probing questions to contextualize their descriptions. Respondents were then asked to expand the tour to include communal lands. These interviews were conducted by the first author (Beck) in English and translated into Shangaan-Tsonga for respondents by an experienced interpreter. Interviews lasted approximately 1.5 hours on average. Each conversation was recorded and transcribed. These data were then coded based on the presence or absence of a give service (1 for present, 0 for absent), and thematically categorized into the four standard ecosystem service classes (e.g. provisioning, cultural, regulating, and supporting) (MEA 2005).

The results of the walking interviews informed the development of a household survey. The survey instrument has five sections: (1) a description of the parcel, currently and at purchase; (2) accounting of ecosystem services on parcels; (3) accounting of ecosystem services in communal lands; (4) a section comparing preferences for ecosystem services between parcels and communal lands; and (5) household demographics and socio-economic status. We then conducted 105 surveys in 6 villages sampled along the same urbanization gradient described above, where communities further from economic centers are more isolated (Figure 2.1). The top three community identified ecosystem services were prioritized by respondents based on their rank order of importance to that individual. The highest priority service was awarded three additional points to emphasize its value, while two or one additional points were added to the second and third highest prioritized services, respectively. The demographic structure of survey respondents is outlined in Table 2.1.

Table 2.1: Walking Interview & Survey Demographics

Walking Interviews

Village	Isolation	Male	Female	Total	Age Range (median/yr)
Welverdiend	High	3	6	9	55+
Hluvukani	Medium	4	5	9	40-45
Timbavati	Low	1	7	8	40-45
TOTALS		**8**	**18**	**26**	**40-45**

Surveys

Village	Isolation	Male	Female	Total	Age (mean/yr)
Welverdiend	High	6	14	20	46
Athol	High	4	12	16	52
Hluvukani	Medium	4	12	16	42
Allandale	Medium	3	13	16	45
Timbavati	Low	6	13	19	43
Rolle	Low	4	14	18	46
TOTALS		**27**	**78**	**105**	**45**

All interviews and surveys were conducted in person (door-to-door) and initial households were chosen using a GIS random sampling method, where parcels are assigned a random number and chosen using a random number generator. Subsequent households were chosen by skipping two streets and visiting the third house on the left. If a respondent declined to be interviewed, or was not home, we crossed the street and moved two houses to the left until an interviewee was willing to participate. These methods allowed us to identify and prioritize the ecosystem services that are valued by local community members (objective 1), and determine where these services are located on the landscape (e.g. parcels, communal lands) (objective 2).

Our third research objective was to link community-identified ecosystem services to land cover. GPS coordinates were taken at highlighted locations during walking interviews. These points were compiled to create a qualitative spatial database of identified ecosystem services and the land covers with which they are associated in each village. Each community-identified service was categorized by the research team into one of the following “true ground” land-cover classes: (1) coarse vegetation; (2) water; (3) buildings; (4) pavement; (5) unpaved roads; (6) fine vegetation; and (7) bare earth. These classes are now commonly used in the field of urban ecology to study the social and ecological characteristics of cities and suburbs (Cadenasso et al. 2007; Pickett et al. 2016). This method allowed us to determine how community identified ecosystem services relate to land cover in different villages (objective 3).

2.2.3. Statistical Analysis

Our final (4^{th}) and overarching research objective is to use the social and spatial information from our first three research objectives to model the characteristics of individuals that influence demand for ecosystem services on parcels and communal lands. To achieve this objective, we built 18 OLS multiple regression models that account for provisioning, cultural, and regulating services in high, medium, and low isolation villages split between parcels and communal lands using our survey and qualitative spatial database. Input variables were chosen based on a hierarchical categorization of indicators that are likely to influence ES values among households. These indicators include demographics, relative wealth, parcel scale morphological factors, and household preferences. A full accounting of these indicators and variable definitions is available in table 2.2.

First, condition indices were calculated to address multi-collinearity among predictor variables, which were reduced until there was no multi-collinearity present. Appropriate variables for models were then chosen by running adjusted-R2 information criterion for model selection. Multiple OLS regressions were then constructed using the variables selected by the information criterion models to predict the proportions provisioning, cultural, and regulating ES received by each household. For example, if a household identified five provisioning ES, three cultural ES and 3 regulating ES, then the proportions of household ES value would be 45% provisioning, 27% cultural, and 27% regulating. These proportions serve as the dependent variables in our OLS regression models.

Finally, the social and spatial characterization of households that predict use and valuation of ES among communities is made by comparing the significance of model predictors in low, medium, and high isolation villages. Model coefficient T-values are used to determine which indicators variables are contributing to model performance (e.g. demographics, wealth, morphology, or preferences). Variables with t-values greater than 2, or less than -2, are significant. T-values that are farthest from zero have a stronger influence over the model, and ultimately determine the characteristics of households that are contributing to ES values and use (objective 4). All statistical analysis was conducted in R/R-Studio (R Core Team 2013).

Table 2.2: Model Input Variable Categories, Measurements, and Definitions

Input Variable	Category	Measurement	Definition
Household Size	Demographics	Count (# in HH)	Number of members living in a given household
Age (18 -)	Demographics	Count (# in HH)	Number of members living in a given household under the age of 18
Age (45 +)	Demographics	Count (# in HH)	Number of members living in a given household over the age of 45
Migrants	Demographics	Count (# in HH)	Number of members belonging to a household who are migrants and might be sending money back home
Education	Demographics	Count (# in HH)	Number of members belonging to a household who are completed some high school education
Employment (Perm)	Wealth	Count (# in HH)	Number of members belonging to a household with permanent employment
Employment (Temp)	Wealth	Count (# in HH)	Number of members belonging to a household with temporary employment
Extra Income	Wealth	Count (# in HH)	Number of members belonging to a household who bring in some type of extra income (selling goods, services)
Grants / Pensions	Wealth	Count (# in HH)	Number of members belonging to a household who receive government grants for support (old age, child, disability). This is an indicator of economically challenged households
Household Structures	Wealth	Count (# Parcel)	Number of structures on a parcel. This is an indicator of household wealth
Assets (Livestock)	Wealth	Count (# Owned)	Number of various livestock owned by a household (chickens, goats, donkeys)
Assets (Cattle)	Wealth	Count (# Owned)	Number of cattle owned by a household. This is a specific indicator of household wealth
Assets (TV)	Wealth	Count (# Owned)	Number of televisions owned by a household
Assets (Satellite)	Wealth	Count (# Owned)	Number of satellite dished owned by a household
Assets (Vehicle)	Wealth	Count (# Owned)	Number of vehicles owned by a household (cars, trucks)
Assets (Fridge)	Wealth	Count (# Owned)	Number of fridges and/or freezers owned by a household
Parcel Age	Morphology	Years	Age of surveyed parcel in years. Older parcels typically have more mature vegetation that provide substantial ES
Parcel Tree Cover	Morphology	% Cover	Percentage of a given parcel that is covered by tree canopy. Higher canopy could provide more ES
Parcel Size	Morphology	Area m^2	Size of a given parcel in meters squared. Larger parcels have a higher potential to provide ES
Parcel Value	Perceptions	Likert (1-10)	Value of parcels to a household on a scale from 1 – 10
Communal Value	Perceptions	Likert (1-10)	Value of communal lands to a household on a scale from 1 - 10

2.3. Results:

2.3.1. Objective 1: Community Identification of Ecosystem Services

The results of the gross thematic categorization based on our walking interview and social surveys showed that communities make use of many ecosystem services on their parcels and in communal lands (Tables 2.3 & 2.4). As expected, most benefits identified by the respondents were provisioning services, but cultural services also featured prominently. Although there were generally fewer regulating and supporting services identified, these were often highlighted as critically important during prioritization – particularly on parcels (Table 2.3).

2.3.2. Objective 2: Locations of Community-Identified Ecosystem Services

99% of households reported receiving at least one provisioning and cultural service, while 94% identified a regulating service, from their parcels. Similarly, a high percentage of households reported receiving provisioning (90%) and cultural services from communal lands (98%) yet only 29.2% of households reported receiving regulating services from communal lands. This comparison demonstrates that individuals value parcel scale services far more notably than is typically reported.

2.3.3. Objective 3: Community-Identified Ecosystem Services and Land Cover

In addition to our thematic results, the walking interviews revealed that communities overwhelmingly identify Tree/coarse woody vegetation cover as the most significant source of ecosystem services. Trees account for 81.25% of services on parcels and 76.9% of services in the communal lands (Table 2.5). Fine vegetation and bare earth account for any remaining percentages on parcels. Fine vegetation, bare earth, and unpaved roads/trails account for remaining percentages in communal areas. Since trees are the most overwhelming source of ecosystem services in this region, they are of interest in this study.

2.3.4. Objective 4: Statistical Characterization of Demand for Ecosystem Services

Our primary goal was to determine whether the proximity of villages to urbanized townships influences where households get their ES – from parcels or communal lands. Additionally, we wanted to understand the social and spatial characteristics of households that that account for any observed variation in ES locations and use among these communities. Household characteristics include demographics, wealth indicators, parcel morphology, and individual preferences. To do this we leveraged the information derived from our walking-interviews and surveys to compare the proportions of ES types (e.g. provisioning, cultural, regulating) used by households in low, medium, and high isolation villages derived from parcels and communal lands. We then constructed 16 multi-OLS regression models to determine the household characteristics that contribute to variation in ES use among high, medium, and low isolation communities. Coefficient t-values allow us to understand which variables contribute most significantly household valuation and use of provisioning, cultural, and regulating ES on both parcels and communal lands. Our statistical analysis of survey and spatial data showed that value and use of ES does indeed vary among villages based on isolation. Additionally, relationships between demographic, wealth, morphological, and preference characteristics and ES values and use are complex, but largely associated with household wealth and parcel scale morphological characteristics.

Table 2.3: Parcel-Scale Community-Identified Ecosystem Services, Percentage of Households Reporting, & Socio-Cultural Weighted Prioritization. Total percentages of HH reporting for service types is the percentage of HH that reported receiving at least ONE service from that category.

		Parcel-Scale Ecosystem Services											
		Athol (n=16) (High Isolation)		**Welverdiend** (n=20) (High Isolation)		**Allandale** (n=16) (Mid Isolation)		**Hluvukani** (n=16) (Mid Isolation)		**Rolle** (n=18) (Low Isolation)		**Timbavati** (n=19) (Low Isolation)	
Service Type	**Services Mentioned**	% of HH	Priority (mean)	% of HH	Priority (mean)	% of HH	Priority (mean)	% of HH	Priority (mean)	% of HH	Priority (mean)	% of HH	Priority (mean)
Provisioning	Cultivated Foods	93.7	2.94	85	2.15	81.3	2.94	100	2.94	94.4	3.39	89.5	2.37
	Marula Fruits	62.5	1.19	75	1.15	62.5	1.69	87.5	1.56	83.3	1.17	78.95	1.42
	Other Wild Fruits	93.3	1.38	75	1	81.3	1.13	93.8	0.94	55.6	0.61	57.9	0.68
	Fuelwood	50	0.88	65	1.7	50	1.19	62.5	1.06	55.6	1	78.95	1
	Building-Wood	12.5	0.13	20	0.6	12.5	0.13	18.8	0.25	38.9	0.61	21.05	0.21
Cultural	Spiritual Benefits	31.3	0.38	35	0.45	37.5	0.56	25	0.44	22.2	0.22	36.8	0.63
	Medicinal	68.8	0.94	70	0.85	50	0.56	75	0.88	50	0.50	57.9	0.84
	Aesthetics	81.2	0.88	85	0.85	62.5	0.56	87.5	0.88	88.9	1	63.2	0.79
	Gathering Space	93.8	1.3	75	1.05	87.5	0.63	93.8	1.25	88.9	1.56	89.5	1.32
	Crafting	25	0.31	0	0	6.25	1.13	18.8	0.44	33.3	0.39	5.3	0.05
Regulating	Shade	1.3	1.4	95	1.95	68.8	1.34	81.5	1.34	88.9	1.83	68.4	1.68
	Wind Protection	56.3	1.7	85	2.05	62.5	1.19	93.8	2.25	72.2	1.11	78.95	1.95
	Soil Retention	87.5	0.56	15	0.2	12.5	0.13	43.8	0.44	38.9	0.50	42.1	0.63
	Lightning Protection	0	0	0	0	0	0	0	0	0	0	5.3	0.05
Supporting	Soil Conditioning	31.3	0.31	0	0	12.5	0.19	0	0	5.56	0.06	10.5	0.21
	Air Quality	18.8	0.19	10	0.2	12.5	0.13	12.5	0.25	33.3	0.33	21.05	0.21
TOTALS	**PROVISIONING**	**100**	**6.5**	**100**	**6.15**	**93.8**	**7.1**	**100**	**6.8**	**100**	**6.72**	**100**	**5.74**
	CULTURAL	**100**	**3.9**	**95**	**3.3**	**100**	**2.94**	**100**	**3.8**	**100**	**3.67**	**100**	**3.36**
	REGULATING	**100**	**3.8**	**95**	**4.2**	**81.3**	**2.69**	**100**	**4.1**	**94.4**	**3.44**	**94.7**	**4.21**
	SUPPORTING	**37.5**	**0.57**	**10**	**0.2**	**18.8**	**0.31**	**12.5**	**0.25**	**33.3**	**0.39**	**31.6**	**0.42**

Table 2.4: Communal-Scale Community-Identified Ecosystem Services, Percentage of Households Reporting, & Socio-Cultural Weighted Prioritization. Total percentages of HH reporting for service types is the percentage of HH that reported receiving at least ONE service from that category.

		Communal-Scale Ecosystem Services											
		Athol (n=16) (High Isolation)		**Welverdiend** (n=20) (High Isolation)		**Allandale** (n=16) (Mid Isolation)		**Hluvukani** (n=16) (Mid Isolation)		**Rolle** (n=18) (Low Isolation)		**Timbavati** (n=19) (Low Isolation)	
Service Type	**Services Mentioned**	% of HH	Priority (mean)	% of HH	Priority (mean)	% of HH	Priority (mean)	% of HH	Priority (mean)	% of HH	Priority (mean)	% of HH	Priority (mean)
Provisioning	Cultivated Foods	25	0.75	50	1.4	37.5	0.75	50	1.06	33.3	0.94	26.3	0.94
	Wild Fruits	62.5	1.06	75	1	62.5	1.06	81.3	0.88	77.8	1.39	52.6	1.39
	Grazing	31.3	0.75	20	0.8	43.8	1.25	31.3	1.13	38.9	0.89	5.3	0.89
	Fuelwood	81.3	1.94	90	2.3	100	3.19	93.8	2.19	94.4	2.39	36.8	2.39
	Building-Wood	50	0.56	50	0.6	37.5	0.5	43.8	0.63	61.1	0.83	21.1	0.83
	Soil (ag/building)	31.3	0.56	60	1.3	37.5	0.63	31.3	0.44	55.6	1.39	26.3	1.39
	Game Hunting	6.3	0.06	10	0.1	6.3	0.13	37.5	0.56	5.6	0.06	5.3	0.06
Cultural	Recreation	50	0.88	45	0.65	43.8	0.5	75	1	77.8	1.22	63.2	1.11
	Medicinal	50	0.69	65	0.95	43.8	0.63	68.8	0.89	11.1	0.11	42.1	1
	Aesthetics	43.8	0.56	20	0.2	25	0.31	25	0.25	11.1	0.11	10.5	0.32
	Trad. Knowledge	100	2.44	90	1.85	93.8	2.31	100	2.88	77.8	1.83	94.7	3.53
Regulating	Wind Protection	56.3	1.44	15	0.3	12.5	0.13	31.3	0.56	50	0.56	10.5	0.21
Supporting	Soil Conditioning	6.3	0.06	0	0	0	0	6.3	0.25	5.56	0.11	5.3	0.16
TOTALS	**PROVISIONING**	**87.5**	**5.69**	**90**	**7.4**	**100**	**7.5**	**100**	**6.8**	**100**	**8**	**68.4**	**3.11**
	CULTURAL	**100**	**4.56**	**95**	**3.65**	**100**	**3.8**	**100**	**5**	**94.4**	**3.28**	**100**	**5.79**
	REGULATING	**56.3**	**1.44**	**15**	**0.3**	**12.5**	**0.13**	**31.3**	**0.56**	**50**	**0.56**	**10.5**	**0.21**
	SUPPORTING	**6.3**	**0.06**	**0**	**0**	**0**	**0**	**6.3**	**0.25**	**5.56**	**0.11**	**5.3**	**0.16**

Table 2.5: Ecosystem Services & Associated Land Cover Types. The number "1" indicates that a service has been associated with that land cover type based on GPS measurements overlaid on a land-cover classification and based on qualitative information.

Parcel-Scale Services

Service Type	Service Mentioned	Coarse Veg	Water	Fine Veg	Bare Earth
Provisioning	Cultivated Foods	1	0	1	0
	Marula Fruits	1	0	0	0
	Other Wild Fruits	1	0	0	0
	Fuelwood	1	0	0	0
	Building-Wood	1	0	0	0
Cultural	Spiritual Benefits	1	0	0	0
	Medicinal	1	0	1	0
	Aesthetics	1	0	1	0
	Gathering Space	0	0	1	1
	Crafting	1	0	1	1
Regulating	Shade	1	0	0	0
	Wind Protection	1	0	0	0
	Soil Retention	0	0	1	0
	Lightning Protection	1	0	0	0
Supporting	Soil Conditioning	0	0	1	0
	Air Quality	1	0	1	0
TOTALS	**# of Services = 16**	**13**	**0**	**8**	**2**
	%	**81.25**	**0**	**50**	**12.5**

Communal-Scale Services

Service Type	Service Mentioned	Coarse Veg	Water	Fine Veg	Bare Earth
Provisioning	Cultivated Foods	1	0	1	0
	Wild Fruits	1	0	0	0
	Grazing	1	0	1	0
	Fuelwood	1	0	0	0
	Building-Wood	1	0	0	0
	Soil (ag/building)	0	0	0	1
	Game Hunting	0	0	0	0
Cultural	Recreation	0	0	0	0
	Medicinal	1	0	1	0
	Aesthetics	1	0	1	0
	Trad. Knowledge	1	0	1	0
Regulating	Wind Protection	1	0	0	0
Supporting	Soil Conditioning	1	0	1	0
TOTALS	**# of Services = 13**	**10**	**0**	**6**	**1**
	%	**76.9**	**0**	**46.2**	**7.69**

2.3.5. Village Isolation and Parcel vs. Communal ES Use

To compare the value and use of ES among communities, we generated proportional density plots for each ES type based on village isolation. These plots allow us to visualize differences in the proportions of provisioning, cultural, and regulating ES used by households from parcels and communal lands. Figure 2.2 shows differences in the proportion of provisioning ES among low, medium, and high isolation communities. As expected, high isolation communities use a higher proportion of provisioning on both parcels and communal lands than less isolated communities, where a smaller number of households use provisioning ES on communal lands.

Figure 2.3 shows differences in the proportions of cultural ES among low, medium and high isolation communities. In general, cultural ES represents a smaller proportion of total ES than provisioning services and the differences among communities are not that substantial. This suggests that cultural ES are similarly important regardless of village location.

Figure 2.4 shows differences in the proportions of cultural ES among low, medium, and high isolation communities. Again, regulating ES represent a smaller proportion of total ES than provisioning and cultural services, although there is clearly a substantial difference between regulating ES provided by parcels versus those provided by communal lands. Additionally, households in high isolation villages appear to place far less emphasis on parcel regulating services than medium and high isolation villages. This suggests that high isolation households are primarily focused on ES provisioning benefits, rather than other ES benefits.

Regardless of village isolation, there is clearly a substantial amount of variation in ES use and values among these communities. We explore the household characteristics that contribute to this variation in the following sections.

2.3.6. Parcel-Scale Models

To understand the household characteristics that contribute to variation in ES values and use among the study communities, we first modeled parcel-scale ES. The parcel-scale models for provisioning ES in high, medium, and low isolation villages (Figure 2.5) explains ~55%, ~46%, and ~55% (R^2) of the variation in these data, respectively. These models show that the relative wealth and morphological characteristics of households are the most important predictors of provisioning ES values regardless of village isolation; however, it does appear that morphological characteristics are more important predictors of high provisioning ES use in low isolation villages, while wealth indicators are more important predictors of household provisioning ES use in medium and high isolation villages.

The cultural ES parcel-scale models (Figure 2.6) account for 53% and 55% (R^2) of the variation in these data among low and high isolation villages, respectively. Interestingly, demographic characteristics of households are the strongest predictors of cultural ES in low isolation villages, while wealth and morphological characteristics predict cultural ES values in high isolation communities. The cultural ES model for medium isolation villages was insignificant, which suggests that other factors not captured in these models are influencing cultural ES values in these communities.

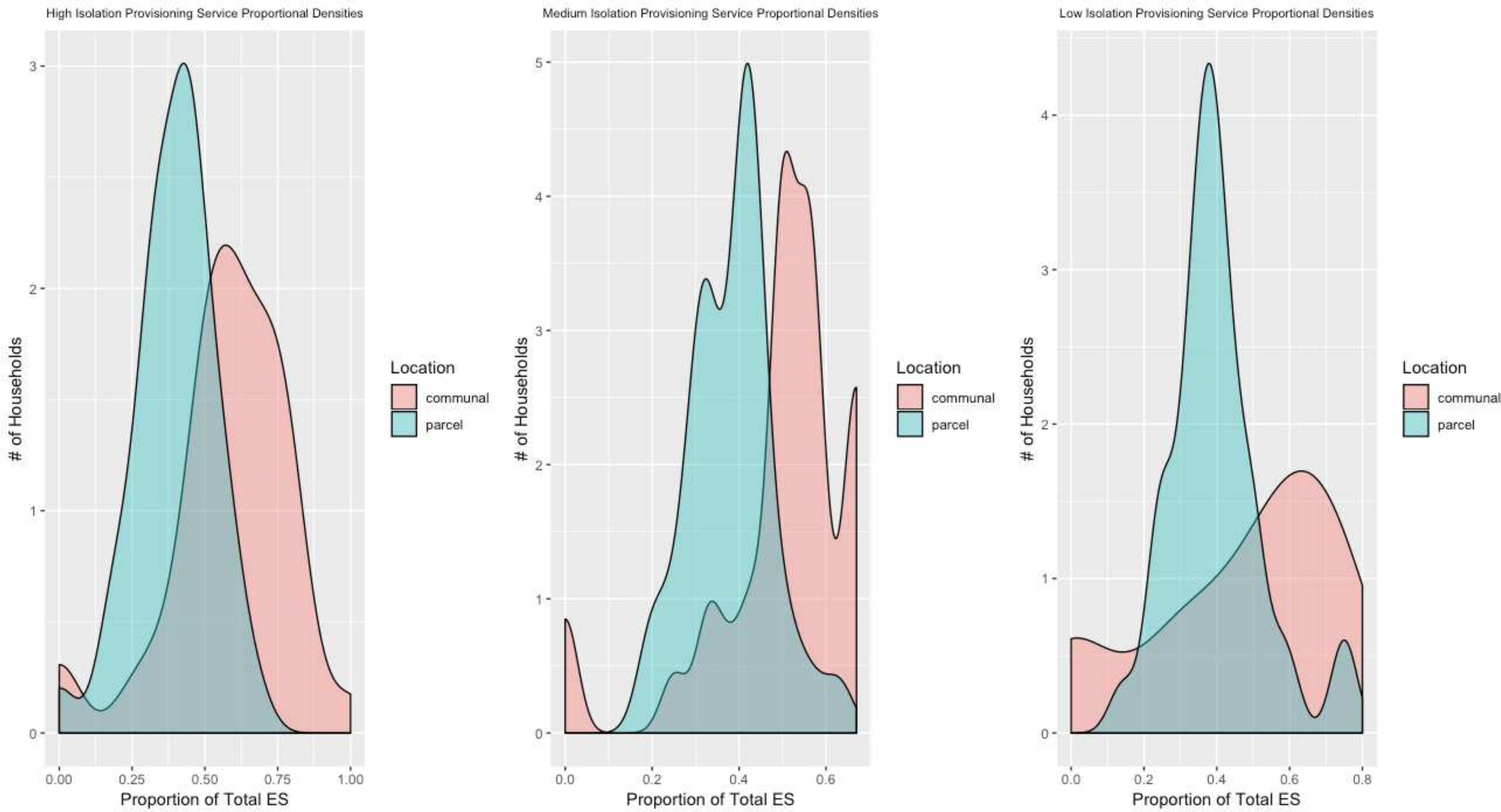

Figure 2.2: Proportional densities for provisioning ES on parcels and communal lands based on village isolation. These figures show that provisioning services represent a substantial proportion of household ES use and value regardless of village location, though the use of communal provisiong ES in low isolation villages is far less common than in high isolatino villages.

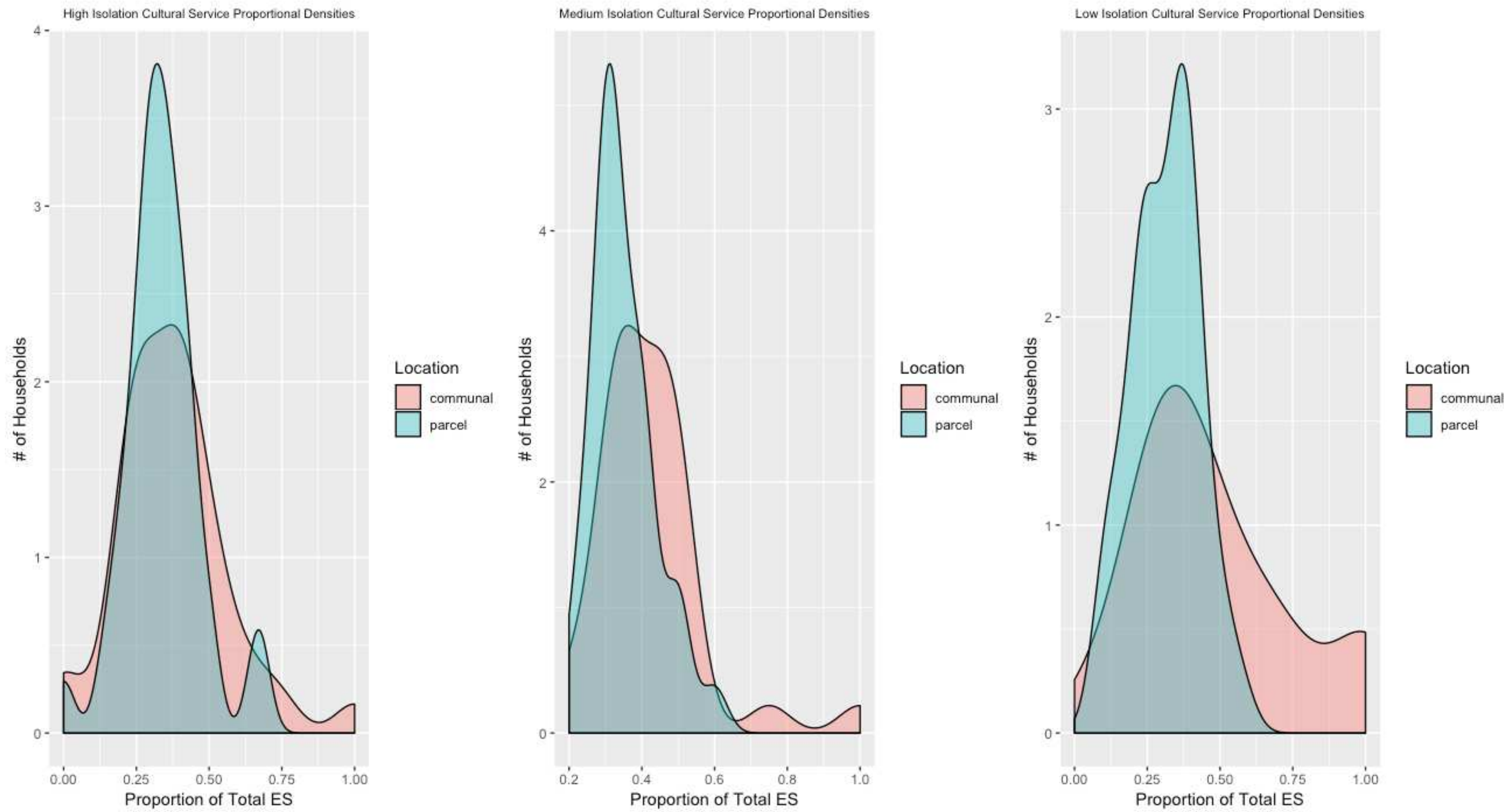

Figure 2.3: Proportional densities for cultural ES on parcels and communal lands based on village isolation. These figures show that cultural ES generally represent a smaller proportion of of household ES use and value than provisioning serviecs, and are generally consistant regardless of village isolation.

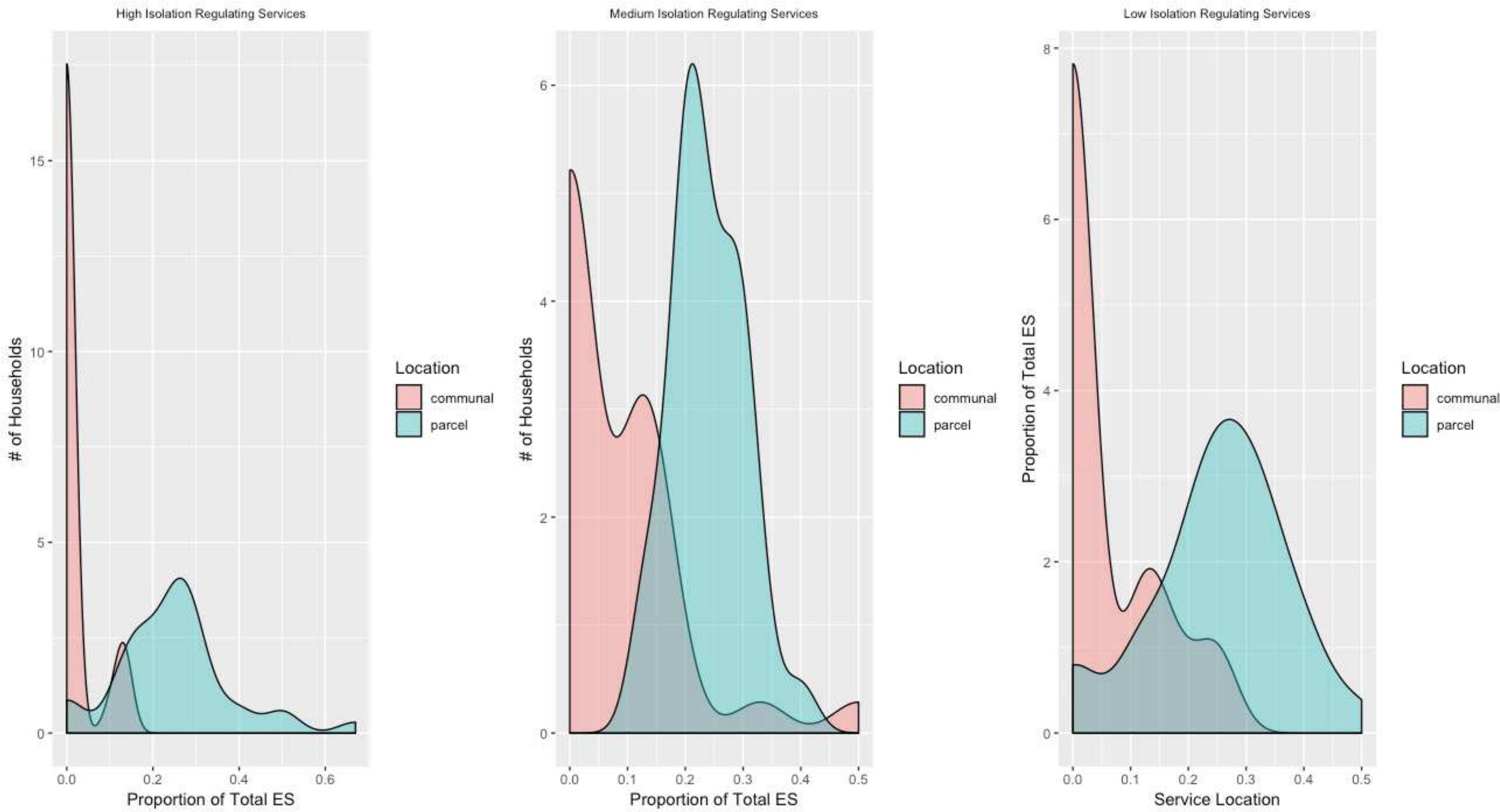

Figure 2.4: Proportional densities for regulating ES on parcels and communal lands based on village isolation. These figures show that regulating services represent a substantially smaller proportion of household ES use and value than provisioning and cultural ES, particularly on communal lands; however, regulating ES use and value on parcels is much less important among housholds in high isolation villages than medium and low isolation villages.

Finally, the regulating ES parcel-scale models (Figure 2.7) account for 56% and 35% (R^2) of the variation in these data among low and high isolation villages, respectively. In these models, household preferences are the strongest predictors of regulating ES in low isolation villages, while wealth and demographic characteristics predict regulating ES values and use in high isolation communities. Once again, the regulating ES model for medium isolation villages was insignificant, which suggests that other factors not captured in these models are influencing regulating ES values and use in these communities.

Overall, the parcel-scale models demonstrate the complexity surrounding community use and values of ecosystem services within villages. The household characteristics that predict the value and use of parcel-scale ecosystem services differ depending on the type of service in question. For instance, demand for provisioning ES is largely predicted by the wealth and morphological characteristics of households regardless of how isolated the village is from urban townships, while the household characteristics that predict cultural and regulating ES vary considerably, and include demographic, wealth, morphological, and preference factors. This makes sense, since provisioning services directly contribute to household livelihoods, and the ability to procure provisioning ES on parcels is likely more important for less wealth households and easier for individuals who live on larger, older parcels. Conversely, a variety of household characteristics determine whether cultural or regulating ES are used and valued

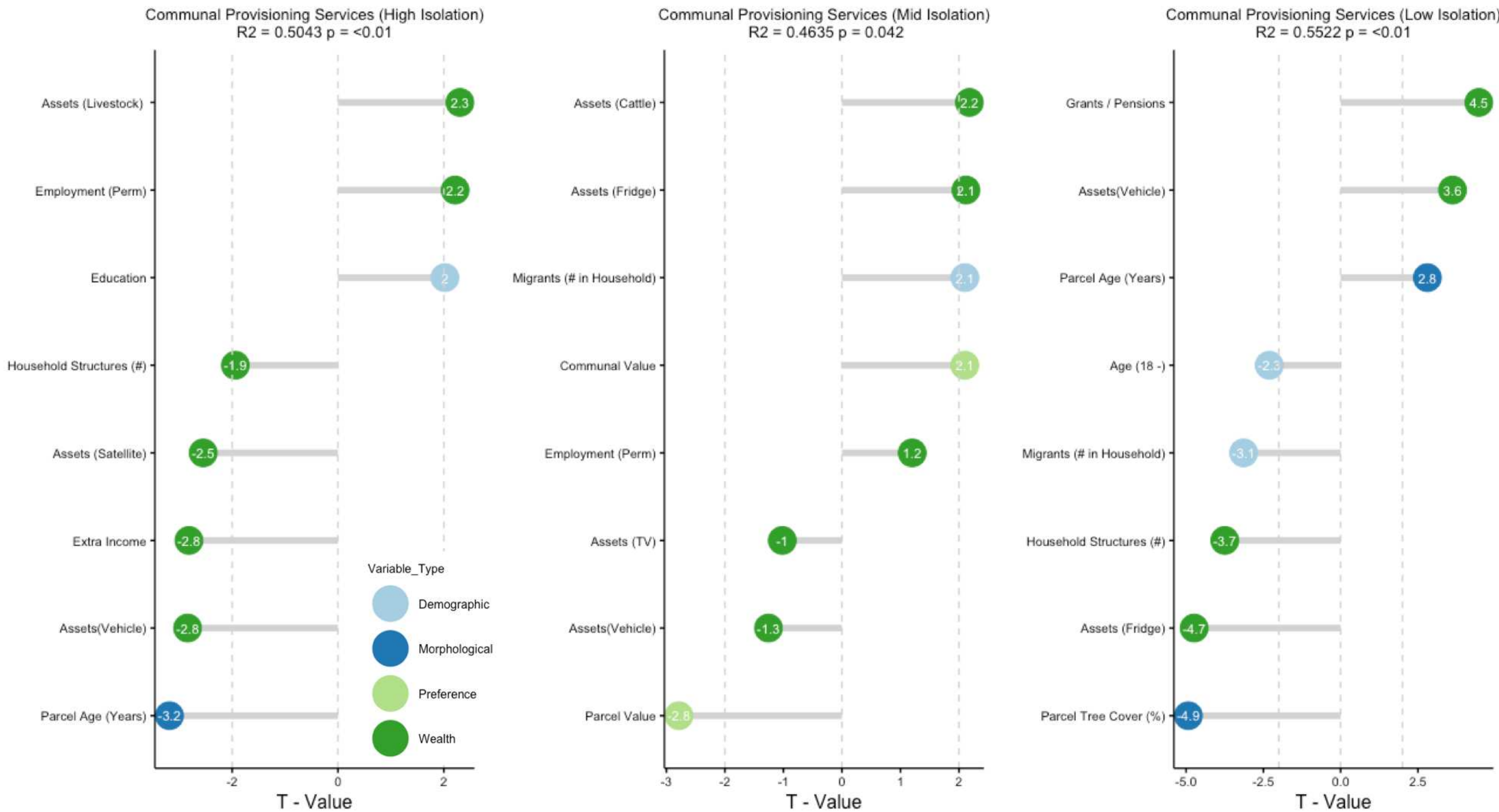

Figure 2.5: *Parcel-Scale provisioning ES Models for high, medium, and low isolation villages show that morphological and wealth characteristics of households predict ES values and use among households on parcels.*

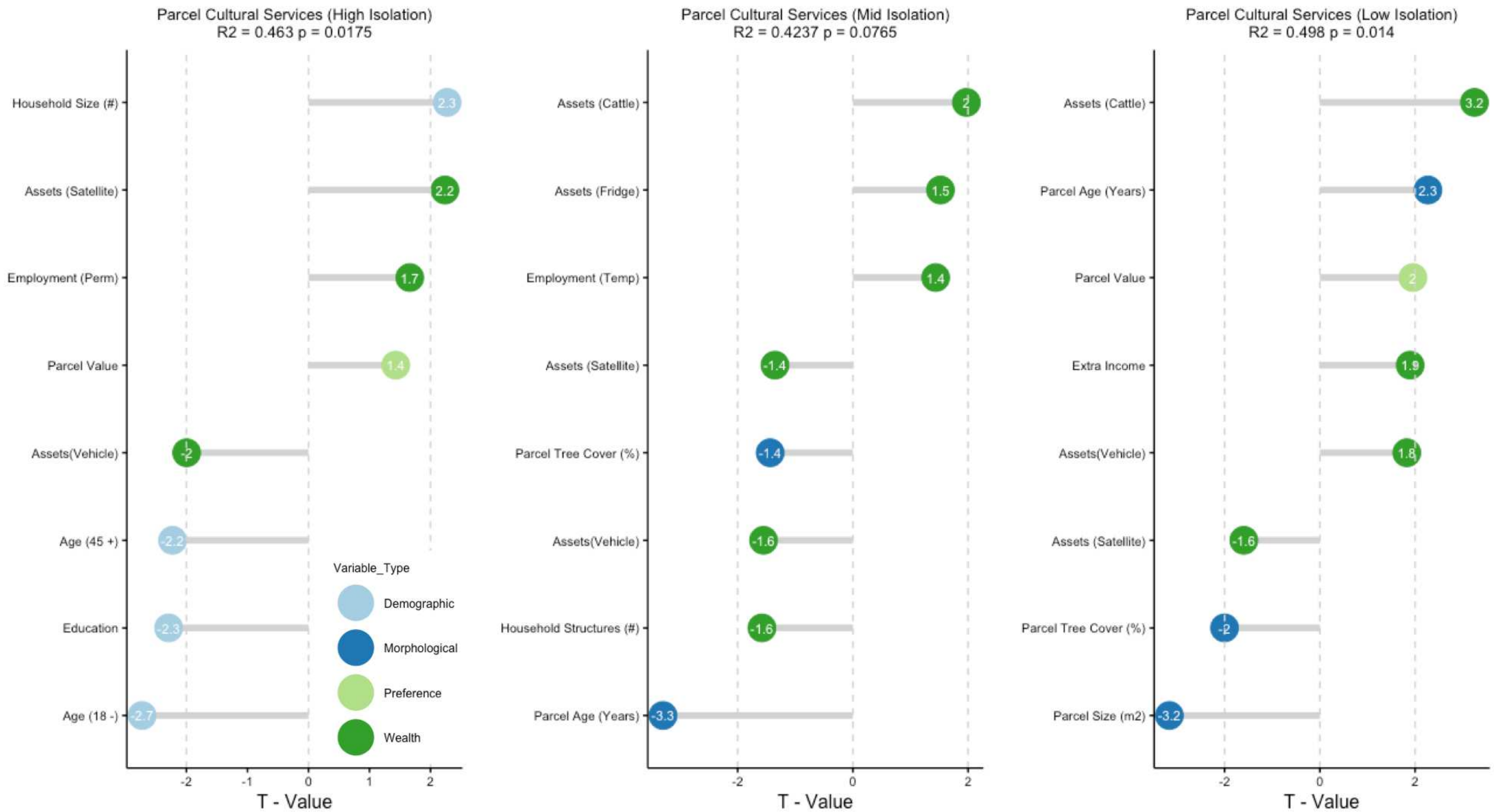

Figure 2.6: Parcel-Scale cultural ES Models for high, medium, and low isolation villages show that morphological and wealth characteristics of households predict ES values and use among households on parcels in medium and high isolation villages, while demographics predict culatural ES values among households in low isolation villages.

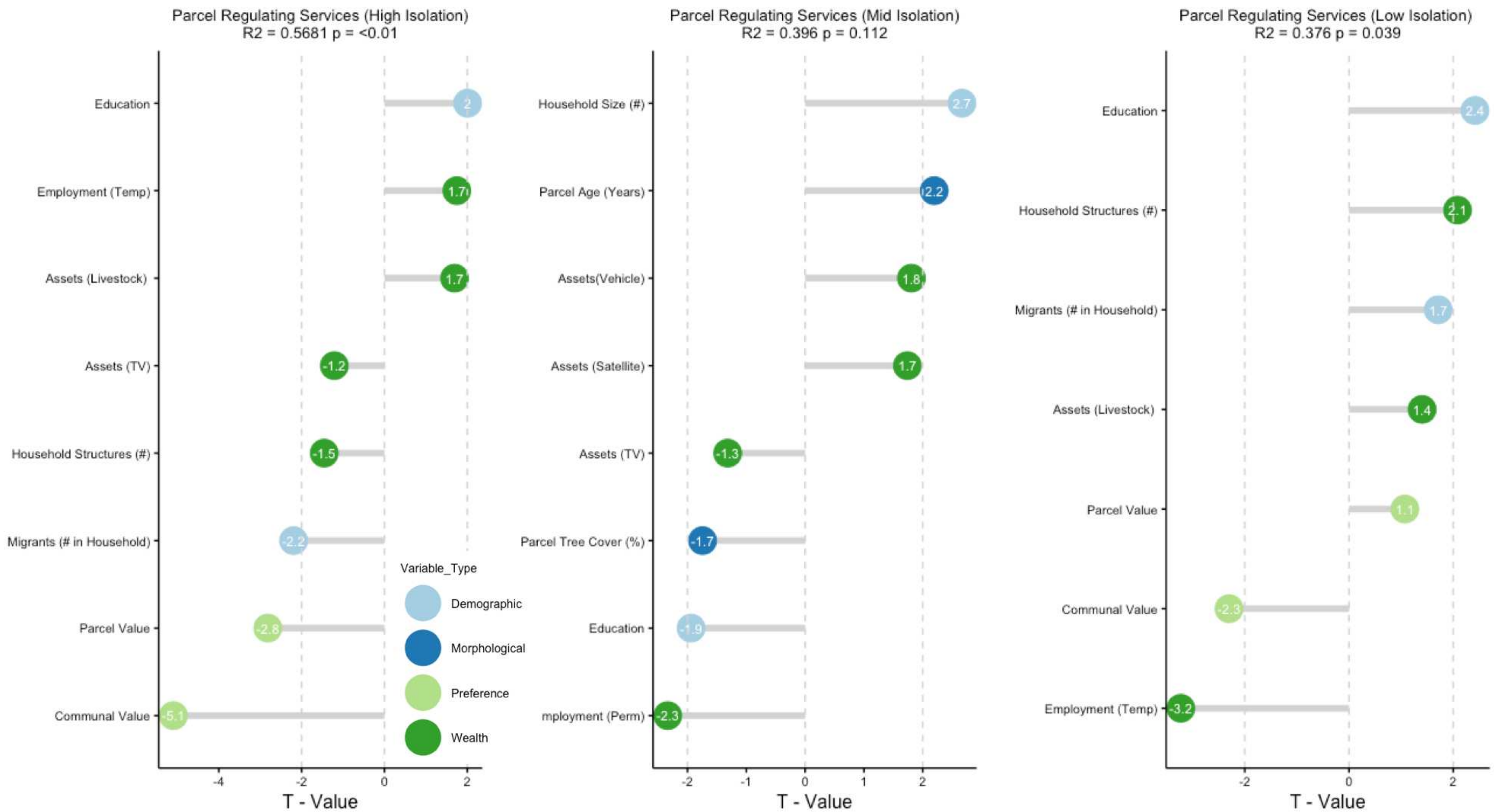

Figure 2.7: Parcel-Scale regulating ES Models for high, medium, and low isolation villages show that morphological and wealth characteristics of households predict ES values and use among households on parcels.

2.3.7. Communal-Scale Models

In addition to uncovering the household characteristics that predict the use and value of parcel-scale ES, we similarly developed models to understand the household characteristics that contribute to ES values derived from communal lands. The communal-scale models for provisioning ES in high, medium, and low isolation villages (Figure 2.8) explains ~55%, ~46%, and ~55% (R^2) of the variation in these data, respectively. These models show that relative wealth, where poorer households and those that own livestock and are likely to use communal areas for grazing, largely predict use and values of provisioning ES, regardless of how isolated villages are. Additionally, parcel morphological characteristics contribute to these models, where older parcels and those with higher tree cover place less emphasis on communal provisioning ES.

The cultural ES communal models (Figure 2.9) account for accounts for 58%, 52%, and 74% of the variation (R^2) in these data among high, medium, and low isolation villages, respectively. Again, the wealth and parcel morphological characteristics of households are the strongest predictors cultural ES values in communal lands; however, preferences also appear to play an important role in cultural ES values. Perhaps most interestingly, wealthier households in the least isolation villages appear to emphasize communal cultural ES, these values are largely dependent on parcel size in the most isolated villages.

The regulating ES communal models (Figure 2.10) account for 56% and 39% of the variation (R^2) among in these data in high and medium isolation villages, respectively. Unlike the provisioning and communal ES models for communal lands, valuation and use of regulating ES in these villages is predicted by a combination of demographic and wealth characteristics, and preferences, of households. Poorer households with larger families tend to emphasize regulating ES in medium isolation villages, while more educated household's value regulating ES in the most isolated villages. The regulating ES model for the least isolated villages was not significant, which suggests that other factors are contributing to the use and valuation of regulating ES in these villages.

Overall, the communal-scale models are generally driven by the wealth and morphological characteristics of households, though regulating ES appear to be an exception. There are certainly interesting comparisons to be made based on the isolation of villages, were ES values differ among wealthier households in low and high isolation villages. Generally, model metrics suggest that individuals who emphasize the value of communal services are relatively less wealthy than those who prioritize parcel-scale services, although some wealthier households that own livestock emphasize communal-scale ES as well.

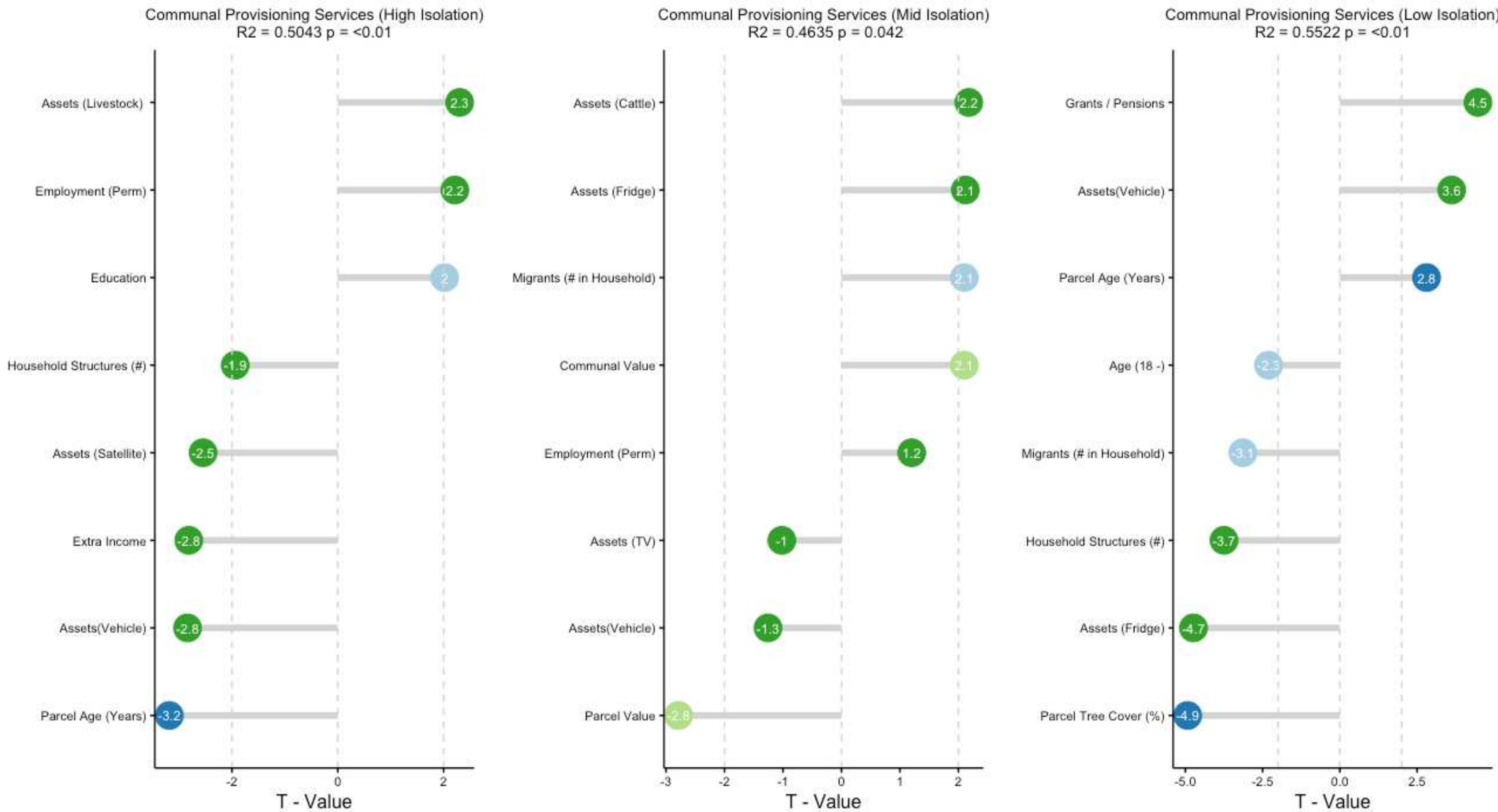

Figure 2.8: Communal-Scale provisioning ES Models for high, medium, and low isolation villages show that morphological and wealth characteristics of households are the primary predictors of ES values and use in communal lands among households.

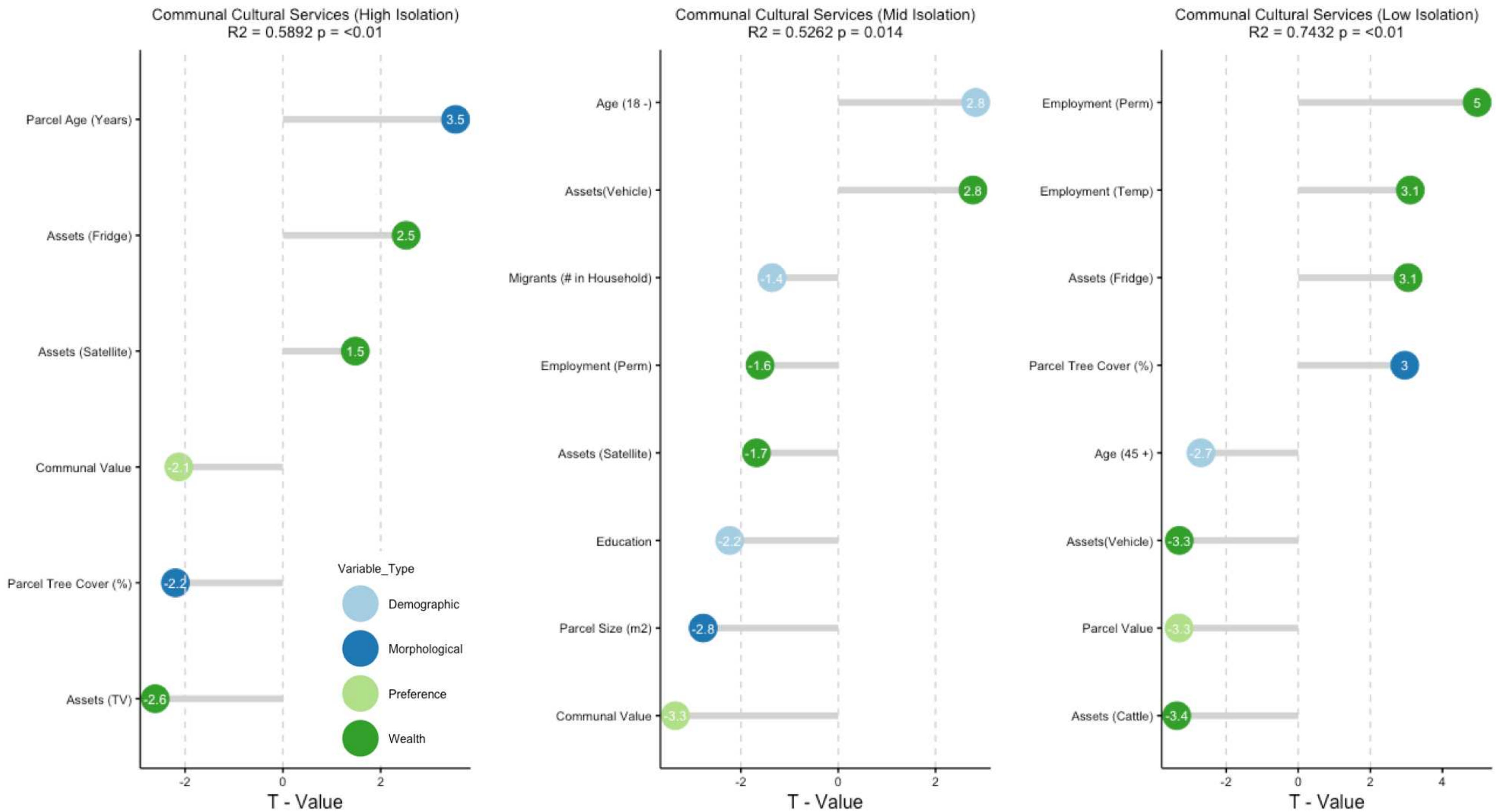

Figure 2.9: Communal-Scale cultural ES Models for high, medium, and low isolation villages show that morphological, wealth, and preferences are the primary characteristics of households that predict cultural ES values and use among households on parcels.

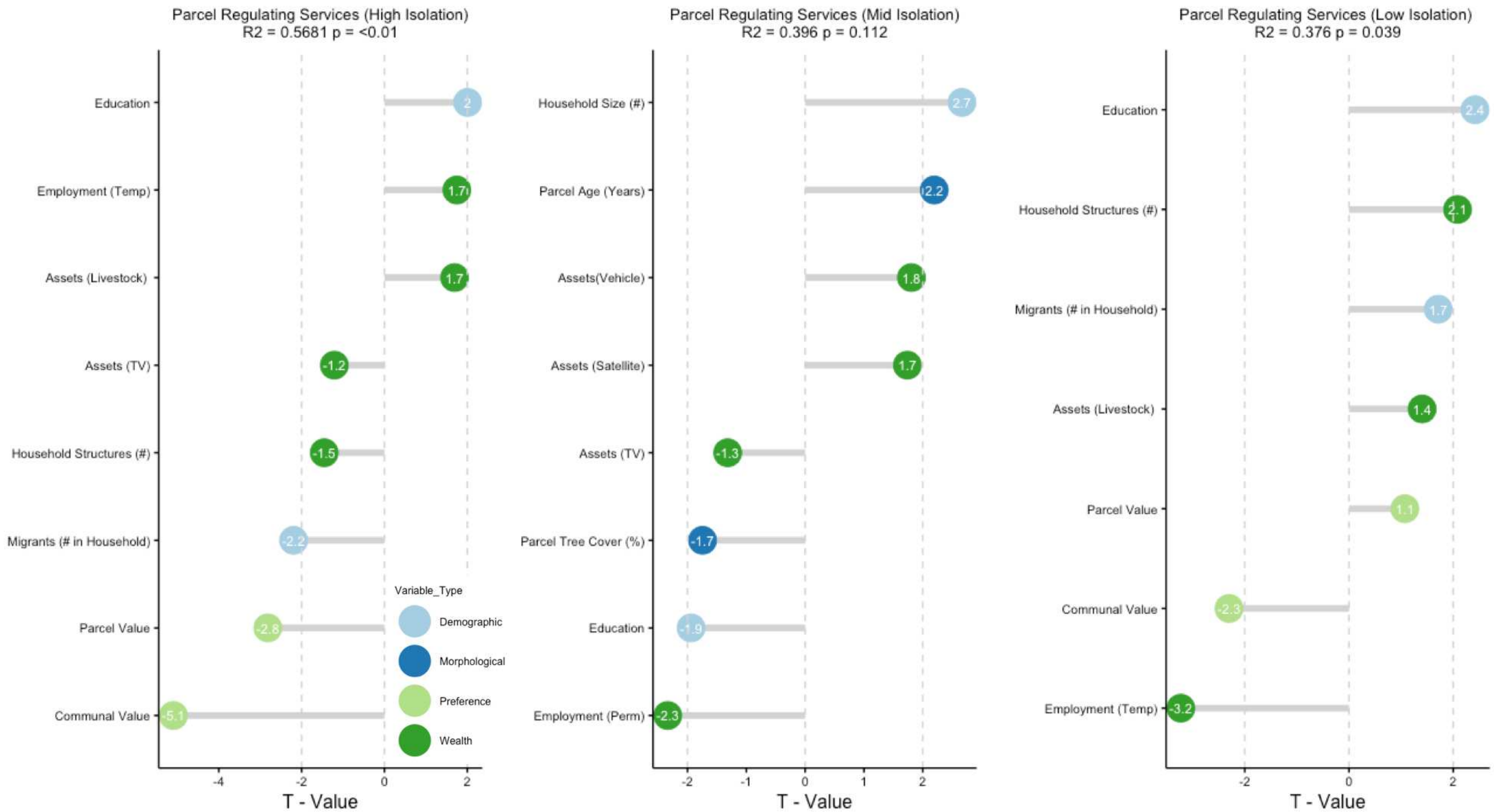

Figure 2.10: Communal-Scale regulating ES Models for high, medium, and low isolation villages show that wealth and demographic characteristics, and preferences of households predict ES value and use among households in communal areas.

2.4. Discussion:

Communities indeed receive a diversity of ecosystem services from the places in which they live, and the value of these services to households does differ between parcels and the communal lands. Additionally, the isolation of villages does influence the proportions of ES derived from parcels and/or communal lands. Since humans are instruments of ecosystem and land change, socio-cultural ES values and demand are likely to influence the future supply and availability of services differently across space. Additionally, development pressures and population growth will only compound existing accessibility issues. In this section, we highlight the implications of these social and spatial demands. Additionally, we examine how socio-cultural assessments, similar to the one reported in this manuscript, can contribute to more holistic and sustainable management strategies.

2.4.1. Location Matters for Community Ecosystem Service Demand & Planning

Roughly 80% of all community identified ecosystem services are supplied by trees, which generally deliver multiple services depending on their location in the landscape; however, there is a distinction between the types of services received from communal lands and parcels. For example, communal trees are thought of collectively as a barrier to wind and a source of wild fruits, while a single tree on a parcel could be a source of food, shade, protection from wind and dust, erosion control, and a prayer alter (Table 2.4). Additionally, 63.8% of respondents indicate that the services they receive from their parcels are more valuable than those they receive from the communal lands. However, 58.1% of respondents indicated that many of the trees on their parcels were found as saplings in the communal lands and brought home for planting. Furthermore, 73.4% of respondents received plants from their neighbors, who might have originally collected them in the communal lands. These connections underscore relationships between services needed from communal lands, villages, and parcels, and should serve as a reminder that the locations from which ecosystem services are derived are inextricably connected.

The isolation of villages also played a role in how communities use and value their ecosystem services. Living near townships constricts the availability of communal resources, as these villages are typically larger and subject to urban encroachment. However, these are also the communities in which parcel-scale services are more highly valued. Of the 37 respondents living in the least isolated sample villages, 65% indicated that parcel-scale ecosystem services were most critical, while 27% favored communal services. Conversely, in the most isolated villages 25% of respondents (n=36) favored parcel services and 73% favored communal services.

While the full suite of mechanisms behind this separation are unclear, the relative wealth and parcel morphology of households within these villages likely plays a role since parcel-scale benefits are generally more often prioritized by wealthier households with larger, older parcels (Figure 2.2). Additionally, these households have greater access to urban amenities and transportation networks that might marginally improve economic prospects (Ogun 2010) as compared to those in more isolated communities. When considering these factors, it becomes clear that the one-size-fits-all management approaches favored by municipalities (e.g. BBR IDP 2015) could lead to greater inequality in the region.

More specialized management strategies have been recommended in the past, and our results are supportive of those studies that identify communal lands as a significant source of economic benefits through fuelwood harvesting (Luoga et al. 2000; Shackleton et al. 2000) and other non-timber forest products (Shackleton 1996; Shackleton & Shackleton 2000). Additionally, they confirm that socio-economic variation within communities can influence how households value non-timber communal forest products (Shackleton & Shackleton 2005). However, since such little attention has been paid to parcel-scale ecosystem services – beyond some meager economic benefits stemming from diverse plantings in home gardens (High & Shackleton 2000) – our results provide additional context regarding the true socio-cultural value of, and linkages between, landscapes that could aid development and conservation planning. Although demand for ecosystem services from parcels and communal lands is high, a more diverse and sustainable array of services are parcel-based.

2.4.2. Tradeoffs in Communal ES Value and Use Reveal Positive & Negative Possibilities

Fuelwood harvesting is pervasive throughout sub-Saharan Africa (Twine 2005; Madubansi & Shackleton 2007), so it is no surprise our data show that communal ES are primarily extractive. Demand for wood has created an unsustainable pattern of harvesting (Wessels et al. 2013). Despite the electrification of more than 90 percent of households in the region, most are still reliant on fuelwood for cooking and heating (Madubansi & Shackleton 2007). Communities are increasingly hard-pressed to meet their resource needs due to the impacts of harvesting on vegetation structure and patterns (Twine 2005; Kirkland et al. 2007). Additionally, resource scarcity could be contributing to escalated overexploitation of communal resources (Hardin 1968; Madubansi & Shackleton 2007).

Although provisioning services represent the most substantial valuation of communal ES, the communal lands were also highly valued as a cultural resource by individuals who do not utilize communal provisioning ES like those in low isolation villages (Figures 2.2 and 2.3). Those who prioritize cultural services highlighted the recreational, medicinal, aesthetic, and generational learning opportunities provided by communal lands. Additionally, individuals who valued parcel-scale cultural services emphasized the importance of communal lands as cultural resources (Figure 2.3), which suggests that ecosystem services losses due to harvesting extend beyond fuelwood and provisioning service extraction. Essentially, important cultural services may be jeopardized by demand for fuelwood.

The situation might seem challenging, but this tradeoff could represent a substantial opportunity to alleviate resource scarcity in communal lands by pivoting towards development policies that allocate parcels more appropriately. For instance, of the 79 respondents who reported visiting the communal lands to harvest food and wood, 67% suggest that they would never venture to the communal lands if their parcels were sized to grow adequate wood and food to meet their needs. This implies that communal resource harvesting is often viewed as a burdensome use of time and labor, which supports previous findings (Madubansi & Shackleton 2007).

2.4.3. Parcels are the Future of Ecosystem Service Provisioning

The socio-cultural value and demand structure observed in this study contradict the oversimplified, business-as-usual management practices that prioritize services from communal and protected lands (e.g. BBR IDP 2016). For instance, official planning maps utilized in the Bushbuckridge Integrated Development Plan (2016) are based on land use and characterize villages and townships as “other” or “least important” (McHale et al. 2018). Our results indicate that parcels are not only more valuable to communities than communal and protected areas, but they provide a more diverse assortment of services (Tables 2.2 & 2.3).

Finding an appropriate balance between parcel size and communal land conservation priorities could ultimately free communities from the burdens of resource harvesting. Additionally, they might allow for more successful management strategies that maximize and sustain cultural ecosystem service delivery. However, there are barriers to this potential solution, including conflicts between those who perceive access to communal resources as a right and the institutional controls that govern communal land use – like traditional versus municipal governance systems (Twine 2005). Furthermore, development and population growth are progressing rapidly in this and many other regions of sub-Saharan Africa, which puts added pressure on already stressed communal resources (Wessels et al. 2013). Despite these challenges, barriers might be overcome through continued community and civic engagement. Management strategies that continue to ignore distinctions between service types and locations will likely perpetuate inequitable access to important ecosystem services.

2.5. Conclusions:

We conducted a socio-cultural assessment of ecosystem services in the Bushbuckridge region of South Africa. Six sample communities were selected along a gradient of isolation from urban townships. We used walking interviews and surveys to identify and value socio-cultural ES. We also used geospatial overlays to link services to land cover types. Finally, we developed OLS regression models of relative importance to characterize individuals who value service types. Our findings indicate that trees provide an overwhelming proportion of services. Additionally, isolation and wealth strongly influence ES use among communities. Villages that are more isolated prioritize services from both communal lands and parcels, while villages closer to townships prefer parcel-scale services alone. Furthermore, there are tradeoffs associated with fuelwood collection and communal resource harvesting that contribute to high parcel-based ecosystem service values. These findings are contrary to current management practices that prioritize communal resources and ignore services in developed lands. Allocation and sizing of parcels represent a possible solution to significant resource and sustainability challenges.

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CHAPTER 3 – MAPPING SOCIO-CULTURAL ECOSYSTEM SERVICES

3.1 Introduction

Ecosystem services (ES) are the benefits provided by nature that improve the quality human life, and have thus become a critical focus for researchers over the past decade (Costanza et al. 1997; Daily 1997; Zhao et al. 2017). Subsequently, a lot of effort has gone into measuring ES at multiple scales to provide insights into the full value of the earth's resources (de Groot, Wilson, and Boumans 2002; de Groot et al. 2010; Zhao et al. 2017). In particular, mapping has shown promise as a mechanism for communicating ES values across landscapes. Despite the recent proliferation of ES mapping frameworks (Mchale et al. 2018) there seems to be a lack of quality ES mapping conducted at local-extents (Egoh et al. 2012), especially in socially vulnerable areas like sub-Saharan Africa (Wangai, Burkhard, and Müller 2016; Beck et al. in prep). This oversight is in spite of the fact that decision-making is primarily enacted at local-scales (Cowling et al. 2008), and misaligned conservation policies disproportionately affect the most vulnerable people living in these places (McHale et al. 2018). It is therefore pertinent that we begin to address these issues surrounding ES mapping to promote more equitable planning.

3.1.1 Progress in ES Mapping

Although it is happening slowly, ES mapping has evolved over the past two decades. Evolutions in ES mapping tend to coincide with the emergence of alternative ES valuation pathways. For instance, as researchers sought to explain the value of biophysical ecosystem processes and functions that could not be expressed through economic valuation, a biophysical ES valuation pathway emerged to fill this need. In response, a substantial number of biophysical ES mapping approaches have materialized (e.g. Egoh et al. 2008; Egoh et al. 2009; Harrison et al. 2014).

More recently, the need to adequately assess and value cultural ES has shifted much of the focus within the ES community towards socio-cultural ES valuation priorities (Chan, Satterfield, and Goldstein 2012; Chan et al. 2012). Although there are a diversity of methods to assess and value socio-cultural ES, two notable characteristics of empirical socio-cultural ES valuations is that they tend to seek stakeholder input, and are often assessed at local scales (Scholte, van Teeffelen, and Verburg 2015). It is these characteristics that make socio-cultural ES valuation a promising mechanism for measuring and mapping the value of the natural environment among vulnerable populations.

3.1.2 Stakeholder Engagement

Stakeholder input is a vital element of socio-cultural ES valuation. For example, how can social or cultural ES be measured if researchers have no understanding of how communities use and value their resources? Regardless of valuation approach, some level of engagement is necessary to elicit social values; however, the underlying purpose of engagement will determine the type of ES values that are identified. For instance, Reyers et al. (2009) sought stakeholder input from managers and beneficiaries to determine which ES to model in response to land-cover change in the Little Karoo, South Africa. Conversely, Fagerholm et al. (2012) used a participatory mapping exercise within communities to identify and map 19 important landscape ES associated with land-cover proxies in Zanzibar, Tanzania. These studies illustrate two of the most common purposes of engagement applied in ES mapping. The first is to determine which ES might be important to map and/or model (e.g. Reyers et al. 2009), and the second is to learn about, identify and map the ES that are used and valued by people at the community-scale (e.g. Plieninger et al. 2013). Although, each approach has its merits, methods that levy stakeholder engagement to identify and map how communities use and value their environments are more likely to lead to equitable planning strategies implemented at local scales.

There are several examples of local-scale, participatory ES mapping of community values that could offer important information to planners. Specifically, Plieninger et al. (2013), used participatory mapping to identify and map cultural ES and disservices in localized communities in Germany. Also, Raymond et al. (2009), used surveys and participatory mapping to assess a suite of community ES values in Australia. Additionally, there is evidence that suggests socio-cultural ES values are influenced by location and proximity to urban centers (Beck et al. in prep) that would be overlooked in regional to global scale analyses. Studies like these, and others (e.g. Bryan et al. 2010; Sherrouse, Clement, and Semmens 2011; Fagerholm et al. 2012), offer insights into community ES values that could not otherwise be captured by more broad analyses, which makes them more appropriate for local decision-making.

3.1.3 Ongoing Needs

Despite these recent developments, socio-cultural ES mapping has been tested almost exclusively in the global north (Egoh et al. 2012; Beck et al. in Prep). This is a surprising development given the tangible relationship that vulnerable communities in the global south have with the natural environment (Shackleton et al. 2007). For example, although important efforts have been made to identify and measure the monetary and non-monetary worth of non-timber forest products among impoverished communities in sub-Saharan Africa (e.g. Shackleton et al. 2007; Kirkland, Hunter, and Twine 2007; Shackleton et al. 2015), almost none of these studies apply mapping for the purposes of planning.

Additionally, these studies tend to focus exclusively on ES provision, or extraction, rather than a full suite of multiple or shared community ES values. Indeed, Fagerholm et al. (2012) is the only example that actually maps a full suite of community-scale socio-cultural values in sub-Saharan Africa; however, the spatial resolution (200 m) at which mapping was applied could make it difficult to accurately measure the landscape impacts of ES demand. If this is the case, then the usefulness of method like these for landscape and conservation management might be limited. This means we still have no real spatial understanding of how these important community values might vary and impact the landscape.

Furthermore, the bulk of studies that map ES in these regions are typically conducted at national to regional extents using low spatial resolution data that are inappropriate for local-scale assessments of heterogeneous human ecosystems (Ridd 1995; Cadenasso, Pickett, and Schwarz 2007). Resolution mismatches like these have led to policies that can have detrimental effects on local communities (McHale et al. 2013; McHale et al. 2018). Furthermore, these studies focus almost exclusively on biophysical processes (e.g. Egoh et al. 2008; Egoh et al. 2009) or ES provision (e.g. Heubes et al. 2012).

This means that culturally important ES, like spiritual and educational values, have largely been overlooked throughout sub-Saharan Africa. Therefore, there is a somewhat urgent need to buck the status quo and reprioritize our efforts towards those that map community ES landscape values at high spatial resolutions to support local-scale planning. Mapping methods that continue to leverage course resolution data for the purpose of conserving biodiversity and biophysical ES without first attempting to understand the dynamics of community values at the local-level do a disservice to vulnerable people whose priorities might be in conflict with conservation agendas (McHale et al. 2018).

The overarching goal of this study is to develop a method for visualizing local-scale, socio-cultural ES at high spatial resolutions (1 m). More specifically, I aim to compare two villages in the Bushbuckridge Local Municipality, South Africa, to determine whether or not alternative socio-cultural ES values can be captured and mapped. To achieve my goals, I aimed to: (1) create a high-resolution land-cover classification to understand the structure of the landscape on the ground; (2) link community ES values to land-cover; (3) develop a method to model these community ES values spatially; and (4) analyze the spatial representation of community ES values in two villages. A method that maps and measures community ES values at appropriate scales could be used to model potential landscape impacts, which will be useful for planning. Additionally, mapping tree ES priorities among communities has implications for the long-term viability and resilience of vulnerable communities throughout sub-Saharan Africa.

3.2 Methods

3.2.1. Study Site:

The Bushbuckridge Local Municipality is an approximately 10,250 km^2 third tier administrative unit situated in Mpumalanga Province, in Rural South Africa. It has a population of roughly 550,000 people (Census 2011). There are 135 individual settlements spread among nine traditional authorities that act as informal governmental organizations headed by "Indunas" (or chiefs). Despite the presence of a centralized municipal government, the traditional authorities are highly influential organizations that govern the development of villages and conservation of communal lands – where a variety of natural resources are shared amongst community members. For instance, although the municipality claims authority over growth in the region, the tribal governments collect annual fees and taxes from individuals, set parcel size limits, and ultimately allocate parcels within settlements.

The region is dominated by arid woodland savannah. It is highly biodiverse and the surrounding private and public conservation reserves, including the Kruger National Park to the east, make it one of the most visited regions in the country (SANParks, 2016). In addition, the area covers a significant portion of the UNESCO Kruger to Canyons biosphere reserve, which extends from the interior of the Kruger National Park to the Blyde River Canyon and Drakensberg Escarpment.

3.2.2. Village Sampling & Social Data Collection:

To link community ES values to tree cover (Objective 1), two villages were selected for analysis based on their proximity to urban centers, where Timbavati is adjacent to a more urbanized township and Welverdiend is among the most isolated villages in the region (Figure 3.1). Spatial extent and land-cover differences among these villages are presented in Table 3.1.

Table 3.1: Characteristics of Villages for Mapping Comparison.

Village	Urban Proximity	# of Households	Village Area (Km^2)	Parcel Scale Tree Cover (% / Total Area)	Communal Scale Tree Cover (% / Total Area)
Timbavati	More Urban	1039	4.94	17.84%	25.36%
Welverdiend	Rural / Isolated	2984	3.02	10.41%	11.94%

Primary social data was collected using walking interviews and surveys. The full methodological description of this effort is available in Beck et al. (in prep). In summary, ES were identified and associated with different land cover types by community members during walking interviews on private parcels and in communal lands. An initial household was chosen using a random address generator. Subsequent households were approached by crossing the street and moving three houses to the left. This pattern was repeated until a respondent was willing to participate.

To initiate a walking interview, the first author (Beck) would ask a respondent if they would take him on a “tour” of their parcel and teach him about all the benefits provided by nature that they use and value. As sites were visited, GPS coordinates were taken, land cover features were noted (e.g. trees), and the ES associated with these land cover features were recorded. Once the tour was completed on parcels, the process was repeated in the communal lands. These walking interview data were used to construct a more quantitative social survey, where ES were prioritized by community members. The same door-to-door sampling method was used to disseminate the surveys and walking interviews. These community-prioritized ES are used to create an ES value scores for provisioning ES, cultural ES, regulating ES, and a combination of All ES that are used in our spatial models.

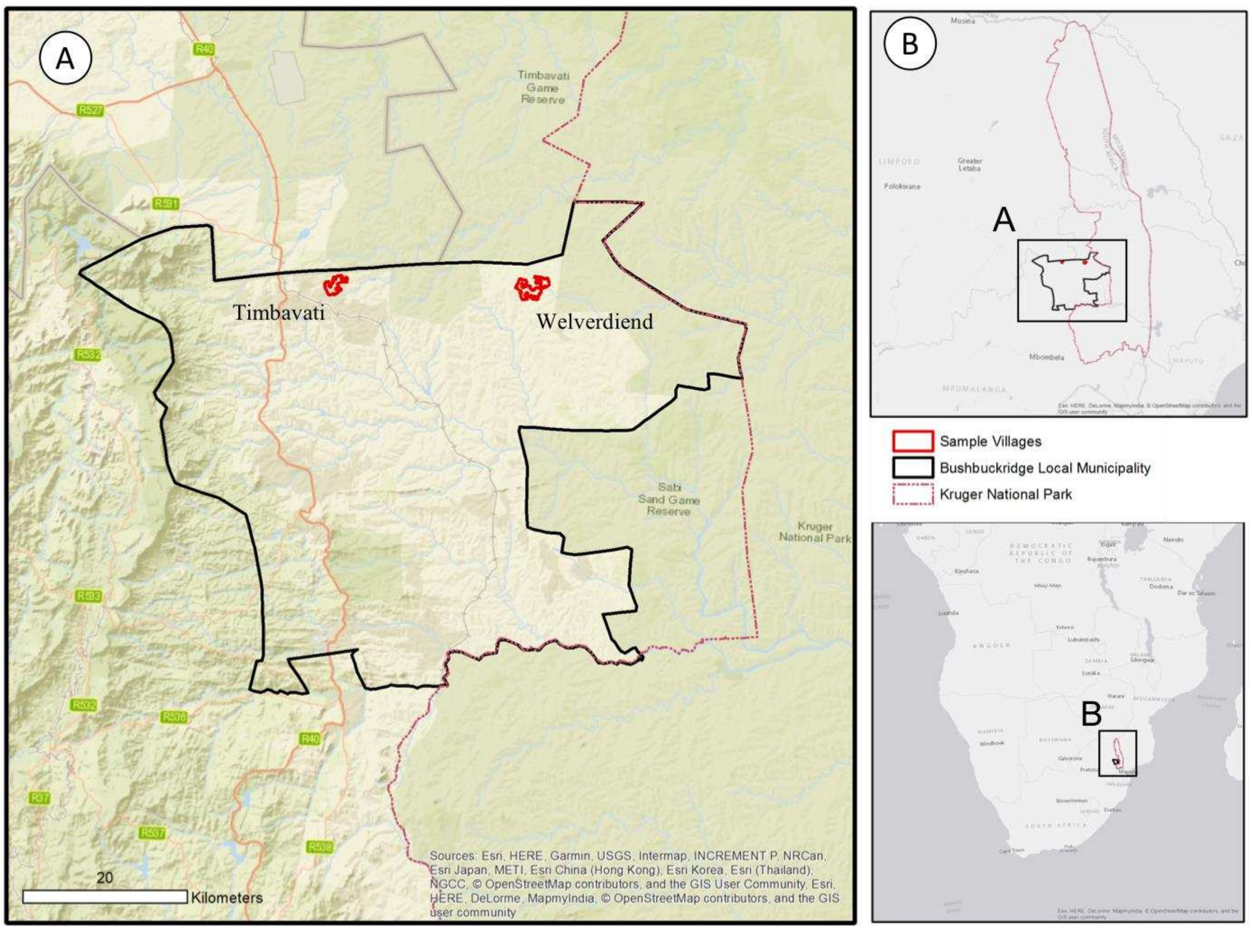

Figure 3.5: Map of Bushbuckridge Local Municipality and Sample Villages along an Isolation Gradient from Townships

3.2.3. Land-Cover Classification:

To characterize community prioritized tree ES (Objective 2), we created an object-oriented, high spatial resolution (1 m) land cover classification. High resolution (1 m) multi-spectral areal imagery of the region from 2012 were obtained from the Global Change and

Sustainability Research Institute at the University of the Witwatersrand. Object oriented classification algorithms that detect textural, spectral, size, and shape similarities among contiguous pixels in the images were applied using Erdas IMAGINE's objective classification software. These algorithms were used to delineate seven true ground features: (1) coarse vegetation (tree and woody vegetation cover); (2) open water; (3) paved roads; (4) unpaved roads; (5) buildings/structures; (6) fine vegetation (e.g. grasses); and (7) bare ground.

A post-processing method developed by Bigsby, McHale, and Hess (2014) was applied to remove shadows, fill in gaps between image objects, and smooth the final the classification product. This process begins by creating an image mask that removes shadows and reclassifies all other features to a single value. We then run a "nibble" function with the mask overlaid on the classification image. The nibble function replaces all shadows in the image using a nearest neighbor interpolation. The result of this process leads to a classification image with no shadows or gaps. Finally, majority filter and boundary clean functions are applied to finalize and smooth the classification product.

The tree cover layer was then extracted from the full classification and used to spatially model tree ES in the sample villages. Since the recognition that high resolution spatial data are needed to accurately identify features and conduct biophysical analyses within the urban matrix (Ridd 1995; Cadenasso, Pickett, and Schwarz 2007), these types of land cover classifications are seeing increased use in urban systems (e.g. Bigsby, McHale, and Hess 2014; Grove, Locke, and O'Neil-Dunne 2014; Schwarz et al. 2015; Beck, McHale, and Hess 2016; Pickett et al. 2016).

3.2.4. Huff and Geospatial Modeling to Map Tree ES:

We applied Huff Probability Models to quantify and visualize tree ES priority areas among the sample villages (Objective 3). The Huff model is an established spatial interaction model, based on gravity models of distance decay, that has a wide range of applications in business analytics (e.g. Okunuki and Okabe 2002; De Beule et al. 2014; Luo 2014). It centers on Waldo Tobler's first law of geography, which was introduced in 1969. Tobler states that "everything is related, but near things are more related than distant things". Tobler's first law serves as the basis of many spatial interpolation models, including gravity distance decay models like Huff. The Huff model is expressed as:

$$P_{ij} = (\frac{W_i}{D_{ij}^a}) \, / \sum_{i=1}^{n}(W_i/D_{ij}^a)$$

Where P is the probability that an individual (i) will visit a site (j) as a function of that sites attractiveness (W) and its distance (D^a), given all of the other options available to that individual, and their attractiveness and distances ($\sum_{i=1}^{n}(W_i/D_{ij}^a)$).

In this case study, we modeled the probability that trees will be utilized by individuals both within the sample villages and the communal lands based on their community-prioritized ES value (ES Value Score). Additionally, we included a place value score by measuring community preferences for communal areas and parcels in each village. ES and Place Value Scores were randomly assigned to each tree patch from within one standard deviation of the overall mean for each ES as estimated from the social surveys.

Attractiveness (Wi) is calculated as: W_i = *ES Value Score* + *Number of Households* + *Tree Cluster Values* + *Place Value Score*. Attractiveness scores are finalized by dividing the square of the distance (D_{ij}^a) of each tree to individuals within the sample villages. The exponent (α) serves as the decay function of these distances and is most commonly set to 2 in Huff Modeling, although it could range from 1.5 to 3. The final Huff probability scores are generated by dividing attractiveness values by the summation of the attractiveness of each tree in the model

$(\sum_{i=1}^{n}(W_i/D_{ij}^{a}))$. We set 2km buffers around each village in to model Huff probabilities for communal lands.

In total, we created eight Huff probability models in each sample village: (1) Provisioning Parcel Services; (2) Provisioning Communal Services; (3) Cultural Parcel Services; (4) Cultural Communal Services; (5) Regulating Parcel Services; (6) Regulating Communal Services; (7) All Parcel Services; and (8) All Communal Services. A full accounting of ES and Place Values used in Huff modeling equations is presented in Table 3.2. All of these analyses were conducted using ArcGIS 10.4.1.

Table 3.2: Village ES Priority Numbers for Parcels and Communal Lands, and ES Specific Huff Model Equations.

Village / ES Location	Mean Provisioning ES Priority	Mean Cultural ES Priority	Mean Regulating ES Priority	Mean ALL ES Priority	Mean Place Scale
Timbavati Parcel	5.74	3.63	4.21	14	7.79
Welverdiend Parcel	6.15	3.3	4.2	13.85	6.5
Timbavati Communal	3.12	5.78	0.21	9.26	6.12
Welverdiend Communal	7.4	3.65	0.3	11.35	7.2

3.2.5. Analysis:

To determine whether variation in ES values/priorities among the study villages are able to be spatially captured (objective 4) we generated combined box and violin plots of the modeled Huff probabilities. Box and violin plots show quartiles, medians, means, and densities of ES Huff Model probabilities for each ES type in these villages. Differences in Huff probabilities among these villages are a result of variances in the attractiveness parameter, which is based on ES value scores and place scores that were measured using social surveys on parcels and in communal lands. Capturing the spatial variation in social values for tree ES could be useful when devising community strategies for conservation planning.

3.3 Results

This analysis answers our primary research question and finds that there are indeed differences in tree ES use probabilities among the study communities that can be accurately captured using Huff Modeling. Additionally, these differences are able to be adequately visualized through mapping and statistical analysis. Although there are subtle variations among ES types in communal lands, the greatest dissimilarities are observed within the two study villages. Comparisons of each Huff probability model by tree ES type among the study villages are outlined in the sections below.

3.3.1. Provisioning ES (Figure 3.2):

Provisioning ES Huff probabilities range from 13-100% on parcels in Welverdiend, and from 8-100% on parcels in Timbavati. Conversely, these probabilities range from 0-99.9% in communal lands in Welverdiend, and from 1-100% in communal lands in Timbavati. More interesting results are evident when evaluating densities of these Huff probabilities. Although differences in densities among Huff probabilities for provisioning ES in communal lands is subtle, variations among densities on parcels are more pronounced (Figures 3.6 & 3.7). Based on this comparison, it appears that individuals in Welverdiend are slightly more likely to utilize trees on parcels for provisioning ES than those in Timbavati. Despite this result, provisioning services are highly valued among both communities, which can be expected due to the necessity of this service type for sustaining livelihoods in the region.

3.3.2. Cultural ES (Figure 3.3):

Cultural ES Huff probabilities range from 2-92% on parcels in Welverdiend, and from 8-100% on parcels in Timbavati. Conversely, these probabilities range from 0-100% in communal lands in Welverdiend, and from 1-100% in communal lands in Timbavati. Similar to the provisioning ES models, differences among cultural ES use probabilities are subtle in communal lands and more pronounced on parcels (Figures 3.6 & 3.7). These results suggest that trees on parcels in Timbavati are more likely to be utilized for cultural ES than those in Welverdiend. These findings lend support to previous results from Beck et al. (in prep) that show higher demand for cultural ES in Timbavati than more isolated villages like Welverdiend (Table 3.2).

3.3.3. Regulating ES (Figure 3.4)**:**

Regulating ES Huff probabilities range from 2-100% on parcels in Welverdiend, and from 0-100% on parcels in Timbavati. Conversely, these probabilities range from 2-100% in communal lands in Welverdiend, and from 2-100% in communal lands in Timbavati. When comparing densities of these probabilities (Figures 3.6 & 3.7), it appears that individuals are slightly more likely to utilize regulating ES in Welverdiend than in Timbavati.

3.3.4. All ES (Figure 3.5):

The combination of All ES Huff probabilities ranges from 7-100% on parcels in Welverdiend, and from 8-100% on parcels in Timbavati. Conversely, these probabilities range from 2-100% in communal lands in Welverdiend, and from 1-100% in communal lands in Timbavati. Densities of these probabilities show very subtle differences in combined services on communal lands among the villages (Figures 3.6 & 3.7). Additionally, trees in both villages are likely to be used for All ES combined on parcels, but trees in Timbavati are more likely to be

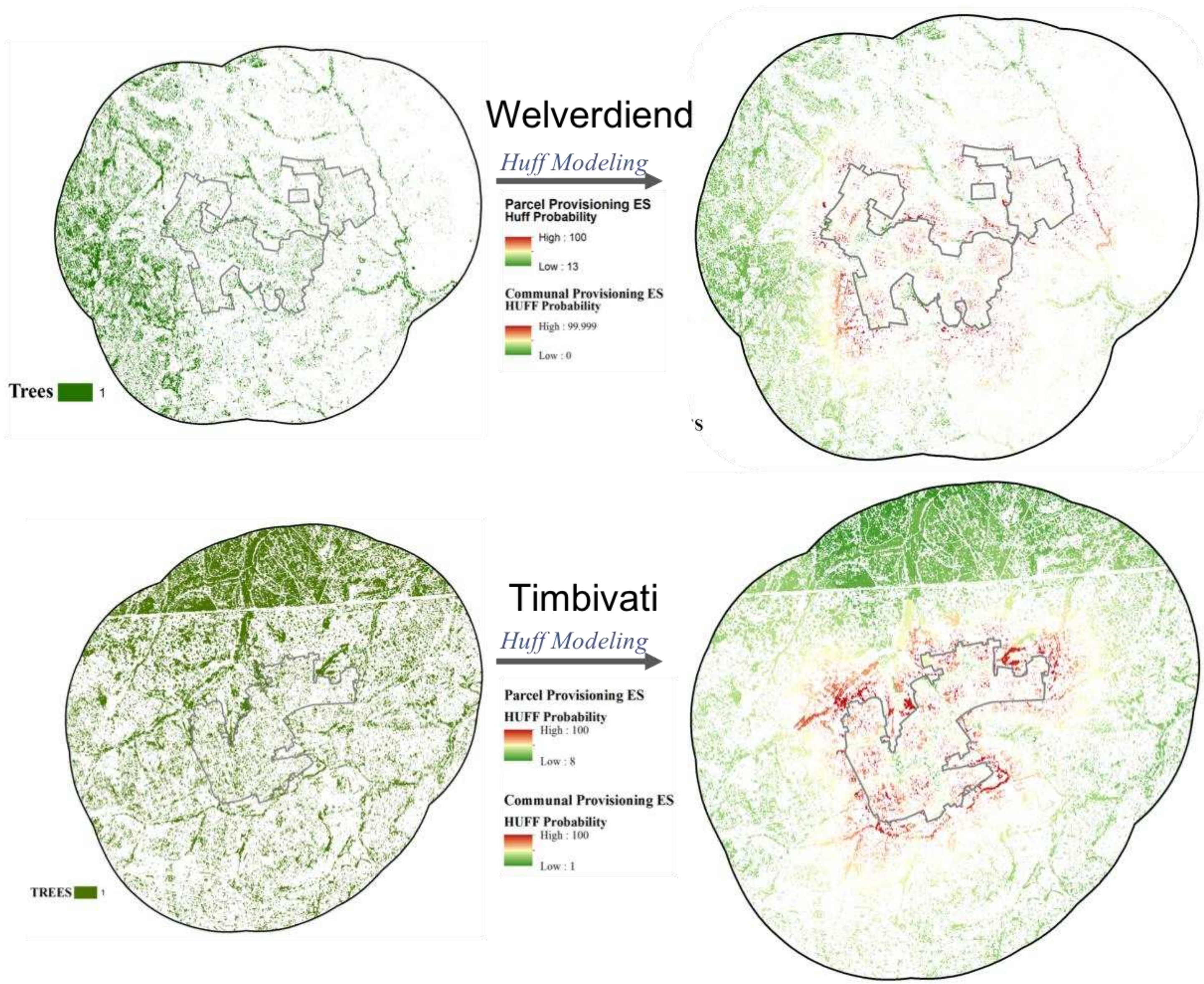

Figure 3.2: Huff Probability Maps for Socio-Cultural Provisioning Services in Welverdiend & Timbivati Villages. Parcel and communal scale probabilities for each village are scaled from green to red, where green areas represent lower probabilities of use and red areas represent higher probabilities of use of provisioning tree ecosystem services.

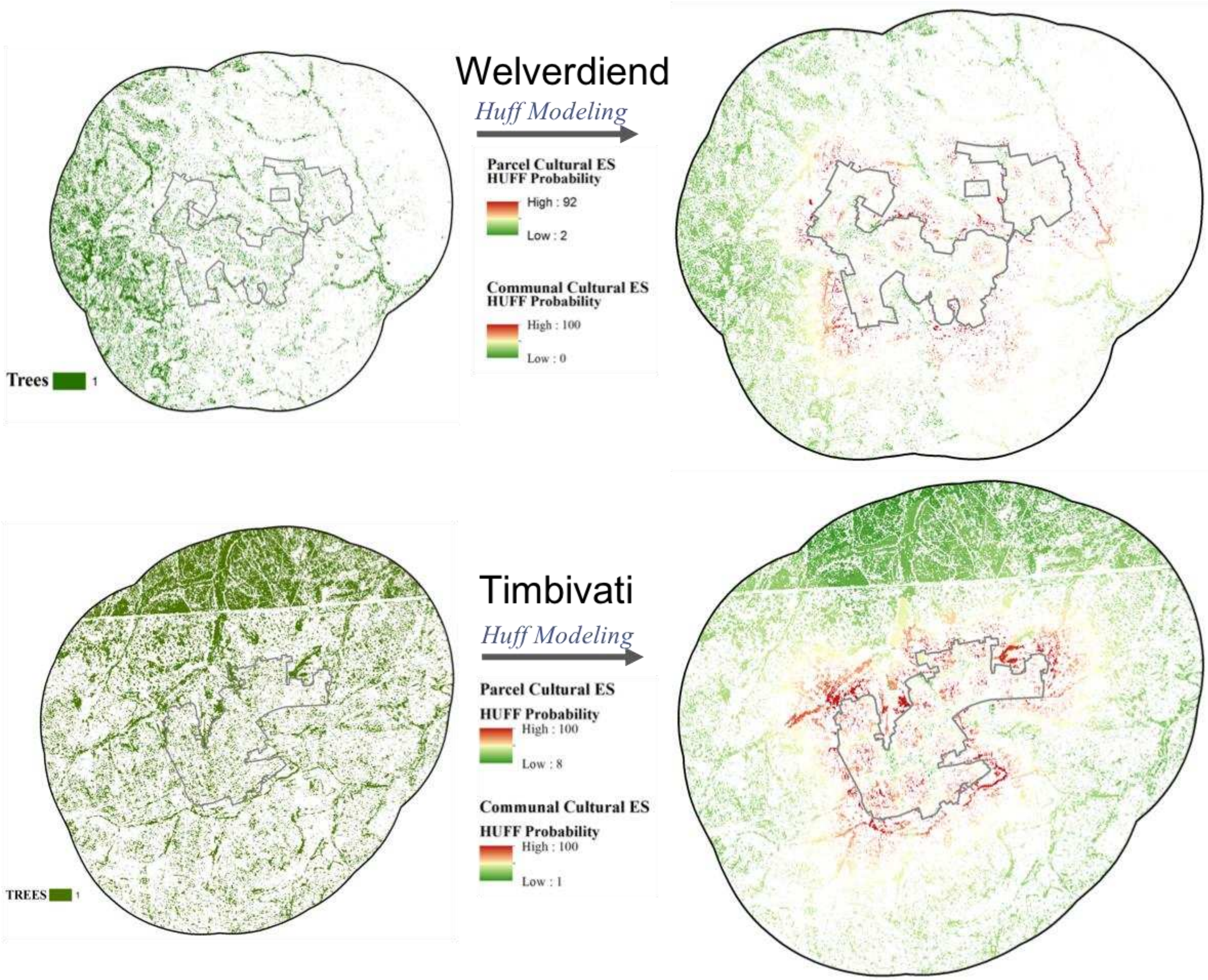

Figure 3.3: Huff Probability Maps for Socio-Cultural Cultural Services in Welverdiend & Timbivati Villages. Parcel and communal scale probabilities for each village are scaled from green to red, where green areas represent lower probabilities of use and red areas represent higher probabilities of use of cultural tree ecosystem services.

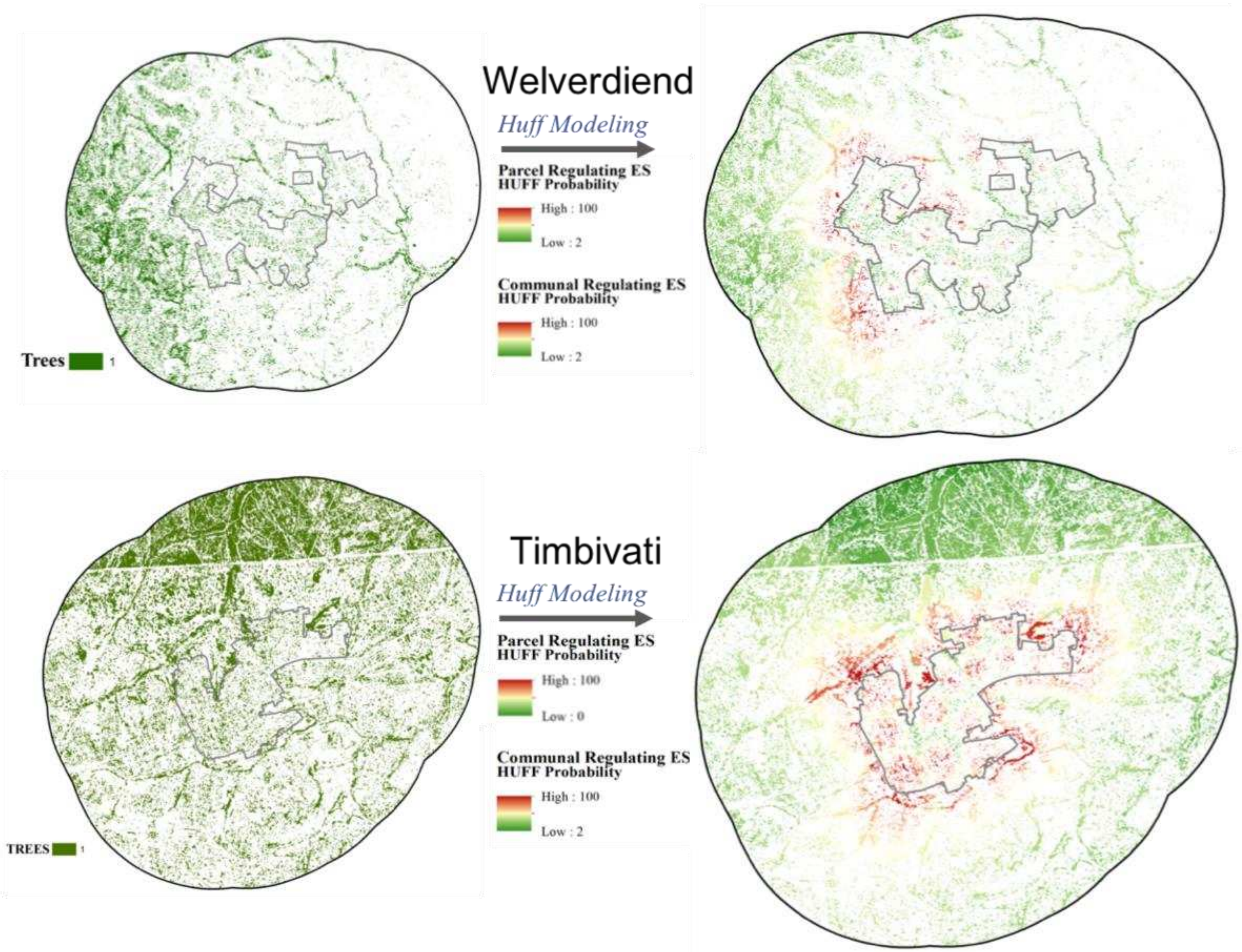

Figure 3.4: Huff Probability Maps for Socio-Cultural Regulating Services in Welverdiend & Timbivati Villages. Parcel and communal scale probabilities for each village are scaled from green to red, where green areas represent lower probabilities of use and red areas represent higher probabilities of use of regulating tree ecosystem services.

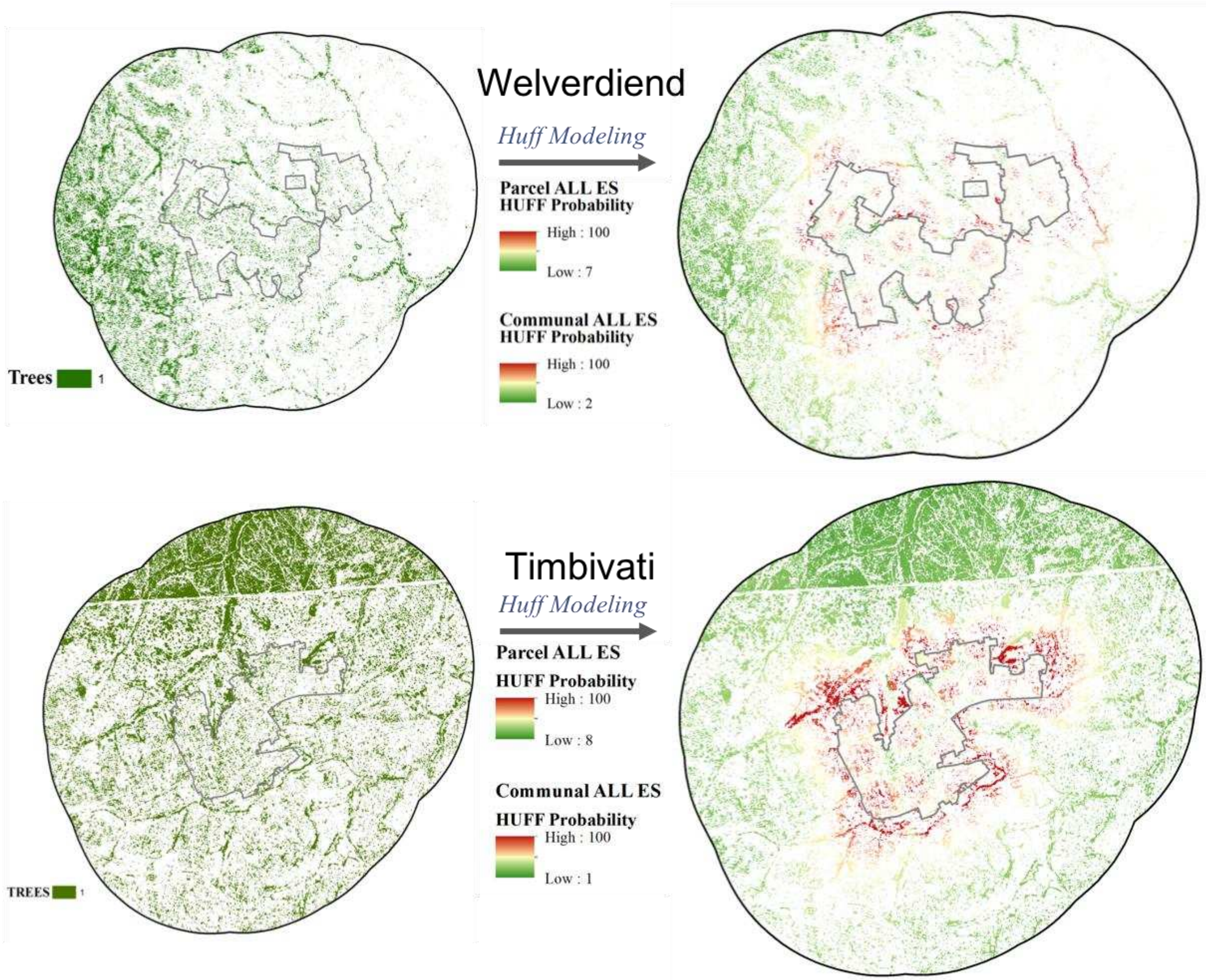

Figure 3.5: Huff Probability Maps for ALL Combined Socio-Cultural Ecosystem Services in Welverdiend & Timbivati Villages. Parcel and communal scale probabilities for each village are scaled from green to red, where green areas represent lower probabilities of use and red areas represent higher probabilities of use of all combined tree ecosystem services.

utilized. These differences are likely a result of the strong influence of provisioning ES in Welverdiend when compared to the more balanced ES priorities in Timbavati.

3.4 Discussion

Our primary goal was to develop a method for mapping a full suite of community prioritized, socio-cultural ES at high spatial resolutions that could be a more useful strategy for local-scale planning than current methods. Through the application of an advanced Huff model that mapped probabilities of tree ES use, we were able answer our research question by accurately capturing social and spatial variation in community ES priorities among two villages sampled from an urbanization gradient in the Bushbuckridge Local Municipality, South Africa. We discuss these findings, their implications for planning, and how this method might help advance land change science and decision-making in the sections below.

3.4.1. Mapping Variation in Socio-Cultural ES Priorities

This fine scale application of the Huff model for mapping socio-cultural ES values allows us to capture the spatial variation of different ES types among communities. Density plots show that although there are only subtle differences in the probabilities that trees will be utilized for ES in the communal lands, there are far more substantial differences in the probabilities of ES use on parcels (Figures 6 & 7). This is likely due to differences in the ways in which these communities prioritize tree ES. For example, communal ES priorities are relatively similar in Timbavati and Welverdiend, while prioritization of parcel scale services is more varied (Table 3.2). Therefore, it is likely that communities with more dramatic variations in ES priorities will show greater shifts in mapped ES Huff probabilities as they are mapped in other regions. The ability to tie ES values directly to a specific land cover type, and capture these variations

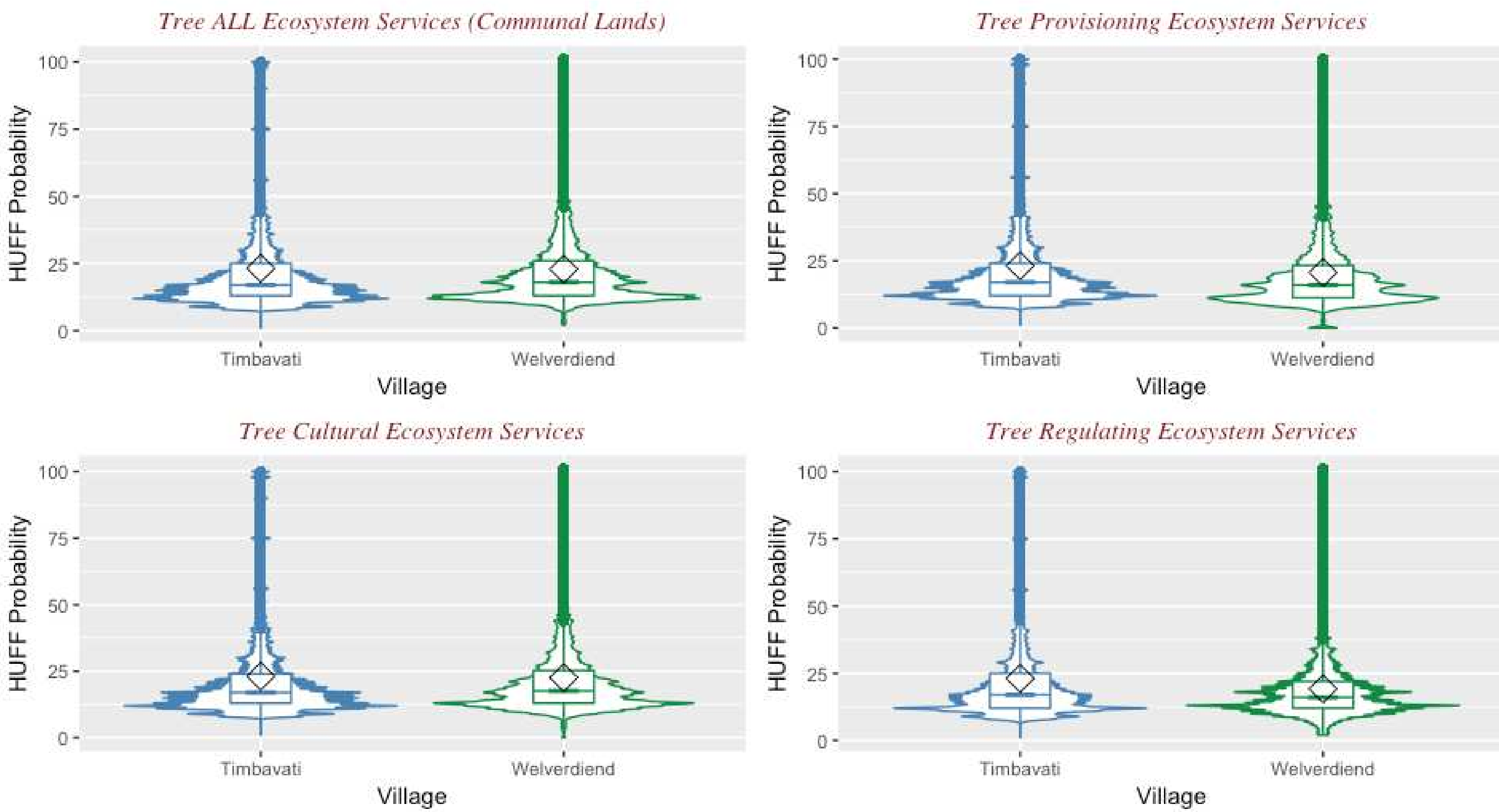

Figure 3.6: Violin and Box Plots of Huff Probability Densities for Communal Scale Provisioning, Cultural, Regulating, and All Combined Ecosystem Service for Village ES Value Comparisons. These plots show the densities of potential tree ES use as a probability of use percentage (y-axis). Most of communal land tree ecosystem service use probabilities in in both villages fall within a 10-40% range, with some subtle differences.

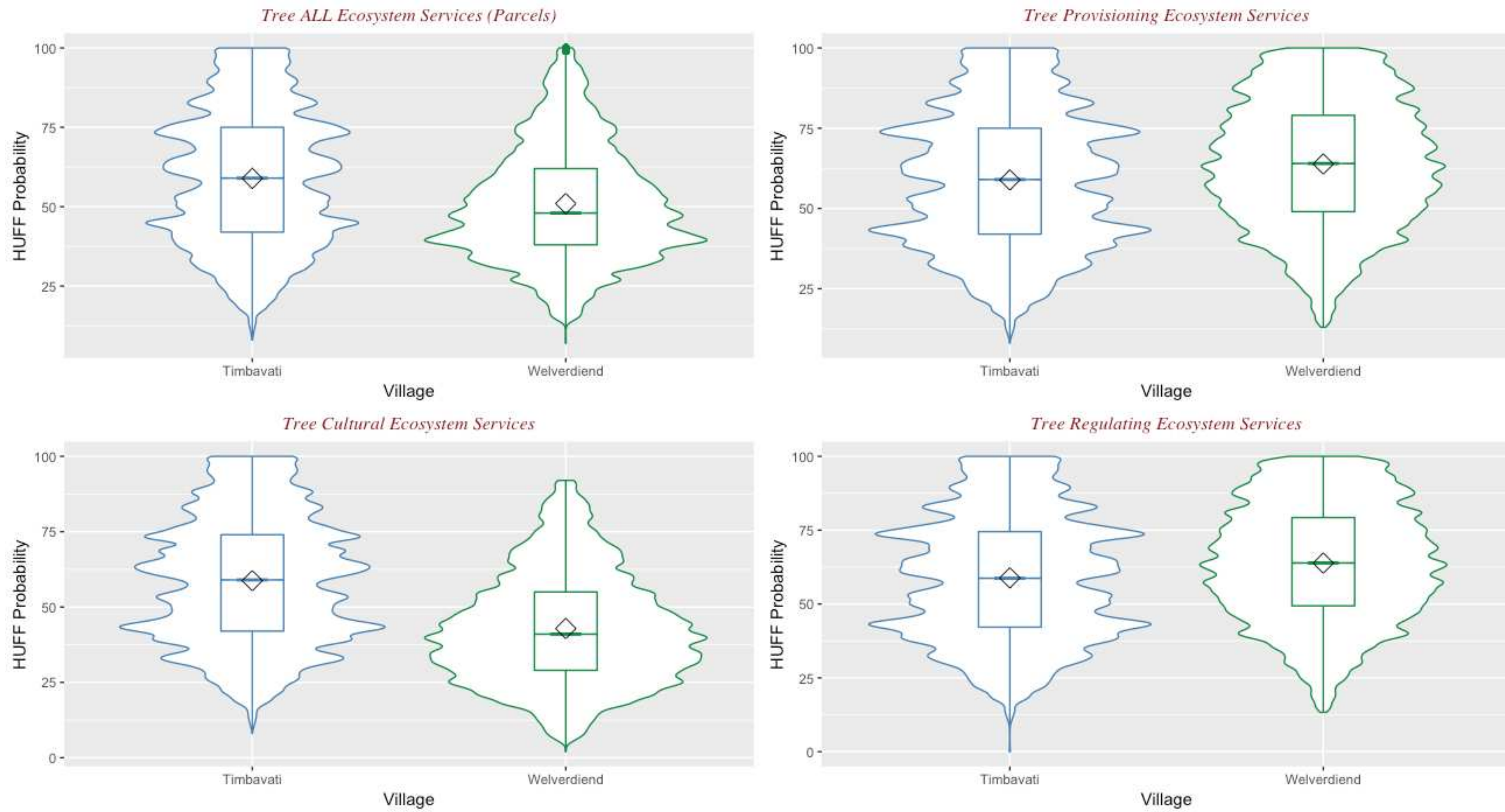

Figure 3.7: Violin and Box Plots of Huff Probability Densities for PARCEL Scale Provisioning, Cultural, Regulating, and All Combined Ecosystem Service for Village ES Value Comparisons. These plots show the densities of potential tree ES use as a probability of use percentage (y-axis). Tree ES use probabilities in parcels are more variable than those in the communal lands.

spatially though high-resolution mapping, could be immensely beneficial to communities and for conservation management.

3.4.2. Implications for Planning & Management

The Millennium Ecosystem Assessment, which attempted to set organizational standards for ES studies (MEA 2005), called for reginal scale information to supplement decision making. Subsequently, van Jaarsveld et al. (2005) synthesized material from a collection of ES studies conducted in Southern Africa as an addendum to the Millennium Ecosystem Assessment. In this synthesis, van Jaarsveld et al. (2005) discusses ongoing needs to fill information gaps associated with identifying priority areas for maintenance of ES in southern Africa, including pinpointing hotspots through mapping ES in the region. Additionally, they discuss the importance and difficulties associated with "incorporating and validating informal local knowledge" in ES studies in order to promote a holistic understanding of ES that spans valuation methods and spatial scales.

The resulting influx of ES mapping studies in southern Africa focused on fulfilling the needs outlined in van Jaarsveld et al. (2005). For instance, a meaningful effort was made to measure and map the potentially synergistic co-occurrence of biodiversity and biophysical ES (e.g. Egoh et al. 2007; Egoh et al. 2008; Egoh et al. 2009; Egoh et al. 2011). Although these studies provide important regional to national scale information to planners, no similar effort has been made to understand the spatial dynamics of local-scale, community ES values, despite recognition of their relevance for local-scale decision-making and planning (Crossman et al. 2008; Wangai, Burkhard, and Müller 2016).

Not only does our method offer a potential solution to the difficulties associated with engaging local communities to better understand ES values and use as outlined by van Jaarsveld et al. (2005), but it also provides an easily replicable and relatively simple model for measuring and mapping these values spatially in a meaningful way. For example, data limitations often force researchers to rely on proxy-based methods to measure and map certain ES, (Crossman, Burkhard, and Nedkov 2012; Ayanu et al. 2012), so there is an overreliance on coarse resolution land-use data for mapping ES. Although these mapping products do provide some useful information to decision-makers, they do not represent a balanced, community-oriented approach to assessing ES at multiple scales. Furthermore, there are several known issues with using land-use proxies for mapping ES, the most problematic of which is that coarse resolution land-use is a poor indicator of ES values at all scales (Eigenbrod et al. 2010; Mchale et al. 2018). Thus, the usefulness of these common proxy-based methods for mapping ES for planning is questionable at best.

The high spatial resolution probability mapping of community ES values presented in this paper ameliorates many of the issues associated with coarse resolution, land-use-based ES mapping. For instance, rather than attempting to leverage coarse resolution land-use data to map community ES values at local-scales, we have linked community ES priorities directly to true-ground land cover types, like tree cover. This method removes much of the guess work associated with proxy-based ES mapping. Additionally, this method allows for mapping to be extended to other true ground land-cover types (e.g. fine vegetation), that might also be valued by communities. Moreover, mapping true-ground cover at high spatial resolutions is the most appropriate way to assess how social values influence urban vegetation structure and patterns (Cadenasso et al. 2007; Pickett et al. 2016).

Decades of research in the field of urban ecology has demonstrated that social values can have dramatic effects on patterns of tree cover in cities (e.g. Bigsby, McHale, and Hess 2014;

Grove, Locke, and O'Neil-Dunne 2014; Schwarz et al. 2015), which has significant implications for how natural resources are managed in urban systems. The method we present applies these same principals to assess the probabilities that tree cover will be utilized for ES based on socio-cultural community values and priorities, which also has meaningful implications for conservation planning in these areas. Perhaps most importantly, this method is poised to finally fulfill the local-scale, community-based ES assessment gaps that have been largely overlooked since ES mapping began in southern Africa. A proliferation of local-scale, socio-cultural ES mapping studies, in coordination with existing regional to national scale biophysical and economic ES assessments, could finally offer a holistic, cross-scale understanding of ES for planners.

3.4.3. Future Applications

Not only does this mapping method have the potential to help fill current gaps in ES research, it also has additional practical applications. Specifically, high-spatial resolution ES maps of community-identified socio-cultural values could help advance our understanding of the spatial-temporal dynamics and ecological feedbacks associated with land change. Theoretically, predicting the ecological dynamics of land change has significant meaning for planners and will ultimately lead to more sustainable land management programs.

Much like ES assessments, land change models are typically conducted at regional extents (e.g. Terando et al. 2014). Additionally, they tend to predict ecological feedbacks stemming from land conversion processes like urbanization (e.g. Terando et al. 2014; Dorning et al. 2015), but with no primary social or behavioral inputs. Answering the question of "why" landscapes change means predicating human behavior and its impacts on local-scale landscapes before scaling up to the regional level. Some emerging methods, like geospatial participatory modeling (Voinov and Bousquet 2010; Voinov et al. 2016), are actively attempting to include human perspectives in the modeling process through engagement (e.g. Mendoza and Prabhu 2006; Etienne, du Toit, and Pollard 2011; Addison, de Bie, and Rumpff 2015). However, we are still unable to realistically predict the “how” and “why” of landscape change at local-scales.

A possible explanation for this disconnect is that the dynamic interactions between people and their landscapes are difficult to capture spatially. Similar to issues with mapping ES, data limitations often force land change researchers to rely on coarse scale land cover/use datasets that cannot accurately capture heterogeneous spatial transitions in human dominated systems (Ridd 1995; Cadenasso et al. 2007). As previously discussed, advancements in urban ecology have helped to alleviate some of these issues by linking social and morphological characteristics to land cover patterns at local scales and high spatial resolutions (e.g. Bigsby, McHale, and Hess 2014; Grove, Locke, and O’Neil-Dunne 2014; Schwarz et al. 2015; Beck, McHale, and Hess 2016). Since our method applies these same principals by directly tying community ES values to landscape features and assesses the probability that those features will be utilized for specific ES, it is a sensible way to include human values in high resolution, local-scale land change models. As these high-resolution land-cover datasets become more common, we can begin to leverage them to build models that incorporate local-scale community values to predict ecological feedbacks.

4.4. Limitations

While we do believe that there are several practical and research applications for our local-scale ES mapping method, there are few caveats that must be discussed. First, since the high-spatial resolution, object-oriented land-cover dataset used in this model does not come from a readily available source, future applications of this method mean that researchers or practitioners will need to create similar datasets from scratch. Doing this requires expertise in object-oriented land cover classification methods, and a high-spatial resolution, multi-spectral satellite or aerial photo data source. Although accomplishing this is by no means impossible, it does require a significant investment of time and resources. Additionally, we presented this research as a case study, and there is no guarantee that an alternative application in different regions will yield similar results without first testing this method in other places. However, our use of the Huff model ensures that a level of stochasticity will be maintained regardless of where this method is applied. Finally, community engagement does not end with the production of a mapping product, and these maps should by no means be considered finalized. Ultimately, additional community and stakeholder engagement will be needed to validate the accuracy of these maps before they should be considered reliable products.

3.5 Conclusions

We have developed a practical method for mapping community-identified, socio-cultural values at high-spatial resolutions. Social values for specific ES types (e.g. provisioning services) and locations (e.g. parcels and communal lands) were collected using walking interviews and surveys and mapped using the Huff model. The Huff model calculates the probability that a given site will be utilized for specific ES based on that site's attractiveness and distance to people. This method has practical applications for planning and research, and implications for community sustainability; however, its usefulness will ultimately hinge on whether it is adopted by decision-makers.

To date, the adoption of scientific ES research in decision-making has been underwhelming, and ES science has arguably failed to deliver on its potential (McHale et al. 2018). In attempting to overcome this disconnect, ES science has continued to evolve towards more holistic and engaging frameworks that prioritize stakeholder processes and local-scale assessments (e.g. Díaz et al. 2015; Mchale et al. 2018). Despite this progress, and advancements in participatory geospatial methods for mapping ES, there is still very little evidence that case studies are influencing decision-making and planning (Brown and Fagerholm 2015). Additionally, local-scale and participatory ES mapping assessments are significantly lagging behind in sub-Saharan Africa (Wangai, Burkhard, and Müller 2016; Beck et al. in prep), where planning and decision-making could have more dramatic impacts on resource dependent populations. Therefore, while we agree with Brown and Fagerholm (2015) that a more effective approach to participatory ES mapping for decision-making would be to focus on long-term case studies and more thoughtful experimental design, we first need to establish a baseline for local-scale ES mapping in many regions of the world before we can effectively engage with decision-makers. The method presented in this case study is poised to get local-scale, participatory ES mapping off the ground in many of these data scares places.

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