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Research article

A multi-method approach for the integrative assessment of soil functions: Application on a coastal mountainous site of the Philippines

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ABSTRACT

The projected increase of the world's population and the sustainability challenges the agricultural sector is facing, call for the enhancement of multi-functionality in agriculture in order to simultaneously provide food while meeting environmental targets.

Here, we use the Functional Land Management (FLM) framework to assess the supply of and the demand for soil functions to inform agri-environmental policy for Udalo, a mountainous site in the Philippines. As many emerging communities in developing nations, Udalo is on the cusp of rapid development due to the construction of a major road increasing its accessibility and attractiveness for land investment.

We assessed the supply of four soil functions in relation to six land-use types and four slope categories. The function "productivity" was assessed by interviews with 128 farmers, "habitat for biodiversity" by a vegetation survey, and "soil conservation" and "water conservation" via a literature review.

The demand for functions was first assessed from the "top-down" policy perspective via interviews and reviews of policy targets, then complemented by integrating the local "bottom-up" demands for functions. These were assessed by applying a Q methodology, providing insights in the prioritisation of functions from the perspective of 22 local actors. Maps of supply and demands were generated for each function: supply maps by overlaying land use and slope category, top-down demand maps from administrative zoning/land-use plans, and bottom-up demand maps from local actors designation of geomorphological areas.

Our results revealed contrasting demands for functions, as well as a heterogeneous spatial distribution of supply and demands. Discrepancies emerged (i) between supply and demand, (ii) between bottom-up (local) demands and the top-down (policy driven) demand, and (iii) among local actors perspectives.

Our study indicates that discrepancies are not necessarily conflicting, but can uncover pathways for defining compromises, representing attainable policy entry points. Not one single development model can meet the needs of every stakeholder; however, a combination of land uses and management strategies can meet divergent interests and allow for optimisation of functions. This integrative approach of FLM provides a socially embedded biophysical analysis and is a valuable tool for the design of customized land-use and agri-environmental policies.

1. Introduction

1.1. Methodological approaches for assessing foodscapes

With the global population projected to grow to 11 billion people by 2100 (United Nations, 2015a), the demand for food is estimated to rise by 60–80% in 2100 (Depenbusch and Klasen, 2019), likely leading to increased land-use changes and competition for land (Runyan and Stehm, 2019). At the same time, humanity is facing a global ecological crisis, with the earth's biocapacity being exceeded for the past 40 years, resulting in natural resources depletion and to a situation of global overshoot (Mancini et al., 2017). Agriculture finds itself at the crossroads of these two global challenges: it has itself a considerable footprint and, at the same time, has to cope with new environmental constraints such as climate change, access to water, decline of soil fertility, loss of arable land, as well as economic constraints such as high price volatility and access to market.

In 2015, the United Nations formulated the 17 universal Sustainability Development Goals, as a blueprint to frame the international policy agenda for 2030 (United Nations, 2015b). Governments are now tasked to set transition pathways and implementation schemes, with a focus on efficient use of resources, including the land resource (United

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Nations, 2012), underlining the need for tools that can adequately guide land management and land-use policy formulation to meet those goals.

Land-use dynamics are marked by both biophysical and socio-economic dimensions, which are brought together in the concept of "foodscapes". We refer to Lowitt and Mackendrick's definition of "a foodscape", based on the consideration of humans as integral components of complex ecosystems, and on the social-ecological interactions that compose the local food system (Lowitt, 2014). Foodscapes designate all places and spaces of a given territory, that relate to food (MacKendrick, 2014). In this way, we define foodscapes as "food systems within landscape settings of natural resources", representing a physical-biological-sociologically integrated system with multiple components, drivers and webs of relations, which strongly condition socio-economic dynamics, and have a major impact on the territory's environment and natural resources. Apprehending foodscape dynamics requires approaches that can capture this complexity. However, most of the existing methods for assessing foodscapes have thus far been either based on biophysical approaches such as the Functional Land Management (FLM) framework, or sociological approaches such as Q methodology (QM).

The FLM framework was developed to assess the demand and supply of land-based ecosystem services, also referred to as "soil functions" (Schulte et al., 2014). It is well suitable to monitor the dynamics of foodscapes through the lens of productive agricultural lands. The FLM framework is useful for agri-environmental policy formation, as it helps identify discrepancies between supply and demand of/for soil functions, as well as land-use scenarios that optimize the suite of soil functions while minimizing trade-offs (Schulte et al., 2015; Coyle et al., 2016). However, the approach has been critiqued for its reliance on top-down assessments of the demand for soil functions, based on policy targets, which may fail to capture the diversity of local demands by the territory's actors.

QM is a socio-analysis methodology allowing for the assessment of stakeholders' perspectives, while helping developing mutual understanding on key issues. Initially used in psychology research and behavioural sciences (Watts and Stenner, 2005; McKeown and Thomas, 2011), it provides a structured representation of stakeholders' viewpoints on a specific topic, by establishing a typology of perceptions. It is a valuable method to reveal divergent and convergent interests, that can be used to help find consensus among multiple actors (Nijnik et al., 2014). In fact, QM makes use of "insiders' views" (Pereira et al., 2016), providing key information based on local inputs and site-specific knowledge. This quantitative and qualitative approach includes "human subjectivity" while treating the collected information statistically (Jaung et al., 2016).

1.2. Research objectives

This paper aims at refining the FLM framework to a more integrative approach to assess soil functions and foodscape dynamics. Through the example of Udalo, a remote agricultural community in the Philippines, we assess both the (top-down) policy demand and the local (bottom-up) demands for soil functions, in order to provide tailored agri-environmental policy recommendations. Udalo, is on the cusp of rapid economic development, resulting from the construction of a new road that will provide access to and from the nearby urban and suburban centres. As such, Udalo reflects numerous contemporary examples of rapid rural development in developing nations, and is representative for so many emerging communities. An integrative approach is essential to assess land-use systems in a changing socio-economic environment. In fact, the demands put on the land may vary across stakeholders (e.g. between government and local actors of the territory), and infrastructure development can alter stakeholders demand for agricultural production, resulting in changes in land use and management, in turn affecting the capacity of the land to fulfil multiple functions (Zawadzka et al., 2017; Alphan, 2018).

In our assessment of the supply of, and the (top-down and bottom-up) demands for soil function, we focus on four soil functions: (i) primary productivity, (ii) habitat for biodiversity, (iii) soil conservation, and (iv) water conservation. These functions are central for addressing the sustainability challenge of increasing production in the face of a growing population, while preserving Udalo's outstanding natural resources and mitigating high erosion risks (MGADI, 2008a; Wagner et al., 2015; DENR, MGADI, 2017). "Primary productivity" refers to the production of food, fibre and fuel (Schulte et al., 2015; Coyle et al., 2016) while the functions "soil conservation" and "water conservation" refer to soil erosion control (Fu et al., 2011), i.e. the ability of the land to regulate water flow by favouring infiltration and limiting surface run-off, thereby preventing erosion. The function "habitat for biodiversity" is defined as the ability of the land to support species diversity, thus sustaining ecosystem functioning by supporting and reinforcing other functions (European Commission, 2015; Kaiser-Bunbury et al., 2017).

2. Materials and methods

2.1. The study site: Udalo at a crossroads

Udalo is a coastal and mountainous area of Mindoro island, in the Philippines (Fig. 1). Over half its land is classified as "very steep slopes" (>50% slope), and nearly three quarters are qualified as "steep" to "very steep" (>18% slope) with no terraces built to ease access or limit erosion (DENR, MGADI, 2017). Agriculture and fishery constitute the main livelihood in the area, since alternative sources of income and employment opportunities barely exist (MGADI, 2008a). Hence, subsistence farming is prevalent, mainly composed of fire-fallow cultivation systems (or "swidden agriculture") on hills and mountain-sides (Wagner et al., 2015). Commercial products include copra (dried coconut flesh for oil industries), wet-rice, cash-crops such as cassava and sweet potato, construction materials (*Imperata cylindrica* grass, bamboo, palm, lumber), cattle, and charcoal. The latter five, along with former intensive logging and small-scale talc mining, partly explain the loss of forest cover since the 1960's (Wagner et al., 2015). Meanwhile, the contribution of swidden agriculture to deforestation is subject to ongoing debate (Amacher et al., 1998; Lasco et al., 2001; Padoch and Pinedo-Vasquez, 2010; Wangpakapattanawong et al., 2010; Mukul et al., 2016). Representative of the rest of the country, the land tenure situation in the region is complex and unclear, with the majority of the population considered as illegal settlers, having no formal access to land (Dingkuhn and Yap, unpublished data). The proximity to bigger cities (Batangas, Manila) and touristic places (Puerto Galera) makes Udalo very attractive to new settlers and tourists. The ambition by the local government to develop tourism in the area is likely to lead to demographic growth (DENR, MGADI, 2017) and increased real-estate investment, resulting in competition for land in the years ahead. The connection to the road network can provide an opportunity for stimulating development and modernization (e.g. by providing access to new markets, employment opportunities, technology and education, and by attracting external capital). However, unregulated development also presents risks of social disruption and increased inequities, as well as over-exploitation and depletion of natural resources (Trousdale, 1999; Erni, 2006; Bacior and Prus, 2018).

2.2. Methodological approach

Using the example of Udalo, we refined the FLM concept by taking into account not only the supply and the policy-oriented ("top-down") demand for soil functions, but also the diversity of local ("bottom up") demands. We employed the classical FLM approach (Schulte et al., 2014, 2015) to assess the supply and top-down demand (see Sections 2.3 and 2.4, respectively). In this approach, the supply of soil functions is framed by combinations of land use and locally relevant pedo-morphological

Fig. 1. Study site location (barangay Udalo, municipality of Abra de Ilog, Occidental Mindoro, Philippines; map data ©2019 Google.

discriminants (Schulte et al., 2014; Coyle et al., 2016; Pinillos et al., 2020); while the demand for soil functions is commonly quantified through socio-economic indicators representative of local, national or international policies (e.g. Schulte et al., 2015; Schulte et al., 2019; Pinillos et al., 2020). We refined this approach by assessing the bottom-up demands via a QM application (see Section 2.4).

First, a literature review and key-informant interviews were conducted in order to (i) identify the relevant metrics that describe spatial variation in the supply of soil functions; (ii) identify the policy targets used to determine the top-down demand; and (iii) determine geomorphological areas to which the local actors can refer to, in order to assess their expectations from the land (i.e. for the assessment of the bottom-up demands). Interviewees included: local experts from University of the Philippines Los-Baños (UPLB), the Philippine Council for Agriculture, Aquatic and Natural Resources Research and Development (PCAARD), the International Rice Research Institute (IRRI) and the World Agroforestry Centre (ICRAF – Philippines); officers of Local Government Units (LGUs), namely from the Department of Agriculture (DA) and the Department of Natural Resources and Management (DENR); and community leaders: the Mayor and officers of the Municipal Government of Abra de Ilog (MGADI), the village Captain and Councillors (village scale Government Units), Indigenous People's Chiefs, the Chairman of the local farmers organization, and religious leaders.

2.3. Supply of soil functions

The supply for soil functions was assessed based on two parameters: land use and pedo-morphological conditions. For the creation of our local "Soil Functions Matrix" (Schulte et al., 2014; Coyle et al., 2016), we selected six land-use types and four slope categories (Fig. 2) as the most representative discriminants. For the Atlantic climate zone of Europe, Coyle et al. (2016) selected the natural drainage status of the soil as the dominant soil characteristic determining soil functionality, reflecting the excess rainfall in that region of the world, based on the review by Schulte et al. (2012). Due to the climatological and geological conditions of our study site, which is characterised by high annual rainfall and high rainfall intensity as well as steep inclinations, this parameter was not suited for a soil functionality assessment here. Instead, numerous studies from the Philippines and other zones of the humid-tropics strongly link soil properties, as well as soil erosion and surface run-off, to slope steepness (Briones, 2010; Asmamaw and Mohammed, 2013; Labrière et al., 2015; Boongaling et al., 2018). We therefore modified this approach (congruent with Schulte et al., 2015) and selected the slope of the terrain (in combination with land use) as

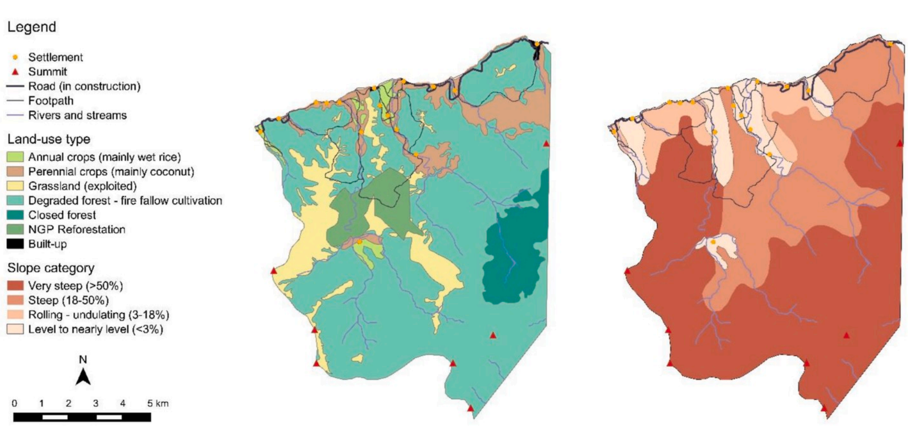

Fig. 2. Land-use map (left) and slope category map (right) of Udalo. Maps were derived from original land-use and slope maps from the Department of Environment and Natural Resources (DENR). (NGP: National Greening Program).

the main determining factor of the supply of soil functions in the region. The effect of the slope discriminant on the supply of each function was informed by literature. The complete narratives constructed for the assessment of the supply of all four functions are presented in Appendix S1.

2.3.1. Productivity

We assessed agricultural productivity in terms of the median gross production (GP) of each land-use type as a proxy-indicator for productivity on a per area basis (ha), similar to Pinillos et al. (2020). GP refers to the total yield per hectare (regardless of its use), multiplied by the market price of the commodity in 2017. "Low", "medium low", "medium high" and "high" productivity classes were attributed to each land-use type based on their relative standing compared to the median. The GP data was obtained by a survey conducted in 2017, during which 128 farmers were interviewed (Appendix S2), representing 21% of the recorded farmers of the study site. Farmers were randomly selected (using the random selection function in CALC open-licensed software) from the municipality's list of households engaged in agriculture (2015 data). When household heads were not to be found in their homes, their relatives were interviewed instead, or the neighbouring household engaged in agriculture. The GP of the degraded forest was based on the results of swidden-fallow systems, for which we summed the GPs of charcoal, cassava, banana and upland rice. Data could not be collected for the reforestation zone subject to the National Greening Program (NGP), due to the early stage of the program which had not yielded any benefit yet, and neither for the closed forest due to haphazard extractions from the forest by the local communities in scattered locations.

2.3.2. Biodiversity

The function "habitat for biodiversity" was expressed in terms of a composite index of the capacity of each land-use type to provide habitat for biodiversity. A vegetation survey was conducted in 2018 in order to complete a vegetation analysis conducted by Wagner in 2013 (Wagner et al., 2015). The vegetation cover of a plot of each land-use type was assessed (except for the reforestation area and the closed forest). On each plot, ranging from 256 m^2 to 1024 m^2, every species present and its scientific name was recorded, as well as its group (tree, shrub or weed) and the tree canopy-cover rate. The composite index was obtained by summing up the z-scores of the variables "species richness" (the number of species present), "tree species richness" (the number of tree species present), and "tree canopy cover abundance" (tree canopy coverage rate). These three variables were summed in order to capture not only the relative habitat richness of the different land-use types (through species richness), but also the biological conditions and related habitats provided by trees specifically (through tree species richness and tree canopy coverage rate), as trees and their understorey vegetation constitute important and different habitats from non-woody plants (Rosenvald and Lõhmus, 2008; Ebeling et al., 2018; Gottschall et al., 2019; Zheng and Chen, 2019).

The effect of the swidden-fallow secondary forest dynamics on the supply of the function "habitat for biodiversity" was modelled by calculating average rates of increase or decrease of the aforementioned variables throughout different stages of regrowth, derived from vegetation surveys conducted on three plots: (a) clear cut, (b) at 15 years of regrowth and (c) at 25 years of regrowth. This allowed for the determination of the average species richness, tree species richness, and canopy cover abundance of the of the secondary forest/swidden system (Appendix S1.2).

2.3.3. Soil and water conservation

The supply of the functions "soil conservation" and "water conservation" were qualitatively assessed based on narratives constructed from literature, complemented with highlights from the key-informant interviews and on-site observations (Appendix S1.3).

2.4. Demands for soil functions

2.4.1. Top-down demand

Analogous to the original FLM approach, the top-down demand for the aforementioned functions was assessed using policy targets as proxies, considering that the top-down demand is reflected in the regulatory environment (Staes et al., 2018; Schulte et al., 2019; Pinillos et al., 2020).

For the functions "habitat for biodiversity", "soil conservation" and "water conservation", policy targets from the municipal Ecological Profile (MGADI, 2008a), the Comprehensive Land-Use Plan (MGADI, 2008b), and administrative zoning from the latest Forest Land-Use Plan (DENR, MGADI, 2017) were combined with outcomes from the key-informants interviews. This allowed for the characterization of zones with different policy priorities such as strict protection zones, open access forests, disposable alienable zones, grazing and haying areas (Appendix S3). For soil and water conservation we also took highly erodible areas into account, such as steep slopes (>18%), very steep slopes (>50%) and river banks (Table 1 and Appendix S3).

As motorways and accessibility to landscape resources determine land use and its spatial distribution (Alphan, 2018), we used accessibility and public infrastructure development (distance from the road and from the sea shore), as a proxy to determine the top-down demand for productivity (Pinillos et al., 2020). In fact, major public infrastructures such as roads significantly enhance productivity and reduce production costs, thereby increasing the demand put on the land (Teruel and Kuroda, 2004, 2005; Llanto, 2013, 2016).

2.4.2. Bottom-up demands

The bottom-up demands for soil functions were assessed by conducting a QM (Watts and Stenner, 2005; Peter Walder, 2018) with a group of 22 local actors, in order to determine their expectations from the land. The participants were sourced from three main different social groups of the study site: "Farmers", "Landowners and traders", "Government agencies and local organizations". Care was taken that the participating farmers were representative of the area's diversity of production and agricultural practices, of the different geographic locations, and of the ethnic diversity of the study site. We formulated 24 statements (Q-statements), relating to different geomorphological areas of the study site, and to local actors' expectations from these areas in terms of delivery of the four focal functions (Appendix S4). In this step, the determination of geomorphological areas was aimed at characterizing areas of the landscape to which local actors can easily refer to. Considering the fact that some participants were illiterate and/or unfamiliar with scientific terminologies, experts' jargon, or maps and administrative zoning designations, we chose areas and terms that the locals themselves use when talking about their landscape. This way, we harnessed local perceptions of the landscape, as increasingly recommended in landscape planning and management (Höchtl et al., 2007; Fagerholm and Käyhkö, 2009; ESF - European Science Foundation, 2010; Ramirez-gomez et al., 2013; Fairclough et al., 2018; Fagerholm et al., 2019), which facilitates local-level, spatially specific discussions between stakeholders and better integration of outcomes at a local level (Fagerholm et al., 2019).

The same actors were then asked to rank the statements in a grid following a quasi-normal distribution, according to the level of importance/priority they attributed to each statement (Hermans et al., 2012; Hermelingmeier and Nicholas, 2017). The ranking results were analysed using the "Q-method package" on R open-licensed software (Jaung et al., 2016): a correlation matrix was established and a factor analysis (principal component analysis) was executed with the focus of inter-correlations on participants (Q-sorts), rather than on traits (Q-statements), which is characteristic of QM (Pereira et al., 2016). In fact, the measuring criteria in QM is "the psychological significance of each statement for each individual" (McKeown and Thomas, 2011), hence the statements themselves are less important than their relative

Table 1
Summary table of soil functions assessment criteria, legend classes definition and corresponding geographic areas.

	Soil functions	Classification criteria	Legend classes and areas definition			
			High	Medium high	Medium low	Low
SUPPLY	Primary productivity	Land-use types gross production (relative standing of medians compared to median)	Land uses within 1st quarter of values range between min. and max. value	Land uses within the 2nd quarter of values range between min. and max. value	Land uses within the 3rd quarter of values range between min. and max. value	Land uses within the 4th quarter of values range between min. and max. value
	Habitat for biodiversity	Vegetation analysis of land-use types (Z-scores summation for composite index calculation)				
	Soil conservation Water conservation	Qualitative ranking of land-use type + slope category (mainly based on literature reviews, completed by key-informant interviews and on-site observations, see Appendix S1)	Remote closed canopy forests on high elevations	Dynamic secondary forests (manually cleared patches) on <18%; semi-intensive wet rice (2 crops/year, moderate use of chemicals); coconut plantations (semi-managed, wild endemic vegetation undergrowth) on <50% slope	Afforestation patches with fast growing tree species implanted in rows	Open areas dominated by *Imperata cylindrica* grass; semi-managed coconut plantations on >50% slope; dynamic secondary forests (manually cleared patches) on >18% slope
TOP-DOWN DEMAND	Primary productivity	Accessibility (distance from the road and the sea shore)	Areas < 1 km from the road and the sea shore	Areas 1–3 km from the road and the sea shore	Areas 3–6 km from the road and the sea shore	Areas > 6 from the road and the sea shore
	Habitat for biodiversity	Land-use zoning	Strict protection zone	Open access forest area	Grazing area	Alienable/disposable area
	Soil conservation	Land-use zoning, slope class and river banks	Protection zone, very steep slopes (>50%), river banks	Steep slope (18–50%) classified as open forest	Rolling-undulating areas (3–18% slope) classified as open forest	Level/nearly level (<3% slope) and alienable disposable areas (aside of river banks)
	Water conservation	Land-use zoning, slope class and river banks				
BOTTOM-UP DEMANDS	Primary productivity Habitat for biodiversity Soil conservation Water conservation	Geomorphological areas ranking by QM clusters (Z-scores value from QM results for each cluster)	Geomorphological area within the 1st quartile	Geomorphological area within the 2nd quartile	Geomorphological area within the 3rd quartile	Geomorphological area within the 4th quartile

importance in the eyes of the participants (Pereira et al., 2016). Based on the Kaiser-Guttman criterion (eigenvalue exceeding 1) (Jaung et al., 2016; Pereira et al., 2016), we retained three factors to run the principal component analysis, and reduce the data (Q-sorts) into components (factors or cluster).

Subsequently, a varimax rotation provided the factors' loadings, which determined the clusters' compositions (i.e. which participants were grouped into which clusters). The calculation of z-scores and the analysis of distinguishing and consensus statements (Appendix S4.1), coupled with an analysis of the most extreme factor-scores (Appendix S4.2), allowed us to characterise the clusters and establish a typology of local actors' perspectives, i.e. of different types of demands for soil functions. In order to map the spatial distribution of these bottom-up demands, we derived legend classes from the way each cluster ranked the Q-statements. The declination of the local demands into "high", "medium high", "medium low" and "low" classes was obtained by ordering the statements' z-scores (of each cluster) in descending order, and grouping them into quartiles (Table 1).

2.5. Mapping supply and demands

Subsequent to the assessment of the supply, the top-down demand and the bottom-up demands of/for the four soil functions and their categorization into "low", "medium low", "medium high" and "high" classes (Table 1), the outputs were mapped using QGIS software, in order to compare their spatial distribution.

The supply maps were generated by overlaying land-use and slope category maps (Fig. 2). The top-down demand maps were derived from administrative zoning/land-use plans. The bottom-up demand maps were generated from the local actors' designation of geomorphological areas (derived from the Q statement and the QM results). The procedure and criteria that determined the legend classes and their corresponding geographic areas are summarized in Table 1.

3. Results

3.1. The classical FLM approach: supply and top-down demand for soil functions

The soil functions supply matrix reveals great variability in the delivery of the focal soil functions, as well as antagonisms between functions (Fig. 3 and Appendix S1). Overall, our results disclose low productivity levels for all land-use types, except for grassland, while the supply of the functions "biodiversity", "soil conservation" and "water conservation" is more heterogeneous.

The functions "soil conservation" and "water conservation" appear to be strongly correlated and presented quasi-identical rates of supply, hence they were merged into one function. On the other hand, antagonistic relations can be observed between "productivity" and the three other functions ("biodiversity", "soil conservation", "water conservation"). For example, grasslands (used for grazing and haying for roofing materials) are the most productive land uses, while they are "poor" suppliers of all other functions, as opposed to the closed forest next to the eastern boundary of the study area, which supplies high levels of biodiversity. This antagonistic relation can be observed in nearly all land-use systems, except for wet-rice production, which is characterised by rather low levels of biodiversity and productivity and a relatively high potential for soil and water conservation (Fig. 3).

The supply of productivity and biodiversity is not strongly influenced by slope, while soil and water conservation decrease on steep slopes and very steep slopes (for coconut plantations and secondary forest areas). In fact, the slope discriminant was applied to the function "soil conservation" and "water conservation", but not to the functions "biodiversity" and "productivity", due to lack of data and poor evidence from literature.

The outcomes of the classical FLM approach, i.e. the assessment of the supply and the top-down demand for soil functions, show contrasting spatial distributions (Fig. 4). In fact, when comparing the supply of

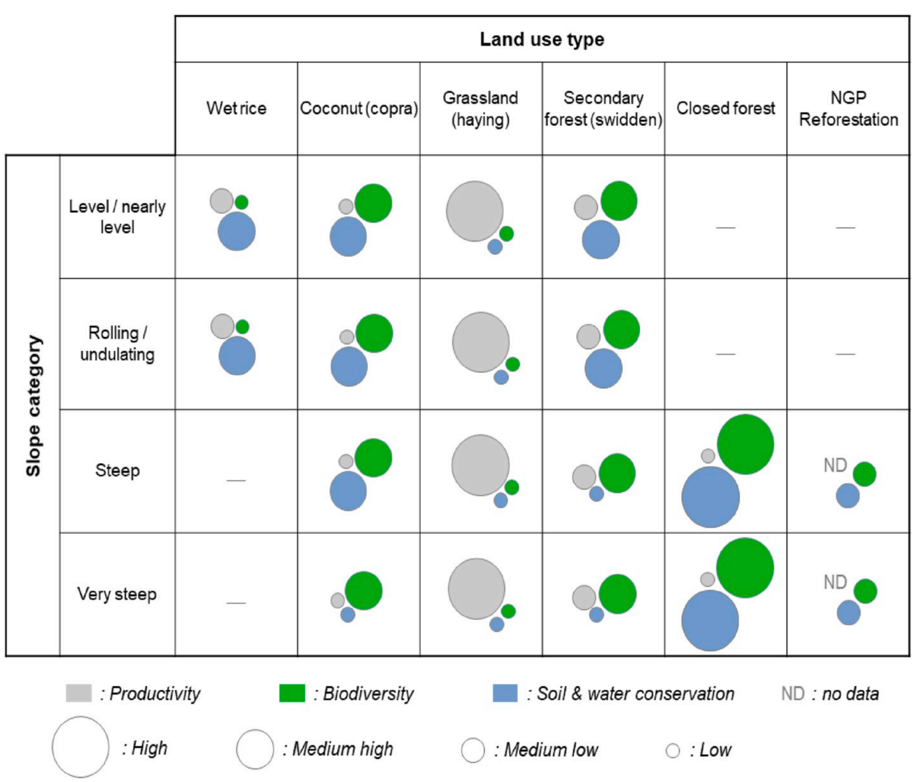

Fig. 3. Soil Functions Matrix depicting the supply of productivity, biodiversity and soil & water conservation in relation to land use (columns) and slope category (rows). As supply for water and soil conservation are strongly correlated and presented quasi-identical results, they were merged into one function.

soil functions to the demand from the policy context, discrepancies between supply and demand are striking for the functions “biodiversity”, “soil conservation” and “water conservation”. Whilst half of Udalo is officially classified as a “protection zone”, with a high demand for the aforementioned functions, this aggregate demand is only fully met by the remaining closed forest. Moreover, the highest demand for productivity is concentrated in the most accessible areas, which are located along the coast and following the main path (meant to become the future road), while these areas show a rather low production potential. Further details of the supply and top-down assessment results are provided in appendices S1 and S3.

3.2. Contrasting bottom-up demands for soil functions

The results of the QM reveal important heterogeneity in (bottom-up) demands for soil functions among local actors, as illustrated by the resulting typology of three clusters, that represent distinct expectations from the land (Figs. 5 and 6). Cluster 1, composed of seven Q-sorts (participants), predominantly attributed high scores to statements relating to soil conservation and, to a lesser extent, to productivity, and was thus attributed the name of “Soil Conservationists”. The second group, of six Q-sorts, associated highest ranks to statements relating to water conservation and, at a lesser extent to soil conservation and productivity, and was thus, named the “Water Conservationists”. Cluster 3, composed of 4 Q-sorts, assigned high scores to statements relating to all four functions, and was thus named the “Multi-Functionalists”. Although statements relating to soil conservation and productivity obtained the highest z-scores computation, this cluster is the only one having attributed maximum scores to statements referring to the function “biodiversity” (Fig. 5). The factor scores and their corresponding z-scores, as well as distinguishing-consensus statements are shown in appendices S4.1 and S4.2, respectively.

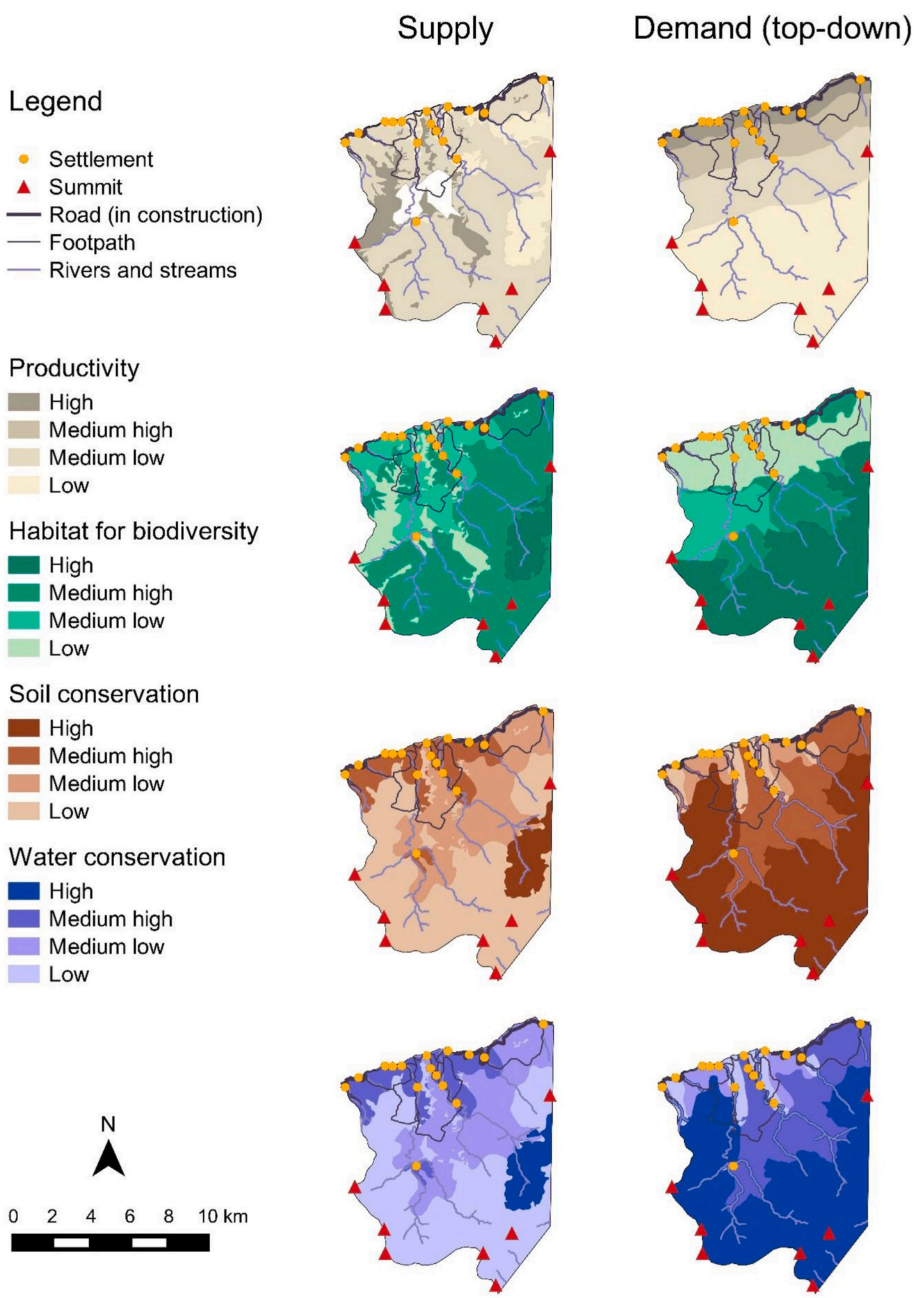

Fig. 4. Supply maps (on the left) and top-down demand maps (on the right) for soil functions. White polygons indicate missing data.

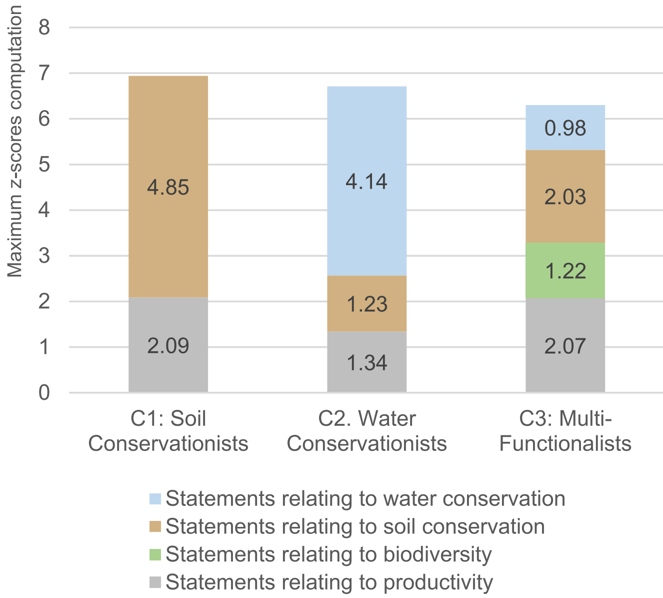

Fig. 5. Resulting clusters from the Q methodology showing contrasting expectations from land. For each cluster, the z-scores of statements that obtained high factor scores (=2 or 3) were categorized by the functions they relate to and were summed up to show the comparative importance of the various functions for each cluster.

The bottom-up demand maps from the three clusters disclose how this heterogeneity of demands is spatially distributed (Fig. 6). First, the output maps clearly illustrate the typology of each cluster, with a high demand for soil conservation being prevalent on the Soil Conservationists demand maps, a high demand for water conservation being prevalent on the Water Conservationists demand maps, and a high demand for biodiversity preservation being prevalent on the Multi-Functionalists demand maps. Secondly, the results reveal areas of contrasting demands, but also areas of convergence. For example, there is a consensus between the clusters on a high demand for soil conservation on slopes and ridges, as well as for biodiversity conservation on slopes. Moreover, a high demand for productivity was attributed to mountain sides (slopes) by cluster 1 (the Soil Conservationists) and cluster 3 (the Multi-Functionalists), along with river sides for cluster 3, and ridges for cluster 1 and cluster 2 (the water Conservationists). In contrast, the demand for water conservation shows the greatest degree of heterogeneity among clusters, with high demand concentrated along river sides for cluster 1; on slopes, ridges and close to the sea for cluster 2; and on ridges and remote inaccessible areas for cluster 3. Finally, divergence (and some convergence) also occur between local demands and top-down demand (Figs. 4 and 6). For example, cluster 2 aligns with high top-down demand for productivity next to the sea shore. Furthermore, areas of high top-down demand correspond with the areas of high demand for soil conservation of the "Soil Conservationists" group (cluster 1). The same applies for high demand for water conservation and the "Water Conservationists" (cluster 2), and for the "Multi-Functionalists" (cluster 3) regarding high demand for biodiversity.

4. Discussion

4.1. Assessing the supply and demand for soil functions

Our results suggest that the supply and demands for soil functions is not only linked to land use and the local geomorphological characteristics of land, but is also greatly influenced by context-specific social and economic drivers that shape farm practices and behaviour (Kleinman et al., 1995). These include the farmers' personal objectives, market prices and value chains developments, land tenure situations, i.e. the degree of land security/insecurity (Neef, 2001; Yirga, 2008; Dube and Guveya, 2013), power distributions (Baynes et al., 2016) and institutional regulatory frameworks (Mattison and Norris, 2005) (Appendices S1 and S3). Our outcomes also expose clear antagonisms between the supply of the selected soil functions, especially between primary productivity and the three other functions.

The complexity of land-use patterns in Udalo makes the assessment of the supply of soil functions a challenging task. In particular, the secondary forest, which is an area of fire-fallow cultivation, is a dynamic system comprising vegetation patches at various growth stages and of various exploitation scales (from small subsistence patches, to larger patches for commodity production), including clear cuts for charcoal production, diversified agroforestry systems and regenerating forest patches. As a result, its ability to supply soil functions presents great variability between patches, and had to be considered as an average representation. Charcoal production for instance, which is the main commodity produced from the degraded forest, is driven by high market demand, as it is extensively used as cooking fuel (Inzon et al., 2016; Martinico-Perez et al., 2018). External demand for charcoal is stimulated by poor and challenging enforcement in the area, in contrast to nearby municipalities where the national ban on logging, and thus on charcoal production (Republic of the Philippines, 1975) is more easily enforced as a result of greater accessibility and visibility (DENR officer, pers. comm., March 2017).

Large imbalances between supply and top-down demand for ecological functions (biodiversity, soil and water conservation) manifested themselves on erosion-prone terrains. The generally poor supply of soil functions in these areas is of concern and reveals a need for integrated conservation efforts. Low productivity in the lowlands, despite more favourable agronomic conditions and high top-down demand, may reflect an under-utilised potential for sustainable intensification of some production systems. Enhancing productivity in these areas could alleviate the concentration of high production systems on erosion-prone terrains, reducing the farmers' dependence on uplands, thereby reducing the magnitude of antagonisms between productivity and ecological functions in these areas.

4.2. Diversity of visions and interests: convergence and compromise

The study allowed for an inner view of Udalo's foodscape, recognizing local actors' representations and expectations from land. Local (bottom-up) demands for soil functions, in particular for productivity, were mostly high on mountain ridges and slopes within the existing degraded forest. This could be explained by the important income generating potential of grasslands on mountain ridges, and by the fact that mountain sides (slopes) with low agronomic potential are the only lands accessible to many farmers. In fact, a substantial part of the farming population doesn't have any formal access to land, but is tolerated by private land-owners, or in the case of public land by the local government, to practise fire-fallow cultivation on mountain sides for subsistence and, to some extent, for commercial purposes.

In contrast to the top-down productivity targets and the common perception that easily accessible lands would be kept for production, all clusters attributed a low demand for productivity in areas close to paths and habitations, implying that these would be prioritized for other purposes. A possible explanation could be the frequent adoption of illegal practices by farmers such as logging, fire-fallow systems, grassland burning to stimulate regrowth (Republic of the Philippines, 1975), leading them to adopt a "strategy of discretion" by cultivating in areas that are not too remote for accessibility ease, but not too visible and accessible neither to remain relatively unnoticed.

The QM analysis revealed heterogeneity in the demands for soil functions, as well as a variety of local perceptions/conceptions of these functions and their utility. For example, for "the Soil Conservationists" (cluster 1), the demand for water conservation is highest along river sides where most annual crop lands are concentrated. In other words,

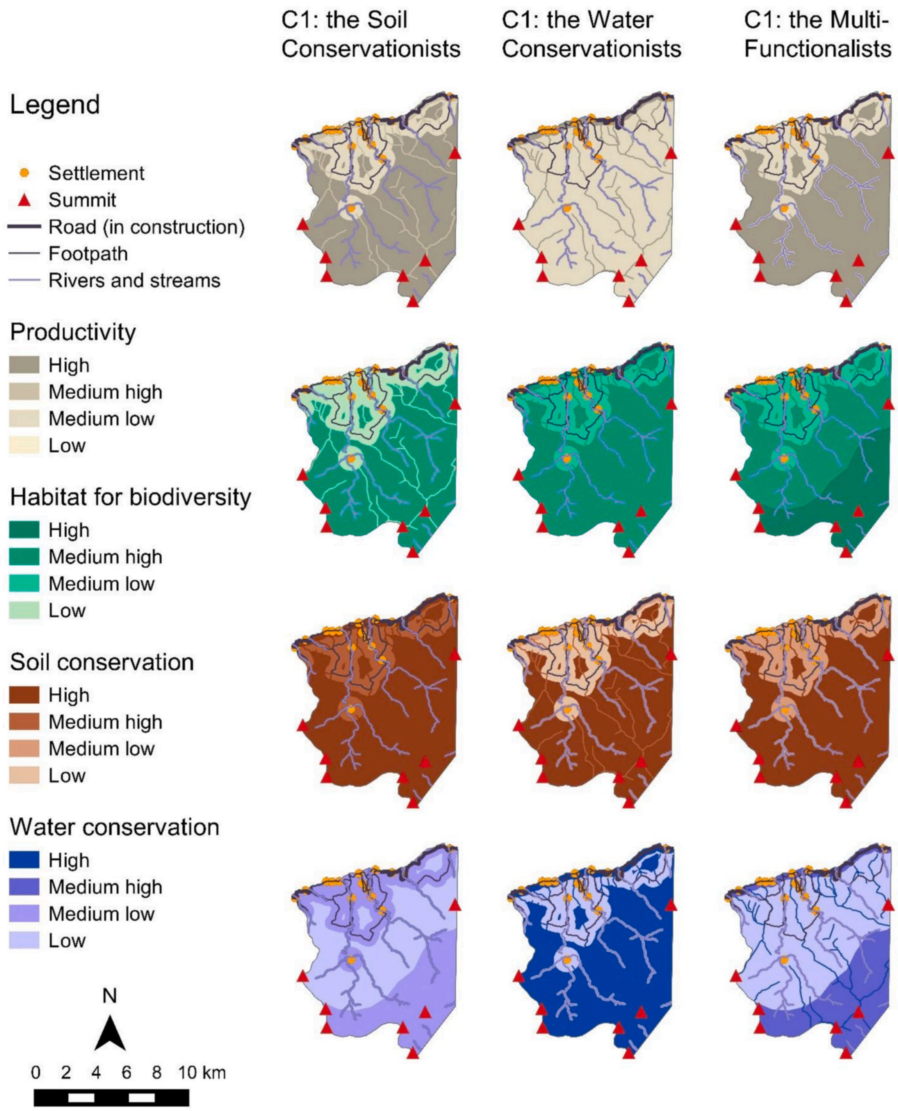

Fig. 6. Bottom-up demands for soil functions per cluster as derived from the Q methodology typology.

this group attributed a high demand to areas where water is extracted for human use (irrigation, domestic use), while "the Water Conservationists" (cluster 2), attributed a high demand for water conservation in areas where water damage occurs (run-off, erosion, land-slides), resulting in a high demand for this function on slopes, mountain ridges and near the sea shore. Finally, for "the Multi-Functionalists" (cluster 3), the highest demand for water conservation is concentrated in remote areas and mountain ridges, at the watershed and sub-watershed basin boundaries, i.e. in areas playing a major role in rebuilding water stocks (Viviroli et al., 2007).

Biodiversity is an outstanding, yet threatened, resource in the region (Wagner et al., 2015; Heaney et al., 2018), while its "functionality" or "utility" to human communities, namely for agricultural production, appears to be less recognized by the inhabitants than soil conservation and water conservation. The fact that the dominant perspectives of the local actors clusters match the top-down policy targets, suggests that a fraction of the inhabitants share the same concern/interest as the government or, in other words, that the spatial distribution of the top-down demand for most soil functions makes sense to only some of the local actors. These differences in perceptions and understanding of the utility of these functions, and how they are delivered, underlines the importance of adequate communication and sensitization from the top down about the purpose of conservation programs and policy targets, in order to be better understood by the inhabitants. This also suggests that hindrances to compliance and to adoption of sustainable land management practices may not only be due to disagreements or divergent interests, but also to misconceptions and miscommunication. This illustrates the importance of including local stakeholders (views) in defining and designing land-use policies, in order for policy targets to "make sense" to the actors of the territory.

Overall, soil conservation appears to be a prevailing concern to local actors (with a computed maximum factor scores in QM of 22), followed by productivity and water conservation (computed maximum scores of, respectively, 13 and 10), while less importance was assigned to biodiversity (computed maximum scores as low as 3). Local concerns about soil erosion reflect actual ecological issues on the study site (Wagner et al., 2015; DENR, MGADI, 2017), while clean water availability was not reported to be an issue until recently (Farmers' Organization Chairman, pers. comm., April 2018; Village Councillors, pers. comm., April 2018). However, inhabitants have reported recent cases of water shortage during the dry season (Hosingco et al., 2016; DENR, MGADI, 2017; Farmers Organization Chairman, pers. comm., March 2018), while participants expressed their concern about the future preservation of water resources, in the face of projected demographic growth and urbanization. Finally, all three QM clusters converge on a high demand for soil conservation on slopes, which also aligns with the top-down demand. This is an important finding, as it can be a stepping stone for the implementation of adapted agri-environmental incentives or soil conservation programs, in which diverging actors have converging interests.

4.3. Challenges for the foodscape

Our study reveals a number of challenges for the foodscape of Udalo, namely substantial imbalances between supply and demand for soil functions. Low yields and poor value of cropland products, in particular rice and coconut (Appendix S1), do not cover the high demand for food and fibre in the lowlands. Thus, improved technical results and developing value chains will be key to meet the growing demand, in particular the demand for staple food (MGADI, 2008a). As put forth by Labao et al. (2017), diversification and access to associated equipment would contribute to address chronic food shortages in the area. Therefore, on the one hand connection to the road network represents a great opportunity by facilitating access to technology, knowledge transfer, and outreach to new market opportunities. However, the antagonistic relation between productivity and other functions must be considered, hence the need to identify and incentivize adapted pathways towards the sustainable intensification of lowland cropping systems, i.e. increasing productivity without hindering the supply of other soil functions (Foreseight, 2011; Schulte et al., 2014), while avoiding cropland expansion in the context of agricultural land scarcity. In fact, agricultural land scarcity in the Philippines (Lasco et al., 2001; Coxhead et al., 2002; Verburg et al., 2006) makes the option of agricultural expansion the least desirable development scenario, while “land intensification” based on increased activity and inputs (Schulte et al., 2014), has to be considered along with ecological risks (e.g. erosion increase and water quality alteration). Moreover, land intensification requires financial resources to purchase inputs, and thus would be accessible to only a small fraction of Udalo’s farmers. Therefore, better-suited development pathways towards agricultural sustainability in Udalo are offered by (1) resource-use efficiency strategies, with more efficient input-use and greater linkage to research and development (Schulte et al., 2014), and (2) agroecological intensification relying on the use of ecological processes and agroecological practices (Wezel et al., 2014, 2015; Wezel and Francis, 2017; Mockshell and Villarino, 2019) and (sometimes) high labour inputs (Castella and Kibler, 2015; Timmermann and Félix, 2015).

Imbalances of supply and demand also occur for biodiversity and soil and water conservation within the grasslands and the degraded forest on slopes. Nonetheless, these areas are important providers of fibre and food, with a high local demand for productivity. Therefore, the high top-down demand for soil, water and biodiversity conservation in these areas, should not necessarily rule out their simultaneous use for primary production. Indeed, Padoch and Pinedo-Vasquez (2010) argue that the potential of swidden agriculture to contribute to natural capital preservation and/or regeneration, due to generally high levels of biodiversity, should be recognized as a land sharing conservation strategy as opposed to a “land-sparing/intensive agriculture strategy”. While policies aim to reducing forest dependency of poor and resource-reliant upland farmers, land sharing strategies afford them greater adaptiveness by providing “dynamic livelihood portfolios”, i.e. multiple sources of food and commodities that evolve as the forest composition evolves (Dressler et al., 2016).

Indeed, although swidden areas (degraded forest) show distinct signs of erosion (Wagner et al., 2015), a recent study conducted in the Philippines demonstrates that smaller but higher number of agricultural patches, separated from each other by riparian buffers, show meaningful reduction of surface runoff and sedimentation (Boongaling et al., 2018). Yet, Mertz et al. (2009) showed that swidden systems are rapidly being converted to/by other land uses, in the cases of Udalo seemingly towards larger and more permanent cultivation plots with cassava, coconut and charcoal as major productions. As swidden areas comprise the largest agricultural land use in Udalo, it is of utmost importance that upcoming land-use changes are prevented from translating into the opening of large aggregated patches on slopes, thereby exacerbating erosion (Boongaling et al., 2018). Following the same reasoning, there is potential to divide the highly erosive grasslands on mountain ridges (Wagner et al., 2015) into smaller patches, for example by integrating zones of shrubs and trees. At the same time, the remaining closed forest should be a priority protection zone on the model of land sparing, as it is currently the only land use that provides high levels of biodiversity and soil/water conservation, including on very steep slopes (Figs. 3 and 4). Lastly, the NGP reforestation zone, a former attempt to improve functionality of grassland soils, shows only moderate multifunctionality (Figs. 3 and 4) that could be improved by increasing the diversity of tree species, and by replacing exotic with indigenous species (Kaiser-Bunbury et al., 2017) while considering the potential of root reinforcement and tree placement on the slope (Cohen and Schwarz, 2017). When combined, these adjustments should enhance the capacity of the ecosystem to provide habitats for biodiversity, to prevent soil erosion, and to contribute to higher productivity of orchards and wild fruit trees through improved pollination (Kaiser-Bunbury et al., 2017).

Considering the complexity of land-use systems, along with the diversity of the interests and visions of actors, we have demonstrated that a combination of land-use systems and management strategies are required to optimize soil functions supply in the Udalo foodscape, and reach greater agricultural and resource-use sustainability in a changing socio-economic environment. This implies that a unique model of development cannot provide a complete answer to achieve agricultural sustainability in the area, but that complementary tailored land-use and land management strategies can, to some extent, meet divergent interests.

4.4. The integrative FLM approach: potential, limits and improvement

The FLM framework enables the assessment of multifunctionality in agriculture through the quantification and spatial representation of the supply and demand for soil functions. As such, it allows for identification of antagonisms in the supply of soil functions and of regional imbalances between supply and demand. In combination with QM to assess local demands for soil functions, discrepancies in demands can be identified amongst groups of local actors, as well as between (top-down) policy-driven demands and local (bottom-up) demands.

Hence, this combination of methods allowed us to refine the FLM framework to a more integrative approach to assess, not only soil functions, but also foodscape dynamics, as it considers the perspectives of the local actors, which are part of the food-system. It constitutes an innovative assessment approach aimed at informing the design of tailored agri-environmental policies, by capturing spatial diversity (heterogeneous spatial distributions), as well as social diversity (contrasting perspectives) in the demands for soil functions, allowing for the prioritisation of zones of intervention for the optimisation of soil functionality.

The combined methodologies allowed us to elucidate compromises and convergence regarding the demands for soil functions, and thus to identify entry points for interventions. Nonetheless, the application of the multi-method also presents challenges. Firstly, the assessment of soil functions supply may be hindered by lack of comprehensive and consistent datasets. Secondly, the collection of qualitative data requires the availability of skilled moderators, as well as a sufficient level of trust from the actors towards the researcher(s) and the moderators.

This study was the first of its kind, in which the refined FLM framework was trialled. For future applications, the statements of the QM, used to build the bottom-up demand maps, could refer to geographic areas that correspond to the top-down demand zones, in order to facilitate comparison between top-down and bottom-up demands. Therefore, visuals such as pictures/maps of the areas could be used instead of written statements, in order to avoid naming the areas by their zoning designation (e.g. "protection zone") and risking to influence the participants' judgement. This implies that all participants can relate to a map of their landscape, and that the area and delimitation of each zone "makes sense" to them (i.e. presents sufficient homogeneous characteristics in their eyes to be represented as one relatively homogeneous unit).

We acknowledge that the use of proxies, although combined with land use and soil/land characteristics (here slope), may not capture all the complex factors that influence the supply of soil functions. For future applications we recommend the use of elevation or slope position in addition to slope steepness as a discriminant in the supply matrix. Numerous studies from the Philippines and other regions of the world directly relate erosion (i.e. soil and water conservation) to slope steepness (Wezel et al., 2002; Asio et al., 2009; Briones, 2010; Asmamaw and Mohammed, 2013; Birhanu et al., 2019) which, in turn, influences land-use choices (Li et al., 2013; Birhanu et al., 2019). However, it could be argued that the productivity and the biodiversity of land may be determined more by its topographic position (lower mid-slope or higher mid-slope position), its location (accessibility, elevation), and its historic cropping frequency than by slope inclination per se (Wezel et al., 2002; Collins et al., 2008; Liu et al., 2009; Fu et al., 2011; Asmamaw and Mohammed, 2013; Campera et al., 2020).

Furthermore, the proxy-indicator choices may be refined. For future applications, the use of composite-indexes (including several variables) may constitute more accurate indicators than single proxies to assess the spatial variability of the supply of soil functions. For instance, it is the limited accuracy of using a single proxy to assess "habitat for biodiversity" that prompted us to use a composite-index instead, combining species richness, tree species richness and canopy cover.

Similarly, soil texture, soil infiltration capacity, and/or slope steepness could constitute a composite index for the function soil/water conservation. Finally, the top-down demand for productivity could be refined by combining the proxy "distance from the road and from the sea shore" with administrative zoning (e.g. exploitable areas, limited-access areas, protected areas).

5. Conclusion

Through the example of Udalo, we refined the FLM framework, by combining it with QM, to assess the bottom-up demands for soil functions. This multi-method approach, combining a primarily biophysical assessment method (FLM) with a socio-analysis method (QM), facilitates the integrative and inter-disciplinary assessment of the functionality of foodscapes. Our results reveal large discrepancies at various levels: between the supply and demand of/for soil functions, between top-down and bottom-up demands, and among local actors' expectations and representations. We show that discrepancies are not necessarily conflicting, but can uncover pathways for defining compromises, and that consensuses/synergies also occur, pointing towards attainable policy entry points. By taking multiple levels of diversity into account (diversity in space and diversity among people), we demonstrate that a unique development model cannot be an answer to multiple levels of heterogeneity, but that a combination of land uses and management strategies can, to some extent, meet divergent interests and allow for optimisation of soil functions. Because it provides a socially embedded biophysical analysis, this innovative assessment approach constitutes a valuable tool for the design of customised land-use and agri-environmental policies. However, further research is needed to refine the choice of proxy-indicators and of the discriminant parameter of the soil functions supply matrix. Further applications are needed to scale-up the method, and to adapt the refined framework to other socio-economic contexts and pedo-climatic zones.

Declaration of competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

CRediT authorship contribution statement

Elsa L. Dingkuhn: Conceptualization, Methodology, Formal analysis, Investigation, Resources, Data curation, Writing - original draft, Writing - review & editing, Visualization, Project administration, Funding acquisition. **Alexander Wezel:** Resources, Writing - review & editing, Supervision, Validation. **Felix J.J.A. Bianchi:** Methodology, Writing - review & editing, Validation. **Jeroen C.J. Groot:** Methodology, Formal analysis, Software, Resources, Writing - review & editing, Supervision. **Adrian Wagner:** Formal analysis, Data curation, Resources, Writing - review & editing. **Helen T. Yap:** Resources, Supervision, Funding acquisition. **Rogier P.O. Schulte:** Conceptualization, Methodology, Formal analysis, Resources, Writing - review & editing, Supervision, Validation.

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Appendix A. Supplementary data

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