D5.6 Delivery of Ecosystem services module

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Executive Summary

AGRICORE is a research project funded by the European Commission under the RUR-04-2018 call, part of the H2020 programme, which proposes an innovative way to apply agent-based modelling to improve the capacity of policymakers to evaluate the impact of agricultural-related measurements under and outside the framework of the Common Agricultural Policy (CAP). The AGRICORE suite stands out for being highly modular and customisable. Thanks to its open-source nature AGRICORE can be applied to a multitude of use cases and easily upgraded as future needs arise.

The assessment of agricultural policy impact is made through a set of impact assessment modules (IAMs) based on the outputs of the simulation of a synthetic population of agents which replicates the characteristics, distribution, and interactions of the real population of interest. One of these modules is the delivery of ecosystem services IAM, which is presented in this deliverable. The purpose is to develop an IAM capable of measuring indicators belonging to different fields (i.e. nature, economics, agriculture, etc.) and to derive from them the assessment of the provisioned ecosystem services. For this reason, biophysical measures are included to monitor changes in ecological conditions of the environment, as well as economic and social measures to quantify the impact of eco-services on human welfare.

Firstly, an analysis of the previous use case studies related to the modelling and assessment of eco-services is carried out in order to understand already existing methodologies and how they can be extrapolated to other use cases. Sections 2 and 3 present a proposal to model and measure eco-services in the Polish use case of the AGRICORE project, based on the available data, demonstrating that it is possible to shape categories of types of eco-services (supplying, regulating and sustaining, and cultural) through indicators under the CAP. These indicators are composed of quantitative and qualitative measurements.

Finally, for modelling eco-services, two existing tools are presented. On the one side, the Ecosystem Services Models Library allows estimating the production of ecosystem goods and services through the interaction of several eco-service modules. On the other side, InVest tool assists in managing natural resources by predicting how changes in ecosystems can alter benefits to human welfare, supporting the decision-making process. Moreover, some of InVest's models of interest are described in detail.

Abbreviations

Abbreviation	Full name
ABM	Agent-based model
BILS	Building Integrated Living Systems
BRI	Benefit-relevant indicator
CICES	Common International Classification of Ecosystem Services
EO	Earth observation
EPF	Ecological production function
ES	Ecosystem service
ESML	Ecosystem Service Models Library
FEGS	Final ecosystem goods and services
ICM	Integrated Compartment Model
KPI	Key performance indicator
RES	Renewable energy system

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1 Introduction

The studies on ecosystem services and their assessments found in subject-related literature include very simplified models developed for the specific conditions of a given area (region, micro-region) and contain many detailed restrictions reflecting these conditions, (some authors directly inform about the impossibility of transferring the results of a given model to other areas). No universal model allowing for the establishment of KPIs for different areas characterized by different conditions in terms of water, soil and climate relations, etc. has been found [1]. The issues of ecosystem services are considered from the point of view of various scientific disciplines: natural, economic, and agricultural production, so gathering sufficiently precise, comprehensive and compatible data to assess them is challenging. The Common International Classification of Ecosystem Services (CICES) categorizes ES into three broad categories: regulating and maintaining services, which help maintain the proper functioning of ecosystems, (e.g. biodiversity); provisioning services, which supply productive output that can be directly exploited, (e.g. crop production); and cultural services, which influence people's mental and physical wellbeing through non-material characteristics of an ecosystem [2]. ES also contain a spatial component, with many ES emerging only if a minimum scale threshold of specific service-providing processes/functions is met [3]. Relevant scale thresholds vary between ES from global (e.g. global climate mitigation) to local (plot-limited) level (e.g. pest control). The human dimension of the human-nature interactions captured by the ES concept is also spatially explicit, with demand for certain services often driven by socio-cultural and/or geographic conditions [4]. From CICES findings on abiotic ecosystems, outputs resulted that there is a need for a complementary approach for all environmental services. There are sometimes necessary trade-offs between the use of different resources. For environmental accounts, it would be helpful to have a more extended classification of ES including provisioning with water which is already included in CICES but it would be also necessary to include other abiotic outputs as well ID: 4493445824) [2]. However, in the comments from those who suggested extending the classification, there was a wide range of different types of abiotic outputs that might also be considered. These included not only those suggested in the survey, such as wind, hydropower and salt but also space (or offering territory or etc.). Also, air (wind), water (transport, energy etc.), and minerals (mining) are very important (ID: 4591640851). Discussing ecosystem services versus abiotic factors suggests that better information on the rationale for what was included in the classification was needed and what the scope of the system was, and whether abiotic outputs were included in the mind-body of the classification uses should be given points to how they might be handled in different contexts.

Within the scientific discussion, one of the most important problems is finding the methods, models and tools of ES assessment that would let integrate economic and social goals with environmental ones. On the other hand, finding the most satisfying solutions for particular stakeholders of ES development depends on their different interests which can also be a challenge both in a spatial context and corresponding scales of action of particular environmental determinants and economic interests. They can be often conflicting with different stakeholders because of their different needs and preferences.

The study presents the theoretical contribution of science to modelling eco-services as well as verified available tools in this regard as well as original methods and their applications for the assessment of eco-services. Finally, we have presented the solutions that can be useful when applied for simulations run with the ABM model to survey mutual dependencies of agricultural production and environmental changes shaping ecosystem services.

2 Methodology of selected regional scenarios modelling and estimation with measures for ES KPI's

2.1 Methodological aspects to consider in ES assessment of ecological and social needs

An important methodological issue concerning ES can be expressed in the question "Who are Ecosystems services KPIs for?". The decision-makers need to know not only where these people are, but who they are, how many, and whether they are affected by potential changes in the provision of services (e.g., reduction in a flood or fire frequency or intensity). For a service used or appreciated by a broader or spatially distributed group of people, such as cultural appreciation of a particular location, the service shed would include the area providing the service and its connections to those using or appreciating the service. Servicesheds for non-market services such as these can be more difficult to identify. A service shed including all those who value the particular service can be national or even worldwide. Servicesheds for nonuse values in particular can often span very great distances [5][6]. The classification of benefits and beneficiaries is not so evident - the link to the beneficiaries depends on the context. Some studies show that in certain cases positive environmental results for a given location may be negative for another location.

Incorporating ecosystem services into decision-making is expected to improve the way that decisions are made and communicated to the public (National Research Council, 2005, PCAST, 2011). Despite consensus around the general concept of ecosystem services and the need to consider them in decision-making, those applying ecosystem service analysis to support decisions typically lack systematic guidance on what factors to measure and how [7]. Incorporating ecosystem services into decision-making can change the way the problem is perceived and the way solutions are formulated because decision-makers consider not only changes to ecological conditions but also how these changes can affect people. Whereas, decision-makers frequently attempt to conduct ecosystem services analysis using biophysical measures or narratives that are poorly matched to the purpose. Common examples include imprecise narrative descriptions of ecosystem services or biophysical measures that lack a clear and identifiable relationship to social benefits. As a result, ecosystem services are often not considered on an equal footing with other costs and benefits when decisions are made [8].

The assessments of ecosystem services require both biophysical measures related to ecosystems; these reflect underlying changes in biophysical structure and function driven by alternative management decisions or environmental change (e.g., climate change) and social or economic measures of preference or value. Those reflect the impact of ecosystem services on human welfare. What is less clear is the hand-off between the biophysical measures and valuation–the link between the biophysical measure and a measure of what that biophysical entity means to (or how it affects) people. This is particularly important when valuation in monetary or non-monetary terms is not feasible or acceptable, but some measurement of what is valued by people is needed for decision-making [9].

However, narrative information is not easily reproducible, testable, or useable in valuation or decision analysis methods in the same ways as information expressed using a well-defined measurement scale. Given these limitations, BRIs, (benefit-relevant indicators), cannot be purely narrative; quantitative data (which includes categorical, ordinal (rank) or continuous data) are required (see Figure 1) instead [8].

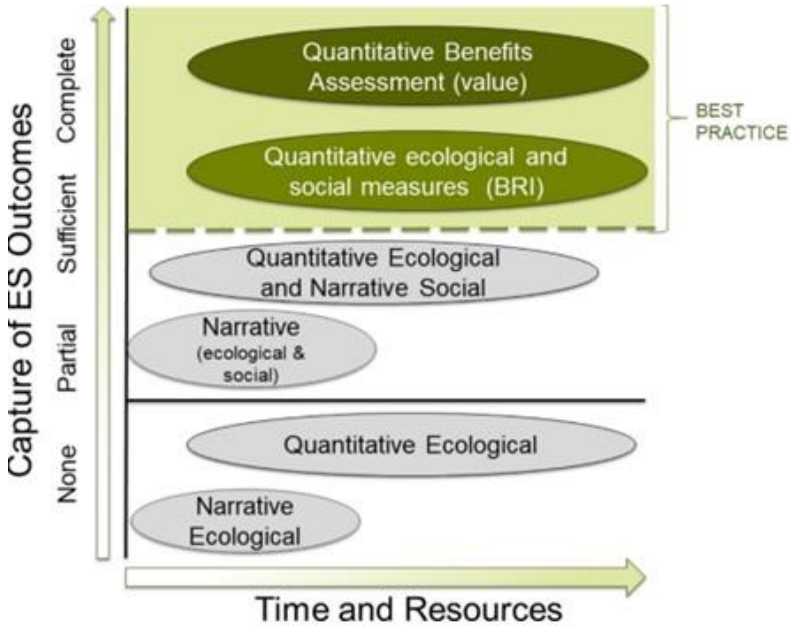

Figure 1: Approaches for capturing of ecosystem services (ES) outcomes in assessments and decision making on

Ecological and ecosystem services assessments and indicators have not to be the same. For example, resource managers wishing to assess the mechanical thinning of forests to reduce the intensity of a fire may undertake an ecological assessment to consider changes in the fuel load, which affects fire intensity as well as other biophysical features. In contrast, an ecosystem services assessment would extend the assessment to outcomes that matter to people, which could then be extended to specific benefits to people such as reducing the incidence of smoke and poor air quality which can reduce exposure and adverse health outcomes for nearby residents [10][11]. Thus, the ecosystem service of interest is a change in airborne particulates that is near populations that could be exposed or, even better, a change in the number of people exposed to this change in air quality. These are the BRIs that can provide quantifiable measures of an ecosystem service that is valuable to people and affects human welfare.

Benefit-Relevant Indicators (BRI) can be used in intuitive decision-making, where preferences, priorities and tradeoffs among conflicting objectives are considered without any explicit analysis. Intuitive comparisons require decision-makers to use their knowledge of preferences (stakeholder or institutional) implicitly, rather than to assess them explicitly. Therefore, an elementary and helpful step can be to construct the so-called “alternatives matrix” that represents each policy option’s associated (measured or modelled) BRI outcomes. An alternatives matrix can include other information in addition to ecosystem services, such as the costs of different alternatives. This approach can help with transparency and with communicating what is known about different alternatives and can place ecosystem services on the same footing as other factors important in decisions taking into account the interests of different stakeholders [8]. The concept of BRIs is designed to be broadly applicable to myriad contexts and scales over which ecosystem services analyses are applied (see: Figure 2).

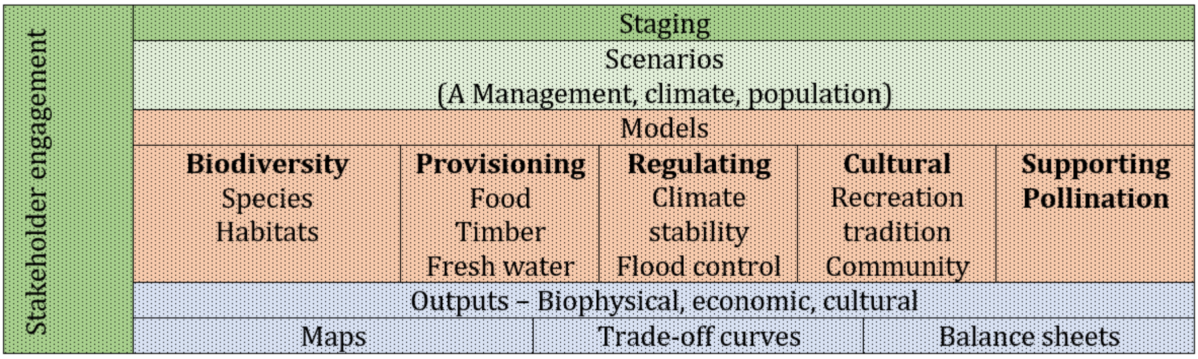

Figure 2: An iterative process for integrating ecosystem services into decisions.

The process starts with stakeholder engagement around the decisions that are to be made, with a focus on realistic, alternative scenarios of the future. The modelling is shaped by stakeholders and typically focuses on the (subset of possible) services and scenarios deemed most important. They are expressed in the form of maps, tradeoff curves, and/or balance sheets in accordance with stakeholder preferences.

Another context of the above-mentioned issue concerns the problem of how to reach economic goals through biodiversity. Individuals maximize utility subject to a budget constraint and perfectly competitive firms maximize profits given technology and prices [12]. Though far less common, such thinking can also be applied to biodiversity conservation and environmental management. For example, several papers have analyzed the objective of maximizing the number of species conserved through habitat protection given the limited resources [13]. Applying an economic approach to conservation and environmental management requires stating a clear objective. In the conservation realm, however, there is no single universal agreement on the objective: In the view of the whole society, it is hardly possible to come close to defining what is the objective. We have to make up our minds as to what it is that we are optimizing. This is the essential problem confounding the preservation of biodiversity today [14]. At present, there is a deep divide within the conservation community about the proper objective for conservation [15]. In the analyzed case study, the choice of a specific objective, however, did matter in terms of specific types of conservation investment to make. For ecosystem services under the base-case assumptions that place a relatively high weight on carbon sequestration, most conservation investments are made in the northeast and southeast portions of Minnesota state, (U.S.A.) to maintain or restore forests. Little investment is made in the western portions of the state where the native habitat is grassland rather than the forest. However, investments for biodiversity conservation are made more evenly throughout the state to restore both forests and grasslands. The findings showed that consideration of management practices, such as fertilizer application rates and tillage practices in agriculture, in addition to land-use change, can provide additional options that allow for improved performance on multiple dimensions. Finally, consideration of spatial interactions, where the benefit of taking action on one land parcel depends upon what actions are taken nearby, and dynamic transition paths, such as the time path of accumulation of carbon with forest maturation rather than analysis of steady-state conditions, could provide additional insights. So, the findings let confirm a high degree of alignment between strategies that target the value of ecosystem services and those that target habitat for biodiversity conservation because the goal for economic and environmental needs was defined in an appropriate way [12].

2.2 The Impact of a context on ES assessment transferability of results from one location to another one

ES concept, as well as an empirical analysis of farm environmental performance strongly depending on the practices. The qualitative assessment indicates that there is a great deal of information already available in the literature on the impact of farm management practices on ES supply in European agricultural systems. Various methodologies exist in the literature, ranging from purely qualitative descriptions (literature review), through biophysical quantitative assessments to purely monetary assessments. We notice that not all ES can be assessed using all possible methodologies. For example, cultural services are most often evaluated using monetary assessments, (sometimes e.g. visitor-days), such as stated preference techniques, while regulating and maintaining services are most often quantified in purely biophysical units (e.g. tons of carbon). Below some cases presented different methodological approaches were described to show relations between a subject of research and the methods to analyse it [8].

2.2.1 Case studies on different methodological approaches considering a differentiation of specificity of research subjects

Building on corresponding literature, one can mention two management practices, grass strips and hedgerows, and the monetary value of a set of six ES within the context of two Belgian agriculture case studies [1]. The next case is on the evaluation of coral reef management effectiveness [16]. Increasing damage to coral reefs requires to, was determined defining tools that evaluate their dynamics and resilience is important to interpret system trajectories and direct conservation efforts. In this context, surveys came out outside conventional monitoring approaches that focus on the abundance and biomass of key groups and quantify metrics that more assess ecological processes and ecosystem trajectories in a more accurate way [16]. The study evaluated the ecosystem responses to community-based management in Fiji by measuring a variety of conventional (e.g. proportional cover of broad benthic groups, the biomass of herbivorous fish) and complementary resilience-based metrics (e.g. algal turf height, coral recruitment rates, juvenile coral densities, herbivorous fish grazing rates). The study was conducted across three paired tabu areas (periodically closed to fishing) and adjacent fished sites. Conventional metrics reflected no management effect on benthic or herbivorous fish assemblages. In contrast, the complementary metrics generally indicated positive effects of management, particularly within the benthos. Significant differences have been observed for turf height (33% lower), coral recruitment rate (159% higher) and juvenile coral density (42% higher) within areas closed to fishing compared to adjacent open reefs. These results emphasize that conventional metrics may overlook the benefits of local management to inshore reefs and that incorporating complementary resilience-based metrics such as turf height into reef survey protocols will strengthen their capacity to predict the plausible future condition of reefs and their responses to disturbances. Most ecosystem assessments have typically focused on quantifying common status metrics, such as biomass and abundance of target groups, as well as species diversity (e.g. [17]). Although such assessments offer the advantage of relying on generally fast and relatively simple estimation methods, their capacity to convey quantitative information on ecosystem function is limited [18]. It is thus important to identify indicators of dynamic processes to capture a further facet that may help to anticipate the likely trajectory of ecosystems over time and in response to disturbances [19]. If such indicators can be practically and cost-effectively integrated into ecosystem assessments, there is scope for evaluating the effectiveness of conservation tools (e.g. marine reserves) more precisely, better understanding the impact of disturbances, and supporting managers in the decision-making process (high vs. low-risk conservation investments). Monitoring should thus focus on measurements that respond rapidly to changing conditions-decision scenarios and that may indicate whether the system is likely to exhibit a stable temporal trajectory or to shift to alternative dominance states in response to future perturbations.

The next case concerns the problem of mapping agricultural ecosystem services based on a survey made in Ethiopia. It is important to gather ecosystem service data at the multiple spatial scales they operate at considering given the cross-scale interactions of agricultural ecosystems. That is why the mapping of ecosystem services helps to assess their spatial and temporal distribution and it is a popular communication tool given its availability and values. For example, maps can be used to quantify the distance between areas of available ecosystem services and their beneficiaries and how services fluctuate with changes in land use patterns over time, allowing for the identification of synergies and trade-offs. However, the lack of local context and too big resolution can reduce the utility of these maps, whilst masking heterogeneities in access due to equity dynamics. From the findings obtained from the SIDERA project made in Ethiopia [20] one can conclude that when mapping agricultural ecosystem services, global approaches tend to rely on expert knowledge, models and EO-derived (Earth Observation) land cover classes and biophysical variables. The local approaches often involve substantial fieldwork to collect social-ecological data in a participatory manner regarding user perceptions of values. Hence, local data collection allows researchers to overcome the limitations of existing maps and generate bespoke land cover maps which are better tuned to the local context. Thus, the focus on providing a set of global ESS products has its limitations - while it will certainly lead to advancements in our understanding of ESS availability at the global scale, such products are unlikely to provide sufficient and relevant information for decision-making at local or national scales [21]. However, this will not negate the need that the investigation of agricultural ESS should be carried out on a range of scales to support management and policy decisions at all scales.

In the next case study the authors [22], using a simple mathematical model, illustrated that more explicit consideration of species identity and composition, (i.e., the community assembly approach), can improve our ability to understand regime shifts and restore degraded ecosystems. So, they proposed a synthetic perspective that merges the community assembly with the regime shift approach to effectively inform the restoration of ecosystems exhibiting alternative stable states. It is an original approach different from the ones used nowadays, where alternative stable states have been addressed from two different angles: community assembly studies, which focus on species and their interactions, and regime shift studies, which focus on changes in ecosystem states following environmental change. In this research, a synthetic perspective that merges the community assembly with the regime shift approach to effectively inform the restoration of ecosystems exhibiting alternative stable states was shown. One can suggest that future efforts to restore feedback mechanisms involving both abiotic environmental conditions and biotic interactions should consider important aspects of a community get-together. Such an integrated perspective will be crucial for broadening our ability to manage alternative stable states and improving the prediction of regime shifts, particularly in the face of global environmental change.

2.2.2 A complexity of methodology for ES assessment resulting from the diversity of a problem being evaluated and necessary the relevant information

Ecosystem service mapping methods are being utilized. For the purposes of the SIDERA project were adjusted the spatial scale to our context, and methods utilized and expanded on below as follows: photo-elicitation, not repeat photography, but one-off images and videos of elements of the landscape community member's values, participatory mapping of ecosystem services at the community, local government unit, and river basin scales.

An analysis was carried out with groups representing local communities with different livelihood strategies, local and national government, and national and international nongovernmental organizations, user perceptions and community values of those ecosystem services, also with expert opinions and professional judgements from local elders, national and international scholars, providing primary data via transect walks, secondary data, and context to knowledge gaps in the mapping. Biophysical and ecological modelling increases local ESS availability and value to create basin-wide maps. Of course, participatory assessment and mapping of ecosystem services in a data-poor region have a special meaning for ES effective assessment [23].

The next case concerns a project on eco-retrofitting with building integrated living systems made in Australia. Building Integrated Living Systems (BILS), such as green roofs and living walls, could mitigate many of the challenges presented by climate change and biodiversity protection. However, few if any such systems have been constructed, and current tools for evaluating them are limited, especially under Australian subtropical conditions. BILS are difficult to assess, because living systems interact with complex, changing and site-specific social and environmental conditions. The past research in design for eco-services has confirmed the need for better means of assessing the ecological values of BILS - let alone better models for assessing their thermal and hydrological performance. The CQ University model for predicting the thermal behaviour of living systems will provide a platform for the integration of ecological criteria and indicators. CQ will also explore means to predict and measure the value of eco-services provided by the systems, which is still largely unexplored territory. This research is ultimately intended to facilitate the eco-retrofitting of cities to increase natural capital and urban resource security - an essential component of sustainability. It will be presented the latest range of multifunctional, eco-productive living walls, roofs and urban space frames and their eco-services. This can provide natural cooling in subtropical cities, and can potentially provide eco-services such as air and water filtration. BILS could go further, and increase the ecological base and access to the means of survival in cities if passive eco-solutions were integrated with structural systems [24]. The above-mentioned approach is the next proof of the narrow scope of the developed model for the aims of measuring the ecological value of eco-services that can be provided by specific prototypes of living walls and roofs.

2.2.3 Integration of socio-economic and environmental objectives in a view of decision-making

The next case study concerned the necessity of understanding the space use of large grazing birds to implement crop preventive management at the appropriate spatiotemporal scale [25]. Such evidence-informed approaches to improving existing proactive measures will facilitate coexistence between large grazing birds and agriculture's interests, and thereby increase the acceptance for conservation of both large grazing bird species and wetlands [26][27]. The findings highlight the necessity of adapting preventive measures against crop damage to the scale of bird space and are used to integrate two goals: they facilitate both bird conservation and agricultural practices at wetland staging sites along the flyways.

The next case study concerns the long-term assessment of ecosystem state changes [28]. An existing coastal ecosystem model was used with forested wetland and fish habitat indicators to evaluate current environmental conditions as well as future restoration projects via 50-year simulations of riverine flow with sea level rise and subsidence. The objective of this study was to utilize the Integrated Compartment Model developed for the Louisiana Coastal Protection and Restoration Authority's 2017 Coastal Master Plan to understand how alternations of riverine flow from existing rivers and future restoration projects may influence the spatial and temporal distribution of wetlands habitats and suitability of fish habitats. Integrated Compartment Model (ICM) framework is a comprehensive and computationally efficient numerical model used to provide insights into coastal ecosystem dynamics and to evaluate restoration strategies. The ICM was developed for modelling the Louisiana 2017 Coastal Master Plan [29] and was built from several individual models that were previously used within coastal Louisiana [30]. One can discover some model limitations in this case study. The ICM framework was developed for multi-decadal, planning-level simulations of coastal zone dynamics. The model subroutines were developed to capture the ecosystem processes important to coastal restoration planners and engineers, while at the same time maintaining a computational efficiency suitable for completing hundreds of 50-year simulations. Therefore, it is important to understand the limitations of the modelling framework. The ICM-Hydro subroutine is the only model subroutine that operates on a continuous timestep; all other subroutines use either monthly or annual timesteps. The primary limitation of the ICM-Hydro subroutine is the spatial resolution required to maintain this continuous timestep, which subsequently limits the spatial representation of hydrologic parameters that are utilized by other ICM subroutines. Despite some limitations of the applied modelling the findings showed that riverine input is essential for the sustainability of the estuaries, wetlands, and swamps into which they flow. Obtained here modelled results greatly depend on the specific restoration projects included and on the assumed future predictions of environmental conditions but provide valuable insight for decision-making aims concerning managing coastal areas.

The next case study concerns research which uncovers the importance of people's place-values on sustainable forest management, and how such values can be incorporated into forest management actions and relevant decision-making [31]. Specifically, it focuses on mapping economic and cultural values on forest ecosystem services; assesses how non-materials and materials benefit from forest ecosystem cause landscape fragmentation; and how this information could help in better forest planning and management. The data were gathered from ten villages surrounding the Ngezi forest reserve in Pemba, Tanzania. The numbers come from participatory mapping, field observation, and focus group discussions. It is acknowledged that there are many problems associated with relying on people's perceptions in conservation planning because their views of landscape values are influenced by their earlier experiences and economic and cultural issues. However, the findings of this study provide evidence that local communities know what is of value in their surrounding environment. Therefore, their knowledge should be seen as a relevant resource of information for undertaking future sustainable forest management practices. The findings let conclude also that forest managers and planners should consider both the economic and social values of forest ecosystems along with direct product-based services to achieve the socio-economic sustainability of both forests and dependent communities.

2.3 Summary

These important conclusions on the link between biodiversity and ecosystem functioning and services then led to the next phase of scientific inquiry which is to link ecosystem services to human well-being, e.g., through quantification of economic benefits. Consequently, the scientific goals of the Eco-services Science Plan [32] are not only to further expand the research on the above conclusions by expanding the scale and complexity of future studies but also to include economic and social researchers to investigate how preferences for certain ecosystem services influence decision-making both at the individual and the societal level and how to translate scientific knowledge about ecosystem services into economics to inform decision-makers about current versus future costs and benefits in comparable units of impact on human well-being [33].

To this end, experimental and field studies need to be supplemented by the development of integrated ecological-economic models to contribute towards a scientific basis for sustainable ecosystem-based management which is essential to achieve a conclusion [34]. Hence, without reliable ecological-economic models, decision-makers and managers will find it difficult to choose policy and management options that maintain the buffering capacity of functional ecosystems and, at the same time, satisfy other societal needs, e.g. the provision of foods and fibres. Hence, quantifying the value of ecosystem services in specific localities and measuring their worth against that of competing land uses is no simple task. For example, a typical tradeoff is to quantify the economic benefits of a particular development project versus the benefits supplied by the ecosystem that would be destroyed. While in many cases the value of ecosystem services remains highly uncertain, the pace of destruction of natural ecosystems and the irreversibility of most such destruction warrants that we begin valuing ecosystem services, even if such an enterprise is fraught with difficulties and difficult to assess it. So, it may be justified to establish fundamental ecosystem protections even though uncertainty over economic values still remains.

The above problems with an objective assessment of ecosystem services resulting from limited availability of the data, limited possibilities of model and tools, and a context of their usage was a reason to try to define solutions for the Polish use case which can, in a limited way, help evaluate the potential for ecosystem services development in Poland.

The challenges in disseminating the concept of ecosystem services under EU regulations have led to the creation of many measures and indicators for assessing their level as well as tools for mapping and modelling. However, the interdisciplinary nature of the concept of ecosystem services, including both environmental production in the form of biomass and the state of the environment as well as its landscape and aesthetic values, means that the measures and indicators of ecosystem services represent different ways of describing the matter to be analysed. Thus, there are direct indicators (indirect), also known as surrogate indicators. Apart from simple indicators relating to one type of measurement, there are also complex indicators (indices) used, which are a mathematical combination of simple indicators, which are additionally normalized.

The use of indicators for modelling and shaping ecosystem services is a complex problem and requires the selection of appropriate indices for individual types of ecosystem services, access to data enabling the calculation of these indicators, selection of an appropriate spatial unit for their assessment and modelling, taking into account trends in temporal variability, e.g. biological progress in agricultural production. It is also necessary to take into account the linkage between ecosystem services and individual indicators of the trade-off type and mutual support - synergy. It assumes a compromise link between biomass production services and regulatory, maintenance and cultural services. On the other hand, a synergistic link is signalled in most cases between the categories of regulating and supportive and cultural services.

In a next part of the elaboration a proposal on how to model and measure ecosystem services in Poland based on available data was presented. The aim of the own research was to demonstrate the possibility of shaping the level of individual types of ecosystem services in particular categories by regulating indicators that can be shaped under the common agricultural policy. The analysis includes both qualitative assessment – a compromise or synergistic link, and quantitative assessment – the impact of the amount of change of a given indicator on the amount of change of a given ecosystem service. It was assumed that the research will lead to the identification and delivery of KPIs, the most universal ones that can be included in the module for modelling ecosystem services.

3 Methodology of KPI eco-services assessment for selected variables

The aim of the work package is to develop modules for modelling the agricultural structures surrounding farmers (markets and land) and their context (environmental and climate impact, socio-economic impact (rural integration), ecosystem service delivery and the political environment). The development of a dedicated module for modelling and delivering KPIs of ecosystem services. Is a task of D5.6.

The aim of the study is the development of dependencies useful for the modules for assessing the impact of agriculture on the environment and climate and the module for ecosystem services, in accordance with the assumptions of T5.6.

3.1 Materials and method

The study used a total of 28 indicators for Polish voivodeships (N = 16)

The indicators are grouped into 4 types:

1. **EU subsidy indicators (2)**
2. **Agricultural productivity indicators (8)**
3. **Agricultural production space valuation indicators (3)**
4. **Natural environment quality assessment indicators (15)**

The indicators were taken directly or calculated independently, mainly using the databases of the Central Statistical Office, Warsaw and the publications of IUNG-PIB in Puławy.

Significant relationships between the indicators were searched for in line with the research objective. Correlation and regression analysis were used. The relationships with the determination coefficients $R^2 \geq 0.2473$ ($p = 0.05$) and 0.3876 ($p = 0.01$) were considered significant.

EU subsidy indicators:

- Value of Rural Development Programme 2004-2013 subsidies for investments in PLN /1 ha of Agricultural Land
- Value of the grant of M.10. in July 2021 thousand PLN per person

Selected Agricultural productivity indicators:

- The share of cereals in the structure of crops %
- The share of cereals and rapeseed in the sown structure %
- The share of potatoes, sugar beet and vegetables in the sown structure %
- Cereal yields in dt/ha ($t*10^{-1}$)
- Animal cast at Large heads index/100ha
- Unit milk yield in thousand litres
- Mineral nitrogen fertilization in kg/ha of Agricultural Land
- Commodity production in thous. PLN/ha of Agricultural Land

Indexes of agricultural production space valuation:

- Index of agricultural production space valorisation (points)
- Valuation index of Agricultural Land (0-1)
- Indicator of the agroecological potential of agriculture (1-5)

Indicators for assessing the quality of the natural environment:

- % share of soils with a favourable pH above 5.5
- % of soils with favourable fertility P
- % of soils with favourable fertility K
- Organic matter content in %
- soil humus index % of Agricultural Land
- Gross Nitrogen Balance Income - expenditure in kg/ha of Agricultural Land
- Forest cover (area%)
- Share of grassland % of Agricultural Land
- Protected areas with special natural values (% of the area)
- The share of areas with agricultural production difficulties due to nature protection % of Agricultural Land
- Area of Agricultural Land in organic farms thous. ha
- Renewable Energy Sources share in energy production%
- Number of days with exceeded daily concentrations of PM10
- Negative assessment of air quality (% of respondents)
- Soil coverage with vegetation per year % of Arable Land

3.2 Provided KPI values for eco-services of selected decision variables

The impact of EU subsidies (the significance of 52 dependencies was tested)

1. The impact of RDP subsidies on investments on the analysed indicators

The amount of RDP subsidies for investments significantly correlated with 5 agricultural productivity indicators

- Negatively with the share of cereals in the sown structure R^2=0,2800*
- Negatively with the share of cereals and rapeseed in the structure of crops R^2=0,4411**
- Positive with the cast of animals R^2=0,6413** (Figure 3: Influence of a Value of Rural Development Programme on Animal cast.
- Positive with milk yield R^2=0,4075**
- Positive with commodity production R^2=0,3331*

The amount of RDP subsidies for investments significantly correlated with 4 indicators of the quality of the natural environment

- Negative with the content of organic matter in the soil R^2=0,2611*
- Negative with the soil humus index R^2=0,2568*

- Positive with nitrogen balance R^2=0,7449** (Figure 4: Influence of a Value of Rural Development Programme on Gross Nitrogen Balance Income.)
- Negatively with the share of areas with handicaps due to nature protection R^2=0,4414**

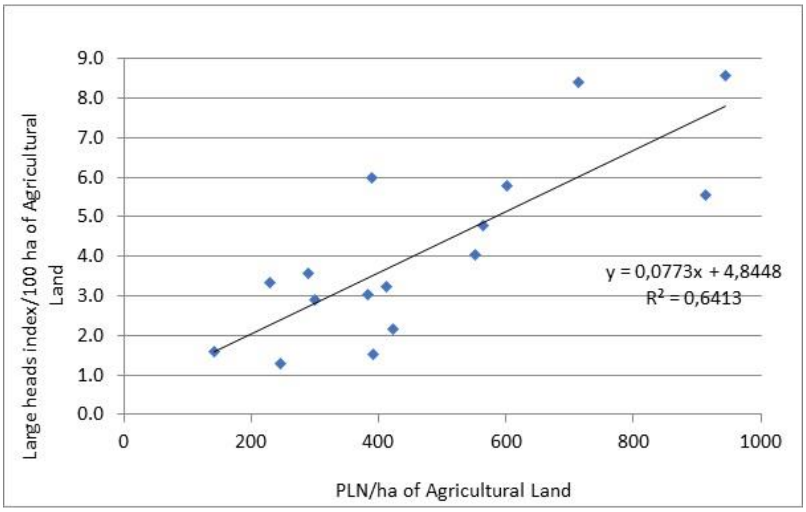

Figure 3: Influence of a Value of Rural Development Programme on Animal cast.

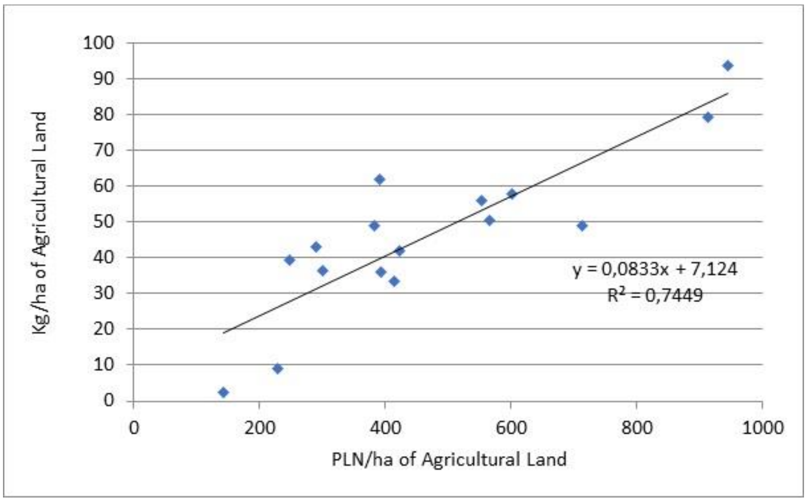

Figure 4: Influence of a Value of Rural Development Programme on Gross Nitrogen Balance Income.

The impact of EU subsidies

1. The impact of grants M.10. on the examined indicators

Grant amount M.10. significantly correlated with 5 indicators of the quality of the natural environment:

- Positive with the participation of soils with a favourable phosphorus content R^2=0,3333*
- Positive with the participation of soils with a favourable potassium content R^2=0,3266*
- Positive with forest cover R^2=0,4606**

- Positive with the area of organic farms R^2=0,2642*
- Positive with the indicator of soil coverage with vegetation during the year R^2=0,6850** (Figure 5: The relationship between Value of the grant of M.10. and Soil coverage with vegetation per year.)

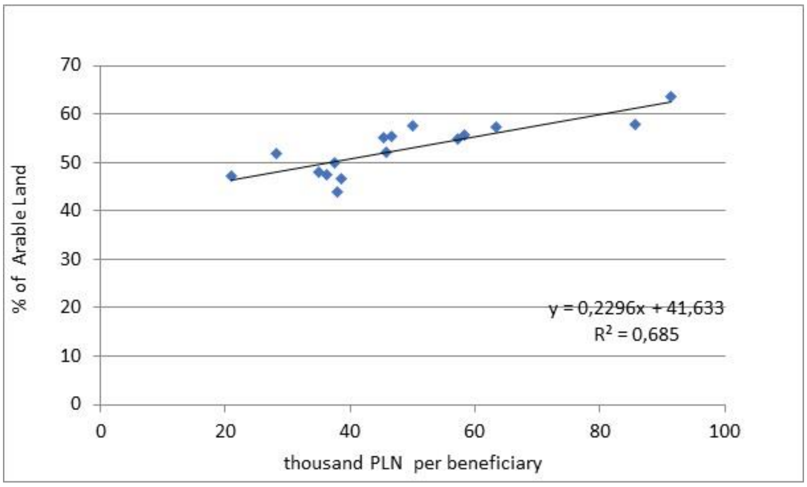

Figure 5: The relationship between Value of the grant of M.10. and Soil coverage with vegetation per year.

The impact of agricultural productivity indicators (the significance of 144 relationships was tested)

The influence of the share of cereals in the structure of crops on the analysed indicators

The share of cereals in the structure of crops significantly correlated with 4 indicators of the quality of the natural environment:

- Negative with the Agricultural Land of organic farms R^2=0,5132**
- Negatively with the share of renewable energy sources in energy production R^2=0,7848**
- Positive with the number of days exceeding the daily concentrations of PM10 R^2=0,7350** (Figure 6: Influence of Sown structure on Air Quality.)
- Positive with the number of days exceeding the daily concentrations of PM10 R^2=0,6518**

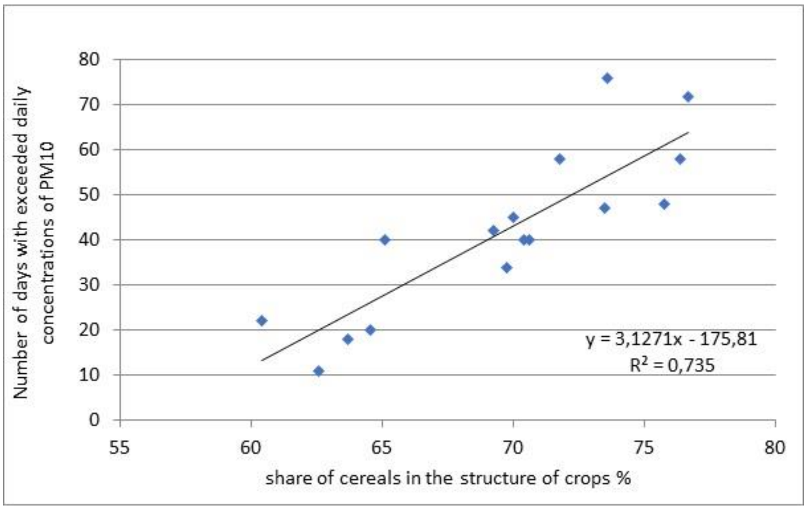

Figure 6: Influence of Sown structure on Air Quality.

Influence of the share of cereals and rapeseed in the crop structure on the examined indicators

The share of cereals and rapeseed in the structure of crops significantly correlated with 6 indicators of the quality of the natural environment:

- Positive with the content of organic matter in the soil R^2=0,3039*
- Positive with the soil humus index R^2=0,3478*
- Negatively with the share of permanent grassland R^2=0,2567*
- Negatively with the share of renewable energy sources in energy production R^2=0,4710** (Figure 7: Influence of Sown structure on Renewable Energy Sources share in energy production.)
- Positive with the number of days exceeding the daily concentrations of PM10 R^2=0,4051**
- Positive with a negative assessment of air quality R^2=0,2578*

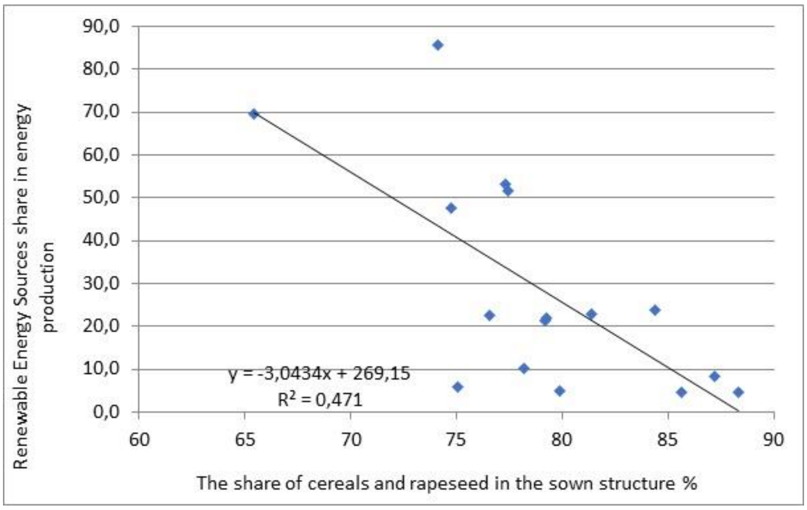

Figure 7: Influence of Sown structure on Renewable Energy Sources share in energy production.

The influence of the share of potatoes, sugar beet and vegetables in the crop structure on the examined indicators

The influence of the share of potatoes, sugar beet and vegetables in the crop structure on the examined indicators

- Negative with the Agricultural Land on organic farms R^2=0,3130*
- Positive with the number of days exceeding the daily concentrations of PM10 R^2=0,2639*
- Positive with a negative assessment of air quality R^2=0,2936*

Dependence on and influence of the amount of cereal grain yields on the investigated indicators

The amount of yields significantly correlated with 3 indicators of the valuation of agricultural production space:

- Positive with the index of agricultural production space valorisation R^2=0,6537** (Figure 8: Relationship between Cereal yields and Valuation index of Agricultural Land.)
- Positive with the soil valuation index R^2=0,5991**
- Positive with the indicator of the agroecological potential of farms R^2=0,6811**

The amount of crops significantly correlated with 5 indicators of the quality of the natural environment:

- Positive with the share of soils with a favourable reaction R^2=0,4707**
- Positive with the participation of soils with a favourable potassium content R^2=0,5089**
- Positive with the content of organic matter in the soil R^2=0,2741*
- Positive with the soil humus index R^2=0,3384*
- Negatively with the share of permanent grassland R^2=0,3514*

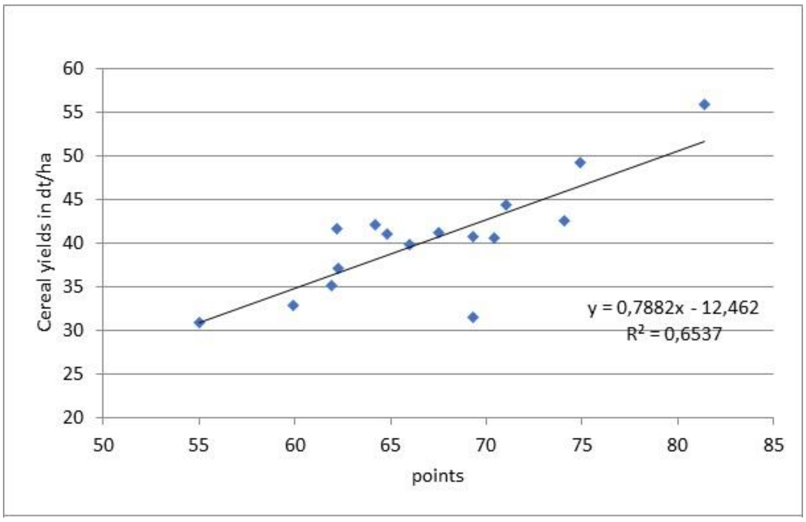

Figure 8: Relationship between Cereal yields and Valuation index of Agricultural Land.

Dependence on and influence of the stocking density on the examined indicators

The stocking of animals significantly correlated with 3 indicators of the valuation of agricultural production space:

- Negative with the agricultural production space valorisation index R^2=0,3316*
- Negative with the soil valuation index R^2=0,3316*
- Negative with the indicator of the agroecological potential of farms R^2=0,3749*

The stocking of animals significantly correlated with the 3 indicators of the quality of the natural environment:

- Positive with nitrogen balance R^2=0,5009** (Figure 9: Influence of Animal cast on Gross Nitrogen Balance Income.)
- Negative with the soil humus index R^2=0,3267*
- Negatively with the share of areas with handicaps due to nature protection R^2=0,2625*

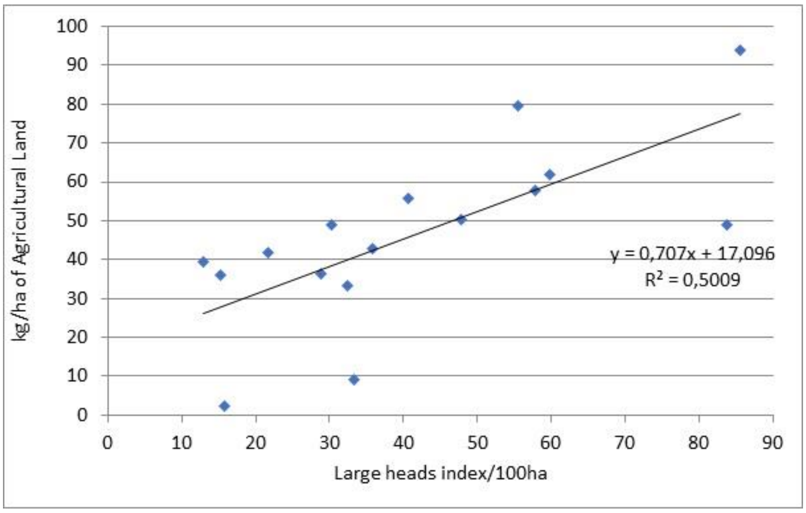

Figure 9: Influence of Animal cast on Gross Nitrogen Balance Income.

Dependence on and influence of unit milk yield on the examined indicators

Milk efficiency significantly correlated with 3 indicators of the quality of the natural environment:

- Positive with nitrogen balance R^2=0,5777**
- Negative with forest cover R^2=0,4365**
- Negatively with the share of areas with handicaps due to nature protection R^2=0,3089*

Dependence on and influence of the level of mineral nitrogen fertilization in milk on the examined indicators

The level of N fertilization significantly correlated with 8 indicators for assessing the quality of the natural environment:

- Positive with nitrogen balance R^2=0,4339** (Figure 10: Influence of Mineral nitrogen fertilization on Gross Nitrogen Balance Income.)
- Positive with the share of soils with a favourable reaction R^2=0,5159**
- Positive with the participation of soils with a favourable content of phosphorus in the soil R^2=0,4096**

- Positive with the participation of soils with a favourable potassium content in the soil R^2=0,2672*
- Negatively with the share of permanent grassland R^2=0,6626**
- Negatively with the participation of protected areas of special value R^2=0,2989**
- Negatively with the share of areas with handicaps due to nature protection R^2=0,3458*
- Positive with the indicator of soil coverage with vegetation during the year R^2=0,2714*

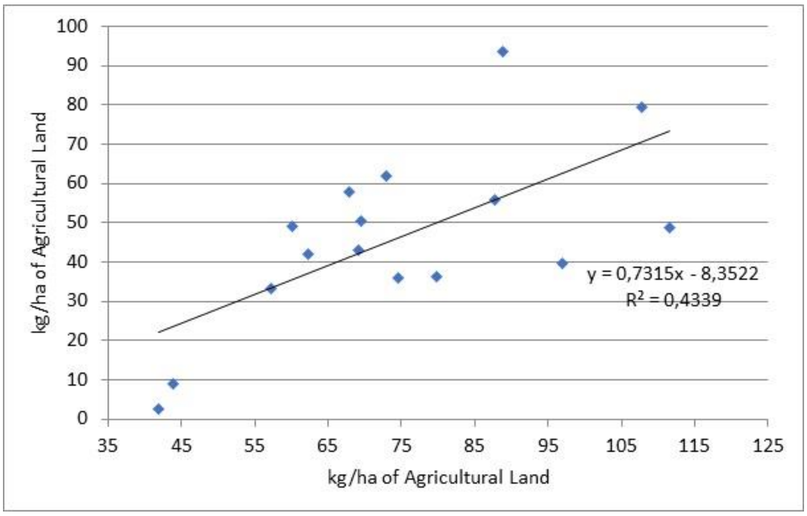

Figure 10: Influence of Mineral nitrogen fertilization on Gross Nitrogen Balance Income.

Dependence on and influence of the level of commercial production - the examined indicators

The level of commercial production significantly correlated with the 1 index of the valuation of agricultural production space:

- Negative with the indicator of the agroecological potential of farms R^2=0,3158*
- Positive with nitrogen balance R^2=0,4676** (Figure 11: Influence of Commodity production on Gross Nitrogen Balance Income.)
- Negative with forest cover R^2=0,3189*

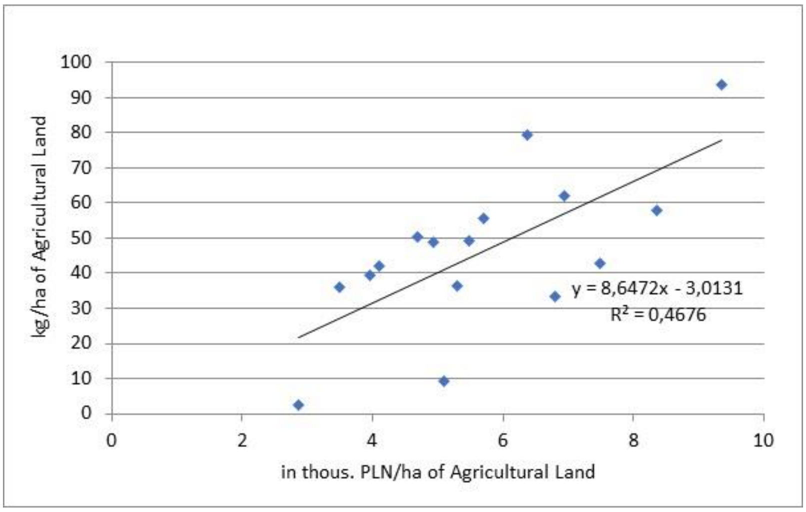

Figure 11: Influence of Commodity production on Gross Nitrogen Balance Income.

3.3 Summary

- The vast majority of significant dependencies confirm the positive impact of investment subsidies on the indicators of agricultural productivity and their negative impact on the quality of the environment.
- The vast majority of significant dependencies confirm the positive impact of pro-environmental subsidies M.10. on the quality of the natural environment.
- The vast majority of significant dependencies confirm the negative impact of agricultural productivity indicators on the quality of the natural environment.
- Significant dependencies make it possible to quantify the impact of the subsidy level and the intensity of agricultural production on the quality of the natural environment.

4 The possibilities of shaping cultural ecosystem services

Ecosystem services involve benefits derived by an individual from ecosystems. They are able to provide basic living requirements without which doing business and the existence of societies would not be possible. According to the Common International Classification of Ecosystem Services (CICES), ecosystem services are classified into three categories: supplying, regulating and sustaining, and cultural, providing benefits in the form of aesthetic, spiritual, recreational and educational values [35].

The analysis of ecosystem services takes into account the mutual relationships between them: trade-offs and mutual support - synergies. Overall, a trade-off is a situation where the use of one ecosystem service directly reduces the benefits of another service. The situation when the use of one service results in an increase in the benefits of another – is called the synergy of services. Most of the theoretical studies and environmental studies to date point to a compromise link between supply services, especially including food production, and regulatory and sustaining and cultural services. On the other hand, there is an indication of a synergistic link is between the categories of regulating, maintenance and cultural services in the majority of cases.

Cultural ecosystem services enable direct, intellectual and identity-forming interactions with living nature, including nature as part of the natural heritage. Certain examples of such services include, e.g., an opportunity to hike along educational paths, observe rare species of plants and animals, photograph nature, meditate, pray, creative work. In principle, they require presence in the natural environment, but such services also include the possibility of watching nature films. An even more utilitarian type of cultural ecosystem service is the possibility of relaxing, including tourism. Specific services include, inter alia, relaxing surrounded by nature, bathing and sunbathing, walking and running, mushroom picking, fishing, kayaking, boating and sailing, diving, as well as the possibility of landscape tours, visiting places of worship, etc. [36].

The potential of ecosystems to provide cultural services can be valued and estimated in a number of ways. Most often, for that purpose, we use direct or subjective indicators, which are difficult to calculate, although supported by scientific knowledge, and expert assessment [37].

The purpose of the study is to demonstrate the possibility of shaping cultural ecosystem services by influencing agricultural productivity indicators (direct route) and to demonstrate the impact of the quality of the natural environment on the level of these services (indirect route). The analysis covers both qualitative assessments – a compromise or synergistic link, as well as the quantitative one – the impact of the amount of change of a given indicator on the amount of change in cultural benefits.

The analysis uses data from the local CSO data bank regarding three indicators that assess cultural ecosystem services: the number of natural monuments, the area of natural reserves and the state of agritourism expressed in the number of agritourism accommodations, the number of tourists and the number of overnight stays. As for monuments and natural reserves, we used data from 2021, and with regard to the condition of agritourism, due to the coronavirus pandemic, we used data from the last five years 2017-2021. When examining the impact of agricultural productivity on the level of these cultural ecosystem services and their dependence on environmental quality indicators, we used data from Polish voivodships [regions] (N = 16). This required ensuring the comparability of the data from various voivodships, so indicators of the level of cultural ecosystem services were converted into a uniform number of inhabitants or into a uniform unit of area.

4.1 A number of natural monuments as an indicator for cultural ecosystem services assessment

We have examined the impact of 8 indicators of agricultural productivity on the number of natural monuments and the dependence of this number on 15 indicators of the quality of the natural environment. The analysis used 2 indicators regarding the number of natural monuments: the number per 100 km2 of a given voivodship and the number per 1000 inhabitants. Thus, we have examined (8+15) x 2 = 46 dependencies. Significant correlations have been found in 6 cases. They are concerned with the significant impact of the structure of sowing, expressed by the share of cereals or cereals and rapeseed, on the number of natural monuments per 1000 inhabitants, as well as the significant dependence of this quantity on the area of agriculturally used land on organic farms, as well as on the share of RES in energy production and on two air quality indicators. In each of these cases, the correlations were significant at a confidence level of 0.01. The number of natural monuments per 1000 inhabitants was most influenced by the share of cereals in the structure of sowing (Figure 12) and mostly depended on the respondents' assessment of air quality as poor (Figure 13). The number of natural monuments per unit area of 100 km2 was not significantly correlated with the indicators of agricultural productivity and with the quality of the natural environment.

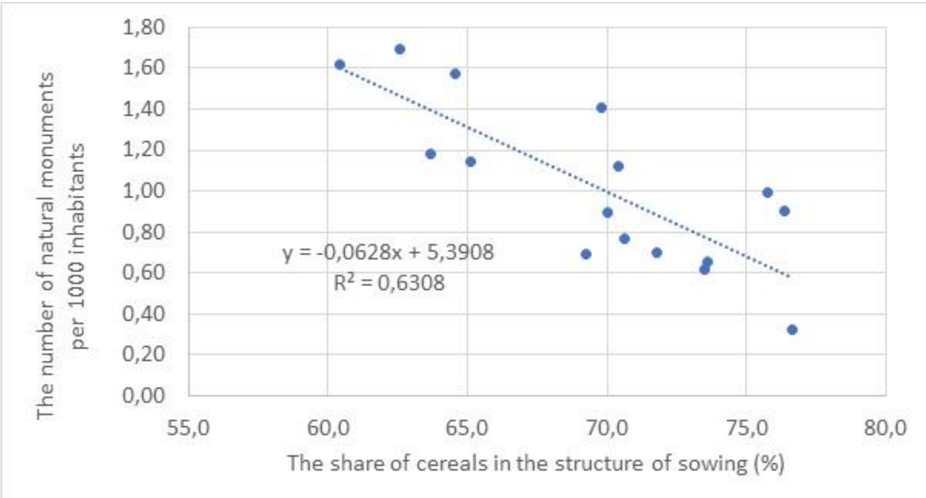

Figure 12: The influence of the structure of sowing on the number of natural monuments.

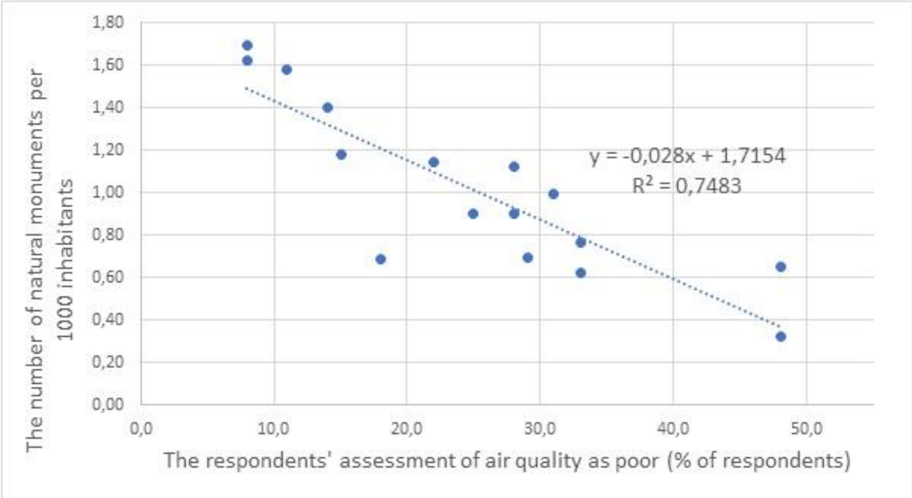

Figure 13: The dependence of the number of natural monuments on air quality.

4.2 A number and areas of nature reserves as an indicator for cultural ecosystem services assessment

We have analysed the impact of 8 indicators of agricultural productivity on the number and on the size of natural reserves and the dependence of this number on 15 indicators of the quality of the natural environment. The analysis used 2 indicators regarding the number of natural reserves: in quantity per 100 km^2 of a given voivodship and the number per 1000 inhabitants, and 2 indicators regarding the area of natural reserves: % of the area of a given voivodship and the number of ha per 1000 inhabitants. Thus, we have examined the significance of (8+15) x (2+2) = 92 dependencies. As for the number of reserves per 1000 inhabitants, the same results have been obtained for the number of natural monuments. Significant correlations have therefore been found in 6 cases. The number of natural reserves per 1000 inhabitants mostly depended on the share of cereals in the structure of sowing (Figure 14) and it most followed by the respondent's assessment of air quality as poor (Figure 15). The number of natural reserves per unit area of 100 km^2 was not significantly correlated with the indicators of agricultural productivity and the quality of the natural environment.

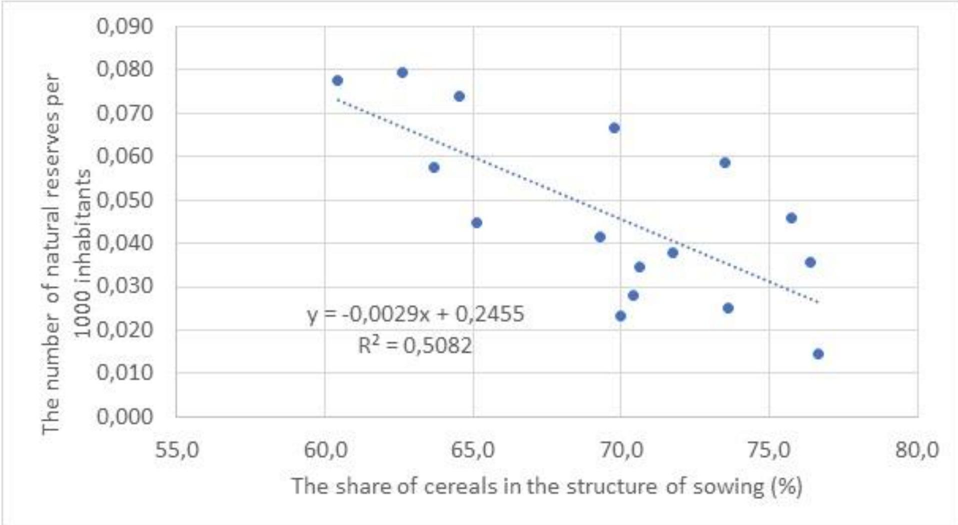

Figure 14: The dependence between the sowing structure and the number of natural reserves.

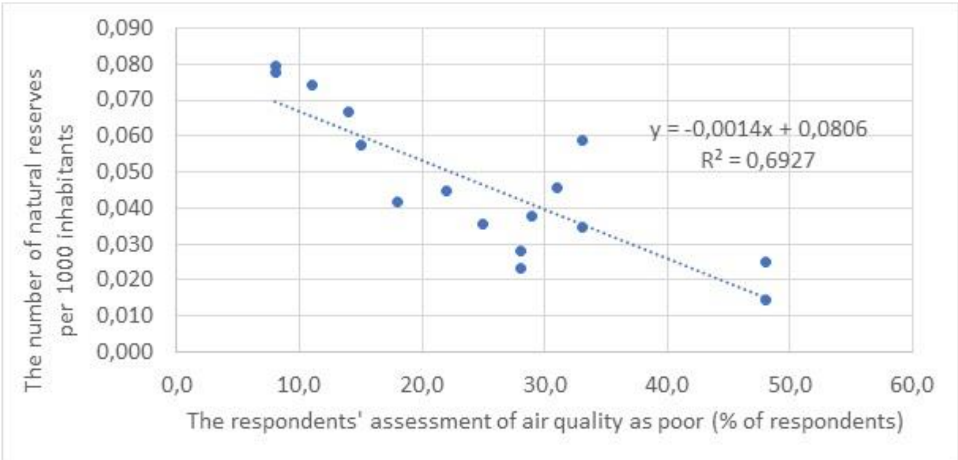

Figure 15: The dependence of the number of natural reserves and the air quality.

As for the area of natural reserves expressed in % of the voivodship area, similar results have been obtained as in the case of the number of monuments and natural reserves. Significant correlations have been found in 8 cases. Apart from the above-mentioned factors, the area of the reserves also greatly depended on the share of beet, potato and vegetables in the sowing structure as well as on the share of permanent grassland. To the greatest extent, the area of nature reserves expressed in % of a given voivodship depended on the share of cereals in the structure of sowing (Figure 16) and it mostly depended on the percentage share of RES in energy production (Figure 17). Exactly the same results applied to the area of natural reserves expressed in ha per 1000 inhabitants. In this case, however, the coefficients of determination and correlation were higher than those that characterized the relationship with the area of natural reserves expressed in % of the area (Figure 18 and Figure 19).

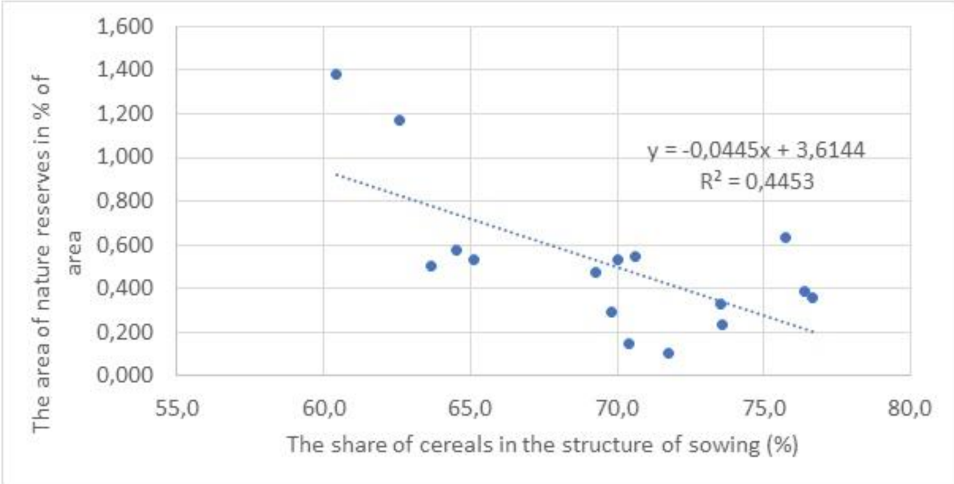

Figure 16: The impact of sowing structure on the surface of natural reserves.

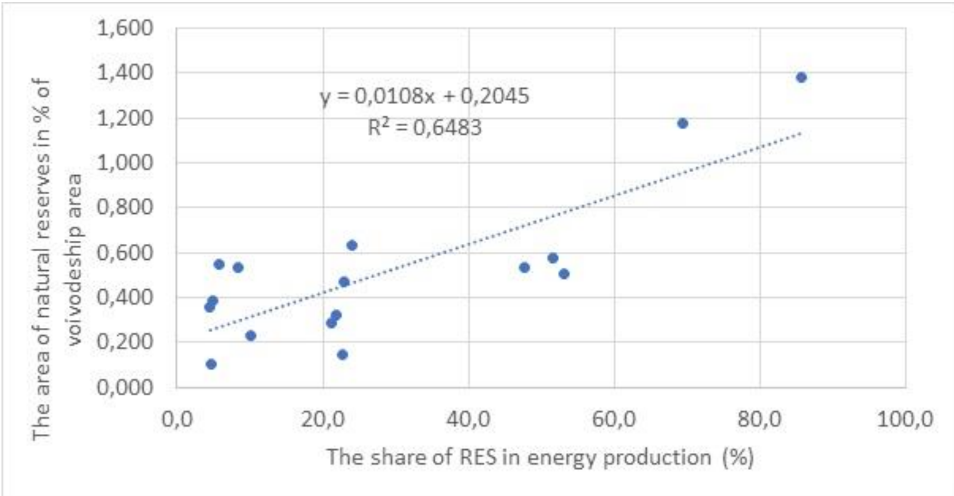

Figure 17: The dependence of the area of natural reserves on the production of renewable energy.

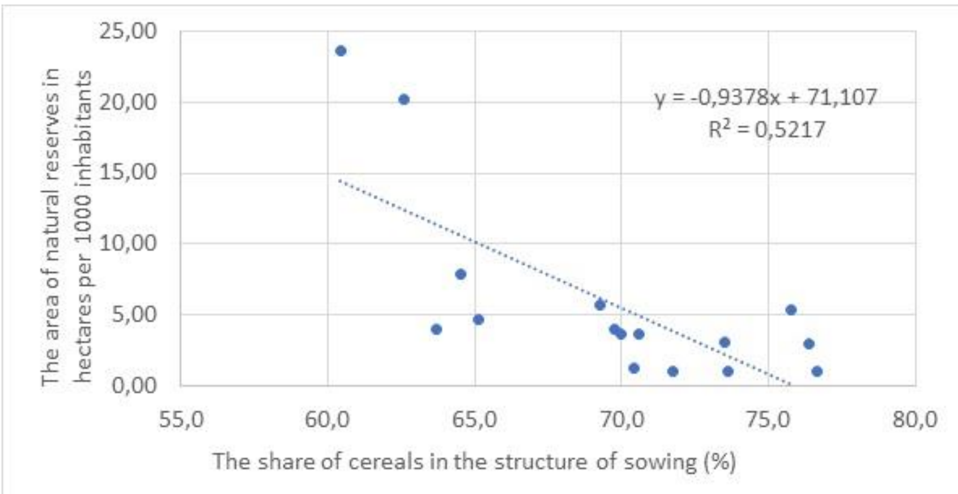

Figure 18: The impact of sowing structure on the surface of natural reserves.

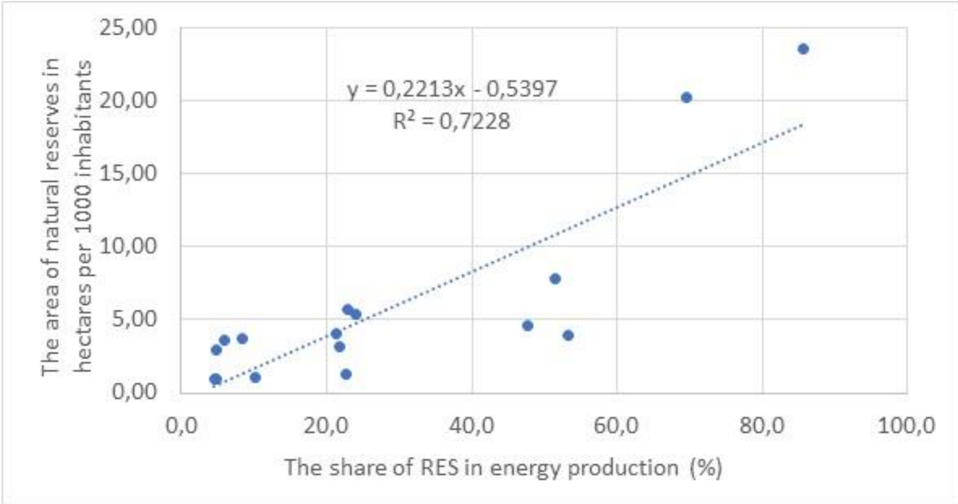

Figure 19: The dependence of the area of natural reserves on the production of renewable energy.

4.3 Diagnosis of the agritourism development as an indicator for the cultural ecosystem services assessment

We have analysed the impact of 8 indicators of agricultural productivity on the state of agritourism and the dependence of this state on 15 indicators of the quality of the natural environment. The analysis used 4 indicators concerning the condition of agritourism: the average annual number of agritourists per 100 km^2 and per 1000 inhabitants and the average annual number of nights in agritourism accommodation per 100 km^2 and per 1000 inhabitants. Thus, we have examined the significance of (8+15) x (2+2) = 92 dependencies. Significant correlations have been found in 10 cases. All of them concerned the condition of agritourism per 1000 inhabitants. The number of agritourists greatly depended on the level of commodity production in agriculture (Figure 20), and the number of nights in agritourism accommodation depended on the structure of sowing, expressed the share of cereals (Figure 21). Significant dependencies regarding the number of agritourists per 1000 inhabitants concerned forest cover (Figure 22), the agricultural area in organic farms, the share of RES in energy production and the number of days exceeding the daily concentrations of PM10. In turn, significant dependencies regarding the number of nights in agritourism accommodation concerned forest cover, the share of RES in energy production, the number of days with excessive daily concentrations of PM10 (Figure 23) and the assessment of air quality in surveys as poor.

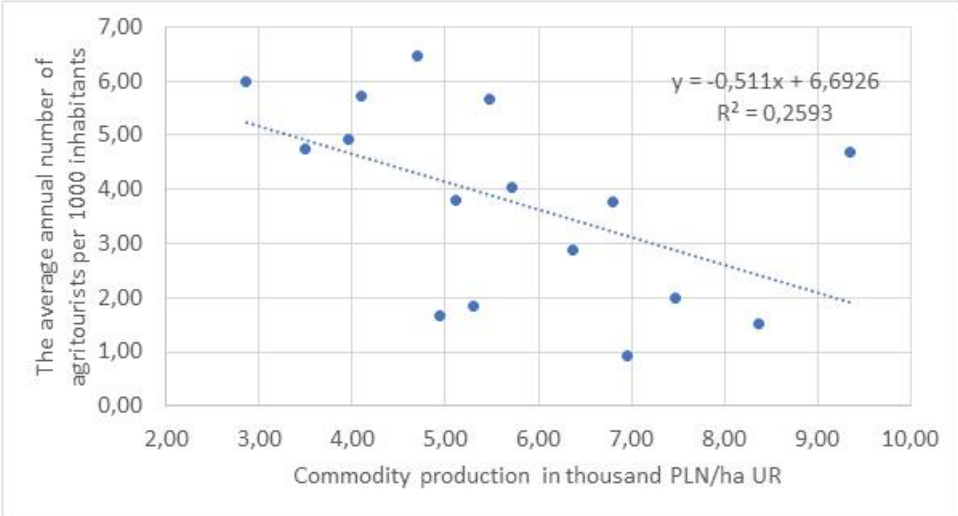

Figure 20: The impact of commodity production in agriculture on the condition of agritourism.

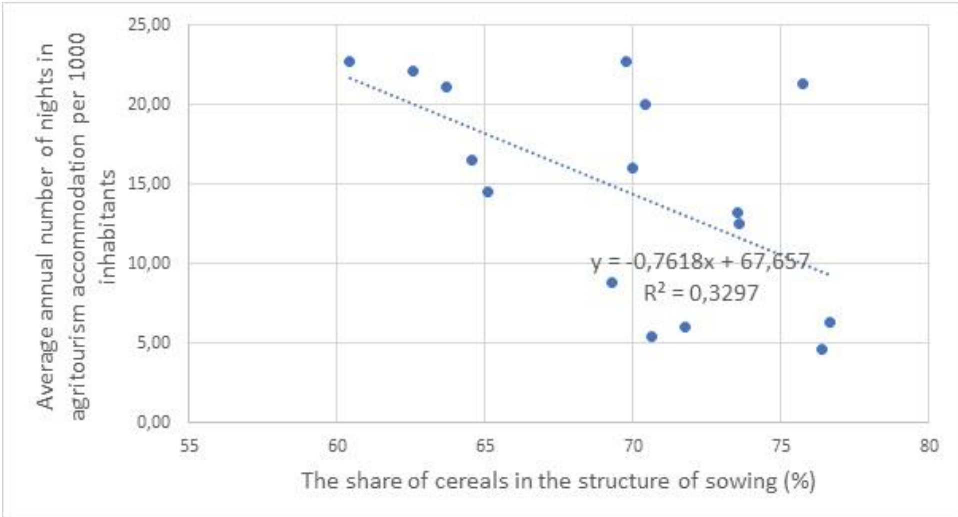

Figure 21: The impact of the structure of sowing on the state of agritourism.

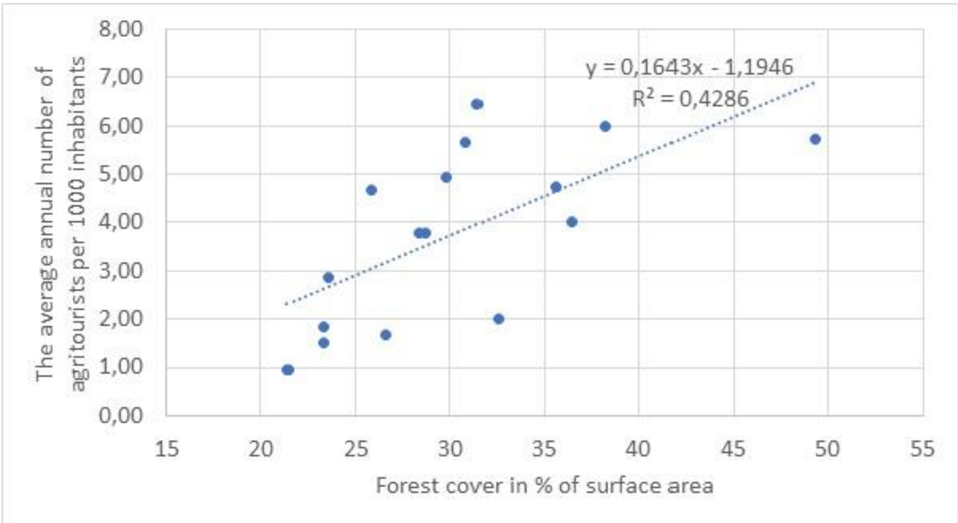

Figure 22: The impact of forest cover on the state of agritourism.

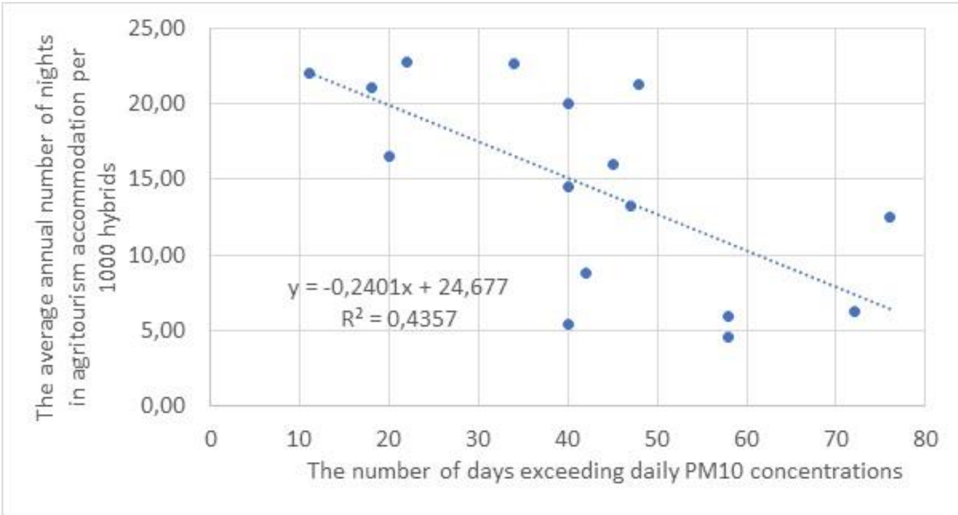

Figure 23: The impact of air quality on the condition of agritourism.

4.4 Summary

The study found a compromise link between agricultural productivity indicators and the level of cultural ecosystem services, and a synergistic link between environmental quality indicators and the level of cultural ecosystem services.

Shaping the level of cultural ecosystem services related to intellectual and identity interactions with living nature, including nature as part of the natural heritage, is possible through the impact on the structure of sowing, air quality, and the share of renewable energy sources in its production.

Shaping the level of cultural ecosystem services related to the development of agritourism is possible by influencing the structure of sowing, air quality, forest cover, and the level of agricultural commodity production.

The models, that were presented as well as the results obtained, could also be useful to assess ES in a comprehensive way related to much smaller spatial scale context of their impact, e.g. at Poviat, municipality, farm or even plot level under conditions that relevant data will become available.

In section 4. some of the Ecosystem Services Models within InVest tool are presented. One can assume that they can be incorporated into the ABM model.

5 Sources of information regarding Ecosystem Services Models

5.1 Ecosystem Services Models Library (ESML)

The complexity of estimating the production of ecosystem goods and services is confirmed by the multitude of case studies from around the world that were collected in the EcoService Models Library (ESML). The goal of ESML is to help users find models that are useful for estimating the production of final ecosystem goods and services (FEGS). We define ecological production functions (EPFs) as quantitative expressions describing the production of final ecosystem goods or services.

For purposes of ESML, an EM is defined as a quantitative relationship (i.e., a "function" or "model" having predictor [independent] and response [dependent] variables) that can help the process of estimating FEGS. Because a cascade of influences link human actions to ecological states and processes, it may be necessary to combine several EMs to develop an EPF that is suitable for a given situation. For this reason, ESML includes many EMs that are not in themselves EPFs but are judged potentially useful for ecosystem service estimation. Moreover, the precise characteristics of a final ecosystem service vary over space and time, because a final service occurs only when a potential human beneficiary exists. For these reasons we use the term EPF to identify models that achieve the goal of estimating FEGS production, but we use the broader term EM to encompass all of the models in ESML.

5.1.1 ESML Variable Classification Hierarchy to categorize Ecosystem Services Models variables

Purpose

Model variables convey much information regarding the functioning of an ecological model, the potential benefits of using the model, and its logistical difficulties. The predictor, intermediate and response variables indicate what is being estimated and what kinds of causal inferences or associations can or cannot be made. The ability to search models based on variable types is valuable. Variable names themselves do not enable this, because in a large database like ESML there are too many names, and their meanings may not be understandable from the name alone. A classification system that bins variables into informative categories can enable the search and investigation of models based on their variable characteristics.

Objective

Categorize model variables so that:

ESML users can locate all models that include a variable type that is of interest (e.g., mammals; nitrogen processing), regardless of how the variables are named in the model.

ESML users can search for models that combine multiple variables of interest (e.g., coastal habitat and fish harvest; wetland characteristics and recreation visits; wind turbines and coastal recreation; tree cover, temperature, and stream flow).

ESML users can identify potential linkages between models -- for example, model 1 has nitrogen attenuation as a response variable; model 2 has nitrogen concentration as a predictor variable and recreation as a response variable.

Structure

The Variable Classification Hierarchy (VCH) has four levels. The categorisation of any given variable uses at least two and as many as four of these levels.

The seven categories comprising the top level (shown in the figure below) are intended to be comprehensive of all possible model variables. Levels 2 - 4 (which may be viewed using the VCH Browser or VCH Spreadsheet; see links above) are not necessarily comprehensive -- that is, they are designed based on the existing variables in ESML; more subcategories at each level could be defined in the future to categorize new types of variables as they are added.

Approach

The classification system has been built based on the set of variables at hand (i.e., ~1900 variables derived from ~150 models or model applications), not based on a theoretical universe.

The existing variable set in ESML is extensive and will be taken as sufficiently representative of ecological model variables. It is assumed that a classification system that accommodates these variables will be robust. While modifications may be needed to accommodate different variables in the future, the intended strategy is to build a sufficient system using the present variables rather than create a more extensive system to contain potential variable types not yet encountered.

This classification system seeks to enable users to find all models that include variables of a particular type, assuming the user who is interested in that variable would benefit from seeing it used in different computational settings. Therefore, the system focuses on classifying each variable according to what quantity or quality it denotes (Figure 24), independent of how it relates to other variables in the model because those relationships will naturally differ from model to model

For example, there is no variable category for “Final Ecosystem Goods and Services,” because identification of FEGS requires the association of an ecological attribute with a human beneficiary, whereas a given variable would most often describe one or the other. Even when a single variable does combine aspects of both (such as a variable that quantifies human populations located in proximity to specific environmental amenities), it is often difficult to determine whether the association (proximity in this case) entails a direct and recognized benefit (as FEGS designation would require). Similar problems occur when trying to determine which ecosystem processes should be considered to be intermediate ecosystem services. Therefore, all ecological processes and attributes, including those that potentially provide intermediate or final ecosystem goods and services, are grouped together in a single, top-level class including ecological attributes, processes and supply of ecosystem services. When variables have both ecological and social attributes, such as the proximity variable just described, the top-level classification depends on whether the variable primarily describes the ecological supply of the attribute (Category 5) or human demand/use/enjoyment associated with the attribute (Category 6 if units are nonmonetary, Category 7 if monetary).

Similarly, although ecosystem-service modelling may seek to quantify the economic benefit, the system does not include a category for economic benefit per se. Even an unambiguously named variable such as “income net of costs” would constitute an economic benefit only if it was computed in reference to an appropriate counterfactual (e.g., computed with and without a given intervention). This determination could be made at the level of the model, but not at the level of the variable. Therefore, while variables generally related to human demand/use/enjoyment of resources are classified as Category 6 if units are nonmonetary and Category 7 if monetary, the economic benefit per se is not a basis for classification.

Examine contributing variables to ensure accurate classification of ambiguously named variables.

While classification is based on each individual variable and not its relationship to other variables, accurate classification of a given variable may require examining other variables – not to determine the relationship, but to ensure correct definition. Variable names are sometimes ambiguous, and it may be necessary to look at the variables contributing to it to gain a clear definition. For example, a variable that modellers have named “Potential value of open space” might appear related to economic value, but examination of its contributors shows that the variable describes only whether a parcel's land cover falls within an open-space definition. Open-space is a broad category of land cover type and does not address actual human demand or value. The variable is therefore categorized as Category 2, Land Surface (or Water Body Bed) Cover, Use or Substrate.

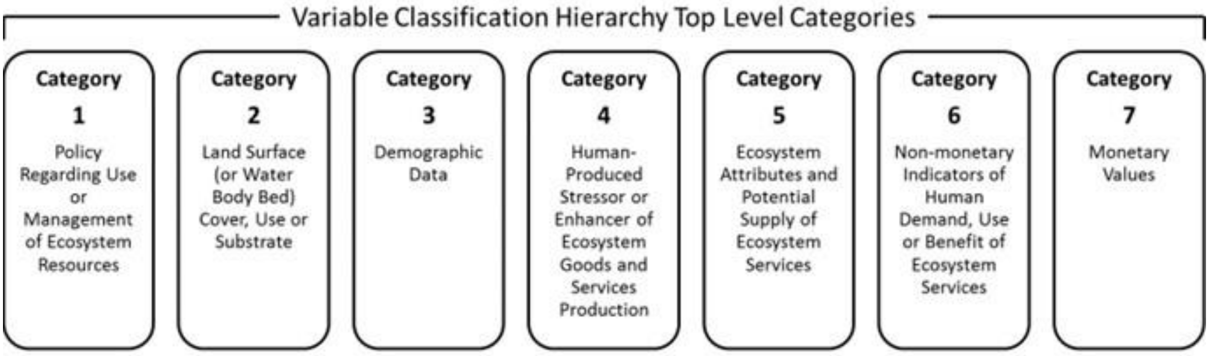

Figure 24: Ecological Model Variable Typology Diagram.

5.1.2 Variables categories in Ecosystem Services Models Library

The following Table 1 provides detailed information used in assigning categories to variables in ESML:

Table 1: Variables categories in EcoService Models Library.

Category Name	Description	Examples (not exhaustive)	Discussion
Category 1. Policy Regarding Use or Management of Ecosystem Resources	Variables that represent policies or prescriptions regarding either ecosystem resources or human actions related to the environment.	o policies (including prescriptions, regulations, requirements, designations, targets, recommendations, etc.), whether new or existing. Note: in future scenarios, any projections (e.g., population, land use) should be treated as descriptive, using Categories 2 - 7 as appropriate; only policy variables should be classed using Category 1 o zonings, easements o conservation area designations o recommended riparian buffer widths (as opposed to observed widths) o targets for water withdrawals or releases, in rivers or reservoirs o allowed releases of chemicals to waters (e.g., permit limits or Total Maximum Daily Loads).	Category 1 comprises variables representing policies, prescriptions, regulations, requirements, designations, targets, recommendations, etc., whether new, existing or projected. This includes zonings, easements, conservation area designations, etc. The crucial difference between Category 1 and Categories 2 - 7 is that Categories 2 - 7 deal with descriptions of environmental or social traits observed or estimated to exist (or, for future scenarios, projected to exist), whereas Category 1 deals with prescriptions -- goals or designations -- for what may or should exist from a policy perspective. Land-based examples of Category 1 could include the designation of biodiversity reserves (which define a protection level, and may or may not correspond to an actual biodiverse condition), or the recommended width of a riparian buffer (as opposed to an observed width). Water-based examples could include policy-based targets for water withdrawals or releases of water in rivers or reservoirs, or allowed releases of chemicals to waters (e.g., permit limits or Total Maximum Daily Loads). Future projections that are not policy-based generally should be treated as descriptive, using Categories 2 - 7, rather than prescriptive, using Category 1.
Category 2. Land Surface (or Water Body Bed) Cover, Use or Substrate	Land cover (e.g., vegetation type, water body type), other basic features of the landscape (soils, topography, bathymetry), and or use, and most geographic boundaries.	o land cover/land use classes, including natural (e.g., forest, shrub-scrub) and human-dominated (e.g., high-density urban, urban greenspace, row crop, grazing) o dominant vegetative cover class o dominant soil/substrate type o broad-scale ecological classifications (e.g., ecoregions) o areas, positions, elevations o distances to other features o watershed, floodplain or geographic feature boundaries o geopolitical boundaries o impervious surface area	Variables describing basic features of the landscape (or the bed of a water body), such as vegetative cover type, substrate type, and/or type of human use, are categorized as Category 2. Category 2 variables are those that classify dominant characteristics of vegetation, substrate or human use. Broad-scale ecological classifications (e.g., ecoregions) are also Category 2. Category 2 variables describing landscape characteristics thus tend to be categorical variables; those that are cardinal are generally limited to those that describe areas, positions, elevations and distances to other features. In general, cardinal variables that describe the characteristics of soils, fauna or vegetation are classified as Category 5. These include cardinal measures related to soil composition, soil water-holding characteristics, or vegetative canopy structure /closure. Classifications derived from more detailed or specialized observation, sampling or mensuration, or requiring ecologically-informed analysis (e.g., habitat suitability for given taxa, or landscape ecological variables) also should be treated as Category 5 Variables that describe geographic boundaries are usually Category 2. These include biophysical demarcations (watershed, floodplain or geographic feature boundaries, broad-scale ecological classifications such as ecoregions) and geopolitical boundaries, which are all categorized as Category 2. Exceptions, treated as Category 1, are those boundaries that represent an

			environmental policy demarcation more than a biophysical distinction; examples include zoning, conservation easements or ecological reserves. The latter are treated as Category 1 unless they clearly serve as a proxy for an actual (and not merely intended) physical/feature boundary, such as a distinct land cover.
Category 3. Demographic Data	Information about human populations, such as age, gender, income, residence, education level, etc.	o human population size o demographic characteristics (as age, gender, income, residence, education level, etc.)	Most variables describing the traits of human populations are categorized as Category 3. Land use/land-cover (LULC) classifications dealing with human characteristics (e.g., high, medium and low housing density) form an exception; LULC information should be classed as Category 2. However, with that one exception, Category 2 is limited to characteristics of the landscape, and any information on human populations and their characteristics is listed as Category 3.
Category 4. Human-Produced Stressor or Enhancer of Ecosystem Goods and Services Production	Human-produced influences or agents that may affect the potential for ecosystem structures or processes to produce services – negatively, in the case of stressors, positively for enhancers – and any human-created feature that is more fine-scale than the LULC class (e.g. roads, bridges).	o NOT land use/land cover changes (those are Category 2) o pollutant loads o water withdrawals o wildland fire o proximity to human-caused disturbance o impacts/disturbance related to the harvest of ecosystem components; for example, "carbon in harvested biomass" or "percentage of soil carbon pool disturbed" o NOT harvested goods themselves (these are Category 6) o introductions of invasive species o impact-specific characteristics of stressors (e.g., the toxicity or partition coefficient of a polluting chemical) o spatial extent or characteristics of management actions (but not management policies; those are Category 1) o controlled burn timing/location o placement of nesting boxes o releases or loadings, to air or water, of phosphorus, reactive nitrogen or sediment o concentrations in air or water of phosphorus, reactive nitrogen or sediment o releases to air, or concentrations in air, of carbon o "water quality," when referring to a particular, human-caused stressor o roads, bridges o cultural heritage sites	Human-produced stressors classified as Category 4 are those physical, chemical or biological agents or influences caused by humans that may have adverse effects on ecosystem structures and processes and are not well described using other Categories. Similarly, human-produced enhancers are influences or agents that have positive effects on ecosystem structures and processes. To avoid overlap with other categories, Category 4 designation should be used sparingly. That is, if "habitat destruction" can be described as a change in LULC class, it should be classified as Category 2; and changes in ecological structure or function should be described as Category 5, even if they result from habitat destruction or restoration and regardless of their effect on species. Stressor examples include pollutant loads, water withdrawals, proximity to disturbance, impacts/disturbance related to the harvest of ecosystem components (though not the harvested goods themselves), and introductions of invasive species. Variables describing impact-specific characteristics of stressors – e.g., the toxicity of a polluting chemical – are also classified as Category 4. However, variables describing the removal of stressors by ecosystems are classified as Category 5. Variables describing harvest activities or quantities as indications of human use or benefit are Category 6 if non-monetary, or 7 if monetary. Variables specific to human management actions – e.g., the spatial extent of a management action such as controlled burning or the placement of non-natural structures such as nesting boxes – are more adequately described by Category 4 than Category 5. Note, however, that management policies, which relate to prescribed as opposed to observed actions, are listed in Category 1. Ecological responses to management, however, would be described using Categories 2 (for land cover changes) or 5 (for ecological structure or process changes). Although wildland fires occur naturally, human interaction with wildlands has dramatically affected fuel levels and ignition sources; therefore, all

			wildland fire is classed as Category 4 (whereas fuel characteristics are generally Category 5). Although phosphorus, nitrogen and sediment are naturally occurring, due to the prevalence of pollution by excess quantities and the disruption of their normal cycling, we have treated variables specific to P, reactive N and sediment loadings to the environment as well as their concentrations in air and water as Category 4. Similarly, carbon concentrations in air, and releases to air, are treated as Category 4. Ecological processes specific to C, N or P sequestration or removal from these media are treated as Category 5. However, resulting changes in pollutant loadings or levels Occurrences in biological materials, or in media other than those specified above, are placed in Category 5. C-, N- or P-related variables explicitly associated with human actions are exceptions to this rule; variables such as "carbon in harvested biomass" or "percentage of soil carbon pool disturbed," are treated as Category 4. When "water quality" is used as a variable without reference to a particular stressor, or when it refers to use suitability (e.g., for bathing), it is classed as Category 5. We have elected to treat any human-created feature of the landscape that is more fine-scale than LULC class, e.g. roads, bridges or docks, as Category 4 since they often appear in models as ecological stressors. However, impervious surfaces, though a human-produced stressor, are treated as a land cover/land-use feature and therefore, like other urban land use categories, are classed as Category 2. Human artefacts such as roads or bridges that are incidental to the presence of the environment and not specifically for the purpose of accessing environmental resources are included in Category 4; artefacts specific to human access (e.g., boat docks, hiking trails) are included in Category 6.
Category 5. Ecosystem Attributes and Potential Supply of Ecosystem Services	Attributes of ecological structure or process, including both Intermediate and Final Ecosystem Goods or Services	o characteristics of fauna, flora, soils, water bodies o dynamics of natural systems, including human-affected systems (e.g., flows of materials, species movements) o meteorology, hydrology o land cover/vegetation detail such as canopy closure, leaf area index o species presence/absence, biodiversity o named or literature-derived process coefficients (e.g., "Zhang coefficient;" "Plant evapotranspiration coefficient," "In-stream nitrogen attenuation coefficient") o landscape ecological indices (e.g., fragmentation indices; corridors) o habitat suitability for given taxa o supply of intermediate ecosystem goods and services o supply of final ecosystem goods and services	Some conceptualizations of ecosystem service production have attempted to distinguish structure and process. However, ecological structural variables and process variables are difficult to distinguish in practice; furthermore, although structures are sometimes seen as determining processes the reverse may also be true. Therefore, variables related to structure and process are combined in Category 5; moreover, ecological "process" is here meant to encompass ecological "function" (i.e., these terms also are not distinguished in this scheme). Ecosystem processes are generally understood as flows or other changes in materials occurring over time. Example process variables include those associated with pollutant attenuation, changes in carbon storage and changes in biota (e.g., production, recruitment). Variables classified as ecosystem structure or process variables (Category 5) may be related to land cover variables (Category 2) but are distinguished from the former in either of two ways. First, they may provide greater detail

		o pollutant attenuation o landscape aesthetic quality o phosphorus or reactive nitrogen concentrations in soils or biological tissues o carbon concentrations in water, soils or biological tissues o potential demand for ecosystem service (e.g., supply of ecosystem flood attenuation service to a populated area, without consideration of actual risk) o water suitability for human uses o nature-based recreation sites	than is available in typical land cover data sets. Biological community structure may include the presence/absence, abundance or diversity of biota observed at various levels of scale or organization. Physical/chemical aspects of structure may include substrate variables, stream channel geometry or measures of vegetation structure such as canopy closure or leaf area index. Second, Category 5 variables may entail an ecologically-informed interpretation of land cover variables (e.g., landscape-ecological variables such as indices of fragmentation, identification of habitat corridors or determinations of habitat suitability). Meteorological data (e.g., temperature, rainfall, humidity) are also considered Category 5 because (a) they are strongly influenced by local ecology and (b) unlike LULC or elevation data they generally have to be locally and repeatedly measured. Certain ecosystem structural or process attributes can be defined as intermediate or final ecosystem services, to the extent that they contribute (indirectly or directly) to human well-being. Because their ability to do so is context-dependent, it is difficult to classify individual model variables according to whether or not they correspond to ecosystem services. Therefore, all ecosystem service variables are lumped with ecosystem structure/process variables in Category 5, even if they are explicitly identified as ecosystem services. Natural landscape features that are defined in terms of their direct value to humans (e.g., "Routes of geological interest," "climbing sites," "nature-based recreation sites") should be included in Category 5. With regard to human interaction with nature, the distinction between Categories 5 & 6 corresponds to the difference between supply and demand. Indicators of human demand or use are classified as Category 6. Category 5 variables have the potential to supply something of value and sometimes are defined in that vein (e.g., "Aesthetic quality of the landscape"). However, supply entails only the potential for benefit, and the existence of human access to an ecosystem good or service, absent an indication of demand, does not in itself indicate use or enjoyment. The supply of flood regulation services to residences in a floodplain does not imply a benefit without an indication that the area is marginally prone to flooding. On the other hand, indicators of investment in access (e.g., number of boat docks) that clearly indicate human use may be classified as Category 6.
Category 6. Non-monetary Indicators of Human Demand, Use or Benefit of	Non-monetary variables related to human demand, use, enjoyment or benefit – including health benefits; excluding land uses covered by Category 2.	o non-monetary indicators of fish, crop or timber harvest yields o user-days at a recreational site o demonstrable (not just potential) human vulnerability to loss of a particular service o amenities that indicate human use of a resource (e.g., boat ramps, marinas, buoys, campgrounds, recreational trails)	Social benefit indicators reflect social welfare by determining the quantity of service use, human preferences for the service, and/or scarcity/substitutability of services. All non-economic indicators of human demand or use/benefit/preference are classified as Category 6 regardless of whether the demand or use results from ecosystem service changes. Examples of demand may include the size of the human population demonstrably vulnerable to loss of a particular service; examples of use may

Ecosystem Services		o measures of health risk related to nature-based recreational opportunities; o hospital admissions related to air quality. o actual appreciation of ecosystem services (whether in the context of use or independent of use) o NOT monetary values associated with use or demand o indicators of specific land use (e.g., housing starts, recreational visits, harvest amounts) o NOT broad land use classification	include: non-monetary indicators of fish, crop or timber harvest yields; user-days at a recreational site; measures of health risk related to nature-based recreational opportunities; and indicators for hospital admissions related to air quality. Social benefit indicators may also relate to appreciation of ecosystem services (e.g., satisfaction related to the current or future existence of an ecological feature) independent of use. Note, however, that monetary values associated with any of these indicators would be classified as Category 7. Broad land use classifications covered by Category 2 are excluded here, but more specific indicators of use (e.g., housing starts, recreational visits, harvest amounts).
Category 7. Monetary Values	Any quantity expressed in monetary terms (including, e.g., benefits, prices, costs).	o monetary measures of human benefit (e.g., consumer or producer surplus) o prices (e.g., of land or commodities) o interest rates	Category 7 includes measures of economic value (i.e., consumer or producer surplus), or reasonable proxies thereof. The value may be that of ecosystem services or that of other inputs or outputs relevant to the EM (e.g., land or commodity prices). When valuing ecosystem services, it should be noted that true social welfare measures reflect supply and demand, including both vulnerability to service loss and the ability to adapt to and substitute for losses in ecosystem services. The value may include use or non-use values.
Non-classified variables	Variables that contribute little further understanding of what kinds of environmental information are being used by an EM	o conversion factors o weighting factors (applied to other variables) o statistically derived coefficients that modify other variables already identified (e.g., "Coefficient on depth x bed slope") o spatial grid or polygon identification codes. o expressions of time (except when specific to events that should be classified; e.g., "Time of timber harvest")	The purpose of variable classification is to enable ESML users to understand what kinds of information are being used by an EM, without relying on variable nomenclature used by the modeller. Certain types of variables are included in ESML because they are important to model functioning yet are excluded from classification because they convey little additional information about the aspects of ecosystems, environmental management or human well-being that the model addresses. These include conversion factors, certain coefficients, weighting factors, and spatial grid or polygon identification codes. Expressions of time also are non-classified, except when they are specific to events that should be classified (e.g., time of timber harvest). Statistically derived coefficients that modify other variables already identified (e.g., "Coefficient on depth x bed slope") typically are non-classified, whereas coefficients that convey more specific information, may have a recognized name, and may be obtainable from literature sources (e.g., "Zhang coefficient;" "Plant evapotranspiration coefficient," "In-stream nitrogen attenuation coefficient") should be classified according to the type of information they convey.

Source: EcoService Models Library (ESML), United States Environmental Protection Agency, https://esml.epa.gov/search/ems

5.2 Examples of Ecosystem Services Models available within the InVest tool

InVEST is designed to inform decisions about natural resource management. Essentially, it provides information about how changes in ecosystems are likely to lead to changes in the flows of benefits to people. Decision-makers, from governments to non-profits to corporations, often manage lands and waters for multiple uses and inevitably must evaluate trade-offs among these uses. InVEST's multi-service, modular design provides an effective tool for exploring the likely outcomes of alternative management and climate scenarios and for evaluating trade-offs among sectors and services. For example, government agencies could use InVEST to help determine how to manage lands, coasts, and marine areas to provide a desirable range of benefits to people or to help design permitting and mitigation programs that sustain nature's benefits to society. Conservation organizations could use InVEST to better align their missions to protect biodiversity with activities that improve human livelihoods. Corporations, such as consumer goods companies, renewable energy companies, and water utilities, could also use InVEST to decide how and where to invest in natural capital to ensure that their supply chains are sustainable and secure.

InVEST can help answer questions like:

- Where do ecosystem services originate and where are they consumed?
- How does a proposed forestry management plan affect biodiversity, water quality, and recreation?
- What kinds of coastal management and fishery policies will yield the best returns for sustainable fisheries, shoreline protection, and recreation?
- Which parts of a watershed provide the greatest carbon sequestration, biodiversity, and tourism values?
- Where would reforestation achieve the greatest downstream water quality benefits while maintaining or minimizing losses in water flows?
- How will climate change and population growth impact ecosystem services and biodiversity?
- In addition to secure locations for renewable energy facilities and food from fishing and aquaculture, what benefits does marine spatial planning provide to society?

InVEST is a tool for exploring how changes in ecosystems are likely to lead to changes in benefits that flow to people. It often employs a production function approach to quantifying and valuing ecosystem services. A production function specifies the output of ecosystem services provided by the environment given its condition and processes. Once a production function is specified, we can quantify the impact of changes on land or in the water on changes in the level of ecosystem service output. The tool uses a simple framework delineating "supply, service, and value" to link production functions to the benefits provided to people (Figure 1). "Supply" represents what is potentially available from the ecosystem (ie. what the ecosystem structure and function can provide). For example, this would be the wave attenuation and subsequent reduction in erosion and flooding onshore provided by a particular location and density of mangrove forest. "Service" incorporates demand and thus uses information about beneficiaries of that service (e.g., where people live, important cultural sites, infrastructure, etc.). "Value" includes social preference and allows for the calculation of economic and social metrics (e.g., avoided damages from erosion and flooding, numbers of people affected).

The toolset includes models for quantifying, mapping, and valuing the benefits provided by terrestrial, freshwater, and marine systems. The models are grouped into four primary categories:

1) supporting services,

2) final services,

3) tools to facilitate ecosystem service analyses and

4) supporting tools.

Supporting services underpin other ecosystem services, but do not directly provide benefits to people. Final services provide direct benefits to people. For final services, we split the services into their biophysical supply and the service to people wherever possible. For some final services, we model the service directly, without modelling the supply separately. Supporting tools include helping to create watersheds, do hydrological processing on a digital elevation model and create scenarios that can be used as inputs to InVEST.

Supporting Ecosystem Services:

- Habitat Risk Assessment
- Habitat Quality
- Pollinator Abundance: Crop Pollination

Final Ecosystem Services:

- Forest Carbon Edge Effect
- Carbon Storage and Sequestration
- Coastal Blue Carbon
- Annual Water Yield
- Nutrient Delivery Ratio
- Sediment Delivery Ratio
- Unobstructed Views: Scenic Quality Provision
- Visitation: Recreation and Tourism
- Wave Energy Production
- Offshore Wind Energy Production
- Crop Production

5.2.1 The InVEST Water Yield Model

Table 2: The InVEST Water Yield Model characteristics

Model	The InVEST Water Yield model
Summary	InVEST estimates the annual average quantity and value of hydropower produced by reservoirs, and identifies how much water yield or value each part of the landscape contributes annually to hydropower production. The model has three components: water yield, water consumption, and hydropower valuation. The biophysical models do not consider surface–groundwater interactions or the temporal dimension of water supply. The valuation model assumes that energy pricing is static over time.
How it works	The model runs on a gridded map. It estimates the quantity and value of water used for hydropower production from each subwatershed in the area of interest. It has three components, which run sequentially. First, it determines the amount of water running off each pixel as the precipitation minus the fraction of the water that undergoes evapotranspiration. The model does not differentiate between surface, subsurface and baseflow, but assumes that all water yield from a pixel reaches the point of interest via one of these pathways. This model then sums and averages water yield to the subwatershed level. The pixel-scale calculations allow us to represent the heterogeneity of key driving factors in water yield such as soil type, precipitation, vegetation type, etc. However, the theory we are using as the foundation of this set of models was developed at the subwatershed to watershed scale. We are only confident in the interpretation of these models at the subwatershed scale, so all outputs are summed and/or averaged to the subwatershed scale. We do continue to provide pixel-scale representations of some outputs for calibration and model-checking purposes only. These pixel-scale maps are not to be interpreted for the understanding of hydrological processes or to inform decision-making of any kind. Second, beyond annual average runoff, it calculates the proportion of surface water that is available for hydropower production by subtracting the surface water that is consumed for other uses. Third, it estimates the energy produced by the water reaching the hydropower reservoir and the value of this energy over the reservoir's lifetime.
Water Yield Model - formula	$$Y(x) = (1 - \frac{AET(x)}{P(x)}) * P(x)$$ Where *AET(x)* is the annual actual evapotranspiration for pixel *x* and *P(x)* is the annual precipitation on pixel *x*.
Realized Supply - formula	$$C = \frac{W - R}{n}$$ where, *C* = the consumptive *use* (m^3/yr/pixel), *W* = withdrawals (m^3/yr), *R* = return flows withdrawals (m^3/yr), and *n* = number of pixels in a given land cover.
Hydropower Production and Valuation - formula	$p_d = \rho * q_d * g * h_d$ Where p_d is power in watts, *p* is the water density *(1000 Kg/m*^{3}*)*, q_d is the flow rate (m^3/s), *g* is the gravity constant *(9.81 m/s*^{2}*)*, and h_d is the water height behind the dam at the turbine *(m)*. In this model, we assume that the total annual inflow water volume is released equally and continuously over the course of each year.
Data needs	▪ Workspace (directory, required): The folder where all the model's output files will be written. If this folder does not exist, it will be created. If data already exists in the folder, it will be overwritten. ▪ File Suffix (text, optional): Suffix that will be appended to all output file names. Useful to differentiate between model runs. ▪ Precipitation (raster, units: mm/year, required): Map of average annual precipitation. ▪ Evapotranspiration (raster, units: mm, required): Map of evapotranspiration values. ▪ Root Restricting Layer Depth (raster, units: mm, required): Map of root restricting layer depth, the soil depth at which root penetration is strongly inhibited because of physical or chemical characteristics. ▪ Plant Available Water Content (raster, required): Map of plant available water content, the fraction of water that can be stored in the soil profile that is available to plants. ▪ Land Use/Land Cover (raster, required): Map of land use/land cover codes. All values in this raster must have corresponding entries in the Biophysical Table. ▪ Watersheds (vector, polygon, required): Map of watershed boundaries, such that each watershed drains to a point of interest where hydropower production will be analysed.

	▪ Field: ws_id (integer, required): Unique identifier for each watershed. ▪ Sub-watersheds (vector, polygon/multipolygon, optional): Map of subwatershed boundaries within each watershed in the Watersheds map. ▪ Fields: subws_id (integer, required): Unique identifier for each subwatershed. ▪ Biophysical Table (CSV, required): Table of biophysical parameters for each LULC class. All values in the LULC raster must have corresponding entries in this table. Columns: o lucode (integer, required): LULC code corresponding to values in the LULC map. o lulc_veg (integer, required): Code indicating whether the LULC class is vegetated for the purpose of AET. Enter 1 for all vegetated classes except wetlands, and 0 for all other classes, including wetlands, urban areas, water bodies, etc. o root_depth (number, units: mm, required): Maximum root depth for plants in this LULC class. Only used for classes with a 'lulc_veg' value of 1. o kc (number, units: unitless, required): Crop coefficient for this LULC class. · Z Parameter (number, units: unitless, required): The seasonality factor, representing hydrogeological characteristics and the seasonal distribution of precipitation. Values typically range from 1 - 30. · Water Demand Table (CSV, optional): A table of water demand for each LULC class. Each LULC code in the LULC raster must have a corresponding row in this table. Consumptive water use is that part of the water used that is incorporated into products or crops, consumed by humans or livestock, or otherwise removed from the watershed water balance. Columns: o lucode (integer, required): LULC code corresponding to the LULC raster o demand (number, units: $m^3/(pixel \cdot year)$, required): Average consumptive water use in this LULC class. · Hydropower Valuation Table (CSV, optional): A table mapping each watershed to the associated valuation parameters for its hydropower station. Columns: o ws_id (integer, required): Unique identifier for the hydropower station. This must match the 'ws_id' value for the corresponding watershed in the Watersheds vector. Each watershed in the Watersheds vector must have its 'ws_id' entered in this column. o efficiency (ratio, required): Turbine efficiency is the proportion of potential energy captured and converted to electricity by the turbine. o fraction (ratio, required): The proportion of inflow water volume that is used to generate energy. o height (number, units: m, required): The head, measured as the average annual effective height of water behind each dam at the turbine intake. o kw_price (number, units: currency/kWh, required): The price of power produced by the station. Must be in the same currency used in the 'cost' column. o cost (number, units: currency/year, required): Annual maintenance and operations cost of running the hydropower station. Must be in the same currency used in the 'kw_price' column. o time_span (number, units: year, required): Number of years over which to value the hydropower station. This is either the station's expected lifespan or the duration of the land use scenario of interest. o discount (per cent, required): The annual discount rate, applied for each year in the time span.

source: http://releases.naturalcapitalproject.org/invest-userguide/latest/annual_water_yield.html

5.2.2 The Recreation Model

Table 3: Recreation Model characteristics

Model	Visitation: Recreation and Tourism
Summary	To quantify the value of natural environments, the InVEST recreation model predicts the spread of person-days of recreation, based on the locations of natural habitats and other features that factor into people's decisions about where to recreate. The tool estimates the contribution of each attribute to the visitation rate in a simple linear regression. In the absence of empirical data on visitation, we parameterize the model using a proxy for visitation: geotagged photographs posted to the website Flickr. Using photo-user-day estimates, the model predicts how future changes to natural features will alter visitation rates. The tool outputs maps showing current patterns of recreational use and maps of future patterns of use under alternate scenarios.
How it works	The model displays the rate of visitation across landscapes (grid cells) or in discrete areas (polygons) and optionally builds a regression model to estimate the contribution of attributes of the landscape to the visitation rate, using a linear regression
Formula	$$y_i = \beta_0 + \beta_1 * x_{i1} + \ldots + \beta_p * x_{ip} \text{ for } i = 1 \ldots n,$$ Where x_{ip} is the coverage of each attribute in each cell or polygon (hereafter called 'cell'), within an Area of Interest (AOI) containing n cells. In the absence of empirical data on visitation for y_i, we parameterize the model using a crowdsourced measure of visitation: geotagged photographs posted to the website Flickr. As stated again, the InVEST recreation model predicts the spread of person-days of recreation in space. It does this using attributes of places, such as natural features (e.g. habitat distributions), built features (e.g. roads), and human uses (e.g. industrial activities), among others. The tool begins by log-transforming all y_i values, by taking the natural log of average photo-user-days per cell + 1. Then, a simple linear regression is performed to estimate the effect of each attribute on log-transformed visitation rates across all grid cells within the study region. These estimates (the β_p values) can be used for an additional scenario, to predict how future changes to the landscape will alter the visitation rate. The model uses ordinary least squares regression, performed by the linalg.lstsq function in python's numpy library[1].
Data needs	▪ Workspace (directory, required): The folder where all the model's output files will be written. If this folder does not exist, it will be created. If data already exists in the folder, it will be overwritten. ▪ File Suffix (text, optional): Suffix that will be appended to all output file names. Useful to differentiate between model runs. ▪ Area of Interest (vector, polygon/multipolygon, required): Map of area(s) over which to run the model. It is recommended that this vector be projected in linear units, especially if it is used to calculate regression and scenarios. Results are aggregated to these polygons. ▪ Start Year (number, units: year, required): Year at which to start photo user-day calculations. Calculations start on the first day of the year. The year must be in the range 2005 - 2017 and must be less than or equal to the End Year. ▪ End Year (number, units: year, required): Year at which to end photo user-day calculations. Calculations continue through the last day of the year. The year must be in the range 2005 - 2017 and must be greater than or equal to the Start Year. ▪ Compute Regression (true/false): Run the regression model using the predictor table and scenario table, if provided. If this is not selected, the results will be limited to a map of current visitation rates in the AOI polygons or grid cells. ▪ Predictor Table (CSV, conditionally required): A table that maps predictor IDs to spatial files and their predictor metric types. The file paths can be absolute or relative to the table. These predictors are the values described in How it Works. Columns: o id (text, required): A unique identifier for the predictor (10 characters or less).

[1] van der Walt, Stéfan, S. Chris Colbert, and Gaël Varoquaux. 2011. The NumPy Array: A Structure for Efficient Numerical Computation. Computing in Science & Engineering 13 (2): 22–30.

	o path (raster or vector, required): A spatial file to use as a predictor. In the example below, the files listed in the path column are located in the same folder as the Predictor_Table.csv file. Predictor files may be located in other places, but either the full path to them must be included in this table or the path relative to this CSV file. o type (option, required): The type of predictor file provided in the 'path' column. Options: o line_intersect_length: {'description': 'Predictor is a line vector. Metric is the total length of the lines that fall within each AOI grid cell.'} o point_count: {'description': 'Predictor is a point vector. Metric is the number of points within each AOI grid cell or polygon.'} o point_nearest_distance: {'description': 'Predictor is a point vector. Metric is the Euclidean distance between the centre of each AOI grid cell and the nearest point in this layer.'} o polygon_area_coverage: {'description': 'Predictor is a polygon vector. Metric is the area of overlap between the polygon and each AOI grid cell.'} o polygon_percent_coverage: {'description': 'Predictor is a polygon vector. Metric is the percentage (0-100) of overlapping area between the polygon and each AOI grid cell.'} o raster_mean: {'description': 'Predictor is a raster. Metric is the mean of values within the AOI grid cell or polygon.'} o raster_sum: {'description': 'Predictor is a raster. Metric is the sum of values within the AOI grid cell or polygon.'} ▪ Scenario Predictor Table (CSV, optional): A table of future or alternative scenario predictors. Maps IDs to files and their types. The file paths can be absolute or relative to the table. This table has the same columns and format as the Predictor Table described above. ▪ Grid the AOI (true/false): Divide the AOI polygons into equal-sized grid cells, and compute results for those cells instead of the original polygons. ▪ Grid Type (option, conditionally required): The shape of grid cells to make within the AOI polygons. Required if Grid AOI is selected. Options: o hexagon: {'display_name': 'hexagon'} o square: {'display_name': 'square'} · Cell Size (number, units: linear_unit, conditionally required): Size of grid cells to make, measured in the projection units of the AOI. If the Grid Type is square, this is the length of each side of the square. If the Grid Type is 'hexagon', this is the hexagon's diameter. The cell size is in the same linear units as the AOI. For example, if the AOI is in a UTM projection with units of meters, the cell si

source: https://invest-userguide.readthedocs.io/en/latest/recreation.html

5.2.3 Crop Pollination model

Table 4: The Crop Pollination Model characteristics

Model	Crop Pollination (Pollinator Abundance)
Summary	The InVEST pollination model focuses on wild bees as a key animal pollinator. It uses estimates of the availability of nest sites and floral resources within bee flight ranges to derive an index of the abundance of bees nesting on each cell on a landscape (i.e., pollinator supply). It then uses floral resources, bee foraging activity and flight range information to estimate an index of the abundance of bees visiting each cell. If desired, the model then calculates a simple index of the contribution of these bees to agricultural production, based on bee abundance and crop dependence on pollination. The results can be used to understand changes in crop pollination and crop yield with changes in land use and agricultural management practices. Required inputs include a land use/land cover (LULC) map, land cover attributes, guilds or species of pollinators present, and their flight ranges. Estimating wild pollinator contributions to crop production requires information on farms of interest, the crops grown there, and the abundance of managed pollinators. The model's limitations include not accounting for pollinator persistence over time or the effects of land parcel size.
How it works	The model is an index-based model, and requires the following biophysical data: ▪ an LULC map; ▪ a biophysical table paired with the LULC raster to map LULC types to nesting suitability and floral resources across seasons; ▪ a pollinator guild table with properties about active seasons, nesting preferences, mean flight distances, and relative abundances for each species or group of wild pollinators; ▪ a farm shapefile indicating the geospatial location of farms, crop type, dependence on pollinators, abundance of managed pollinators, as well as on-farm nesting sites and floral resources.
Pollinator Supply and Abundance - formula	*PS(x, s)* is the pollinator supply index at a pixel for species *s* defined as: $$PS(x,s) = FR(x,s) * HN(x,s) * sa(s)$$ where *FR(x, s)* is the accessible floral resources index at pixel *x* for species *s* Pollinator supply is an indicator of where pollinators originate from on the landscape. Pollinator abundance indicates where pollinators are active in the landscape. Pollinator abundance depends on the floral resources that attract pollinators to a cell, and the supply of pollinators that can access that cell. The pollinator abundance for species *s* index on cell, *x* during season *j, PA(, s, j,)*, is the product of available floral resources on a cell during a given season, weighted by a pollinator's relative activity during that season with the pollinator supply and normalized by the floral resources index in surrounding cells such that: $$PA(x,s,j) = (\frac{RA(l(x),j) * fa(s,j)}{FR(x,s)}) * \frac{\sum_{x' \in X} PS(x',s) * exp(-D(x,x')/\alpha_s)}{exp(-D(x,x')/\alpha_s)}$$
On-Farm Abundance and Yield - formula	On-farm pollinator abundance is given as: $$PAT(x,j) = \sum_{s \in S} PA(x,s,j)$$ The potential contribution of on-farm pollinator abundance to pollinator-dependent crop yield is calculated using a tunable half-sigmoid function as: $$FP(x) = \frac{PAT(x,j(f(x))) * (1 - h(f(x)))}{h(f(x)) * (1 - 2PAT(x,j(f(x))) + PAT(x,j(f(x))}$$ where is the half-saturation constant for farm *f* at pixel *x* indicating the abundance of wild pollinators needed to reach half of the total potential pollinator-dependent yield.

	The actual contribution of wild pollinators to pollinator-dependent yield depends on the degree to which pollination needs are already being met by managed pollinators. The total pollinator-dependent yield, from both wild and managed pollinators, is given as: $$PYT(x) = min(mp(f(x)) + FP(x),1)$$ assuming a value of 0 indicates 0% of pollinator-dependent yield is achieved, and 1.0 indicates 100% of pollinator-dependent yield is achieved. Note the max/min notation constrains the value of *PYT* to 0…1 where *mp(f(x))* is the proportion of pollination that needs to be met by managed pollinators available at pixel *x* within farm polygon *f*. The proportion of pollinator-dependent yield attributable to wild pollinators is given as: $$PYW(x) = max(0, PYT(x) - mp(f(x)))$$ Thus, in cases where managed pollinators are sufficiently abundant, i.e, *mp(f(x))* =1, there is no additional yield attributable to wild pollinators. The total crop yield attained is a function of the crop's dependence on pollination and the degree to which its pollination needs are met. Some crop species are self-compatible or wind-pollinated and yield is less dependent on animal pollinators while other species obligately require pollinators to generate any yield. Total crop yield is calculated per farm as: $$YT(f) = 1 - v(f) * (1 - \sum_{x \in X(f)} PYT(x)/\|X(f)\|)$$ Where *f* is a particular farm, *X(f)* are the set of pixels covering farm *f*, and |*X(f)*| is the count of pixels covered by farm *f*. The function *v f* is a scalar *v f* representing what proportion of yield for the crop grown on farm *f* is dependent on pollinators. The proportion of total crop yield attributable to wild pollinators is given as: $$YW(f) = v(f) * (\sum_{x \in X(f)} PYW(x)/\|X(f)\|)$$
Data needs	▪ Workspace (directory, required): The folder where all the model's output files will be written. If this folder does not exist, it will be created. If data already exists in the folder, it will be overwritten. ▪ File Suffix (text, optional): Suffix that will be appended to all output file names. Useful to differentiate between model runs. ▪ Land Use/Land Cover (raster, required): Map of LULC codes. All values in this raster must have corresponding entries in the Biophysical Table. Used to map biophysical properties about habitat and floral resources of landcover types to a spatial layout. This must be of fine enough resolution to capture the movements of bees on a landscape. If bees fly 800 meters on average and cells are 1000 meters across, the model will not fully capture the movement of bees from their nesting sites to neighbouring farms. ▪ Biophysical Table (CSV, required): A table mapping each LULC class to nesting availability and floral abundance data for each substrate and season in that LULC class. All values in the LULC raster must have corresponding entries in this table. Data can be summarized from field surveys, or obtained by expert assessment if field data is unavailable. Columns: o lucode (integer, required): LULC code representing this class in the LULC raster. o nesting_[SUBSTRATE]_availability_index (ratio, required): Index of availability of the given substrate in this LULC class. Replace [SUBSTRATE] with substrate names matching those in the Guild Table, so that there is a column for each substrate. o floral_resources_[SEASON]_index (ratio, required): Abundance of flowers during the given season in this LULC class. This is the proportion of land area covered by flowers, multiplied by the proportion of the season for which there is that coverage. Replace [SEASON] with season names matching those in the Guild Table, so that there is a column for each season. For example, a LULC class comprised 100% of a mass flowering crop that flowers the entire season with an abundance cover of 80% would be given a suitability value of 0.80. A LULC

	class that flowers only half of the season at 80% floral coverage would be given a floral suitability value of 0.40. The SEASON name must exactly match a season given in the Guild Table. · Guild Table (CSV, required): A table mapping each pollinator species or guild of interest to its pollination-related parameters. 'Guild' refers to a group of bee species that show the same nesting behaviour, whether preferring to build nests in the ground, in tree cavities, or in other habitat features. If multiple species are known to be important pollinators, and if they differ in terms of flight season, nesting requirements, or flight distance, provide data on each separately. If little or no data are available, create a single 'proto-pollinator' with data taken from average values or expert opinions about the whole pollinator community. Each row is a unique species or guild of pollinator and columns must be named and defined as follows: Columns: o species (text, required): Unique name or identifier for each pollinator species or guild of interest. o nesting_suitability_[SUBSTRATE]_index (ratio, required): Utilization of the substrate by this species, where 1 indicates the nesting substrate is fully utilized and 0 indicates it is not utilized at all. Replace [SUBSTRATE] with substrate names matching those in the Biophysical Table, so that there is a column for each substrate. Substrates are user-defined but might include ground nests, tree cavities, etc. o foraging_activity_[SEASON]_index (ratio, required): Pollinator activity for this species/guild in each season. 1 indicates maximum activity for the species/guild, and 0 indicates no activity. Replace [SEASON] with season names matching those in the biophysical table, so that there is a column for each season. Seasons are user-defined but might include spring, summer, fall; wet, dry, etc. o alpha (number, units: m, required): Average distance that this species or guild travels to forage on flowers. The model uses this estimated distance to define the neighbourhood of available flowers around a given cell and to weigh the sums of floral resources and pollinator abundances on farms. This value can be determined by the typical foraging distance of a bee species based on an allometric relationship. o relative_abundance (ratio, required): The proportion of total pollinator abundance that consists of this species/guild. Setting this value to the same value for each species will result in each species being weighted equally. · Farms Map (vector, polygon/multipolygon, optional): Map of farm sites to be analyzed, with pollination data specific to each farm Fields: o crop_type (text, required): Name of the crop grown on each polygon, e.g. 'blueberries', 'almonds', etc. For farms growing multiple overlapping crops, or crops in multiple seasons, a separate overlapping polygon must be included for each crop. o half_sat (ratio, required): The half-saturation coefficient for the crop grown in this area. This is the wild pollinator abundance (i.e. the proportion of all pollinators that are wild) needed to reach half of the total potential pollinator-dependent yield. This is a tunable parameter that may be most useful to adjust following an initial run of the model and an examination of the results. o season (text, required): The season in which the crop is pollinated. Season names must match those in the Guild Table and Biophysical Table. o fr_[SEASON] (ratio, required): The floral resources available at this farm for the given season. Replace [SEASON] with season names matching those in the Guild Table and Biophysical Table, so that there is one field for each season. o n_[SUBSTRATE] (ratio, required): The nesting suitability for the given substrate at this farm. given substrate. Replace [SUBSTRATE] with substrate names matching those in the Guild Table and Biophysical Table, so that there is one field for each substrate. o p_dep (ratio, required): The proportion of crop dependent on pollinators. See[2] for estimates for common crops. o p_managed (ratio, required): The proportion of pollination required on the farm that is provided by managed pollinators. This can be estimated as the proportion of the recommended hive density or stocking rate. See Delaplane & Mayer (2000) for recommended stocking rates in the United States. Agricultural extension offices are also a good source of this information.

source: https://invest-userguide.readthedocs.io/en/latest/croppollination.html

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6 Conclusions

In the elaboration were presented the opportunities and the barriers of ecosystem services assessment on the basis of current scientific achievements in this area. The resulting models, tools and data let assess provisioning, regulating, supporting and cultural services under strictly assumptions and limitations made. The results of the application of particular models presented herein point out to rather a narrow scope of application and to difficulties to be considered all social and economic and environmental aspects of a given eco-services enterprise. Even more, a subjective point of view of a concrete eco-service impact on different stakeholders can change the results of their assessment dramatically.

The selected models of eco-service services will allow developing the ABM model with the desired environmental parameters and predicting different assessments of the impact of these services on the economic and farm results. Data from ABM on agricultural production in a given area will allow the modelling of predicted changes in the state of the environment.

The multitude of models used to estimate ecosystem services presented in the literature proves the complexity of this issue.

The choice of the appropriate model to estimate a particular type of service will always depend on the needs of decision-makers, data availability, the economic conditions of the area, and the geographic and climatic context.

The available types of models, defined as global models, always require modifications imposed by the specificity of a given area and supplemented with information through data from participatory research or expert research.

The lack of data or the lack of continuity of data applied to global models of ecosystem services prompts the search for simple relationships (e.g. linear regression equations) between human activities and the state of the environment.

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For preparing this report, the following deliverables have been taken into consideration:

Deliverable Number	**Deliverable Title**	**Lead beneficiary**	**Type**	**Dissemination Level**	**Due date**
D5.1	State of the art review of agricultural policy assessment models, tools and indicators	AKD	Report	Public	M12
D7.1	Use case planning and set of involved stakeholders	CAAND	Report	Public	M25