# USING A GIS WEB-BASED TOOL TO MAP AND ASSESS ECOSYSTEMS AND THEIR SERVICES IN A VERY HIGH BIOLOGICAL AND CULTURAL AREA: THE CASE OF ALTO MAYO WATERSHED (PERU)

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***ABSTRACT***
*Mapping and assessing pressures and threats on ecosystems and the spatial distribution of their services are even more important in decision making processes for conservation planning and natural resource management.*
*To support decision makings, different ES policy support system tools are at present developed, involving a variety of models, data sources, processes and output.*
*Hence, we carried out a research project in an Andes-Amazon area of Peru, called Alto Mayo, where several anthropic pressures and conservation projects overlap on a high biological and cultural diversity area. We focused on the use and validation of Costing Nature, an ES web-based tool developed by King’s College London.*
*Input data and models used by this tool were validated and used to perform a 2013 baseline of the area, comparing and integrating with the data, information and knowledge about Alto Mayo provided by different local sources, field surveys and decision makers. Output maps, their possible suitability to this Andes-Amazon context, their relationships with Protected Areas and the usefulness to policy makers are evaluated for some ecosystem services such as water provisioning, carbon storage and sequestration, conservation priority, current pressures on Alto Mayo ecosystems.*

***Keywords:*** *ecosystem services, Costing Nature, conservation, Peru, Alto Mayo.*

## INTRODUCTION

The Ecosystem services (ES) paradigm is constantly gaining importance since 1970, focusing on the human-environment interactions to increase the interest of people regarding biodiversity conservation and the importance of ecosystems for human life, in front of evidences of a more and more unsustainable use of natural resources [1],[2]. By this concept, ecosystems are considered as a “natural capital” that produces a services flow useful and often indispensable for human well-being and subsistence, and that is influenced both positively either negatively by natural and anthropic factors [3].

The big boost in ES evaluation, quantification and management is related to Millennium Ecosystem Assessment [1] (2005), after which different studies and projects are carried out to try to bring this concept from the academic side to an operational one, using different ecosystems and their services frameworks in decision making processes, land planning, natural resource management and conservation projects, among others. These efforts also bring out the need of consistent and reliable assessment, quantification, evaluation and mapping methods of ecosystems, their functions, services, trade-offs and beneficiaries at different temporal and spatial scale that integrate biophysical, socio-cultural and economical aspects [4], [5]. Particularly, quantification methods vary widely according to the availability of data, temporal and spatial scale, ES types and other aspects investigated, involving primary data and proxies, quantitative and qualitative data, such as statistic and survey information, data from empirical studies and/or from remote sensing, expert opinions, participatory processes [4], [6].

Key component to make this process effective and operational is the spatialization of ES, especially whereas analyses are performed within a landscape framework, where various biophysical and socio-economic factors interact at different spatial and temporal scales, producing a complex heterogeneity in the distribution, quantity and quality of ES produced and consumed [7]. Ecosystems and their services have an intrinsic spatial connotation [5] and their mapping turns into a functional tool that enables the following research issues: a) relationships between supply and demand and the generated ES flow; b) understanding the effects of different impacts and pressures; c) investigating possible future threats; d) analysing outcomes of different land use policies; e) identifying priority areas for biodiversity conservation; f) visualizing future alternative scenarios; g) being a communication and educational tool [4], [8], [9], [10], [11]. Challenges and limitations of mapping processes depend on the availability and production of useful spatial data; the use of standard but flexible methodologies that allow its application in different contexts and the comparison between different areas; the fact that not all ES are easily "mappable"; and aspects related to the critical cartography approaches, such as who has the power to map and who take decisions about what map and the scale to use, what are the effects to consider certain ES or certain beneficiaries and not others [9].

The increasing interest about ES mapping is also possible thanks to the progress in GIS and Remote Sensing technologies, the creation of geodatabases with spatial and temporal continuity and available for free, the development of ES modelling tools, that combine and integrate ecological, socio-economical and geographical aspects to investigate socio-ecological systems and produce spatial scenarios that can help and support decision making processes [10], [12], [13].

Mulligan [14] emphasizes the importance of the increasing use of policy-support system models, which are part of an extensive group of decision-support system models, which assists decision makers in different decision making processes, providing tools to test and assess policies.

Bagstad [13] presents a review and comparison between different modelling tools designed to incorporate ES assessment in decision making processes, highlighting an increasing development of specific ES analysis tools. The purposes of these GIS tools are to quantify, to assess and often to map, at different spatial and temporal scales, multiple ES. The author evaluated 17 ES tools using the following criteria: a) if they are enough flexible and generic to be used in different contexts and compare their results; b) their need of data, time and resources; c) the usefulness and reliability of cartographic output, and d) their understandability for decision makers.

The general aim of this study is to assess some key ES in a very high biologically and culturally area of Peru. Specific aims are: 1) to spatially assess current pressure of human activities on tropical ecosystems; 2) to highlight areas of conservation priority; 3) to map provisioning and regulating ES such as water provisioning and carbon sequestration; 4) to test and validate a GIS-based ES software applied in a data poor context.

## DATA AND METHODS

### Study area

Alto Mayo is the upper part of Rio Mayo watershed, an Andes-Amazon watershed of Peru in the north-west of San Martin Region. Alto Mayo territory includes both the Moyobamba and Rioja Provinces, covering an area of 6,620 $km^2$ with a population of about 263,000 inhabitants [15]. Rio Mayo and its tributaries have modeled an important and flat valley NW-NE oriented, surrounded by mountains, particularly in the north and west part. This complex territory is strictly depending on the Amazon natural resources of tropical forest ecosystems, and its biological and cultural diversity.

During the last 40-50 years the area is affected by relevant deforestation activities and anthropic pressures on ecosystems, mainly driven by uncontrolled agriculture expansion (coffee, rice, corn, cocoa) carried out by new settlers. Since 2006 the Regional Government together with different national and international NGOs promoted different biodiversity conservation, natural resource management and land planning projects to target the goal "San Martin Green Region in 2021" [16], [17], [18]. Figure 1 shows the study area and its main geographical characteristics: the location of the capital cities of the two Provinces and the other main cities; the main roads built since about 1970 and the agricultural expansion; the areas assigned to the main protected area, i.e. the "Bosque de protección Alto Mayo (BPAM)" and to the indigenous communities; the presence of oil, gas and mines concessions (2013); and the land use land cover (LULC), updated at 2010, derived from a study commissioned by the Environmental Ministry of Peru [18].

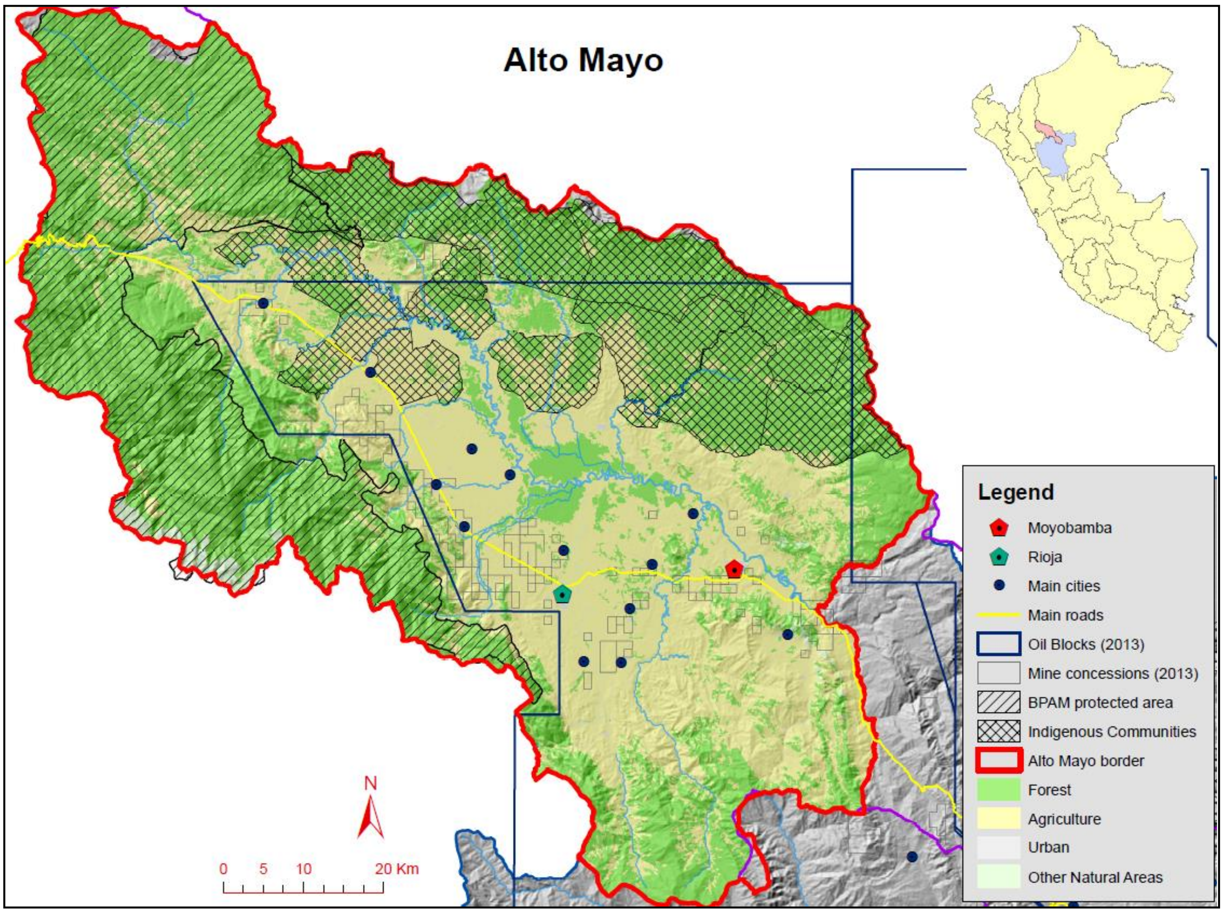


**Fig. 1.** Geographical framework: the Alto Mayo territory and its main territorial characteristics.

## Costing Nature

Costing Nature (CN) is a web-based, ES policy support system tool created to model and to map different ecosystem services in different areas at different scales. It has been designed to help and to support policy makers, at a global level, in sustainable management of ecosystem and their services, mainly defining priority conservation areas. It is developed by King's College London with the support of AmbioTEK and UNEP-WCMC. It integrates information concerning the supply and beneficiaries of these ES in conservation and planning activities [20].

ES assessments currently performed by CN are a) water provisioning (provisioning service), b) carbon stock and sequestration (regulating service), c) natural-tourism (cultural service), d) hazard mitigation (regulating service). Every service is analyzed as potential (located in an area, but nobody uses it) or realized (located and used by users). CN is also able to model and to map also other important environmental features, such as current pressure, future threats, biodiversity and priority conservations, which are combined with the 4 ES in order to better understand their status, relationship and trade-offs [21].

CN works through different mathematical models using and combining more than 100 dataset (such as precipitations, roads, cropland, digital elevation model, etc.) input at different temporal and spatial scale, provided by the system from the global database SimTerra [22] and other international institutions (such as FAO, IUCN, WWF), Moreover, this web-based platform is able to use other dataset which every user may upload and use. This software produces more than 30 different thematic maps and statistics using an index between 0 and 1, with a spatial resolution of 1 $km^2$ for 10 degree tiles (1000 km) or 1 hectare (ha) for 1 degree tiles (100 km) [21].

By selecting the study area and the spatial resolution the CN models perform the spatial analysis by creating a baseline about the recent status calculating the value index as local index (within the selected tile) or as global index (for the tile compared at global level); the former is useful to compare different areas and combine different tiles. User can then apply scenarios of land use and land cover changes or priority conservation changes through different policy options and examine the impacts on the ES and implications for the beneficiaries. The scenario simulations are carried out using a benefit transfer model [19]. Figure n. 2 shows the workflow and the main characteristics of CN.

The type of simulations and output depends on the available license and the version of the software, which is continuously developed and updated. Our analyses are based on Costing Nature v. 2.49 and a DATAUSER license which allow a full usage of the software and to analyze output maps for every single ES; on the contrary restricted licenses allow the production of bundled ES maps.

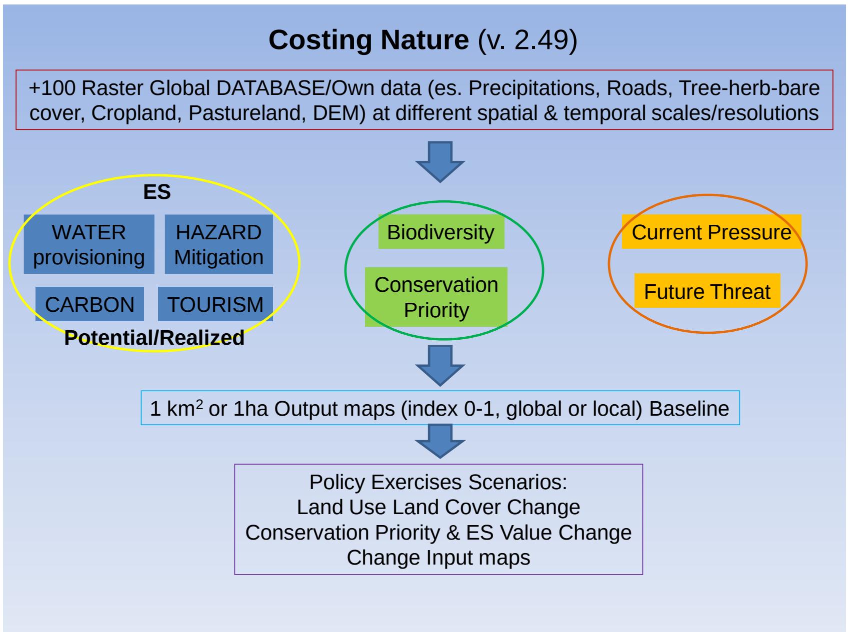


**Fig. 2.** Workflow and main characteristics of Costing Nature.

Input data and models used by CN were validated and used to perform a 2013 baseline of the area, comparing and integrating with the data, information and knowledge about Alto Mayo provided by different local sources, field surveys and decision makers. Output maps, their possible suitability to this Andes-Amazon context, their relationships with Protected Areas and the usefulness to policy makers are evaluated for some ecosystem services such as water provisioning, carbon storage and sequestration, conservation priority, current pressures and future threat on Alto Mayo ecosystems.

Models and main dataset performed for spatial simulation by CN are the followings:

current pressure map is modeled combining the mean of these dataset: relative population density, recent land use change, relative fire frequency, relative grazing density, relative agricultural density, relative dam density, relative infrastructural density;

conservation priority map is modeled combining these dataset produced by different organizations: endemic bird areas, WWF global 200 priority ecoregions, conservation hotspots, important bird areas, last of the wild areas, key biodiversity areas;

realized water services map is modeled combining the potential water services cumulated downstream (clean water produced by rainfall less evapotranspiration, minus the water contaminated by the presence of human activities, such as pastures, croplands, roads, etc.) and the presence of beneficiaries, represented by the presence of dams, population and irrigation projects downstream;

carbon stock and sequestration is the product of the combination of different global database related to above and below ground carbon stock and dry matter productivity for carbon sequestration.

Baseline preparation and data validation.

We started with a baseline setup and dataset pre-processing method following two steps.

The first stage was performed to validate every input map about their spatial consistency, their socio-ecological correspondence and, whereby was possible and necessary, updating the dataset at local scale through the "change input maps" option, available in the policy exercise section of the tool. Global dataset have been changed and updated with local data provided by Regional Government. Integration and validation with local data include the following geographic features: road system, mining concessions, oil & gas concessions, planned transportation routes and rural populated places.

In the second step we updated the land cover dataset for trees, herbs and bare covered ground up to the beginning of 2013, using the LULC change option available in policy exercises scenario section of Costing Nature. This operation was necessary because of the massive deforestation processes taking place in the region in the last years, not recognized by the land cover dataset dated 2000 (Landsat 2000). Therefore, we used the difference of the forest cover loss map during 2000-2012 (LUCC: forest loss 2000-2012, Hansen/ UMD/ Google/ USGS/ NASA, % of pixel) to perform the LULC downscale analysis based on the following criteria: to convert the 90% of pixels to 30% of tree, 60% of herb, and 10%, whereby LULC changes (forest loss 2000-2012) is >= 31% and where tree covered ground is > 30.001%. We therefore converted these changed pixels to cropland with 0.7 intensity (range 0-1) (figure 3 shows in blue the pixel changed during this period and the tree cover at 2000).

Hence, we ran the models in order to perform the 2013 baseline. The study area covers 4 tiles at 1ha resolution and we ran the model for every tile using global index to compare and merge the different results. Results were cropped into a Zone of Interest (ZOI) framed within the limits of Alto Mayo.

Therefore, every map was downloaded in ascii grid format and merged in one single map with the use of ESRI ArcMap 10.1.

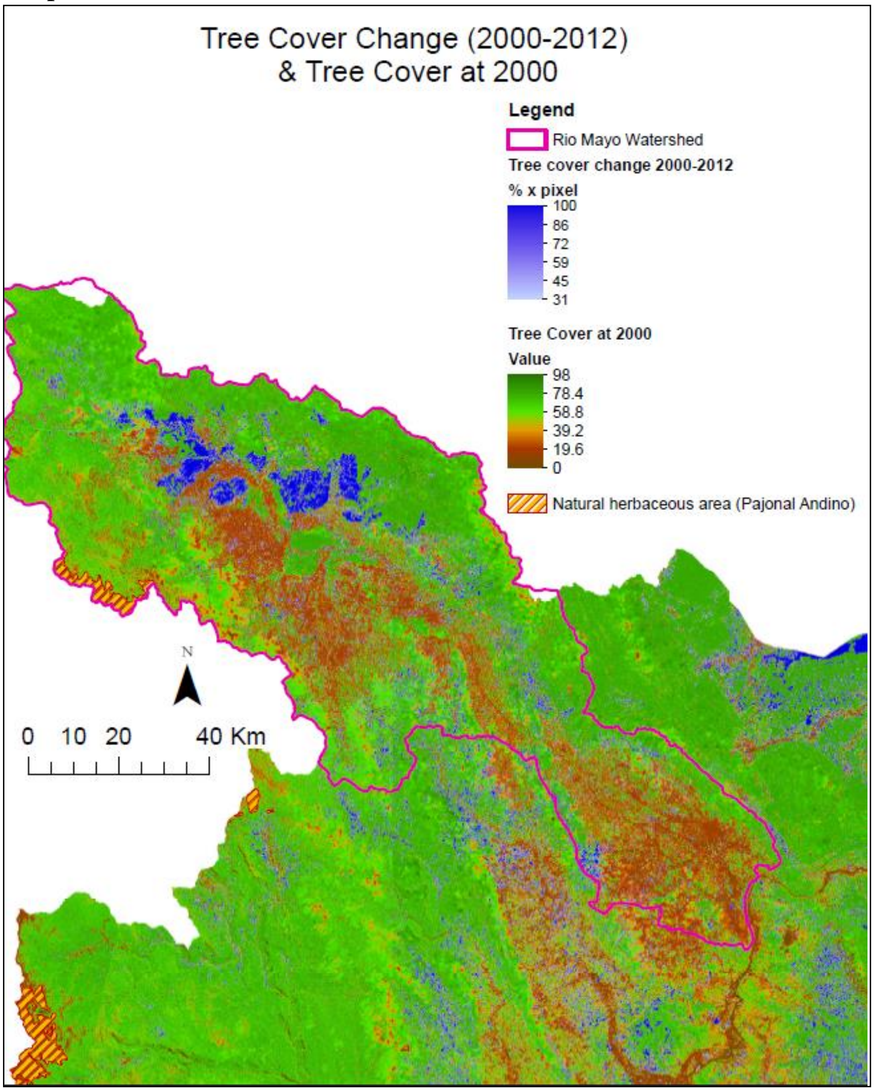


**Fig. 3.** Tree cover change in the period 2000-2012 and tree cover at 2000.

## RESULTS AND DISCUSSION

Results are expressed by spatial analysis and cartographic output, by which just geometries of the index value and spatial relationship are considered. Generally, output maps show that in every ES assessment value index is very low, particularly for locally realized ES such as water provisioning. This is due to the use of the global index relating Alto Mayo area with the global one.

Results of current pressures (figure 4) map shows the general trend of anthropic impacts in the area, according to the global input data used by CN and the changed local data, where the recent deforested areas correspond to the highest values of pressure. This issue involves mainly the flat part of Alto Mayo along the main roads and cities where intensive agriculture activities are in development and in the areas of some indigenous communities, which experienced to rent the community land to external settlers for intensive agricultural use [19]. The spatial pattern of the value index produced with the global dataset used by CN agrees quite well with the information collected during the fieldwork, but updates in the road dataset with local road network was required. This model could improve its potential use for decision makers considering the possibility to upload and take into account other variables, whereas data at local level are available. For instance, decision makers of Alto Mayo consider a very important pressure the illegal logging inside protected areas, dataset which CN may consider.

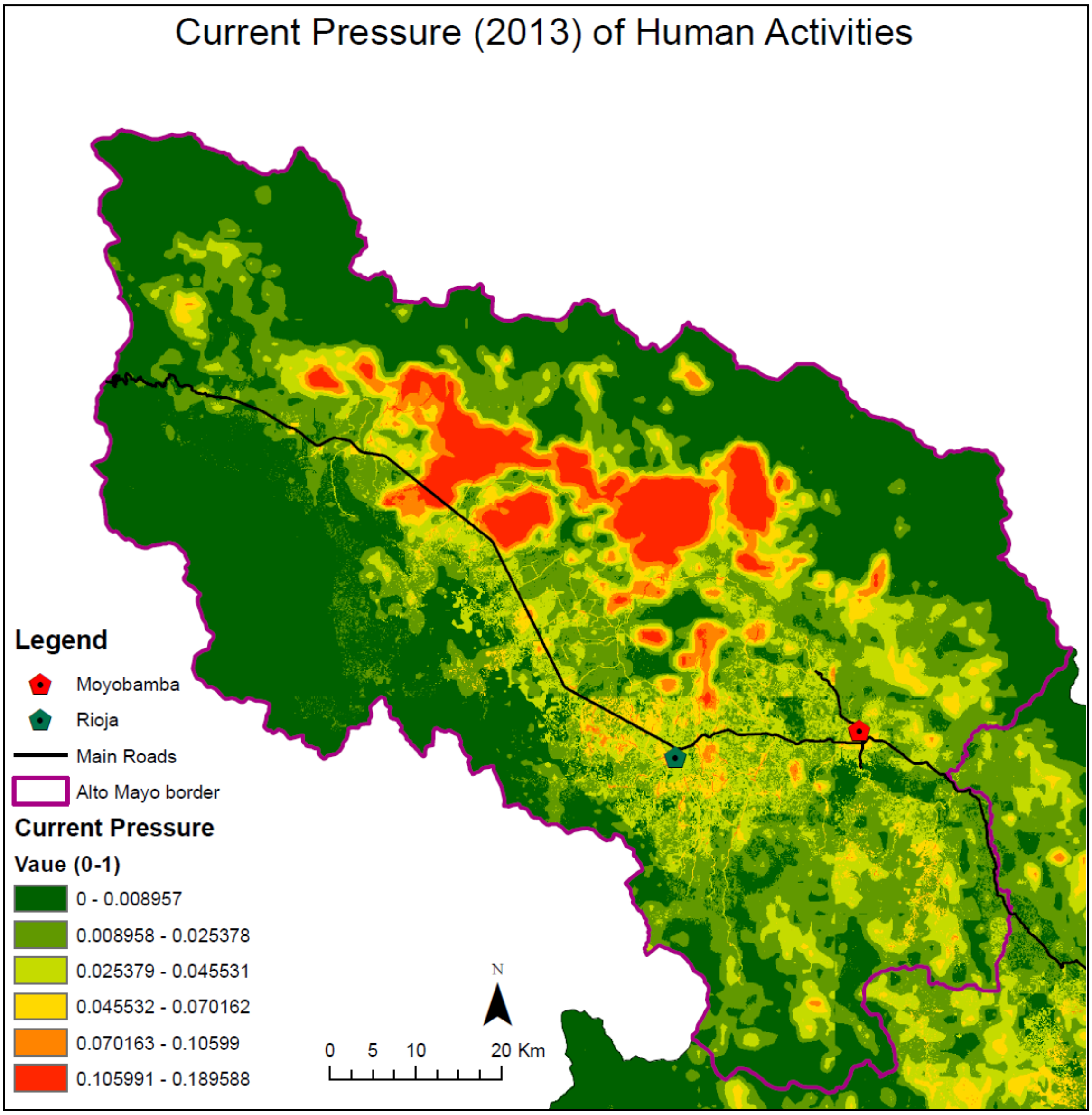


**Fig. 4.** Current pressure (2013) of human activities.

Spatial analyses about conservation priorities show that most of high value areas (value index 0.6-1) are under some degree of protection at a national or local level, highlighting that in this zone biodiversity conservation strategies are in development. This is evident mainly for the area protected at national level, that is BPAM, which is totally covered by the highest values. However, differences in conservation priority on local protected areas were recorded, showing index values almost close to 0. These differences are perhaps related to the different criteria used by international organizations expressed by this index, and the regional criteria used to create some of these local protected areas and/or resolution aspects due to the global scale used in the construction of these input maps by international organizations.

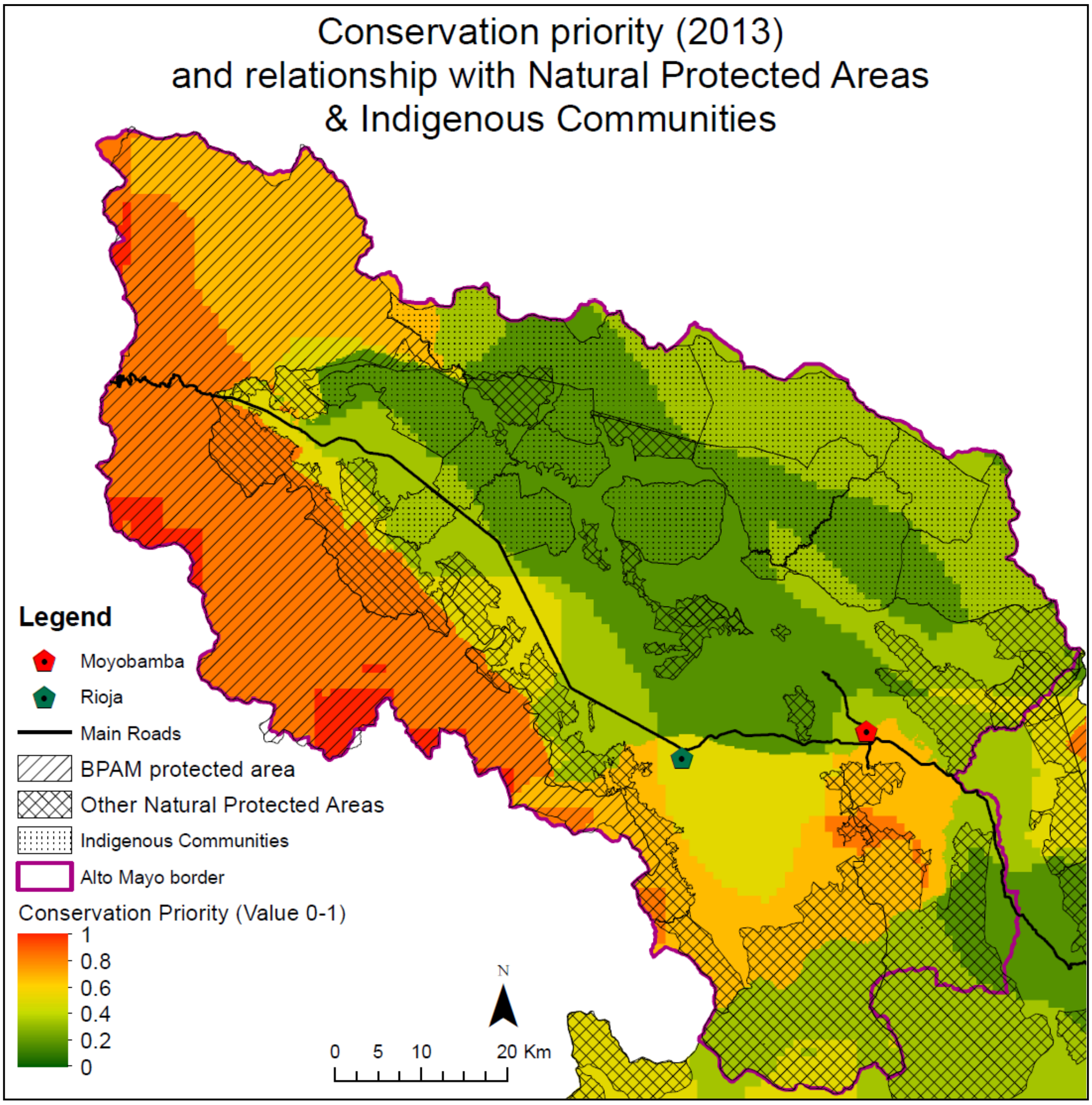


**Fig. 5.** Conservation priority and relationship with natural protected areas and indigenous communities.

Concerning water service assessment, results (figure 6) show that there is a good correspondence to the general local status, where the highest values correspond to the Eastern sector of the valley where, downstream in the flat part, are located the most part of the beneficiaries. The map also highlights the decreasing of the index due to the contamination of the water caused by human activities, such as urban areas, agriculture, and roads. We can appreciate the change in the index obtained with the update of the baseline, where we have a loss of forest in the last years and conversion to cropland, with an increasing in the human activities and a consequence decreasing in the index value (see the northern part of figure 6, where yellow pixels corresponds to blue pixels of figure 3). Results modeled in the map fit quite well with our knowledge on the field. However, on one hand we expected a higher index value in the upstream area surrounding the main cities, on the other we found the lack of an existing hydropower plant in the global input map of the dams (see blue asterisk in figure 6).

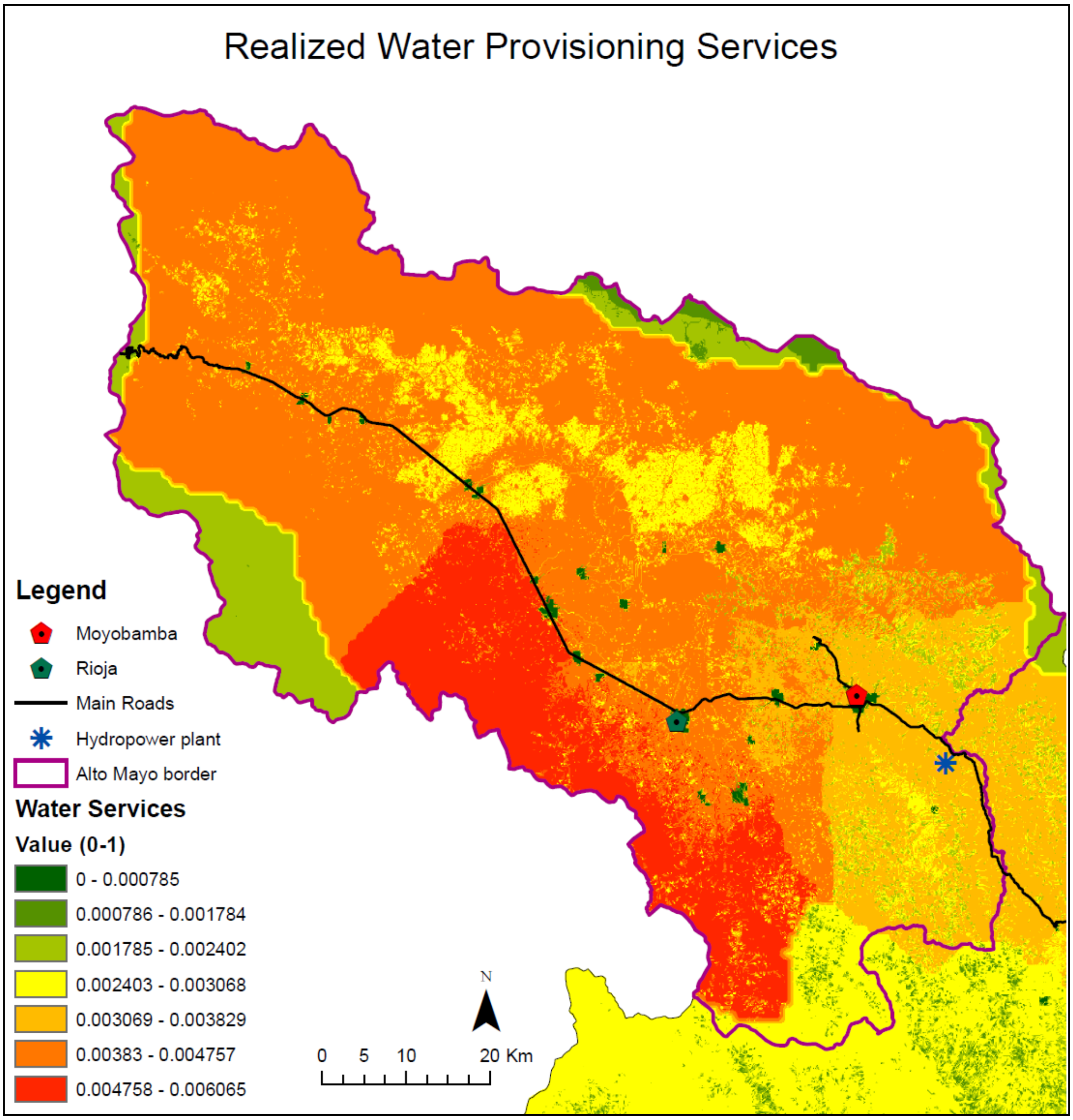


**Fig. 6.** Realized provisioning water services.

Concerning carbon map, we found that the area shows a high value of carbon stock and sequestration, by index values reaching 0.44 in the northern and eastern part of Alto Mayo. This is an expected result due to the high productivity of tropical forests; however, it seems that this model does not consider the strong deforestation occurred in the last years in the northern part of the area (blue pixels in figure 3) where the value is very high (figure 7). We found the lowest values in the western part of Alto Mayo, mainly in correspondence of high slope mountains and herbaceous ecosystems. Most of the part of this area with low values is under the protection of BPAM. This issue is interesting as far as this protected area is prioritized by the local government and NGO for a REDD+ project. A comparison with other studies about carbon stock and sequestration for the area is necessary in order to deeply investigate this issue.

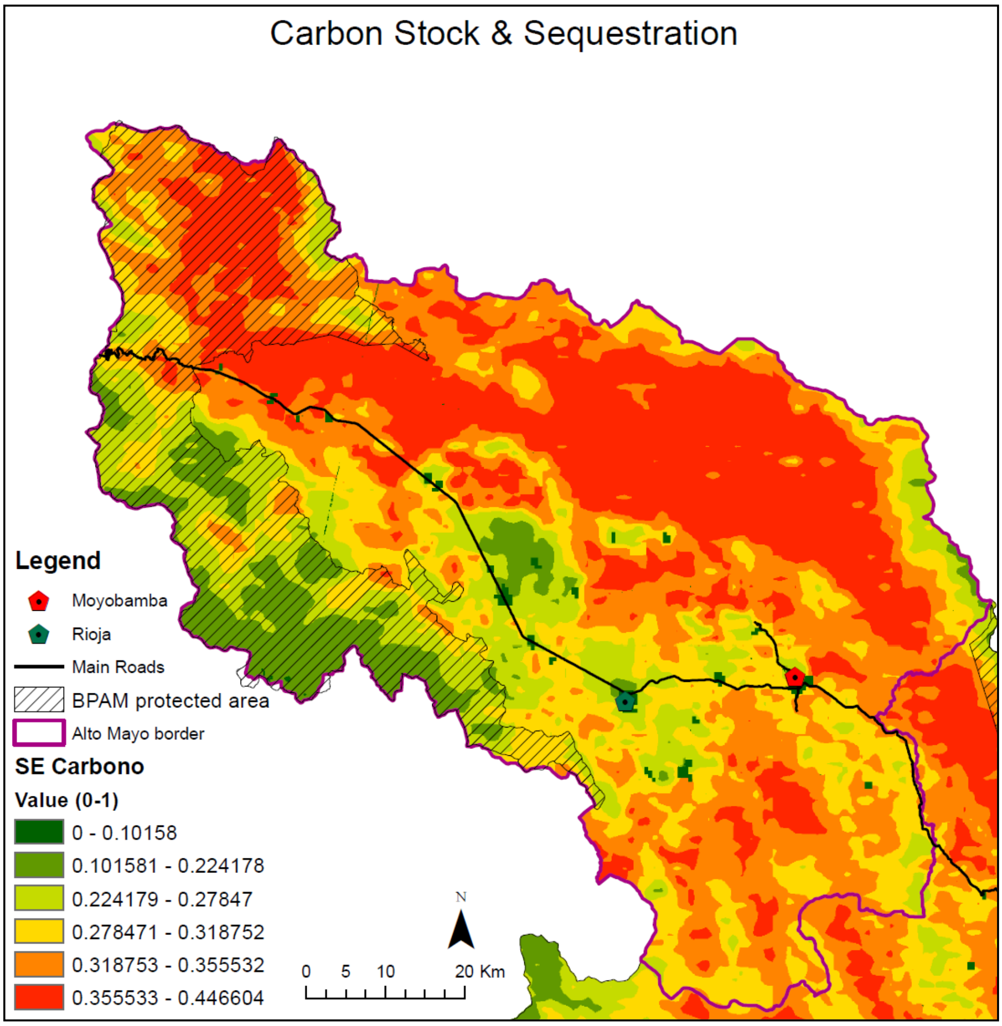


**Fig. 7.** Carbon stock and sequestration.

## CONCLUSIONS

We performed and validated a Costing Nature spatial analysis at regional scale in a typical poor data context area, comparing and integrating local detailed data produced both from government and NGOs, and fieldwork activities.

Concerning the baseline at 1 ha resolution, Costing Nature seems to perform good results to map the actual trend at a landscape scale, due to the flexibility of its models which processes different variables, a great availability of input data, the possibility to change them with local data, and the many ways to produce, combine and analyze the result maps. However, some input features and geographical aspects should be considered to improve ES analyses and running CN models at multiple scales: evaluating to change dataset according to the scale of survey and the local need of policy makers; integrating information on metadata about the spatial input dataset; use thematic maps to cross-validate CN cartographic outputs. Some limitations about input dataset at global level have been recorded, due to the spatial resolution often not useful for decision making processes at a landscape level.

As written in the work of Bagstad [13], the use of CN may be suggested in a screening phase of ES assessment to define priority areas where deep investigations should be addressed. This is the case of CN license use which allows the production of only bundled ES. Thanks to its continuous improvement, the possibility to analyze each single ES, and the possibility to change/modify input data and other parameters with a middle knowledge in GIS, we think it is useful also to investigate better trade-offs, synergies and relationships between potential, realized services and other related socio-ecological aspects.

## REFERENCES


[1] MA – Millennium Ecosystem Assessment. Ecosystems and Human Well-Being. Synthesis. Island Press. Washington DC, 2005.

[2] Gómez-Baggethun, E., de Groot, R., Lomas, P. L., & Montes, C. The history of ecosystem services in economic theory and practice: From early notions to markets and payment schemes. Ecological Economics, 69(6), 1209–1218, 2010.

[3] Huitric, M., Walker, B., Moberg, F., Österblom, H., Sandin L., Grandin U., Olsson P., Bodegard J. Biodiversity, Ecosystem Services and Resilience Governance for a Future with Global Changes. Background Report for the scientific workshop "Biodiversity, ecosystem services and governance – targets beyond 2010" on Tjarno, Sweden, 4-6 September 2009. Stockholm, 2009.

[4] Crossman, N. D., Burkhard, B., Nedkov, S., Willemen, L., Petz, K., Palomo, I., Maes, J. A blueprint for mapping and modelling ecosystem services. Ecosystem Services, 4, 4–14, 2013.

[5] Burkhard, B., Kroll, F., Nedkov, S., & Müller, F. Mapping ecosystem service supply, demand and budgets. Ecological Indicators, 21, 17–29, 2012.

[6] Busch, M., Notte, A. La, Laporte, V., & Erhard, M. Potentials of quantitative and qualitative approaches to assessing ecosystem services. Ecological Indicators, 21, 89–103, 2012.

[7] Hermann, A., Schleifer, S., & Wrbka, T. The Concept of Ecosystem Services Regarding Landscape Research: A Review. Living Rev. Landscape Res., 5 (1), 1–37, 2011.

[8] Locatelli, B., Imbach, P., & Wunder, S. Synergies and trade-offs between ecosystem services in Costa Rica. Environmental Conservation, 41(01), 27–36, 2013.

[9] Hauck, J., Görg, C., Varjopuro, R., Ratamäki, O., Maes, J., Wittmer, H., & Jax, K. "Maps have an air of authority": Potential benefits and challenges of ecosystem service maps at different levels of decision making. Ecosystem Services, 4, 25–32, 2012.

[10] Maes, J., Egoh, B., Willemen, L., Liquete, C., Vihervaara, P., Schägner, J. P., & Bidoglio, G. Mapping ecosystem services for policy support and decision making in the European Union. Ecosystem Services, 1(1), 31–39, 2012.

[11] Bowles-Newark, N. J., Arnell, A. P., Butchart, S., Chenery, A., Brown, C., & Burgess, N. D. Incorporating and utilizing spatial data and mapping for NBSAPs: Guidance to support NBSAP Practitioners. UNEP-WCMC, Cambridge, UK, 2014.

[12] Ayanu, Y. Z., Conrad, C., Nauss, T., Wegmann, M., & Koellner, T. Quantifying and mapping ecosystem services supplies and demands: a review of remote sensing applications. Environmental Science & Technology, 46(16), 8529–41, 2012.

[13] Bagstad, K. J., Semmens, D. J., Waage, S., & Winthrop, R. A comparative assessment of decision-support tools for ecosystem services quantification and valuation. Ecosystem Services, 1-13, 2013.

[14] Mulligan, M. Models Supporting Decision Making and Policy Evaluation. In Wainwright, J., & Mulligan, M. (eds). Environmental modelling: finding simplicity in complexity. John Wilsey & Sons, Ltd, 2013.

[15] INEI, Instituto Nacional de Estadística e Informática. http://www.inei.gob.pe/. Visited on 18/01/2013.

[16] GORESAM, PEAM, IIAP, & GTZ. Zonificación Ecologico-Economica de la cuenca del Alto Mayo. Moyobamba, 2007.

[17] Proyecto Segunda Comunicación Nacional de Cambio Climático. Evaluación Local Integrada y Estrategia de Adaptación al Cambio Climático en el Rio Mayo. MINAM. Lima, 2009.

[18] Heredia, J. A. Experiencia de construcción y avance de la Autoridad Regional Ambiental del Gobierno Regional San Martín. GORESAM, GIZ. Lima, 2013.

[19] CANDES S.A.C. Servicio de Consultoría para la edición y actualización del mapa de vegetación y clasificación agrícola para la cuenca del Alto Mayo. Primer Informe. Unpublished, 2012.

[20] Policy Support. Costing Nature. http://www.policysupport.org/costingnature. Visited on 07/06/2016.

[21] Mulligan, M. Globally relative but locally relevant nature conservation priorities with Co$ting Nature: I. concepts. Ecosystem Services. In Press, 2014.

[22] Policy Support. SimTerra. http://www.policysupport.org/simterra. Visited on 07/06/2016.

## SPATIAL DATASET SOURCES

CANDES S.A.C.

Ministry of Environment of Peru

Policysupport.org

Regional Government of San Martin