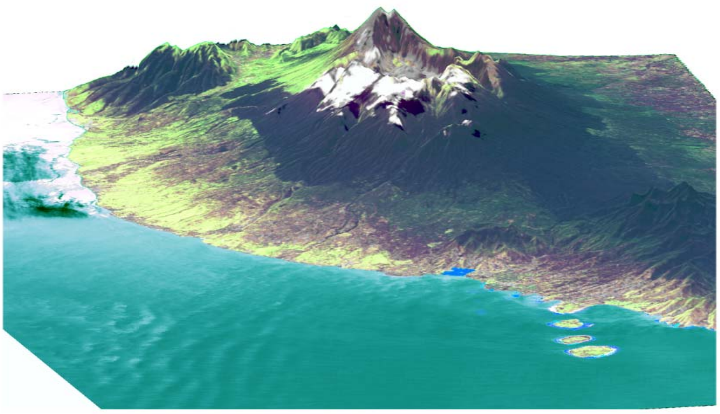
EARTH OBSERVATION FOR ECOSYSTEM SERVICES VALUATION

ESRIN Contract No. 4000107226/12/I-NB

Trial Report

Issue 4.0



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1. Introduction and objectives

Ecosystem services, the services provided by the natural environment that benefit people, determine human well-being[1]. The conservation and the best management of ecosystems will affect the long-term provision of those ecosystem services[2]. For this reason, the most recent **policies to conserve biodiversity** have adopted, as a complement to the protection of designated habitats and species, the arguments of protecting and maintaining ecosystem services. The Convention on Biological Diversity (CBD) developed a global Strategic Plan for the period 2011-2020 where ecosystem services are a key element for biodiversity protection and restoration. By 2020 the main goal is to have resilient ecosystems that continue to provide essential services, thereby securing the planet's variety of life and contributing to human well-being. The EU, being a signatory to the CBD, has also put forward a Biodiversity Strategy by 2020, emphasizing the link between biodiversity and ecosystem services. In the United Nations Conference on Sustainable Development, April 2012, more than 90 governments defined natural capital and ecosystem services as a key part of any developmental strategy and agreed to establish the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES). The United Nations have, through the Millennium Developmental Goals, fixed targets on poverty eradication and the maintenance and safeguarding of ecosystem services through sustainable development. Most of these international agreements set up commitments to map and/or assess the provision of ecosystem services by 2015-2020. Within this international framework, fast, cost-effective tools are needed to provide reliable assessments on ecosystem services' supply and demand that could be used by decision-makers, local managers and stakeholders.

The objective of the **EO Services for Ecosystem Services Valuation project** (Ecoserve) is to demonstrate the value of Earth Observation (EO) -based information products for the emerging sector of ecosystem services valuation. The Ecoserve project is closely linked to G-ECO-MON, investigating market opportunities and promoting EO-services for ecosystem service valuation and identification (Figure 1). EO-based services have the potential to provide objective baselines and are an important component of environmental monitoring systems. The geographic areas upon which EO services can provide information are far greater than what would be feasible by manual survey methods. EO services are not merely a cost-effective replacement for in-situ surveys but can facilitate a deeper level of understanding of spatial relationships between ecosystems and human environment. This understanding can be very useful to meet the current challenges of the valuation of ecosystem services. In particular, EO products can play a vital role by providing independent information on the state, quality and change/trends of natural resources within the terrestrial and marine ecosystems. These products are important for the application of ecosystem services models and estimations.

Furthermore, the Ecoserve project highlights **benefits of EO products for the valuation of ecosystem services**:

- With high resolution EO data it is possible to achieve a new level of resolution and accuracy for the InVest model results.
- EO data can support various services (e.g. land cover maps, forest maps, road and water network) for any point of the world in shorter time and at lower cost compared to on site survey.

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[1] MillenniumEcosystemAssessment (2005) Ecosystems and Human Well-being: Synthesis. Washington DC: Island Press.
[2] Costanza R, D'Arge R, De Groot R, Farber S, Grasso M, et al. (1997) The value of the world's ecosystem services and natural capital. Nature 387: 253–260.

Figure 1: Distribution of service trials in the Ecoserve and Gecomon projects. The ecoserve projects presented in this report are; Lombok, Huong Son & Vinh Tu, Ucayali, North Yucatan and Lizard Island. The remaining trials are part of the Gecomon project.

The **task on "Monitoring and Valuation of Ecosystem Services"** aims to quantify and map relevant ecosystem services in each of the trials making use of the final EO products, the identified EO baselines and indicators and the available ancillary data. The modelling tool used for the Ecoserve trials is the Integrated Valuation of Ecosystem Services and Trade-Offs (InVEST) tool developed by the Natural capital project. A summary of some conceptual issues of applying the InVEST models is provided in section 2. The specific objectives of this task were to:

- Develop baselines and indicators based on the EO products for monitoring selected ecosystem services on each trial
- Produce secondary information layers derived from the EO products required by the InVEST models
- Implement and set-up selected InVEST models
- Run different scenarios with the InVEST models
- Provide the modelling results in relative or absolute values, and if possible provide in biophysical and economic terms
- Interact with the local stakeholders to integrate and analyse modelling results and/or indicators

This **Trial Report** (TR) contains a summary of all activities conducted in the Monitoring and Valuation of Ecosystem Services task. The present section establishes the context, relevance and goals of the 'EO Services for Ecosystem Services Valuation' project (Ecoserve) and the 'Monitoring and Valuation of Ecosystem Services' task. The following section describes the theoretical basis of the analysis and the steps followed, with special focus on the development of scenarios. Section 3 reviews the main issues faced to estimate the monetary value of ecosystems services. Section 4 describes in detail the methods and results obtained during the assessment of each ecosystem service within each trial. Section 5 explores briefly some alternative uses of EO products to quantify and value ecosystem services, apart from the InVEST tools. Finally, Section 6 wraps up the main conclusions of this report and proposes some recommendations for future applications.

The results from this task and this report intend to help integrating ecosystem services into everyday decision making, either by providing relevant information to local stakeholders and decision makers (e.g. individuals, corporations, administrations), or by providing illustrative examples that could be replicated in other case studies.

2. Conceptual overview of models and scenarios

The **InVEST tools**[3] quantify and map the biophysical flow and the values of ecosystem services. InVEST relies on spatially explicit ecological production functions. The economic valuation, which is available only in a few models, often follows avoided costs (e.g. in coastal vulnerability) or market values (e.g. timber), but do not use benefit transfer. The modelling suite is best suited for analyses of multiple services and multiple objectives. The current models can identify areas where investment may enhance human well-being and nature.

InVEST models are spatially explicit, using maps as information sources and producing maps as outputs. InVEST returns results in either biophysical terms (e.g. tons of carbon sequestered) or economic terms (e.g. net present value of that sequestered carbon). Using InVEST in an iterative process, the stakeholders might choose to create new scenarios based on the information revealed by the models until suitable solutions for management action are identified.

InVEST has a tiered design. While Tier 0 models map relative levels of ecosystem services and/or highlight regions where particular services are in high demand without performing a valuation, Tier 1 models are theoretically grounded but simple. They are suitable when more data are available than are required for Tier 0, but they still have relatively simple data requirements. Tier 1 models can identify areas of high or low ecosystem service production and biodiversity across the landscape, and the trade-offs and synergies among services under current or future conditions. All tier 1 models give outputs in absolute terms, and provide the option for economic valuation (except for biodiversity). More complex Tier 2 models are under development for biodiversity and some ecosystem services. Tier 2 models provide increasingly precise estimates of ecosystem services and values, which are especially important for establishing contracts for payments for ecosystem services programs (PES). The InVEST models used in this task are:

- Biodiversity: Habitat Quality & Rarity (Tier 0)
- Carbon Storage and Sequestration (Tier 1)
- Water Purification: Nutrient Retention (Tier 1)
- Managed Timber Production (Tier 1)
- Coastal Vulnerability (Tier 0)

Figure 2 shows the **steps of an ecosystem service's analysis**. The analysis should start with the stakeholders' identification and a series of consultations, with focus on doing the whole process relevant for decision-making. Stakeholders should be involved in the development of scenarios to explore the consequences of different drivers of change on ecosystem services (more information about the development of scenarios below). The next, more technical step is the compilation of data and information required to model ecosystem services. The models can focus on the natural capacity to provide goods and services (usually biophysical models) or on the benefits that people get from them (typically economic models). Economic valuation models should always be based on some kind of biophysical measure. The InVEST tools are examples of these kinds of models (as mentioned above, InVEST relies on spatially explicit ecological production functions and only sometimes provide valuation tools). The results obtained from the modelling tasks should serve as a feedback for stakeholder's discussion and, eventually, for the adaptation of the entire methodology (tuning up the scenarios and models applied). The final interpretation should integrate all the results, conclusions and lessons learnt to support decision-making.

[3] http://www.naturalcapitalproject.org/InVEST.html

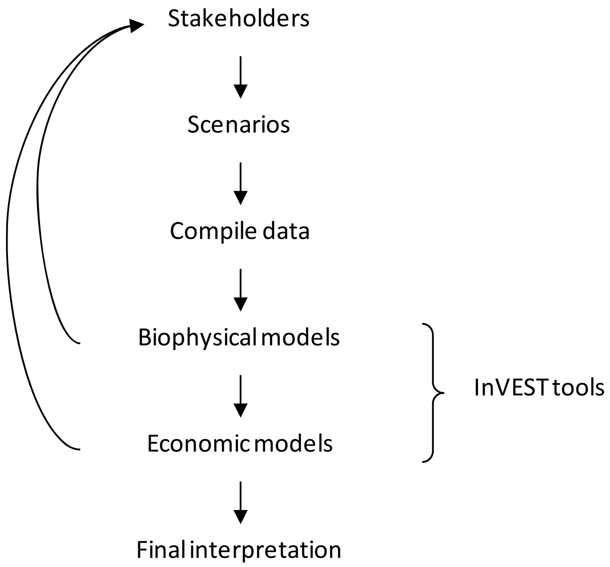

Figure 2: Work flow of an assessment of ecosystem services, inspired in the Natural Capital project.

InVEST is often most effective when used to assess ecosystem services under **alternative scenarios**. When used in this way, InVEST provides information on the comparative change in ecosystem services under possible alternatives (past, present or future). It can thereby inform real choices and involve stakeholders in a powerful learning process. In the context of InVEST, scenarios are stories that describe possible future or present situations. They can take many forms, such as[4]:

- alternative designs for policies, plans, projects or payment schemes
- explorations of possible futures, which depict how events might unfold
- idealized visions of the future reflecting the desires of stakeholders, communities or organizations
- optimized landscapes or seascapes designed to meet particular goals
- projections that describe business as usual, such as predictions based on historical trends

To tell the story, scenarios can include qualitative descriptions of changes (i.e., a narrative) and quantitative representations (i.e., numbers). For an InVEST analysis, the majority of scenario elements are depicted spatially (i.e., a map of land use and land cover).

Scenarios can be developed using participatory methods or by technical experts (or a combination of both). Optimally, the scenarios should be based on an open participatory process that engages all possible stakeholders. However, those processes are time- and resource-consuming and require at least two years for completion (E. McKenzie, InVEST team, pers.comm.). Since participatory processes were not forecasted within the EO Services for Ecosystem Valuation project and as the Monitoring and Valuation of Ecosystem Services task was allocated only 3 months, we base the scenarios presented in this report on technical expertise and data availability, trying to keep the scenarios always plausible and understandable. In general, the ecosystem management scenarios used for each service within each trial are different and not comparable, but they are judged to be the most meaningful for each local case.

Future improvements of this approach may include local participatory workshops and a long-term iterative process to identify the most relevant and legitimate scenarios. It may be especially interesting in this regard to follow the development of InSEAM, a new InVEST online interactive mapping tool that could be used to survey

[4] McKenzie, E., Rosenthal A. et al. (2012). Developing scenarios to assess ecosystem service tradeoffs: Guidance and case studies for InVEST users. World Wildlife Fund, Washington, D.C.

remote stakeholders about their future visions. It will enable people anywhere in the world with high-speed internet access to update maps simultaneously. Still, the stakeholder engagement is crucial for the success of any participatory scenario development.

Regarding the implementation of scenarios in the InVEST models, it is limited to the few input parameters that can be modified within each tool. In section 4 we describe in detail the parameters and values used to define each scenario hypothesis. Obviously, the constraint in the number of parameters that can be modified limits the flexibility of scenario development, but it can be also useful in future projects to identify the main controlling factors for each ecosystem service and to structure the discussions about scenarios' development around those factors.

3. Challenges to assess the total economic value in the trials

The quality and quantity of EO products developed under this project allows for a high resolution biophysical assessment of the trials. The maps produced are crucial inputs to assess the ecosystems' trends and conservation status in the trials. In fact, the quality of the spatial input data has been proven to affect the resulting provisioning service maps and quantifications due to the identification/omission of ecosystem services, their extent and change[5]. However, in order to derive practical and spatially explicit information about the delivery of ecosystem services and their valuation, the **EO products need to be integrated with local environmental and socio-economic data** (e.g. on species, carbon pools, maintenance costs and statistics on tourism). Local data mining (if not supported by local stakeholders) has demonstrated to be one of the limiting factors of this process, becoming extremely time-consuming and sometimes unsuccessful. Different approaches were followed, ranging from internet searches (e.g. Mexican demographic information), to local researchers and stakeholders involvement (e.g. Vietnam local precipitation data), or delegation (e.g. Peruvian environmental consultant). In other cases (e.g. estimation of carbon pools) only global data or proxies were finally available for individual trials.

Linked to the previous challenge about local data is the **involvement of local stakeholders in the project**. It should allow for (i) the production of relevant outputs adapted to the needs and expectations of potential end users, (ii) mid-term and final evaluations of the results, and (iii) the provision of in-situ data for the valuation modelling. The interaction between project partners and local stakeholders differs among the trials. For instance, in Ucayali (Peru) WWF has demonstrated interest and collaboration not only from the Peruvian bureau but also from the offices in Germany and USA. However, the main potential end user of the final results, the CFA forestry company, has declined repeatedly its involvement in this project. This fact limited the availability of in-situ information and feedback for the valuation modelling and, consequently, it slowed the production and decreased the relevance of the results in this trial. The lack of CFA participation in the coming task of the project will certainly hamper the evaluation (in terms of relevance and quality) of the modelling results.

Probably the most important challenge to estimate the monetary value of ecosystems and their services is the selection and application of suitable **economic valuation methods**. The economic valuation of nature and, in particular, ecosystem services valuation is a controversial and complex discipline[6], which ranges between two extreme schools of thought: the pure economist and the pure environmentalist[7], with many intermediate positions. The most common techniques that have been developed and applied to value ecosystem services are listed below[8].

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[5] Kandziora M., Burkhard B., Müller F. (2013). Mapping provisioning ecosystem services at the local scale using data of varying spatial and temporal resolution. Ecosystem Services 4: 47–59.

[6] Liu S., Costanza R., Farber S., A., T., 2010. Valuing ecosystem services. Theory, practice, and the need for a transdisciplinary synthesis. Annals of the New York Academy of Sciences 1185, 54-78.

[7] Bartelmus, P., 2008. Quantitative Eco–nomics. How sustainable are our economies?, first ed. Springer Science and Business Media B.V.

[8] Haines-Young R.H., Potschin M.B. (2009). Methodologies for defining and assessing ecosystem services. Final Report, JNCC, Project Code C08-0170-0062. 69 pp.

a) The Total Economic Value (TEV) framework has been widely employed to estimate both the use and non-use values that individuals and society gain or lose from marginal changes in ecosystem services. It is usually measured by the preference of individuals. The most recent developments in this field try to clarify how different methods can be used to estimate the various components of TEV, and how such data can be used to value changes under different conditions.

b) Some authors[9] have attempted to make an estimate of the value of the world's ecosystem services and natural capital. Those values are broadly applied for benefit transfer when some habitat mapping is available. Despite the wider availability of valuation databases (e.g. Envalue[10]), the current consensus is that benefit transfer methods need to be used carefully and to be developed further for comprehensive valuations[11].

c) Payment for Ecosystem Services (PES) schemes have emerged as one policy response that might help realign the private and social benefits resulting from different management options of the environment. In their purest form, such schemes enable direct beneficiaries to pay individuals or communities (providers) to undertake actions that increase the delivery of the desired services, normally by securing the integrity of ecosystems or restoring it. Such schemes are often difficult to negotiate because they challenge traditional property rights. However, they can be very effective, like in the SCaMP initiative led by United Utilities (UK)[12] that improved water quality through more sustainable forms of land management in the uplands.

d) A broad range of monetary techniques, ranging from direct market valuations, to stated preferences or replacement costs (amongst others) have been applied in individual cases, both within the schemes mentioned above or as independent approaches.

e) Last but not least, some recent initiatives try to value ecosystem services using alternative non-monetary terms, like health value or social shared value (the value people hold for ecosystem services as citizens in terms of social rights and wrongs). Some examples are the incidence and severity of respiratory illnesses, or the social cost of CO_2 emissions. It is also claimed that a pure scientific or mathematical approach (like a standard economic valuation of all ecosystem services) would not respect the complexity of the social decisions. Different stakeholders with different interests may need different “currencies” to measure ecosystem services.

The aim of all these (and other) approaches is to capture the contribution that nature and ecosystems have to human well-being, which is traditionally excluded from the way market systems operate. More extensive systematic overviews of valuation methods of ecosystem services, contexts and limitations have been conducted[13,14].

As a conclusion, there is no perfect economic valuation for ecosystem services, each valuation is context-specific and responds to the needs and objectives of each study. Given this complexity and the time needed to develop appropriate and specific economic models or monetary valuation techniques for each ecosystem services within each trial, we confine our approach to the use of the InVest valuation tools. These tools assess the biophysical provision of each ecosystem service and, in the best developed models (Tier 1 or 2) and when economic data is available, they can provide estimates of economic and social values (e.g. population affected by coastal inundation, timber revenues). Developing tailored valuation methods (either in economic or social

[9] Costanza R, D’Arge R, De Groot R, Farber S, Grasso M, et al. (1997) The value of the world’s ecosystem services and natural capital. Nature 387: 253–260.

[10] http://www.environment.nsw.gov.au/envalueapp/

[11] Plummer M (2009) Assessing benefit transfer for the valuation of ecosystem services. Frontiers in Ecology and the Environment 7: 38–45.

[12] http://corporate.unitedutilities.com/scamp-index.aspx

[13] Farber S., Costanza R., Childers D.L. et al. (2006). Linking ecology and economics for ecosystem management. Bioscience 56(2): 121-133.

[14] Pagiola S., von Ritte, K., Bishop J.T. (2004). Assessing the Economic Value of Ecosystem Conservation. TNC-IUCN-WB, Washington DC.

terms), as well as participatory scenarios, requires more time than available under this task, but it would increase the impact and relevance of this kind of projects both for the local communities and for the global/regional policy-making.

4. Ecosystem services' monitoring and valuation in the trials

4.1. Service trial #1 – Lombok (Indonesia)

Lombok is part of the Lesser Sunda Ecoregion that stretches from Lombok in West to Flores in the East. Mount Rinjani on Lombok is the highest mountain in the area. The islands in the Lesser Sunda Ecoregion are all volcanic and have all been created by the volcanic activity that is caused by the subduction of the Australian tectonic plate under the Eurasian. The volcanoes and the islands of the Lesser Sunda Ecoregion are divided between the Sunda and Banda Volcanic arcs. The area is dominated by dry tropical deciduous forests and woodland savannah. The ecoregion is rich in biodiversity with 50 mammal and 273 bird species of which five and 29 species are endemic respectively. The ecoregion also covers the range of the endemic Komodo dragon, though not occurring on Lombok.

The present land cover at Lombok is divided between two major domains, the forested and the agricultural. Between these two domains the agroforestry domain is situated, mainly on the lower slopes of Mount Rinjan. The forested domain has three main forest types: 1) Tropical rain and cloud forest at the higher slopes of Mount Rinjani, to a large extent protected by the Gunung Rinjani National park; 2) the dry deciduous forest mainly in the south western peninsula of Lombok and to some extent protected by the Batugengang Game reserve and 3) regenerating dense forest on the lower slopes of Mount Rinjani and dense forest patches in the agricultural domain. The agricultural domain is mainly established in areas that would have been covered with deciduous forests and woodland savannah in a natural state.

The climate is seasonal with dry and wet seasons, August is the centre of the dry season. The water catching capacity of the forest on the Mount Rinjani upper slopes is thus very important for the water provision over the whole island. The other islands with lower volcanoes are to a larger extent dominated by dry forests and more exposed to the seasonality. In general the southern slopes of the islands in the Lessers Sunda Ecoregion are more humid as they can capture the water content in the moist air of the trade winds.

The ecosystem services that have been evaluated on Lombok are water yield quality parameters, biodiversity potential and carbon storage and sequestration. Water quality is of importance as large areas of Lombok are agricultural land and most of the water purification takes place in the forest parts. EO services have been produced over Lombok and some of the small adjacent islands. The products are a detailed land cover and land use map, a forest map and a forest change map over the central part of Lombok.

The scenario for Lombok is intensification and polarisation of the landscape into one forested part, the primary and dense forest of 2012, and one open agricultural domain, the agricultural land and open forest of 2012 (Figure 3). The agroforestry areas with open forest will according to the scenario be transformed into open agricultural land. The consequences of a development like this were tested in the water and nutrient model as well as in the carbon stock and biodiversity models. This scenario is likely and similar development have been seen in many other parts of the world and is to some extent present on Lombok today, though not as evident as in the scenario. It would be possible to distinguish other scenarios like agroforestry over large areas, deforestation of the dense and primary forest, etc. The current land cover map was used to model the current or status quo scenario. The future scenario is based on a modification of the current land cover and land use map and not on actual modelling in a scenario building tool. The scenario should not be seen as the view on landscape development by either the authors or the companies involved; it is just an example of the strength of Invest to model scenario outcomes. These outcomes should be used for iteration and the results of the scenarios tested in this trial should be seen as input to a discussion on land use and landscape development on Lombok.

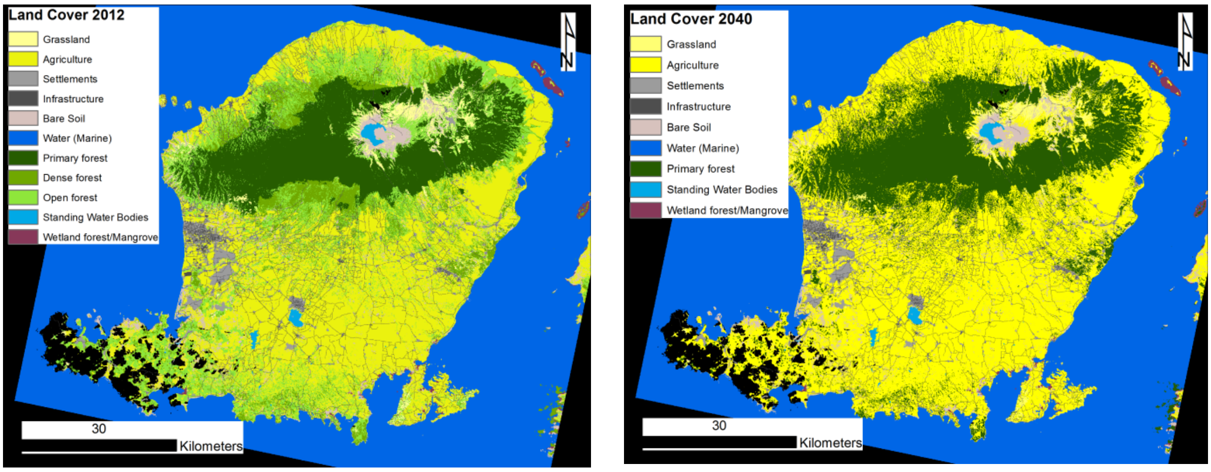


Figure 3: Current Land Cover on Lombok and the modelled scenario for 2040. The scenario is based on an assumption of polarisation of the landscape and agricultural intensification. The scenario should be seen as an example to demonstrate the functionality of Invest, and not as the view of the authors on landscape change on Lombok

4.1.1. Nutrient retention and water purification

Water yield is calculated per watershed and based on the specific characteristics for each land cover in combination with water flow models combing soil properties, land cover characteristics and topography. The water yield model does not consider ground water and surface water interaction.

The two most important nutrients for agricultural are nitrogen and phosphorous. The ecosystem services related to phosphorous are both regulating and providing services. In an eutrophication context the regulating services are for example nutrient uptake by biomass growth and de-nitrification. Nutrient retention, the capacity of the ecosystem to stop the leakage of nutrients to the surrounding land, is together with nutrient export of great importance for both terrestrial and aquatic ecosystem. The nutrient retention and water yield model that is part of the Invest suite and that has been used to produce the results presented here need a lot of parameters that are not part of the EO-services produced. There is a need for a number of different information layers and products on soil type and depth, different meteorological data and topographic information for the calculations on nutrient retention and water purification. The land cover and land use information is used to attribute parameters such as root depth and water purification potential.

The data sources used for the modelling is a mixture of local data, land cover data, national data, soil and precipitation data and global datasets on soil moisture, potential evapotranspiration and elevation. The data differ both in accuracy, minimum mapping unit and acquisition or survey time.

Input data for InVEST model: Water yield: nutrient retention

Table 1: Description of the data inputs as required by the Nutrient Retention InVEST tool (first and second columns) and data sources used in the Lombok trial (third column).

Model input	***General data description***	***Data source used in this trial***
Digital elevation model (DEM) (required)	A GIS raster dataset, with an elevation value for each cell. Make sure the DEM is corrected by filling in sinks, and if necessary ‘burning’ hydrographic features into the elevation model (recommended when you see unusual streams). To ensure proper flow routing, the DEM should extend beyond the watersheds of interest, rather than being clipped to the watershed edge.	Worldtopo 30 from Intermap.

Soil depth (required)	A GIS raster dataset with an average soil depth value for each cell. The soil depth values should be in millimeters (plant restriction layer in model).	Local data provided by user Solum_utm50.shp -provided by WWF Indonesia
Precipitation (required)	A GIS raster dataset with a non-zero value for average annual precipitation for each cell. The precipitation values should be in millimeters.	curah_hujan_tahunan.shp -provided by WWF Indonesia
Plant Available Water Content (required).	A GIS raster dataset with a plant available water content value for each cell. Plant Available Water Content fraction (PAWC) is the fraction of water that can be stored in the soil profile that is available for plants' use. Defined as the difference between the fraction of volumetric field capacity and permanent wilting point. Often plant available water content is available as a volumetric value (mm). To obtain the fraction divide by soil depth.	NOAA soil moisture data divided by soil depth data to obtain PAWC fraction.
Average Annual Potential Evapotranspiration (required)	A GIS raster dataset, with an annual average evapotranspiration value for each cell. Potential evapotranspiration is the potential loss of water from soil by both evaporation from the soil and transpiration by healthy Alfalfa (or grass) if sufficient water is available. The evapotranspiration values should be in millimeters.	MOD16A3_ET_2012.tif (converted to mm)
Land use/land cover (LULC) map (required)	A GIS raster dataset, with a LULC code for each cell. The dataset should be projected in meters and the projection used should be defined. All landuse / land class categories should be defined. Gaps in data that break up the drainage continuity of the watershed will create errors. Unknown data gaps should be approximated.	There is a land cover map 2012 for the study area at 10 m resolution with 13 classes.
Watersheds (required).	A shapefile of polygons. This is a layer of watersheds such that each watershed contributes to a point of interest where water quality will be analysed.	The watersheds and sub watersheds were constructed from DEM using the basin and watershed functions in ArcGIS
Sub-watersheds (optional).	A shapefile of polygons. This is a layer of sub-watersheds, contained within the Watersheds (described above) which contribute to the points of interest where water quality will be analysed. See the Working with the DEM section for information on creating sub-watersheds.	N/A
Biophysical Table (required)	A table of land use/land cover (LULC) classes, containing data on water quality coefficients used in this tool. Name: File can be named anything. File type: *.dbf or *.cvs Rows: Each row is an LULC class. Columns: Each column contains a different attribute of each land use/land cover class, and must be named as follows: lucode (Land use code): Unique integer for each LULC class (e.g., 1 for forest, 3 for grassland, etc.), must match the LULC raster above. LULC_desc: Descriptive name of land use/land cover class (optional) root_depth: The maximum root depth for vegetated land use classes, given in integer millimeters. Non-vegetated LULCs should be given a value of 1. etk: The evapotranspiration coefficient for each LULC class,	<u>Kc:</u> Grasslands (650), Agriculture (600), Settlements (100), Infrastrukture (100), Bare soil (200), Water (1000), Primary forest (1000), Dense forest (1000), Open forest (850), Settlements smaller (300), Standing Water Bodies (1000) and Wetland forest/Mangrove (1000) <u>Root depth:</u> Grasslands (2000), Agriculture (2600), Settlements (10), Infrastrukture (10), Bare soil

	used to obtain actual evapotranspiration by using plant energy/transpiration characteristics to modify the reference evapotranspiration, which is based on alfalfa (or grass). Coefficients should be multiplied by 1000, so that the final etk values given in the table are integers ranging between 1 and 1500 (some crops evapotranspire more than alfalfa in some very wet tropical regions and where water is always available). = Kc in table/model load_n / load_p: The nutrient loading for each land use. If nitrogen is being evaluated, supply values in load_n, for phosphorus, supply values in load_p. The potential for terrestrial loading of water quality impairing constituents is based on nutrient export coefficients. The nutrient loading values are given as integer values and have units of g. Ha-1 yr -1. eff_n / eff_p: The vegetation filtering value per pixel size for each LULC class, as an integer percent between zero and 100. If nitrogen is being evaluated, supply values in eff_n, for phosphorus, supply values in eff_p. This field identifies the capacity of vegetation to retain nutrient, as a percentage of the amount of nutrient flowing into a cell from upslope. In the simplest case, when data for each LULC type are not available, high values (60 to 80) may be assigned to all natural vegetation types (such as forests, natural pastures, wetlands, or prairie), indicating that 60-80% of nutrient is retained. An intermediary value also may be assigned to features such as contour buffers. All LULC classes that have no filtering capacity, such as pavement, can be assigned a value of zero.	(10), Water (500), Primary forest (7000), Dense forest (7000), Open forest (4750), Settlements smaller (500), Standing Water Bodies (500) and Wetland forest/Mangrove (7000) <u>Load N:</u> Grasslands (4), Agriculture (10.00), Settlements (7.500), Infrastrukture (0.01), Bare soil (4), Water (0.001), Primary forest (1.800), Dense forest (1.800), Open forest (1.800), Settlements smaller (7.500), Standing Water Bodies (0.001) and Wetland forest/Mangrove (2) <u>Efficiency N;</u> Grasslands (0.4), Agriculture (0.25), Settlements (0.05), Infrastrukture (0.05), Bare soil (0.05), Water (0.05), Primary forest (0.8), Dense forest (0.8), Open forest (0.75), Settlements smaller (0.1), Standing Water Bodies (0.05) and Wetland forest/Mangrove (0.8) <u>Load P</u> Grasslands (0.05), Agriculture (4.300), Settlements (1.200), Infrastrukture (1.200), Bare soil (0.100), Water (0.001), Primary forest (0.011), Dense forest (0.011), Open forest (0.011), Settlements smaller (1.200), Standing Water Bodies (0.001) and Wetland forest/Mangrove (0.05) <u>Efficiency P</u> Grasslands (0.4), Agriculture (0.25), Settlements (0.05), Infrastrukture (0.05), Bare soil (0.05), Water (0.05), Primary forest (0.9), Dense forest (0.8), Open forest (0.75), Settlements smaller (0.05), Standing Water Bodies (0.05) and Wetland forest/Mangrove (0.8)
Threshold	Integer value defining the number of upstream cells that	Use default in model

flow accumulation value (required)	must flow into a cell before it's considered part of a stream. This is used to generate a stream layer from the DEM. The default is 1000	
Water Purification Valuation table.	This is a table containing valuation information for each of the points of interest. There must be one row for each watershed in the Watersheds layer.	N/A in this trial.
Water Purification threshold table	A table containing annual nutrient load threshold information for each of the points of interest. There must be one row for each watershed in the Watersheds layer. Name: File can be named anything. File type: *.dbf or *.mdb for ArcGIS models, the standalone model requires a .csv file Rows: Each row corresponds to a watershed. Columns: Each column contains a different attribute of each watershed and must be named as follows: ws_id (watershed ID): Unique integer value for each watershed, which must correspond to values in the Watersheds layer. thresh_n / thresh_p: The total critical annual nutrient loading allowed for the nutrient of interest at the point of interest. Floating point value. It has units of Kg.yr-1	N/A in this trial.

Table 2: Contribution of EO products, in-situ data and global information as inputs for this InVEST model. Green dot = direct contribution specifically designed for this project. Yellow dot = indirect contribution usually coming from global/regional data sets.

Nutrient retention	**EO**	**in-situ**	**other**
Digital elevation model (DEM) (required).	🟡		🟢
Soil depth (required).		🟢	
Precipitation (required).		🟢	
Plant Available Water Content (required).	🟡		
Average Annual Potential Evapotranspiration (required).	🟡		
Land use/land cover (required).	🟢		
Watersheds (required).			🟢
Sub-watersheds (optional)	N/A	N/A	N/A
Biophysical Table (required).			🟡

Water yield

In the current status scenario two watersheds provide larger quantities of water compared to the others. This is due to a number of causes like the topography of the island, the precipitation, evapotranspiration and precipitation, soil- and root-depth and other biophysical aspects of land cover.

The future scenario provides higher water yields in general. The pattern remains with more water provided in the south western parts of Lombok. The only thing that has changed between the scenarios is the land cover, the patterns of precipitation and potential evapotranspiration has not changed with the land cover. Both rainfall and precipitation are dependent on the land cover, especially in tropical regions like Lombok, where part of the evapotranspiration from the forest might return as precipitation. This dynamic is though not considered in the models. There has not been any adjustment done to future climate scenarios. It would have been interesting to analyse the effect of different climatic scenarios, but this was not within the scope of this trial.

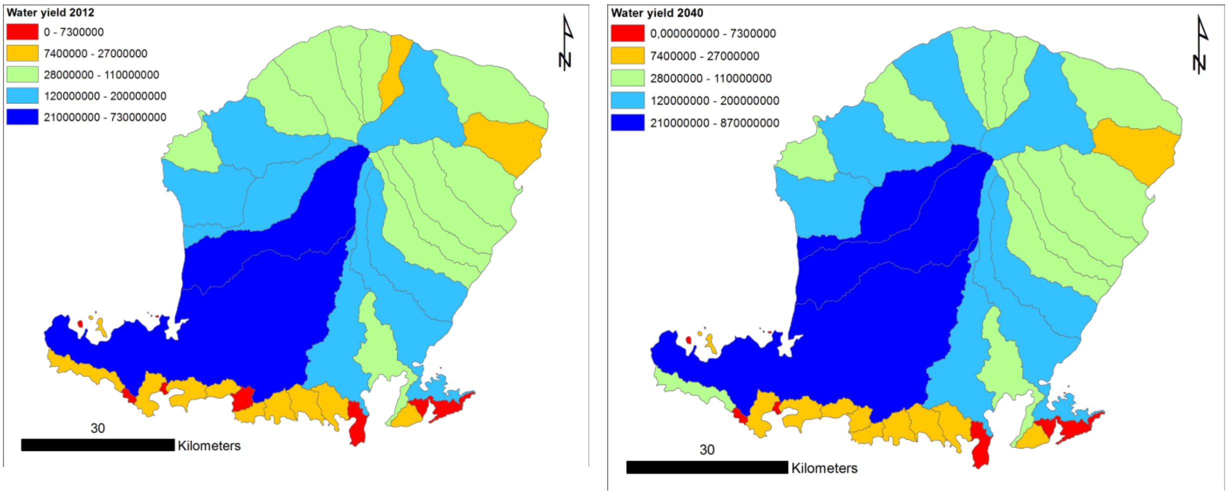
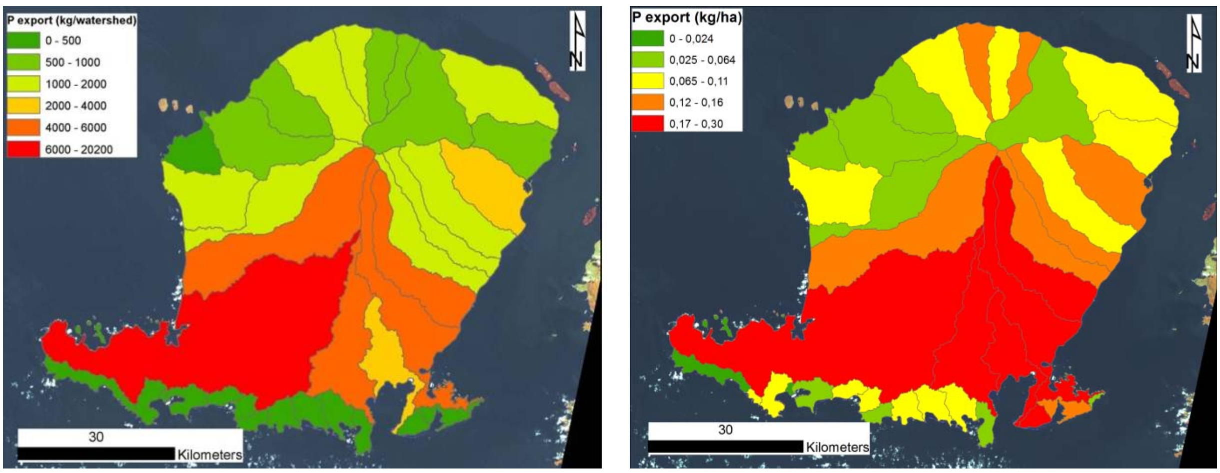


Figure 4: Water yield on Lombok according to the applied scenarios: present – 2012 (left) and future – 2040 (right). The water yield is higher in 2040 compared to 2012. Dark blue means high and red low water yield (m^3) per watershed and year.

Nutrient retention and export

The nutrient flows are calculated based on national and global datasets on soil and climatic characteristics as well as the EO-services produced on 2010-2012 imagery. The same watershed can have both retention and export as the different land covers contribute to both processes in different ways. The results are aggregated at watershed level, both as total amount and as kg per hectare. The analyses highlight the watersheds in the southern parts of Lombok as those with the largest nutrient export. The model assumes that all land cover classes are managed in the same way and no adjustments have been made based on different management practices for the scenarios investigated. There were no data available for verification of the model outputs.



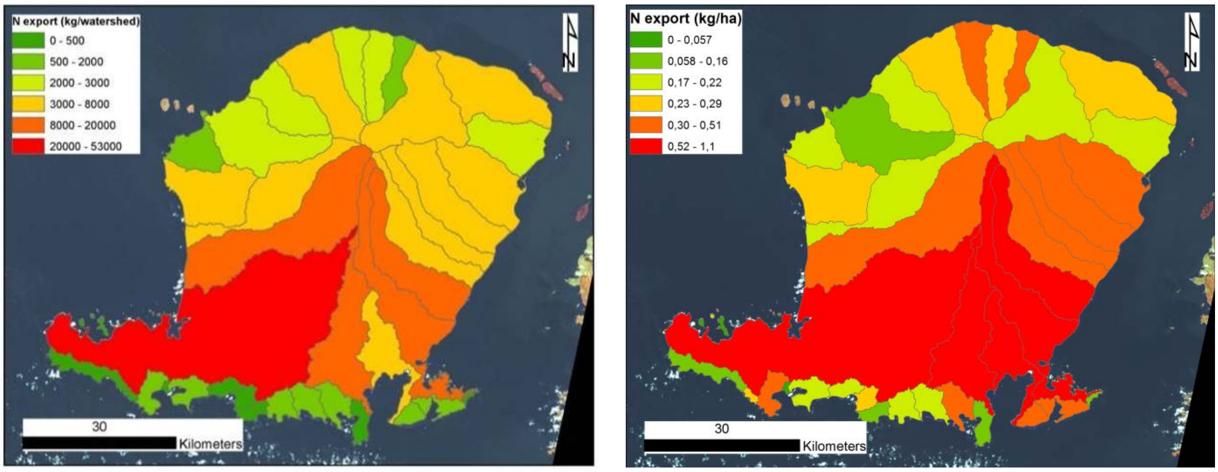
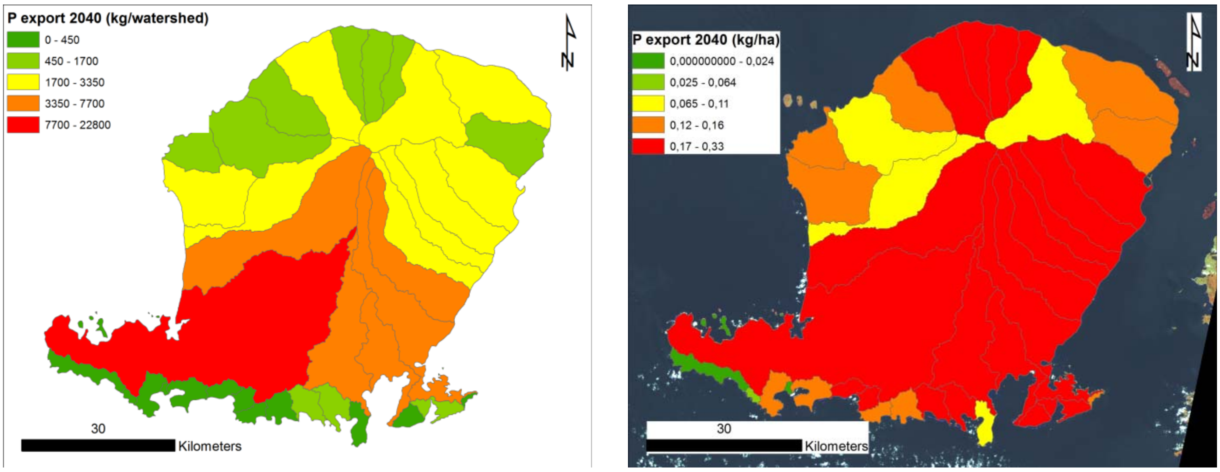


Figure 5: Nutrient export according to the 2012 scenario. The export is calculated per watershed and per hectare in the watershed. Red means that the export is high and green that the export is low.

The nutrient export follows the same pattern as the water yields; the watersheds with the highest water yields export the largest amounts of both phosphorous and nitrogen. The watersheds with the highest export of nutrients per hectare are also the watersheds dominated by agriculture. The effect of intense agricultural areas is highlighted with the 2040 scenario with less agroforestry areas and intensified agriculture. As a result the nutrient export rises significantly in areas with previous moderate net export of nutrient. Most of Lombok has high nutrient exports in the 2040 scenario. This is caused by the higher nutrient load in combination with lower nutrient efficiency on agricultural land.



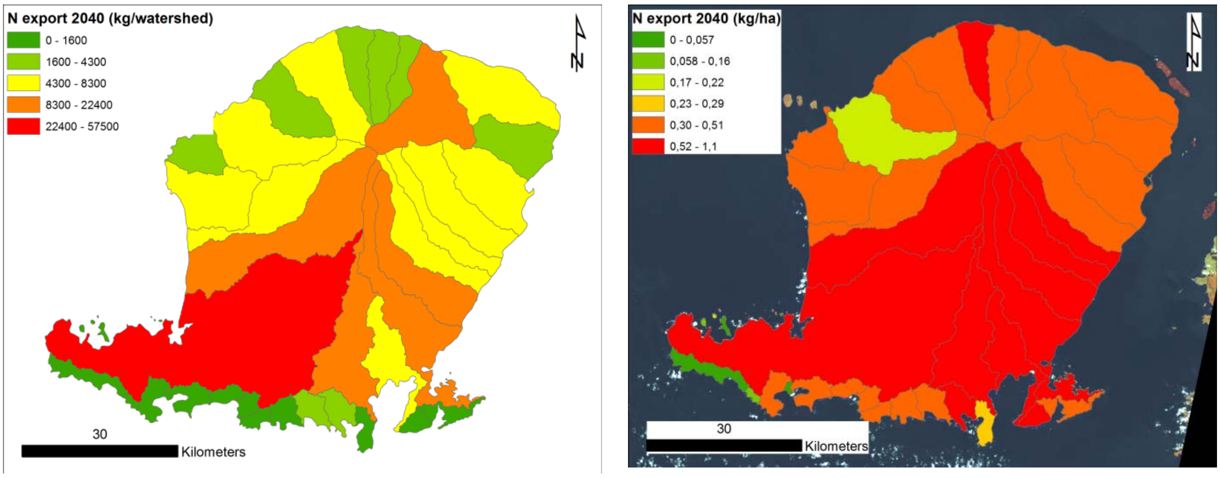


Figure 6: Nutrient export in the 2040 scenario. The export is calculated per watershed and per hectare in the watershed.

The nutrient retention follows the same pattern as the nutrient export. Areas with high load of nutrients from agricultural land have a higher nutrient retention. The worst scenario is to have high loads and low retention, which will result in high export of nutrients and high pressure on the recipients. The recipients in Lombok are the rivers, dams and the marine environment. High levels of phosphorous in combination with nitrogen in the marine environment can lead to algal blooms and growth of filamentous algae which in turn can affect the coral leaves, sea grass and algae beds.

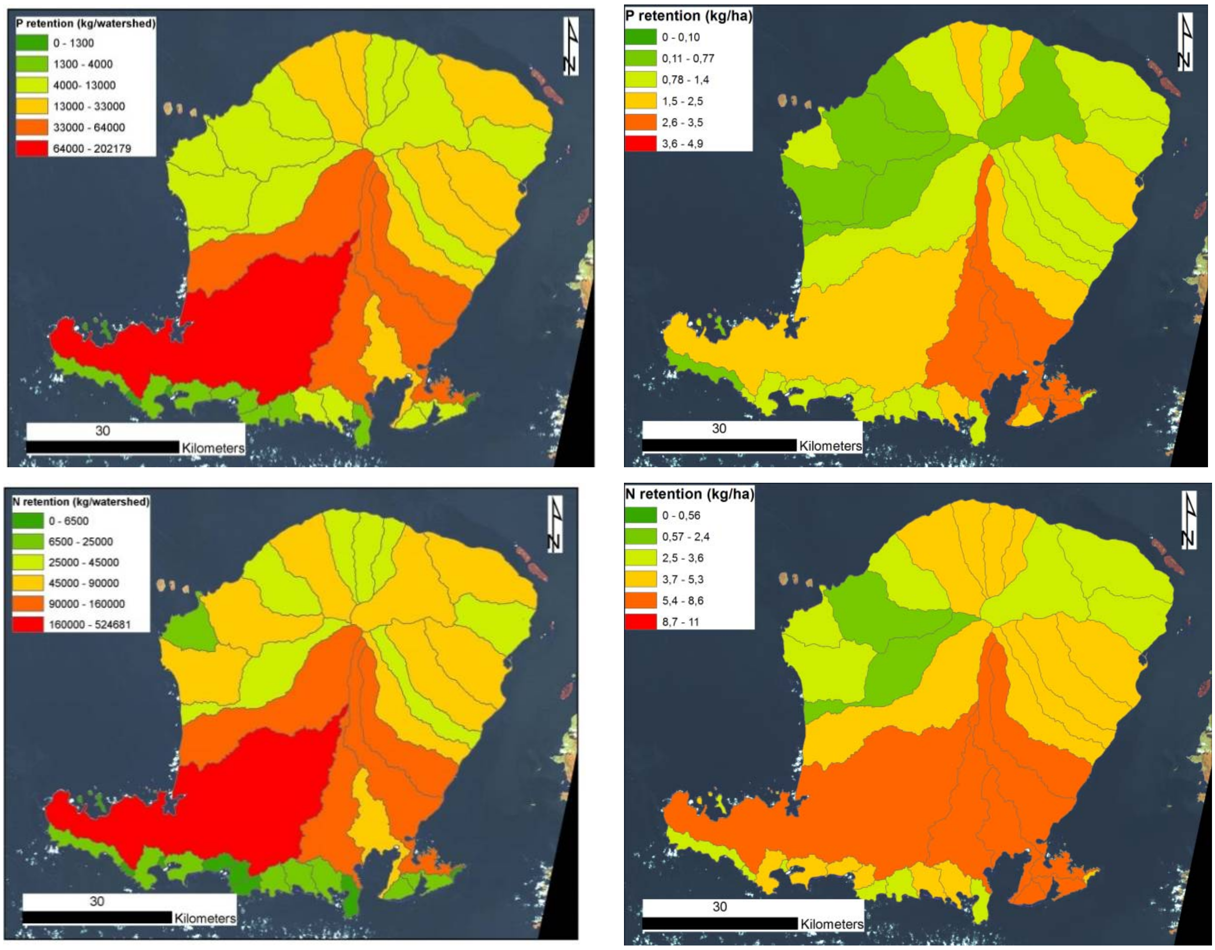


Figure 7: Nutrient retention according to the 2012 scenario. The export is calculated per watershed and per hectare in the watershed.

The nutrient retention follows the nutrient export pattern for the 2040 scenario. The higher loads of fertilisers in the agricultural land compared to the loads in the open woodland affects the retention as well as the export of nutrients. The watersheds with a high proportion of agricultural land in the southern part of Lombok have a high retention due to the loads on agricultural land. The watersheds with a high proportion of forest and woodland retain lower nutrient load, resulting in relatively lower nutrient retention despite a rise between the scenarios.

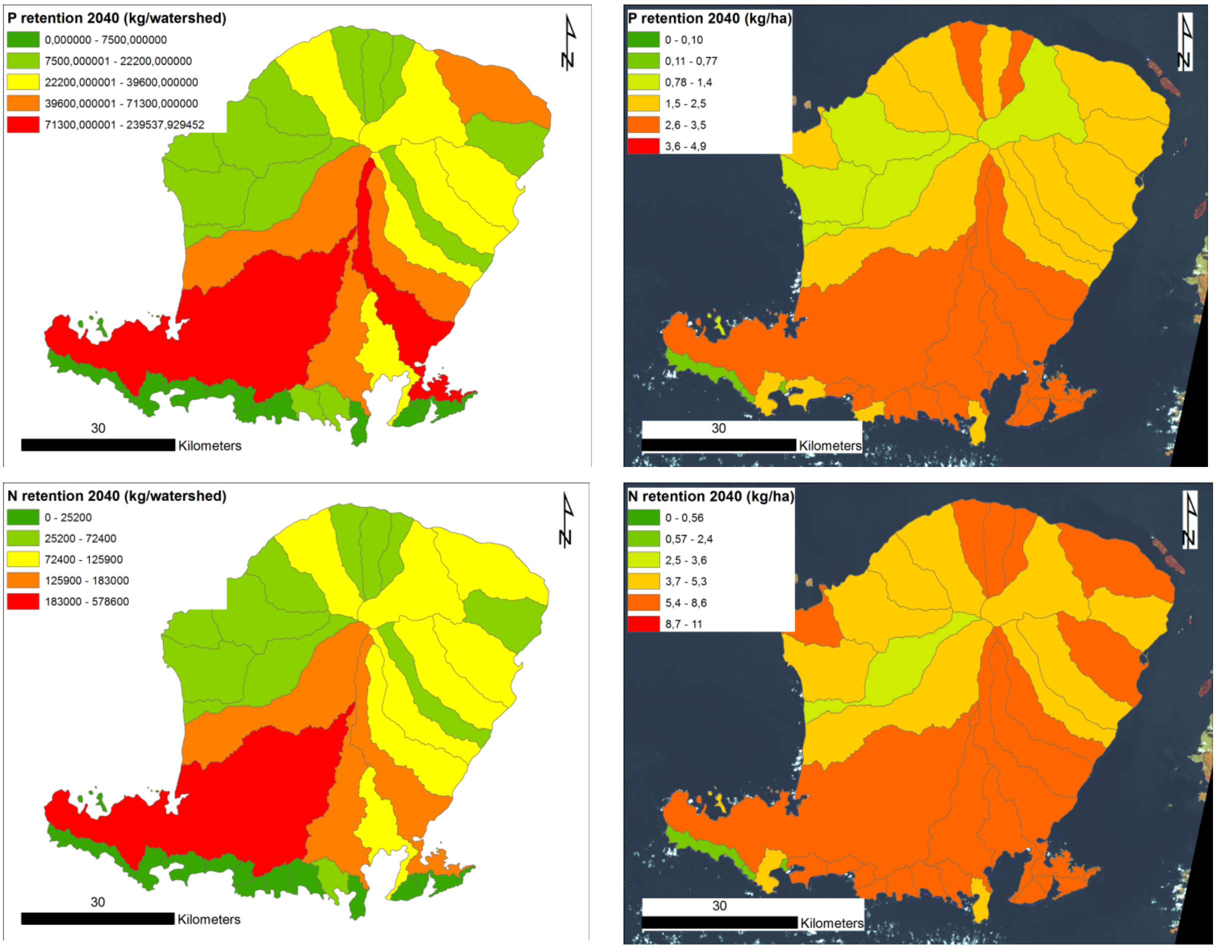


Figure 8: Nutrient retention in the 2040 scenario. The export is calculated per watershed and per hectare in the watershed.

Conclusions

Higher nutrient loads results in both higher retention and export. This shows the potential to elaborate not only the land cover but also to test the effects of different management practices. This can be done by adjustments in the biophysical table. The effects of e.g. agroforestry practices with nitrogen fixating acacias or other leguminous trees could be tested. Both nitrogen load and efficiency values will be affected by changes in management practices. Other scenarios could include effects of estuarine and inland march management for nutrient retention.

Lessons learnt

- Specific information on crop type and local agricultural practices are important to set the right parameters in the biophysical tables.
- Climatic trends and changes in e.g. potential evapotranspiration should be modelled for the future scenarios.

4.1.2. Climate regulation – carbon sequestration

Trees accumulate large amounts of carbon in their biomass. The carbon is divided between leafs, branches stems and roots. When a tree dies or when leafs and branches fall to the ground the decomposers of the ecosystem release the carbon in the biomass to the atmosphere as carbon dioxide. Mature forests are to a large degree in equilibrium with regard to greenhouse gases, there are though circumstances when the carbon content is accumulating or carbon is released. When the decomposition of dead material is slower than the growth, e.g. in wet or dry forests, carbon is accumulated or sequestered. If the climatic conditions change and the equilibrium is altered and large amounts of greenhouse gases might be released, or sequestered. When a forest is cut down, large amounts of carbon dioxide is released to the atmosphere

The University of Mataram has conducted research on the carbon content of different land cover and land use classes on Lombok. Figures from this study were used for the parameterisation of the biophysical tables needed for the carbon model. The carbon pools are divided according to the IPCC and are parameterised for the carbon content of the above- and below ground biomass, litter and soil. The soil types of Lombok differ regarding carbon content, with high carbon content in the andosoil of the upper and lower slopes of the caldera.

Input data for the InVEST model: Carbon Storage and Sequestration

Table 3: Description of the data inputs as required by the Carbon Storage and Sequestration InVEST tool (first and second columns) and data sources used in the Lombok trial (third column).

Model input	***General data description***	***Data source used in this trial***
Current land use/land cover (LULC) map (required)	A GIS raster dataset, with a LULC code for each cell. The dataset should be projected in meters and the projection used should be defined. The model requires the following two pieces of information about the LULC map which are prompted for in the interface. • The *year* depicted by the LULC map, for use in calculating sequestration and economic values (labeled “Year of current land cover” in the interface). • The *spatial resolution* (desired cell size in meters) at which you would like the model to run (labeled “Resolution (optional)”). You can only define a new resolution that is coarser than the resolution of the LULC map (this is the default resolution).	There is a land cover map 2012 for the study area at 10 m resolution with 13 classes. So for this model we used a LULC where the classes are divided by primary soil type. Forest classes primary use carbon content values from local sampling data all other classes use default data from IPCC. In general, all the other land cover is set to zero carbon content.
Carbon pools (required)	A table of LULC classes, containing data on carbon stored in each of the four fundamental pools for each LULC class. Carbon storage data can be collected from field estimates from local plot studies, extracted from meta-analyses on specific habitat types or regions, or found in general published tables (e.g., IPCC). If information on some carbon pools is not available, pools can be estimated from other pools, or omitted by leaving all values for the pool equal to 0. The following columns are required:	The carbon pools are based on a combination of default data from IPCC and on local studies by the University of Mataramn. **C_above:** • Primary and dense forest: carbon content information from local study sites. • Open forest default data from

	• lucode: code of land use/land cover class (e.g., 1 for forest, 3 for grassland, etc.). The LULC code should match the LULC codes from the current LULC map (dataset #1 above) • LULC_name: descriptive name of LULC class (optional) • C_above: amount of carbon stored in aboveground biomass (in Mg ha-1) • C_below: amount of carbon stored in belowground biomass (in Mg ha-1) • C_soil: amount of carbon stored in soil (in Mg ha-1) • C_dead: amount of carbon stored in dead organic matter (in Mg ha-1)	IPCC. • Mangrove: default values from IPCC. • Other LC classes: default values from IPCC. Settlement and infrastructure are assumed to have insignificant carbon content. <u>Carbon content was attributed in tonnes per hectare:</u> Grasslands (4.7), Agriculture (4.7), Settlements (0), Infrastrukture (0), Bare soil (0), Water (0), Primary forest (178.6), Dense forest (84.6), Open forest (47), Settlements (0), Infrastrukture (0), Bare soil (andsoil) (0), Standing Water Bodies (0) and Wetland forest/Mangrove (47) **C_below:** For land dominated by woody biomass, belowground biomass can be estimated roughly with the “root to shoot” ratio (belowground to aboveground biomass). Default estimates are given in Table 4.4 of IPCC 2006. <u>Carbon content was attributed in tonnes per hectare:</u> Grasslands (6.2), Agriculture (6.2), Settlements (0), Infrastrukture (0), Bare soil (0), Water (0), Primary forest (66.1), Dense forest (31.3), Open forest (17.4), Settlements (0), Infrastrukture (0), Bare soil (andoil) (0), Standing Water Bodies (0) and Wetland forest/Mangrove (17.4) **C_soil:** Local soil maps and information are provided for Lombok. Main soil types are various Andosols and High activity clays (HAC) such as Inceptisols. From table 2.3 of IPCC (2006) we take C_soil in 0-30 cm depth for HAC soils in tropical wet for all vegetated classes = 44 t C/ha and for Andosols = 130 t C/ha. Wetlands have a default carbon content of 86 t C/ha in tropical

		wet areas. Settlements and infrastructure LC classes are assumed to have 0 Mg/ha. Carbon content was attributed in tonnes per hectare: Grasslands, (44), Agriculture, (44), Settlements, (0), Infrastrukture, (0), Bare soil, (44), Water, (0), Primary forest, (44), Dense forest, (44), Open forest, (44), Grasslands (andosoil), (130), Agriculture (andosoil), (130), Settlements, (0), Settlements smaller, (44), Infrastrukture, (0), Bare soil (andoil), (130), Standing Water Bodies, (0), Wetland forest/Mangrove, (86), Primary forest (andosoil), (130), Dense forest (andosoil), (130) and Open forest (andosoil), (130). **C_dead:** We use default estimates for carbon content in litter from IPCC table 2. Carbon content was attributed in tonnes per hectare: NoData, (0) Grasslands, (0) Agriculture, (0) Settlements, (0) Infrastrukture, (0) Bare soil, (0) Water, (0) Primary forest, (2.1) Dense forest, (2.1) Open forest, (2.1) (0) Settlements, (0) Infrastructure, (0) Bare soil (andoil), (0) Standing Water Bodies, (0) Wetland forest/Mangrove,)
Current harvest rates map (optional)	A GIS shape file of polygons (parcels), contains data on: • Parcel ID • Amount of carbon, in the form of woody biomass, typically removed from the parcel over the course of a harvest period • Date that the modeller wants to begin accounting for wood harvests in the parcel • Frequency of harvest periods in the parcel in the past • Average decay rate of products made from the wood harvested from a parcel • Average carbon density of the wood removed from the parcel in the past • Average tree volume per ton of wood removed from the parcel in the past.	Not applicable in this trial

Future Scenarios (optional – required for valuation)	If you have a LULC map (data input #1) for a future landscape scenario, then expected sequestration rates in the four major carbon pools on the landscape can be measured. Similarly, sequestration rates in the HWP carbon pool can be measured with a harvest rate map (data input #3) for this future landscape. If REDD scenario analysis is enabled, then this should represent the landscape for the future baseline scenario, against which the REDD scenario will be compared. A future land cover map (a raster dataset) should be formatted according to the same specifications as the current land cover map (input #1).	We use a modified LULC where the dense forest is converted to primary forest and the open forest class is converted to agricultural land. This is done to make a plausible scenario when lack of data/information on land use practices is lacking.
REDD scenario LULC map (optional)	REDD scenario analysis requires a LULC map for a landscape scenario under a REDD policy. This should be formatted according to the same specifications as the current and the baseline future land cover map. The REDD scenario LULC map must be for the same year as the baseline future scenario LULC map.	Not applicable in this trial
Economic data (optional – required for valuation)	Three numbers are not supplied in a table, but instead are input directly through the tool interface: • The **value of a sequestered ton of carbon** (labelled “Price of carbon per metric ton (optional)” in the tool interface), in dollars per metric ton of elemental carbon (not CO2, which is heavier, so if the social value of CO2e is $Y per metric ton, then the social value of C is $3.67*Y per metric ton). • The **market discount rate**, which reflects society’s preference for immediate benefits over future benefits (labelled “Market discount rate (%) (optional)” in the tool interface). • The **annual rate of change in the price of carbon** (labelled “The annual rate of change in the price of carbon (%) (optional)” in the tool interface), which adjusts the value of sequestered carbon as the impact of emissions on expected climate change-related damages changes over time	Not applicable in this trial

Table 4: Contribution of EO products, in-situ data and global information as inputs for this InVEST model. Green dot = direct contribution specifically designed for this project. Yellow dot = indirect contribution usually coming from global/regional data sets.

Carbon sequestration	**EO**	**in-situ**	**other**
Land use/land cover (LULC) (required).	🟢		
Carbon pools (required)		🟡	🟡
Current harvest rates map (optional).	N/A	N/A	N/A
Future Scenarios (optional – required for valuation)	🟢		
Economic data (optional – required for valuation).	N/A	N/A	N/A

Scenarios

The carbon stock on Lombok was 62.4 million tonnes in 2012 and the major carbon pool is the primary forest of Mount Rinjani. In the scenario for 2040 the carbon stock rises to 65.8 million tonnes giving a sequestration of 3.4 million tonnes of carbon or a rise in carbon stock with 5.5 % for Lombok.

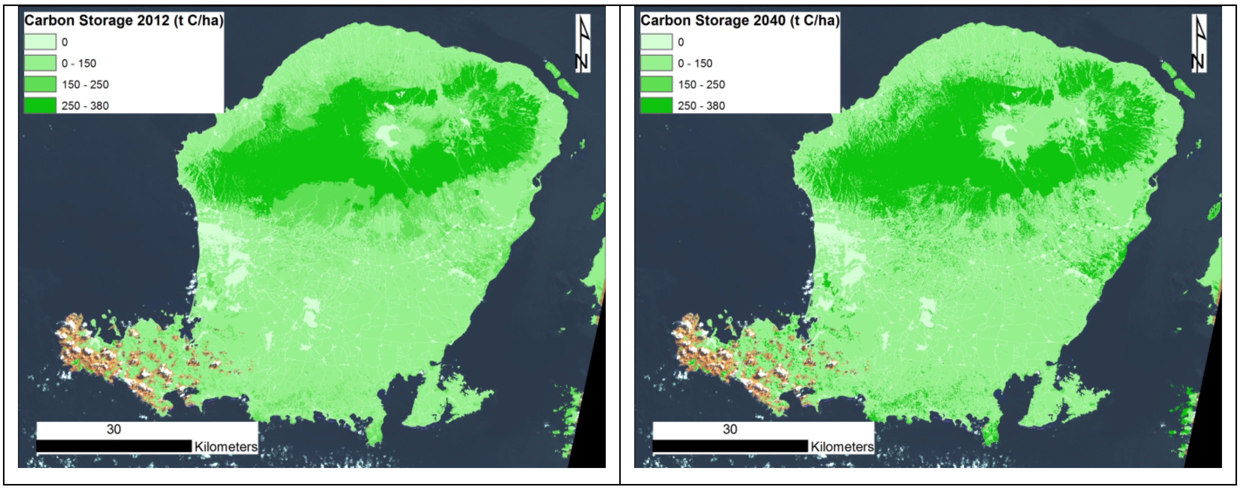


Figure 9: Carbon stocks on Lombok according to the applied scenarios, 2012 left and 2040 right. Dark green areas have the highest carbon stocks, lighter green lower stocks.

The important message of this is that the primary forest of Mount Rinjani is important as carbon stock and that intensification of the agricultural practices should be complemented with increase in dense forest and a target to let the dense forest mature to primary forest. To let more trees be part of the agricultural landscape would also be a way to increase the carbon stock in the ecosystem.

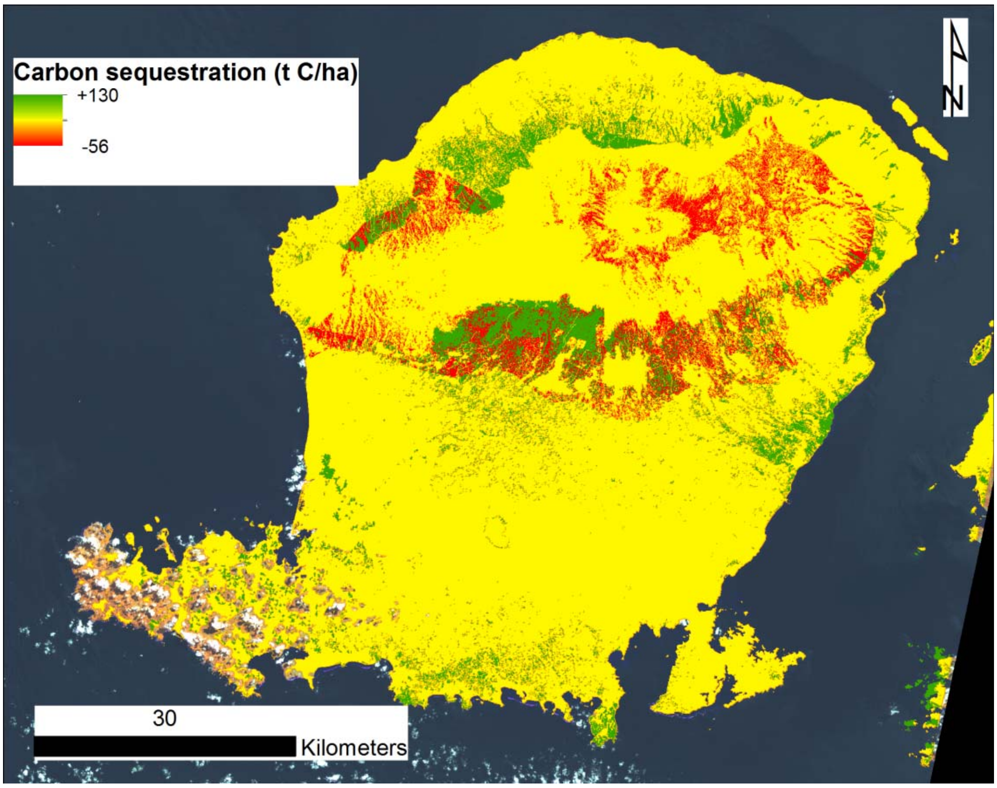


Figure 10: Carbon sequestration on Lombok following according to the scenario. Yellow areas are more or less indifferent while read areas have a decrease in carbon content and the green areas an increase. For the 2012-2040 scenario applied, there was a small increase.

Conclusion

Carbon storage and sequestration is a very important ecosystem service in tropical forests. The strength of the invest tool is to display the result of land use policy. The carbon stocks and flows on Lombok are to a large extent connected with the land use, forest management and agricultural practices. The stocks are large and important to protect, but the opportunity for sequestration is big as well as large parts of the Island are agricultural land with few trees.

4.1.3. Biodiversity

The biodiversity model in the Invest toolset focus on two aspects of importance for biodiversity, the habitat quality and rarity at landscape level. This is done using land cover and land use information as proxy for habitat quality. Some of the quality aspects like amount of dead woody debris and effects of selective logging in forests or species composition and nutrient status in grasslands are not part of land use and land cover information. To adapt to this different threats to habitat quality are modelled based on the distance from the sources of threats, i.e. human exploitation. The main threats considered in the biodiversity modelling are the distance to villages and roads. Population density and accessibility are important factors for degradation of natural habitats.

Table 5: Description of the data inputs as required by the Biodiversity InVEST tool (first and second columns) and data sources used in the Lombok trial (third column).

Model input	***General data description***	***Data source used in this trial***
Current land use/land cover (LULC) map (required)	A GIS raster dataset, with a numeric LULC code for each cell. The dataset should be in a projection where the units are in meters and the projection used should be defined.	There is a land cover map 2012 for the study area at 10 m resolution with 13 classes.
Future LULC map (optional)	A GIS raster dataset that represents a future projection of LULC in the landscape. This file should be formatted exactly like the “current LULC map” (input #1). LULC that appears on the current and future maps should have the same LULC code.	There is a land cover map 2040 for the study area at 10 m resolution with 13 classes. The future scenario is based on knowledge of local land use practices and discussions with the user.
Baseline LULC map (optional)	A GIS raster dataset of LULC types on some baseline landscape with a numeric LULC code for each cell. This file should be formatted exactly like the “current LULC map” (input #1). The LULCs that are common to the current or future and baseline landscapes should have the same LULC code across all maps. LULC types unique to the baseline map should have codes not used in the current or future LULC map. If possible the baseline map should refer to a time when intensive mamagement of the land was relatively rare.	N/A

Threat data (required)	A table of all threats you want the model to consider. The table contains information on the each threat's relative importance or weight and its impact across space. Name: file can be named anything File Type: *.dbf or *.xls if using ArcGIS 9.3 Rows: each row is a degradation source Each column contains a different attribute of each degradation source, and must be named as follows: • THREAT: the name of the specific threat. Threat names must not exceed 8 characters. • MAX_DIST: the maximum distance over which each threat affects habitat quality (measured in km). The impact of each degradation source will decline to zero at this maximum distance. WEIGHT: the impact of each threat on habitat quality, relative to other threats. Weights can range from 1 at the highest, to 0 at the lowest.	The threats are derived from the EO services are settlements (max dist. 10, weight 1), rural settlements (max dist. 10, weight 0.9), roads (max dist. 5, weight 0.8) and agricultural land (max dist. 6, weight 0.5)
Accessibility to sources of degradation (optional)	A GIS polygon shapefile containing data on the relative protection that legal / institutional / social / physical barriers provide against threats. Polygons with minimum accessibility (e.g., strict nature reserves, well protected private lands) are assigned some number less than 1, while polygons with maximum accessibility (e.g., extractive reserves) are assigned a value 1.	Polygon file covering the protected areas on Lombok.
Habitat types and sensitivity of habitat types to each threat (required)	A table of LULC types, whether or not they are considered habitat, and, for LULC types that are habitat, their specific sensitivity to each threat. Columns contain data on land use types and their sensitivities to threats. Columns must be named according to the naming conventions below. • LULC: numeric code for each LULC type. Values must match the codes used in the LULC maps submitted in inputs # 1 through 3. All LULC types that appear in the current, future, or baseline maps (inputs # 1 through 3) need to appear as a row in this table. • NAME: the name of each LULC • HABITAT: Each LULC is assigned a habitat score, Hj, from 0 to 1. If you want to simply classify each LULC as habitat or not without reference to any particular species group then use 0s and 1s where a 1 indicates habitat. Otherwise, if sufficient information is available on a species group's habitat preferences, assign LULC a relative habitat suitability score from 0 to 1 where 1 indicates the highest habitat suitability. For example a grassland songbird may prefer a native prairie habitat above all other habitat types (prairie is	Identified habitats from the EO-services produced, their habitat values and sensitivity to the identified threats (settlements, roads, agricultural land and rural settlements). Grasslands (0.20, 1.0, 1.0, 0.50, 1.0), Agriculture (0, 1.0, 1.0, 0, 1.0), Water (1, 1.0, 1.0, 1.0, 1.0), Primary forest (1, 1.0, 1.0, 1.0, 1.0), Dense forest (0.50, 1.0, 1.0, 1.0, 1.0), Open forest (0.30, 1.0, 1.0, 1.0, 1.0), Grasslands (0.20, 1.0, 1.0, 0.50, 1.0), Bare soil (0, 0.50, 0.50, 0.50, 0.50), Standing Water Bodies (1, 1.0, 1.0, 1.0, 1.0), Wetland forest/Mangrove (1, 1.0, 1.0, 1.0, 1.0), Primary forest (1, 1.0, 1.0, 1.0, 1.0), Dense forest (0.50, 1.0, 1.0, 1.0, 1.0), Open forest (0.30, 1.0, 1.0, 1.0, 1.0)

	given a "Habitat" score of 1 for grassland birds), but will also use a managed hayfield or pasture in a pinch (managed hayfield and pasture is given a "Habitat" score of 0.5 for grassland birds). L_THREAT1, L_THREAT2, etc.: The relative sensitivity of each habitat type to each threat. You will have as many columns named like this as you have threat, and the italicized portions of names must match row names in the "Threat data" table noted above (input # 4). Values range from 0 to 1, where 1 represents high sensitivity to a threat and 0 represents no sensitivity. Note: Even if the LULC is not considered habitat, do not leave its sensitivity to each threat as Null or blank, instead enter a 0 and the model will convert it to NoData.	
Half-saturation constant (required)	This is the value of the parameter k in equation	By default it is set to 0.5 but can be set equal to any positive number.

Table 6: Contribution of EO products, in-situ data and global information as inputs for this InVEST model. Green dot = direct contribution specifically designed for this project. Yellow dot = indirect contribution usually coming from global/regional data sets.

Biodiversity	**EO**	**in-situ**	**other**
Current land use/land cover (LULC) map (required)	🟢		
Future LULC map (optional)	🟢		
Baseline LULC map (optional)	N/A	N/A	N/A
Threat data (required)	🟡		
Accessibility to sources of degradation (optional)		🟢	
Habitat types and sensitivity of habitat types to each threat (required)	🟡		🟡
Half-saturation constant (required)			🟡

Two biodiversity models were run, one for the current status and one for the 2040 scenario. The difference is of course great as there are large areas with dense forest gaining scores of habitat quality as they are left to achieve primary structures. The results could also be seen as the difference between habitat quality for species requiring primary attributes and species for which dense forest attributes are sufficient. As Lombok is densely populated the areas with potential degradation are large and wide spread, the threats are increasing on Lombok with regard to the scenarios as the low threat agroforestry and open woodland areas are converted into agricultural land. Considering the habitat quality and degradation maps, the importance of the primary forest of Mount Rinjani is evident.

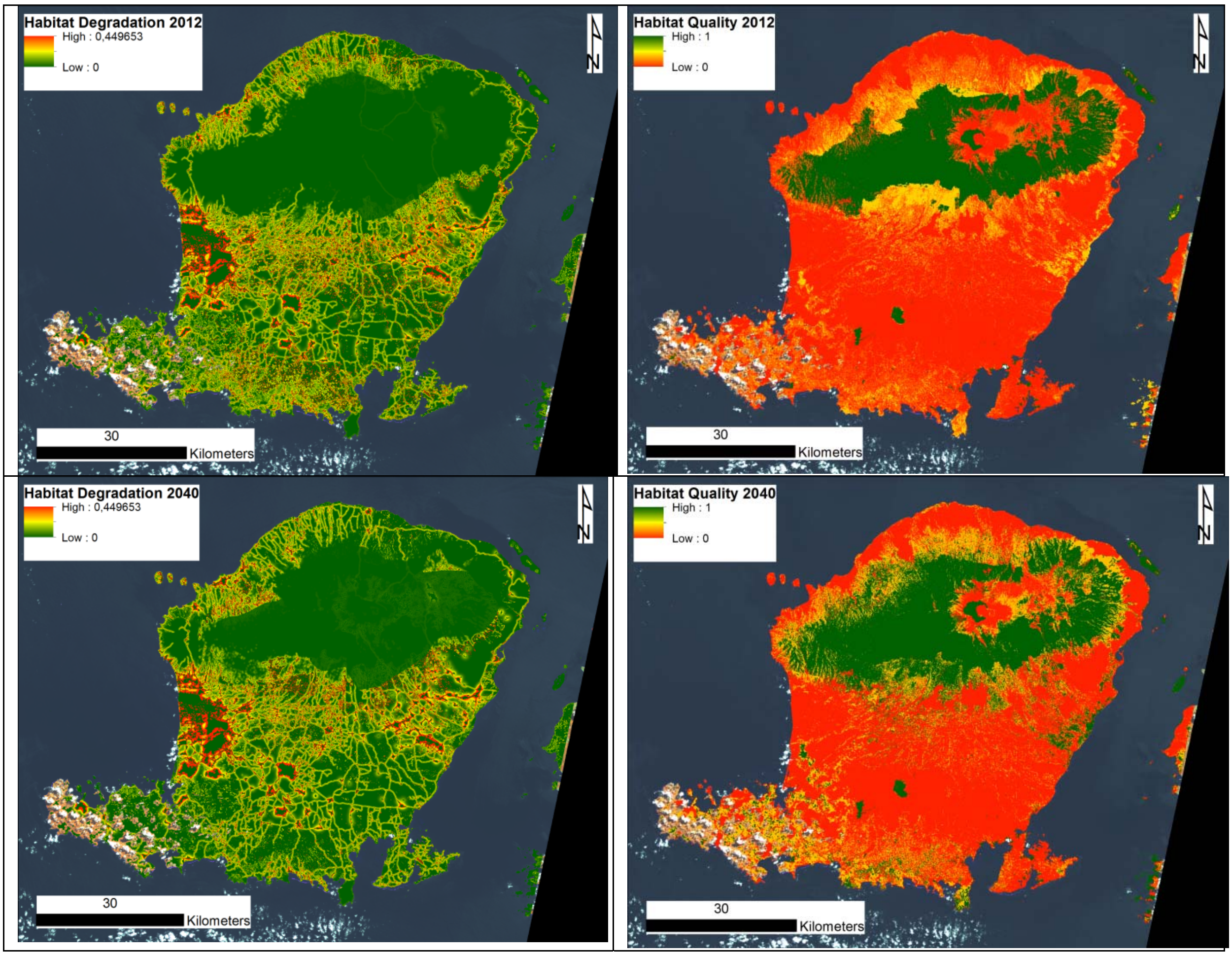


Figure 11: two scenarios regarding biodiversity are displayed for Lombok. One considering only the primary forest as suitable habitat and one considering the dense forest that has achieved primary structures according to the 2040 scenario to be suitable habitat. The threats are though increasing between 2012 and 2040. Green are suitable habitat or low threats in the images.

Conclusion

The forest of Mount Rinjani is the main biodiversity area and this needs to be considered in the land use policies. Strengthening the core areas, with agroforestry areas and letting some of the dense forest develop to host primary features is one approach that might be taken. InVEST together with field surveys might help to analyse the consequences of different policy measures and the implications on the ecosystems of Lombok.

4.2. Service trial #2A – Huong Son (Vietnam)

Huong Son is located in the Northern Annamites Rainforest, an ecoregion of global importance with high biodiversity. A number of threatened species are found within the ecoregion, among them charismatic species like tigers and Asian elephants. The number of bird species found in the ecoregion is extraordinary 525 and new mammal species have been found in the 1990's. The biodiversity and the rainforest are threatened by illegal logging, poaching and slash and burn agriculture. The Northern Annamites Rainforest is shared between Laos and Vietnam.

4.2.1. Biodiversity

EO services have been produced over the Huong Son area in central Vietnam. The products are a detailed land cover and land use map and a forest change.

The Huong Son Landscape is situated between the Ho Chi Min highway and the border to Laos. It is bordered by protected areas to the north, south and west. This is important to consider when analysing habitat degradation and quality. As the area is not protected and there has not been any field data made available on the biodiversity of the area, the main function considered is the connectivity between the protected areas and the green infrastructure in the area. As there is a major road crossing the area, the QL8A along the major river, there is risk that the connectivity between the protected areas is affected. This should be considered in the forest and landscape management plan securing the connectivity between the protected areas. Roads do also give access to areas for poachers and are in many tropical regions followed by slash and burn farmer creating an agricultural buffer along roads, this process is often called ribbon development.

Habitat quality depends on natural conditions and is impacted by historic land use. According to the forest management plan the forest have been selectively cut and depleted on the most valuable tree species. This has affected the biodiversity of the area, but how other species and communities have been affected is unclear and must be revealed by field surveys.

Input data for InVEST model: Biodiversity

Table 7: Data inputs as required by the Biodiversity InVEST tool (first column) and data sources used in the Huong Son trial (second column). See the general data description of these inputs in Table 5.

Model input	***Data source used in this trial***
Current land use/land cover (LULC) map (required)	There is a land cover map 2012 for the study area at 10 m resolution with 15 classes.
Future LULC map (optional)	N/A
Baseline LULC map (optional)	N/A
Threat data (required)	The threats are derived from the EO services are settlements (max dist. 10, weight 1), rural settlements (max dist. 8, weight 1), roads (max dist. 5, weight 0.5).
Accessibility to sources of degradation (optional)	N/A
Habitat types and sensitivity of habitat types to each threat (required)	Identified habitats from the EO-services produced, their habitat values and sensitivity to the identified threats (settlements, roads, and rural settlements). Primary forest (1, 1.0, 1.0, 1.0), Open forest (1, 1.0, 1.0, 1.0), Woodland (1, 1.0, 1.0, 1.0), Plantation (0.50, 0.50, 0.50, 0.250), Burnt areas/clear cuts unvegetated (0, 0.20, 0.20, 0.10), Grasslands/agriculture (0.50, 1.0, 1.0, 1.0), Bare areas (0.10, 0.20, 0.20, 0.20), Sand/gravel (0.10, 0.20, 0.20, 0.20), Water (0.20, 1.0, 1.0, 1.0), Rivers (0.20, 1.0, 1.0, 1.0), Wetlands (1, 1.0, 1.0, 1.0).
Half-saturation constant (required)	By default it is set to 0.5 but can be set equal to any positive number.

Table 8: Contribution of EO products, in-situ data and global information as inputs for this InVEST model. Green dot = direct contribution specifically designed for this project. Yellow dot = indirect contribution usually coming from global/regional data sets.

Biodiversity	EO	in-situ	other
Current land use/land cover (LULC) map (required)	🟢		
Future LULC map (optional)	N/A	N/A	N/A
Baseline LULC map (optional)	N/A	N/A	N/A
Threat data (required)	🟡		
Accessibility to sources of degradation (optional)			N/A
Habitat types and sensitivity of habitat types to each threat (required)	🟡		🟡
Half-saturation constant (required)			🟡

Scenarios for the InVEST model

Status Quo

The habitat of the Huong Son area is only to a small extent degraded, as detectable by the EO services. The area has though been selectively logged, which of course have degraded the habitat and the species composition. The important north-south connectivity between the adjacent national parks is cut by infrastructure and should be considered in both forest management and other landscape level policy processes. There are still wild elephants in the Ha Tinh province where Huong Son is located. It is therefore important that the construction of timber roads and the negative impact this might have on poaching is mitigated in a proper way. Before 1980 wild elephants were distributed throughout the Annamite mountain ranges. The decline since then due to poaching and habitat degradation puts an extra emphasis on mitigation on negative consequences of the remaining population.

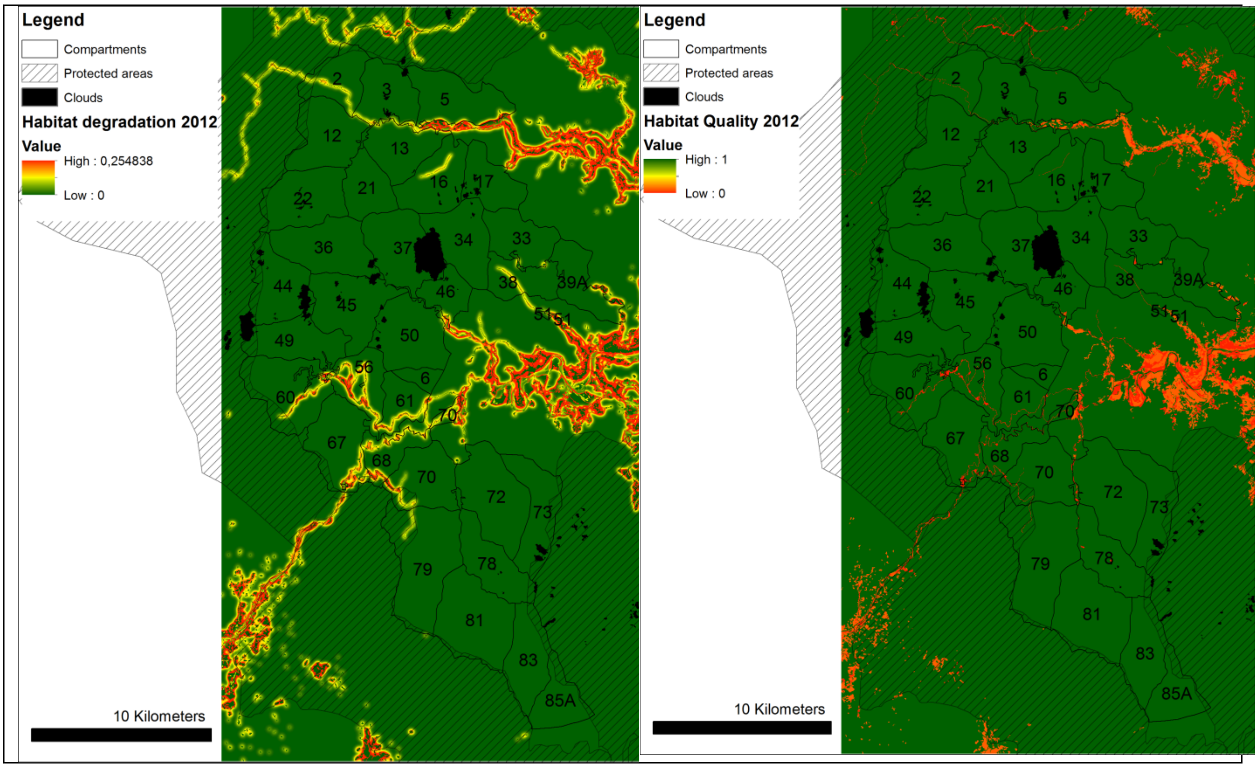


Figure 12: The degradation is mostly taking place along the road and river network, which is not very extended into the forest. The forest is homogenous in its appearance. Green is undisturbed habitat in the left image and unfragmented forest in the right. Areas that are green in both have potential for high biodiversity. The striped areas are conservation areas and the compartments are digitised from the forest management plan, black are no data areas due to cover cloud.

Conclusions

It is of importance to monitor how the connectivity between the protected areas is affected by infrastructure development as well as of the forest management in the area. As the forestry practices are based on selective cutting of the species with high market value some of the degradation is not visible with EO. The timber roads are visible and the development of the road network is the most important measure of habitat quality and ecosystem integrity.

Antipoaching measures should be taken so that the construction of logging roads does not jeopardize the remnant elephant population that might utilise the forest.

Lessons learnt

- The land cover of the study area is relatively homogeneous and dominated by dense forest. For biodiversity purposes it would be important with more field survey based information.
- The importance of the north-south connectivity depends on the biodiversity in the area; this also implies the need for field surveys.

4.2.2. Climate regulation – carbon sequestration

In the Huong Son case study, the forest cover shows only minor changes between 2002 and 2012.

Input data for the InVEST model: Carbon Storage and Sequestration

Table 9: Data inputs as required by the Carbon Storage and Sequestration InVEST tool (first column) and data sources used in the Ucayali trial (second column). See the general data description of these inputs in Table 3.

Model input	***Data source used in this trial***
Current land use/land cover (LULC) map (required)	There is a land cover map 2012 for the study area at 10 m resolution with 15 classes. All classes use default data from IPCC.

Carbon pools (required)	**C_above:** Forest and shrubs (136.), Open forest/Shrub (28.2), Woodland (28.2), Plantations (66.7), Burnt areas and unvegetated clear 0), Grassland and agricultural area (2.), Settlements (0), Isolated rural villages (0), Roads and associated areas (0), Bare areas (0), Sand/gravel (0) and Standing water bodies, Wetlands and irrigated areas (0) **C_below:** Forest and shrubs (33), Open forest/Shrub (12.28), Woodland (12.28), Plantations (15.6), Burnt areas and unvegetated clear (0), Grassland and agricultural area (6.2), Settlements (0), Isolated rural villages (0), Roads and associated areas (0), Bare areas (0), Sand/gravel (0) and Standing water bodies, Wetlands and irrigated areas (0) **C_soil:** For Vietnam we use data from HWSD, the main soil type is high activity clays (HAC). Table 2.3 of IPCC (2006) contains estimates of soil carbon stocks by soil type, assuming these stocks are at equilibrium (under native vegetation) and have no active land management. Thus, we take C_soil in 0-30 cm depth for HAC soils in tropical moist from Table 2.3 for all vegetated classes = 65 t C/ha. Wetlands have a default carbon content of 86 t C/ha in tropical moist areas. Settlements and infrastructure LC classes are assumed to have 0 Mg/ha. **C_dead:** We use default estimates for carbon content in litter from IPCC table 2.2 Forest and shrubs, Open forest/Shrub, Woodland and Plantations (2.1)
Current harvest rates map (optional)	Not applicable in this trial.
Future Scenarios (optional – required for valuation)	Not applicable in this trial
REDD scenario LULC map (optional)	Not applicable in this trial
Economic data (optional – required for valuation)	Not applicable in this trial

Table 10: Contribution of EO products, in-situ data and global information as inputs for this InVEST model. Green dot = direct contribution specifically designed for this project. Yellow dot = indirect contribution usually coming from global/regional data sets.

Carbon sequestration	**EO**	**in-situ**	**other**
Land use/land cover (LULC) (required).	●		
Carbon pools (required)		●	●
Current harvest rates map (optional).	N/A	N/A	N/A
Future Scenarios (optional – required for valuation)	N/A	N/A	N/A
Economic data (optional – required for valuation).	N/A	N/A	N/A

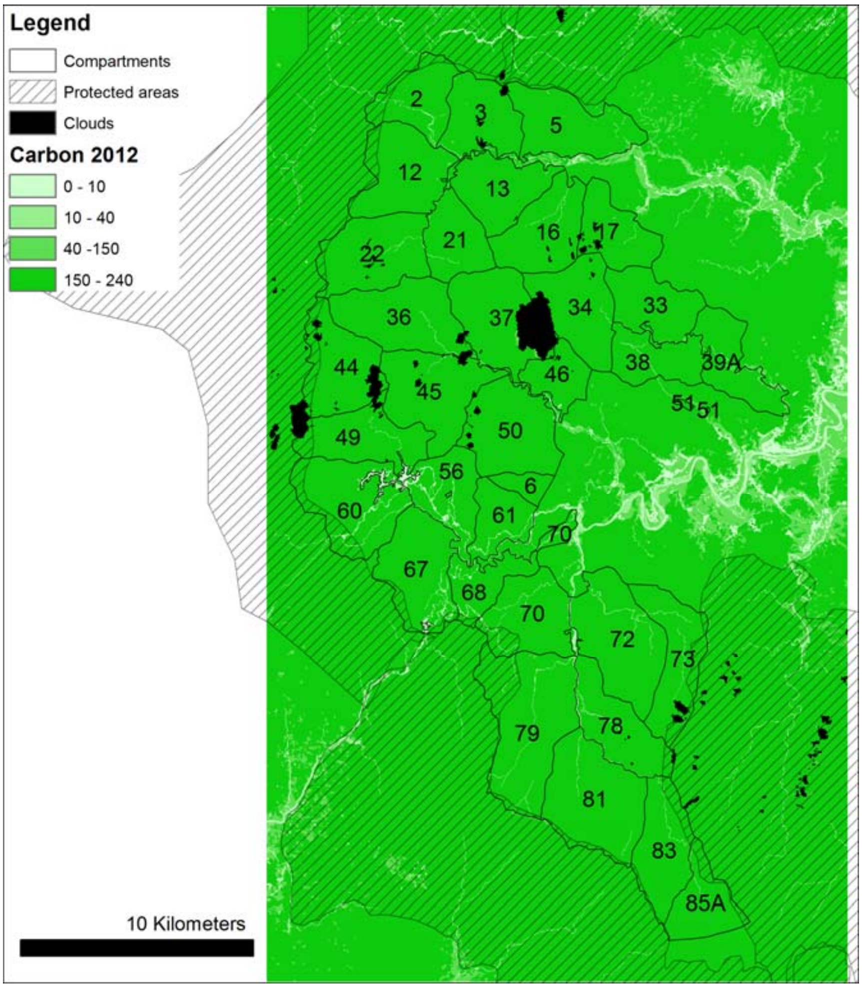


Figure 13: Carbon stock from land cover the dark green areas are high stock and the lighter green areas are low stock areas. As the dense forest is relatively homogenous, there is little variation within the analysed area. The striped areas are conservation areas and the compartments are digitised from the forest management plan, black are no data areas due to cloud cover.

Conclusions

Based on EO classification the Invest modelled carbon content of the forest becomes quite homogenous. Integrating crown cover percentage and tree heights give a much more heterogeneous result. Both of the methods do need to be calibrated to reflect the actual carbon content at any given location. Using field data for calibration of the relationship between crown cover and crown height as well as forest type, would greatly improve the calculations of stored carbon in the landscape. It would also make it possible to calculate the potential stocks and flows of carbon in the landscape if managed to optimise this relation with a global carbon budget in mind. However, doing this requires both new tools and new data, since the InVEST models do not run growth- or biomass-estimations, and high resolution data on crown heights are mostly unavailable.

Lessons learnt

To make sense from a carbon management point of view there is a need for more detailed information on both carbon content and management practices and their implications. The InVESTmodel was run with the same land cover in both the current and future baselines, but with a management grid. This approach did not seem to work, the management effects must be implemented in the future scenario and the forest be divided into a larger number of density and biomass classes. This means that landscape dynamics must be modelled outside of Invest.

4.2.3. Provision of timber

The spatial basis for the valuation of timber production as a major provisioning ecosystem service is an up-to-date land cover map depicting forested areas and other land uses with high spatial detail. Spatially highly detailed EO products, including detailed forest changes, have been produced by GeoVille for the Huong Son site in Vietnam in the frame of this project. These datasets can also be used as basis for developing potential future land use scenarios.

In addition to land cover, there is a need for integration of ancillary information like statistics providing local data for the use in the InVEST model. In particular, information about timber extraction cost and management cost (including cost for maintenance, harvesting and sales) are required per individual parcel.

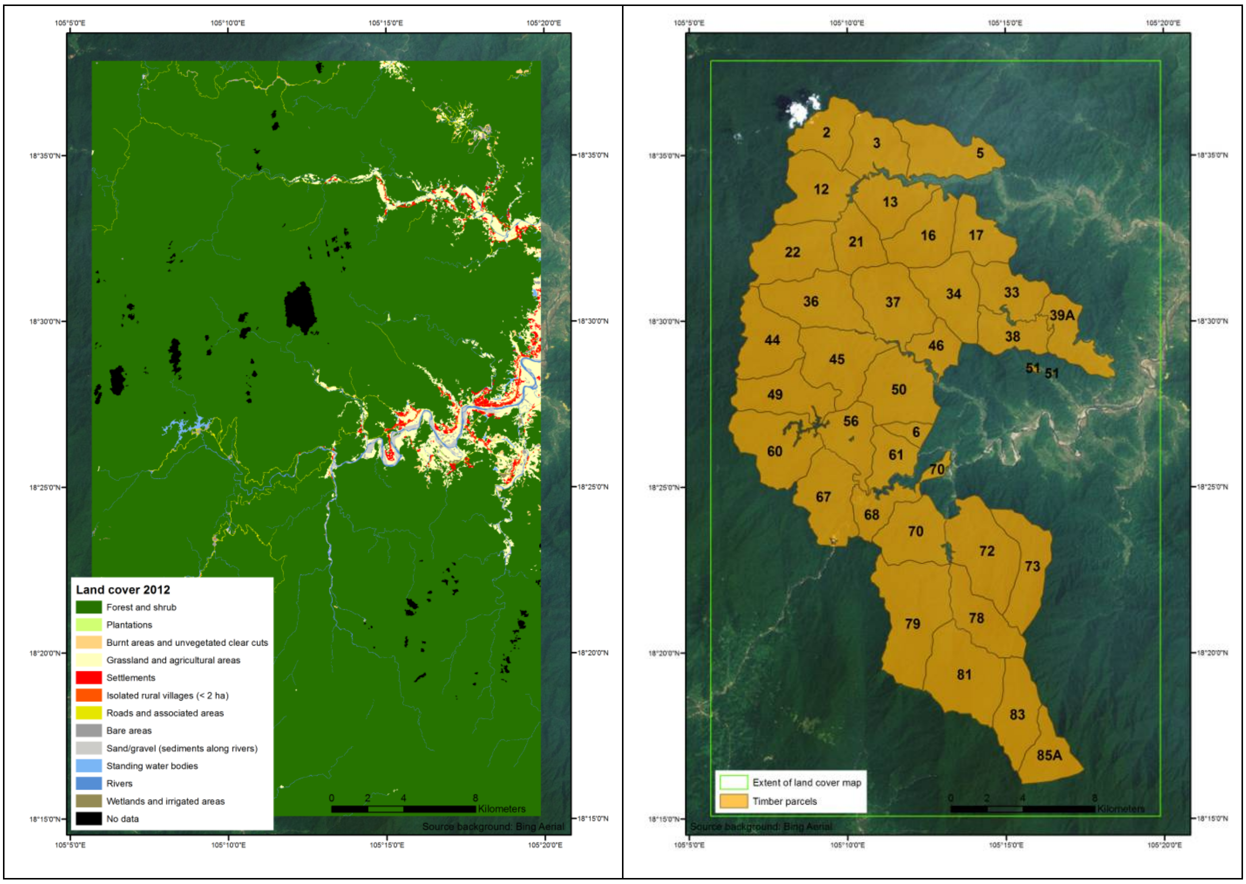


Figure 14: Comparison of the extent of land cover map and the concession for managed timber production in Huong Son. Left: Land cover map 2012. Right: Timber parcels derived from SNV map.

In the area, the Huong Son Company is responsible for the exploitation of timber for a concession of 35 parcels located in the centre of the study area in the Ha Tinh province in Vietnam bordering the Lao People's Democratic Republic. Hence, there is only information about the managed production area of Huong Son (see Figure 14).

In general, the InVEST Managed Timber Production model estimates the economic value of harvested timber (=produced good) in an area composed of a company-led forest concession based on the wood market prices and related harvest and management costs. The result of the model is a map providing the economic value of timber as well as the total volume and biomass of harvested wood in the different management units. Hence, the model does consider the economic value and the harvested wood removed from the timber parcels and provides no information about the impact of the exploitation to the nature.

Input data for the InVEST model: Managed Timber Production

Table 11: Description of the data inputs as required by the Managed Timber Production InVEST tool (first and second columns) and data sources used in the Huong Son trial (third column).

Model input	***Field***	***Data source used in this trial***
Managed area map (required).		Shapefile digitised from a map of the soil loss by compartment in Huong Son provided by SNV. The results are 35 extraction parcels. The projection of all the layers is WGS84 UTM 48N.
Plantation production table (required).	Price	The average market price was extracted from the management plan based on the available information on a 4-year logging period. The price was counterchecked with the “REDD+ Country Report” on “Cost implications for pro-poor REDD+ in Lam Dong Province, Vietnam”[15] providing information on timber market prices in Ha Tinh Province.
	T	Number of years the parcel will be valued. We use values between 1 and 35, which is the envisaged logging cycle of Huong Son Company.
	BCEF	$BCEF_R$ taken from IPCC 2006[16] table 4.5 assuming a maximum growing stock level >200 m3 for humid tropical forests ($BCEF_R$ =1.05).
	Parcel_ID	35 production parcels.
	Parcl_area	Forest area calculation per parcel based on land cover map 2012.
	Perc_harv	According to the envisaged harvest area defined in the management plan for the 35 year logging period an average proportion of 22.63 % per parcel was derived for model calculations.
	Harv_mass	The envisaged annual mass of wood harvested per hectare for the 35 year period was extracted from the management plan and then transformed into weight.
	Freq_harv	How often will each parcel be harvested within the number of years it will be valued. In the model, the meaning of Freq_harv is closely related to T. The logging cycle is 35 years. Due to missing information about the whole harvest period a simplified approach was used assuming that one parcel is logged per year.
	Maint_cost	An average annualized cost per ha was used based on the information provided by the forest management plan.
	Harv_cost	The annual costs specified in the forest management plan for the first 5 year-period are varying moderately. However, the envisaged cost for the full 35-year logging cycle is about three times higher than the forecast based on the 5 year-period would expect. Therefore an average harvest cost was used for calculations.

[15] Ogonowski , M. and Enright A. (2013): REDD+ Country Report. Cost implications for pro-poor REDD+ in Lam Dong Province, Vietnam. Opportunity costs and benefit distribution systems. Available at: http://pubs.iied.org/pdfs/G03677.pdf
[16] IPCC (2006). Guidelines for National Greenhouse Gas Inventories. Volume 4: Agriculture, Forestry and Other Land Use. Chapter 4: Forest Land.

	Immed_harv	"No" to model the 35-year rotation entirely and to allow for future projections.
Market discount rate (optional – required for valuation)		Default value (7%).

Table 12: Contribution of EO products, in-situ data and global information as inputs for this InVEST model. Green dot = direct contribution specifically designed for this project. Yellow dot = indirect contribution usually coming from global/regional data sets.

Timber provision	EO	in-situ	other
Managed area map		🟢	
Market price (required)		🟢	
No of year of valuation (required)		🟢	
BCEF (mass to volume) (required)			🟡
Parcel ID (required)		🟢	
Parcel area (required)	🟢		
Perc_harvested (required)	🟡	🟢	
Harv_mass (required)		🟢	
Freq_harv (required)		🟢	
Maint_cost (required)		🟢	
Harv_cost (required)		🟢	
Immd_harv (required)		🟢	
Market discount rate (required)			🟡

Scenario for the InVEST model

The Managed Timber Production model takes into account harvest related information like harvest mass, frequency and costs as well as maintenance cost and considers also a market discount rate for the whole logging period. Therefore local data, i.e. from the timber production company, is needed for the calculation of the model.

The forest management plan of the Huong Son Company is based on a 35-year logging period for 35 compartments (derived from a map provided by SNV). The management plan provides information about historic logging for a period of four years (2006-2009) and forecasts for a selection of parcels for a period of 5 years (2011-2015). Information for the remaining logging cycle like envisaged harvest area, volume and costs is only provided for the whole concession and not for each parcel. Therefore, a simple approach was used for calculations, i.e. each parcel should be logged during one year (year 1: T=1, Freq_harv=1, Immed_harv=N → year 35: T=35, Freq_harv=35, Immed_harv=N) for the whole concession period. The cutting intensity, the volume of timber harvested as well as the costs within the period from 2006 to 2009 as well as the envisaged area and volume of timber harvested from 2011 to 2015 varies moderately. Therefore, due to the absence of detailed parcel specific data, it has to be taken into account that **only averaged values can be used for the Timber Managed Production model for the logging period 2011-2045.**

The marketplace value of the wood harvested from the parcel ("PRICE") was calculated based on information of the forest management plan and additional data on forest quality for the study area. The price was also counterchecked with timber market prices provided by the “REDD+ Country Report” on “Cost implications for pro-poor REDD+ in Lam Dong Province, Vietnam”[17]. For this scenario the market discount rate remains constant at 7 %.

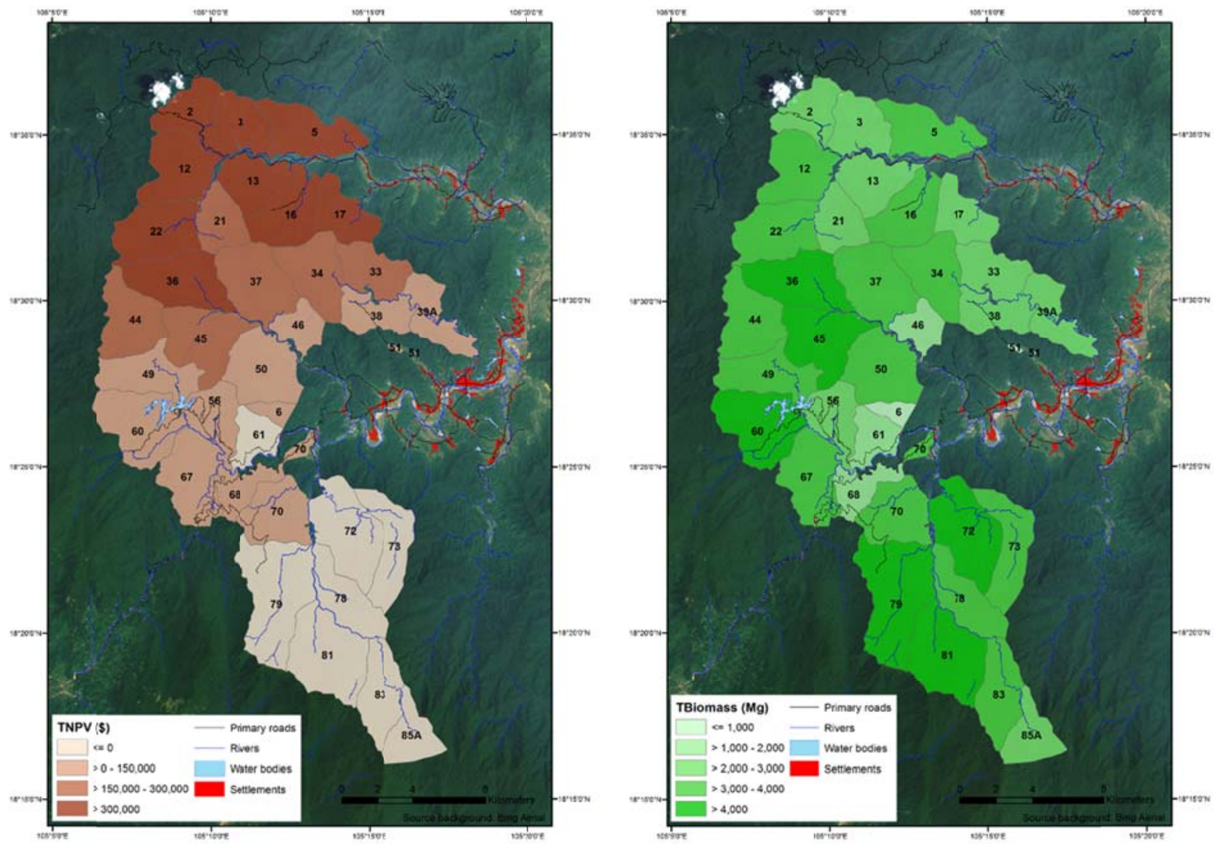


Figure 15: Results from the Managed Timber Production model applied to the concession of Huong Son Company. TNPV: total net present value of the forecasted timber extraction until 2045 (based on averaged values). TBiomass: total harvested biomass. Numbers correspond to the parcels listed in the forest management plan of the Huong Son Company.

Conclusions

The model calculates the total net present value (TNPV) of the managed timber production for the 35-year concession period as well as the total biomass (TBiomass) harvested. For visualising purposes the TNPV of harvest for the current year is provided in US-$ but can easily be transformed into Vietnamese dong (VND) (1 US-$ = 20,700 VND).

The TNPV calculated for the 35 parcels of the Huong Son concession shows a trend of high economic benefit in the first years (northern parcels) towards low benefit respectively economic loss (southern parcels) in the final years of the logging period. It has to be noted that the calculation are based on approximate values assuming that one parcel is harvested per year in numerical order and based on data of a 4-year historic period (2006-2009) and the planning for a 5-year period (2011-2015). Also, the fixed market prices and the application of a 7 % market discount rate for this long period are probably underestimating the future benefits. This seems also to be the reason for the parcels with negative TNPV located in the southern part of the concession area.

[17] Ogonowski , M. and Enright A. (2013): REDD+ Country Report. Cost implications for pro-poor REDD+ in Lam Dong Province, Vietnam. Opportunity costs and benefit distribution systems. Available at: http://pubs.iied.org/pdfs/G03677.pdf

Furthermore, potential fluctuations of timber market prices along the logging cycle are not considered due to the long period of the logging cycle of 35 years.

Related to the forest management plan, 10 parcels are harvested in the first 5-year period but due to missing further information about the remaining years a simple approach was used for this scenario assuming that one parcel is harvested per year in numerical order. This would be also an explanation for the decreasing economic benefit for the parcels harvested at a later stage of the logging cycle.

The TBiomass map visualizes the volume of harvested timber during the full logging period of 35 years. Due to missing data for each parcel an average value was calculated based on the envisaged volume of timber harvested within the whole logging cycle. Due to this approach the parcels with a high areal percentage of forest also have a high potential of timber biomass.

Despite all limitations due to approximated inputs the model is a powerful tool to get economic values of region with managed timber production. However, **spatial information on forest is one of the main inputs to the Managed Timber Production model** where EO products of high resolution, as they have been produced in this project, are important to generate results of high quality.

Lessons learnt

- A management plan of the full logging cycle with detailed in-situ information about foreseen harvest practices, cost and prices from the managed timber exploitation are crucial to run this kind of models. **With limited data only simplified approaches can be used for the model.**
- The results and the definition of the scenarios would benefit from a deeper analysis of the prices and cost trends.
- The market discount rate is a critical factor in such a long-term analysis and should be adapted to the actual regional conditions.
- More accurate results would be obtained if the mass of timber extracted (instead of the volume) could be available. Alternatively, the volumes should be transformed into mass species by species with specific density data.
- Accuracy (the spatial resolution of model results) is limited to the exploitation parcels' size.
- This InVEST model shows serious limitations to account for the natural provision of ecosystem services. It mostly focuses on the exploitation of natural resources (timber) and their economic returns (the final value of the benefits), without considering other key factors such as sustainable practices, conservation zones, clear-cut vs. selective logging, etc. The application of other (more natural-based) ecosystem service models would provide a more complete picture of the study area.

4.3. Service trial #2B – Vinh Tu (Vietnam)

Vinh Tu is situated on the shoreline of the South Chinese Sea in the Vietnamese lowland Rainforest eco region. The forest of the eco region is to a large extent transformed into agricultural land and the remnant forest patches are potentially important for biodiversity and ecosystem function, a bit dependent on the site specific circumstances. Along the shoreline there are problems with wind driven erosion and different measures are taken to stabilise the sand and stop it from drifting into fertile soils.

4.3.1. Climate regulation – carbon sequestration

The carbon pools are calculated in accordance with the to the IPCC tables of the 2006 report. There is no local information on actual biomass in the Vinh Tu area or on how much biomass that is extracted during harvest. In the Vinh Tu case study, the forest cover shows major changes between 2002 and 2012. The turnover rate in the landscape is high due to short rotations, six years, in the acacia plantations that dominate the forested parts. The carbon balance will hence be depending on the release of carbon from the products made of the extracted wood.

Input data for InVEST model: Carbon Storage and Sequestration

Table 13: Data inputs as required by the Carbon Storage and Sequestration InVEST tool (first column) and data sources used in the Vinh Tu trial (second column). See the general data description of these inputs in Table 3.

Model input	***Data source used in this trial***
Current land use/land cover (LULC) map (required)	There is a land cover map 2012 for the study area at 10 m resolution with 15 classes. All classes use default data from IPCC.
Carbon pools (required)	**C_above:** Forest and shrubs (136), Open forest/Shrub (28.2), Woodland (28.2), Plantations (66.7), Burnt areas and unvegetated clear 0), Grassland and agricultural area (2), Settlements (0), Isolated rural villages (0), Roads and associated areas (0), Bare areas (0), Sand/gravel (0) and Standing water bodies, Wetlands and irrigated areas (0) **C_below:** Forest and shrubs (33), Open forest/Shrub (12.28), Woodland (12.28), Plantations (15.6), Burnt areas and unvegetated clear (0), Grassland and agricultural area (6.2), Settlements (0), Isolated rural villages (0), Roads and associated areas (0), Bare areas (0), Sand/gravel (0) and Standing water bodies, Wetlands and irrigated areas (0) **C_soil:** For Vietnam we use data from HWSD, the main soil type is high activity clays (HAC). Table 2.3 of IPCC (2006) contains estimates of soil carbon stocks by soil type, assuming these stocks are at equilibrium (under native vegetation) and have no active land management. Thus, we take C_soil in 0-30 cm depth for HAC soils in tropical moist from Table 2.3 for all vegetated classes = 65 t C/ha. Wetlands have a default carbon content of 86 t C/ha in tropical moist areas. Settlements and infrastructure LC classes are assumed to have 0 Mg/ha. **C_dead:** We use default estimates for carbon content in litter from IPCC table 2.2 Forest and shrubs, Open forest/Shrub, Woodland and Plantations (2.1)
Current harvest rates map (optional)	Not applicable in this trial.
Future Scenarios (optional – required for valuation)	Not applicable in this trial
REDD scenario LULC map (optional)	Not applicable in this trial
Economic data (optional – required for valuation)	Not applicable in this trial

Table 14: Contribution of EO products, in-situ data and global information as inputs for this InVEST model. Green dot = direct contribution specifically designed for this project. Yellow dot = indirect contribution usually coming from global/regional data sets.

Carbon sequestration	EO	in-situ	other
Land use/land cover (LULC) (required).	●		
Carbon pools (required)		●	●
Current harvest rates map (optional).	N/A	N/A	N/A
Future Scenarios (optional – required for valuation)	N/A	N/A	N/A
Economic data (optional – required for valuation).	N/A	N/A	N/A

Status Quo

Most of the carbon dynamics in the Vinh Tu area is due to the management of the acacia plantations in the area. There are a few forest patches with some dynamics, but they seem to be quite stable. Lacking information on the dynamics of the acacia plantations it is more relevant to describe the carbon pool in the landscape in the most recent imagery. The Carbon Stock in Vinh Tu is 777 000 tons of carbon. To calculate more accurate figures field data on the carbon content of both the stable forest patches and the plantations are needed.

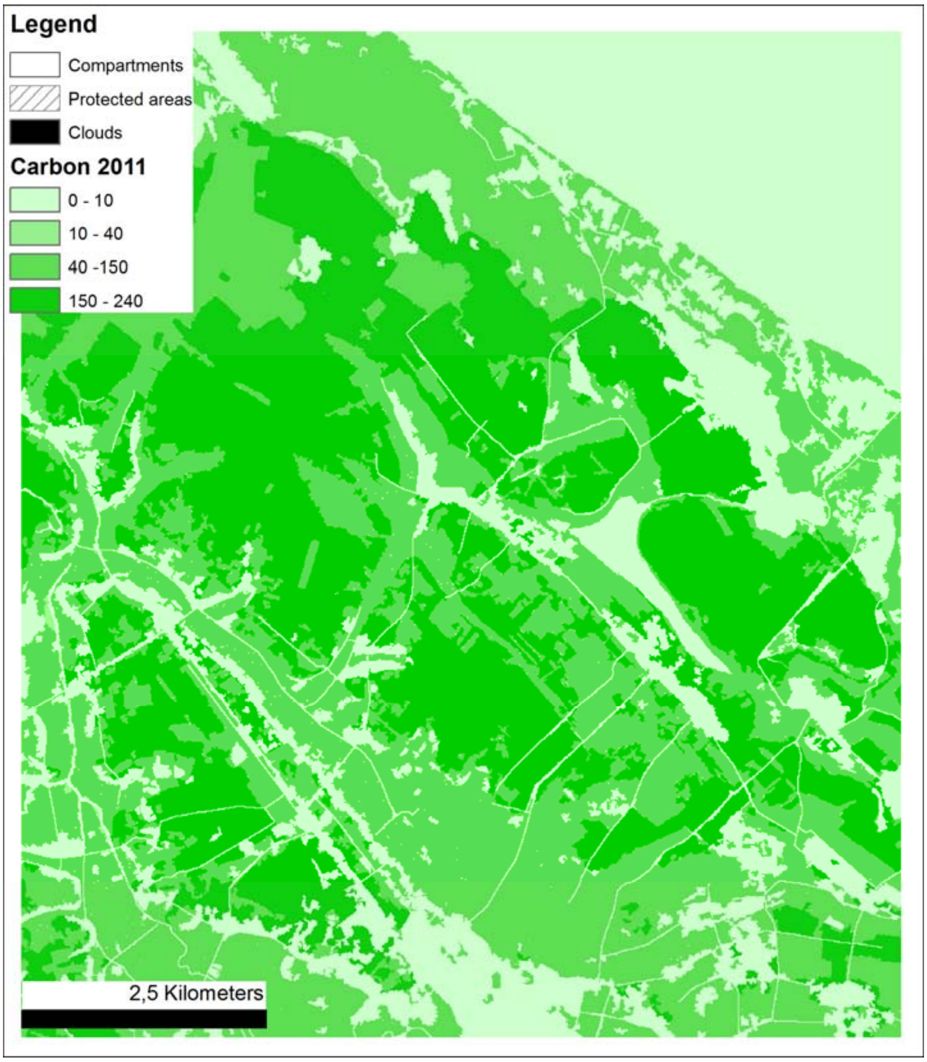


Figure 16: Carbon stocks in the Vinh Tu area. Dark green areas have the highest carbon stocks, lighter green lower stocks. As most of the biomass is in a short rotation plantation system, the carbon map should be seen as a snapshot.

Conclusion

In areas with intensive forestry practices, like in the Vinh Tu area the most important factors that must be considered are the forestry practices and how the extracted biomass is used. The effect on the global carbon budget will vary considerably depending on the end use of the product. If the wood is used for biofuel, pulp or construction, the estimated time for carbon release vary between xx and xx according to IPCC.

Lessons learnt

The turnover in small short rotation plantations should be considered doing carbon modelling. Forest inventory data is important to accurately calculate the carbon pools, especially in

4.4. Service trial #3 – Ucayali (Perú)

4.4.1. Provision of timber

EO products, including detailed forest change maps and a land cover map, were produced for the CFA concession (the largest logging exploitation in the Ucayali Province), the Puerto Esperanza indigenous community area, and a surrounding buffer of 10 km. This area is mostly covered by primary, natural forest (forest that retains much of its natural structure and function) which is in transition to slightly managed forest. The EO-derived information can be directly used to derive proxies or indicator of ecosystem services; for example, the percentage and location of forest degradation shown in the forest change maps indicate a decrease in the capacity to provide timber, carbon storage, or water and soil retention.

However, in order to apply more specific ecosystem service models, like the InVEST tools, we need to integrate the EO products with detailed local environmental and socio-economic data. In particular, the InVEST Managed Timber Production model requires comprehensive information about the timber extraction and management practices per individual parcel. This information is only available from the CFA concession, since Puerto Esperanza has not been formally managed and documented before 2012 and the 10 km buffer area is not under managed production.

Therefore, the application of the Managed Timber Production model described below refers to the CFA extraction area. Also, within the CFA concession there are four conservation zones excluded from the extraction activities that are not taken into account in the model. In fact, one of the main characteristics of the Managed Timber Production model is that it only considers the final economic benefit from timber extraction. This model does not consider either the natural capacity of the forested area to provide timber or other important ecosystem services, nor the potential long-term degradation of the exploitation. Thus, the final results from this model have to be interpreted as an indication of the profit for the logging companies (benefit from the ecosystem service) more than of the ecosystem status (natural capacity to provide ecosystem services). This is one of the reasons to complement these results with the Carbon Sequestration model (next section). Optimally, the whole range of ecosystem services provided in the study area (e.g. water retention, recreation) should be quantified to get an estimation of the natural/ecosystem capital of the region.

Input data for the InVEST model: Managed Timber Production

Table 15: Data inputs as required by the Managed Timber Production InVEST tool (first and second columns) and data sources used in the Ucayali trial (third column). See full description of inputs in Table 11.

Model input	***Field***	***Data source used in this trial***
Managed area map (required).		Shapefile digitised from an image of the CFA Forestry Management Plan 2011[18]. The results are 30 extraction parcels and 4 conservation parcels. The projection of all the layers is UTM 18N WGS84.
Plantation production table (required).	Price	The specific species and volume of wood (m3) extracted and sold each year between 2006 and 2012 were extracted from SPDE data[19]. This was converted into market prices using the Peruvian annual log timber price per wood type (US$/m3) from SPDE data and MINAG 2012[20]. We assume that CFA sells only roundwood (not processed logs). Based on the price statistics and the average (basic) wood density for the most common species in CFA (0.5075 Mg/m3), we estimate the final market price ($/Mg).
	T	Number of years the parcel will be valued. Depending on the different scenarios, we use values between 1 and 30, which is the maximum concession period of CFA.
	BCEF	$BCEF_R$ taken from IPCC 2006[21] table 4.5 assuming a maximum growing stock level >200 m3 for humid tropical forests ($BCEF_R$ =1.05).
	Parcel_ID	30 production parcels (the 4 conservation zones have to be excluded from the analysis).
	Parcl_area	Area calculation per parcel.
	Perc_harv	The actual proportion of the timber parcel area that is harvested can be estimated from the EO products, in particular from the classes deforestation & degradation defined in the forest change maps 2002-2007-2012. Final values range between 1.3-3.1% (very selective logging), even if there may be some missing values under NoData coverage). However, in the model this parameter refers to the parcel area that can be exploited (not what is actually cut off). It is, therefore, a management parameter that we can fix as to 90% of each parcel (the maximum allowable rate by national regulation). The biomass and volume results obtained with this value have been checked and confirmed with the available data series of the years 2006-2012.
	Harv_mass	The annual commercial production (in volume) was extracted from SPDE data and then transformed into weight using the average basic density of the 4 most common commercial species in the concession[22] (average density of Cachimbo Colorado, Tornillo, Mohena blanca and Cumala 0.5075 g/cm3).
	Freq_harv	How often will each parcel be harvested within the number of years it will

[18] Consorcio Forestal Amazónico SAC (2011). Resumen del plan general de manejo forestal. Available at: http://fsc.org.pe/blog/wp-content/uploads/

[19] Sociedad Peruana de Ecodesarrollo (http://www.spde.org/) has processed the public information obtained through various state agencies such as the Regional Government, the Ministry of Agriculture, or the Direction of Forestry and Wildlife.

[20] Ministerio de Agricultura de Perú – Dirección Gnral. Forestal y de Fauna Silvestre (2012). Anuario de precios de productos maderables y no maderables. Available at: http://dgffs.minag.gob.pe/index.php/produccion-y-comercio/estadistica-forestal

[21] IPCC (2006). Guidelines for National Greenhouse Gas Inventories. Volume 4: Agriculture, Forestry and Other Land Use. Chapter 4: Forest Land.

[22] Centro de Innovacion Tecnologica de la Madera (2010). Tu Madera Peru: 48 maderas de la Amazonia peruana. Lima. www.citemadera.gob.pe.

		be valued. In the model, the meaning of Freq_harv is closely related to T. The concession period of CFA is 30 years and the plan is logging one parcel per year. The InVEST support team has instructed us to use coupled values between 1 and 30 (more details in the scenarios below).
	Maint_cost	Annual management and administrative costs estimated from SPDE data and distributed by the CFA extraction area. The CFA concession is a natural forest based on natural seedling without pesticides use. Values range between 7.80-10.70 $/ha depending on the parcel and the scenario.
	Harv_cost	Annual management and administrative costs estimated from SPDE data and distributed by the CFA extraction area. These costs increased importantly during the first years of exploitation due to investment in machinery, but they are distributed by a vast concession area. There are no processing facilities or highly mechanised processes. Values range between 19.99-35.04 $/ha depending on the parcel and the scenario.
	Immed_harv	"No" to model the 30-year rotation entirely and to allow for future projections.
Market discount rate (optional – required for valuation)		Default value (7%).

Table 16: Contribution of EO products, in-situ data and global information as inputs for this InVEST model. Green dot = direct contribution specifically designed for this project. Yellow dot = indirect contribution usually coming from global/regional data sets.

Timber provision	**EO**	**in-situ**	**other**
Managed area map	🟢	🟢	
Market price (required)		🟢	
No of year of valuation (required)		🟢	
BCEF (mass to volume) (required)			🟡
Parcel ID (required)		🟢	
Parcel area (required)	🟢		
Perc_harvested (required)	🟡	🟢	
Harv_mass (required)	🟡	🟢	
Freq_harv (required)	🟡	🟢	
Maint_cost (required)		🟢	
Harv_cost (required)		🟢	
Immd_harv (required)		🟢	
Market discount rate (required)			🟡

Scenarios for the InVEST model

The CFA management plan is based on 30 production parcels corresponding (broadly) to the 30-year concession period, i.e. each parcel should be logged during one year over the concession period, although there have been some delays and overlaps at the beginning of the activities. The cutting intensity, the number of species harvested and the company equipment (as well as the costs) have continuously grown between 2006 and 2012. Still, the EO information shows that CFA performs a very selective logging within the legal boundaries.

The Timber Managed Production model considers the revenues coming from the timber production, takes into account the maintenance and harvest costs and applies a market discount rate for the 30 years rotation period. For the different scenarios of this InVEST model, the inputs 'managed area map' and 'market discount rate' remain invariable, as well as the rotation scheme established in the CFA management plans. Thus, the scenarios are based on the variation of some parameters of the 'plantation production table', in particular: Price (the log market price), Harv_mass (the mass of wood harvested), Maint_cost (maintenance costs), and Harv_cost (harvest costs).

Scenario Status Quo

Description of the scenario: timber extraction will continue to increase within the CFA concession at the present rate until it reaches the maximum allowed values (nearly 48800 m^3 of timber[23]) in 2015. Management practices and costs per hectare as well as timber prices per tonne will follow the present trend until that moment (2015) after which they are assumed to remain more or less constant while adapted by a 7% market discount rate. Modelled period: 2006-2036.

In the 'plantation production table', we set up each parcel so it only gets harvested once during the 30-year rotation. In this case, the first parcel is only harvested during year 1 (T=1, Freq_harv=1, Immed_harv=N), and second parcel is cut during year 2 (T=2, Freq_harv=2, Immed_harv=N), and so on until the last harvested parcel (T=30, Freq_harv=30, Immed_harv=N). The annual maintenance and harvest costs per hectare are also included. Since the CFA-sold log prices per tonne or hectare are extremely variable (mainly depending on the species composition and the amount of timber harvested each year), we used the average price of the last 6 years to forecast future harvests' prices.

The model should correctly account for the market discount rate and offer the total net present value (TNPV) of the managed timber production for the 30-year concession period as well as the total biomass (TBiomass) harvested. The model produces the TNPV of harvests in the currency of the current year. In this scenario, maximum economic benefits are supposed to come from parcels 2, 7 and 8, although it has to be noted that this scenario does not include any rise in timber market price along the years. The least valuable parcels after this scenario are 1, 5, 29 and 30. The amount of biomass harvested is generally increasing until the maximum allowable cut is reached (from parcel 9 onwards).

[23] Forest Stewardship Council (2011). Informe de Auditoría Re-evaluación 2011 Consorcio Forestal Amazónico SAC. Available at: http://info.fsc.org/Detail?id=a0240000005sRjfAAE

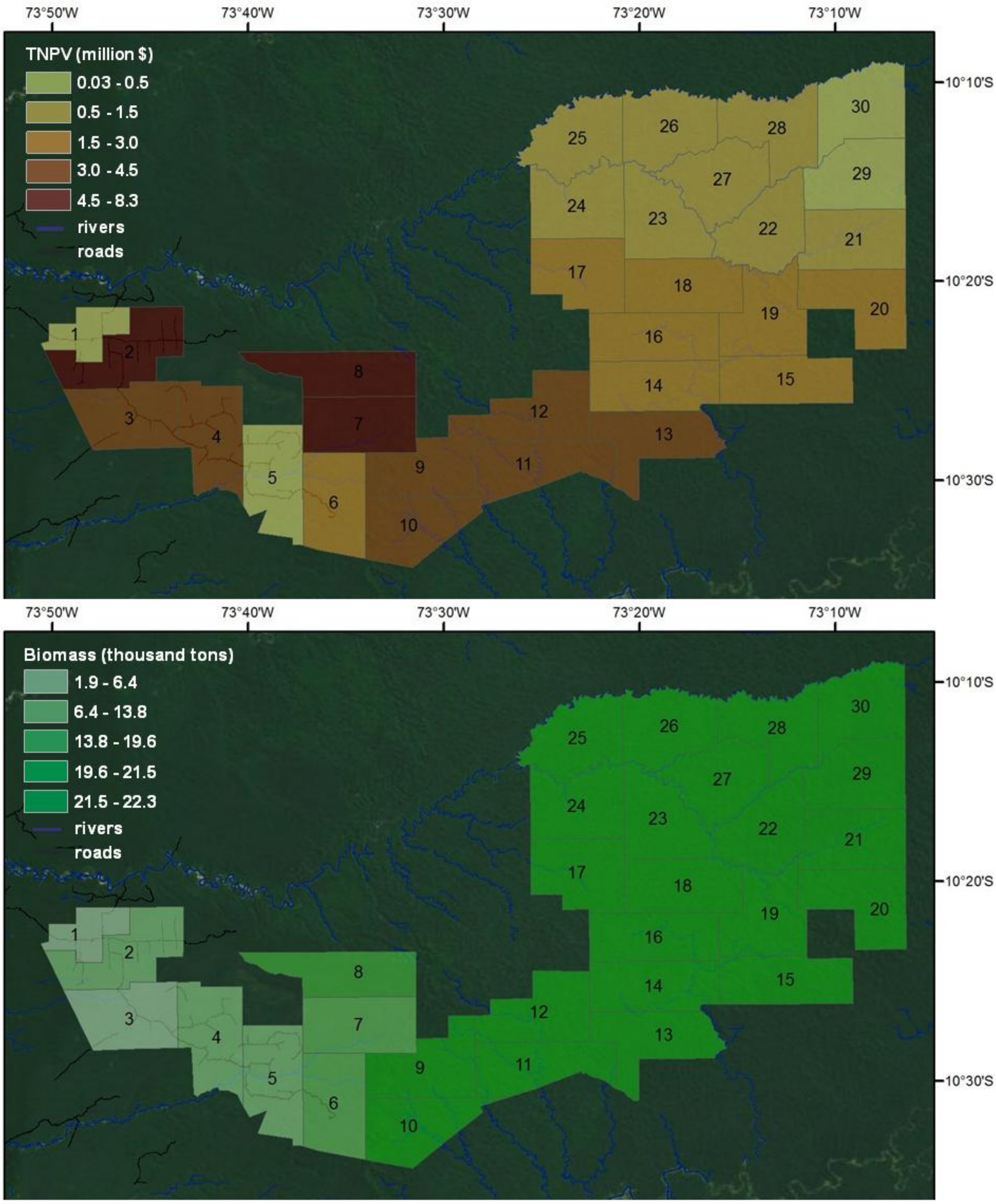


Figure 17: Results from the Managed Timber Production model applied to the CFA concession under the Status Quo scenario (i.e. continuation of the present situation). TNPV: total net present value of the forecasted timber extraction until 2036. Biomass: total harvested biomass. Numbers correspond to the parcels listed in the CFA management plan.

Scenario Exploited

The conditions are basically the same as in the Status Quo scenario but increasing the allowable cut to 60,000 m^3 and escalating accordingly the maintenance and harvest costs. Maintenance costs are raised about 4% per year; and harvest costs increase about 7% annually in parallel with the exploitation rise and then, once the maximum allowable cut is reached, they raise at about 4%. Modelled period: 2006-2036.

In this model run, the maximum economic benefits are supposed to come from parcels 2 and 7-11, and the minimum ones from parcels 1, 5 and 26-30. Actually, parcels 29 and 30 show negative TNPV, indicating a net loss. The amount of biomass harvested is generally increasing until the maximum allowable cut (as defined for this scenario) is reached, i.e. from parcel 10 onwards.

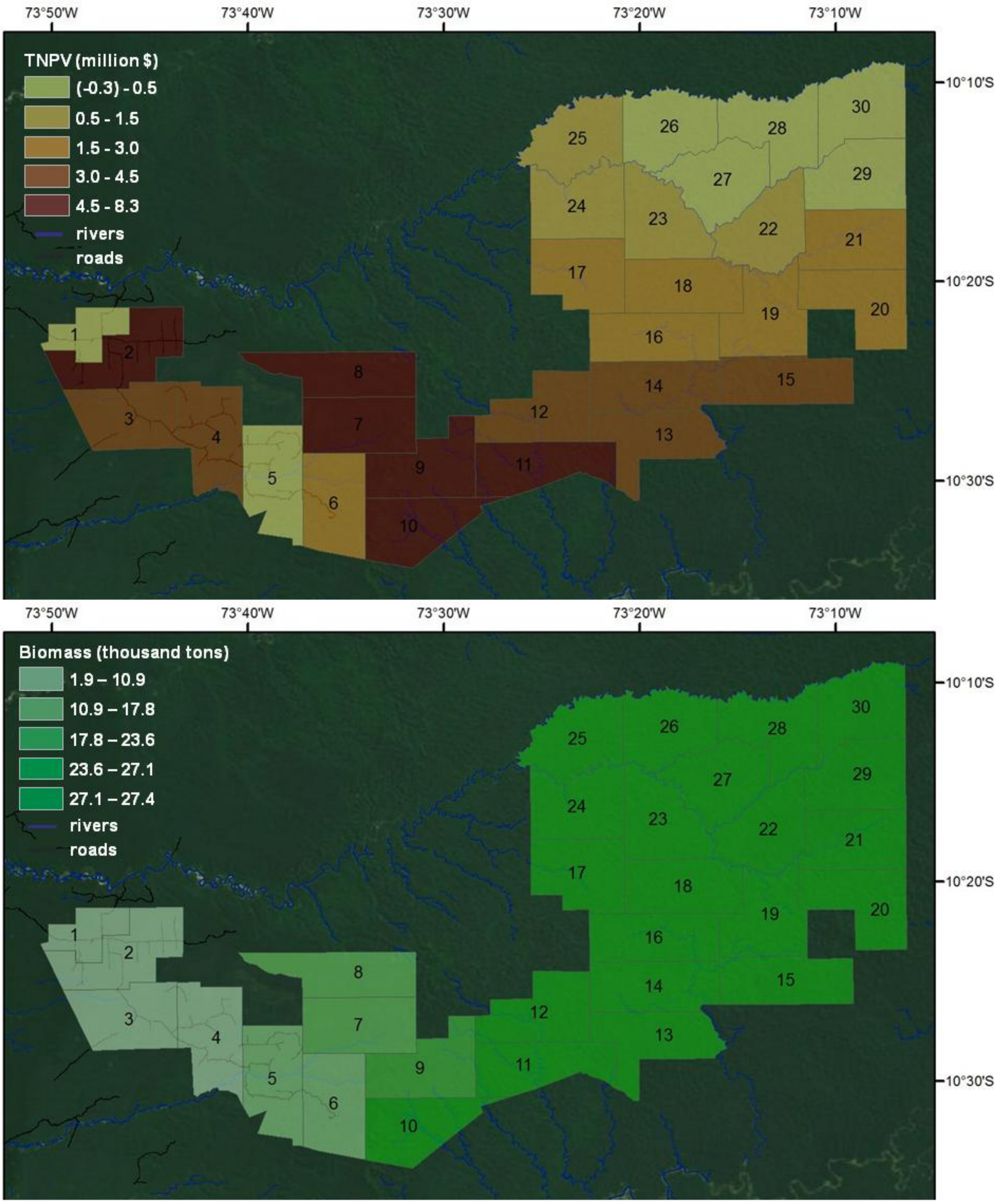
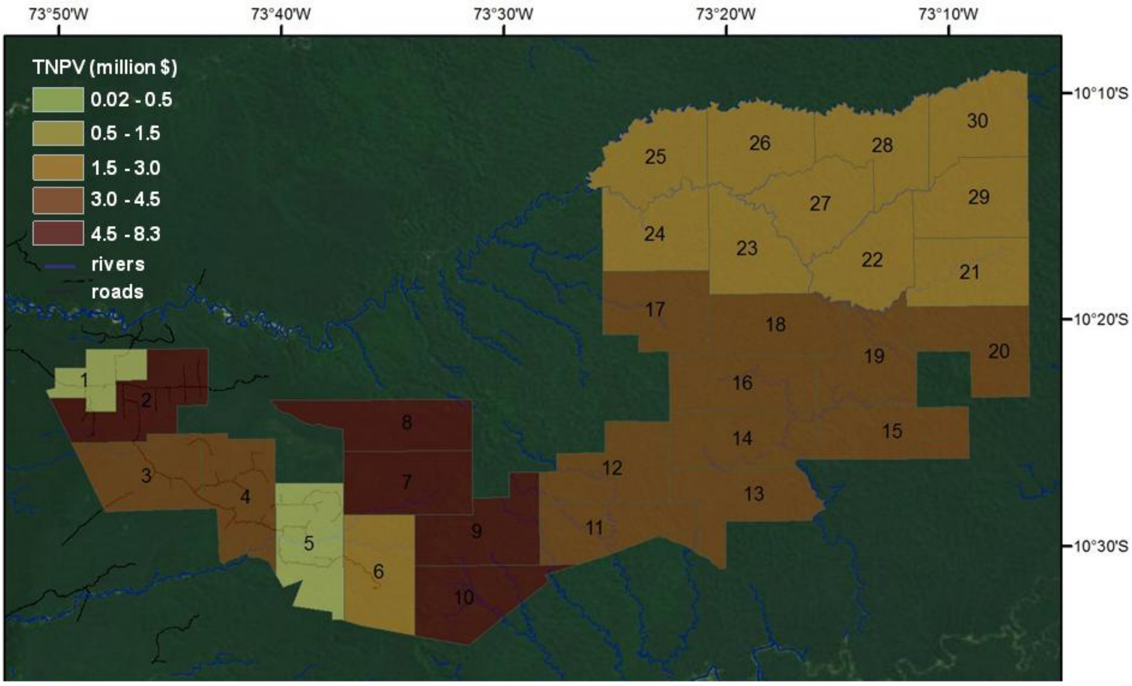


Figure 18: Results from the Managed Timber Production model applied to the CFA concession under the Exploited scenario (i.e. allowed annual timber extraction raised by 11,000 m^3). TNPV: total net present value of the forecasted timber extraction until 2036. Biomass: total harvested biomass. Numbers correspond to the parcels listed in the CFA management plan.

Scenario Price Rise

The conditions are basically the same as in the Status Quo scenario but increasing the timber prices by 3.7% annually starting from 2013. This increase rate comes from the analysis of the trend of international prices extracted from the available information[24]. Specifically, it corresponds to the average price evolution of three relevant species in the study area (Pumaquiro, Cumala and Cumaru) between January 2006 and December 2011. Modelled period: 2006-2036.

Under this scenario, maximum economic benefits are supposed to come from parcels 2 and 7-10, while the least valuable parcels are 1 and 5. The economic differences with respect to the first scenario are visible after parcel 9. The amount of biomass harvested follows the same trend as in the Status Quo scenario since the harvest practices remain unchanged.



[24] Data gathered and processed by Sociedad Peruana de Ecodesarrollo (http://www.spde.org/) from various state agencies such as the Regional Government, the Ministry of Agriculture, or the Direction of Forestry and Wildlife.

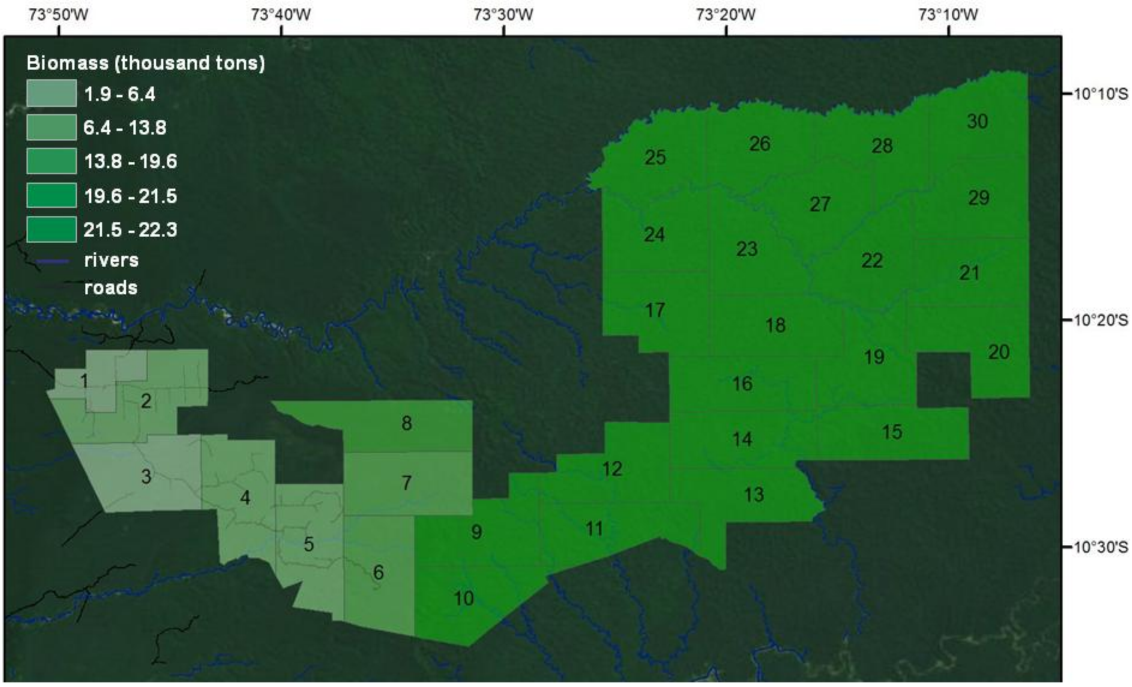


Figure 19: Results from the Managed Timber Production model applied to the CFA concession under the Price Rise scenario (i.e. continuation of the present management but including a 3.7% rise in timber prices). TNPV: total net present value of the forecasted timber extraction until 2036. Biomass: total harvested biomass. Numbers correspond to the parcels listed in the CFA management plan.

Conclusions

The total biomass extracted from the CFA concession follows a growing trend from the beginning of the extraction activities until the maximum allowable cut per year is attained, after which there are not expected variations.

In general, the central parcels of the CFA concession (7-11) seem to be the ones providing maximum profits under all the scenarios, while the last parcels tend to present relatively low net present values. However, these results are heavily dependent on the market discount rate and the prices and costs' trends, which could be better tailored for CFA. The smaller benefits obtained from some of the first parcels just reflect the start of the extraction activities.

Lessons learnt

- Detail management and harvest practices, cost and prices from the managed timber exploitation are crucial to run this kind of model.
- Accuracy (the spatial resolution of model results) is limited to the exploitation parcels' size.
- The results and the definition of the scenarios would benefit from a deeper analysis of the prices and cost trends (economic and market analysis).
- The market discount rate is a critical factor in such a long-term analysis and should be adapted to the actual regional conditions.
- More accurate results would be obtained if the mass of timber extracted (instead of the volume) could be available. Alternatively, the volumes should be transformed into mass species by species with specific density data.

- This InVEST model shows serious limitations to account for the natural provision of ecosystem services. It mostly focuses on the exploitation of natural resources (timber) and their economic returns (the final value of the benefits), without considering other key factors such as sustainable practices, conservation zones, clear-cut vs. selective logging, etc. The application of other (more natural-based) ecosystem service models would provide a more complete picture of the study area.

4.4.2. Climate regulation – carbon sequestration

Carbon storage on land depends on the sizes of four carbon pools: aboveground biomass, belowground biomass, soil and dead organic matter. Aboveground biomass comprises all living plant material above the soil (e.g. trunks, branches, leaves); belowground biomass encompasses the living root systems; soil organic matter is the organic component of soil (normally the largest terrestrial carbon pool); and dead organic matter includes litter and both lying and standing dead wood. The InVEST Carbon Storage and Sequestration model aggregates the amount of carbon stored in these four pools according to the land use maps and input data.

The ideal data source for all carbon stocks is a set of local field estimates for each of the classes of the LULC map, where carbon storage for all relevant stocks has been directly measured. However, in most of the cases these measurements are not available. In the Ucayali trial we use detailed land cover maps derived from the EO products together with global data sources adapted to the case study, mostly coming from IPCC (2006)[25].

The InVEST carbon model is divided into different modules. First, it runs the biophysical model which depends on the land cover and associated carbon pools. The biophysical analysis can be used to estimate carbon storage (the amount of organic carbon trapped by the ecosystem) and/or carbon sequestration (the rate of carbon removed or emitted into the atmosphere during a certain period). Then, the tool includes a valuation model that approximates the market value of the carbon sequestered by the ecosystems during a specific time. As already mentioned by the InVEST documentation, the CO_2 market values (e.g. European Union Emission Trading Scheme, Australia's Carbon Price Mechanism, Chicago Climate Exchange) may reflect policies, subsidies and other purely market factors and may not indicate the true value of this service to society[26]. If any valuation is to be applied, it is recommended to use the social cost of carbon (SCC) defined as the avoided damage cost associated with the emission of CO_2 into the atmosphere.

In the Ucayali case study, the Amazonian dense forest covers nearly 97% of the area (as for 2002) and shows relatively minor changes between 2002 and 2012. Thus, the estimated carbon sequestration among those dates (as calculated by the InVEST tool) is relatively low compared with the total carbon stock. Providing an economic valuation of that minor carbon sequestration could be misleading, since the most important role provided by this forest habitat is carbon storage and avoided CO_2 emissions from deforestation. In the absence of a tool to value carbon storage and avoided emissions, we prefer to quantify this ecosystem service only in biophysical terms.

In order to select the appropriate input data from global databases for this model, we had to establish the eco-region of the study area. Ucayali is located at the fringe between Mixed mountain system (or Tropical mountain system), Amazonian moist forests, and Tropical and subtropical moist broadleaf forests (or Tropical rain forest), depending on the source of information that define different eco-regions. Based on the ancillary

[25] IPCC (2006). 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Volume 4: Agriculture, Forestry and Other Land Use. Prepared by by the National Greenhouse Gas Inventories Programme, Eggleston, HS, L. Buendia, K. Miwa, T. Ngara, and K. Tanabe (eds). Published: Institute for Global Environmental Strategies (IGES), Hayama, Japan. Available at: http://www.ipcc-nggip.iges.or.jp/public/2006gl/

[26] Murray, B., B. Sohngen, M. Ross (2007). Economic consequences of consideration of permanence, leakage and additionality for soil carbon sequestration projects. Climatic Change 80:127-143.

information of the project, on maps extracted from [27,28], and on the fact that the maximum altitude of the study area is around 500 m, we fixed Tropical and subtropical moist forests as the eco-region of this trial.

Input data for the InVEST model: Carbon Storage and Sequestration

Table 17: Data inputs as required by the Carbon Storage and Sequestration InVEST tool (first column) and data sources used in the Ucayali trial (second column). See the general data description of these inputs in Table 3.

Model input	***Data source used in this trial***
Current land use/land cover (LULC) map (required)	There is a land cover map 2012 for the study area at 30 m resolution with 12 classes. However, for this model we will need more detailed information within the class forest and shrub. Thus, we better use the Forest Maps 2002, 2007 and 2012 (depending on the scenario) that specify primary and dense forest, open forest and shrub, and woodland and shrub. In general, all the other land cover is set to zero carbon content.
Carbon pools (required)	**C_above:** Dry matter had been estimated from the EO products based on forest density and biomass ranges for tropical forests (IPCC 2006 – Table 4.7). • Primary and dense forest: it is assumed to have the largest biomass (dry matter) of the study area (400 t dm/ha) which is transformed into carbon fraction using Table 4.3 of IPCC 2006 (0.47 t C/t dm for Tropical and Subtropical domains) = 188 Mg/ha • Open forest and shrub: it is assumed to have just half the biomass of the dense forest (which agrees with the InVEST tool default values) = 94 Mg/ha • Woodland and shrub: biomass is taken from Table 4.12 of IPCC 2006 (70 t dm/ha for tropical shrubland) and transformed as above = 33 Mg/ha • Other LC classes are assumed to have insignificant carbon storage compared with the forested classes = 0 Mg/ha **C_below:** For land dominated by woody biomass, belowground biomass can be estimated roughly with the “root to shoot” ratio (belowground to aboveground biomass). Default estimates are given in Table 4.4 of IPCC 2006. • Primary and dense forest: conversion factor for tropical moist deciduous forest with aboveground biomass >125 t/ha = 0.24 • Other woody classes: conversion factor for forest with aboveground biomass <125 t/ha = 0.20 **C_soil:** We extract soil maps and information for Ucayali from[29 30]. CFA has Ferralsols and Acrisols (i.e. low activity clay minerals (LAC), highly weathered soils). Table 2.3 of IPCC (2006) contains estimates of soil carbon stocks by soil type, assuming these stocks are at equilibrium (under native vegetation) and have no active land management. Thus, we take C_soil in 0-30 cm depth for LAC soils in tropical moist from Table 2.3 for all forested classes = 47 t C/ha. Other LC classes are assumed to have 0 Mg/ha. **C_dead:** We follow Delaney et al. (1998)[31], who estimated carbon stored in standing and down dead wood in six tropical forests of South America being typically 1/10 of the aboveground biomass. For non-forested types, litter is 0.

[27] Global Ecoregions Map developed by the World Wildlife Fund from a synthesis of existing ecological classifications 2001. http://www.fao.org/geonetwork/srv/en/resources.get?id=1009&fname=1009.zip&access=private.

[28] Global Ecoregions Map by Robert G. Bailey of the U.S. Fish and Wildlife Service (1989, last update 2002). http://www.fao.org/geonetwork/srv/en/resources.get?id=1038&fname=bailey.zip&access=private.

[29] ISRIC - World Soil Information (2005). The Soil and Terrain database for Latin America and the Caribbean (SOTERLAC) version 2, 1:5M. Update from the: FAO, ISRIC, UNEP and CIP 1998. Land and Water Digital Media Series 5. FAO, Rome.

Current harvest rates map (optional)	Not applicable in this trial. The main reasons are: (1) the harvested timber volume and area are insignificant in comparison with the entire forested zone or are not documented (in particular beyond the CFA concession); and (2) the decay rate of the timber products is not known.
Future Scenarios (optional – required for valuation)	For some scenarios we use the 2012 Forest Map as the future LULC map.
REDD scenario LULC map (optional)	Not applicable in this trial
Economic data (optional – required for valuation)	Not applicable in this trial (see explanation above this table).

Table 18: Contribution of EO products, in-situ data and global information as inputs for this InVEST model. Green dot = direct contribution specifically designed for this project. Yellow dot = indirect contribution usually coming from global/regional data sets.

Carbon sequestration	**EO**	**in-situ**	**other**
Land use/land cover (LULC) (required).	🟢		
Carbon pools (required)	🟡		🟡
Current harvest rates map (optional).	N/A	N/A	N/A
Future Scenarios (optional – required for valuation)	🟢		
REDD scenario (optional)	N/A	N/A	N/A
Economic data (optional – required for valuation).	N/A	N/A	N/A

Scenarios for the InVEST model

Scenario 2002

It reflects the carbon stored in the forested classes of the Ucayali trial in the year 2002. It is based on the Forest Map 2002 and the carbon pools estimated for Ucayali. It is calculated with the InVEST biophysical model (without sequestration, uncertainty, or valuation) and provides a map of tonnes of carbon per grid cell that has been transformed into tonnes of organic carbon per hectare (Figure 20). The estimated carbon stored in the study area in 2002 was 127,997,397 tonnes of carbon.

[30] Digital Soil Map of the World (SMW) of FAO/Unesco. Described at http://www.fao.org/icatalog/search/dett.asp?aries_id=103540 and available at http://worldmap.harvard.edu/data/geonode:DSMW_RdY

[31] Delaney M, S Brown, AE Lugo, A Torres-Lezama, NB Quintero (1998). The quantity and turnover of dead wood in permanent forest plots in six life zones of Venezuela. Biotropica 30: 2-11.

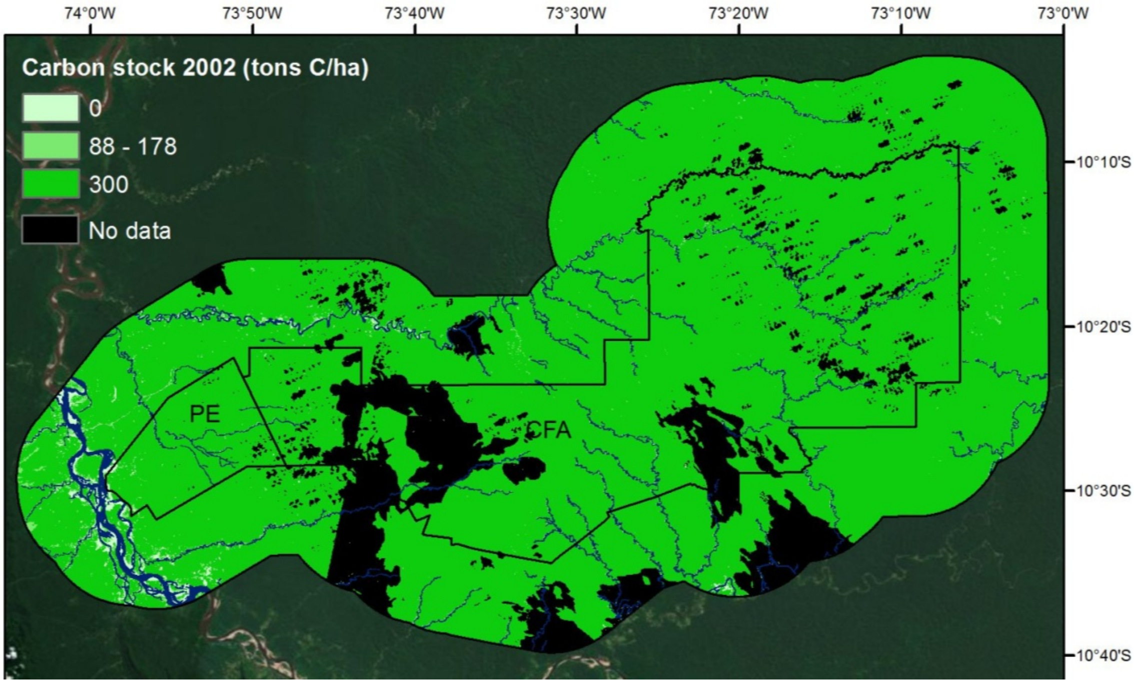


Figure 20: Results from the carbon storage module applied to the Ucayali trial under the 2002 conditions. The total estimated carbon stored is about 128 million tons. Note that the black areas were cloud-covered and were left out of the calculations.

Scenario 2007

It reflects the carbon stored in the forested classes of the Ucayali trial in the year 2007. It is based on the Forest Map 2007 and follows the same procedure as above. The estimated storage for 2007 was 143,848,889 tonnes of carbon (Figure 21).

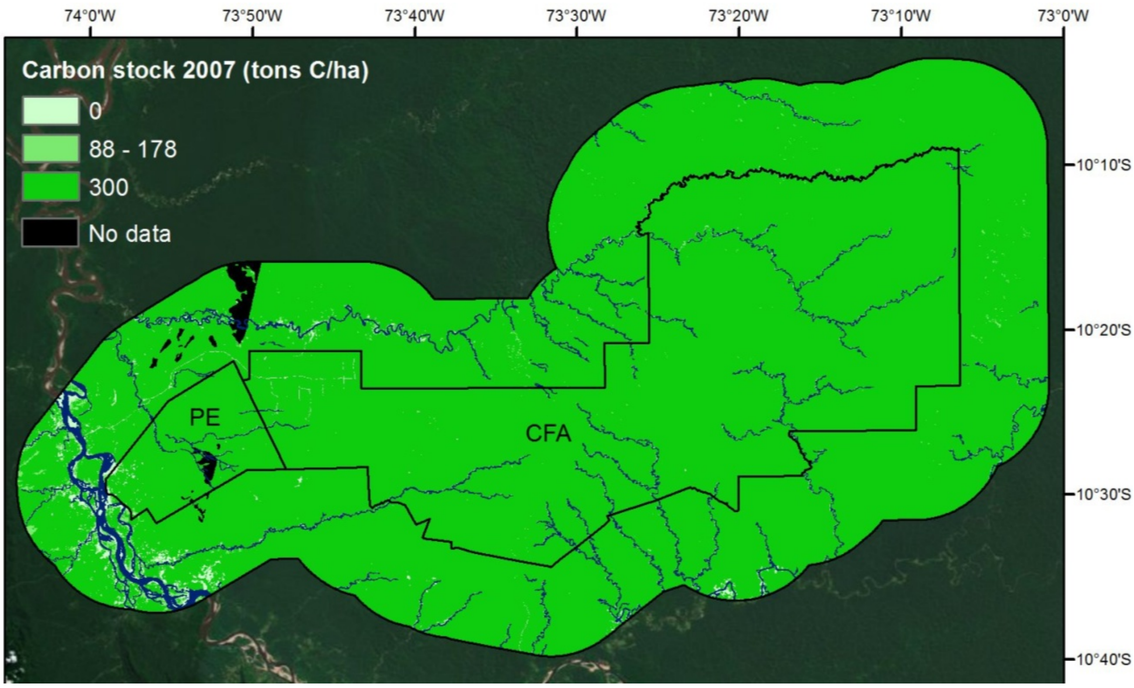


Figure 21: Results from the carbon storage module applied to the Ucayali trial under the 2007 conditions. The total estimated carbon stored is about 144 million tons. Note that the black areas were cloud-covered and were left out of the calculations.

Scenario 2012

It reflects the carbon stored in the forested classes of the Ucayali trial in the year 2012. It is based on the Forest Map 2012 and same procedure as above. The approximate carbon storage in 2012 was of 135,815,973 tonnes (Figure 22).

The estimated storage derived from these scenarios cannot be directly compared since the original EO-derived forest maps contained variable patches of no data (clouds cover) that were assigned a 0 carbon pool. As a result, the total carbon stored is expected to be slightly underestimated. For the analysis of temporal trends, the carbon sequestration module should be applied, as below.

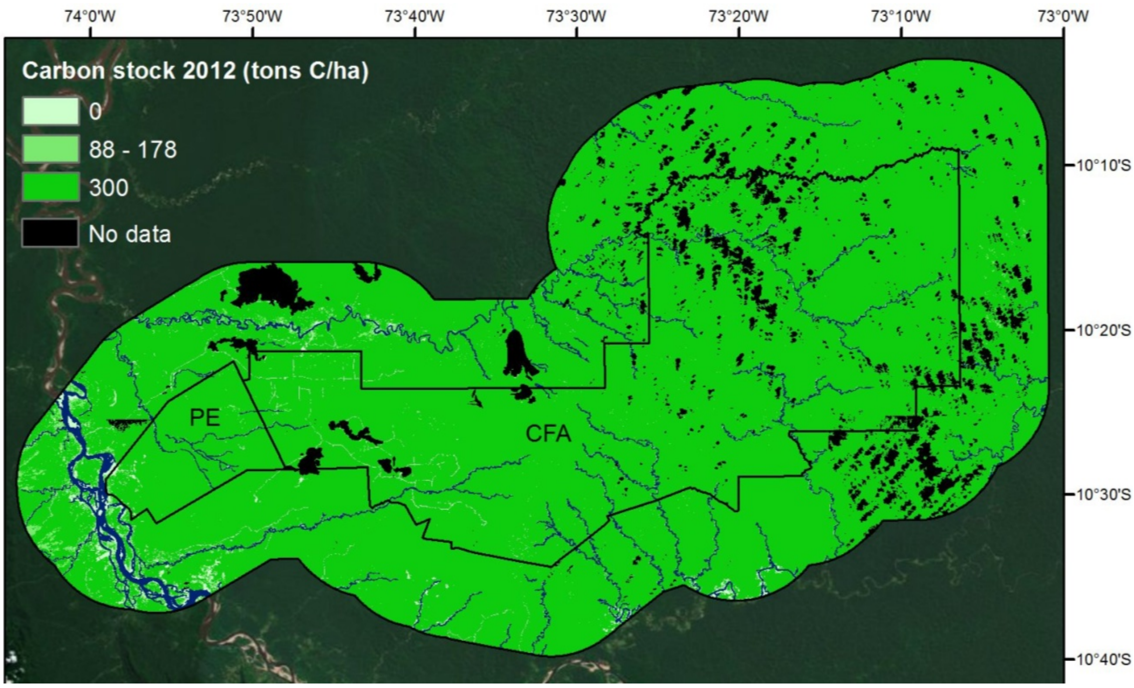


Figure 22: Results from the carbon storage module applied to the Ucayali trial under the 2012 conditions. The total estimated carbon stored is about 136 million tons. Note that the black areas were cloud-covered and were left out of the calculations.

Scenario 2002-2012

It reflects the carbon sequestered in the forested classes of Ucayali between the years 2002 (current LC) and 2012 (future LC), using modified forest maps that exclude all the no data patches in all the original maps (in order to make them comparable), and the same carbon pools as above. It is calculated with the InVEST biophysical model with sequestration (without harvest, uncertainty, or valuation) and provides a map of tonnes of carbon retained/emitted per grid cell between 2002 and 2012 that has been transformed into tonnes of organic carbon per hectare (Figure 23). The estimation of overall carbon sequestered is a loss of 1,082,733 tonnes of carbon.

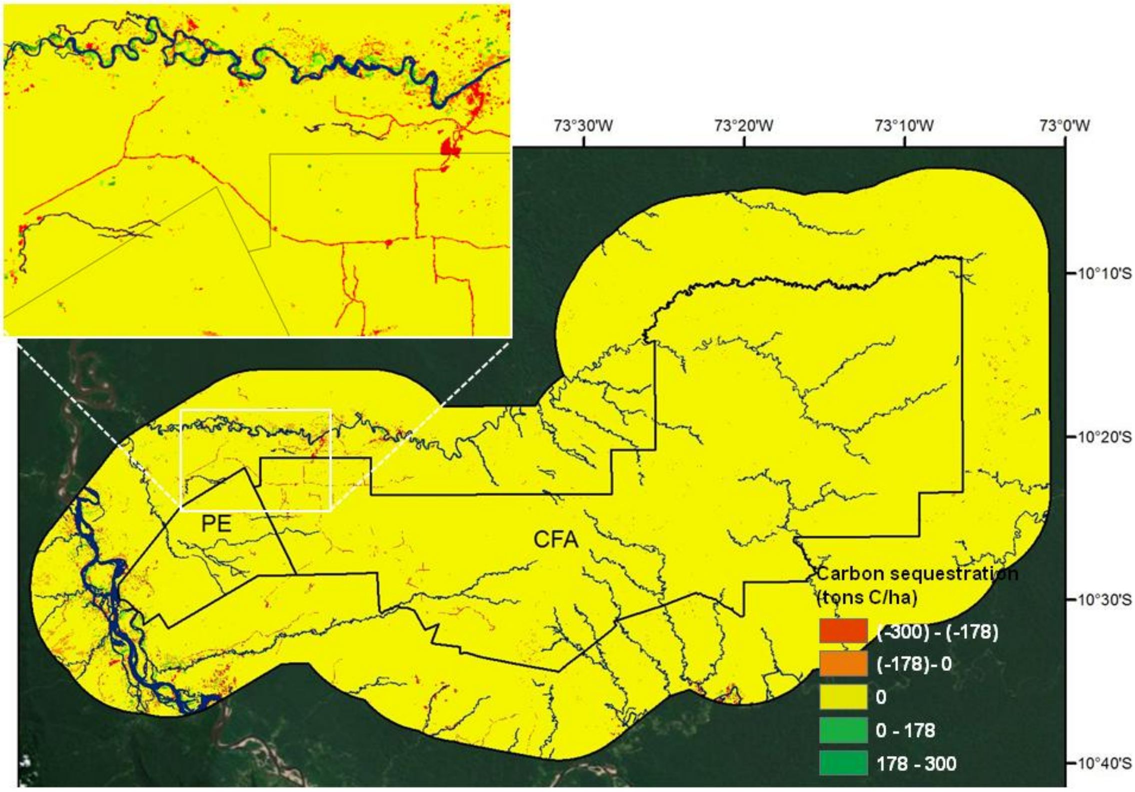


Figure 23: Results from the carbon sequestration module applied to the Ucayali trial between 2002 and 2012. Positive numbers point to areas where carbon has been sequestered while negative values correspond to net releases of carbon to the atmosphere. No data values have been excluded from the calculation. CFA: concession area of the Consorcio Forestal Amazonico. PE: Puerto Esperanza native community area. The upper inset shows a zoom between the two concessions and the outer buffer zone.

The results from this scenario have been disaggregated into the area of the CFA concession, the Puerto Esperanza community and the surrounding 10 km zone (Table 19). The areas with positive trends in terms of carbon sequestration are always smaller than the ones with negative trends. CFA has the most stable situation (minor changes), with only 0.4% of its total coverage responsible of net carbon releases. This proportion is four times larger in the area controlled by the native community Puerto Esperanza. Deforestation and carbon emissions are particularly important (up to 2.2% of areal coverage in 10 years) in the surrounding zones.

Table 19: Summary of carbon sequestration results under the 2002-2012 scenario (as illustrated in Figure 23).

Zone	Total area (km^2)	Positive change (%)	No change (%)	Negative change (%)
CFA	1804	0.1	99.6	0.4
PE	187	0.6	97.7	1.6
Buffer zone	3001	0.9	96.9	2.2

Conclusions

Carbon storage and sequestration is a very important ecosystem service in tropical forests. The results of carbon storage in the Ucayali trial for the years 2002, 2007 and 2012 are very consistent, depend mostly on the dense forest class and show some major variations linked to data gaps (clouds cover) in the original EO products.

In general, the most important changes in carbon content are concentrated in the westernmost part of the study area, around the major river courses or along the new roads for the timber exploitation activities. The observed temporal changes in forest coverage between 2002 and 2012 show a net release of carbon to the atmosphere of about 100,000 t/yr or 0.9% of the total carbon stored in 2002.

Lessons learnt

- The land cover of the study area is relatively homogeneous and dominated by dense forest, so to appreciate differences in carbon storage and sequestration we should focus on smaller, more detail cases. The resolution of the EO products (from 5 to 30 m resolution) would allow for such detailed analyses.
- The differentiation among forested classes (like the one provided in the forest maps) allows for a more accurate analysis of carbon storage and sequestration than a standard land cover map.
- The availability of local estimations of carbon pools (aboveground, belowground, soil and dead material) per forested class would improve the quality of the results. The use of global carbon pools provides only a first approach.
- The differences in forest density observed within the timber extraction concessions in this trial can only have a minor influence in the final outputs of the carbon storage and sequestration model, at least at the scale of this analysis.
- We miss some kind of valuation of the carbon stock (carbon storage) found in natural habitats, especially for areas where there are not major changes in land cover, like this trial. The economic valuation of the model is only based on the net carbon retained/emitted (carbon sequestration). In addition, a deep knowledge of carbon economy (market fluctuations, social values, market discount rate, etc.) would be needed to apply a correct monetary valuation in these cases.

4.4.3. Biodiversity

The spatial basis for the evaluation of biodiversity and threatended habitats is an up-to-date land cover map depicting forested areas and other relevant land cover types with high spatial detail. Spatially highly detailed EO products, including detailed forest changes, have been produced by GeoVille for the Ucayali site in Peru in the frame of this project. These datasets can also be used as basis for developing potential future land use scenarios.

The study area of Ucayali covers the concession area of CFA and the native community of Puerto Esperanza including a buffer of 10 km surrounding the two core areas. Forest is the dominating land cover class criss-crossed by meandering rivers. Settlements and agricultural areas are predominately located in the western part of the area of interest along rivers outside the core areas. But there is also a road network within the CFA concession expanding along the defined parcels used for the exploitation of timber. Therefore, the main threats for biodiversity in the study area besides the settlements (incl. isolated rural villages) and the agricultural areas are the transport infrastructure used for exploitation of timber. The land cover map reveals that settlements, agricultural areas and grassland are located along roads and rivers. So the river network can be identified not only as habitat but also as threat for habitats (i.e. medium for transport and exploitation).

Threats have different impacts on habitats declining with increasing distance. Therefore, the biodiversity model not only takes into account the weight and the maximum distance of the effects of the threats but also the sensitivity of habitats to specific threats. As a result the model provides non-monetized information about the habitat degradation and quality within the study area.

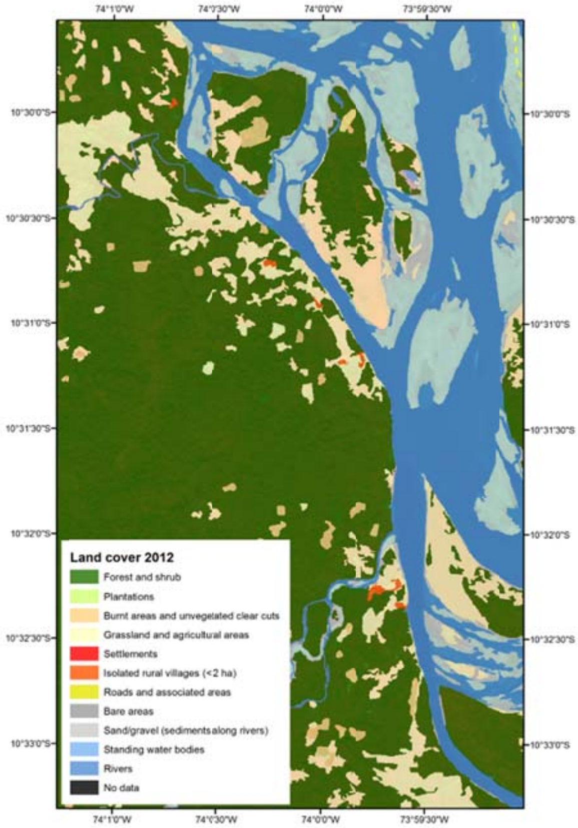


Figure 24: Example of land cover along rivers in Ucayali 2012.

Input data for the InVEST model: Biodiversity

Table 20: Data inputs as required by the Biodiversity: Habitat Quality & Rarity InVEST tool (first and second columns) and data sources used in the Ucayali trial (third column). See the description of input data in Table 7.

Model input	***Field***	***Data source used in this trial***
Current land use/land cover (LULC) map (required).		There is a land cover map 2012 for the study area at 5 m resolution with 12 classes.
Future land use/land cover (LULC) map (optional).		N/A
Baseline LULC map (optional)		N/A
Threat data (required).	THREAT	The LC classes like “grassland and agricultural areas”, “plantations”, “settlements/villages”, “roads and associated areas”, “water” (as potential transportation route) were defined as threats.
	MAX_DIST	Due to missing in-situ data values from 1 to 10 km for the specific threats were used for calculations.
	WEIGHT	Due to missing in-situ data relative values from 0.5 to 1 were used for calculations.

Sources of threats (required)		Due to missing in-situ data values from 1 to 10 km for the specific threats were used for calculations.
Accessibility to sources of degradation (optional)		N/A
Habitat types and sensitivity of habitat types to each threat (required).	LULC	Numbers correspond to those from the land cover map
	NAME	Names correspond to those from the land cover map
	HABITAT	Each land cover class was assigned 1 for habitats and 0 for none-habitats.
	L_THREAT1, L_THREAT2, etc.	Values from 0 to 1 were assigned to every land cover class depending on its sensitivity to specific threats. For example the relative sensitivity of land cover class “forest” to the threat “urban areas” is at maximum (1). Otherwise, the relative sensitivity of forest to the threat “water” is 0.7.
Half-saturation constant (required)		Default value of 0.5 was used for calculations.

Table 21: Contribution of EO products, in-situ data and global information as inputs for this InVEST model. Green dot = direct contribution specifically designed for this project. Yellow dot = indirect contribution usually coming from global/regional data sets.

Biodiversity	**EO**	**in-situ**	**other**
Current land use/land cover (LULC) map (required)			
Future LULC map (optional)	N/A	N/A	N/A
Baseline LULC map (optional)	N/A	N/A	N/A
Threat data (required)			
Accessibility to sources of degradation (optional)	N/A	N/A	N/A
Habitat types and sensitivity of habitat types to each threat (required)			
Half-saturation constant (required)			

Scenario for the InVEST model

The idea behind the following scenario is to visualize the effects of human influence to the site based on the high resolution land cover map generated for 2012. Therefore, a simple approach was chosen assuming that all land cover classes created or influenced by humans, like settlements, road network, plantations, agricultural areas and grassland (as well as water in this particular context) were defined as threats to habitats. The land cover class “water” was defined as threat because the rivers are an important medium for transport and exploitation. The results of the biodiversity model should therefore visualize the general degradation of biodiversity caused by human impact as well as the quality of habitats.

Due to the consideration of rivers as potential threat to habitats the degradation in the western part is relatively high in comparison to regions (i.e. dense forest). Clearly visible is also the road network used for the exploitation of timber. In the eastern part of the study area the source of degradation are the rivers. Due to missing information no distinction was made whether specific rivers are currently used for exploitation or not.

It has to be taken into account that a maximum relative value of 0.151976 is very low compared to less remote areas which are more influenced by anthropogenic pressures (e.g through urbanisation, intensive agriculture or widespread deforestation)

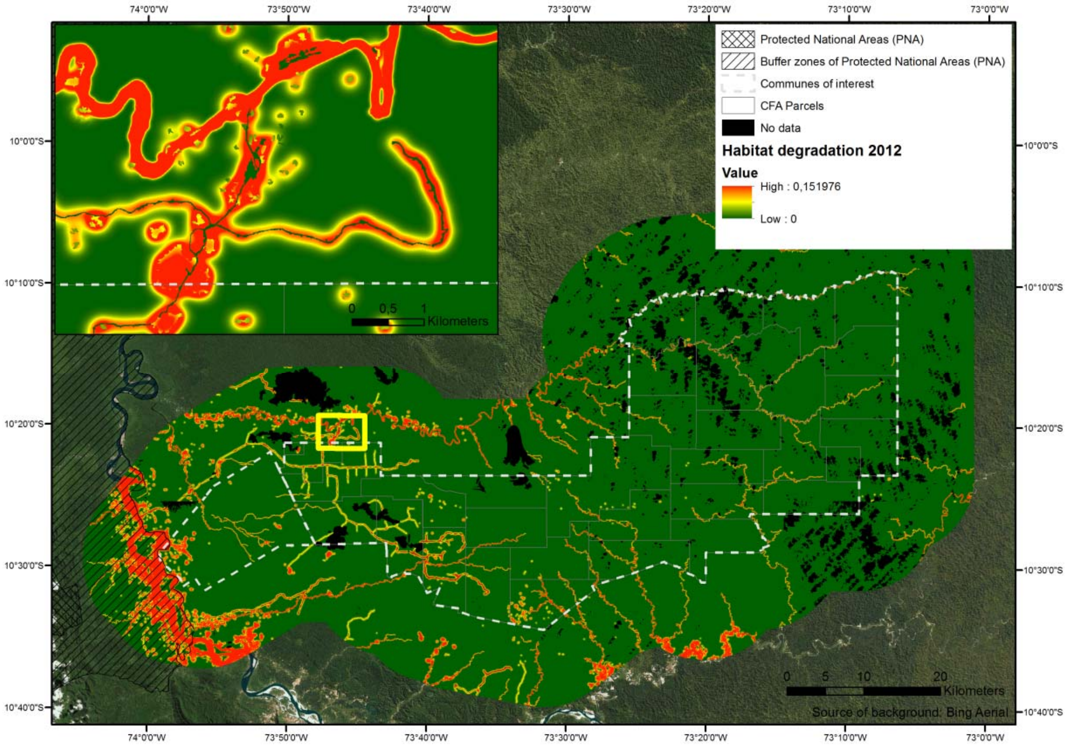


Figure 25: The habitat degradation is predominantly along the rivers and roads used for transport and the exploitation of the forest. Green is undisturbed habitat; yellow to red visualize raising degradation. The striped and chequered areas in the eastern part of the trial area are protected areas resp. buffer zones around the protected areas. Areas without data coverage like clouds are visualised in black. The result from the Biodiversity model applied to the Ucayali trial for 2012.

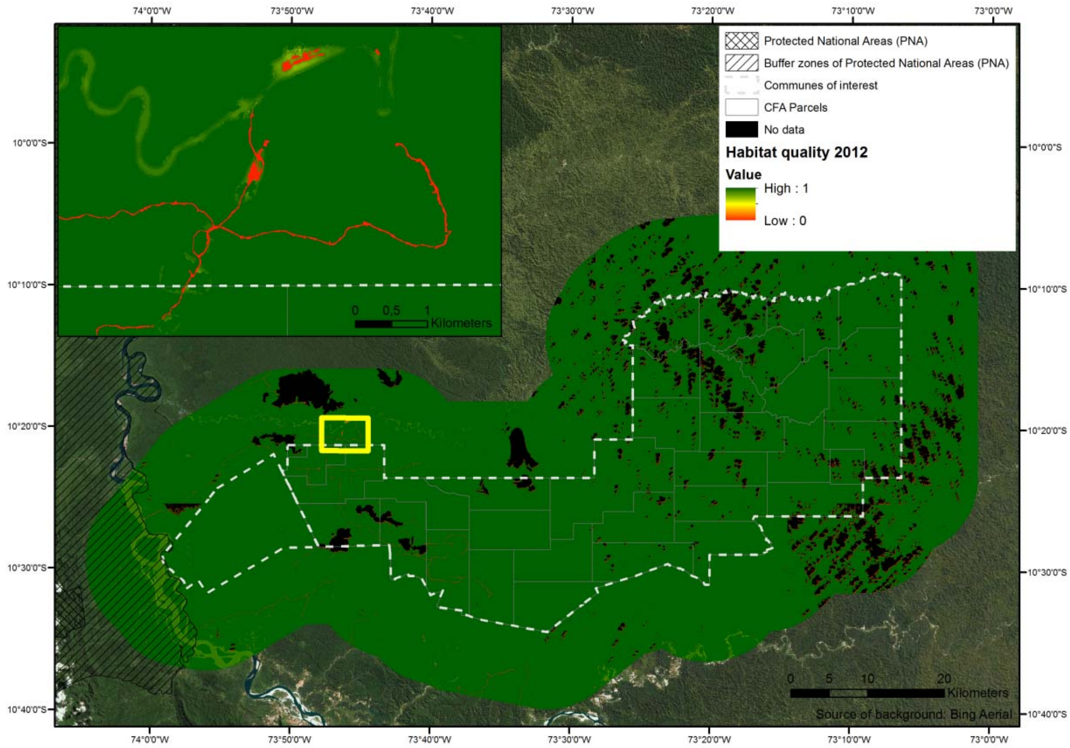


Figure 26: The habitat quality is quite high in the trial area (green). The decline of the habitat quality is intensifying (from yellow to red) towards infrastructure and settlements as visualised in the detailed view. Areas without data coverage like clouds are visualised in black. The result from the Biodiversity model applied to the Ucayali trial for 2012.

Figure 26 visualizes the habitat quality of the study area. Higher numbers indicate better habitat quality vis-a-vis the distribution of habitat quality across the rest of the landscape. Areas on the landscape that are not habitat like roads and associated areas, settlements and no data areas (i.e. clouds) get a quality score of 0.

Conclusions

Due to the homogeneity of the study area especially in the eastern part of the AOI which is dominated by natural and dense forest the overall quality of biodiversity is high. The results of the biodiversity model reveal the considerable human impact on habitats predominately through the development of roads, rivers used for transport and exploitation, extension of agricultural land and urban growth. Thanks to the high degree of detail from the EO input data (i.e. land cover map with 5 m resolution) **it would be possible to identify even small scale impacts from threats (e.g. hamlets) to biodiversity.**

Lessons learnt

- The homogeneity of the study, dominated by natural and dense forest, as well as missing detailed in-situ data enables only a generic approach.
- Due to the size of the study area (~5000 km²) and the high resolution of the input data (resolution: 5 m) it was not possible to calculate the whole area at once. Therefore, the study area was divided into overlapping tiles for the calculation of the biodiversity model. Finally they were put together to get a single result for the whole study area.
- High resolution EO products are main inputs for the models used for the valuation of ecosystem services defining the resolution and quality of the outputs.
- Detailed in-situ data would improve calculation and results of the biodiversity model.

4.5. Service trial #4A – Yucatán (México)

4.5.1. *Coastal vulnerability*

Coastal areas provide essential resources for wildlife (e.g. key nursery habitats), human well-being (e.g. recreation opportunities) and economy (e.g. fisheries). Coastal ecosystems may contribute between 36% and 77% of global ecosystem services value[32,33]. Coasts are also the preferred space for human settlement with three times the average population density compared to the global average density[34]. The increasing pressure and demand for coastal resources causes habitat loss and degradation, pollution and overexploitation, thus leading to the degradation of coastal ecosystems. This degradation may have large negative social and economic consequences. In the case of the Yucatan trial, the coastal area is not only a natural monument (part of the Mesoamerican Reef System, the second largest reef barrier in the world) but also a major source of income for the local population (mainly through tourism and fisheries).

The InVEST Coastal Vulnerability model helps understand how modifications of the biological and physical environment can affect coastal exposure to storm-induced erosion and flooding. The model requires at least seven bio-geophysical variables (geomorphology, relief, natural habitats, sea level change, wind exposure, wave exposure and surge potential) and a spatial representation of population. It provides as an output a qualitative Vulnerability Index, which differentiates areas with relatively high or low exposure to erosion and inundation during storms. This information can help coastal managers, planners, landowners and other stakeholders identify regions of greater risk to coastal hazards.

Input data for the InVEST model: Coastal Vulnerability

Table 22: Description of the data inputs as required by the Coastal Vulnerability InVEST tool (first and second columns) and data sources used in the Yucatán trial (third column).

Model input	***General data description***	***Data source used in this trial***
Output area	Specify whether all or only the sheltered shoreline segments appear in the output. This option has no effect on the computation performed by the model, and only affects the shore segments that appear in the output files.	Both
Area of Interest (AOI, required)	Users must create a polygon feature layer that defines the Area of Interest (AOI). An AOI instructs the model where to clip the Land Polygon input data (inputs #2-3) in order to define the spatial extent of the analysis. The model uses the AOI's projection to set the projection for the sequential intermediate and output data layers and must have a WGS84 datum. In order to allocate wind and wave information from the Wave Watch 3 data (WW3), this AOI must also overlap one or more of the provided WW3 points. If users are including the Surge Potential variable in the computation of the exposure index, the depth contour specified in the Coastal Vulnerability model	An elongated rectangle perpendicular to the coast that fulfils all the requirements of the description was assigned as AOI. The projection of all layers is UTM Zone 16N WGS 1984 (EPSG: 32616).

[32] Martínez, M.L., Intralawan, A., Vázquez, G., Pérez-Maqueo, O., Sutton, P., Landgrave, R., 2007. The coasts of our world: Ecological, economic and social importance. Ecol. Econ. 63(2-3), 254-272.
[33] Costanza, R., 1999. The ecological, economic, and social importance of the oceans. Ecol. Econ. 31(2), 199-213.
[34] Small, C., Nicholls, R.J., 2003. A global analysis of human settlement in coastal zones. J. Coast. Res. 19(3), 584-599.

	must be specified, and the AOI must intersect that contour. If the AOI does not intersect that contour, the model will stop and provide feedback.	
Land Polygon (required)	This input provides the model with a geographic shape of the coastal area of interest, and instructs it as to the boundaries of the land and seascape. A global land mass polygon shapefile is provided as default, but other layers can be substituted. If users have a more accurate, local polygon shapefile representing land masses, they are encouraged to use this data rather than the provided shapefile.	Land mask derived from the EO products, in particular from an intermediate processed image from 2009.
Bathymetry layer (required)	This input is used to compute the average depth along the fetch rays to determine the exposure of each shoreline segment, and in the computation of surge potential. It should consist of depth information of bodies of water within the AOI as marked by the land polygon shapefile.	Estimated seafloor topography of the Gulf of Mexico based on SRTM3 PLUS V6.0[35]. The high resolution bathymetric map derived from satellite images did not cover the entire AOI.
Layer value if path omitted (optional)	Integer value between 1 and 5. If bathymetry is omitted, replace all shore points for this layer with a constant rank value in the computation of the coastal vulnerability index. If both the file and value for the layer are omitted, the layer is skipped altogether.	Not applicable.
Relief (required)	Digital Elevation Model (DEM). This input is used to compute the Relief ranking of each shoreline segment. It should consist of elevation information covering the entire land polygon within the AOI. Focal statistics are computed on the input DEM within a range defined by the user (see Elevation averaging radius). The average of elevation values within this range is ranked relative to all other coastline segments within the AOI. Although the default raster for this layer is the same as for Bathymetry, each entry can refer to a separate raster, where one computes elevations above water, and the other below water.	DEM of the Quintana Roo region, Mexico, extracted from [36].
Layer value if path omitted (optional)	Integer value between 1 and 5. If relief is omitted, replace all shore points for this layer with a constant rank value in the computation of the coastal vulnerability index. If both the file and value for the layer are omitted, the layer is skipped altogether.	Not applicable.
Elevation averaging radius (meters, required)	This input determines the radius around within which to compute the average elevation for relief.	250 m (default was 5000, but with our input data we can apply a higher resolution)
Mean sea level datum (meters, required)	This input is the elevation of Mean Sea Level (MSL) datum relative to the datum of the bathymetry layer that they provide. The model transforms all depths to MSL datum by subtracting the value provided by the	0 m (default)

35 http://gcoos.tamu.edu/products/topography/Introduction.html, http://topex.ucsd.edu/WWW_html/srtm30_plus.html
36 Instituto Nacional de Estadistica y Geografia (2010). Continuo de Elevaciones Mexicano 2.0, 30x30 m, http://www.inegi.org.mx/geo/contenidos/datosrelieve/continental/.

	user to the bathymetry. This input can be used to run the model for a future sea-level rise scenario.	
Smallest detectable feature (segment size in meters, required)	This input determines the spatial resolution at which the model runs and the resolution of the output rasters. To run the model at 250 x 250 meters grid cell scale, users should enter “250”. A larger grid cell will yield a lower resolution, but a faster computation time.	250 m (default)
Rays per sector (required)	Number of rays used to sample the ocean depth and land proximity within each of the 16 equiangular fetch sectors.	1 ray (default)
Fetch Distance Threshold (meters, required)	Used to determine if the current segment is enclosed by land. This input is used in conjunction with the average ocean depth and exposure proportion to differentiate sheltered and exposed shoreline segments.	After several trials aimed at detecting sheltered or enclosed coast in the study area, we fixed 8000 m (default was 12000)
Depth Threshold (meters, required)	Used to determine if the current segment is surrounded by deep water. This input is used in conjunction with the fetch distance threshold and exposed segment to differentiate between sheltered and exposed shoreline segments.	5 m (default was 0)
Exposure proportion (meters, required)	The model uses this input (between 0.0 and 1.0) to determine if shore segments are exposed or sheltered. This is done in four steps: Compute the number of fetch rays (N) that correspond to the proportion N segments over water*exposure proportion Determine if the current segment is in deep water (at least N sectors project over water that is at least “depth threshold” meters) Determine if the current segment is enclosed by land (at least N fetch rays have to be blocked by land, i.e. fetch distance is less than “ocean effect cutoff” meters). Determine segment exposure: a shore segment is exposed if it is both in deep waters, and not enclosed by land (facing open water), otherwise, it is sheltered. In other words, if the fetch threshold is 12 km and the depth threshold is 5 m, and the exposure proportion is 0.8, the model will classify a segment as sheltered if less than 80% of the segments have a fetch distance lower than 12 km *or* the average depth along each fetch segment is less than 5 m.	After several trials aimed at detecting sheltered or enclosed coast in the study area, we fixed 0.7 (default was 0.8)
Oceanic effect cutoff (meters, required)	Used as a threshold to determine if a shore segment is enclosed by land. See Exposure proportion, step 3.	12000 m (default)
Geomorphology: Shoreline Type (optional)	This input is used to compute the Geomorphology ranking of each shoreline segment. It does not have to match the land polyline input, but must resemble it as closely as possible. If it doesn’t, the model will try to match the coastlines using the coastal overlap parameter. Additionally, the polyline shapefile must have a field called “RANK” that identifies the various shoreline type ranks with a number from 1-5.	Two different inputs were created based on (1) the coastline derived from the 2009 land mask, and (2) the shoreline type observed and interpreted from the satellite images of 1992 (1st input) and 2009 (2nd input). In both cases, the geomorphology

		fields were ranked as follows: reef=1, mangrove=2, beach with natural dune=3, beach with constructions=4, port=4.
Layer value if path omitted (optional)	Integer value between 1 and 5. If geomorphology is omitted, replace all shore points for this layer with a constant rank value in the computation of the coastal vulnerability index. If both the file and value for the layer are omitted, the layer is skipped altogether.	Not applicable.
Coastal overlap (meters, required)	Tolerance threshold in meters (that should be a multiple of cell size), to make 2 non-overlapping shorelines match. If the tolerance is twice the cell size, the model will be able to match shorelines that are 2 pixels off. If it is 4 times the cell size, the model will be able to match shorelines that are 4 pixels off, and so on. It's used when the shoreline from geomorphology doesn't overlap exactly with the shoreline from the land polygon shapefile.	250 m (default)
Natural Habitat (optional)	Directory that contains habitat layers. The model uses these input layers to compute a Natural Habitat ranking for each shoreline segment. All data in this directory must be polyline or polygon shapefiles that depict the location of the habitats, and must be projected in meters. Additionally, each layer must end with an underscore followed by a unique alpha-numeric number. The model uses that number to match the habitat layer to the information that users provide in the CSV table (see next input). The model allows for a maximum of eight layers in this directory. Do not store any additional files that are not part of the analysis in this directory. The distance at which this layer will have a protective influence on coastline can be modified in the natural habitat CSV table.	Individual maps of the main protective seabed habitats (coral reef, sparse coral, dense seagrass and medium seagrass) derived from the EO products of 1992 and 2009.
Natural Habitat Layers CSV (Table optional)	Users must provide a summary table to instruct the model on the protective influence (rank) and distance of natural habitat. Use the sample table provided as a template since the model expects values to be in these specific cells.	The protective influence has been ranked from highest to lowest as: coral reef=1, sparse coral=2, dense seagrass=3, medium seagrass=4. The assumed protection distance is 2 km for corals and 1 km for seagrass.
Layer value if path omitted (optional)	Integer value between 1 and 5. If natural habitats is omitted, replace all shore points for this layer with a constant rank value in the computation of the coastal vulnerability index. If both the file and value for the layer are omitted, the layer is skipped altogether.	Not applicable.
Climatic forcing grid (optional)	This input is used to compute the Wind and Wave Exposure ranking of each shoreline segment. It consists of a point shapefile that contains the location	The AOI was constructed so that it overlaps one point (lat 21°N, long

	of the grid points as well as wave and wind values that represent storm conditions at that location.	273.5°E) from the Wave Watch III[37] reanalysed data provided by InVEST, which is our main source of wind and wave data.
Layer value if path omitted (optional)	Integer value between 1 and 5. If climatic forcing grid is omitted, replace all shore points for this layer with a constant rank value in the computation of the coastal vulnerability index. If both the file and value for the layer are omitted, the layer is skipped altogether.	Not applicable.
Continental Shelf (optional)	This input is a global polygon dataset that depicts the location of the continental margin. It must intersect with the AOI polygon (input #2).	A more accurate polygon depicting the continental margin of the Gulf of Mexico (below 150 m depth) was derived from the bathymetry layer.
Depth contour level (meters, optional)	If no continental shelf is specified, the model will use the bathymetry data to trace a user-defined depth contour level and use it instead of the edge of the continental shelf.	Not applicable.
Sea Level Rise (optional)	Polygon Indicating Net Rise or Decrease. This input must be a polygon delineating regions within the AOI that experience various levels of net sea level change. It must have a field called “Trend”, which represents the rate of increase (mm/yr) of the sea level in a particular region.	Mean sea level trend (in mm/yr) was derived from satellite altimetry data between 1992 and 2010[38]. The altimeter products are produced by Ssalto/Duacs and distributed by Aviso with support from Cnes. In general, net sea level is rising significantly (over 2 mm/yr) in the study area.
Layer value if path omitted (optional)	Integer value between 1 and 5. If sea level rise is omitted, replace all shore points for this layer with a constant rank value in the computation of the coastal vulnerability index. If both the file and value for the layer are omitted, the layer is skipped altogether.	Not applicable.
Structures (optional)	Polygon shapefile that contains the location of rigid structures along the coast.	Not applicable.
Layer value if path omitted (optional)	Integer value between 1 and 5. If structures layer is omitted, replace all shore points for this layer with a constant rank value in the computation of the coastal vulnerability index. If both the file and value for the layer are omitted, the layer is skipped altogether.	Not applicable.
Population Raster (optional)	If provided, a raster grid of population is used to map the population size along the coastline of the AOI	A local population raster layer was built based on

[37] Tolman, H.L. (2009). User manual and system documentation of WAVEWATCH III version 3.14, Technical Note, U. S. Department of Commerce Nat. Oceanic and Atmosph. Admin., Nat. Weather Service, Nat. Centers for Environmental Pred., Camp Springs, MD.
[38] CNES (Centre National d’Etudes Spatials), 2010. AVISO Products: Map of Regional Patterns of Observed Sea Level. Available at: http://www.aviso.oceanobs.com/en/news/ocean-indicators/mean-sea-level/

	specified (input #4). A global population raster file is provided as default, but other population raster layers can be substituted.	the location of Mexican towns[39] and census data from 2010[40]. The number of inhabitants is quite consistent with the global data set suggested by InVEST but the distribution is more accurate in the local raster.
Min. population in urban centres (required)	Minimum population that has to live in the vicinity of a shore segment to be considered a urban centre. The vicinity is defined in the next input, "coastal neighbourhood".	2500 inhabitants (default was 5000)
Coastal neighbourhood (radius in m, required)	Radius defining the vicinity of a shore segment that is used to count the population living on or near the coast.	5000 m (default was 1000)
Additional layer (optional)	This additional layer can be any additional variable that users desire to add to the exposure index. It can be values of long-term shoreline change, for example. This layer must be a shapefile. Once all segments have a value, we rank them according to quartile distribution.	Not applicable.
Layer value if path omitted (optional)	Integer value between 1 and 5. If additional layer is omitted, replace all shore points for this layer with a constant rank value in the computation of the coastal vulnerability index. If both the file and value for the layer are omitted, the layer is skipped altogether.	Not applicable.

Table 23: Contribution of EO products, in-situ data and global information as inputs for this InVEST model. Green dot = direct contribution specifically designed for this project. Yellow dot = indirect contribution usually coming from global/regional data sets.

[39] INEGI (2010). Localidades de la República Mexicana, 2010, escala 1:1. Obtenido de Principales resultados por localidad (ITER). Censo de Población y Vivienda 2010. Editado por Comisión Nacional para el Conocimiento y Uso de la Biodiversidad (CONABIO). México, D.F. http://www.conabio.gob.mx/informacion/gis/layouts/loc2010gw.png.
[40] INEGI (2010). Censo de Población y Vivienda 2010. Principales resultados por localidad (ITER). http://www.microrregiones.gob.mx/catloc/

Coastal vulnerability	EO	in-situ	other
Area of Interest (AOI, required)	🟢		
Land Polygon (required)	🟢		
Bathymetry layer (required)	🟡		🟢
Layer value if path omitted (optional)	N/A	N/A	N/A
Relief (required)	🟡	🟢	
Layer value if path omitted (optional)	N/A	N/A	N/A
Elevation averaging radius (meters, required)			🟢
Mean sea level datum (meters, required)			🟡
Smallest detectable feature (segment size in meters, required)			🟡
Rays per sector (required)			🟡
Fetch Distance Threshold (meters, required)			🟢
Depth Threshold (meters, required)			🟢
Exposure proportion (meters, required)			🟢
Oceanic effect cutoff (meters, required)			🟡
Geomorphology: Shoreline Type (optional)	🟢		
Layer value if path omitted (optional)	N/A	N/A	N/A
Coastal overlap (meters, required)			🟡
Natural Habitat (optional)	🟢		
Natural Habitat Layers CSV (Table optional)			🟢
Layer value if path omitted (optional)	N/A	N/A	N/A
Climatic forcing grid (optional)			🟢
Layer value if path omitted (optional)	N/A	N/A	N/A
Continental Shelf (optional)			🟢
Depth contour level (meters, optional)	N/A	N/A	N/A
Sea Level Rise (optional)	🟢		
Layer value if path omitted (optional)	N/A	N/A	N/A
Structures (optional)	N/A	N/A	N/A
Layer value if path omitted (optional)	N/A	N/A	N/A
Population Raster (optional)		🟢	
Min. population in urban centres (required)			🟢
Coastal neighbourhood (radius in m, required)			🟢

Scenarios for the InVEST model

The final result of the model running is the integrate Coastal Vulnerability (CV) index, but the outputs also provide the distribution along the shoreline of individual parameters like coastal population, geomorphology, relief, natural habitats, wind exposure, wave exposure, surge potential, or habitat role. According to the outputs of the model, all the coastline of the trial is exposed to open ocean conditions, i.e. there is no sheltered coast.

Scenario 1992

Description of the scenario: It shows the vulnerability of the shore under the conditions of 1992, with the coastal geomorphology and the habitats distribution derived from the EO products. Sea level change is not included in this scenario. Two cases are run: one with the known distribution of protective seabed habitats (corals and seagrasses) and another one without protective habitats (assuming they are damaged or disappeared).

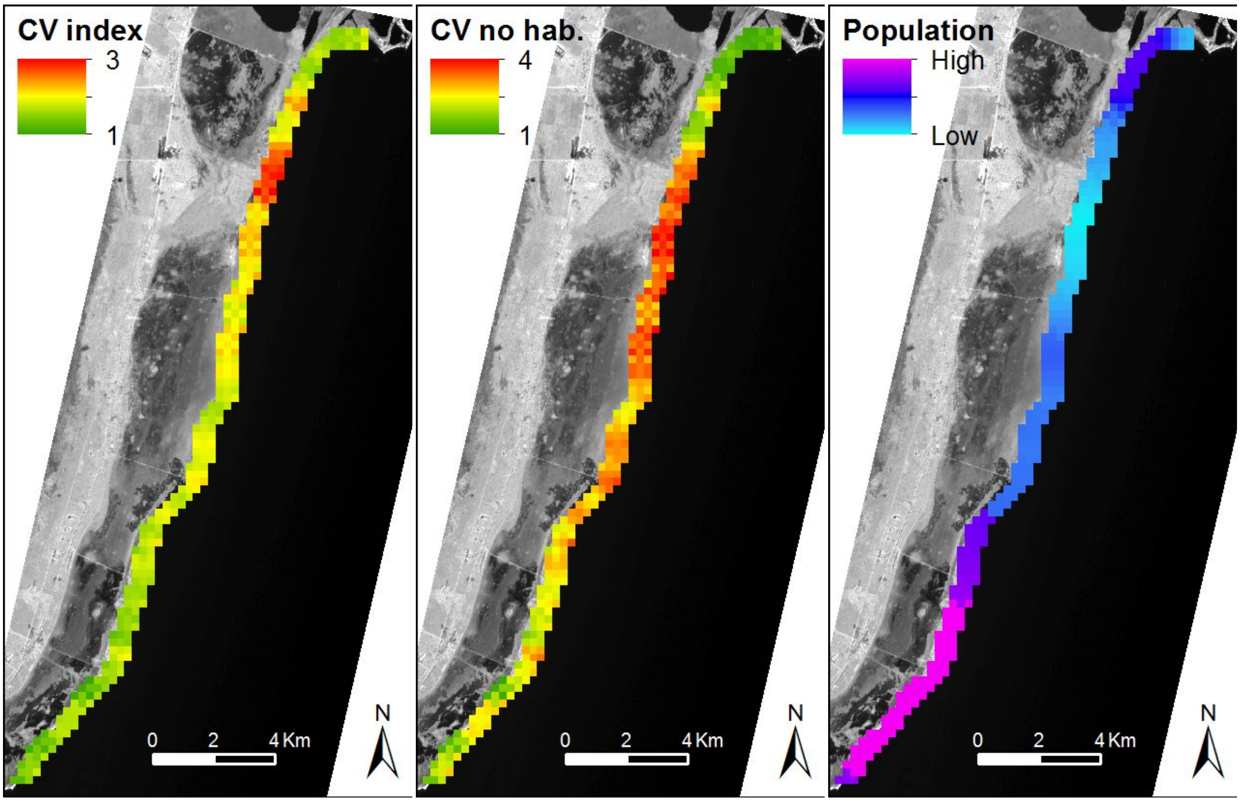


Figure 27: Results from the Coastal Vulnerability (CV) model applied to the Yucatan trial under the 1992 conditions. The CV index represents the relative exposure of the coastal area to storms given the 1992 distribution of natural habitats. Left: model run with the 1992 seabed habitats. Middle: model run without the presence of protective seabed habitats (note the increase in the vulnerability index). Right: coastal population potentially affected by erosion or inundation which can be applied to all the scenarios (since the population input layer is the same under all the scenarios).

Scenario 1992 SLR

Description of the scenario: It shows the vulnerability of the shore under the conditions of 1992, with the coastal geomorphology and the habitats distribution derived from the EO products, including the sea level trend extracted from altimetry observations (which shows an important sea level rise). Two cases are run: one with and the other one without protective seabed habitats.

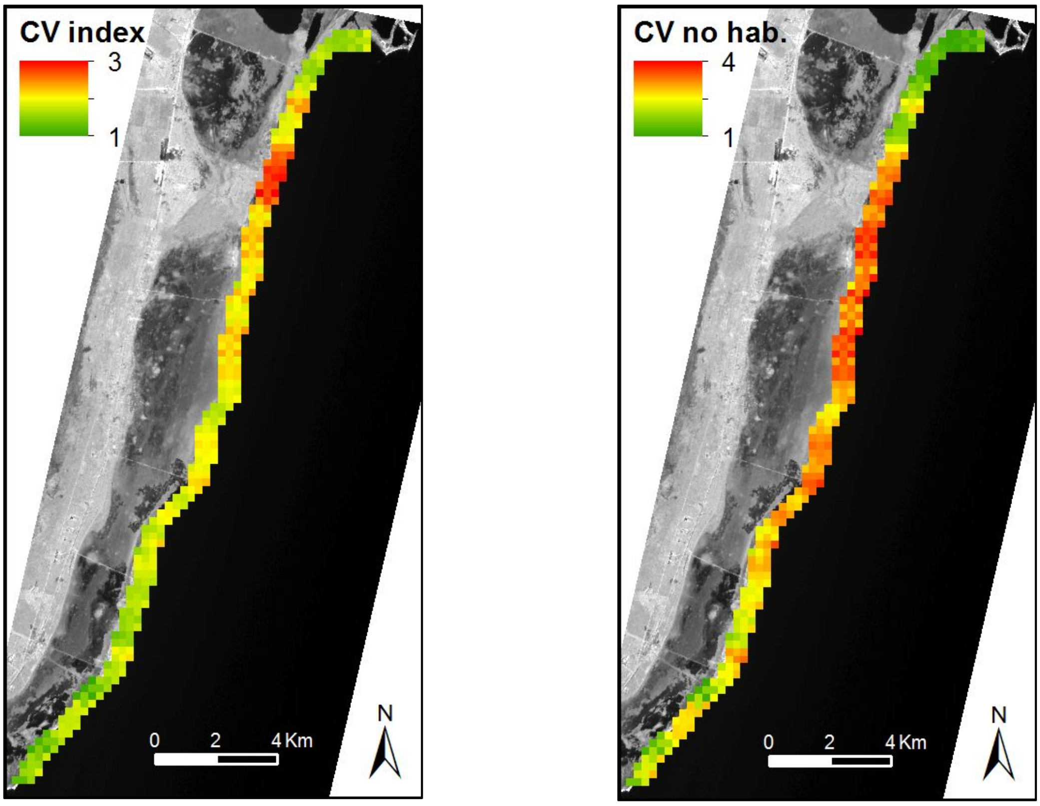


Figure 28: Results from the Coastal Vulnerability (CV) model applied to the Yucatan trial under the 1992 conditions including the effect of sea level rise. The CV index represents the relative exposure of the coastal area to storms given the 1992 distribution of natural habitats. Left: model run with the 1992 seabed habitats. Right: model run without the presence of protective seabed habitats (note the increase in the vulnerability index).

Scenario 2009

Description of the scenario: It shows the vulnerability of the shore under the conditions of 2009, with the coastal geomorphology and the habitats distribution derived from the EO products. Sea level change is not included in this scenario. Two cases are run: one with the known distribution of protective seabed habitats (corals and seagrasses) and another one without protective habitats (assuming they are damaged or disappeared).

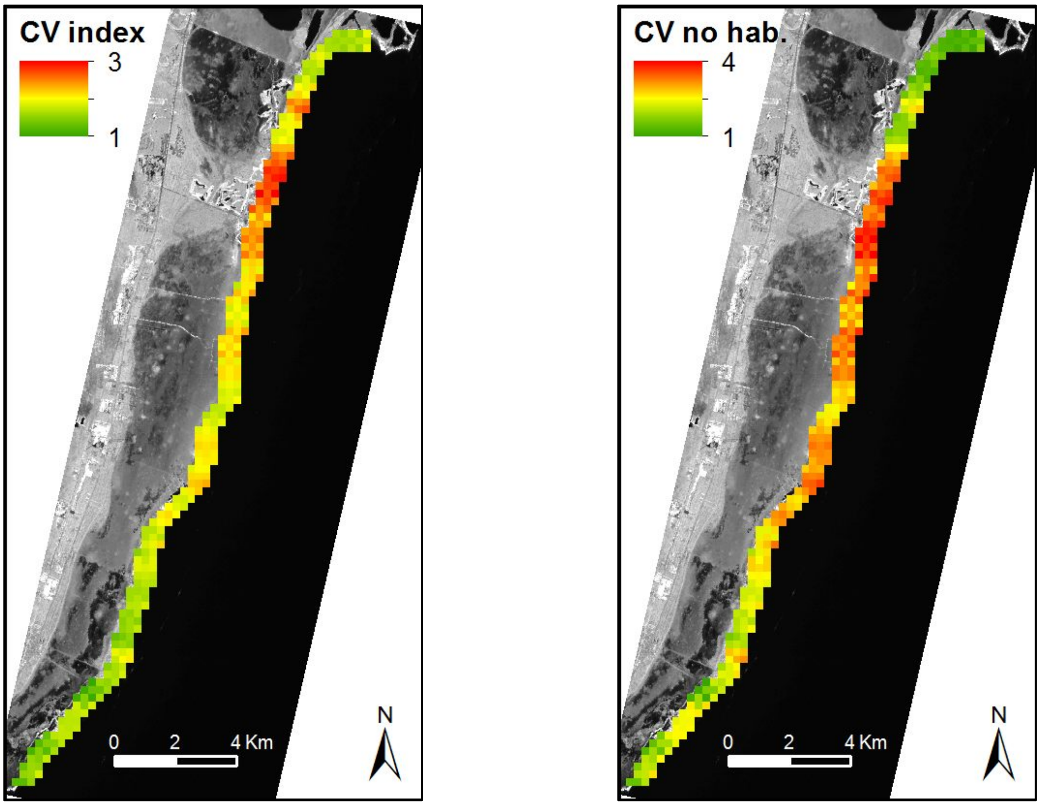


Figure 29: Results from the Coastal Vulnerability (CV) model applied to the Yucatan trial under the 2009 conditions. The CV index represents the relative exposure of the coastal area to storms given the 2009 distribution of natural habitats. Left: model run with the 2009 seabed habitats. Right: model run without the presence of protective seabed habitats (note the increase in the vulnerability index). Note also the expansion of urban sprawl between the 1992 and 2009 images.

Scenario 2009 SLR

Description of the scenario: It shows the vulnerability of the shore under the conditions of 2009, with the coastal geomorphology and the habitats distribution derived from the EO products, including the sea level trend extracted from altimetry observations (which shows an important sea level rise). Two cases are run: one with and the other one without protective seabed habitats.

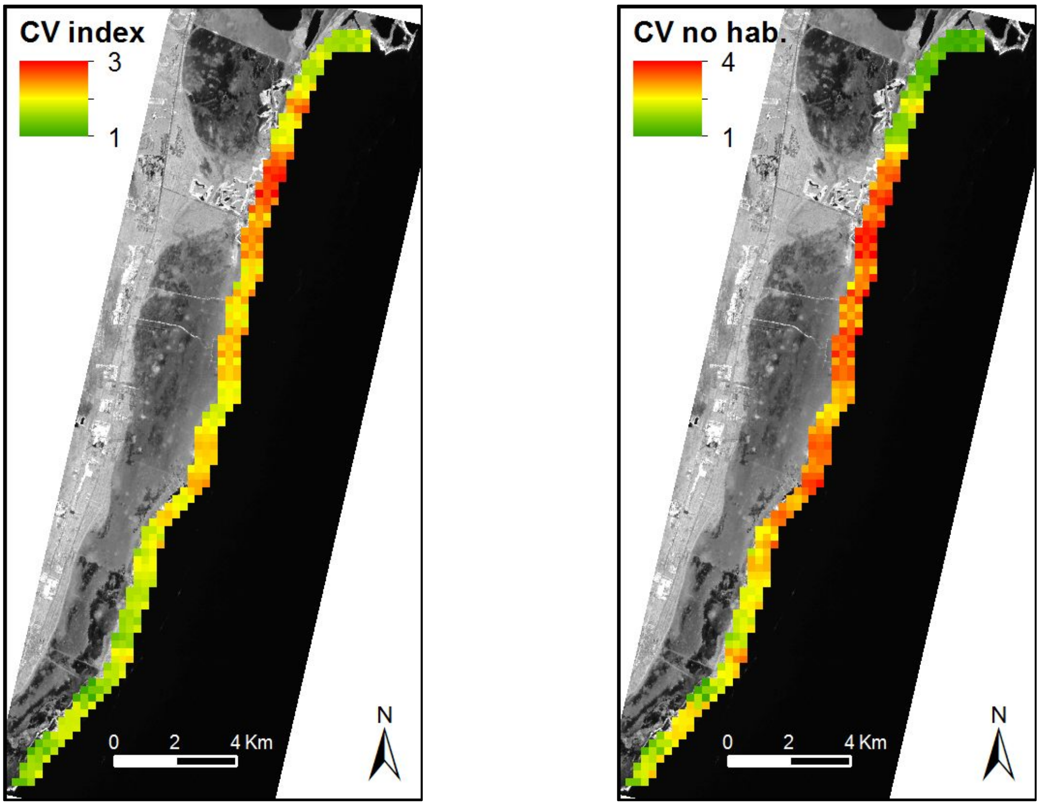


Figure 30: Results from the Coastal Vulnerability (CV) model applied to the Yucatan trial under the 2009 conditions including the effect of sea level rise. The CV index represents the relative exposure of the coastal area to storms given the 2009 distribution of natural habitats. Left: model run with the 2009 seabed habitats. Right: model run without the presence of protective seabed habitats (note the increase in the vulnerability index).

Conclusions

In general, the vulnerability of the coast in the Yucatan trial remained stable or increased between 1992 and 2009. The central stretch of coast seems more prone to inundation or erosion, while the northern bay seems the most protected area.

The protective role played by corals and seagrasses is remarkable in all the model runs, especially in the central part of the study area. This is demonstrated by the higher CV values obtained without habitats than with them. Sea level rise has also a negative effect in CV that is more evident in areas with medium-to-low CV values.

Lessons learnt

- The InVEST Coastal Vulnerability model is quite demanding in terms of data inputs (even if some of the input parameters are optional or can be entered as constant ranked values between 1 and 5). Still, it is also one of the most complete and interdisciplinary InVEST models.
- The model could be more accurate if the EO products provide also emerged habitat maps (e.g. mangroves, marshes, dunes) from the coastal area. This would also cover some of the effects of the observed urban sprawl.
- The model scripting is relatively complicated (it comprises several sub-models) and it is not fully mature. Numerous bugs and unexpected errors were faced during the development of the work. In fact, several days were invested in applying this model to the Lizard Island trial with unsuccessful results due to programming errors. Similarly, the use of the input parameter 'mean sea level datum' to

simulate sea level rise scenarios (as proposed in the model documentation) did not work. We had to use 'sea level rise' for that purpose.

- The output has the form of a vulnerability index (showing relative values) which is very clear and understandable; optimal for communication purposes. The accuracy (pixel size of the output) is selected by the user, but it is advised to set at maximum 250 m resolution.
- This model is design to be applied in populated coastal areas where the vulnerability can be high. For this reason the application of this model if the unpopulated Lizard Island could not have so much sense.
- The HR bathymetry layer derived from the EO products could not be finally used as an input for this model because the bathymetry layer should reach the shelf edge (100-200 m depth) and does not need to have HR.

4.5.2. Climate regulation – blue carbon

The InVEST carbon model was not designed for marine environments, but a specific InVEST blue carbon model is still under development and will not be ready before 2014. In order to illustrate some tentative, spatially explicit results of the carbon stored in some seabed habitat maps, we apply the InVEST carbon model in the Yucatan trial in a simplified way that avoids any terrestrial/marine bias in the calculations.

This model run is based on the distribution of seagrass meadows in the shallow sea around the Puerto Morelos National Park. The level of detail of the results could be improved with local data that account more specifically for the different carbon pools in the habitat classes: dense and medium seagrass. Also, the inclusion of mangroves and salt marshes would provide a more complete estimation of blue carbon in the study area.

The rates of organic carbon sequestration in sediments in vegetated coastal ecosystems are known to be more than one order of magnitude higher than in soils in terrestrial forests. Thus, despite the smaller aboveground biomass and areal coverage of vegetated coastal ecosystems, they have the potential to contribute substantially to long-term carbon sequestration globally[41].

Input data for the InVEST model: Carbon Storage and Sequestration

Table 24: Data inputs as required by the Carbon Storage and Sequestration InVEST tool (first column) and data sources used in the Yucatán trial (second column). See the general data description of these inputs in Table 3.

Model input	*Data source used in this trial*
Current land use/land cover (LULC) map (required)	The distribution and status of seagrass beds (dense and medium) were extracted from the habitat maps derived from EO products for the years 1992 and 2009.
Carbon pools (required)	**C_above & C_below:** • Medium seagrass: mean values from a metadata analysis of carbon in seagrass biomass[42]. Values are 0.755 and 1.176 Mg/ha respectively. • Dense seagrass: mean values plus the 95% Confidence Interval (i.e. maximum value within the 95% CI) from the same source than above. It corresponds to 0.883 and 2.131 Mg/ha respectively.

[41] Mcleod E., Chmura G.L., Bouillon S., et al. (2011). A blueprint for blue carbon: toward an improved understanding of the role of vegetated coastal habitats in sequestering CO2. Frontiers in Ecology and the Environment 9(10): 552-560.
[42] Fourqurean J.W., Duarte C.M., Kennedy H., et al. (2012). Seagrass ecosystems as a globally significant carbon stock. Nature Geoscience 5(7): 505-509.

	C_soil: • Medium seagrass: Mean value of the organic carbon soil under seagrass in the Tropical Western Atlantic region from Fourqurean et al. (2012) Table S2 = 150.9 Mg/ha. It is supposed to be a conservative value for 1m depth soil. • Dense seagrass: same value as above plus the 95% Confidence Interval = 177.2 Mg/ha. **C_dead:** is not applicable in this marine case. Other submarine habitat classes are assumed to have insignificant organic carbon storage compared with the seagrass beds = 0 Mg/ha.
Current harvest rates map (optional)	Not applicable in this trial.
Future Scenarios (optional – required for valuation)	In one scenario we use the 2009 Habitat Map as the future LULC map.
REDD scenario LULC map (optional)	Not applicable in this trial
Economic data (optional – required for valuation)	Not applicable in this trial.

Table 25: Contribution of EO products, in-situ data and global information as inputs for this InVEST model. Green dot = direct contribution specifically designed for this project. Yellow dot = indirect contribution usually coming from global/regional data sets.

Carbon sequestration	EO	in-situ	other
Carbon pools (required)	●		●
Current harvest rates map (optional)	N/A	N/A	N/A
Future Scenarios (optional – required for valuation)	●		
REDD scenario LULC map (optional)	N/A	N/A	N/A
Economic data (optional – required for valuation)	N/A	N/A	N/A

Scenarios for the InVEST model

Scenario 1992

It reflects the carbon stored in the seagrass habitats in the Yucatan trial in the year 1992. It is based on the seabed habitat map 1992 and the carbon pools roughly estimated for seagrass beds (see Table 24). It is calculated with the InVEST biophysical model (without sequestration, uncertainty, or valuation) and provides a map of tonnes of organic carbon per grid cell that has been transformed into tonnes of organic carbon per hectare (Figure 31). The estimated storage in 1992 was 622,608 tonnes of carbon.

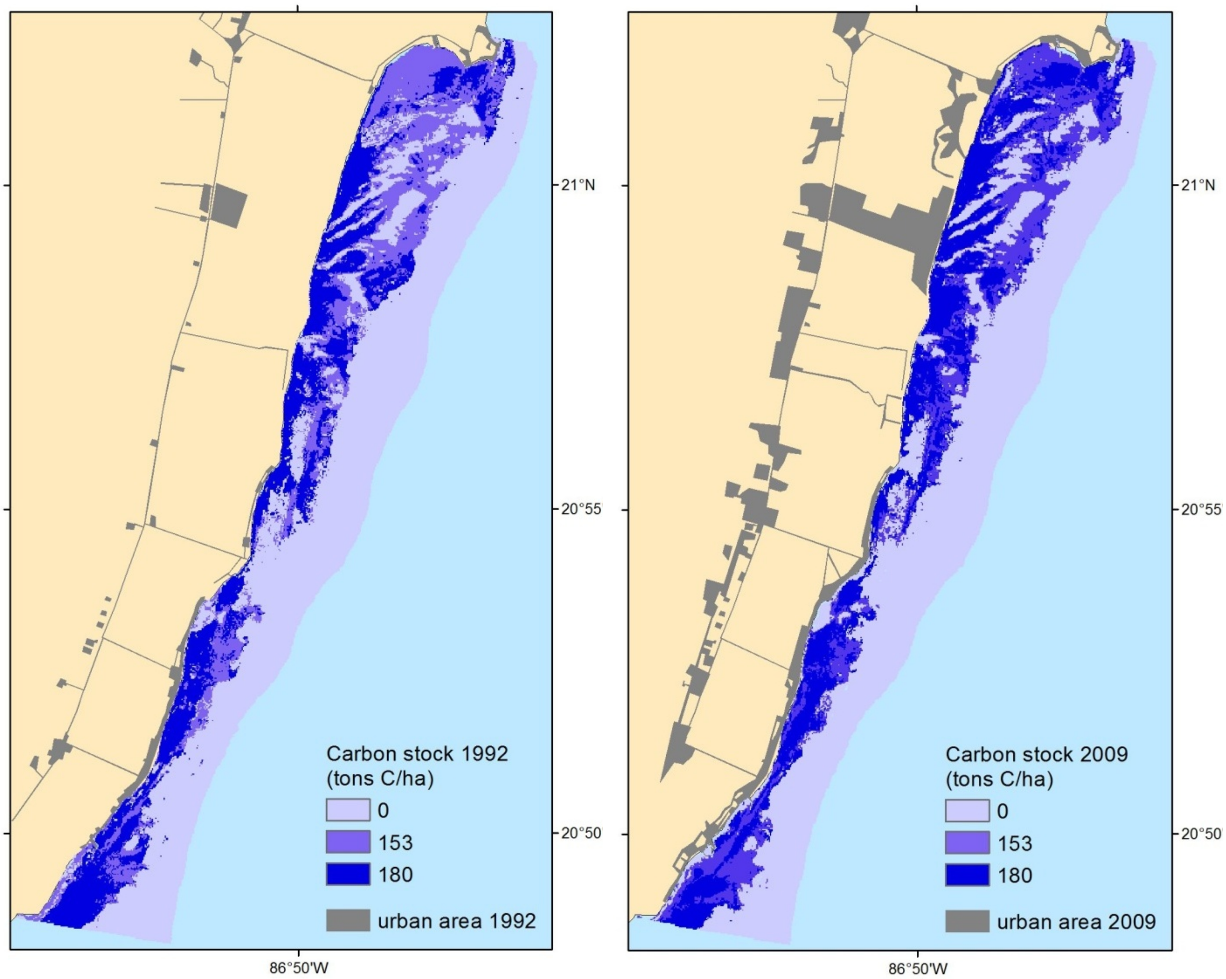


Figure 31: Results from the carbon storage module linked to the Yucatan seagrass habitats under the 1992 scenario (left) and the 2009 scenario (right). The total estimated carbon stored is about 625 thousand tons in 1992 and 600 thousand tons in 2009. Note the increase in coastal urban area between the two dates (see Table 26).

Scenario 2009

It reflects the carbon stored in the seagrass habitats in the Yucatan trial in the year 2009. It is based on the seabed habitat map 2009 and follows the same procedure as above. The estimated storage in 2009 was 595,581 tonnes of carbon (Figure 31).

Scenario 1992-2009:

It reflects the carbon sequestered in seagrass habitats between the years 1992 (current LC for the model) and 2009 (future LC for the model). It is calculated with the InVEST biophysical model with sequestration (without harvest, uncertainty, or valuation) and provides a map of tonnes of carbon retained/emitted per grid cell between 1992 and 2009 that has been transformed into tonnes of organic carbon per hectare (Figure 32).

In general, the most important changes in carbon content are concentrated in the northern half of the study area, showing both increases and decreases in carbon content. The overall temporal changes resulted in a net release to the atmosphere of 25,101 tonnes of carbon trapped by seagrasses between 1992 and 2009.

Table 26: Summary of the coverage changes in the Yucatan trial between 1992 and 2009 (negative values indicate area loss). Note the expansion of the urbanized area.

Domain	*Habitat*	*ha*	*%*
Marine	Predominatly sand	88.0	14.8
	Medium seagrass	-166.2	-9.4
	Dense seagrass	-8.5	-0.4
	Sparse coral	-60.5	-10.8
	Coral reef	27.6	12.1
	Reef slope	89.7	5.8
Terrestrial	Urbanized area	1403.8	267.0

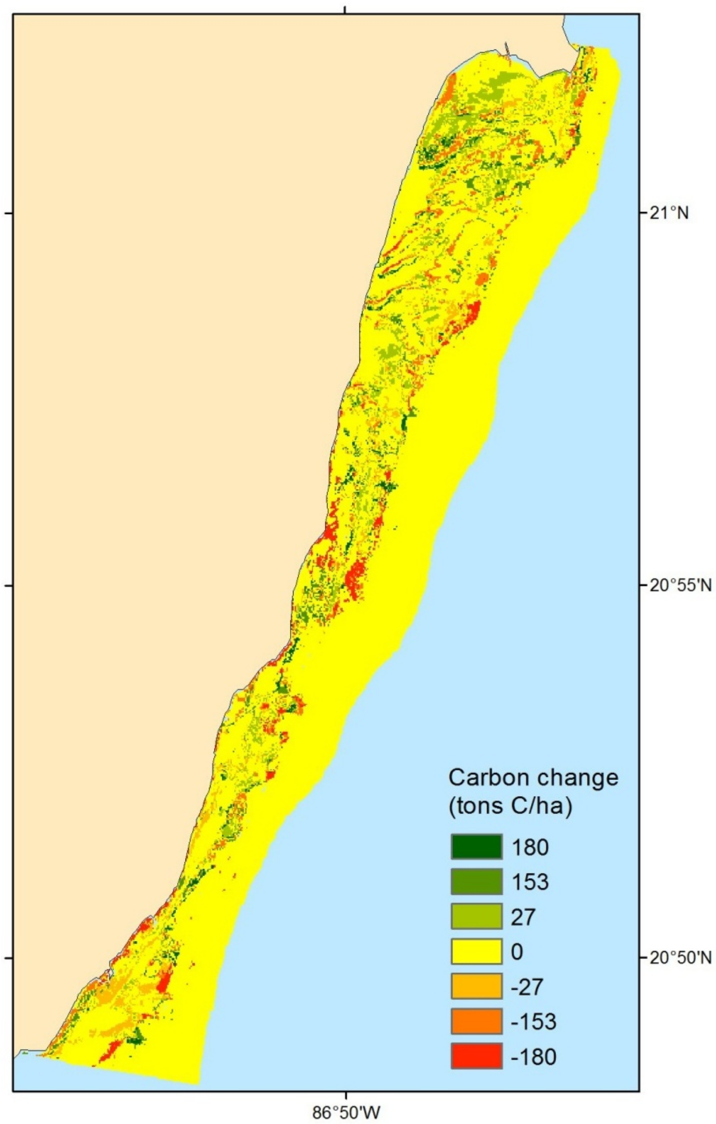


Figure 32: Results from the carbon sequestration module linked to the Yucatan seagrass habitats between 1992 and 2009. Positive numbers point to areas where carbon has been sequestered while negative values correspond to net releases of carbon to the atmosphere due to changes in seabed habitats.

Conclusions

The relative area coverage of seagrass habitats in the Yucatan trial is very high and, consequently, also the organic carbon trapped in those seabed ecosystems. Even if some expansion of seagrass meadows are observed in the northernmost bay of the trial, there is a net decay of seagrass habitats in the whole study area between 1992 and 2009. This decay is larger for medium seagrass than for dense seagrass. Some important pressures such as urban sprawl, which shows an increase of more than 250%, can be monitored through EO.

The net change of organic carbon content between 1992 and 2009 represents an average release of 1477 t/yr or 4% of the initial carbon storage.

Lessons learnt

- Coastal environments are amongst the most productive of the planet (in terms of ecosystem services). However, analysing the distribution and condition of submarine habitats through ship cruises, bio-geophysical data and direct observations is extremely time- and resource-consuming. The capacity to derive not only seabed habitat maps (e.g. coral and seagrass cover) but also ecosystems' condition maps (e.g. dense seagrass or medium seagrass) from EO products is crucial for the assessment of ecosystem services. In this example, different seagrass meadows can store different carbon amounts depending on their density, which affects the flow and benefit of ecosystem services in the study area.
- The coastal area should be analysed as a continuum from land to sea, i.e. covering both emerged and submerged habitats. The inclusion of mangroves, marshes or other coastal habitats in this analysis could provide the whole blue carbon estimation.
- More specific measures of the different carbon pools (either local measurements or density analysis) could improve this model results. The available estimates of aboveground, belowground and sediments' carbon content come from scientific publications. There are no global reference values comparable to the IPCC tables for forests.
- As for the price of carbon to be applied for an economic valuation of the results, we could not find an established (reviewed) value of damage costs associated with the release of an additional ton of carbon (the social cost of carbon). Deeper economic analyses are needed to select or estimate the economic loss linked to coastal disasters.

4.5.3. Recreation

Cultural ecosystem services are defined as "non-material benefits people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation, and aesthetic experience"[43]. Examples of cultural ecosystem services are: appreciation of natural scenery; opportunities for tourism and recreational activities; inspiration for culture, art and design; sense of place and belonging; spiritual and religious inspiration; education and science. Outdoor recreation and tourism represent an important ecosystem service that interest millions of people and contributes to connect them to nature. Information on patterns of recreation and tourism and the factors that influence them is typically collected using site-specific surveys or interviews. This method is expensive and provides limited spatial and temporal coverage.

Recreation and tourism have been analysed in the Yucatan trial using the new InVEST recreation model. This tool is still under development (alpha version), without full documentation, and should not be used for planning or management support. Still, the relevance of the touristic sector in the study area made the case for this tentative modelling attempt. In fact, 15% of GDP in the Caribbean region is coming from tourism and 17% of the workforce is employed in the tourism sector[44].

[43] Millennium Ecosystem Assessment (2005). Ecosystems and human well-being: biodiversity synthesis. Washington D.C. (USA), World Resources Institute.
[44] Carr L. M., Heyman W. D. (2009). Jamaica bound? Marine resources and management at a crossroads in Antigua and Barbuda. Geogr J 175: 17–38.

The InVEST recreation model uses a new source of information to approximate visitation rates and travellers' origins worldwide, the flickr online social media. This source of data, as well as the spatial and statistical model, has been tested and peer-reviewed[45]. This model helps to understand which elements of nature attract people and whether changes in ecosystems will alter visitation rates.

The model is divided in two parts: the Initialization tool and the Scenario tool. Outputs of the Initial tool serve mostly as inputs to the Scenario tool. The user decides the set of predictors that best define the local patterns of recreation and tourism. For the Yucatan trial, we defined and created our own set of predictors (focused on recreational opportunities provided by nature and infrastructures at a local level) instead of using global, low resolution data sets. One of the main attractions of the area is the National Park 'Arrecife de Puerto Morelos', which is part of the Mesoamerican Reef System (the second largest reef barrier in the world) and covers almost 100 km^2 along 21 km of coast. A detailed management plan[46] was developed by the local authorities integrating all economic, scientific and social interests. This plan defines areas for fishing, tourism, recreation or research, among others.

Input data for the InVEST model: Recreation

Table 27: Description of the data inputs as required by the Recreation Initialization InVEST tool (first and second columns) and data sources used in the Yucatán trial (third column).

Model input	***General data description***	***Data source used in this trial***
Area of Interest (projected, required)	This input provides the model with a geographic shape of the area of interest in which the grid will be located. It must be projected (see supported projections) and have an associated linear unit. The extent of the area of interest is used to create the grid and only cells that fall within the area of interest are included.	Same AOI as in the Coastal Vulnerability model.
Grid type (required)	This input provides the model with the shape of the grid cells. Rectangular grids contain squares oriented parallel to the coordinate system of the area of interest. Hexagonal grids contain hexagons oriented with a long diagonal parallel to the horizontal component of the coordinate system.	Hexagonal
Cell size (projection units, required)	This input provides the model with the size of grid cells in the same linear unit as the projection.	250 m
Data Directory (optional)	The user can optionally specify a data folder that contains additional geographic data to use as predictors. The data can be in a geographic or projected coordinate system, but it must be known and specified in the projection file (.prj). Additionally, the geographic data can be classified if an optional classification table (.csv) is specified.	List of predictors (.shp): - Towns: location of Mexican towns[47] - Road network[48] - Accommodation: location of hotels and resorts extracted from Google Earth.

[45] Wood S.A., Guerry A.D., Silver J.M., Lacayo M. (2013). Using social media to quantify nature-based tourism and recreation. Scientific Reports 3: 2976.

[46] Instituto Nacional de Ecología (2000). Programa de Manejo del Parque Nacional Arrecife de Puerto Morelos. Mexico. 224 pp.

[47] INEGI (2010). Localidades de la República Mexicana, 2010, escala 1:1. Obtenido de Principales resultados por localidad (ITER). Censo de Población y Vivienda 2010. Editado por Comisión Nacional para el Conocimiento y Uso de la Biodiversidad (CONABIO). México, D.F. http://www.conabio.gob.mx/informacion/gis/layouts/loc2010gw.png.

[48] Digital Chart of the world (1985). Red de carreteras, escala 1: 1000000, México. Prepared by CONABIO (Comisión Nacional para el Conocimiento y Uso de la Biodiversidad) 2008: http://www.conabio.gob.mx/informacion/gis/layouts/carre1mgw.gif

		- Beaches: extracted from the 'shoreline type' shapefile created for the Coastal Vulnerability model, based on EO imagery of 2009. - Live coral: derived from the EO products of 2009. - Zones for recreational use within the 'Parque Nacional Arrecife de Puerto Morelos' processed from [49]. - Navigation zones in the lagoon of 'Arrecife de Puerto Morelos' (as above). The input data are not classified (i.e. all predictors are assumed to have the same weight or importance).
Download Data (optional)	The user can optionally have the processed predictors, including the user supplied predictors, returned with the model results.	Yes

Table 28: Contribution of EO products, in-situ data and global information as inputs for this InVEST model. Green dot = direct contribution specifically designed for this project. Yellow dot = indirect contribution usually coming from global/regional data sets.

Recreation	**EO**	**in-situ**	**other**
Area of Interest	🟢		
Predictor 1: Towns	🟡	🟢	
Predictor 2: Road network	🟡		🟢
Predictor 3: Accomodation			🟢
Predictor 4: Beaches	🟢		
Predictor 5: Live coral	🟢		
Predictor 6: Zones for recreational use		🟢	
Predictor 7: Navigation zones		🟢	

Optionally, the model provides the following global datasets that can be selected and used in the absence of better local data. These datasets were not used in the Yucatan case but provided some insights about relevant information to be used as predictors.

- 2010 Population (optional). Oak Ridge National Laboratory LandScan (2010) population data. http://www.ornl.gov/sci/landscan/
- OSM Points (optional). Open Street Map (2012) point features categorized into cultural, industrial, natural, structural, and miscellaneous features. http://www.openstreetmap.org/
- OSM Lines (optional). Open Street Map (2012) line features categorized into cultural, industrial, natural, structural, and miscellaneous features. http://www.openstreetmap.org/

[49] CONANP (Comision Nacional de Areas Naturales Protegidas) (2013). Areas del Parque Nacional Arrecife de Puerto Morelos. Available at: http://app.databasin.org/app/pages/datasetPage.jsp?id=1959d99414a442419b6f0cd4768fe005

- OSM Polygons (optional). Open Street Map (2012) polygon features categorized into cultural, industrial, natural, structural, and miscellaneous features. http://www.openstreetmap.org/
- Protected Areas (optional). UNEP-WCMC World Data Base on Protected Areas (2012) polygon features. http://protectedplanet.net/
- LULC (optional). ESA GlobCover (2008) land use and land cover data. http://ionia1.esrin.esa.int/
- Mangroves (optional). UNEP-WCMC Ocean Data Viewer Mangroves (1997). http://data.unep-wcmc.org/
- Coral Reefs (optional). UNEP-WCMC Ocean Data Viewer Coral Reefs (2010). http://data.unep-wcmc.org/
- Seagrasses (optional). UNEP-WCMC Ocean Data Viewer Seagrasses (2005). http://data.unep-wcmc.org/

Table 29: Description of the data inputs as required by the Recreation Scenario InVEST tool (first and second columns) and data sources used in the Yucatán trial (third column).

Model input	***General data description***	***Data source used in this trial***
init.json (required)	The initial tool configuration file.	Output from the previous model run (Initialization tool)
Data Directory (required)	The user must specify a data folder that contains the modified predictors for the scenario. The data can be in a geographic or projected coordinate system, but it must be known and specified in the projection file (.*prj). Additionally, the geographic data can be classified if an optional classification table (*.csv) is specified.	Scenarios were based on a modification of: - Beaches: all the beaches with a constructed dune system were excluded, so that only natural beaches remain. - Live coral: all the coral patches smaller than 3 ha were deleted.

Scenarios for the InVEST model

Scenario Status Quo

This scenario represents and tries to model the present conditions. We run the Recreation Initialization InVEST tool with seven predictors: towns, roads, accommodation, beach, live coral, recreational zones (Arrecife de Puerto Morelos National Park) and sailing zones (Arrecife de Puerto Morelos National Park) (Table 27 and Figure 33). The model extracts the georeferenced photos uploaded into the flickr site between 2005 and 2012; it analyses the photos to distinguish between local and distant visitors and to avoid user redundancies; and finally it estimates the average annual photo-user-days (PUD) as a proxy for visitation rate (Figure 34). PUD is the dependent variable of a multiple linear regression model while the input predictors are the independent variables. The tool performs a linear regression, relating the arrangement of predictor variables in each cell to user-days across all cells.

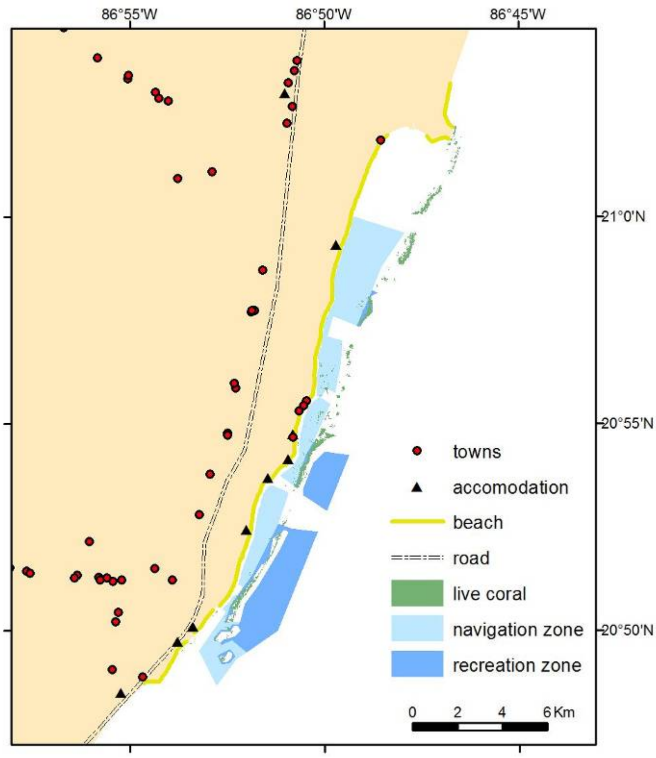


Figure 33: Distribution of the seven local input predictors for the Yucatan trial (factors that may condition tourism and recreation in the study area). These predictors are used by the Recreation Initialization model to forecast the visitation rates and their main causes (by building a linear regression model).

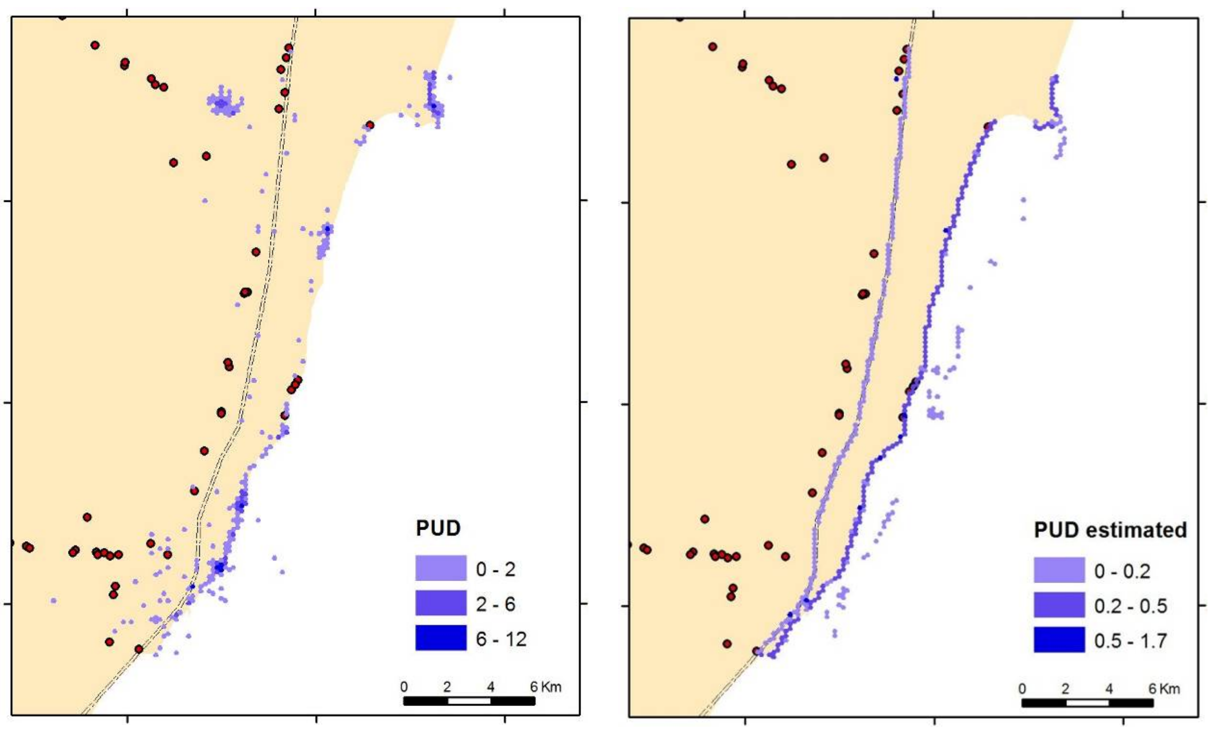


Figure 34: Results of the Recreation Initialization model under the scenario Status Quo (i.e. present conditions). Left: Actual annual photo-user-days (PUD) values derived from an analysis of flickr online. PUD is assumed to be proportional to the visitation rate. The spot concentrating large PUD values in the northernmost part of the map to the west of the road corresponds to the location of the Cancun International Airport. Right: estimated

PUD values by the regression model based on the seven local predictors (note the strong effect of 'beach' and 'road' in the distribution).

Scenario Degraded Coast

The regression model estimated by the Recreation Initialization tool is used to forecast a potential Degraded Coast scenario where the beaches get reduced by 67% (all the beach strips with constructions in the backshore or in dune system are deleted, considering they could get degraded to the point of being no longer attractive for tourism) and where the live corals get seriously damaged (all the patches smaller than 3 ha disappear). The tool uses the coverage of predictors and the coefficients estimated by the former regression to forecast user-days values.

Under this scenario, the inland attraction points (predictors: towns, accommodation, beach and road), which were the most relevant factors in the previous model, do not seem to influence the visitors rate. The estimated user-days (PUD) by the model (Figure 35) concentrate offshore and get extremely large values. This could reflect that the motivation for tourists moved from the beach towards the recreational zones within the Puerto Morelos National Park, but we tend to conclude that this model is not accurate enough in this trial and the results are misleading.

Scenario Without Park

The regression model estimated by the Recreation Initialization tool is used to estimate the visitors rate under a scenario without the Puerto Morelos recreation and navigation zones. The tool uses the coefficients estimated by the former regression and the coverage of the remaining five predictors to forecast user-days values.

Again, the estimated PUD by the model (Figure 35) concentrate around offshore attractions and get extremely large values, even if the beach (the most important predictor in the original model) remains intact and the protected areas by the National Park are cancelled. This scenario provides more importance to certain live coral spots, but we assume (after these and other attempts) that the original linear regression in which the model bases the scenarios is not a good representation for the study area.

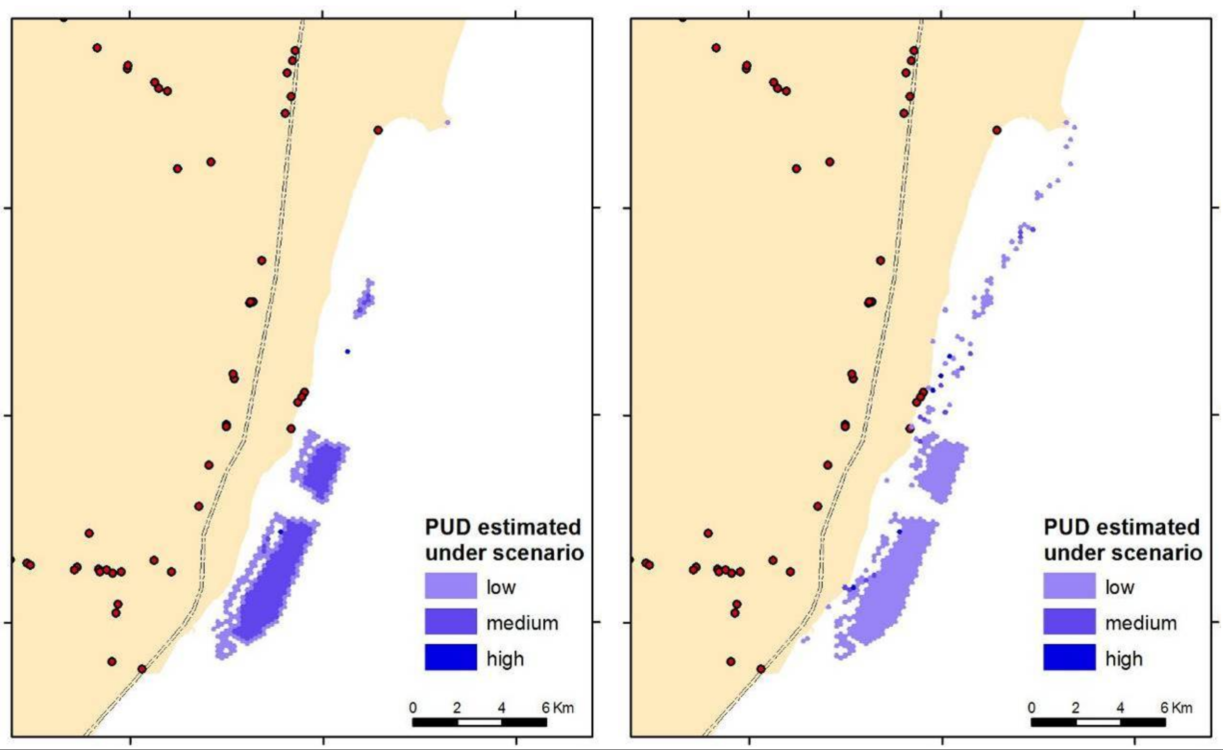


Figure 35: Visitations rates forecasted by the Recreation Scenario model under two different scenarios: left = Degraded Coastal scenario (i.e. beach environments and live corals are seriously deteriorated); right = scenario Without Park (i.e. elimination of the Puerto Morelos recreation and navigation zones). PUD = annual photo-user-days, which are assumed to be proportional to the visitation rate. Note that the linear regression equation in which the model is based was not statically significant.

Conclusions

Tourism and recreation are known to be very important in the Yucatan trial. A quick analysis of the photo-user-days and main touristic predictors may not be accurate enough to quantify the recreation ecosystem service in the area. The visitor's rate (as reflected by the actual photo-user-day) is mainly linked to transport infrastructures (road and airport) and to beach environments, especially beaches near accommodations. The offshore touristic points are probably underrepresented and tend to be located within the Puerto Morelos National Park. The different scenarios run tend to give more importance to the live corals and the National Park and less to the beach.

The design and assumptions of the InVEST recreation model may be used to analyse tourism trends under any perspective, not necessarily with the goal of assessing the natural capacity of ecosystems to provide ecosystem services. In this sense, we consider this model more suitable to assess the benefit perceived from a cultural ecosystem service more than the natural capacity to provide it (similarly to what happened with the InVEST timber model).

Lessons learnt

- The new source of information provided by the InVEST models to estimate visitors rate (photo-user days) is a promising way to assess tourism and recreation around the world. The tool is easy to use and delivers the user-days data and the model statistics.
- However, this model has to be carefully tailored for local case studies. The predictors and regression equations have to be adapted to each specific situation, which requires more time than the initially available for this task. Equations have to be adjusted until the parameters make sense (are significant). Also, while adjusting the equations, the resolution of the output grid can be modified, although it is not advised to go for high resolution (cell size below 250 m).
- Multiple sources of data coming from different disciplines have to be explored to feed the model. EO products (e.g. land use, habitats distribution, infrastructures...) are an important part of those inputs.
- It is assumed that this model works better for broader areas (e.g. where the inclusion of airports may be relevant) and for more accessible sites (i.e. inland). The amount of georeferenced photos found on the sea is limited due to by technological constraints.
- The outputs of the any model have to be critically analysed. A second round of consultation with local stakeholders could clarify the main reasons for model inconsistencies and highlight the most important predictors and scenarios.

4.6. Service trial #4B – Lizard Island (Australia)

4.6.1. Climate regulation – blue carbon

The InVEST carbon model was not designed for marine environments, but a specific blue carbon model is still under development. In order to illustrate some tentative, spatially explicit results of the carbon stored in some seabed habitat maps, we apply the InVEST carbon model in the Lizard Island trial in a simplified way that avoids any terrestrial/marine bias in the calculations. The model does not include oceanographic processes or disturbances that may affect the carbon cycle in seagrass beds, but provides a rough quantification of the carbon pools in the trial and their change through time.

This model run is based on the distribution of seagrass meadows around the Lizard Island, in the Coral Sea (NE Australia). The level of detail of the results could be improved with local data that account more specifically for the different carbon pools in the dense and medium seagrass habitats.

A long time was invested in applying the Coastal Vulnerability model to this trial, but unfortunately it was not possible due to programming errors.

Input data for the InVEST model: Carbon Storage and Sequestration

Table 30: Data inputs as required by the Carbon Storage and Sequestration InVEST tool (first column) and data sources used in the Lizard Island trial (second column). See the general data description of these inputs in Table 3.

Model input	***Data source used in this trial***
Current land use/land cover (LULC) map (required)	The distribution and status of seagrass beds (dense and medium) were extracted from the habitat maps derived from EO products for the years 1988 and 2010.
Carbon pools (required)	**C_above & C_below:** • Medium seagrass: mean values from a metadata analysis of carbon in seagrass biomass[50]. Values are 0.755 and 1.176 Mg/ha respectively. • Dense seagrass: mean values plus the 95% Confidence Interval (i.e. maximum value within the 95% CI) from the same source than above. It corresponds to 0.883 and 2.131 Mg/ha respectively. **C_soil:** • Medium seagrass: Mean value of the organic carbon soil under seagrass in the Tropical Western Atlantic region from Fourqurean et al. (2012) Table S2 = 150.9 Mg/ha. It is supposed to be a conservative value for 1m depth soil. • Dense seagrass: same value as above plus the 95% Confidence Interval = 177.2 Mg/ha. **C_dead:** is not applicable in this marine case. Other submarine habitat classes are assumed to have insignificant organic carbon storage compared with the seagrass beds = 0 Mg/ha.
Current harvest rates map (optional)	Not applicable in this trial.
Future Scenarios (optional – required for valuation)	We use the 2010 Habitat Map as the future LULC map.
REDD scenario LULC map (optional)	Not applicable in this trial
Economic data (optional – required for valuation)	Not applicable in this trial.

[50] Fourqurean J.W., Duarte C.M., Kennedy H., et al. (2012). Seagrass ecosystems as a globally significant carbon stock. Nature Geoscience 5(7): 505-509.

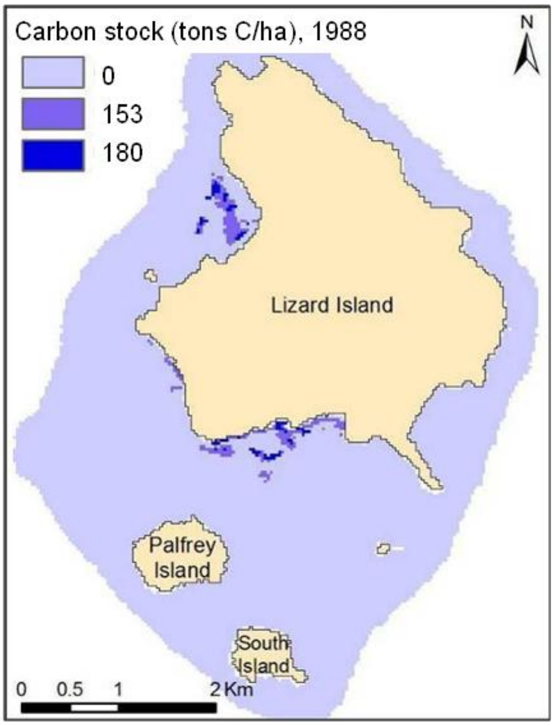
Table 31: Contribution of EO products, in-situ data and global information as inputs for this InVEST model. Green dot = direct contribution specifically designed for this project. Yellow dot = indirect contribution usually coming from global/regional data sets.

Carbon sequestration	EO	in-situ	other
Carbon pools (required)	●		●
Current harvest rates map (optional)	N/A	N/A	N/A
Future Scenarios (optional – required for valuation)	●		
REDD scenario LULC map (optional)	N/A	N/A	N/A
Economic data (optional – required for valuation)	N/A	N/A	N/A

Scenarios for the InVEST model

Scenario 1988

It reflects the carbon stored in the seagrass habitats in the Lizard trial in the year 1988. It is based on the seabed habitat map 1988 and the carbon pools roughly estimated for seagrass beds (see Table 29). It is calculated with the InVEST biophysical model (without sequestration, uncertainty, or valuation) and provides a map of tonnes of organic carbon per grid cell that has been transformed into tonnes of organic carbon per hectare (Figure 36). The estimated blue carbon stored in the seagrass in 1988 was 4,761 tonnes of carbon.



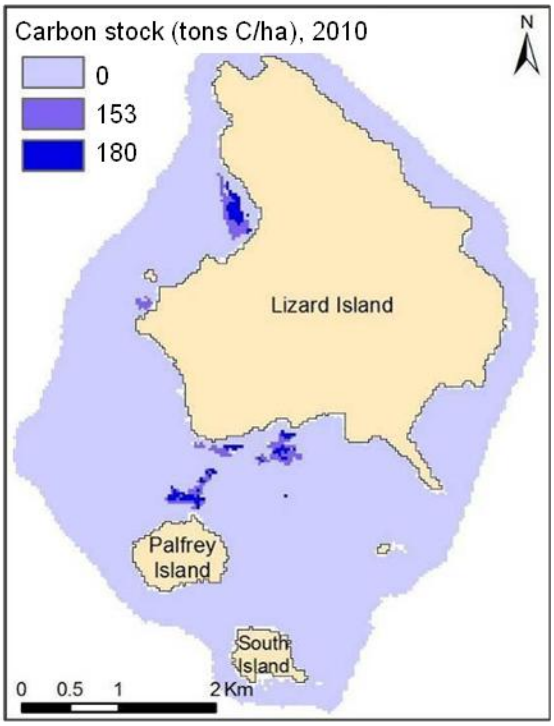


Figure 36: Results from the carbon storage module linked to the Lizard Island seagrass habitats under the 1988 scenario (left) and the 2010 scenario (right). The total estimated carbon stored is about 4.8 thousand tons in 1988 and 4.9 thousand tons in 2010.

Scenario 2010

It reflects the carbon stored in the seagrass habitats in the Lizard trial in the year 2010. It is based on the seabed habitat map 2010 and follows the same procedure as above. The estimated storage in 2010 was 4,872 tonnes of carbon (Figure 36).

Scenario 1988-2010

It reflects the carbon sequestered by seagrass habitats between the years 1988 (current LC for the model) and 2010 (future LC for the model). It is calculated with the InVEST biophysical model with sequestration (without harvest, uncertainty, or valuation) and provides a map of tonnes of carbon retained/emitted per hectare between those two dates (Figure 37). The overall temporal changes resulted in a net capture of carbon from the atmosphere of 223 tonnes between 1988 and 2010.

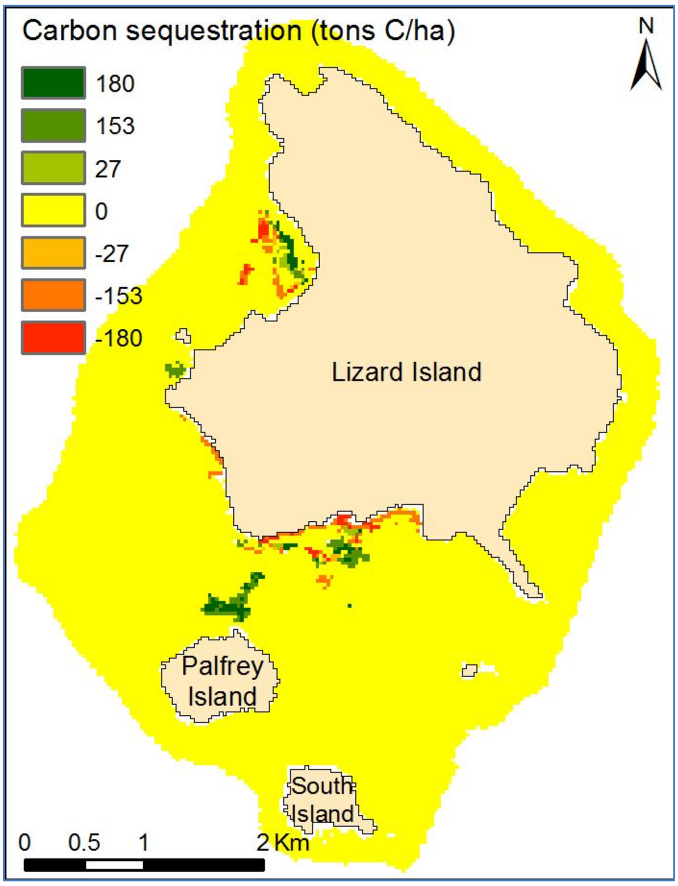


Figure 37: Results from the carbon sequestration module linked to the Lizard Island seagrass habitats between 1988 and 2010. Positive numbers point to areas where carbon has been sequestered while negative values correspond to net releases of carbon to the atmosphere due to changes in seabed habitats.

Conclusions

In general, the distribution and density of seagrasses around the Lizard Island is highly dynamic, with most of the seagrass patches showing significant changes between 1988 and 2010. The most important changes in blue carbon content are concentrated in the north-western bay of Lizard Island and in the lagoon between Palfrey Island and Lizard Island.

Approximately 67% of the seagrass habitats observed in the year 1988 have suffered degradation, especially near the Lizard Island shoreline. The cause of that widespread degradation should be analysed. Still, there is an overall expansion of the seagrass coverage in the study area towards more compact patches. The most prominent of those patches is a new seagrass meadow located to the north of the Palfrey Island.

The net change of blue carbon content between 1988 and 2010 represents an average capture of 18.6 t/yr or 4.7% of the initial carbon storage.

Lessons learnt

See the lessons learnt under section 4.5.2.

5. Other potential approaches to map the value of ecosystem services

The initial objective of the tasks presented in this Trial Report was to explore and test the InVEST tools in the study sites of Ecoserve. The InVEST tools had been identified as some of the best-developed and feasible ecosystem services models freely available. This objective is covered in section 4. The present section aims to provide a short introduction to the feasibility of using the EO products to assess and map (but not necessarily to model) ecosystem services.

The spatially explicit information about ecosystem services is highly demanded for management and policy-making. While the comprehensive models about ecosystem services are being developed and applied, a number of simpler proxies are being used to describe those services both qualitatively and quantitatively. The HR EO products generated during this project could be used to estimate and map other ecosystem services' indicators more undemanding (and, probably, less complete) than the InVEST results.

The following bullet points summarise the existing approaches to map and assess ecosystem services (elaborated from Maes et al. 2012[51]) and their potential link to EO. More time would be required to explore those links in detail; it will be one of the objectives of the on-going ESA-funded G-ECO-MON project.

a) Derive information about ecosystem services directly from LULC maps. This is a relatively simple approach for areas with limited data availability or expertise, or for large AoI where the supply of ecosystem services can be broadly attached to the presence of a certain land cover. It is typically used for crop or timber production, assuming an average production per unit area. Approaches such as the one proposed by Burkhard et al. (2009)[52] are not advisable for the small scale trials of this project. However, this methods based on LULC maps can be easily supported by EO.

b) Similar to the previous approach but making the bound directly from LULC to economic valuation is the benefit transfer method, where ecosystem service values are transferred from primary valuation studies to the AoI. There is an assortment of methodologies to select the studies and to adjust the values to the local and spatial circumstances, which determines the quality of the resulting maps. This approach can be supported by EO products only if there are economic experts to establish the transfer rules.

c) Mapping biological data (such as functional traits or ecosystem structure) as a proxy of ecosystem services (e.g. Lavorel et al. 2011[53]). This approach tries to develop ecological function maps that are

[51] Maes J, Egoh E, Willemen L, Liquete C, Vihervaara P, et al. (2012). Mapping ecosystem services for policy support and decision making in the European Union. Ecosystem Services 1(1): 31-39.
[52] Burkhard B, Kroll F, Müller F, Windhorst W (2009). Landscapes'capacity to provide ecosystem services: a concept for land cover based assessments. Landscape online 15: 1–22.
[53] Lavorel S, Grigulis ., Lamarque P, Colace M, Garden D, et al. (2011). Using plant functional traits to understand the landscape distribution of multiple ecosystem services. Journal of Ecology 99: 135–147.

closely linked to the delivery and flow of ecosystem services. A simpler version of this approach seeks to produce ecosystem condition maps. This is actually a further elaboration and integration of the LULC approach and the proxies approach, with a robust ecological basis. EO has a great potential for this approach if integrated with biological data, which may require a lot of resources. The mapped parameters have to be defined and analysed in detail.

d) Collection of primary data (statistics). It is usually time-consuming and locally focused. It works better for provisioning services (e.g. food and water) and it is rarely available for regulating services. The reporting units usually follow some administrative delimitation. The approach by Kandziora et al. (2013)[54] combines LULC maps and primary data, but it is relatively time-consuming to provide results only on food provisioning.

e) Identification and mapping of reliable proxies of ecosystem services. This indirect approach is often the only available way to quantify regulating and maintenance ecosystem services as well as most of cultural services. The proxies may come from environmental monitoring or from models, for example using deposition velocity on leaves as an indicator of the capacity of ecosystems to capture and remove air pollutants, as proposed by Karl et al. (2010)[55]. This is a quickly developing field of research that is trying to find criteria (proxies or indicators) to measure the capacity, flow or benefit coming from each ecosystem service. EO can make an important contribution to most of the established criteria and mapping approaches, although the link between EO products and ecosystem service indicators needs to be analysed carefully. It can be specially useful to look at the latest reviews and compilations, like Layke et al. (2011)[56], Egoh et al. (2012)[57] or Liquete et al. (2013)[58].

f) Use of specific ecosystem service models, such as dynamic process-based ecosystem models (e.g. Schröter et al. 2005[59]) or models based on ecological production functions, like InVEST. The application of specific EO or EO-derived products as inputs for these models have to be analysed in a case-by-case basis, as shown in this report with the InVEST tools. This approach requires significant investment in terms of data acquisition/gathering and expert knowledge.

6. Conclusions and recommendations

Rational

Biophysical assessments are needed to provide an understanding of how ecosystem services are generated, and socio-economic analyses are necessary to estimate the relative worth of services through market and non-market valuation techniques. By understanding how the quantity and quality of ecosystem services changes in physical terms, natural science can provide a robust framework in which valuation studies can be based.

[54] Kandziora M, Burkhard B, Müller F (2013). Mapping provisioning ecosystem services at the local scale using data of varying spatial and temporal resolution. Ecosystem Services 4: 47–59.
[55] Karl T, Harley P, Emmons L, Thornton B, Guenther A, et al. (2010). Efficient atmospheric cleansing of oxidized organic trace gases by vegetation. Science 330: 816-819.
[56] Layke C, Mapendembe A, Brown C, Walpole M, Winn J (2011). Indicators from the global and sub-global Millennium Ecosystem Assessments: an analysis and next steps. Ecological Indicators 17, 77–87.
[57] Egoh B, Drakou EG, Dunbar MB, Maes J, Willemen L (2012). Indicators for mapping ecosystem services: a review. Report EUR 25456, doi:10.2788/41823.
[58] Liquete C, Piroddi C, Drakou EG, Gurney L, Katsanevakis S, et al. (2013). Current Status and Future Prospects for the Assessment of Marine and Coastal Ecosystem Services: A Systematic Review. PLoS ONE 8(7): e67737.
[59] Schröter D, Cramer W, Leemans R, Prentice IC, Araújo MB, et al. (2005). Ecosystem Service Supply and Vulnerability to Global Change in Europe. Science 25: 310 (5752), 1333-1337.

In general, the results of this task show that during the last 1-2 decades, there has been a decrease in the provision of ecosystem services in the trials (e.g. increased vulnerability of the coast in Yucatan; net carbon release from the Ucayali AOI; habitat degradation in Huong Son). A more detailed analysis of certain trials, with multiple ecosystem services quantified under comparable scenarios, would allow to build a comprehensive ecosystem services' map. This would also require a statistical analysis of trade-offs and synergies among the different services.

Model capabilities

The results shown in section 4 illustrate the delivery and, when feasible, the valuation of 5 ecosystem services in 6 trials. The InVEST models are flexible, open-source tools to assess spatially and temporally some environmental services. However, they also have some limitations like the different degrees of development (lacking in many cases the economic valuation step), or the ambiguous system of errors' detection. Each of the models requires specific data inputs and an in-depth analysis for a correct interpretation of inputs and outputs. This means that all the outputs have to be critically analysed. In some cases, the models are not capable to respond the management or scientific questions posed due to technical constrains. One example is the recreation model in Yucatan that did not reach a consistent regression equation and did not show comparable parameters inland and offshore. The main conclusion in this regard is that more time is needed to run and extract meaningful results from an InVEST modelling exercise, especially given the need to define alternative scenarios and share them with stakeholders; and to search for multiple data sources. In particular, a second round of consultation with local stakeholders could clarify the main reasons for model inconsistencies and highlight the most important predictors and scenarios.

Challenges for mapping scenarios

The InVEST results are organised in scenarios (model runs) that may represent past, present or future situations (cf. Section 2). EO products provide for past and present landscape characterisation, while for most of the models future scenarios would require a tentative land cover/land use map. It means that, in order to run a future scenario that integrates the stakeholders' options, the management effects on landscape dynamics must be modelled outside of Invest with software such as IDRISI. This extra step was explored and tested in the Lombok trial but could not be performed in the rest of the trials. This could be a potential future prospect for this kind of analysis.

In situ data availability

The integration of local environmental and socio-economic data with EO products (as input data) is a crucial factor for estimating the economic value of ecosystem services. In addition, a deep knowledge of the local situation and management practices is usually needed to interpret precisely the model results (outputs). In most of the cases, the availability of local measurements improves the quality or is necessary to get ecosystem services results. Due mainly to the non-availability of specific in-situ data in the trial areas only a few ecosystem services could be valued. As an example of the outputs' interpretation, the distribution of net values from timber production across the Ucayali parcels might be closely linked to the commercial species selected each year, or to the company investments, but there is no such detailed information available. This and other models would benefit from a closer involvement of the land use managers in the definition of scenarios.

Selection and interpretation of model results

Each trial has specific objectives and interests that can be extracted from different model results. For instance, the relative importance of carbon stocks is the crucial argument in the Amazonian forest (Ucayali trial), while the opportunity for carbon sequestration in agricultural land is more important in places such as the Lombok trial. Similarly, the aim of each model should be confronted with the local objectives. In this sense, the coastal vulnerability model was tried to apply in the Lizard Island (despite model errors finally made it impossible) even if this model is focused on population vulnerability and the Lizard Island is practically unpopulated.

Endeavours in marine/coastal trials

The high resolution sea bed habitat maps derived from EO provide a key instrument to assess coastal ecosystem services. They allow mapping the condition of ecosystems and its temporal evolution, which is usually highly dynamic (e.g. Yucatan habitats change in Table 26). Local data is usually necessary to understand the reasons of such evolution (e.g. why the sea grass disappears near the coast and expands over the lagoon to the south of Lizard Island); although EO may support the impact analysis (e.g. urban sprawl in Yucatan). One observation extracted from the coastal vulnerability model is the remarkable protective role played by corals and seagrasses. Future developments of this kind of studies should consider the coastal area as a continuum from land to sea, i.e. covering both emerged and submerged habitats for a complete ecosystem services characterization.

Carbon sequestration

Carbon content and sequestration was the only ecosystem service analysed in all the trials, and it is especially important in tropical forests. From a natural perspective, the total carbon stock (and not only the carbon change) should be valued in some way. Alternatively, the rate of carbon sequestration should be related to the initial carbon stock to estimate the relative importance of the change in carbon content. From an economic perspective, the absolute values of tonnes of carbon emitted/sequestrated are key for international negotiations or trading systems. In areas with intensive changes, like the forestry activities in Vinh Tu, both forestry practices and the end use of the extracted biomass (biofuel, construction, ...) should be analysed to estimate the overall impact on the global carbon budget.

Illustration of management options

InVEST tools are designed for management support. Management decisions can be based on economic returns or in socio-economic aspects. Some InVEST models (e.g. timber and recreation) provide information on both, though not covering all aspects. For example, the timber model focuses on the exploitation of natural resources (timber) and their economic returns (the final value of the benefits), without considering other key factors such as sustainable practices, conservation zones, clear-cut vs. selective logging, etc. The inclusion of the ecosystem-based perspective in those cases depend on the selection of input parameters (especially important in the recreation model) and, if feasible, in the analysis of multiple ecosystem services within the AoI.
A strong point of the InVEST focus on management is that the models can be used to display the outcome of the implementation of a particular land use policy, like in the case of carbon sequestration in Lombok. The carbon stocks and flows in this trial were to a large extent connected with the land use, forest management and agricultural practices.

EO as input for valuation

The resolution of the EO products allow for detailed land cover classes to feed ecosystem services' models (e.g. different forested classes with different carbon pools). However, in some cases it is important to have field survey based information (e.g. for the biodiversity model). On the other hand, only after a practical implementation of the models, all the data requirements are clarified. For instance, the bathymetry layer required for the coastal vulnerability model needs to cover the continental shelf (down to 100-200 m depth) and, thus, the high resolution coastal bathymetry derived from EO is not sufficient.
The EO products and their analysis highlighted also some ecosystem and habitat characteristics that should be taken into account apart from the pure ecosystem services' quantification. One example is the connectivity issue in Houng Son, brought to light during the analysis of biodiversity (section 4.2.1). EO is, thus, a mean to design more complete ecosystem assessments.

A word on economic analysis

More specific economic knowledge would be ideal to tackle some of the valuation issues, like the market fluctuations (for timber prices), social values (for biodiversity or carbon), estimate avoided damage costs (for coastal protection), or market discount rates (for all Tier 2 models). In the absence of InVEST or other predefined economic valuation tools, the selection and application of suitable valuation methods requires a thoroughly understanding of environmental or ecological economy (cf. Section 3).