EARTH OBSERVATION FOR ECOSYSTEM SERVICES VALUATION

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Project Summary

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Project objectives

The European Space Agency (ESA) has promoted Earth Observation (EO) for ecosystem mapping and assessment of ecosystem performance in several projects. The projects, in addition to the EO Services for Ecosystem Valuation project (Ecoserve), include the G-ECO-MON and the Heart of Borneo projects. Heart of Borneo showcases the capability of Earth Observation as input to ecosystem service valuation in Borneo, whereas the G-ECO-MON project involves 11 trial sites distributed globally with a diversity of ecosystems in temperate to tropical biomes. Other projects with ecosystem connections are Globe Wetland, Biodiversity I and II and the work that has been initialized within the scope of the Copernicus, which form the Global Monitoring for Environment and Security (GMES) program on environmental applications of EO data.

The objective of Ecoserve is to demonstrate the value of EO-based information products for the emerging sector of ecosystem services valuation. EO-based services have the potential to provide objective baselines and are an important component of environmental monitoring systems. Importantly, the geographical extent that EO services can provide information is far greater than what is feasible through manual survey methods. EO services are not merely a cost-effective complement to in-situ surveys but can facilitate a deeper level of understanding of spatial relationships between ecosystems and human environment. This understanding is necessary to meet the current challenges of sustainable growth.

Accounting for the full value of ecosystems, supported by objective and independent measurements from space, can help manage business risks as well as lead to new services marketing natural assets, such as payment schemes for ecosystem services, sustainable corporate development, renewable energy, water management, certification of sustainable forest management and carbon trading. EO data can play an important role in assessing the value of ecosystem services, in particular elucidating the spatial extent and inter-relationships between ecosystems, and their relationship to the areas of human habitation and activity that are dependent upon them. Use of EO data is the only practical method to evaluate the spatial dynamics of ecosystem services and the consequences of development on all scales from local to global.

Project Outcomes

The Ecoserve project has produced and delivered EO services and ecosystem service assessments and valuations to local and global users at four pilot sites in tropical marine and terrestrial areas that are globally distributed. The EO services have provided data on land cover, benthic substrates, forest classes and their dynamics that was previously unavailable.

The project proved that EO can provide valuable input to Ecosystem Service (ES) valuation. This is especially evident in remote areas, where EO helps to overcome lack of data for land cover, habitats and ecosystems. The data delivered in the Ecoserve project include spatially explicit and consistent information on land cover and land cover derived information. The EO services provided have been used for ecosystem services valuation combined with local, regional and global data using models from the InVest toolbox.

EO is an important information source for monitoring of changes in land cover and ecosystem function. EO provides objective and unbiased information on changes in reflectance of solar radiation. The changes in reflectance can be attributed to processes influencing the ecosystem services, e.g. forestry activities in remote areas leading to soil erosion, habitat loss and carbon release on one hand and contributing with timber on the other. These initial activities are often followed by other secondary processes, all detectable from space and hence possible to monitor and transform to impact on ecosystem services.

Policy Background

Ecosystem services, the services provided by the natural environment that benefit people, determine human well-being. Thus, the conservation and the best management of ecosystems will affect the long-term provision of those ecosystem services. 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 to 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.

Service Utility

There is significant interest to incorporate ecosystem services into the scope of land and water resource management. The users of the pilot trials have shown a great interest and acknowledged the strength of EO-to provide data supporting management decisions with ecosystem services as a special concern.

The Forest Stewardship Council (FSC) is involved, amongst other initiatives, through the Forces project aiming at a certification system for forest management considering ecosystem services. World Wide Fund for Nature (WWF) is involved as they see the ecosystem service approach as an important input to conservation of natural areas and sustainable development. WWF are amongst other initiatives part of the Natural Capital project developing the Invest toolkit. Both approaches (FSC aiming at certification and WWF and impact on forest management) require reliable geodata and tools for ecosystem service assessment. FSC need tools that can be used for management as well as for follow up purposes. WWF needs tools that can meet the internal requirements of the organisation and make their communication with policymakers and managers reliable.

The users of the marine cases, the Institute of Marine Sciences and Limnology (ICML) and the Australian Museum, are interested in determining how EO can be used to support decisions in development of sustainable tourism in the northern Yucatán peninsula and on Lizard Island, Great Barrier Reef. They are both conducting research on the issue of sustainable management of reef and sea grass ecosystems.

The products meet the requirements according to the Statement of Work and the users have expressed their satisfaction with the provided services.

Below follow some quotes:

"The basic map products and the ecosystem service assessments have great utility for management, understanding the dynamics of local environmental processes, for guiding economic decisions of investors and communicating to policy makers." -ICML

"…this is a very interesting result that has clear implications to maintenance of biodiversity at the site: not just in terms of the seagrasses, but also the in-fauna and herbivorous species such as turtles." –Australian Museum

"The project allowed seeing the possibilities EO offers for ES visualization, monitoring and valuation." –FSC

"This is an area where we otherwise had no data, so this is a significant improvement for future work in this area. This has helped to literally discover a relatively unknown area." –WWF

Lessons learned

Working with ecosystem services highlights the importance of good user and service provider interaction. The concept of ecosystem services is not commonly known and adds complexity to service provision. When working with novel areas it is particularly important to begin the project with start-up meetings at the facilities of the local users.

With respect to ecosystem services, the start-up meetings with the users ideally have the form of workshops with the explicit target of providing a common understanding of the expectations on the outcomes of the project, transformed into a SLA redefining deliveries of EO services, AOIs, ecosystem services to be valuated as well as quantifying the contribution expected from the users regarding participation in meetings and provision of in situ data.

Collection of Ecosystem Service Valuation input takes time and it is important to do this as an integrated part of the Service Readiness Review. Focusing too much on the production of EO-services imposes a risk for the ecosystem valuation part of such projects. As part of the Service Readiness Review and the start-up meetings it is also important to see which EO-services that will support the valuation of the specified ecosystem services for each individual trial. For some trials, the biomass estimates will be most important. For other trials, vegetation regulating soil erosion or water purification will be the priority during production of EO services.

The Ecoserve project has shown that the actual valuation of ecosystem services is a highly complex issue, not only with regard to the needed user interaction but also in terms of data requirements. As indicated by the Mapping and Assessment of Ecosystems and their Services (MAES) scheme, ES valuation is the concluding stage 4 of an ecosystem service assessment representing the most demanding stage.

I. Biophysical baseline mapping and assessment of the status of major ecosystems;
II. Biophysical baseline mapping and assessment of defined ecosystem services;
III. Alignmnet of ecosystem service assessmnets with scenarios of future changes (future outlooks), developed together with policymakers and stakeholders to ensure their salience and legitimacy and consequently the use of the results in decision making;
IV. Valuation of ecosystem services for baseline and contrasting scenarios and integration into environmental economic accounting

(Maes J, et al. (2013): Mapping and Assessment of Ecosystems and their Services. An analytical framework for ecosystem assessments under action 5 of the EU biodiversity strategy to 2020. Publications office of the European Union, Luxembourg.)

Ecoserve has addressed stage 1 (land cover mapping) well, and made some advancements in stages 3 (scenarios) and 4 (valuation). However, it has almost completely skipped stage 2 (ecosystem services mapping) due to the limited time and resources devoted to user interaction, as well as the lack of actual data on the services under consideration.

Rather than targeting many ecosystem services for a specific region in the form of an 'holistic' assessment – which can never be complete due to the limited time frame of the project - it might have been beneficial to focus on one specific ecosystem service per user, which could have been addressed more deeply. One example is the Huong Son hydropower project in Vietnam, which could be further analysed in terms of impacts on different ecosystem services and where EO can play a substantial role in supporting such assessments. Such project-like activities (for different users and in different geographic areas) are conducted in G-ECO-MON, and this progress (beyond pure EO land cover mapping) will be an important 'learning factor' for the EO community and one of the success factors of the project.

With regard to ecosystem services mapping (stage 2 of MAES scheme), a widely accepted standard for transforming land cover into a geospatial representation of ecosystem services is still missing. From a user's perspective, this is however an intrinsic expectation that could not be fully fulfilled by the project (e.g.

actual timber harvest value could not be estimated in detail due to the lack of data on tree species). One notable achievement of the project is that land cover is increasingly acknowledged as an indispensable tool for assessing the state and change of ecosystems. But there is still a missing link towards mapping of ecosystem services that needs to be addressed by the EO community. That is, how EO nomenclatures can be transferred into known schemes such as CICES or EUNIS? Here, ESA could take a leading role in pushing that important research topic further for mainstreaming Earth Observation technology into that emerging market.

Case study sites

Global distribution of the Ecoserve trial sites.

Lombok, Indonesia

EO products delivered:

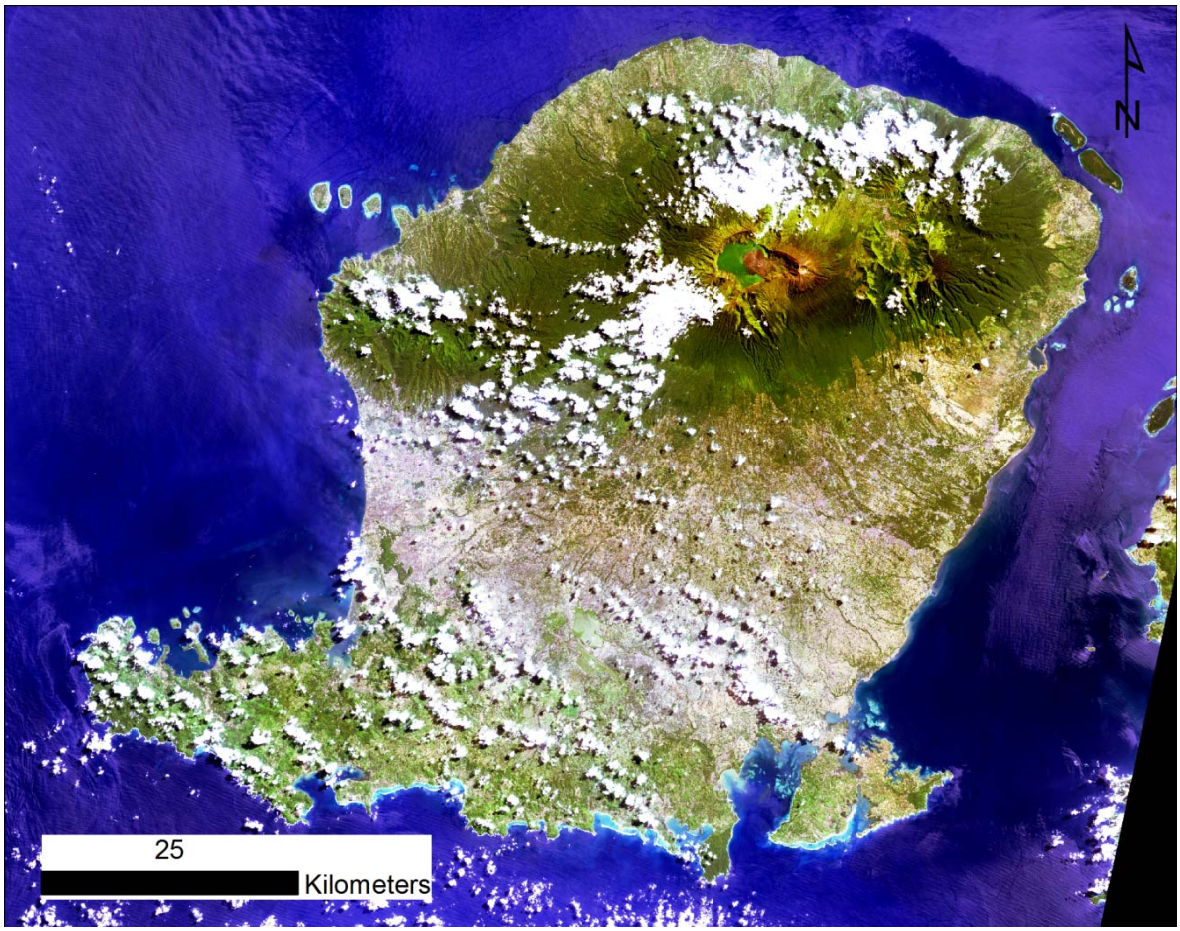
Land cover, forest classification, forest biomass, forest change, road and river network, fragmentation analysis

Ecosystem Services analysed:

Water supply, Nutrient retention, carbon sequestration and biodiversity.

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.

WWF Indonesia has, together with the municipality of Mataram and the Water Utility Company, initiated a payment for ecosystem service project with an aim to reforest the areas that were deforested in the 1990s and secure the water provisioning services of the ecosystems on Mount Rinjani. The project involves individual persons in Mataram as buyers of services maintained by upstream communities. The communities upstream get revenues for maintenance of forests and reforestation.



Landsat 8 image (2013) over Lombok. The caldera with the remaining cloud forest is clearly visible in the upper part of the image. And the more or less constant cloud cover over the south western tip is also present.

The present land cover on Lombok is divided between two major domains: forest and agriculture. Between these two domains the agroforestry domain is situated, mainly on the lower slopes of Mount Rinjani. 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.

Huong Son & Vinh Tu, Vietnam

EO products delivered:

Land cover, forest classification, forest biomass, forest change, road and river network, fragmentation analysis

Ecosystem Services analysed:

Managed timber production, carbon sequestration and biodiversity

In Vietnam, only 56,000 ha of forest are certified by FSC, accounting for less than one percent of the government's target area. FSC certification has typically focused on the certification of timber products sourced from sustainably managed forests as determined by a set of principles and criteria.

The Huong Son and Vinh Tu service trials have been defined in collaboration with FSC supporting the Forest Certification for Ecosystem Services (ForCES) project. This project tests the expansion of the FSC certification standard beyond the certification of 'sustainable' timber to include other important ecosystem services such as carbon, water quality, and soil erosion control and biodiversity conservation.

AOI of Huong Son

AOI of Vinh Tu

Maps of Huong Son (left) and Vinh Tu (right) trial sites in Vietnam shown on Google Earth imagery. Huong son is forest dominated with ecosystem services connected to the forest ecosystems, Vinh Tu is situated at the coast and the landscape provide services related to both the agricultural and forest domains.

Huong Son is located in the Ha Tinh Province in the Northern Annamites Rainforest, an ecoregion of global importance with high biodiversity. A large part of the trial site of 1,050 km² is classified as production forest and managed by Huong Son State Forest Company and faces considerable threats from deforestation and degradation, as well as wildlife poaching. Ha Tinh is one of the proposed new sites for the UN REDD program. There is considerable local awareness of pressures on ES and efforts to protect these.

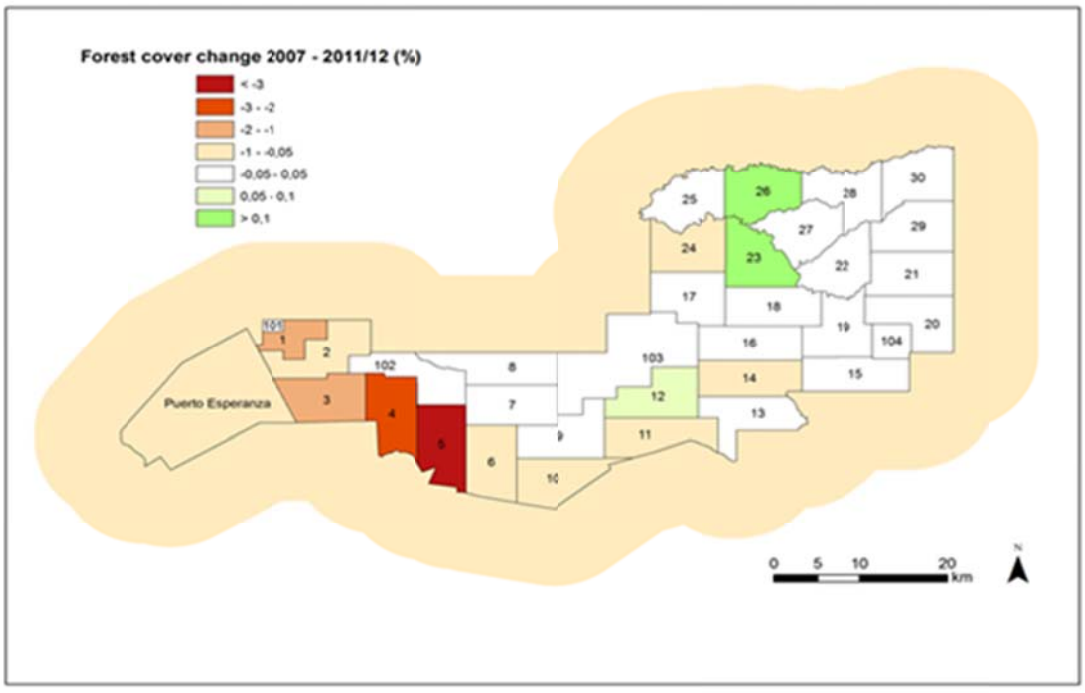
Vinh Tu with its rather small trial site (approx. 100 km²) is situated in the Quang Tri province on the shoreline of the South Chinese Sea in the Vietnamese lowland Rainforest eco region. In 2012, 249 ha of Acacia plantations across 112 households in Vinh Tu received FSC certification. Field observations by SNV have highlighted general stakeholders' awareness and interest in extended certification for a range of ecosystem services including watershed protection, forest protection and recreational services. A large extent of the forest of the eco region is transformed into agricultural land and the remnant forest patches are potentially important for biodiversity and ecosystem function.

Ucayali, Peru

EO products delivered:
Land cover, forest classification, forest biomass, forest change, road and river network, fragmentation analysis

Ecosystem Services analysed:
Managed timber production, carbon sequestration and biodiversity

Peru is among the top ten countries with the largest coverage of natural forest accounting for 75.8 million hectares, of which 69.8M ha are rainforest. Peru's forests are also an important biodiversity hotspot, for example the Ucayali Province has the largest inventory of mammals in the world.
The objective of the Ucayali region (Peruvian Amazon) service trial was to identify relevant ecosystem services, mainly timber production. For WWF, the objective of the trial was to improve the efficiency of gathering and monitoring data associated with sustainable forest management, biodiversity as well as ecosystem service mapping in privately owned forest concessions. The project area is located in the district of Raymondi, Atalaya province of in Ucayali region and comprises a forest concession of Consorcio Forestal Amazonico (CFA) as well as an indigenous community (Puerto Esperanza) forest concession, which are legally enabled to develop forest management, as well as surrounding areas without formal land title. In 2007, the CFA Company, member of the WWF-led Global Forest Trade Network (GFTN), was certified under FSC forest management standards. The area under certified management has 180,471 ha. An area of ca 160,000 ha (89 %) is assigned for timber production while 20,000 (11 %) is conservation forest. The CFA concession is surrounded by indigenous communities, e.g. Puerto Esperanza with ca 19,000 ha of titled area. It is located in CFA west and adjoins the Ucayali River. In 2012, this community obtained the certification for their forest management practices, with the assistance of the Living Amazon Project financed by the European Union and WWF Germany.



Delineation of the CFA forest concession and Puerto Esperanza community forest and the forest change rates from the satellite-based change analyses.

Yucatán

EO products delivered:
SST: average and stdev., Chl-a: average and stdev., Kd(490) : average and st. dev., Coral reef habitat and seagrass map, Bathymetric map

Ecosystem Services analysed:
Carbon sequestration, touristic values and coastal protection

The Yucatán site is the Puerto Morelos Marine Park, a National Park, on the Mesoamerican barrier reef, providing important services to tourism and coastal protection. The total area of interest is less than 200 km^2, stretching for approximately 25 km south of Cancun to Puerto Morelos on the Yucatán peninsula, Mexico. The Yucatán coral reef and seagrass service trial was developed with guidance from local users at the Institute of Marine Sciences and Limnology (ICML) and the Arrecife de Puerto Morelos National Park (Puerto Morelos National Marine Park).

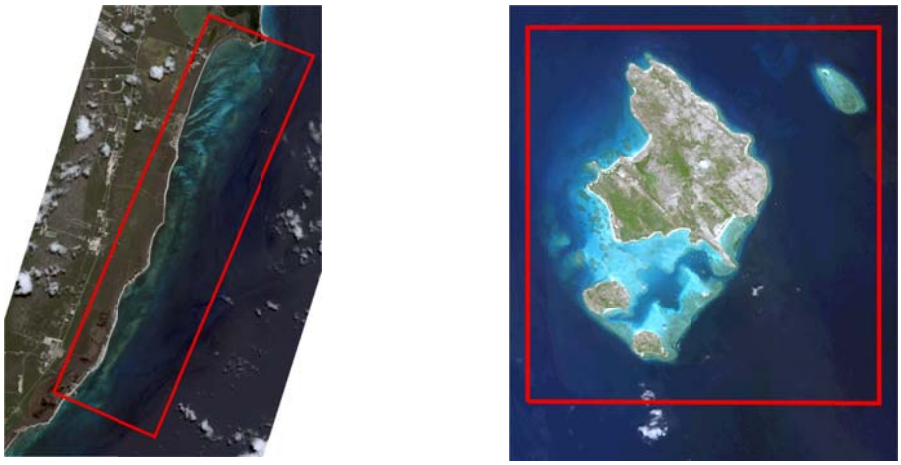
The Yucatán site is a National Park and the Mesoamerican barrier reef provides important services to tourism and coastal protection, and is a major source of income for the local population (mainly through tourism and fisheries). The coastal region in Yucatán has undergone substantial coastal development over the last twenty years, with many hotels and other tourist developments having been built literally on the beach front. This site was chosen for its extensive seagrass beds that have been well studied by one of our local user organisations. A change in seagrass cover is understood to have occurred in recent years. Changes in seagrasses can be both early indicators and buffers of environmental change, for example, eutrophication of the lagoon from the extensive coastal development.

Lizard Island

EO products delivered:
SST: average and stdev., Chl-a: average and stdev., Kd(490) : average and stdev., Coral reef habitat and seagrass map, Bathymetric map

Ecosystem Services analysed:
Carbon sequestration

Lizard Island in the Great Barrier Reef, Australia is part of the world's largest reef system. The Great Barrier Reef provides services, such as fisheries and tourism, which have direct economic value. The area of interest is 120 km2 surrounding Lizard Island. The service trials here were guided by the Australian Museum (lease-holders on Lizard Island) and information from the Queensland Parks and Wildlife Service who are responsible for the management of the site. Tourism is a major economic activity in the region and the island has a resort. In addition, there is a scientific research lab on the island. The Queensland Parks and Wildlife Service have a particular interested in seagrass dynamics with respect to turtle and dugong populations.



Location of the marine trials with seagrass and reef ecosystems. Puerto Morelos, Yucatán (left) and Lizard Island, Australia (right). The areas of interest are the red boxes on the images.

Projects and users

FSC

FSC was the global user for the service trials at Lombok, Indonesia and Huong Sn &Vinh Tu, Vietnam.

FSC works to improve forest management worldwide and creates an incentive for forest owners and managers to follow best social and environmental practices, through certification. The growing demand for FSC certified products communicate to forest owners that businesses and consumers prefer products from well managed forests.

FSC has devoted an entire principle to the maintenance of ES and environmental values. It is important that services and values present in an area are known and the adverse impacts on them minimised. Foresters should protect threatened species and ensure the continued existence of biological diversity. Water courses and bodies, as well as riparian zones, need to be protected, and the forest structured so that it is in harmony with natural landscape dynamics.

Another principle requires forest managers to identify and respect outstanding values inherent in their forests and to use a precautionary approach for their conservation. These High Conservation Values have been divided into broader categories ranging from species diversity to cultural values.

WWF

Building a future in which people live in harmony with nature is the mission of the World Wide Fund for Nature. From the experience as the world's leading independent conservation body, WWF know that the well-being of people, wildlife and the environment are closely linked. That's why WWF is striving to safeguard the natural world, helping people live more sustainably and take action against climate change. WWF started in Switzerland in 1961 and works now in more than 100 countries supported by more than 5 million people worldwide.

WWF Germany

WWF Germany was the global user for the service trial in Ucayali region, Peru.

In Germany, WWF was founded in 1963 and became the largest and most influential environmental organization focusing on themes and projects to protect nature. Hence, WWF Germany contributes in the Amazonía Viva project to stop illegal deforestation, to reduce the loss of biodiversity and to support local farmers and indigenous peoples in the sustainable use of resources. In the frame of the Amazon Region Protected Area Programme (ARPA), the largest and most comprehensive project for the protection of tropical forest, WWF Germany took responsibility for an area in the middle of the deforestation front. Since 2013 WWF also supports the "Mosaico da Amazonia Meridional" project in order to preserve protected areas.

WWF Indonesia

WWF Indonesia was the local user for the service trial at Lombok, Indonesia.

WWF started to work with conservation issues in Indonesia in the early 60's. The focus at that time was to save the Javanese rhino from extinction. Since then the activities has expanded to encompass projects on marine environments, forests, species conservation as well as climate mitigation and energy. Despite the presence since the early 60's, WWF Indonesia was established first in 1998. WWF Indonesia has 3 main offices in located in Sundaland, Wallacea and Sahul, with conservation projects in approximately 23 sites distributed in 16 provinces

WWF Peru

WWF Peru was the local user for the service trial in Ucayali region, Peru.

WWF began to work in Peru in 1969 when it contributed towards the creation of the first protected area for wildlife management in Peru. In 1994, WWF established its first project office in Peru and later in 1998, the WWF Peru Programme Office was formed. Following this WWF Peru intensified its efforts to guarantee biodiversity conservation in key coastal ecosystems, the Andes and the Amazon. WWF Peru work together with indigenous federations and communities, governmental bodies and private companies to increase the knowledge of and capacity for sustainable use of forests and forest products.

SNV

SNV was the local user for the service trial in Huong Son Vinh Tu, Vietnam.

Starting out in the Netherlands more than 40 years ago, SNV now works in 36 countries in Africa, Asia, and Latin America. The main fields of work are Agriculture, Renewable Energy and Water, Sanitation & Hygiene to contribute to solving some of the leading problems facing the world today.

SNV is the leading implementing partner in Vietnam and focus its efforts on improving and promoting sustainable forest management for a range of ecosystem services. To demonstrate the feasibility of this approach, SNV pilot tests the expanded ES certification in the two Vietnamese test sites.

Forces

FSC are together with the partners UNEP, CIFOR, WWF Indonesia and SNV currently conducting a project, Forest Certification for Ecosystem Services (ForCES), aiming at research, analyses and field testing of innovative ways to evaluate and reward the provision of critical ecosystem services, such as biodiversity conservation, watershed protection and carbon storage/sequestration.
The ForCES project will be implemented over four years (2011-2015) through the support of the Global Environment Facility (GEF) and Embassy of Finland, spanning four countries: Chile, Nepal, Indonesia and Vietnam. This project will test the expansion of the Forest Stewardship Council (FSC) certification standard beyond the certification of 'sustainable' timber to include other important ecosystem services (ES) such as carbon, water quality, soil erosion control and biodiversity conservation.

CIFOR

CIFOR is a partner of the ForCES projected and had an advisory role in the Lombok and Huong Son & Vinh Tu trials

The Center for International Forestry Research (CIFOR) advances human wellbeing, environmental conservation and equity by conducting research to inform policies and practices that affect forests in developing countries. CIFOR is a CGIAR Consortium Research Center. CIFOR's headquarters are in Bogor, Indonesia and it also has offices in Asia, Africa and South America. The research focuses on the cross-sectorial nature of forest management. CIFOR and partner organizations are also undertake over four years in a major global comparative study on the implementation of 11 pilot REDD+ (United Nations program for Reducing Emissions from Deforestation and forest Degradation) projects in Africa, Asia and Latin America, including Vietnam and Peru.

IMCL

IMCL was the local user in the Yucatán trial, through collaboration with,.

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EL FILO KINORRINCOS:
LOS DRAGONES DEL FANGO

The Yucatán site is the Puerto Morelos Marine Park, in North Yucatán, Mexico; this is a National Park and the Mesoamerican barrier reef providing important services to tourism and coastal protection. It was designated a protected National Marine Park in 1998.

The total area of interest is less than 200 km^2, stretching for approximately 25 km south of Cancun to Puerto Morelos (20.8536° N, 86.8753° W) on the Yucatán peninsula, Mexico. This site was chosen for its extensive seagrass beds that have been well studied by one of our local user organisations and for which a change in seagrass cover is understood to have occurred in recent years. The Yucatán coral reef and seagrass service trials were developed with guidance from the Institute of Marine Sciences and Limnology (ICML) and the Arrecife de Puerto Morelos National Park (Puerto Morelos National Marine Park).

The IMCL Unit (http://www.icmyl.unam.mx/arrecifes/rsu.html) forms part of the Institute of Marine Sciences and Limnology of the National Autonomous University of Mexico (UNAM

The mission of ICML is to investigate various parts of this reef system, including the lives of the diverse plants and animals that inhabit it, their interrelations, the physical structure they collectively produce, and the coastal and oceanic environments that they influence and protect.

Australian Museum

Australian Museum was the local user in the Lizard Island, Australia trial

Australia Museum (australianmuseum.net.au) delivers services to clients and stakeholders in three main fields:

- collection management - the Museum maintains and develops the largest natural history and cultural collection in Australia with over 16 million registered items or lots
- scientific research - the Museum undertakes scientific research on its collection of objects and in the field to expand our understanding of the biota and indigenous cultures of Australia and the Pacific region
- Public programs - the Museum presents a wide array of exhibitions, programs and events to raise community awareness of the biota and indigenous cultures of Australia and the Pacific region.

In particular, the Australia Museum plays a leading role in taxonomic and systematic research, and at its research station at Lizard Island conducts significant research on coral reef ecology.

InVEST toolkit

The InVEST toolkit has been developed in a partnership between Stanford University, The Nature Conservancy, the World Wildlife Fund, and the University of Minnesota as part of the Natural Capital Project aiming at the integration of ecosystem services into every day's decision-making. The InVEST models quantify and map the values of ecosystem services, in particular assessing multiple services and multiple objectives. The current models, which require relatively little data input, can identify areas where investment may enhance human wellbeing and nature.

InVEST has a tiered design. While Tier 0 models map relative levels of ecosystem services and 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 will provide increasingly precise

estimates of ecosystem services and values, which are especially important for establishing contracts for payments for ecosystem service programs.

InVEST is most effectively used within a decision-making process that starts with a series of stakeholder consultations. Following stakeholder consultations and scenario development, InVEST can estimate the amount and value of ecosystem services that are provided on the current landscape or under future scenarios.

Finally, one of the main reasons for selecting InVEST, the models are spatially explicit, using geographic data as information sources and producing maps as outputs.

Example from the coastal vulnerability analyses on how EO fits into the Invest models together with, in-situ data and global datasets. Green dot = direct contribution specifically designed for this project. Yellow dot = indirect contribution usually coming from global/regional data sets.

Coastal vulnerability	EO	in-situ	other
Area of Interest (AOI, required)	🟢		
Land Polygon (required)	🟢		
Bathymetry layer (required)	🟡		🟢
Relief (required)	🟡	🟢	
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)	🟢		
Coastal overlap (meters, required)			🟡
Natural Habitat (optional)	🟢		
Natural Habitat Layers CSV (Table optional)			🟢
Climatic forcing grid (optional)			🟢
Continental Shelf (optional)			🟢
Sea Level Rise (optional)	🟢		
Population Raster (optional)		🟢	
Min. population in urban centres (required)			🟢
Coastal neighbourhood (radius in m, required)			🟢

EO-services

Terrestrial EO services

There were three distinct product groups derived at each of the terrestrial trial sites:

1. Forest and land cover classifications;
2. Forest change assessment by means of recent and historical image comparison;
3. Biomass estimation.

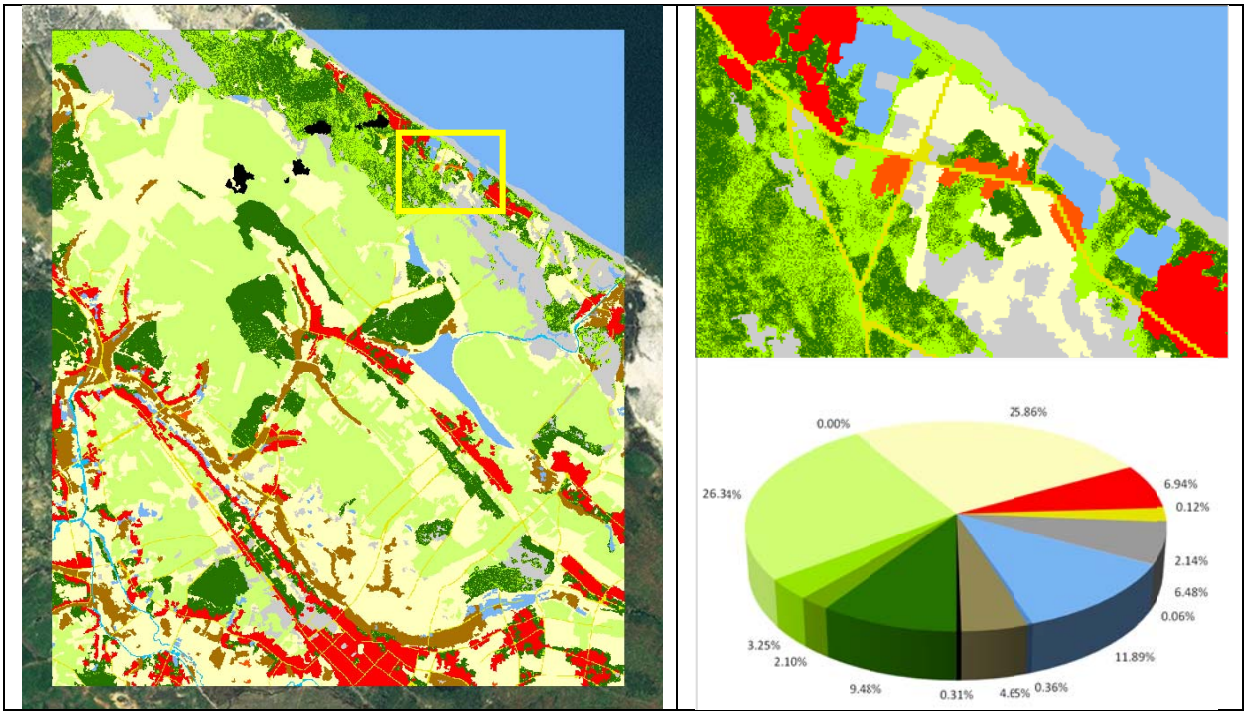
In addition to this a landscape fragmentation analysis was performed in the terrestrial trial sites.

Land cover

Produced for:
Lombok, Huong Son &Vinh Tu and Ucayali

Used in assessment of:
Biodiversity, Water yield, Nutrient retention, Habitat fragmentation and Carbon Sequestration

Land cover classification is based on the spectral characteristics of the respective land cover classes. Areas outside the forest have no or few trees and the main land cover types are shrub land, grassland, water, marches and sparsely- or non-vegetated areas. Most of the open areas are open as a result of human land use and are referred to different land use domains, e.g. the agricultural domain and infrastructure.
The agricultural domain is dynamic with regard to land cover. A rice field can shift accordingly: from non-vegetated to water followed by vegetated and back to non-vegetated over the course of a couple of months. Infrastructure on the other hand is permanent non vegetated areas, typically stretching out in a narrow interconnected mesh over the landscape. Local knowledge and image analysis techniques together with some degree of visual interpretation make it possible to collect information on both land cover and land use with multispectral high resolution imagery. Combined with in situ data and other auxiliary data sources the accuracy of the classification of both land use and land cover classification can be increased.



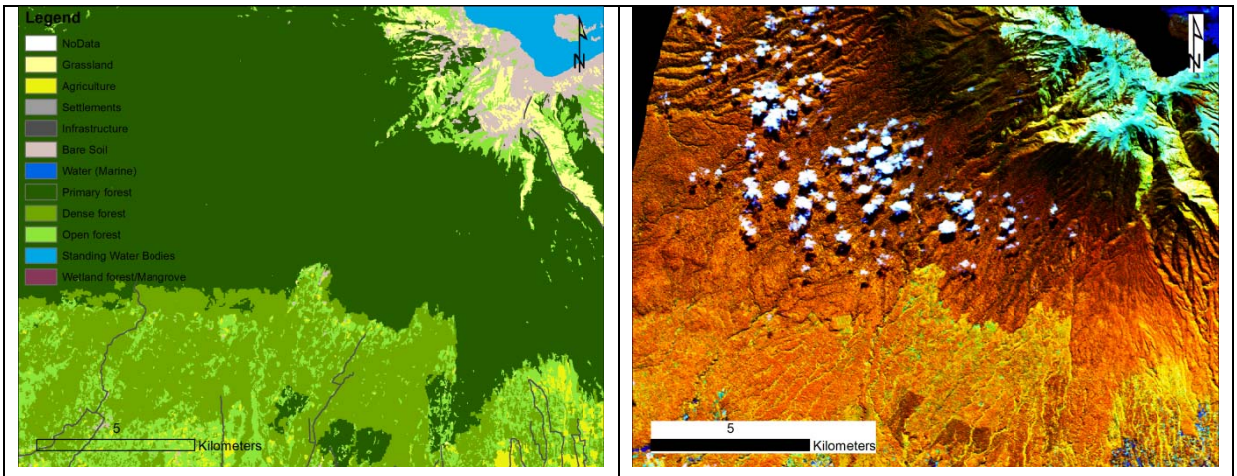
Recent land cover map for Vinh Tu. Note: No MMU is applied for the forest density classes to avoid suppressing small features. ©GeoVIlle

Forest classification

Produced for:
Lombok, Huong Son &Vinh Tu and Ucayali

Used in assessment of:
Biodiversity, Water yield, Nutrient retention, Timber production and Carbon Sequestration

Forest classification is based both on the crown density of the forest but also on the spectral characteristics of different tree species and tree maturity. Crown density analysis of high resolution imagery is based on the transition of spectral signatures from patches with only signatures of tree crowns to patches dominated by ground vegetation. This range is divided into different density classes. The larger the contrast is between the crowns and the ground the higher accuracy is achieved. Spectral characteristics of forest patches differ depending on species, species composition, crown size and growth phase etc. Diverse forests with large crowns and a closed understory differ accordingly considerably from managed forests and plantations with only one or two species. This makes it possible to distinguish between young and old forest and managed and unmanaged forests. Information on local conditions significantly improves quality of the classification.



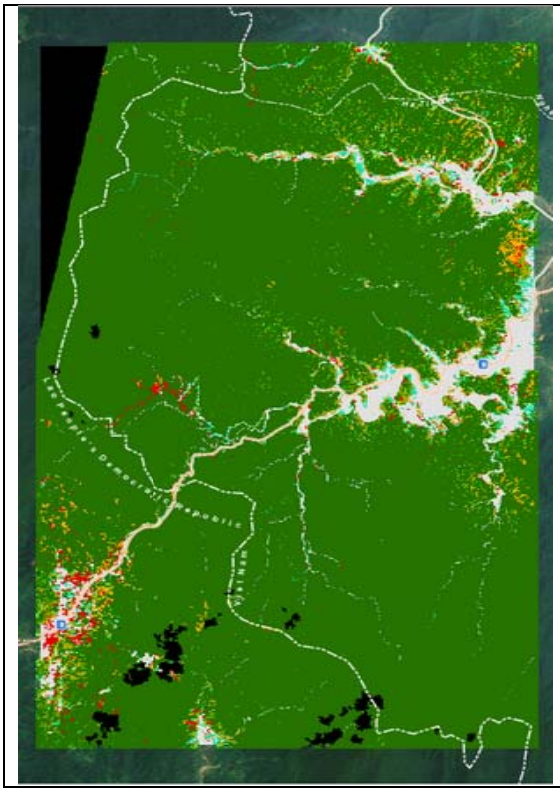
Forest classification on the slopes of Mount Rinjani with different density classes and differentiation between primary (dark green) and secondary forest (lighter green colours). The untouched rainforest is high up at the caldera the more accessible areas further down are degraded or transformed to agricultural land. The corresponding SPOT 5 image is from 2011-06-02. © Metria

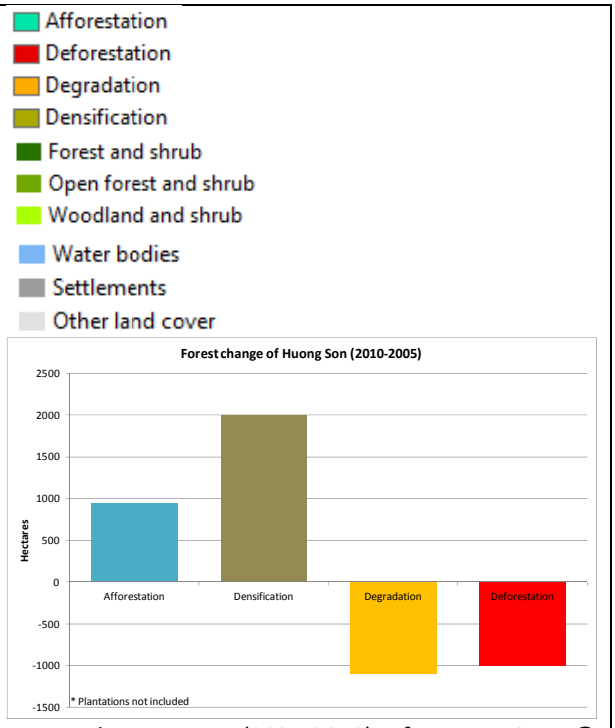
Change analysis

Produced for:
Lombok, Huong Son &Vinh Tu and Ucayali

Used in:
Carbon sequestration modelling and scenario design

EO based land cover mapping has been conducted using high to very high resolution optical satellite data from sensors such as SPOT, RapidEye and Landsat. The spatial detail, timeliness and accuracy of such Earth Observation information offers significantly superior information content to any existing public land cover data available, for example for analyses of changes in forest cover, the localisation of logging activities and degradation impacts. One important quality factor for multi-temporal land cover mapping is to achieve as homogeneous image coverage as possible for each single time step. Besides the minimisation of atmospheric influences such as clouds or haze, seasonal changes of the phenology need to be taken into account. Therefore, multi-temporal image coverage of different seasons would improve the quality of the result. Furthermore, shifts of species are probably identified as forest with lower density in comparison with surrounding forest, providing the wrong indication of an actual degradation. This can only be avoided by using additional available satellite sensors to optimize the satellite image coverage or even higher-resolution imagery to check such effects more locally, possibly also supported through field work.





Forest change map (2005-2010) of Huong Son. © GeoVille

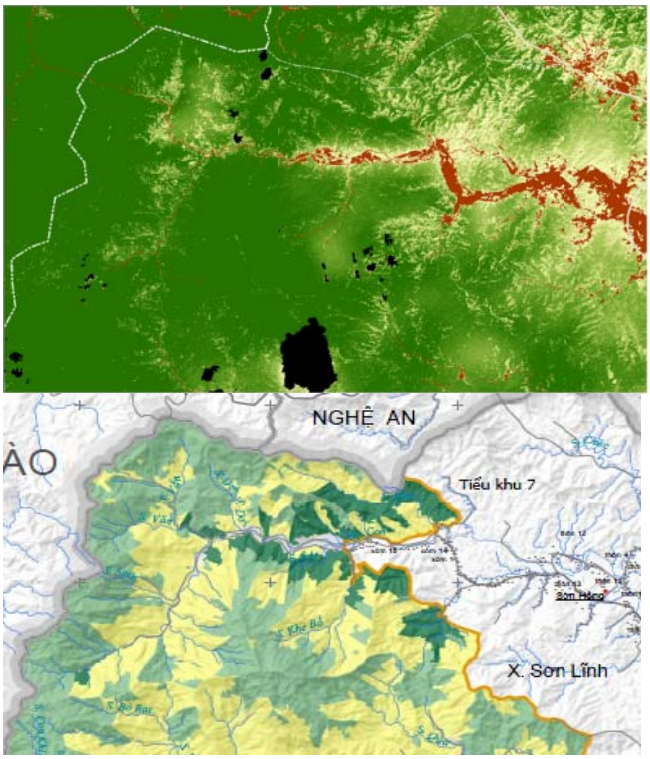
Forest change map (2005-2010) of Huong Son. © GeoVille

Above-ground Biomass estimation

Produced for:
Lombok, Huong Son &Vinh Tu and Ucayali

Used in assessment of:
Specific EO product produced I a different way compared to the carbon sequestration model of InVest.

Estimates of above ground biomass in forested areas have been generated through a combination of EO and in-situ data sources. Multi-sensor approaches, utilising both information on vegetation types/structures and canopy height, can give reliable estimates of above ground biomass. The approach used is based on the forest classification and vegetation height data derived from the Geoscience Laser Altimeter System (GLAS) instrument on ICEsat, providing Global Land Surface Altimetry Data as a standard data product already available. Canopy height measures are combined with information on the forest structure/tree cover density from the forest classification product in order to estimate above-ground biomass (EAGB) within forests. As reference forest and region specific values published in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories are used for the Carbon models. For Asian tropical rainforest it was necessary to slightly modify the original values according to local experience. The implementation of a growth indicator to take into account forest and region specific gain of biomass over a certain time (e.g. per year) would be a potential further improvement for the change of above ground biomass. However, this would require a detailed forest species map of the trial areas, which was not available at the time of production. The comparison below visualizes the benefit of using high resolution EO data as input for the generation of indicators like EAGB, as compared to more aggregated indicators.



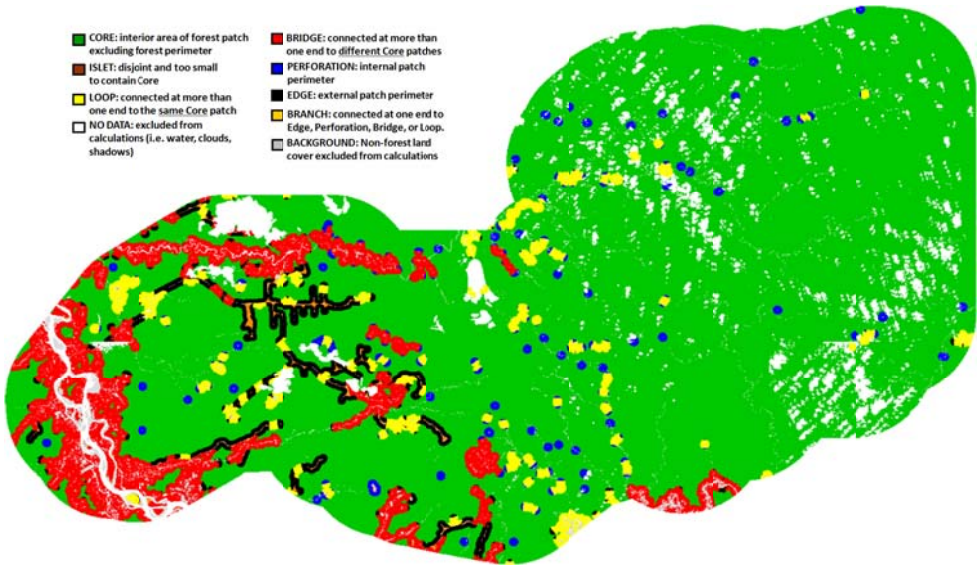
Comparison of distribution of above ground biomass for northern part of Huong Son in 2012 (above) and forest carbon map provided by SNV as reference (below). The EO services gives much higher spatial resolution of the biomass estimates compared to the data that was available for the carbon estimate. ©GeoVille

Habitat fragmentation

Produced for:
Lombok, Huong Son &Vinh Tu and Ucayali

Used in assessment of:
Specific EO delivery that was not used for the Ecosystem Service Valuation.

Habitat fragmentation is important for the processes and species occurring in natural and semi-natural environments. By request of WWF Germany, the GUIDOS toolbox (Graphical User Interface for the Description of image Objects and their Shapes) has been applied enabling Morphological Spatial Pattern Analysis, describing the geometry and connectivity of the landscape patches. The landscape metrics are based on the forest and land cover classification and contain different measures related to habitat area, shape and neighbourhood. These metrics are provided in map format and depict various types of forest fragmentation in the trial sites for further consideration in ecosystem assessments.



Forest fragmentation in Ucayali 2012. Green areas are unfragmented while the others are fragmented in different ways, either isolated or connecting core areas. ©GeoVille

Marine EO services

There were four distinct product groups derived at each of the marine trial sites:

1. Open ocean (deep water) biophysical parameters. These contribute the reef and lagoon environment, and in some cases (such as temperature) can be related to stress;
2. Bathymetric mapping;
3. Coral reef and seagrass habitat classification;
4. Change assessment by means of recent and historical (~20 years previous) habitat classification.

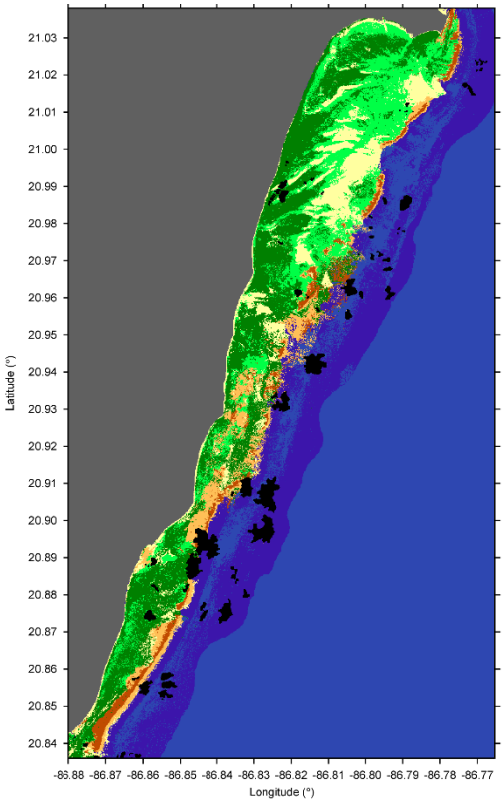
Benthic Habitat

Produced for:
Yucatán and Lizard Island

Used in:
Carbon sequestration and Coastal Vulnerability Models

Maps of coral reef habitats and seagrasses at two time points were produced by unsupervised classification. Quickbird data from 2011 for Lizard Island and WorldView 2 data of the Yucatán site from 2011 were utilized. Masking of land, cloud and deep water areas beforehand was required and this was achieved by a combination of automatic mask generation from near infra-red (NIR) band for land and clouds and manual delineation of deep water areas. Several thematic classes were defined for coral reef and seagrass habitats. The classes were chosen based on the need to support an ecosystem service assessment and also to align with available validation data.

The relative area coverage of seagrass habitats in the Yucatán 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, the results imply is a net, but small, decrease in seagrass coverage in the whole study area between 1992 and 2009.



Code		Name	Notes
1		Land	
2		Deep Water	Bottom type indeterminate
3		Sand	Pure sand or very sparse seagrass or algae in sand
4		Medium Seagrass	May be mixed canopy with algae
5		Dense Seagrass	May be mixed canopy with algae
6		Rubble / Sparse Coral	Sandy coral rubble area with sparse corals and algae
7		Reef Matrix	Locations of live coral cover
8		Reef Slope / Deep Reef	Fore reef slope and deep reef area with soft corals

High resolution habitat map displaying different benthic habitats at the Yucatán site, notice the extent of dense seagrass meadows. ©ARGANS

Bathymetry

Produced for:
Yucatán and Lizard Island

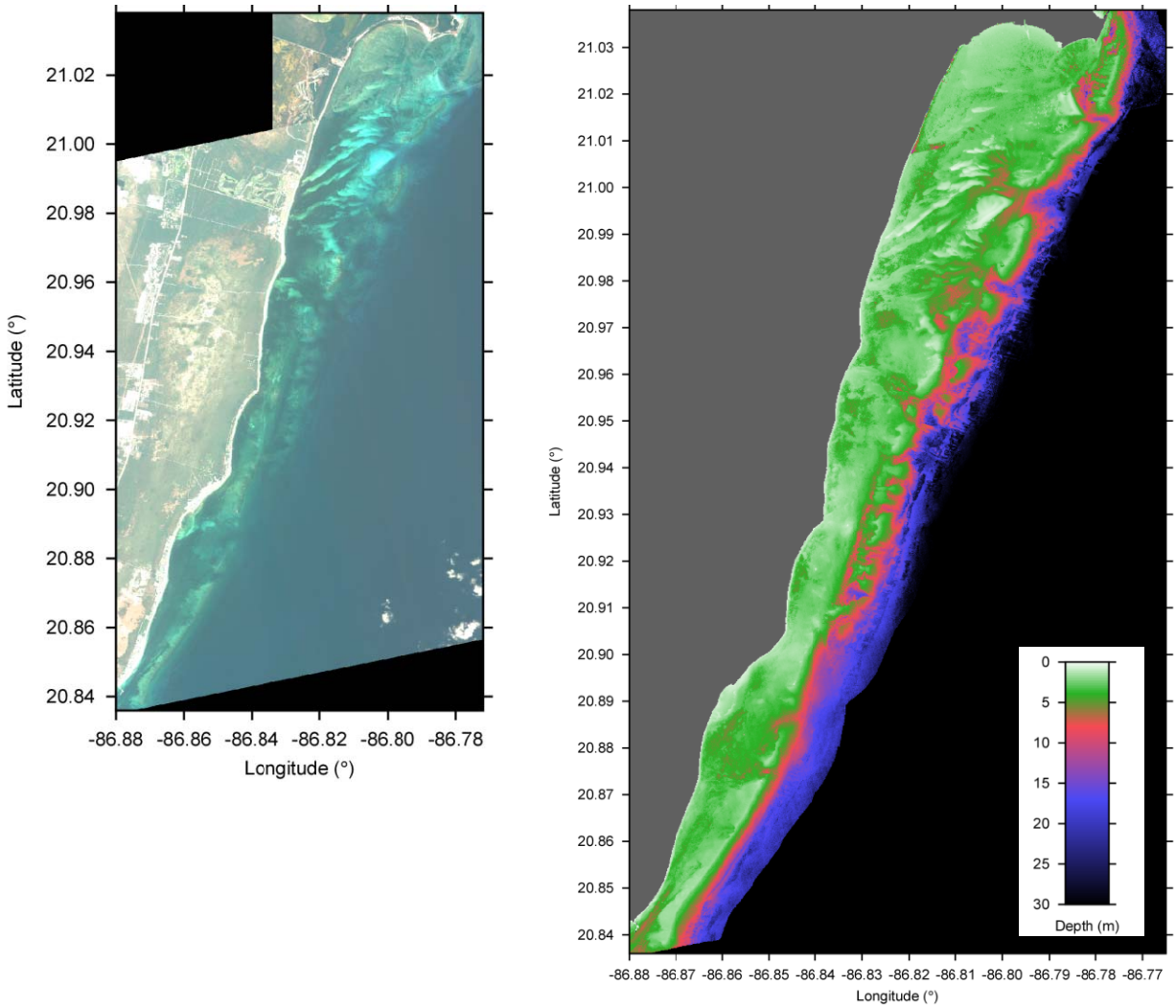
Used in:
Coastal protection model

Bathymetry accuracy is normally summarised as the spread of a regression visually assessed; nevertheless here we provided a quality statement based on an absolute value, which is more meaningful for interpretation.

Product/service delivered at each site and accuracy for the bathymetric mapping products

Service Trial	Spatial resolution	Accuracy	Temporal resolution
Puerto Morelos, Yucatán.	2.4 m	Within ±1 m for depths less than 10 m, over 81% of the image	present
Lizard Island, GBR.	4.0 m	Within ±1 m for depths less than 10 m, over 76% of the image	present

At both sites the basic pattern of the bathymetry maps appears qualitatively very good and more than adequate for assessment of coastal protection, which relies on the shallowness and spatial extent of the lagoon and for reef area.



LEFT: Imagery of Puerto Morelos Reef National Park in a composite of two Kompsat 2 images from 2008 and 2009; RIGHT: Bathymetric map of Puerto Morelos Reef National Park. Spatial resolution is 4 m; Dark grey is land and black is unprocessed deep water. ©ARGANS

Open Ocean

Produced for:
Waters outside Yucatán and Lizard Island

Used in:
Environmental information supporting the ecosystem services assessment at Yucatán and Lizard Island

Sea surface temperature (SST) is a well-known stress indicator for coral reefs. Prolonged excessively high temperatures are a primary trigger for coral bleaching, where corals expel their photosynthetic symbionts and have a high chance of suffering mortality. We provided climatological statistics for SST, chlorophyll and turbidity (measured as attenuation, $K_d(490)$). For each oceanographic product a 10 year time series of data in the regions of interest was extracted from the source data (primarily AATSR, MERIS and MODIS). SST is a standard and well understood product. Therefore, the quoted accuracy of the products applies (within 0.3K) have been assumed to be valid. In reducing 10 years of almost daily data to monthly mean will substantially reduce noise in the data. Therefore the spatial and temporal patterns in the SST are likely to be reliable and represent genuine features, except in the possible contamination by land for pixels that overlap the land. Likewise, chl-a and $K_d(490)$ are standard and well understood products, and we assume the quoted accuracy of the products applies (< 35% each). However chl-a is a product derived from visible wavelengths and designed only to work in deep 'Case 1' waters where there is no influence of bottom

reflectance and chlorophyll is assumed to be the dominant contributor to the variable optical properties of the water. Therefore chl-a and $K_d(490)$ are invalid over shallow reefs or close to the coast, wherein the waters are frequently complex in their composition, containing dissolved organic matter or other constituents of terrestrial origin. Hence in the delivered products only the deep water pixels could be considered valid; the apparent high chlorophyll close to land or over shallow regions does not typically accurately represent the chl-a and $K_d(490)$ in the water column.

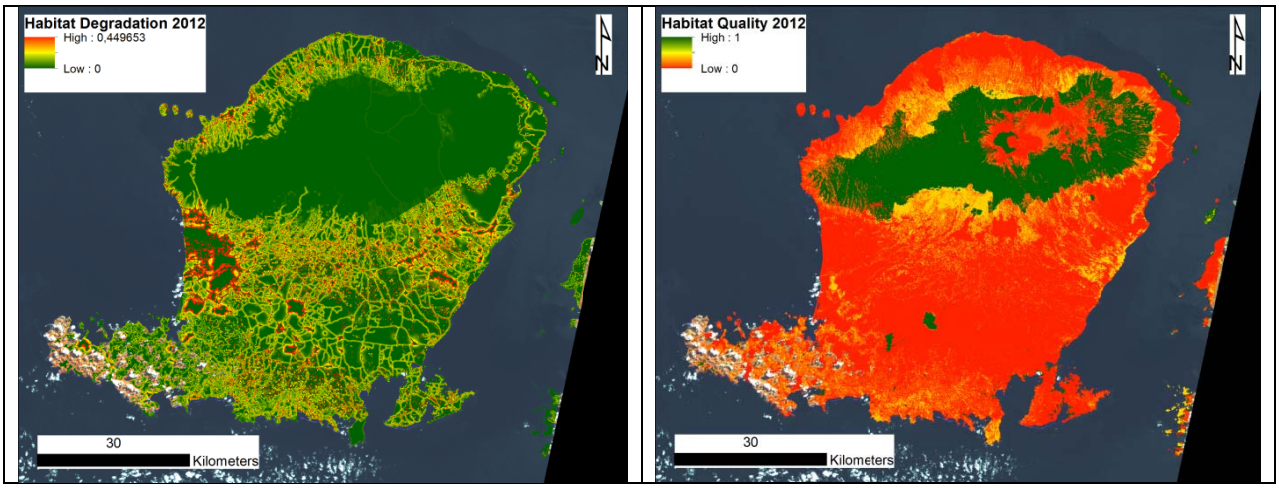
Ecosystem services valuation

Biodiversity

Produced for

Lombok, Huong Son &Vinh Tu and Ucayali trials

The multitude of processes, genes and habitats constituting ecosystems are referred to as biological diversity. The biological diversity is the backbone of the ecosystems services delivered to promote human wellbeing. When biological diversity diminishes it is an indication of ecosystem change and hence an indication of a change of the ecosystems capacity to deliver services for human wellbeing. EO-data give important information on the distribution of habitats as well as the distribution of land covers and structures threatening species and landscape processes.



Map of the threat situation for biodiversity in natural ecosystems and of the distribution of high quality habitat as derived from the land cover map and system knowledge. Green areas have a low threat level or high habitat quality. ©Metria

Carbon sequestration

Produced for:

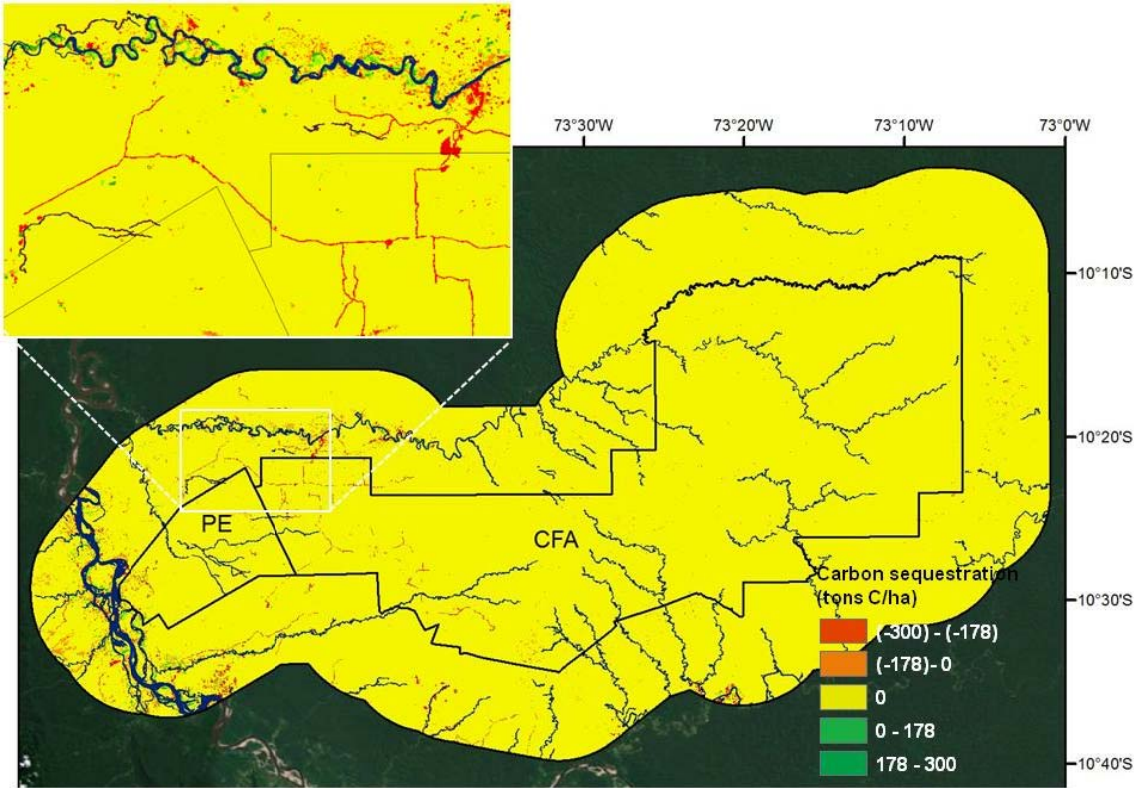
Lombok, Huong Son & Vinh Tu, Ucayali and Yucatán

Carbon storage and sequestration is a very important ecosystem service in tropical forests. To estimate the carbon content information on biomass from four carbon pools: above-ground biomass, below-ground biomass, soil and dead organic matter. Above-ground biomass comprises all living plant material above the soil (e.g. trunks, branches, leaves); below-ground 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.

EO-based data can partially satisfy the information requirements for one of the four parameters: above-ground biomass. The availability of local estimations of carbon pools (above-ground, below-ground, soil and dead material) per forested class would significantly improve the quality of the results. However, in most of the cases these measurements are not available.

Carbon sequestration has been modelled for three of the terrestrial demonstration sites, mainly differentiated by the structure of the landscape:

- The Lombok test site in Indonesia is characterized by forest stands of different stages of maturity and thus carbon sequestration capacity. Next to an already high carbon stock, the test site has a high capacity for additional carbon sequestration by maturing trees and conversion of agricultural lands into forest.
- The Peruvian and the Huong Son case are characterized by very dense, homogeneous tropical forests. As a consequence *differences* in carbon storage and sequestration of scenarios between different years are low.
- Most of the carbon dynamics in the Vinh Tu area are due to the management of the tree plantations in the area. The most important factors that must be considered are the forestry practices and how the extracted biomass is used, i.e. for biofuel, pulp or construction which will have an impact on the amount of carbon released.



Carbon sequestration or forest cover change map for the years 2006 and 2010. The establishment of a road network is evident within the concession as well as the agricultural and hydrological dynamics close to the river. Red is the loss of biomass, visible as timber roads and clearings. The riverine forest dynamics are also visible as red and green (gain) areas along the rivers. ©GeoVille

Analysing the experiences from all trials, it can be concluded that earth observation data can provide valuable input data for two of the model input parameters (i.e. land cover/use and future scenarios). Information on carbon pools is best obtained from site-specific in-situ data. Only in case where such in-situ data are lacking they can be roughly approximated from EO data of global estimates of carbon pools from literature.

Timber production

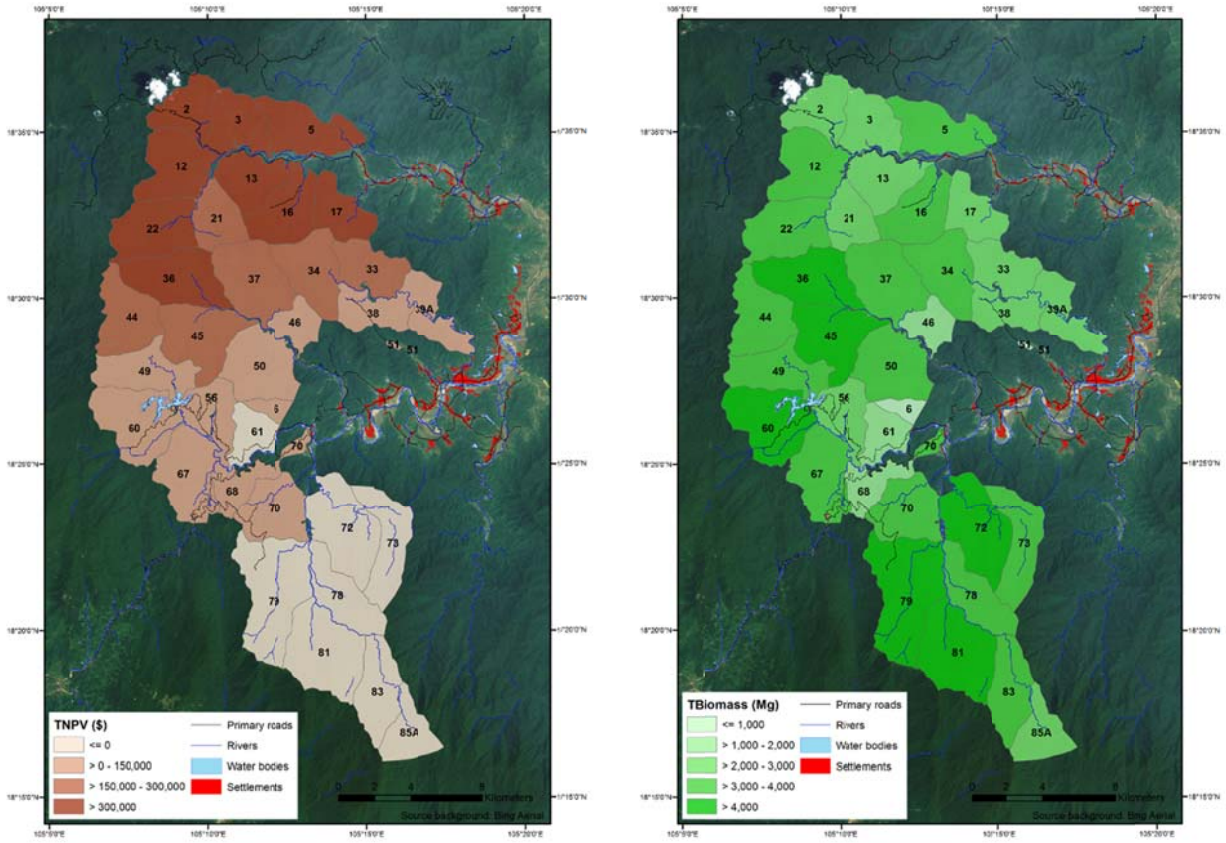
Produced for:
Huong Son and Ucayali

Forest related ecosystem services have been assessed in three of the four project test sites (Indonesia, Vietnam and Peru). The assessment of timber production ecosystem services requires two main sets of input data:

1) Earth Observation based map information on forest extent, changes in forest extent (i.e. harvested parcels) as well as the forest management parcels.
2) A series of production and management related data, specific to the exploitation plan of the forest area.

While the EO-based information on forest extent, type and density can be obtained with reasonable accuracy and effort, information on production and management is very site specific (e.g. tree type and mass harvested, investment and maintenance cost of the exploitation or the market value of the timber and its trends over time) and needs to be supplied by the user of the data. Despite these limitations related to approximated inputs the model is a powerful tool to get economic values of the region with managed timber production. On the other hand, the "Managed Timber Production" model of InVEST shows serious limitations in accounting 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, additional (more natural-based) ecosystem service models would provide a more complete picture of the study area.

In conclusion, EO data are perfectly suited data for the provision of independent information on the concession area and the progress of the exploitation activities. In case of selective logging the information on harvest volumes is a bit more difficult, especially in very dense forests, otherwise EO data can provide important information parameters in those cases where detailed in-situ data (from the exploitation company) are lacking.



Information on land cover, market values and forest management was used as input to the managed timber production model of the Invest toolkit and applied to the Huong Son forest concession. The left image displays the total net present value of the forecasted timber extraction until 2045 (based on averaged values), the darker the greater value. The legend of the right image display the biomass foreseen to be extracted by the forest operations within each parcel, the darker green the more biomass is foreseen to be extracted in the parcel. Numbers correspond to the parcels listed in the forest management plan of the Huong Son Company. ©GeoVille

Fresh water yield and Nutrient retention

Produced for:

Lombok

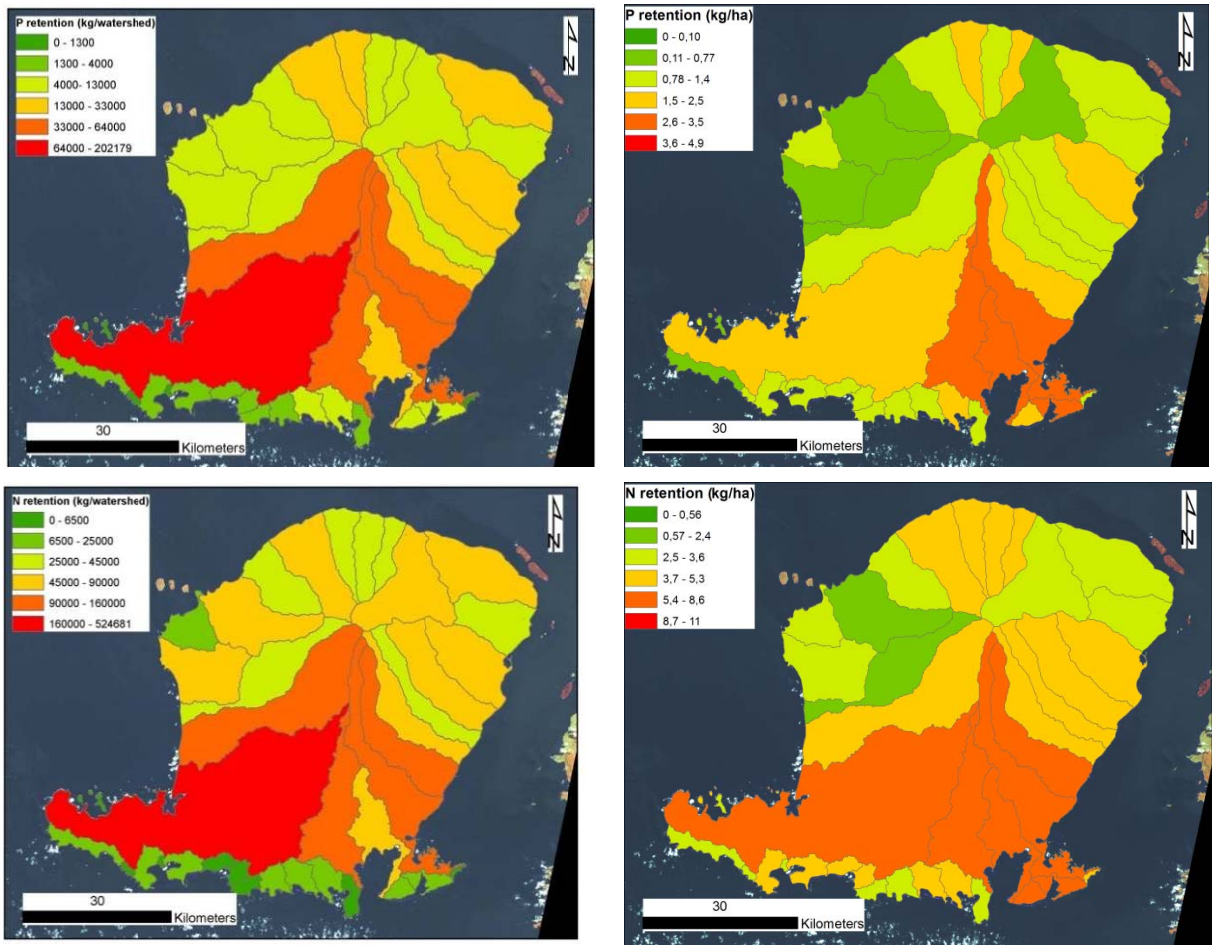
Water falling on land is filtered by vegetation, soil and to some extent bedrock. Purification of water is one of the most important and basic ecosystem services. Pure water is a prerequisite for human well-being as drinking water, source of irrigation and for healthy aquatic environments. The aquatic environments provide services such as recreation and populations of edible fish and other aquatic organisms. Clean water, in lakes ponds and rivers, is important for game populations. Clean water availability is one of the most important factors for primary production. Water filtration hence provides the base for a cascade of ecosystem services at landscape and global level. EO derived data is important to estimate the ecosystem services delivered, serving as key information to support policies on nutrient retention.

The two most important nutrients for agriculture are nitrogen and phosphor. 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.

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 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.



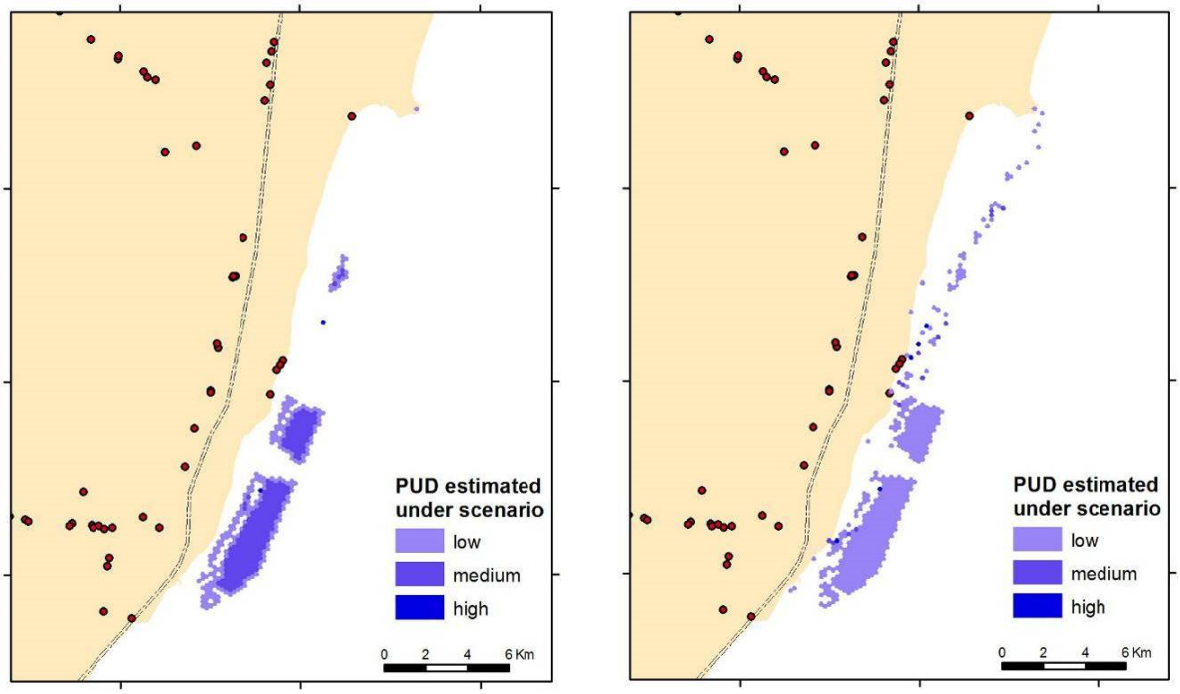
Phosphorous and nitrogen retention map, based on most recent land cover data in combination with a digital elevation model and metrological data on e.g. rainfall and soil characteristics. Green areas have low retention orange areas high. The retention is closely connected to the nutrient load. © Metria

Recreation

Produced for:
Yucatán

Cultural ecosystem services are defined as “non-material benefits people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation, and aesthetic experience“. 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. Recreation and tourism have been analysed in the Yucatán trial using the new InVEST recreation model. This tool is still under development without full documentation.

Tourism and recreation are the primary economic activities in the Yucatán trial area. 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.



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. ©GeoVille

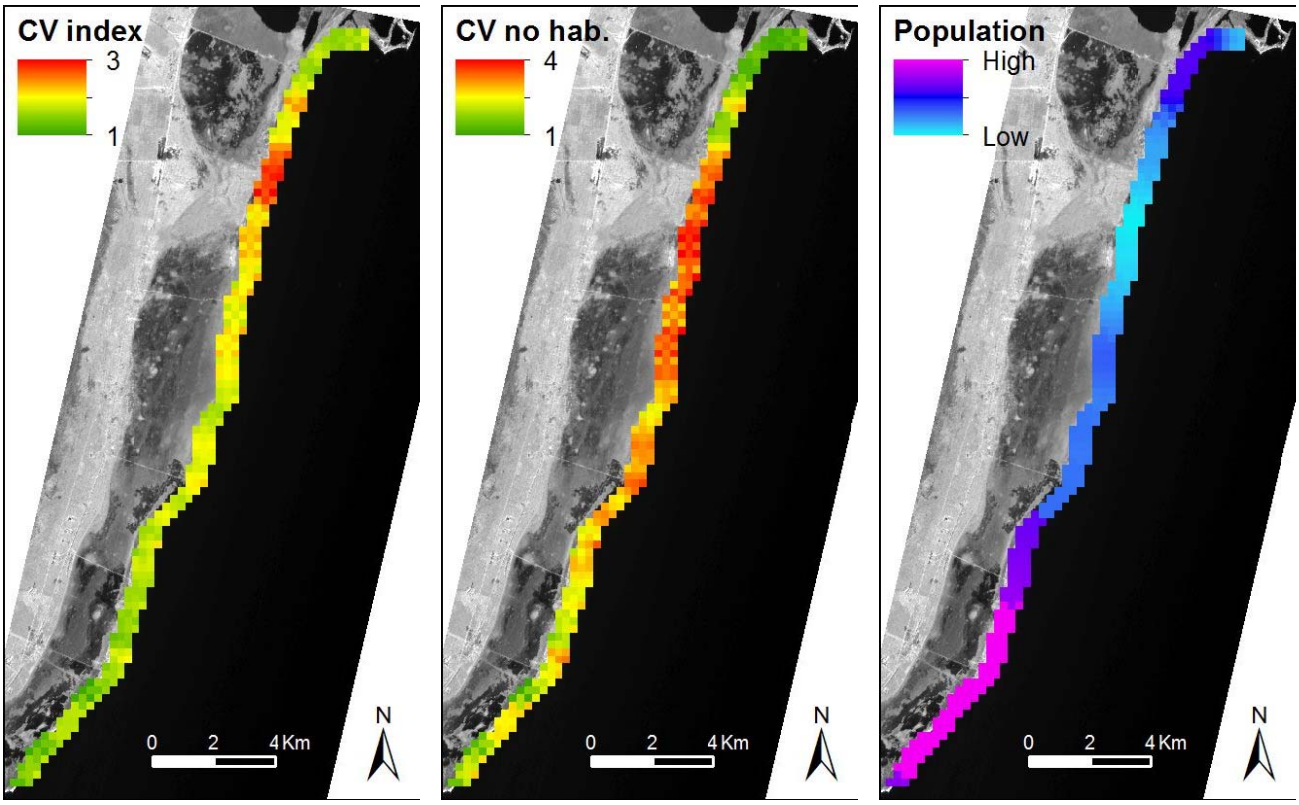
Coastal protection

Produced for:
Yucatán

Marine and coastal ecosystems provide a wide range of services to human society including supporting, regulating, cultural and provisioning services. These services influence human wellbeing both directly, through human use, and indirectly, via impacts on supporting and regulating services in other environments. But they are increasingly under threat from widespread and growing pressures on marine and coastal resources such as overfishing, water contamination, coastal habitat destruction, and general loss of biodiversity.

Coastal protection can be defined as the natural defence of the coastal zone against inundation and erosion from waves, storms or sea level rise. Habitats and other environmental features act as physical barriers protecting any asset or population present in the coastal zone. This includes several processes like attenuation of wave energy, flood regulation, erosion control or sediment retention. The consequence of natural hazards on the coastal zone and their impacts on humans (usually referred to as coastal vulnerability) is a topic of high interest for science, society and policy-making.

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). On the other hand, the model is one of the most complete and advanced InVEST models. The output has the form of a vulnerability index (showing relative values) which is very clear and understandable; optimal for communication purposes.



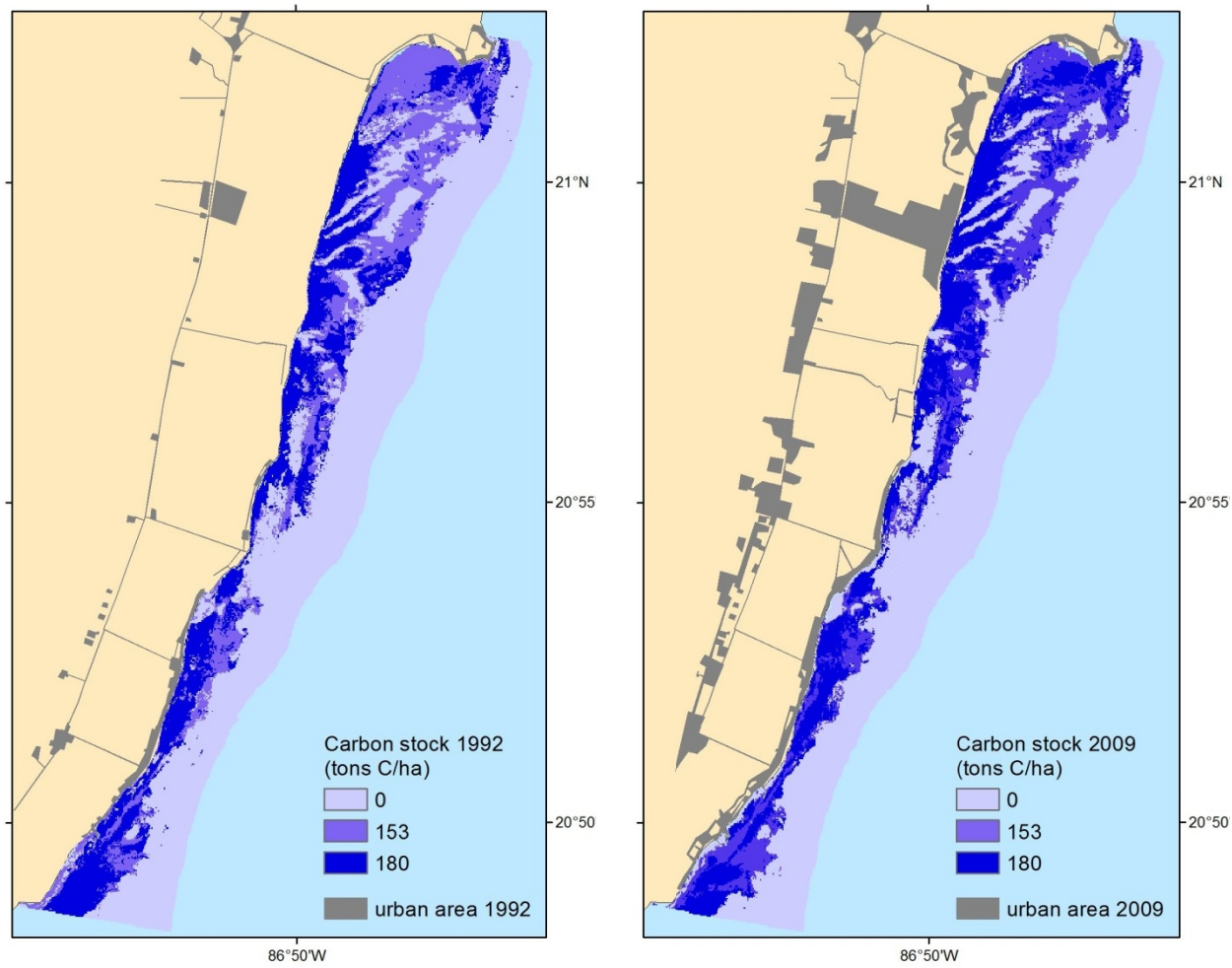
Coastal vulnerability analyses for Yucatán displaying the importance of the protective capacity of the reef and seagrass beds. The left image show the vulnerability in the present state and the mid image show the vulnerability without the reef and the seagrass. The right image shows the population density, with notably lower population in the most vulnerable areas. ©GeoVille

Blue Carbon

Produced for:
Yucatán and Lizard Island

Seagrasses provide a valuable role in carbon sequestration, and coral reefs provide many services of direct economic value, such as fisheries and tourism. Seagrasses provide an important supporting role for bio-diversity, both in terms of invertebrate in-fauna and as food for turtles and dugongs. Coral reefs and associated seagrass beds are interdependent habitats as seagrasses occur in the sheltered lagoons formed by reefs, and conversely seagrass beds are key nursery habitats for reef fish.

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 applied the InVEST carbon model in the Lizard Island trial in a simplified way that avoids any terrestrial/marine bias in the calculations. In general, the distribution and density of seagrasses around the Lizard Island is dynamic, with most of the seagrass patches showing significant changes between 1988 and 2010.



Results from the carbon storage module linked to the Yucatán 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.

Conclusions

EO provides a great input to ecosystem service valuation. It is however important to be aware that EO in itself is not enough. There is a need to combine EO with a large number of other data sources. This ads complexity to the analyses and the need for user consultation is therefore high. The results must be iterated with the users both to achieve acceptance for them, but also to make sure that the local knowledge of the users is transferred into the analyses and the following results.