

UKSA International Partnership Programme (IPP)



EO4cultivar

Project No 417000001416

EO4cultivar sustainable livelihoods
case studies: Ecosystem stock, risk
and opportunity mapping in the Viru
valley region, Peru



Report prepared by:

G. Bell
J.A. Parker

Environment Systems Ltd.

9 Cefn Llan Science Park
Aberystwyth
Ceredigion
SY23 3AH
UK

Tel: +44 (0)1970 626688
www.envsys.co.uk

and

M.A.E. Smith

Joint Nature Conservation Committee

Monkstone House
City Road
Peterborough
PE1 1JY
UK

Tel: +44 (0)1733 562626
<https://jncc.gov.uk/>

Contents

1	Introduction.....	4
1.1	Ecosystem Approach	4
1.2	Project Background.....	5
1.3	Rationale to achieve impact.....	5
2.	The SENCE Approach.....	6
2.1	Data Collation and Creation.....	7
2.2	Data Suitability.....	7
2.3	Rule-Base Development.....	8
2.4	GIS and Map Production	10
3.	Surface Water Regulation.....	11
3.1.	Surface Water Regulation Stock Map	11
3.2.	Surface Water Regulation Opportunities.....	12
4.	Risk of Soil Erosion by Precipitation	14
5.	Habitat Networks: Places of Key Importance for Biodiversity	14
5.1	What are Ecological Networks?	14
5.2	Mapping Existing Ecological Networks ('Stock').....	16
5.3	Ecological Network Opportunity Mapping	17
6.	Ecosystem Service Multi-benefits	19
6.1	What are Multi-benefits?	19
6.2	Multi-benefit Stock Map: Biodiversity and Surface Water Regulation	19
6.3	Multi-benefit Opportunity Map: Biodiversity and Surface Water Regulation.....	19
7.	Conclusion	19
8.	Next Steps	20
	References	20
	Appendix A –Dataset Details.....	21
	Appendix B – Datasets Used in Each Map	22
	Appendix C – Ecosystem Service Maps.....	23

1 Introduction

This report accompanies mapped and modelled evidence that identifies places where international partners and stakeholders of the EO4cultivar project, in the Viru valley region of Peru, can focus activity to deliver sustainable land management. The mapping concerns local priorities to reduce the risk of flooding and soil erosion and to improve ecological connectivity.

The maps are part of a case study to demonstrate how different stakeholders can make the best use of data products and services derived from earth observation, alongside existing local knowledge, to inform activities that support sustainable livelihood development. It identifies the potential for working with practical, nature-based solutions.

The study uses the Spatial Evidence for Natural Capital Evaluation (SENCE) toolkit for mapping and modelling ecosystem services. Following background study and consultation with stakeholders the study focussed on the following ecosystem services:

- **Surface water regulation (flood risk mitigation):** identifying places where there is the opportunity to undertake land interventions that are likely to slow the flow of water runoff.
- **Soil erosion risk:** mapping the risk of soil erosion by precipitation, resulting in the loss of a non-renewable soil resource, watercourse sedimentation and habitat damage.
- **Ecological connectivity:** mapping the eco-connectivity of semi-natural habitats to show where restoring habitats can have the greatest effect in terms of enhancing the resilience of biodiversity, the ecosystems it supports in the area, and the ecosystem services these areas provide to people.

The study identifies places where a land management intervention can benefit more than one ecosystem service. Deploying action in these places is likely to be most cost-effective by delivering multiple benefits.

The outputs of this work are suitable for any organisations aiming to undertake environmental improvement work in the area. Consistent understanding of the nature of the opportunities and where action can be focussed can strengthen coordination between organisations and provide the best chance of increasing ecosystem resilience and ensuring the maintaining of the natural functions and processes required for the land to continue to support human activities.

1.1 Ecosystem Approach

Adoption of an ecosystem approach in land-use and spatial planning is increasingly being used to assist decision-making at a strategic and local level. The approach strongly focuses on the holistic and integrated management of land, water and living resources to promote their conservation and sustainable use. It allows the often hidden, benefits of nature to be incorporated into decision-making processes. We call these natural benefits that an ecosystem provides, Ecosystem Services. The approach ensures that society is aware of

the true value of the natural environment, and is able to maintain a healthy and resilient natural environment for current and future generations.

1.2 Project Background

The overarching objective of the EO4cultivar Project (EO4c) is to strengthen commercial agricultural supply chains operating between Colombia, Peru and the UK. It is developing a better understanding of ways to sustainably manage production and identify opportunities for sustainable growth and land management. The project is achieving this by delivering new forms of evidence and advice to growers, supporting them to adapt farming practices in response to new knowledge derived from earth observation. It aims build capacity in partner countries (Colombia and Peru) and supporting the use of data derived from earth observation data and technology.

The project, through partnership working, seeks the following impacts:

- Make a positive contribution towards sustainable food production systems and the implementation of resilient agricultural practices.
- Increase productivity and manage risk in agricultural supply chains.
- Support inclusive and sustainable economic growth in target agricultural sectors.
- Help maintain natural ecosystems
- Ensure smallholder farmers benefit from project activities.

1.3 Rationale to achieve impact

To ensure the outputs produced under the Sustainable Livelihoods work package are pertinent to local stakeholder requirements a series of ongoing face-to-face meetings were held with key project partners, which included an interactive workshop held in Trujillo in July 2017. The objectives of these activities were to meet with key project stakeholders to outline the overarching objectives of the work package and to discuss ways in which data products and services derived from earth observation could be used to inform sustainable land use challenges they currently face, primarily through the lens of adopting an ecosystem approach, including the use of the concepts of ecosystem services.

Through these scoping activities the project collected views from key stakeholders, which included large international agricultural businesses, small holder growers that support the regional supply chain, organisations providing agricultural extension service and representatives from the Project Chavimochic irrigation scheme. These parties identified similar challenges regarding: water provisioning (quality and quantity) and water transport; protection from soil erosion and maintenance of soil biomass; flood regulation; and maintenance of biodiversity.

During the field visit the area of interest within the Viru valley was selected due to it containing high levels of economic output; biotic and abiotic factors influencing sustainability; and the presence of small growers and local communities. This provided a higher probability of success regarding the main project objectives of:

- increasing the area of land under sustainable, earth observation-based management practices;
- increasing the number of small-holder farmers directly benefiting from information derived from satellite imagery; and
- increasing the yield rates and revenues for participating grower organisations for specified crops.

Whilst the last objective is more aligned with the crop data services element of EO4c, the Sustainable Livelihoods work package has developed the Peruvian case study to demonstrate how different users can make the best use of data products and services, alongside existing local knowledge, to inform activities that support sustainable livelihood development. The ecosystem service maps discussed here will be used to guide future stakeholder engagement and inform long-term evaluation as to how these approaches meet the project objectives.

2. The SENCE Approach

This project employs the SENCE (Spatial Evidence for Natural Capital Evaluation) approach to ecosystem service mapping, an approach developed by Environment Systems. SENCE mapping displays the contribution of each area of land to providing the ecosystem services under consideration.

The SENCE approach aims to identify and use the most suitable data for analysis. It can utilise both directly measured, and modelled data. The methodology assesses possible data limitations during a data audit process, ensuring that data are used appropriately.

SENCE takes a pragmatic approach to mapping and modelling of ecosystem services; it is possible, using existing data, to grade the importance of any area of land into a simple categorisation of high, medium and low effect, based on expert knowledge and development of a scientific rule base. The maps can be used to inform decisions at national, regional and local levels.

The scientific rule base assessment is based on consideration of key factors which interact together in different ways for individual parcels of land for each service under consideration. The key factors are:

- land cover classification (e.g., grassland, woodland, wetland etc.)
- soil and geology substrate beneath the site
- location of the land parcel in the landscape (e.g., valley bottom, steep slope, proximity to water or urban areas)
- management of a site (e.g. intensive or extensive agriculture, or ecological focus area).

The SENCE process in this project required the completion of nine successive tasks in order to prepare the final ecosystem service map outputs and supporting report:

- Stakeholder engagement
- Data collation and creation

- Data suitability assessment
- Rule base development
- Mapping of ecosystem service stocks
- Mapping of ecosystem service risks
- Mapping of opportunities for land management interventions
- Further stakeholder engagement
- Refinement of rule base and mapping

2.1 Data Collation and Creation

The study utilised existing freely available data to make the products widely accessible, and the analysis as repeatable as possible. The study used:

- 30 m resolution SRTM elevation data captured in 2000 (USGS, 2004); and
- 250m resolution SoilGrids modelled soil data (Hengl *et al.*, 2017)

Existing habitat data were not available; therefore a habitat map was created from analysis of Earth Observation (EO) imagery; this process has been described in the habitat report that accompanies this project.

SoilGrids250m datasets relating to percentage clay, percentage sand, and organic carbon stocks for the 0-5 cm, 5-15 cm and 15-30 cm soil fractions were utilised for the project. Datasets for additional fractions up to 200 cm depth were available, but following visual assessment of the datasets and considering the absence of comparative accuracy data for the different fractions, only datasets relating to the top 30 cm were used. Furthermore, the composition of soil within the 0-30 cm fraction is more significant for plant growth and surface water regulation, than the deeper fractions.

Datasets for the 0-5 cm, 5-15 cm and 15-30 cm soil fractions were averaged in order to provide single datasets representing mean sand, clay and organic matter content in the top 30 cm.

2.2 Data Suitability

All data collected were assessed for quality and relevance to the study. The key factors considered were:

- **Extent:** does the dataset cover the area of interest? Is this in full or in part?
- **Data age/currency:** the age of the dataset and whether it is considered a reasonable representation of current conditions on the ground.
- **Spatial accuracy:** are features delineated to sufficient detail for the intended application?
- **Detail:** are the numeric data or attribute classes and values sufficiently detailed for the intended application?
- **Accuracy and confidence:** to what scale has each dataset been produced at? What are the units of measurement? How confident are we in the data?
- **Data lineage:** What methodologies were used to capture/record/process the data?

- **Topology and projection quality:** does the projection provides an accurate image of the conditions on the ground
- **Availability and licensing:** is data subject to licensing or open access?

The scale of data is an important overarching factor in assessing if datasets are fit for purpose. Broad scale data are most suitable for use at a national strategic level; informing national policy and regional planning issues. At a local level, broad scale data could potentially over-simplify the context, lacking the detail needed to accurately inform decisions applying to specific local sites.

For any individual ecosystem service there is no one single dataset that meets all of the important criteria, including: being readily available; appropriate to use; simple to map; and fully representative of that particular ecosystem service. As a result, the ecosystem service maps and models utilise a range of spatial datasets, collected at a variety of different scales, at different dates and with a variety of accuracies and resolutions. See Appendices of this report for datasets used.

The ecosystem service maps are a modelled approximation of the situation at the current time mapping took place, based on the data available. Therefore, any proposed local action (e.g. on individual sites) must be assessed at a site level to validate the mapping and check the appropriateness of the proposed action. If individual site surveys are undertaken, the results can be fed back into the model layers to help enhance the spatial and temporal accuracy of the maps.

Ecosystem services are changeable and rarely have fixed boundaries and, therefore, do not neatly fit within a single spatial scale. Mapping of ecosystem services is a constantly evolving area. Where further data become available, the mapping models can be re-run and updated utilising new knowledge.

2.3 Rule-Base Development

SENCE uses a rule-based approach to combine individual environmental datasets of relevance to the ecosystem service in question. This provides a stepped approach to representing the complex ecosystem interactions. Depending on the nature of the ecosystem processes involved (some processes are better-understood than others, and some lend themselves to mapping better than others) and the nature of the available data, it may be possible to represent the whole of the system/interaction, or it may only be possible to represent it in part.

The rule base is built around a series of key factors (land cover, soil, geology, landform, and management) which interact in different ways, creating spatial variability in the level of ecosystem service provision.

As an example, the key factors can be used to describe how the biophysical characteristics of a parcel of land can be applied (Figure 1). By understanding these characteristics, it is possible to infer the type of functions that each parcel of land provides, and therefore identify the societal benefits and dis-benefits.

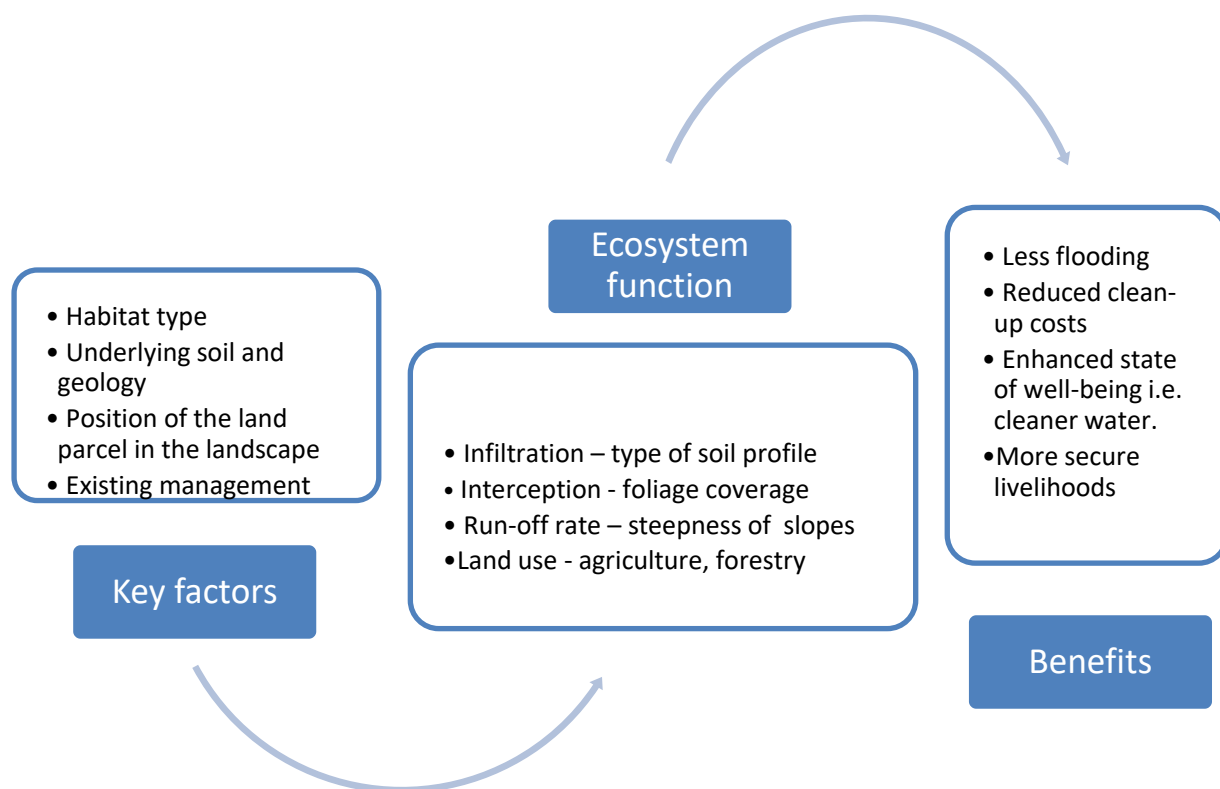


Figure 1: Linking SENCE key factors to ecosystem functions and the flow of ecosystem service in the case of surface water regulation.

The rule base is transferable and uses scientific knowledge (Medcalf *et.al.*, 2012 and 2014; Natural England, 2014) and expert interpretation. The method is iterative in nature, benefiting greatly from local knowledge input to refine and ground-truth the outputs.

For the ecosystem service, the rule-base identified:

- specific attribute information of each dataset considered important for mapping that service;
- relative value to be assigned to each element to enable mapping; and
- if applicable, details on the weightings required when applying combined datasets.

Within the ecosystem service rule bases, existing scientific knowledge of ecosystem process is used to assess attribute categories and/or values as contributing a high, medium or low level to the ecosystem service. This approach has been tested and demonstrated in a number of previous studies commissioned by JNCC and is described in-depth in Medcalf *et al* (2014).

2.4 GIS and Map Production

Once the dataset attributes are scored based on their influence on the ecosystem service under consideration, they are combined in a Geographical Information System (GIS). Overlay analysis is a well-established method available in the GIS toolkit. To bring together the datasets, they are modelled into a grid (example shown in Figure 2), where each individual grid square is assigned the score for the environmental variable. The analysis used a grid size of 10m².

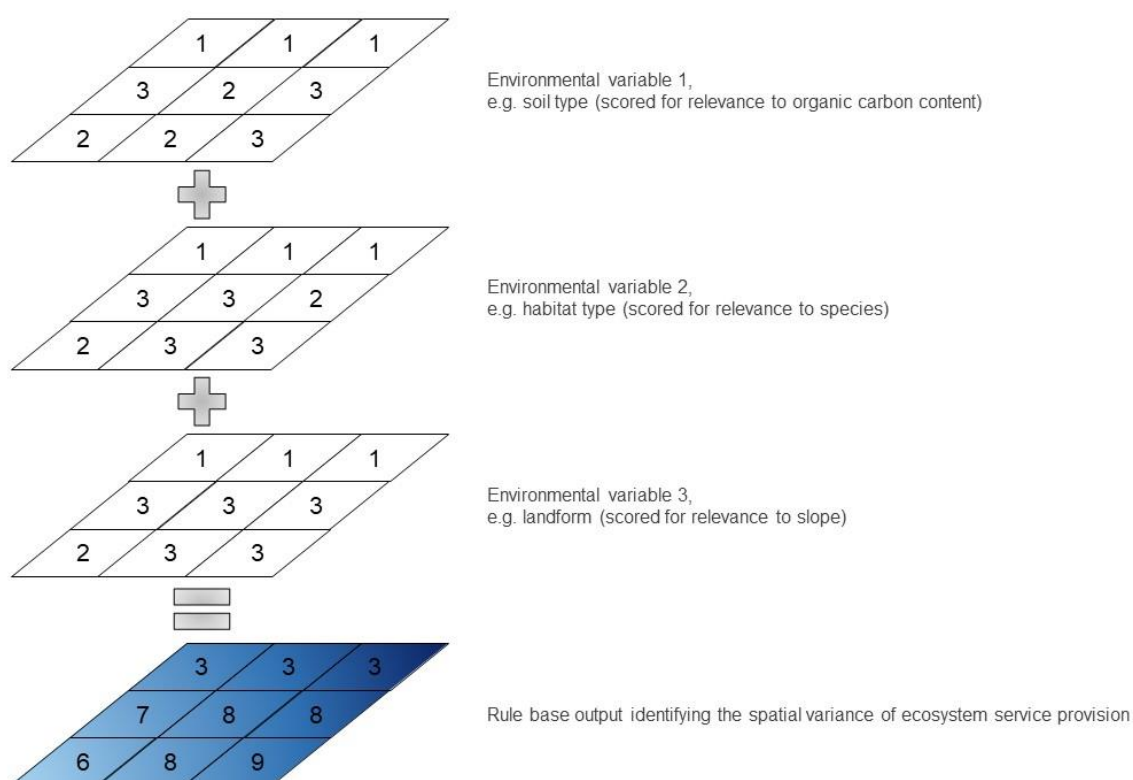


Figure 2: A graphical representation of the GIS data analysis

2.5 Map Scale and Interpretation

The maps have been produced at the landscape scale and are more indicative at a local scale; site visits should be conducted before any management decisions are taken. The habitat/land use dataset was derived from analysis of 2 m Pleiades, 10 m Sentinel-1 and Sentinel-2 imagery, 12 m WorldDEM Digital Terrain Model and 30m and SRTM (elevation) data. Details of the data processing and habitat mapping methodology are provided in the accompanying habitat report.

Many of the maps used 250 m resolution modelled soil data due to an absence of higher resolution, open access data. However, if higher resolution datasets become available in the future, these could be used to refine the models and map outputs. For example, high resolution, validated data on soil properties relating to drainage (particularly sand, clay and organic matter content) would particularly enhance the modelling of surface water regulation.

3. Surface Water Regulation

3.1. Surface Water Regulation Stock Map

Surface water regulation is a form of natural flood management, where the natural hydrological and morphological processes, and the type of vegetation present, work together to manage the sources and pathways for waters during meteorological events, particularly events with high rainfall. Four main mechanisms exist for enhancing an area's ability to slow the flow of water, these are:

- **Slowing the flow of water reaching streams, rivers and lakes:** Trees, hedges or areas of rough grassland break up overland flow by forming a physical barrier.
- **Slowing the flow of water within stream and rivers:** Natural meanders of rivers, streams and ditches form a physical barrier to water, and increase temporary storage capacity (especially in the mid and upper catchment). Management intervention can include re-meandering and installation of leaky dams
- **Increasing penetration of the water into the soil:** Penetration is highest on deep loamy soils which have deep rooting plants upon them, such as native trees. These deep roots encourage water to be stored all the way down through the soil profile.
- **Managing land which floods:** Reed beds, riparian scrub and saltmarshes all hold a great deal of water naturally, which can reduce the likelihood of damage to property during flood events.

The stock map (Map 1) was generated by considering four key factors: geology, soil, slope, habitat and management, and their influence on flooding due to high rainfall or increased river flow. Coastal flooding and storm surge regulation were not considered.

Datasets representing the key factors were scored based on their functional contribution to mechanisms for natural regulation of overland flow including: infiltration; interception; storage capacity; and sediment load control. For example, attributes given high scores, representing high natural regulation include: deep, well-drained soils (e.g. soils with a high sand and/or organic matter content); dense natural woodland; and flat or gently sloping land. Conversely, attributes given low scores, representing low natural regulation include: bare ground; thin, poorly drained soils (e.g. soils with a high clay content); impermeable rock; and steep slopes.

The sand, clay and organic matter datasets were scored individually for water regulation function, and then combined to produce a single water regulation dataset for soils, containing the mean value. All of the key factor datasets (soil, habitat and landform) were then summed to produce the final ecosystem service dataset.

In the resulting map (Map 1) the strong effect of bare rock areas and sheer topography can be seen, with the areas mapped as bare rock, and areas on steep slopes appearing as pale blue, representing low water regulation provision. Conversely, areas of dense vegetation on more gentle slopes are shown in darker shades of blue, representing higher water regulation provision. There are a number of important natural and semi-natural habitats along the coastal region which provide high water regulation service, shown in dark blue.

3.2. Surface Water Regulation Opportunities

Maps 2 and 3 show opportunities to increase the land's ability to retain water, either by slowing the flow, increasing infiltration into the soil, or managing areas which store water, therefore helping to reduce flood risk. Undertaking management actions in these areas can be regarded as an alternative or supplement to hard infrastructure and other flood defences. Currently it is not possible to give an exact value on how much water will be deflected or slowed by each action. However, it is very likely that taking action in these opportunity areas would help by:

- Diversifying the lag times between flood waters reaching lower catchment areas – thereby increasing capacity of infrastructure to deal with a greater range of flood magnitudes.
- Increasing infiltration by, for example, reducing soil compaction of agricultural land, or increasing organic matter content.
- Increasing hydraulic roughness to slow overland flow.
- Increasing storage capacity in rivers and floodplains.
- Trapping sedimentation.

Map 2 has been created by identifying areas where the current vegetation cover could be enhanced, for example by habitat restoration that will increase vegetation surface roughness and soil management. The selected areas were then further analysed in terms of their placement within the river drainage basin.

Areas shown in white on the map are areas where there are no opportunities. All of the coloured areas on the map are opportunity areas; these have been coloured and shaded according to whether they are located in the lower, mid or upper catchment. The location will influence the way in which areas will be prioritised for taking action, and the types of action that will be possible or most appropriate (Table 1).

Major flow paths are areas where the topography of the region where more surface water will flow through, so land providing high water regulation function could be said to be providing a greater function than areas receiving lower flow rates. Therefore, taking action in a major flow path area could be considered better value for money than actions taken in a minor flow area (areas where the topography directs less water flow). However, the differentiation into major and minor flow paths is not the only factor that decision-makers must consider when prioritising areas for action. For example, it may still be cost-effective and highly desirable to take action in a minor flow path area, in order to protect assets and infrastructure of high social or economic value (e.g. buildings, roads, utilities).

A second surface water regulation opportunity map has been produced (Map 3), showing only the opportunity areas located within major flow paths.

The Viru Valley catchment was divided into sub-basins by topographic analysis of the conflated SRTM-WorldDEM elevation dataset, which allowed the largest flow pathways to be identified.

On this map, opportunity areas that are located within sub-basins directly adjoining a main river or channel are highlighted. These places provide the strongest opportunities for increasing water storage capacity (particularly in the lower catchment areas), or engineering solutions. Action in these areas could provide additional ecosystem service benefits by

controlling sediment load into watercourses, delivering improvements in water quality and biodiversity.

Table 1: Interpretation of Maps 2 and 3: Opportunities to enhance surface water regulation

Map colour	Catchment position	Interpretation
Green	Lower catchment	Action here will reduce surface water regulation, but will affect the smallest downstream area; a large upstream area sheds water into these places. Action here may be appropriate in order to protect particular high-value assets or infrastructure. Water storage measures such as wetland creation may be the most appropriate action, increasing storage capacity of flood waters and limiting their spread.
Light blue	Mid-catchment	In these mid-catchment areas there are strong opportunities to slow the movement of water into watercourses, increasing the lag time to flooding, providing benefits to a considerable downstream land area and population. These areas may be more accessible and cost-effective for taking action than the upper catchment areas.
Dark blue	Upper catchment	Action here will reduce surface water regulation in an area which contributes to the largest downstream area. In these upper-catchment areas there are opportunities to slow the movement of water into watercourses, increasing the lag time to flooding, benefiting the largest downstream land area and population. However, these areas may pose practical challenges to implementation, such as topography and accessibility, which bring cost implications.

4. Risk of Soil Erosion by Precipitation

Soil is a non-renewable resource which contributes to the delivery of many ecosystem services, being intricately involved in water regulation, plant growth and nutrient cycling. Soil loss directly affects agricultural productivity and water regulation at the site of soil loss. When eroded soil is washed into watercourses this can cause problems such as sedimentation, a decrease in water quality, and negatively impact habitats and wildlife far downstream, due to the nutrient and chemical loads held within the soil particles.

Map 4 shows the risk of erosion by precipitation across the landscape. Habitat classes were scored according to their relative erodibility; habitats with dense, stable vegetation cover were given the lowest erodibility scores and habitats and land use characterised by higher frequency and extent of bare ground were given higher erodibility scores.

The scored habitat data were then analysed using the SCIMAP module for SAGA (Durham University, 2016). This combines the erodibility of the habitat classes with topographic attributes (e.g. steepness of slope, hydrological connectivity) to show areas at highest erosion risk (e.g. areas where the most erodible habitat types are present on the steepest slopes).

Only part of the Viru Valley catchment area was analysed in the production of this map, corresponding to areas where WorldDEM data coverage was available. The resolution and extent of gaps in the SRTM imagery was insufficient to capture the topographic detail necessary for modelling erosion pathways in the most mountainous areas.

5. Habitat Networks: Places of Key Importance for Biodiversity

5.1 What are Ecological Networks?

An ecological network is a representation of the movement and interactions among organisms within an ecosystem. Ecological networks consist of 'source' and 'supporting' habitats.

'Source' habitats are areas of natural or semi-natural vegetation, such as native forest, which are large enough to support resilient species populations. They provide sufficient ecological niches for a population of a species to maintain genetic diversity and, therefore, be able to adapt to change. Ecological networks contribute to resilience of habitats and species, which is a key component of biodiversity maintenance and underpins ecosystem function.

At the edge of these 'source' habitats, conditions are less suitable for many specialist species that have specific requirements for their survival. Factors affecting the edge of

habitat may include the spread of fertiliser and pesticides from surrounding areas or disturbance from people. However, genetic diversity can still be maintained if there is suitable habitat that allows the species to travel from one source habitat to another. In other words, if the connecting habitats are permeable it allows gene flow between individuals moving between different patches of habitat.

Areas of habitat that do not provide ideal conditions for species to breed and form persisting populations, for example because they are too small or do not provide enough shelter, can still be useful areas for foraging or temporary habitation during dispersal. These are known as 'permeable habitats' because, although they cannot support viable populations in isolation, but when they lie in close-enough proximity to facilitate movement, they support the populations within the core habitats, and make the entire ecosystem more robust. This combination of source habitats and permeable supporting habitats is referred to as a functioning ecological network (Figure 3).

In order to indicate the extent of the network, pseudo species are often used (Watts et al., 2010). A pseudo species for the purposes of ecological network analysis is described as a generalist species which is reliant on the source habitat in question, but able to move through the permeable habitat.

In Figure 3, dark green areas are the source habitats. Light green areas are supporting habitats that the pseudo species can typically travel through. How far they can travel depends on the type of habitats, with some types of land cover forming active barriers to species movement – in reality this could be a road, river or mountain.

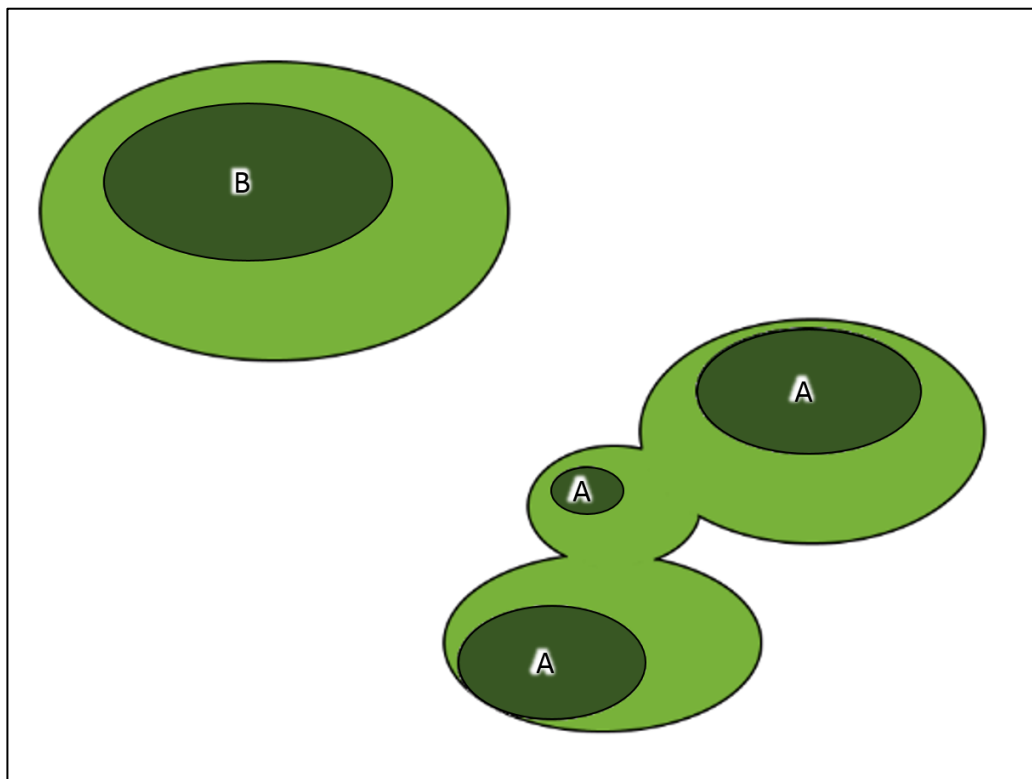


Figure 3: Schematic representation of an ecological network, with source habitat shown in dark green, and permeable supporting habitat in light green. Populations within source habitats marked 'A' are genetically connected; population 'B' is isolated.

In the example shown, generalist species could move between the three blocks of source habitat using the supporting habitats, forming genetically connected populations (habitat network A). The source habitat in the top left of Figure 3 is not presently connected to the adjacent blocks, forming a single, isolated population (habitat B). This type of network analysis allows the functional network to be described, which will be relevant to most of the species of interest. In addition, the supporting habitat (light green) can be regarded as the best place to identify where to reinstate source habitats. This is because seed bank, relevant pollinator species and soil microbial communities are all near enough to move into the newly established habitat and create a functioning community within a reasonable timescale. Creating a green corridor or new supporting habitat to link the isolated source habitats (connecting A with B) will also strengthen the network, but is likely to be more difficult to achieve.

When considering potential places to restore or recreate habitats to enhance the networks, a limiting factor which should be considered is places where habitat is unsuitable for management intervention. These could be areas that are already under regulated management, or sites with biophysical characteristics that do not allow for a specific habitat to be (re-)established (for example on a steep, dry slope it is not possible to establish wetland habitats). These factors are taken into account when creating opportunity maps, which show where management action benefitting a specific network could be undertaken.

Ecological network analyses for the case study area were carried out for:

- Woodland (Map 7);
- Wetland (Map 8); and
- Scrubland habitats (Map 9);

In addition to the individual network and network opportunity maps, a map has been created showing the combined source habitats for the woodland, wetland and scrubland networks (Map 5), showing the existing stock of key habitats of importance for biodiversity. This stock map can help to identify key biodiversity areas, as these more 'natural' areas are likely to support a higher number of specialist species, and a higher number of species and individuals in general.

Two opportunity maps have been produced; one identifying all suitable locations for enhancing the three networks (Map 10), and one identifying those locations next to an existing source habitat of the same type, where propagule sources will be strongest and most success may be achieved from investments in interventions (Map 11).

5.2 Mapping Existing Ecological Networks ('Stock')

An ecological network is identified by considering the land around the existing large blocks of habitat (source habitats) to identify areas well connected where seedbanks, pollinators and soil micro-organisms could help with the colonisation of the new area. In the ecological network maps, all areas of source habitat type have been considered 'source', regardless of patch size. These places allow species to move from one area to another and are therefore considered fully 'permeable' to species. The permeability of other habitats adjacent to the source areas were next considered.

All habitats present in the area of interest were scored in terms of how easily a species, for example a pollinator, might move through them (how permeable the habitats are), producing a 'permeability score' dataset of equal extent to the input habitat map. The habitat permeability scores varied according to which network was being considered; scrubland, wetland or grassland, to express how difficult, in relative terms, it might be for a species associated with the source habitats to move through them. For example, a species mainly associated with dense woodland could disperse through an area of scrub and scattered trees much more easily than through an urban area or arable farmland; the permeability score will represent this. Urban areas were considered the least permeable land cover type in all of the networks, and assigned the lowest permeability score of all of the habitat types.

To calculate the total area supporting the source habitats, forming the effective network, a raster cost-distance model was applied using the habitat map and the habitat permeability scores for each network. The cost-distance model shows that areas further away from a source habitat are less connected than areas close-by, but in areas where the habitat and land cover types are more permeable, a species will find it easier to travel greater distances from the source habitat.

The resulting cost-distance raster datasets for each network were then calibrated by eye, using expert judgement to identify the numeric values in the data which represented the likely maximum dispersal distances of the pseudo species. These values were applied in a colour ramp and used to illustrate the existing effective woodland (Map 7), wetland (Map 8) and scrubland (Map 9) ecological networks for the woodland, wetland and scrubland pseudo species, respectively.

Map 7 shows a highly connected woodland network in the mountainous upper catchment, which becomes more fragmented in the valley bottoms, particularly in the more intensively cultivated areas, due to a decrease in source and supporting habitats.

Map 8 shows that the wetland habitat network is largely restricted to the coastal wetland habitats and ephemeral watercourses, due to the specialist hydrological and nutrient requirements of species associated with these habitats. There are numerous small pockets of wetland habitat that are currently poorly connected to the network.

The scrubland network (Map 9), which includes upland cactus habitat, is well-connected in the upper catchment, and there is also an important network of well-connected source habitats in the coastal sand dune region. Within the intensively cultivated lower catchment zone there are many isolated pockets of source habitats, that are poorly connected and much less likely to function as part of the ecological network.

Where individual species requirements are known, such as habitat requirements during all life-stages, home range size, and maximum dispersal distances, these ecological network maps can be further refined to represent the effective networks for specific species of interest.

5.3 Ecological Network Opportunity Mapping

Opportunity Map 10 identifies places where it would be possible to restore or re-create habitats to improve ecological connectivity of the woodland and wetland networks, and the ease at which this should be possible. For example, it is expected that restoration of

existing dense scrub to woodland habitat would be easier and more cost-effective than planting woodland or shrub habitat on an area of dry, bare earth.

Opportunities located close to source habitat areas could allow for faster establishment of additional source habitat, with higher probability that the new habitat will develop to be biologically diverse and fully-functional. This is because the neighbouring source habitat supplies seeds, pollinators, beneficial soil microbial communities, and target plant and animal species, to colonise the new area. For this reason, only areas located within 50m of source habitat were considered in the opportunity analysis.

Generally, it is not considered appropriate to change one high value habitat to another. This is why any habitat identified as 'source' for at least one of the networks under consideration was not considered an opportunity area, but are shown as 'places with habitat of key importance for biodiversity' (Map 5).

In places located close to several source habitats of different types (e.g. equidistant between a scrubland source and a woodland source), and where habitat restoration could therefore focus on either network, a decision must be taken as to which network type takes priority. During the analysis, preference was usually given to creating woodland; if a woodland opportunity existed, it was mapped as such, regardless of whether it was also feasible to create scrubland or wetland. The exception to this was within the coastal sand dune zone, where wetland opportunities were given preference. The map shows many opportunities for enhancing ecological connectivity; particularly in the many field margins within the lower catchment.

Field boundaries were considered an important component of the opportunity space in the lower catchment. Therefore field boundaries were mapped through image analysis of a composite of Sentinel-2 images captured throughout 2018, followed by manual aerial photography interpretation against Bing aerial photography. These were incorporated into the SENCE mapping as an additional scored input layer.

Map 11 shows a subset of opportunity areas from Map 10, showing only opportunity areas that lie adjacent to existing source habitat of the same network type (i.e. wetland opportunities next to wetland source habitat; and woodland opportunities next to woodland source habitat). Opportunities directly adjacent to existing source habitat present very strong opportunities to enhance the network in question, as the very close proximity to existing source habitat will facilitate easier habitat restoration. Taking action directly adjacent to an existing source will result in increasing the size of the source habitat patch and increasing the ecological resilience which underpins ecosystem function. These are places where action to enhance the ecological networks are most likely to be successful and cost effective.

Map 11 shows far fewer opportunities for enhancing the woodland network in the lower catchment than were seen in Map 10, which highlights how poorly connected the woodland habitats are in this area. Many of the restoration opportunities that were mapped as easiest to achieve in Map 10 are not present in Map 11; this highlights that choosing an easy option may not necessarily deliver the level of benefits hoped for, and that the location of management intervention must be carefully considered in order to achieve the desired results.

6. Ecosystem Service Multi-benefits

6.1 What are Multi-benefits?

When considering land management interventions related to a specific problem or ecosystem service, decision-makers should widen their scope to consider other ecosystem services that could be affected by different decisions. This is to ensure that taking action to address one problem will not unwittingly create or enhance another problem.

It may be possible to take a management action that will increase multiple ecosystem services simultaneously, increasing the total benefits delivered to people; this can be used as a way to maximise the cost-effectiveness of action.

6.2 Multi-benefit Stock Map: Biodiversity and Surface Water Regulation

Map 6 shows key areas for biodiversity that also provide high levels of surface water regulation. These are predominantly located in the high Andean region/upper catchment, and in the coastal sand dune zone, with a thin line of habitat following the river, connecting these two areas.

6.3 Multi-benefit Opportunity Map: Biodiversity and Surface Water Regulation

Map 12 shows places where it should be possible to restore or create new habitat to strengthen the existing scrubland, wetland or woodland ecological networks to enhance biodiversity, while simultaneously enhancing the level of surface water regulation.

7. Conclusion

A set of 12 maps has been produced to assist with identifying and prioritising nature-based solutions to reduce the risk of flooding and soil erosion, and to improve ecological connectivity in the study region. These maps are aimed at supporting land-use planning and local field work, to promote sustainable land management, increase overall resilience of the ecosystem, including the agricultural sector, and manage risk in agricultural supply chains through potential implementation of interventions to reduce impacts of flooding and soil loss. The maps can also be used as an evidence-base for community and stakeholder engagement, and to support business cases for funding land management action.

This report and the accompanying maps are intended as a mechanism for increasing understanding of the valuable role that existing ecosystems plays in maintaining functions and processes at a landscape scale that are critical to social and economic activities in the area of interest. The outputs help demonstrate that there are opportunities for nature-based solutions that will improve business resilience and human wellbeing, but that careful

consideration needs to be given regarding where action is taken to ensure tangible results are achieved in a cost-effective manner.

8. Next Steps

The ecosystem service products discussed in this report will be presented to Peruvian stakeholders at a series of follow-up meetings and webinar in June 2020. These activities will be used to present the outputs, seek feedback from stakeholders on their perspectives of the project and to identify how the products may inform activities, such as particular land interventions. These discussions will be documented and will form a critical component of the monitoring and evaluation to document and demonstrate EO4c impact.

There is also a level of expectation that the products and services delivered act as a starting point for longer term collaboration and support for the uptake and application of earth observation and ecosystem modelling capabilities across the region.

References

Durham University (2016) SCIMAP – Diffuse Pollution Risk Mapping.

<http://www.scimap.org.uk> [Accessed 2019-06-06]

Hengl, T., Mendes de Jesus, J., Heuvelink, G.B.M., Ruipererez Gonzalez, M., Kilibarda, M., Blagotić, A., Shangguan, W., Wright, M.N., Geng, X, Bauer-Marschallinger, B., Guevara, M.A., Vargas, R., MacMillan, R.A., Batjes, N.H., Leenaars, J.G.B., Ribeiro, E., Wheeler, I., Mantel, S., Kempen, B. SoilGrids250m: Global gridded soil information based on machine learning. *PLOS ONE* **12**(2) DOI:10.1371/journal.pone.0169748

Medcalf, K., Small, N., Finch, C. & Parker, J., (2012), Spatial framework for assessing evidence needs for operational ecosystem approaches, JNCC Report 469, ISBN 0963 8091. Available at: <http://jncc.defra.gov.uk/default.aspx?page=6867> [Accessed 2019-07-26]

Medcalf, K., Small, N., Finch, C., Williams, J., Blair, T., Haines-Young, R., Potschin, M. & Parker, J., (2014). *Further development of a spatial framework for mapping ecosystem services*, JNCC Report 514, ISSN 0963 8901. Available at: <http://jncc.defra.gov.uk/default.aspx?page=6867> [Accessed 2019-07-26]

Natural England (2014) Ecosystem Services Transfer Toolkit (NECR159). Available from: <http://publications.naturalengland.org.uk/publication/5890643062685696> [Accessed 2019-06-18]

USGS (2004) Shuttle Radar Topography Mission, Global Land Cover Facility, University of Maryland, College Park, Maryland, February 2000.

Watts, K., Eycott, A. E., Handley, P., Ray, D., Humphrey, J. W. & Quine, C. P. (2010). Targeting and evaluating biodiversity conservation action within fragmented landscapes: an approach based on generic focal species and least-cost networks. *Landscape Ecol.*, **25**: 1305–1318.

Appendix A – Dataset Details

Theme	Data set	Source	Coverage	Licensing
Base mapping	OpenStreetMap 2017-09-26T20:43:02z	OpenStreetMap	Partial mapping of roads, buildings, water features	Open Database 1.0 License https://opendatacommons.org/licenses/odbl/1-0/index.html
Habitat	Broad habitat map	JNCC	All	CC BY-SA 4.0 https://creativecommons.org/licenses/by-sa/4.0/
	Field margins map	Environment Systems Ltd	Lower catchment agricultural zone	CC BY-SA 4.0 https://creativecommons.org/licenses/by-sa/4.0/
Soils and Geology	% Sand, 0-30cm depth	SoilGrids250m	All	Open Database License (ODbl v1.0)
	% Clay, 0-30cm depth	SoilGrids250m	All	
	Organic carbon stocks (t.ha ⁻¹), 0-30cm depth	SoilGrids250m	All	
Land Form	Conflation of SRTM 30m and WorldDEM™ 12m, resampled to 10m.	JNCC (SRTM source: USGS; WorldDEM™ source: Airbus Defence and Space GmbH)	All	Commercial license

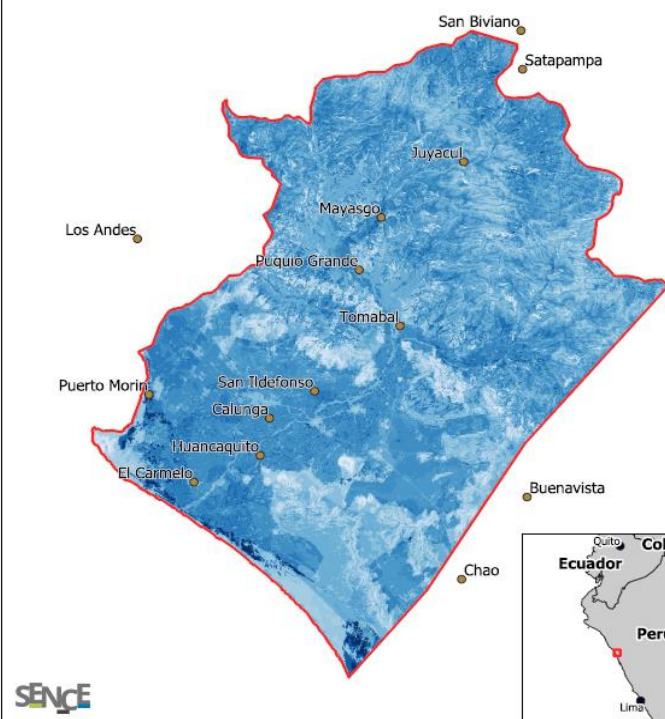
Appendix B – Datasets Used in Each Map

Map	Habitat/ Management ¹	Soil	Geology	Landform
1. Ability of the land to moderate surface water runoff	✓	✓	✓	✓
2. Opportunities to enhance surface water regulation	✓			✓
3. Opportunities to enhance surface water regulation: places receiving high volumes of surface water flow	✓			✓
4. Risk of soil erosion caused by precipitation	✓			✓
5. Places with habitat of key importance for biodiversity	✓			
6. Places delivering multiple ecosystem service benefits; key areas for biodiversity and surface water regulation	✓	✓	✓	✓
7. Ecological Network Connectivity - Woodland Ecosystem	✓			
8. Ecological Network Connectivity - Wetland Ecosystem	✓			
9. Ecological network connectivity - Scrubland Ecosystem	✓			
10. Opportunities to strengthen ecological networks	✓			
11. Opportunities to strengthen ecological networks: priority places for action (those adjoining existing key habitats of high-biodiversity value)	✓			
12. Opportunities to deliver multiple ecosystem services: ecological connectivity and surface water regulation	✓			✓

¹ Landform data used in the production of this dataset

Appendix C – Ecosystem Service Maps

1. Ability of the land to moderate surface water runoff Ecosystem service: Regulation of overland flow.



How to interpret the map:

The darkest colours represent where the land makes the greatest contribution to slowing over-land water flow after heavy rainfall events. This helps prevent flooding.

What the service is:

Vegetation can help water soak into the ground and can also form a barrier to water moving rapidly over the land surface. This helps reduce the amount of surface water that can cause flooding. Flat land holds water whilst steep slopes shed water. Some types of soil can hold a lot of water, particularly in wetlands, whilst others hold very little, so soil and geology are important influencing factors.

Why it is important:

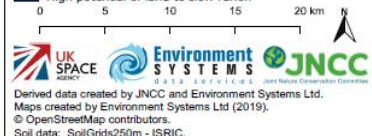
Surface water regulation is a form of natural flood management where hydrological and morphological processes together with the habitat features work together to manage the sources and pathways for flood waters.

How the map was created:

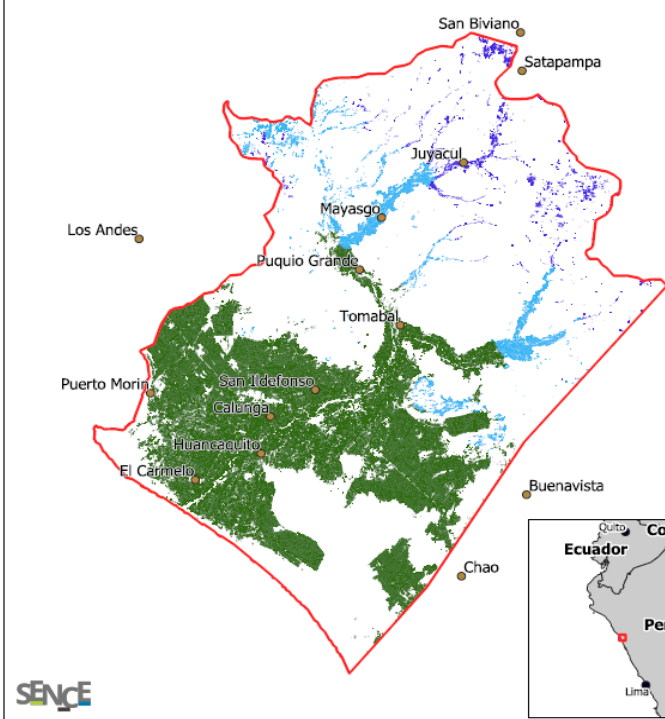
This map was generated by assessing key factors at each location: geology, soil, slope, habitat and management. Habitat classes were generated using Pleiades, Sentinel 1 and Sentinel 2 satellite imagery. Datasets representing each key factor were scored based on their functional contribution to mechanisms for natural regulation of overland flow: infiltration; interception; storage and sediment load control. Once scored, the datasets were combined. The current map has been created at the strategic scale and is indicative at a field level. Field visits should be made before any site-specific management decisions are taken. Additional data could be sourced to refine the maps at the local scale; methods for doing this are discussed in the project report.

Legend

Low potential of land to slow runoff
High potential of land to slow runoff



2. Opportunities to enhance surface water regulation Ecosystem service: Regulation of overland flow.



How to interpret the map:

This map shows places with agriculture and grassland where it would be possible to improve surface water regulation to slow the flow of runoff into watercourses. Places shown in dark blue are located in the upper catchment of the study area. Places shown in light blue are in the mid-catchment, and places shown in green are in the lower catchment. All of the coloured areas on the map are hydrologically connected, and action taken in these areas should enhance the existing water regulation capacity of the land. However, the types of action that are most appropriate, and whether these are logistically possible and cost-effective, depend on the position of the opportunity within the catchment.

Why it is important:

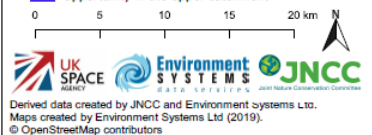
Generally, interventions in the mid- and upper-reaches of the catchment (light and dark blue) will benefit a larger downstream area, but can be more challenging to implement, e.g. due to topography and accessibility. In the lower reaches of the catchment the effects of management intervention become more localised (as there is less downstream area), but can be easier to achieve. In the lower reaches of the river wetland creation can enhance the capacity of land to store flood waters and limit their spread, which might protect valuable assets and infrastructure. In the upper reaches afforestation can slow the volume and rate at which water enters the watercourses.

How the map was created:

This map was created by analysing the restoration potential of habitat and land use classes generated using Pleiades, Sentinel 1 and Sentinel 2 satellite imagery. The river basin boundary was determined by analysis of SRTM elevation data.

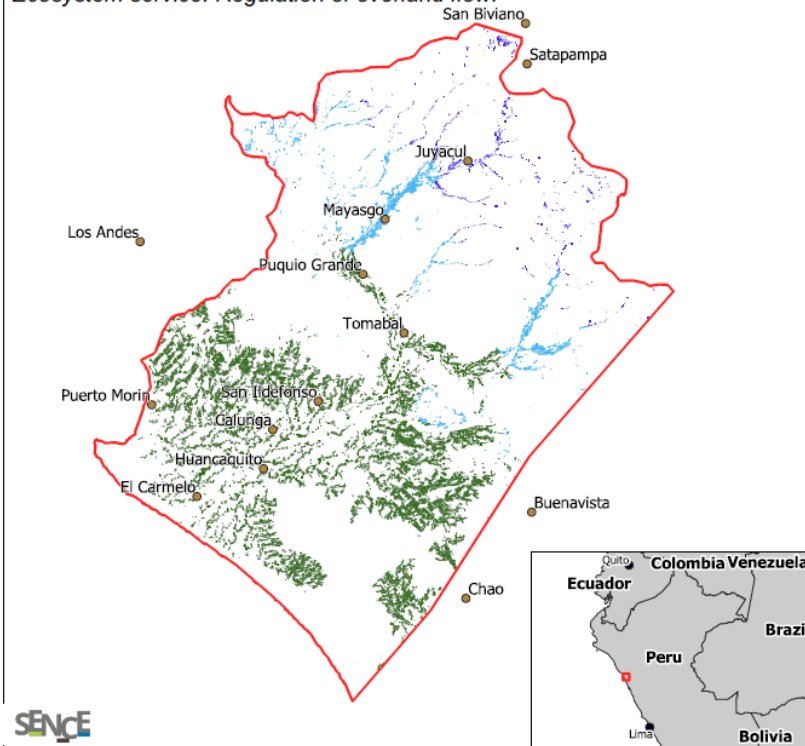
Legend

Opportunity in the lower catchment
Opportunity in the mid catchment
Opportunity in the upper catchment



3. Opportunities to enhance surface water regulation: places receiving high volumes of surface water flow

Ecosystem service: Regulation of overland flow.



How to interpret the map:

This map shows places that are currently agriculture or erosion gullies within major flow paths, where taking action to improve surface water regulation, to slow the flow of runoff, would be most effective. These places receive the largest proportion of the runoff water and, particularly in the lower catchment, may be more likely to flood.

What the service is:

Water regulation is a form of Natural Flood Management where hydrological and morphological processes, along with vegetation type, together manage the sources and pathways for flood waters.

Why it is important:

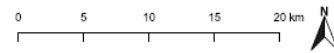
Generally, interventions higher up the catchment should benefit a larger area downstream, but can be more challenging to implement (e.g. due to topography and accessibility). In the lower reaches of the catchment the effects of management intervention become more localised (as there is less downstream area), but may be necessary to protect important assets/infrastructure. In all parts of the catchment, considering the location of major flow paths and places adjacent to channels will assist assessment of risk, and the value of benefits derived from taking action in different locations.

How the map was created:

This map was created by analysing the restoration potential of habitat and land use classes generated using Pleiades, Sentinel 1 and Sentinel 2 satellite imagery, and flow paths derived from SRTM elevation data.

Legend

- Opportunity in the lower catchment
- Opportunity in the mid catchment
- Opportunity in the upper catchment

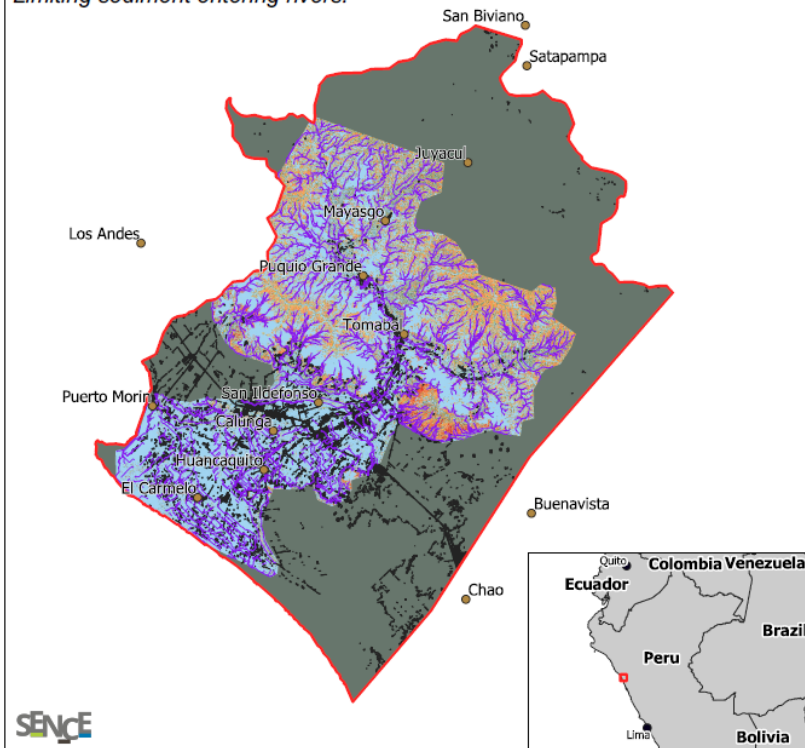


Derived data created by JNCC and Environment Systems Ltd. Maps created by Environment Systems Ltd (2019).
© OpenStreetMap contributors

4. Risk of soil erosion caused by precipitation

Ecosystem services: Conservation of soil and water quality.

Limiting sediment entering rivers.



How to interpret the map:

Places of highest risk are coloured red. Places of lower risk are coloured blue.

What the service is:

Land erosion risk is a significant factor leading to loss of soil, soil quality degradation, siltation of rivers, damage to habitats and wildlife, and damage to buildings, roads, and other infrastructure.

Why it is important:

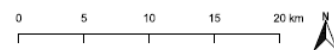
Soil is a non-renewable resource and where it is lost through erosion, it can take hundreds to thousands of years to re-form. Losing soil disrupts the physical structure of the soil and the balance of biological communities which regulate soil functions, degrading soil quality. Nutrients and chemicals in the soil can be detrimental to the freshwater, wetland and marine habitats they reach, as well as the associated wildlife.

How the map was created:

This map was created using SCIMAP which is a framework for modelling and mapping diffuse pollution risk across landscapes. It considers slope, habitats and average precipitation. The map has been created using WorldDEM, WorldClim, Pleiades, Sentinel 1 and Sentinel 2 data. The current map has been created at the strategic scale and is indicative at a field level. Field visits should be undertaken before any site-specific management decisions are taken. Additional data could be sourced to refine the maps at the local scale.

Legend

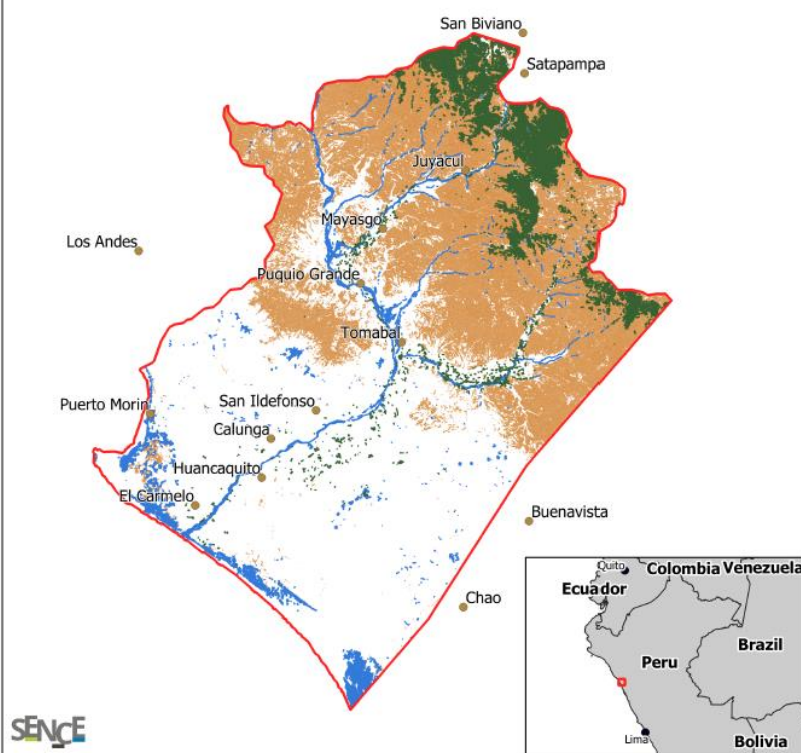
- Low risk of erosion
- Medium risk of erosion
- High risk of erosion
- Erosion channel
- Urban and roads
- Not assessed



Derived data created by JNCC and Environment Systems Ltd. Maps created by Environment Systems Ltd (2019).
SCIMAP by Sim Reaney, Durham University is licensed under a Creative Commons Attribution-NonCommercial-ShareAlike 3.0 Unported License.
© OpenStreetMap contributors.

5. Places with habitat of key importance for biodiversity

Ecosystem services: Population maintenance & genetic diversity.



How to interpret the map:

The map shows existing areas of natural or semi-natural scrubland, wetland (including ephemeral watercourses) or woodland that are important for supporting biological and genetic diversity.

What the service is:

The map shows areas of natural or semi-natural vegetation, that are likely to support populations of a wide range of species, and high overall biodiversity. Biodiversity is a supporting service which underpins many other ecosystem services such as soil quality, pollination, food provision and surface water regulation.

Why it is important:

These habitats are core components of the ecological networks, which facilitate gene flow between species populations and increase ecological resilience to disturbances such as land management and climate change. Natural and semi-natural habitats function as a complete system and so generally provide a higher level of ecosystem services than less natural and structurally diverse habitats. Loss of these habitats would reduce the ecological resilience, and have an impact on related ecosystem services, such as the ability of land to regulate surface water runoff, and habitat for pollinators.

How the map was created:

The habitat classes were generated using Pleiades, Sentinel 1 and Sentinel 2 satellite imagery. The map has been created at the strategic scale and is indicative at a field level. Field visits should be undertaken before any specific management decisions are taken.

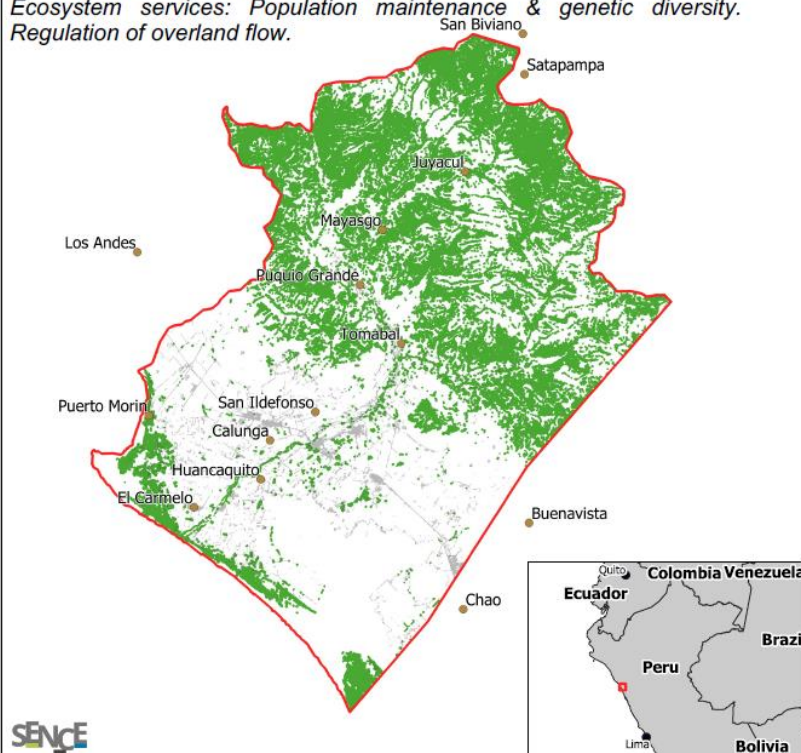
Legend

- Scrubland habitats
- Wetland habitats (including ephemeral watercourses)
- Woodland habitats

Derived data created by JNCC and Environment Systems Ltd.
Maps created by Environment Systems Ltd (2019).
© OpenStreetMap contributors.

6. Places delivering multiple ecosystem service benefits: key areas for biodiversity and surface water regulation

*Ecosystem services: Population maintenance & genetic diversity.
Regulation of overland flow.*



How to interpret the map:

The map identifies areas of source habitat (grassland/cactus, woodland, wetland) which coincide with areas providing high surface water regulation.

What the service is:

Source habitats function as the core of ecological networks. The structure and naturalness of the vegetation in these areas provides high biodiversity value. These vegetation characteristics combine with characteristics of the soil, geology and slope and together they provide high levels of surface water regulation. Biodiversity is a supporting service which underpins many other ecosystem services such as soil quality, pollination and food provision. Surface water regulation is a form of natural flood management, where hydrological and morphological processes, together with the habitat features, work together to manage the sources and pathways for flood waters.

Why it is important:

Surface water regulation and biodiversity are important ecosystem services in their own right. However, places providing high levels of multiple ecosystem services could be considered more valuable than those providing a single ecosystem service. The protection of places of high biodiversity value that also provide high levels of natural flood management is likely to be a good investment.

How the map was created:

This map was derived by combining information from two other ecosystem service maps in this series: "Ability of the land to moderate surface water runoff" (Map 1; areas with highest levels of provision) and "Places with habitat of key importance for biodiversity" (Map 5).

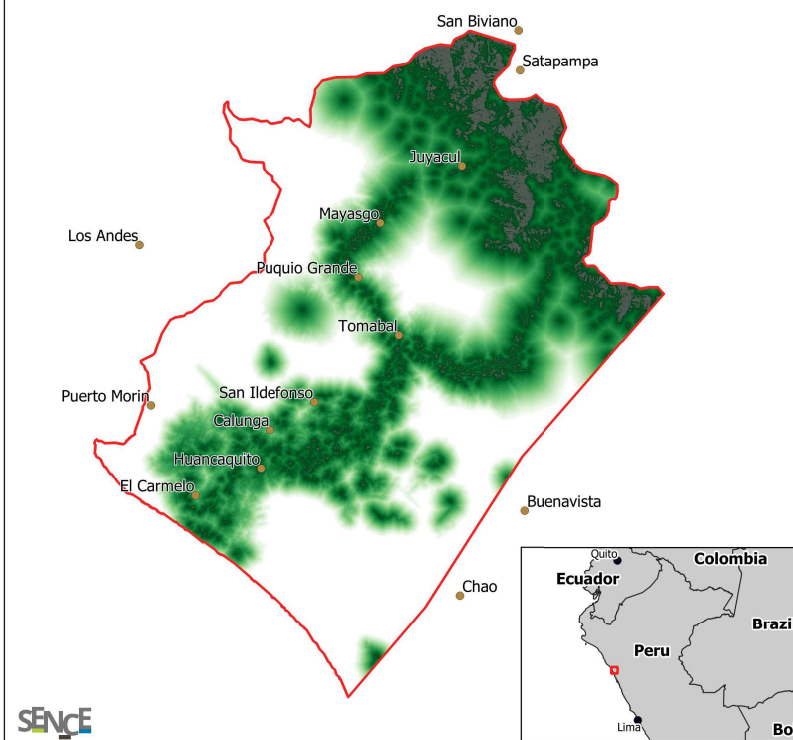
Legend

- Areas important for both biodiversity and surface water regulation
- No multi-benefits
- Roads and urban

Derived data created by JNCC and Environment Systems Ltd.
Maps created by Environment Systems Ltd (2019).
© OpenStreetMap contributors.
Soil data: SoilGrids250m - ISRIC.

7. Ecological Network Connectivity - Woodland Ecosystem

Ecosystem service: Population maintenance & genetic diversity



How to interpret the map:

Dark green areas are more highly connected to the ecological network. Grey areas are existing source woodlands.

What the service is:

The map shows the existing woodland network within which plant and animal species can move to maintain genetic diversity and sustain viable populations of woodland species. Existing woodlands act as 'source habitat', where the main population of woodland species is based. Land adjoining and close to the source habitats can be used for foraging and as dispersal routes (permeable habitats). Some habitats and land uses are more permeable than others; for example scrub could be expected to provide greater levels of food and shelter for woodland species, whereas bare ground would provide less.

Why it is important:

Areas of native natural and semi-natural woodlands that are connected in a landscape, forming a network, are more resilient to changing climate or land management. Inside the network, woodlands generally provide higher levels of ecosystem services, such as the ability to clean water or regulate runoff, provide timber products and support nature tourism (e.g. bird watching). Within the network, restoration of structurally-diverse and species-rich woodlands will be far more effective as propagules, pollinators and important species will be available for colonisation.

How the map was created:

The habitat classes were generated using Pleiades, Sentinel 1 and Sentinel 2 satellite imagery. Each habitat and land use was evaluated for its importance and role played in supporting the woodland network.

Legend



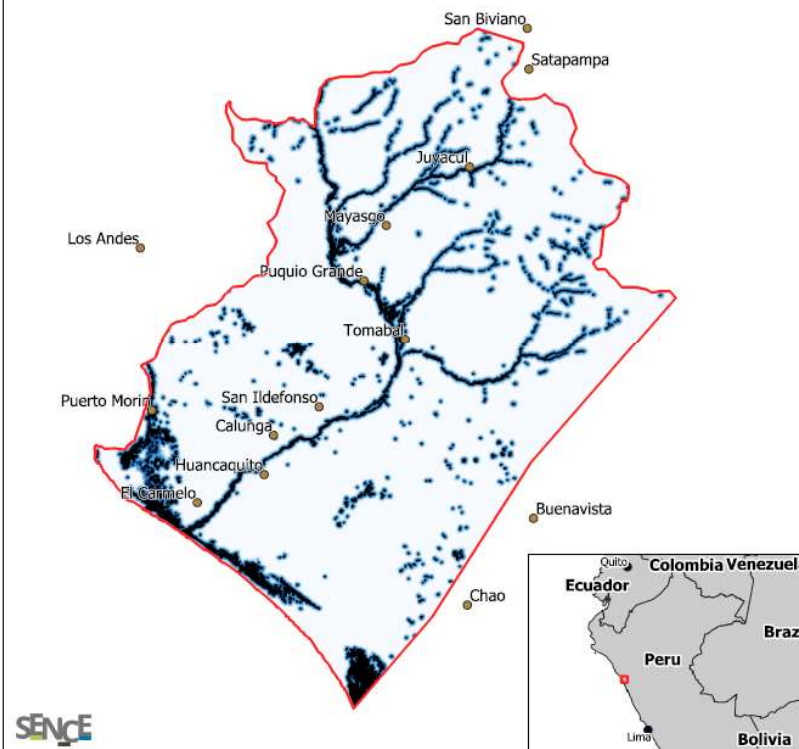
Derived data created by JNCC and Environment Systems Ltd.

Maps created by Environment Systems Ltd (2019).

© OpenStreetMap contributors.

8. Ecological Network Connectivity - Wetland Ecosystem

Ecosystem service: Population maintenance & genetic diversity.



How to interpret the map:

Darker blue areas are more highly connected to the ecological network. Black areas are existing source habitats, comprising permanent and ephemeral river channels, and wetland habitats (excluding reservoirs).

What the service is:

The map shows the existing wetland network within which plant and animal species can move to maintain genetic diversity and sustain viable populations of wetland species. Existing wetlands act as 'source habitat', where the main population of wetland species is based. Land adjoining and close to the source habitats can be used for foraging and as dispersal routes (permeable habitats). Some habitats and land uses are more permeable than others; for example rivers could be expected to provide suitable conditions for many wetland species, whereas terrestrial habitats are less suitable.

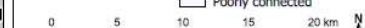
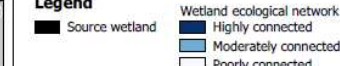
Why it is important:

Areas of native natural and semi-natural wetlands that are connected in a landscape, are more resilient to changing climate or land management. Inside the network, wetlands with low chemical and nutrient levels, and structurally-diverse and species-rich emergent vegetation, generally provide a higher level of ecosystem services, such as clean freshwaters, erosion control, and nursery fisheries. Within the network, restoration of structurally-diverse and species-rich emergent vegetation will be far more effective as propagules, pollinators and important species will be available for colonisation.

How the map was created:

The habitat classes were generated using Pleiades, Sentinel 1 and Sentinel 2 satellite imagery. Each habitat and land use was evaluated for its importance and role played in supporting the wetland network.

Legend



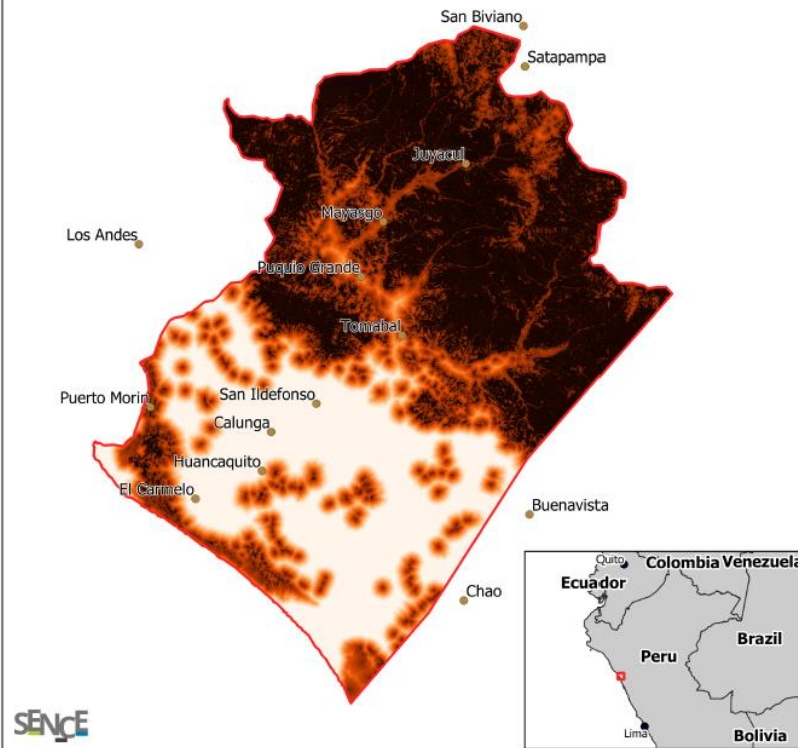
Derived data created by JNCC and Environment Systems Ltd.

Maps created by Environment Systems Ltd (2019).

© OpenStreetMap contributors.

9. Ecological Network Connectivity - Scrubland Ecosystem

Ecosystem services: Population maintenance & genetic diversity.



How to interpret the map:
Darker orange areas are more highly connected to the ecological network. Black areas are existing source scrublands.

What the service is:

The map shows the existing scrubland habitat network within which plant and animal species can move to maintain genetic diversity and sustain viable populations of scrubland habitat species. Existing scrublands act as 'source habitat', where the main population of scrubland species is based. Land adjoining and close to the source habitats can be used for foraging and as dispersal routes (permeable habitats). Some habitats and land uses are more permeable than others; for example scattered scrub could be expected to provide better conditions for scrubland species than dense woodland.

Why it is important:

Areas of native natural and semi-natural scrublands that are connected in a landscape, are more resilient to changing climate or land management. Inside the network, structurally-diverse and species-rich scrublands generally provide a higher level of ecosystem services, such as surface water regulation. Within the network, restoration of structurally-diverse and species-rich scrublands will be far more effective as propagules, pollinators and important species will be available for colonisation.

How the map was created:

The habitat classes were generated using Pleiades, Sentinel 1 and Sentinel 2 satellite imagery. Each habitat and land use was evaluated for its importance and role played in supporting the scrubland network.

Legend

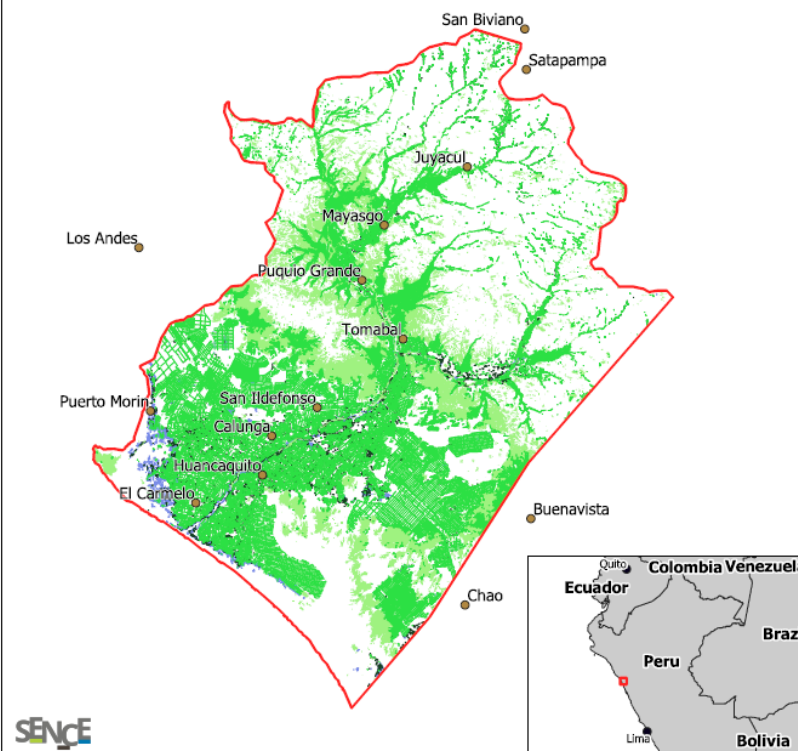
Scrubland ecological network
 ■ Source scrubland ■ Highly connected
 ■ Moderately connected
 ■ Poorly connected



Derived data created by JNCC and Environment Systems Ltd.
 Maps created by Environment Systems Ltd (2019).
 © OpenStreetMap contributors.

10. Opportunities to strengthen ecological networks

Ecosystem service: Population maintenance & genetic diversity.



How to interpret the map: The map shows places where it should be possible to restore or create new habitat to strengthen the existing ecological networks, to enhance biological and genetic diversity. Places in darker shades are areas where habitat restoration/creation are expected to be most easily implemented and more successful. For example, developing a woodland from an area of dense scrub or bare ground may be a suitable choice in both places, but restoration is quicker, less labour intensive and less costly from the dense scrub vegetation, and on shallower slopes.

What the service is:

Biodiversity is a supporting service which underpins many other ecosystem services.

How the map was created:

This map considered all places where the existing habitat type could be enhanced to strengthen ecological networks. However, places in close proximity to existing source habitat are most likely to be effective at supporting existing populations (shown in Map 11). Field margin areas were mapped through analysis of Sentinel-2 imagery, and used to refine the opportunity selection within the permanently cropped areas. Habitats and land use were assessed as to the ease with which they could be restored to support the ecological networks. Where restoration to woodland was possible, this option was chosen, except in cases located in close proximity to existing source wetland habitat; in these places, the wetland option was chosen.

Legend

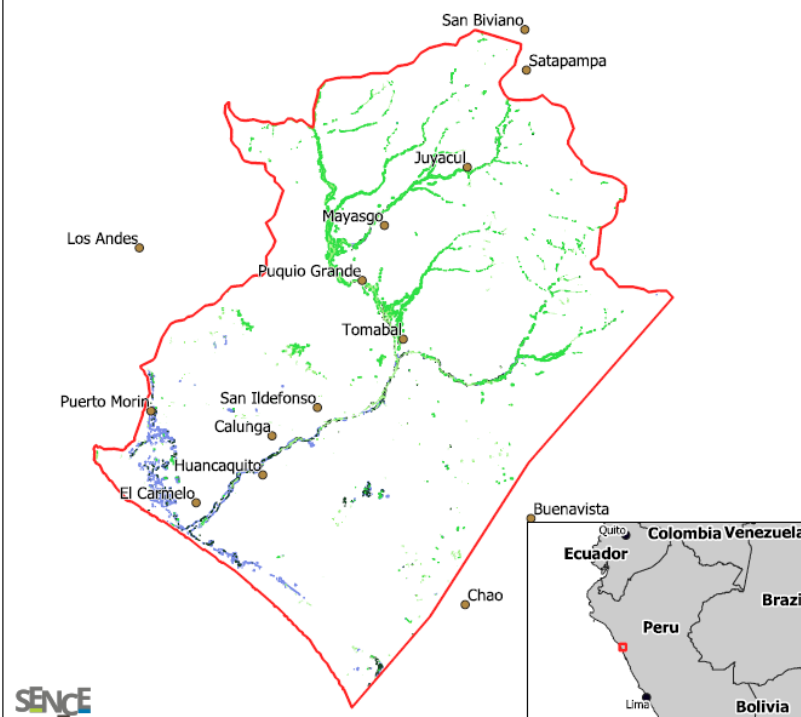
Ease of restoration
 ■ Wetland opportunity: High
 ■ Wetland opportunity: Medium
 ■ Wetland opportunity: Low
 ■ Woodland opportunity: High
 ■ Woodland opportunity: Medium
 ■ Woodland opportunity: Low



Derived data created by JNCC and Environment Systems Ltd.
 Maps created by Environment Systems Ltd (2019).
 © OpenStreetMap contributors.

11. Opportunities to strengthen ecological networks: priority places for action (those adjoining existing key habitats of high-biodiversity value)

Ecosystem service: Population maintenance & genetic diversity



How to interpret the map:

This map is a subset of Map 10 and shows only those places that adjoin existing source habitat, where habitat restoration is likely to be most successful and beneficial to existing habitat of key biodiversity value. Areas next to existing biodiversity hotspots are likely to provide most benefit to existing species populations, allowing the expansion of local native species via dispersal or territory expansion. Restoration of structurally-diverse and species-rich habitat will be far more effective close to the source habitats, as propagules, pollinators and important species will be available for colonisation.

What the service is:

Biodiversity is a supporting service which underpins many other ecosystem services such as soil quality, pollination and food provision.

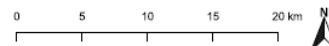
How the map was created:

This map considers places immediately adjoining existing source habitat, as defined by the ecological network maps in this series. Habitats and land uses next to the source habitats were assessed as to the ease at which they could be restored to support the wetland or woodland network. In this analysis, the 'wetland' network includes both permanent wetlands and ephemeral watercourses.

Legend

Ease of restoration

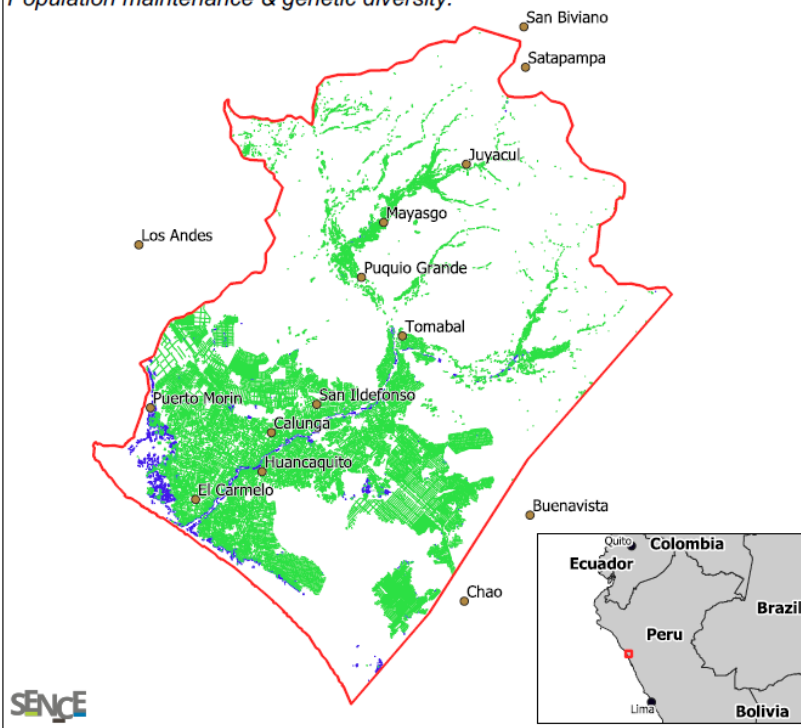
- Wetland opportunity: High
- Wetland opportunity: Medium
- Wetland opportunity: Low
- Woodland opportunity: High
- Woodland opportunity: Medium
- Woodland opportunity: Low



Derived data created by JNCC and Environment Systems Ltd.
Maps created by Environment Systems Ltd (2019).
© OpenStreetMap contributors.

12. Opportunities to deliver multiple ecosystem services: ecological connectivity and surface water regulation

*Ecosystem services: Regulation of overland flow.
Population maintenance & genetic diversity.*



How to interpret the map:

The map shows places where it should be possible to restore or create new habitat to strengthen the existing wetland or woodland ecological networks to enhance biodiversity, while simultaneously enhancing the level of surface water regulation.

What the service is:

Biodiversity is a supporting service which underpins many other ecosystem services such as soil quality, pollination and food provision. Surface water regulation is a form of natural flood management, which manages the sources and pathways for flood waters.

Why is it important:

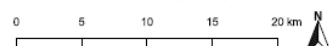
Surface water regulation and biodiversity are important ecosystem services in their own right. However, identifying places which provide high levels of multiple ecosystem services can help to inform the decision-making process when prioritising areas for land management action, in order to provide best value-for-money.

How the map was created:

This map is derived by combining information from two other ecosystem service maps in this series: "Opportunities to enhance surface water regulation" (Map 2) and "Opportunities to strengthen ecological networks" (Map 10). It identifies places that could be restored to support the ecological networks, and which currently provide relatively low surface water regulation.

Legend

- Wetland opportunity
- Woodland opportunity



Derived data created by JNCC and Environment Systems Ltd.
Maps created by Environment Systems Ltd (2019).
© OpenStreetMap contributors.
Soil data: SoilGrids250m - ISRIC