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EO4cultivar

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# EO4cultivar sustainable livelihoods case studies: Ecosystem stock, risk and opportunity mapping in the Magdalena region, Colombia

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# Contents

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# 1 Introduction

This report accompanies mapped and modelled evidence that identifies places where international partners and stakeholders of the EO4cultivar project, in the Magdalena region of Colombia, 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 (See Appendix C) 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 wind and 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 and the ecosystems it supports in the area and the ecosystem services these areas provide.

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 to 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 face-to-face meetings and an interactive workshop were held in Santa Marta, Magdalena region, Colombia in April 2018. The objectives of these activities were to meet with key project stakeholder to outline the overarching objective 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 agricultural businesses, NGOs working with small holder growers and local communities and local government agency representatives. These parties all 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 Zona Bananera 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 crop data services element of EO4c, the Sustainable Livelihoods work package has developed the Colombian 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. All of the ecosystem service maps developed for this project can be viewed online at: https://jncc.gov.uk/eo4cultivar

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
- a 1:100,000 scale soil/geology map (Geographic Institute Agustín Codazzi, 2009).

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.

## 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.

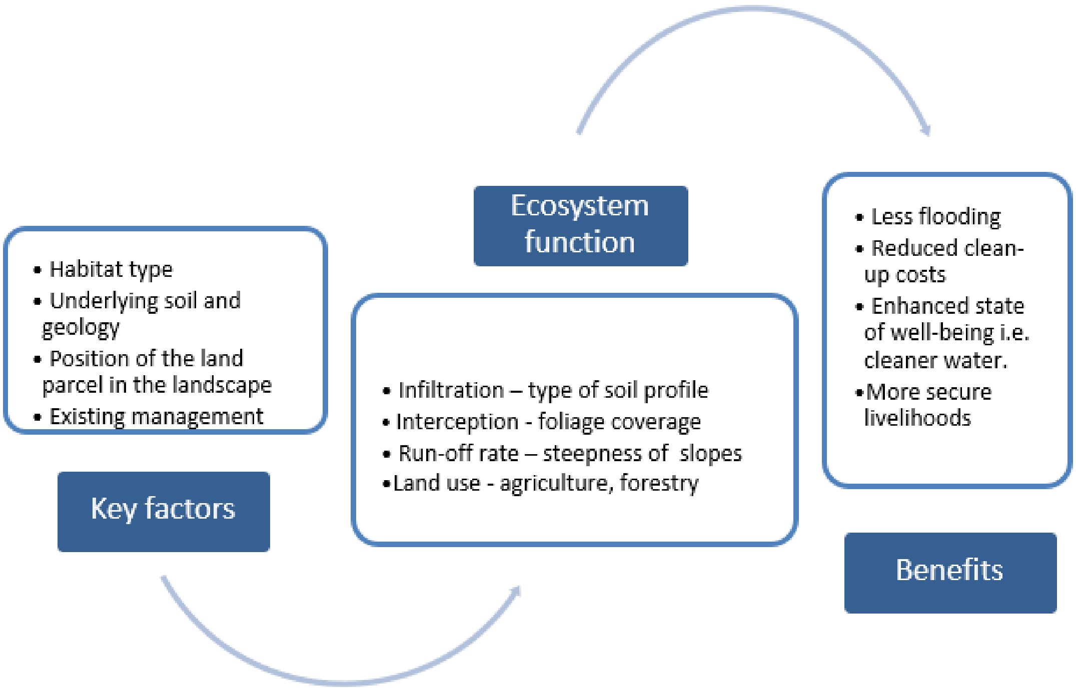


**Figure 1: Linking SENCE key factors to ecosystem functions and the flow of ecosystem service in the case of surface water regulation.**

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 $10m^2$.

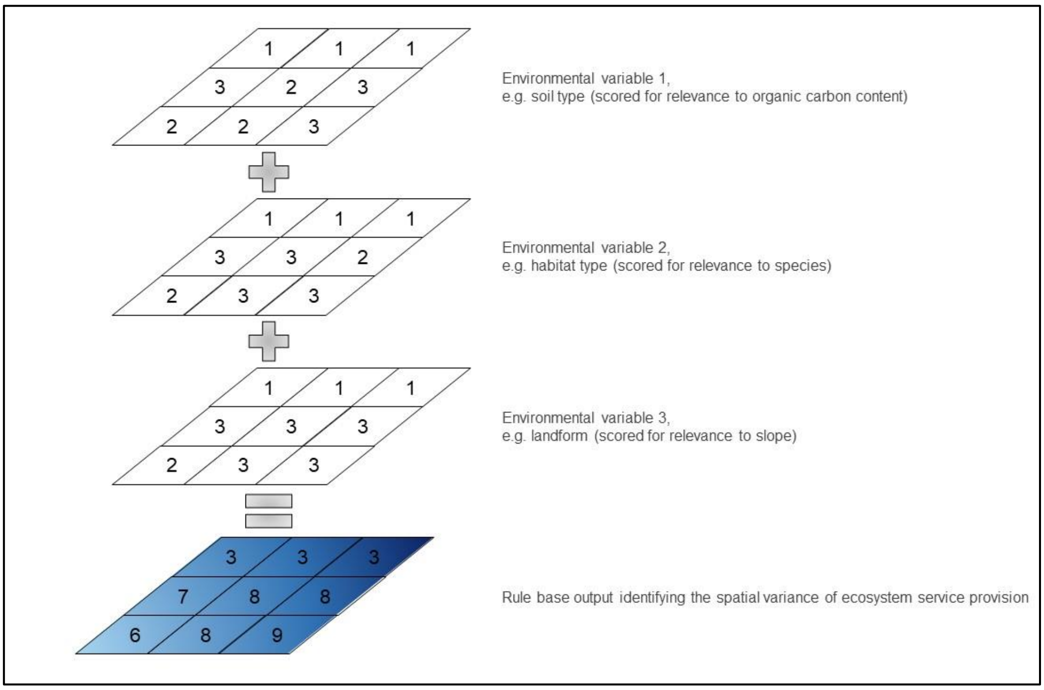


**Figure 2: A graphical representation of the GIS data analysis**

## 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 10m Sentinel-1 and Sentinel-2 satellite imagery, along with 30m Landsat and SRTM (elevation) data and is discussed in the accompanying habitat report.

If higher resolution datasets become available in the future, these could be used to refine the models and map outputs. For example, high resolution elevation data (derived from LiDAR, for example) would particularly enhance the modelling of catchment boundaries and flow paths in the flat coastal plain of the study area, while very high resolution (5m or better) optical satellite imagery would enable finer definition of small habitat features, and enhance the habitat classification.

# 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, and baffles.

- **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:** Wet woodland, reed beds and swamps all hold a great deal of water naturally, which can reduce the likelihood of damage to property during flood events.  Wet woodlands in particular have a high evapotranspiration rate in the summer helping return water from the ground back into the atmosphere.

The stock map was generated by considering four key factors: geology, soil, slope, habitat and management, and their influence on fluvial and pluvial flooding. 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; and sediment load control. For example, attributes given high scores, representing high natural regulation include: deep, well-drained soils; porous geology; dense natural woodland; and flat/ gently sloping land. Conversely, attributes given low scores, representing low natural regulation include: bare ground; thin, poorly-drained soils; impermeable rock; and steep slopes.

Habitats with high water regulation capacity, that are present at higher elevations in the catchment, were given higher scores than similar habitats present in the lower reaches of the catchment. This is because moderating the flow of water closer to source can be more effective and benefits a larger downstream area.

Each key factor dataset was weighted according to the degree of effect on the regulation of overland flow; habitat, soil and landform were all given equal weighting, but geology was weighted at one quarter. It should be borne in mind that this does not imply that differing geological types are unimportant for surface water regulation in the study area, but that our ability to discern the different levels of water regulation provision is not as strong, given the nature of the attribution held within the dataset.

In the resulting map (Appendix C - Map 1) the wetland system of the Ciénaga Grande is shown as providing relatively low surface water regulation capacity, although the habitat type itself was scored highly for regulation capacity. This is a result of the position of the wetland at the very bottom of the catchment, where the watercourses drain into the Ciénaga Grande Santa Marta. The downstream area which the wetland can influence, as well as the number of people which could benefit from provision of this service, is small, hence low scoring for service delivery. Although the map appears to show that the Ciénaga wetland is of low value, it must be borne in mind that the map does not specifically consider marine flood regulation and that the values are relative. The map demonstrates the significance of the intact woodland habitats higher in the catchment.

## 3.2 Surface Water Regulation Opportunities

Maps 2 and 3 (See Appendix C) focus on a subset of the main project study area; the hydrological catchment of the Rio Frio. They 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 (Appendix C) 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 (e.g. managing grass height and species composition of grasslands) 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 (Appendix C - Map 3), showing only the opportunity areas located within major flow paths.

The Rio Frio basin was divided into sub-basins by topographic analysis of the SRTM elevation dataset, which allowed the largest flow pathways to be identified. This provided good flow-path definition in the mid- and upper catchment regions, but became less reliable in the flatter parts of the lower catchment. This is because the resolution of the data (30m pixels) is unable to detect the fine-scale differences in slope and aspect present in the flood plain. In these locations, where the topographic differences are very small, elevation values can be disproportionately affected by vegetation height, resulting in artefacts that become manifest in the flow path analysis.

In order to address these limitations manual image interpretation was undertaken in the lower catchment area to identify the true course of major rivers and channels through the flat landscape. All sub-basins bordering the major flow paths were 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 Map 2: Opportunities to enhance surface water regulation in the Rio Frio catchment**

| 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, with large cost implications. |

# 4. Erosion Risk

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.

## 4.1 Risk of Soil Erosion by Precipitation

This map (Appendix C - 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).

## 4.2 Risk of Soil Erosion by Wind

Soil erosion by wind can be a locally significant factor, and the type of impacts of wind-driven soil loss are the same as for precipitation-driven erosion. Susceptibility of soil to wind erosion is determined by many interacting factors such as the extent of vegetation cover, vegetation structure, climate, soil to stone ratio, steepness of slope, soil moisture, texture and clay mineral structure. Land use management can have a large influence on wind erosion, particularly if vegetation cover is removed from dry, susceptible soils where erosive winds are likely to occur.

The map (Appendix C - Map 5) was produced by analysis of the Digital Soil Map of the Department of Magdalena, Republic of Colombia. Soil classes and their relative abundances were assessed for their susceptibility to wind erosion as determined by the general characteristics of the soil class name and this was moderated by the composition of different soil types within each polygon. Soil classes of highest susceptibility to wind erosion, that were present in over 60% of an area, were assigned as being at highest risk of wind erosion. Areas where the same soil type is present but in lower proportions, were assessed as lower risk.

# 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).

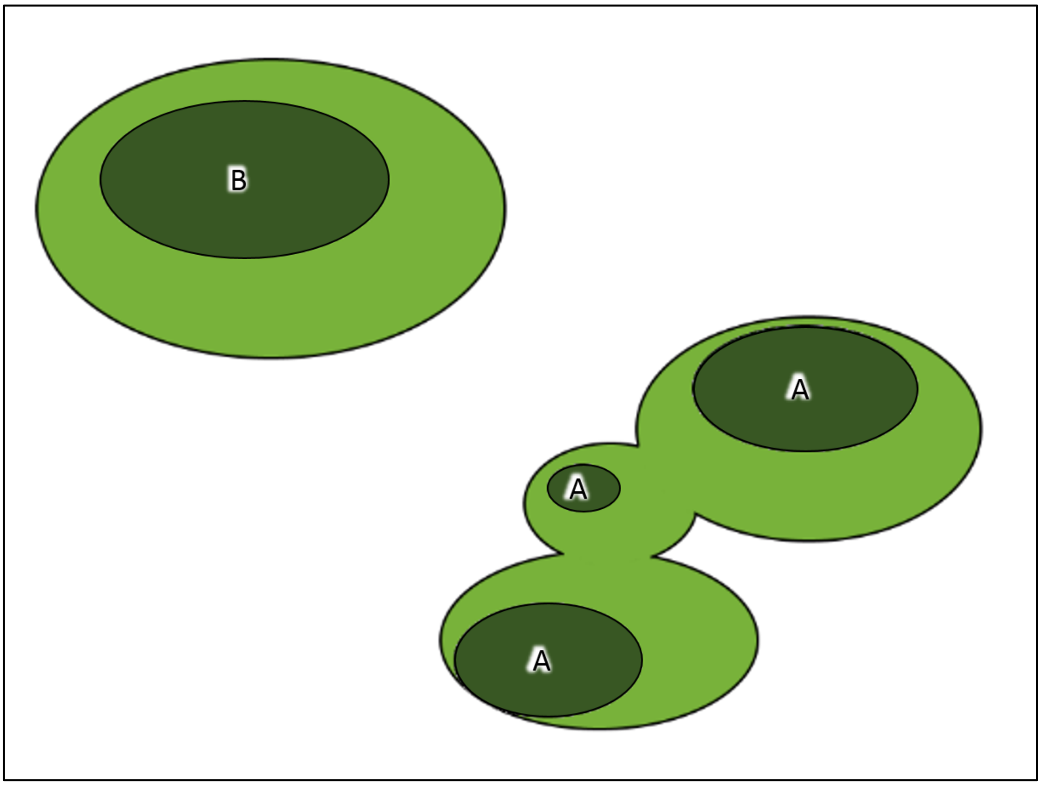


**Figure 3: Schematic representation of an ecological network, with source habitat shown in dark green, and permeable supporting habitat in light green. Populations within source habitats marked 'A' are genetically connected; population 'B' is isolated.**

In 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.

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 (Appendix C - Map 8);
- Wetland (Appendix C - Map 9); and
- Grassland habitats (Appendix C - Map 10);

In addition to the individual network and network opportunity maps, a map has been created showing the combined source habitats for the grassland, wetland and woodland networks (Appendix C - Map 6), 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 (Appendix C - Map 11), 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 (Appendix C - Map 12). The opportunity maps also identify locations where there are opportunities for more than one network type.

## 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 (e.g. 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; woodland, wetland or grassland, to express how difficult, in relative terms, it might be for a species associated with the source habitats to move through each habitat. For example, a species mainly associated with dense woodland could disperse through an area of scrub and scattered trees more easily than through an urban area or arable farmland; the permeability score reflects 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 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 (Appendix C - Map 8), wetland (Appendix C - Map 9) and grassland (Appendix C - Map 10) ecological networks for the woodland, wetland and grassland pseudo species, respectively.

Map 8 (Appendix C) shows a highly connected woodland network in the mountain region of the study area, with a break in connectivity in the valley region owing to a lack of source and supporting habitats. Map 9 (Appendix C) shows a large area of source wetland habitat around the Ciénaga, with smaller wetland areas providing some connectivity upstream, but the specificity of this habitat type mean that the network is small and fragmented. The grassland network consists of many small, scattered source habitats that are connected-enough to form a network, which overlaps with parts of the woodland and wetland networks. In these places of network overlap it could be possible to take action to enhance both habitat networks simultaneously; if this is not possible, one network would be prioritised over another.

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 11 (Appendix C) identifies places where it would be possible to restore or re-create habitats to improve ecological connectivity of each network, 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 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 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’ (Appendix C - Map 6).

In places located close to several source habitats of different types (e.g. equidistant between a grassland 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 always given to creating woodland; if a woodland opportunity existed, it was mapped as such, regardless of whether it was also feasible to create grassland or wetland.

In cases where the grassland and wetland opportunities overlapped, but no woodland opportunities were present, these were mapped separately as ‘dual’ opportunities. In these places it would be possible to enhance either the grassland or wetland network, and possibly both simultaneously, but further consideration of priorities and practicalities would be required in the decision-making process.

Map 12 (Appendix C) shows a subset of opportunity areas from Map 11 (Appendix C), 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; grassland opportunities next to grassland 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. Furthermore, 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.

# 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

This map (Appendix C - Map 7) shows key areas for biodiversity that also provide high levels of surface water regulation. The Ciénaga Grande Santa Marta is not mapped as an important area in this map, despite being a key site for biodiversity, and a wetland site with a high capacity for flood water storage. This is because of the position of the Ciénaga within the catchment; with is being located at the bottom of the catchment it has very little influence over much of the downstream terrestrial area, therefore there are very few human benefactors from any surface water regulation it may provide, relative to other habitats, particularly dense woodland, present in higher catchment zones.

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

Map 13 (Appendix C) shows places where it should be possible to restore or create new habitat to strengthen the existing grassland, wetland or woodland ecological networks to enhance biodiversity, while simultaneously enhancing the level of surface water regulation.

# 7. Conclusion

A set of 13 maps (See Appendix C) 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 Colombian stakeholders at a series of follow-up meetings and workshop in September 2019. 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 a s a starting point for longer term collaboration and support for the uptake and application of earth observation and ecosystem modelling capabilities across the region.

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# 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 | Bespoke dataset | Environment Systems Ltd | All | CC BY-SA 4.0 https://creativecommons.org/licenses/by-sa/4.0/ |
| Soils | Soil Classification 100k | Geographic Institute Agustín Codazzi | All | Open License |
| Geology | Soil Classification 100k | Geographic Institute Agustín Codazzi | All | Open License |
| Land Form | SRTM 30m | USGS | All | Open License |

# Appendix B – Datasets Used in Each Map

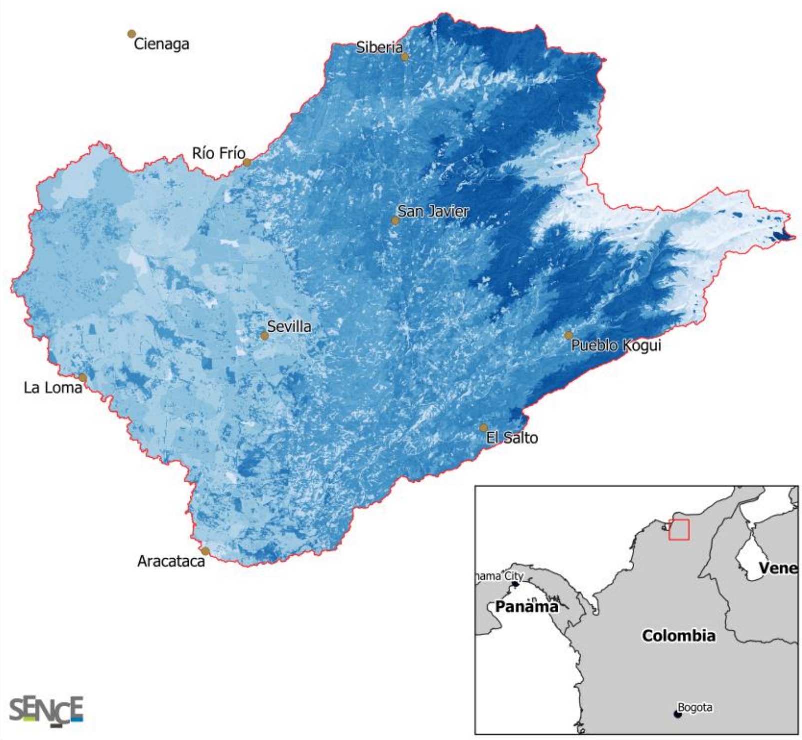
| Map | Habitat/ Management[1] | Soil | Geology | Landform |
|---|---|---|---|---|
| 1. Ability of the land to moderate surface water runoff | ✓ | ✓ | ✓ | ✓ |
| 2. Opportunities to enhance surface water regulation in the Rio Frio catchment | ✓ | | | ✓ |
| 3. Opportunities to enhance surface water regulation in the Rio Frio catchment: places bordering major drainage channels | ✓ | | | ✓ |
| 4. Risk of soil erosion in the Sierra Nevada caused by precipitation | ✓ | | | ✓ |
| 5. Risk of soil erosion caused by wind | | ✓ | | |
| 6. Places with habitat of key importance for biodiversity | ✓ | | | |
| 7. Places delivering multiple ecosystem service benefits: key areas for biodiversity and surface water regulation | ✓ | ✓ | ✓ | ✓ |
| 8. Ecological Network Connectivity - Woodland Ecosystem | ✓ | | | |
| 9. Ecological Network Connectivity - Wetland Ecosystem | ✓ | | | |
| 10. Ecological Network Connectivity – Grassland Ecosystem | ✓ | | | |
| 11. Opportunities to strengthen ecological networks | ✓ | | | |
| 12. Opportunities to strengthen ecological networks: priority places for action (those adjoining existing key habitats of high-biodiversity value) | ✓ | | | |
| 13. Opportunities to deliver multiple ecosystem services: ecological connectivity and surface water regulation | ✓ | | | ✓ |

[1] Landform data used in the production of this dataset

# Appendix C – SENCE 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. 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**

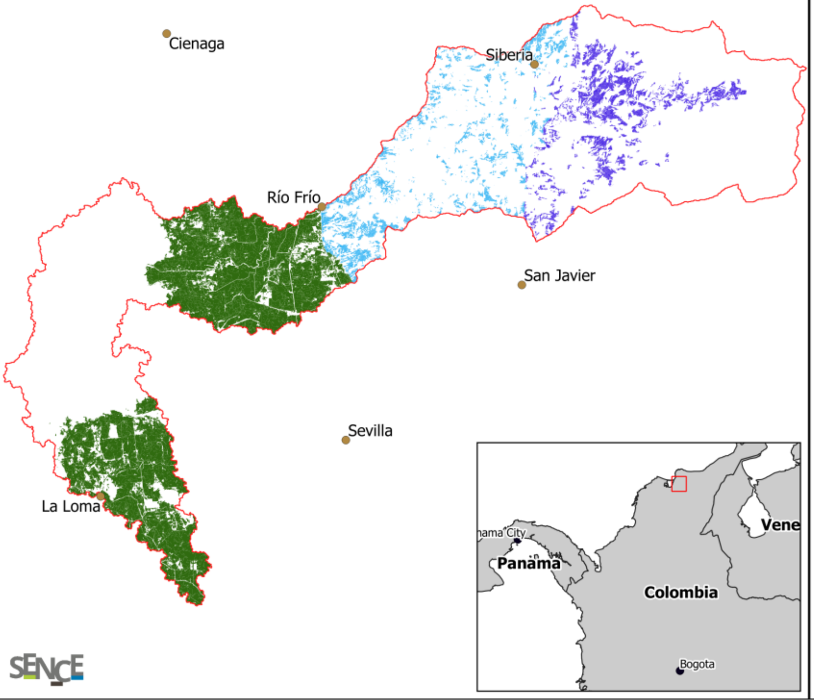
Low potential of land to slow runoff
High potential of land to slow runoff

0 5 10 15 20 km N

Data and maps created by Environment Systems Ltd (2019)
© OpenStreetMap contributors
Soil data: Geographic Institute Agustin Codazzi

**2. Opportunities to enhance surface water regulation in the Rio Frio catchment**

*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 the river Frio. Places shown in dark blue are located in the upper catchment of the Rio Frio. 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 is it 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 Sentinel 1 and Sentinel 2 satellite imagery. The river basin boundary was determined by analysis of SRTM elevation data.

**Legend**

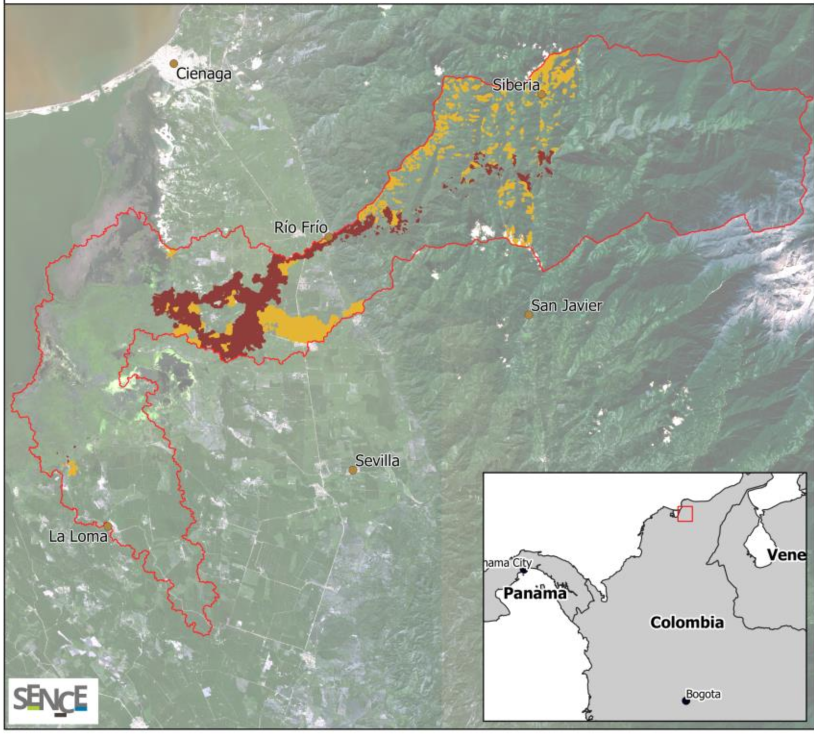
Opportunity in the lower catchment
Opportunity in the mid catchment
Opportunity in the upper catchment

0 3 6 9 12 15 km N

Data and maps created by Environment Systems Ltd (2019)
© OpenStreetMap contributors

## 3. Opportunities to enhance surface water regulation in the Rio Frio catchment: 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 grassland within major flow paths, where taking action to improve surface water regulation, to slow the flow of runoff into the river Frio, would be most effective. Dark brown places directly adjoin a major river, tributary or channel. They receive the largest proportion of the runoff water and may be more likely to flood; action should be most effective here. Lighter orange places are also within major flow paths but have less influence on flow into the major channels.

**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 Sentinel 1 and Sentinel 2 satellite imagery, and flow paths derived from SRTM elevation data.

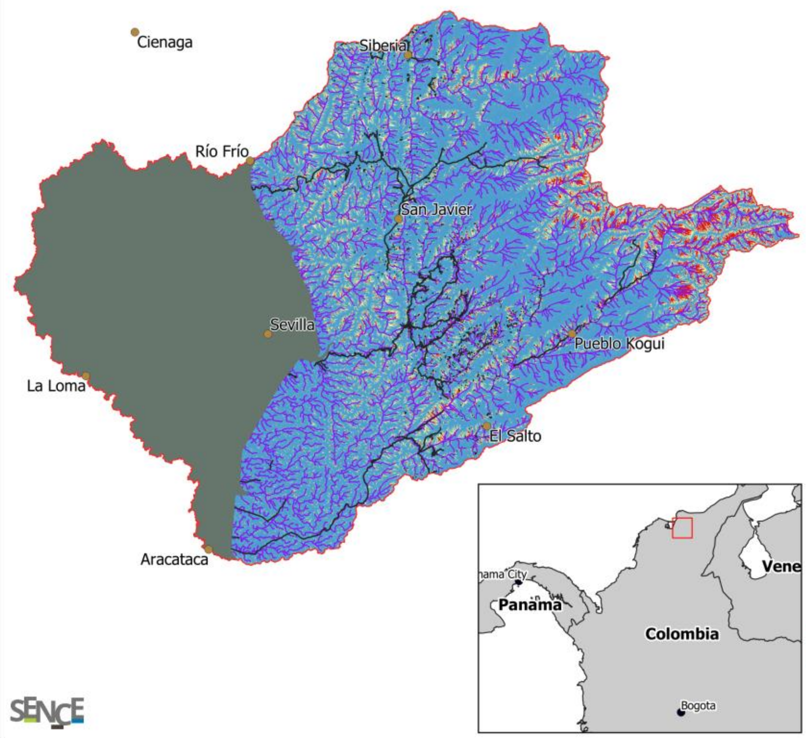
**Legend**
- High priority opportunity area adjoining main channel
- Other high priority opportunity areas

0 3 6 9 12 15 km

Data and maps created by Environment Systems Ltd (2019)
© OpenStreetMap contributors
Sentinel-2 image: European Space Agency - ESA

## 4. Risk of soil erosion in the Sierra Nevada 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 SRTM, WorldClim, Landsat, 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; methods for doing this are discussed in the project report.

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

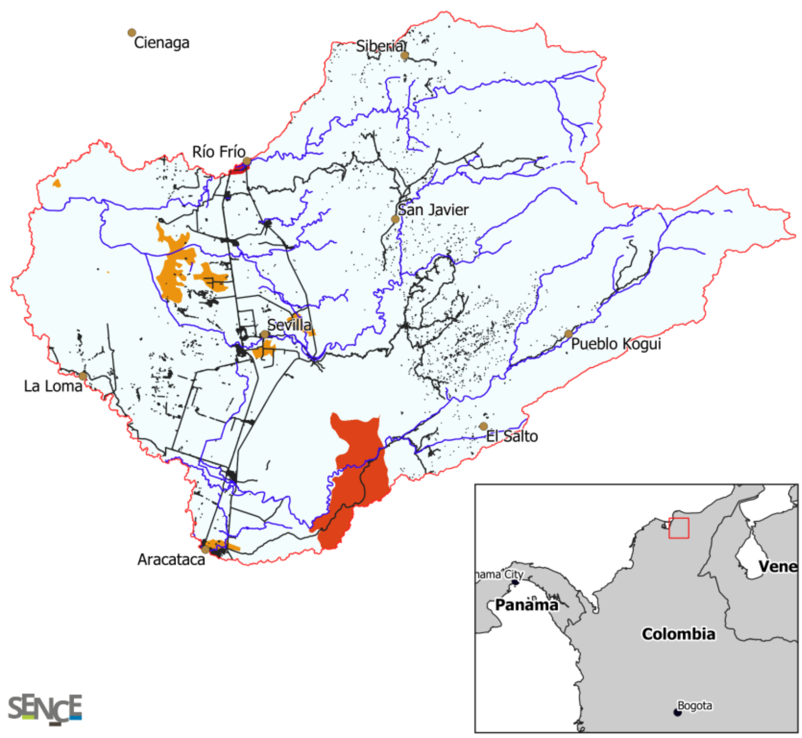
0 5 10 15 20 km

Data and maps created by Environment Systems Ltd (2019)

© OpenStreetMap contributors

## 5. Risk of soil erosion caused by wind

*Ecosystem services: Conservation of soil and water quality. Limiting sediment entering rivers.*




**How to interpret the map:**
Orange colours are places where soils are susceptible to wind erosion, with dark orange places being most susceptible.

**What the service is:**
Topsoil erosion risk is a significant factor leading to loss of soil, soil quality degradation, reduction in agricultural productivity, and siltation of rivers and streams. Some soil types are more susceptible to wind erosion due to their texture, stoniness and organic matter content.

**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 topsoil removes a nutrient-rich growing-medium for plants, and also reduces the water infiltration capacity of the soil, leading to increased runoff. Land use management can have a large influence on wind erosion, particularly if vegetation cover is removed from dry, susceptible soils when erosive winds are likely to occur.

**How the map was created:**
This map is based on an analysis of soil characteristics as mapped within the Digital Soil Map of the Department of Magdalena, Republic of Colombia. Scale 1: 100,000 (2009). Soil classes and their relative abundances were assessed for their susceptibility to wind erosion, so that soils with the highest risk and which are present in over 60% of an area, are given the highest risk. Areas where the same soil type is present, but in lower proportions, are assessed as lower risk.

**Legend**

Urban and roads
Rivers

Wind erosion risk
Soils of low susceptibility to wind erosion
Soils of moderate susceptibility to wind erosion
Soils with highest susceptibility to wind erosion

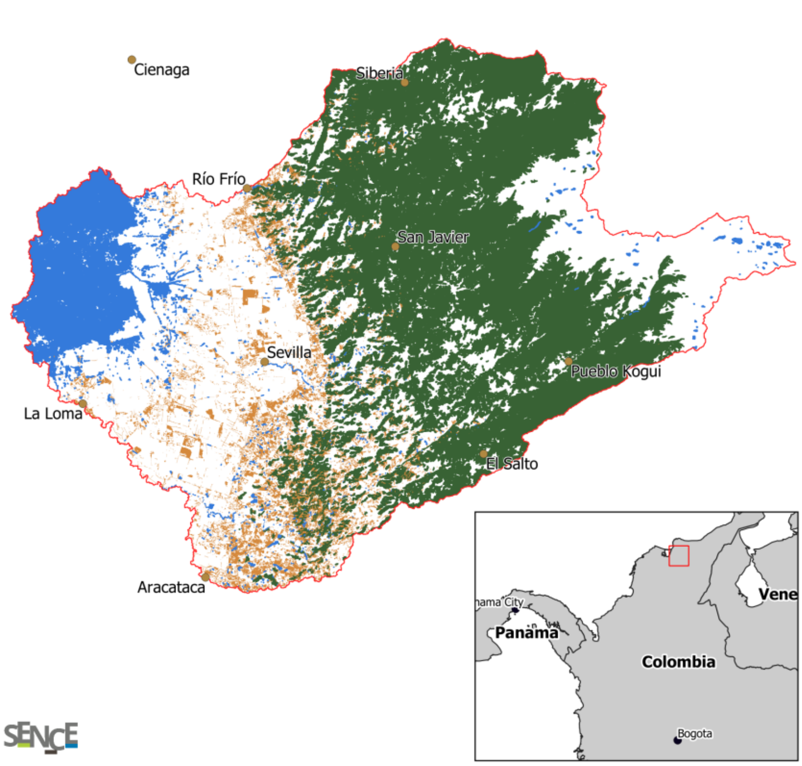
0 5 10 15 20 km N

Data and maps created by Environment Systems Ltd (2019)

Soil data: Geographic Institute Agustin Codazzi

## 6. 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 grassland, wetland or woodland that are important for supporting biological and genetic diversity. Areas of disturbed woodland are not included as they are likely to be less diverse than undisturbed woodland.

**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 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**

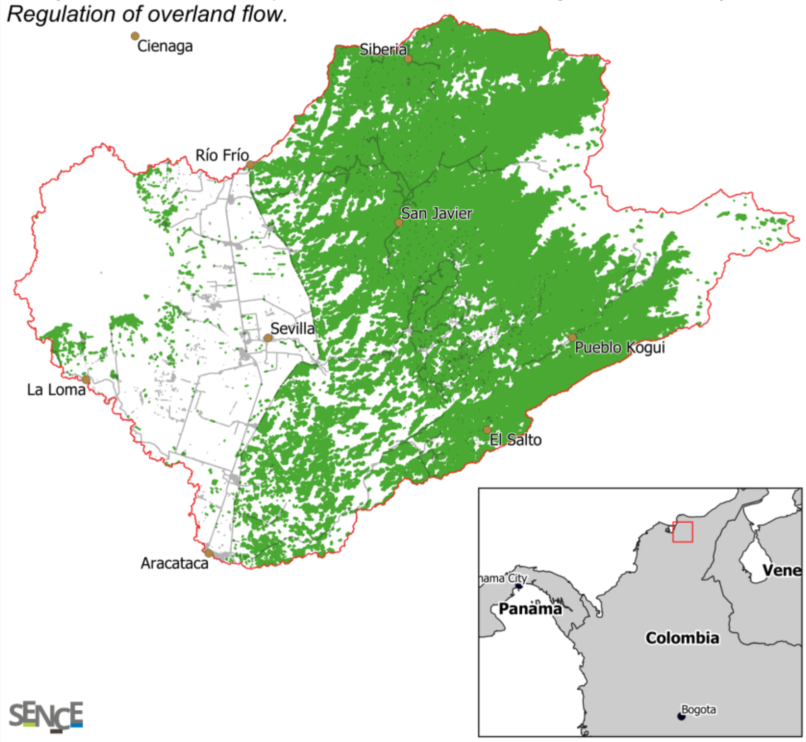
Wetland habitat
Woodland habitat
Grassland habitat

0 5 10 15 20 km N

Data and maps created by Environment Systems Ltd (2019)

## 7. 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, 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 ecosysterm 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 6).

**Legend**

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

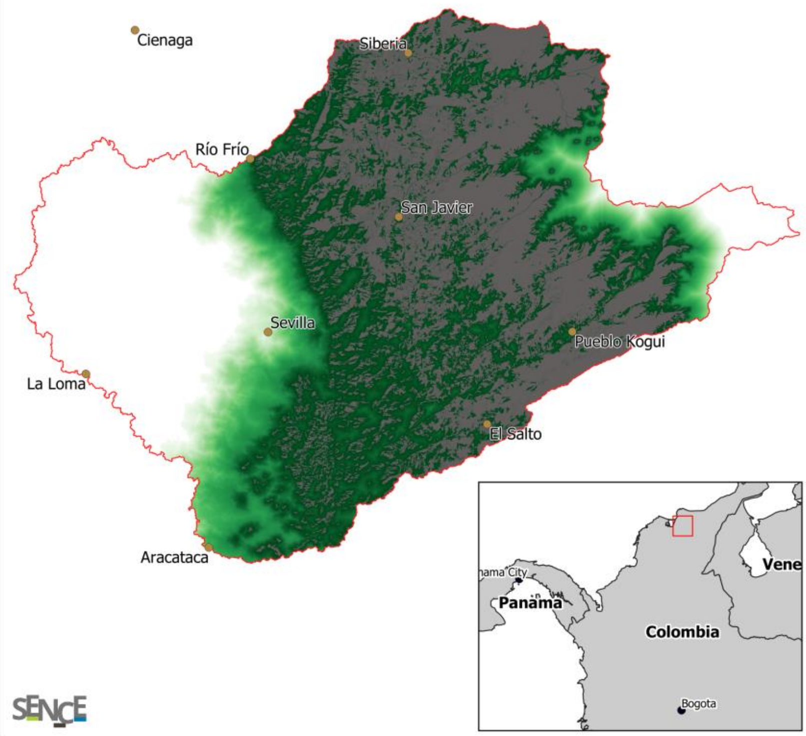
0 5 10 15 20 km

Data and maps created by Environment Systems Ltd (2019)

Soil data: Geographic Institute Agustin Codazzi

## 8. 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 (excludes disturbed 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 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**

- Source woodland

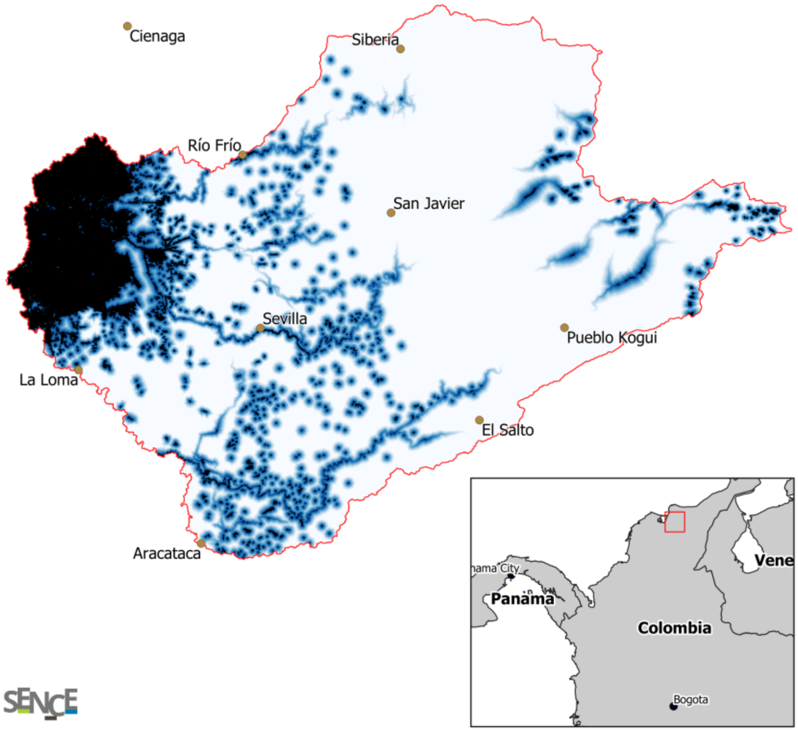
Woodland ecological network
- Highly connected
- Moderately connected
- Poorly connected

0 5 10 15 20 km

Data and maps created by Environment Systems Ltd (2019)

## 9. 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 the wetland, mangrove and waterbody habitats (except artificial waterbodies).

**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 nad 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 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**

Source wetland

Wetland ecological network
- Highly connected
- Moderately connected
- Poorly connected

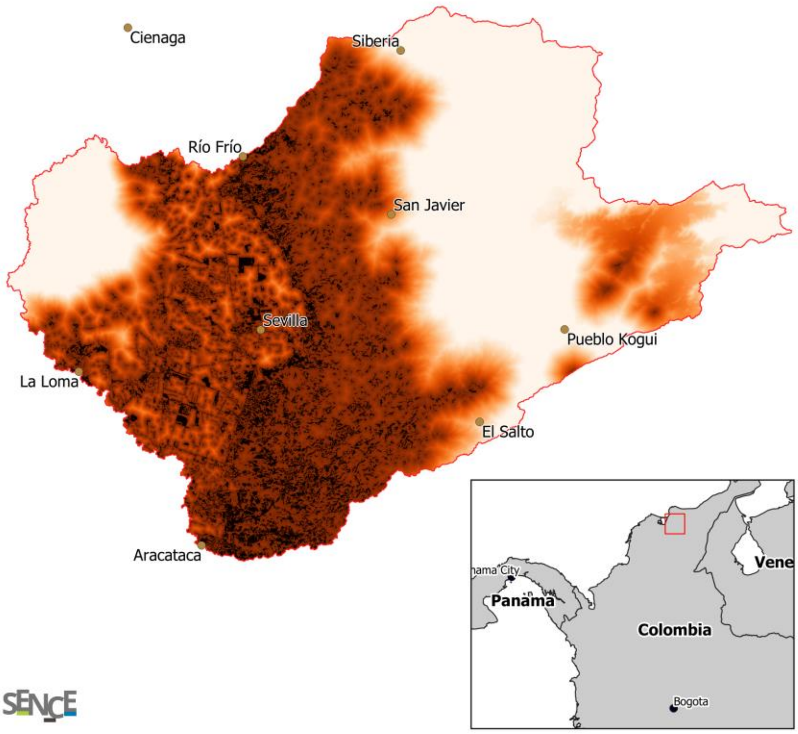
0 5 10 15 20 km

Data and maps created by Environment Systems Ltd (2019)



## 10. Ecological Network Connectivity - Grassland 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 grasslands.

**What the service is:**
The map shows the existing grassland network within which plant and animal species can move to maintain genetic diversity and sustain viable populations of grassland species. Existing grasslands act as 'source habitat', where the main population of grassland 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 grassland species than dense woodland.

**Why it is important:**
Areas of native natural and semi-natural grasslands that are connected in a landscape, are more resilient to changing climate or land management. Inside the network, structurally-diverse and species-rich grasslands generally provide a higher level of ecosystem services, such as surface water regulation. Within the network, restoration of structurally-diverse and species-rich grasslands 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 Sentinel 1 and Sentinel 2 satellite imagery. Each habitat and land use was evaluated for its importance and role played in supporting the grassland network.

**Legend**

Source grassland

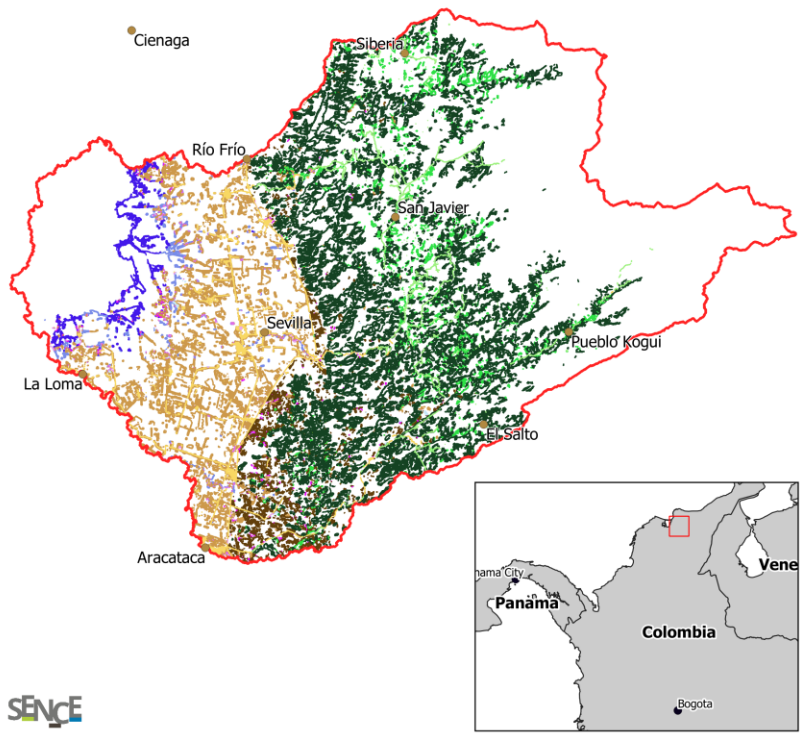
Grassland ecological network
- Highly connected
- Moderately connected
- Poorly connected

0 5 10 15 20 km

Data and maps created by Environment Systems Ltd (2019)

## 11. 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 is quicker, less labour intensive and less costly from the dense scrub vegetation.

**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 in close proximity to existing source habitat; these areas are most likely to be effective at supporting existing populations. Habitats and land use within this proximity zone 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 always chosen. In other places, where restoration to either grassland or wetland is possible, this is indicated.

**Legend**

Ease of restoration

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

0 5 10 15 20 km N

Data and maps created by Environment Systems Ltd (2019)
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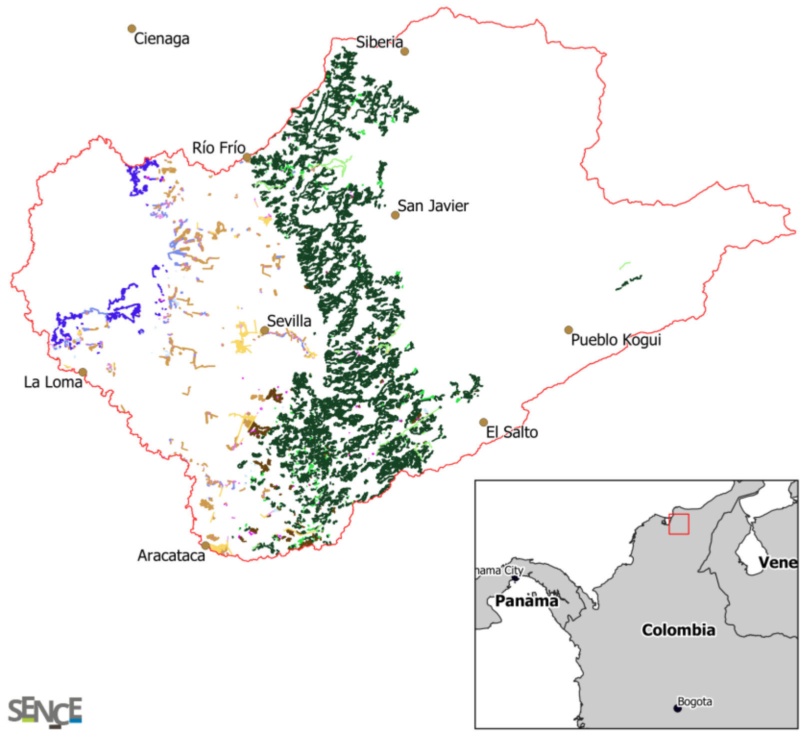
## 12. Opportunities to strengthen ecological networks: priority places for action (those adjoining existing key habitats of high-biodiversity value)

*Ecosystem service: Population maintenance & genetic diversity*




**How to interpret the map:**
This map is a subset of Map 11 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 considered 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 grassland, wetland or woodland network.

**Legend**

Ease of restoration

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

0 5 10 15 20 km N

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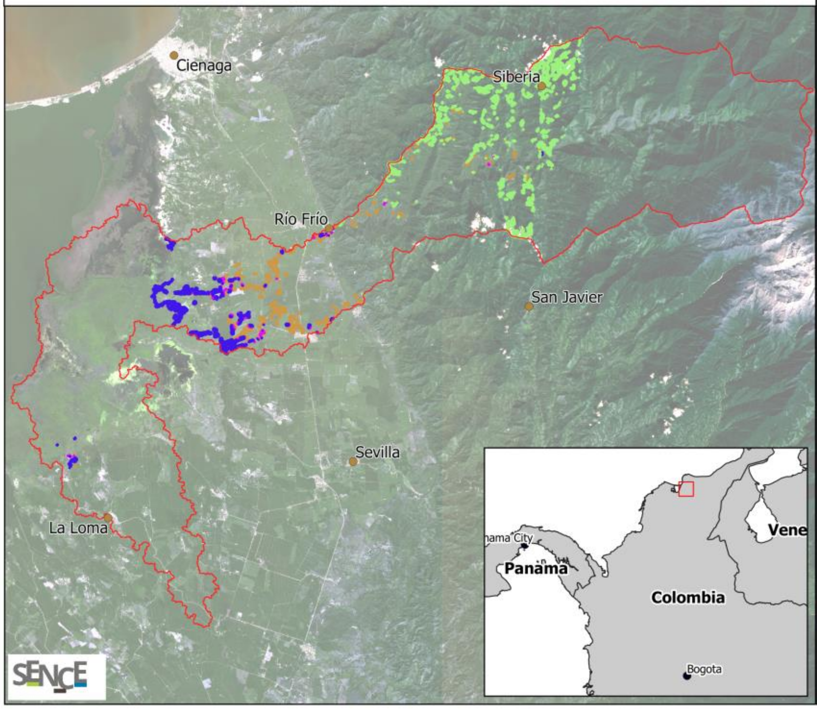
## 13. Opportunities to deliver multiple ecosystem services: ecological connectivity and surface water regulation

*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 grassland, 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 in the Rio Frio catchment (Map 2)" and "Opportunities to strengthen ecological networks (Map 11)". It identifies places that could be restored to support the ecological networks, and which currently provide relatively low surface water regulation.

**Legend**
- Grassland opportunity
- Grassland or Wetland opportunity
- Wetland opportunity
- Woodand opportunity

0 3 6 9 12 15 km

N

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Soil data: Geographic Institute Agustin Codazzi
Sentinel-2 image: European Space Agency - ESA