**UKSA International Partnership Programme (IPP)**

EO4cultivar

Project No 417000001416

# EO4cultivar sustainable livelihoods case studies: Habitat mapping in the Magdalena region, Colombia

Version control:

| | |
|---|---|
| Version number: | Final |
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| On the: | 11 June 2019 |
| Last update by: | Matt Smith |
| On the: | 9 June 2020 |
| Distribution: | External |

# Contents

**Citation:**

Bell, G., Parker, N., Parker, J.A. and Smith, M.A.E. 2020. EO4cultivar sustainable livelihoods case studies: Habitat mapping in the Magdalena region, Colombia. EO4cultivar Project Report. UK Space Agency International Partnership Programme, Project No 417000001416


# Acknowledgements

The project team would like to thank Kareen Cuello from EO4cultivar Colombian partner ASBAMA for her input and enthusiasm in organising the stakeholder workshops and in facilitating the engagement of local organisations with the project. Our thanks also go to staff at Fundeban and Indhira Reyes for their help with ground truthing the case study areas and to the many organisations that contributed to the stakeholder workshops.

EO4cultivar is co-funded by the UKSA International Partnership Programme (IPP) and project partners. IPP uses expertise in space-based solutions, applications and capability to provide a sustainable economic or societal benefit to emerging nations and developing economies. IPP is funded by the Global Challenges Research Fund, a £1.5 billion fund announced by the UK Government, which supports cutting-edge research and innovation on global issues affecting developing countries. The GCRF forms part of the UK's Official Development Assistance (ODA) commitment.

# 1 Introduction

## 1.1 Project Background

The EO4cultivar Project (EO4c) aims to strengthen commercial agricultural supply chains operating between Colombia, Peru and the UK. It is developing a better understanding of ways to increase production and identify opportunities for growth and sustainable 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 will increase the skills levels in partner countries (Colombia and Peru) by capacity building and supporting the use of earth observation data and technology.

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

- To make a positive contribution towards sustainable food production systems and the implementation of resilient agricultural practices.
- To increase productivity and manage risk in agricultural supply chains.
- To support inclusive and sustainable economic growth in target agricultural sectors.
- To help maintain ecosystems and ensure smallholder farmers benefit from project activities.

## 1.2 Rationale

Habitat maps are an important part of any spatial decision-making toolkit, showing the type of natural and semi-natural habitats, as well as other land uses present, their distribution and extent. They are an essential dataset for understanding how land is being managed, where the natural assets of an area are located, and the functions they serve. They provide a basis for considering the implications of an accumulation of small-scale activities across the landscape scale, and can assist in identifying problems and solutions that may not be visible when focussing only at a localised scale.

Habitat maps form a baseline for change detection and monitoring over time, and are a key component of spatial modelling of ecosystem services and risk and opportunity mapping. Due to an absence of existing habitat data to form a baseline for the sustainable livelihoods case study area of interest, this project was tasked with creating a habitat map using readily available satellite imagery and supporting datasets.

# 2. Defining the region of interest

The broad case study region was identified in consultation with key local stakeholders and is located within the Magdalena region in northern Colombia, and in particular the Zona Bananera.  The area is of great economic significance in the region and contains a high number of both commercial and small-scale producers. As the purpose of the habitat mapping was to produce a dataset to support ecosystem service, risk and opportunity mapping, which require a catchment-scale approach, the focal Area of Interest (AOI) was defined based on hydrological catchment boundaries that include the Zona Bananera. The catchments were defined by watershed analysis of 30m  Shuttle Radar Topography Mission (SRTM) data, an area of 1799.7 km$^2$ (**Figure 1**).

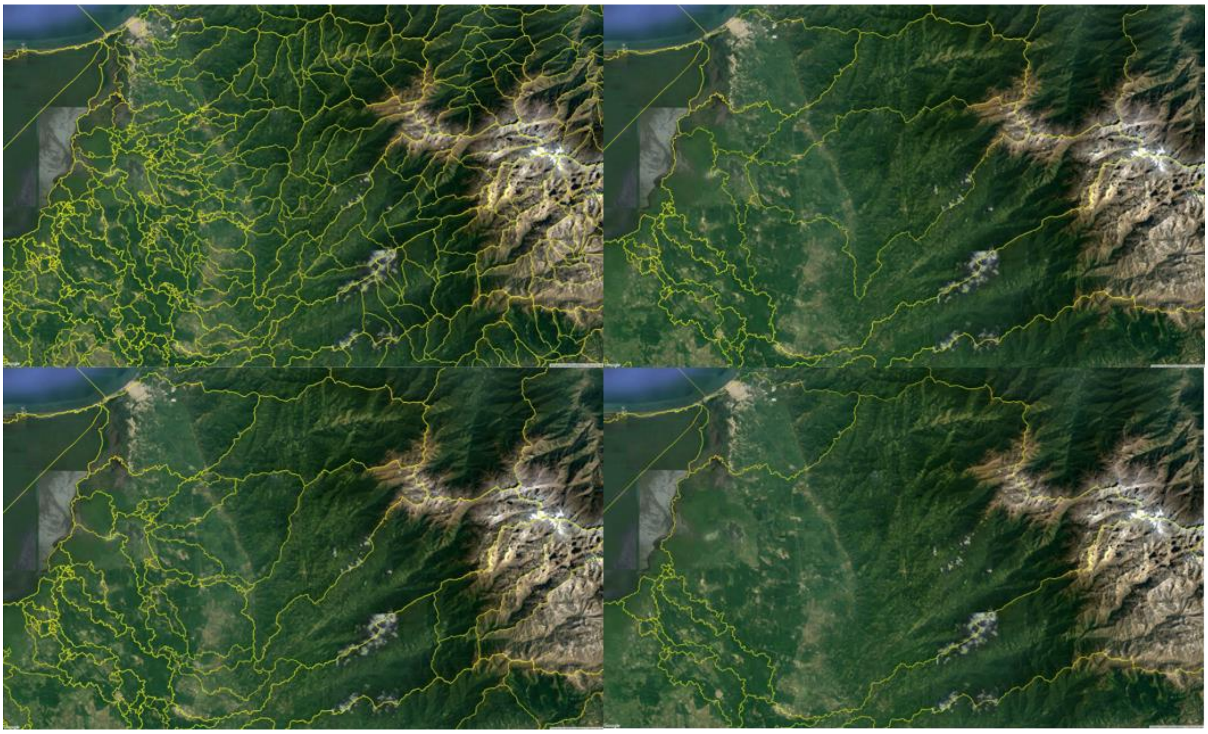

**Figure 1: Step-wise derivation of hydrological catchment boundaries using SRTM elevation data**

The final area of interest for production of the habitat map (
**Figure 2**) extends from sea level, at the fringes of the Ciénaga Grande Santa Marta, to a maximum elevation of 5696m in the Sierra Nevada mountain range. Within this area, there is extreme climatic variation based on elevation gradients, which influences the types of habitat and land-use present in each climatic zone.

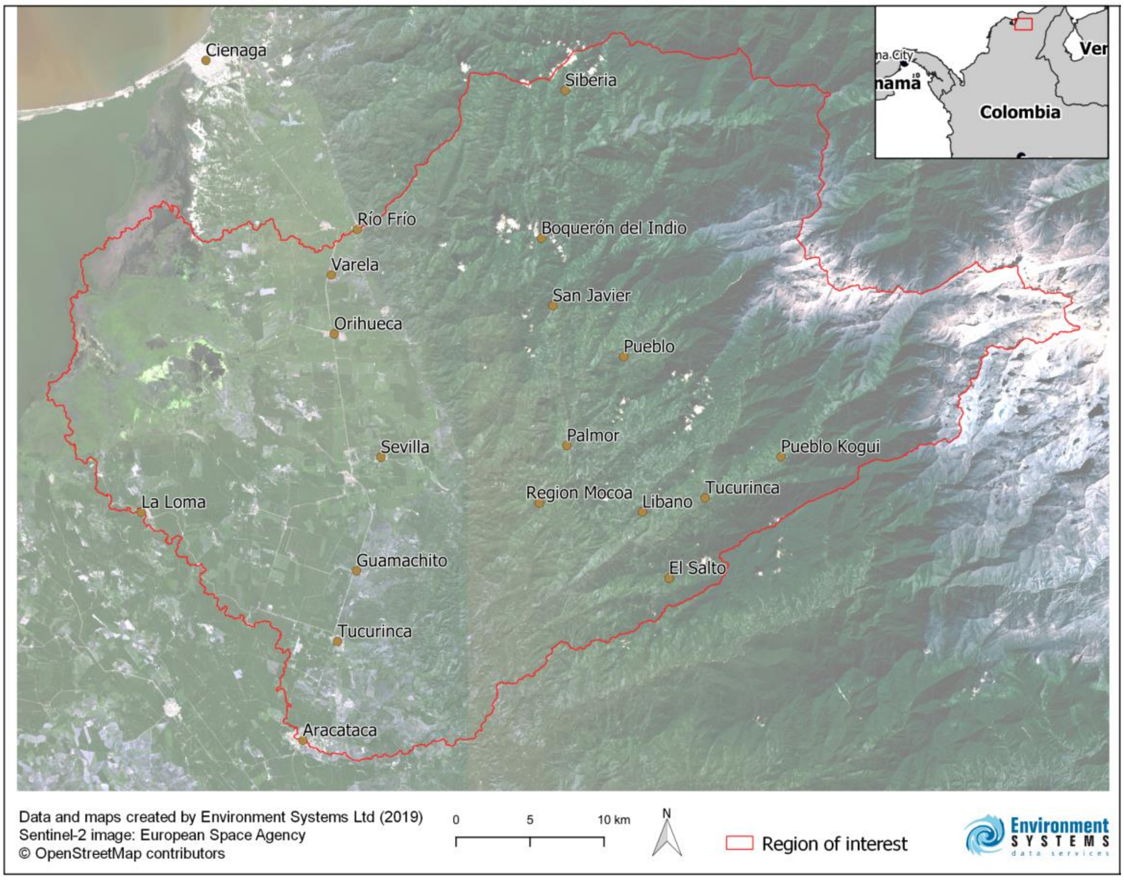


**Figure 2: Area of Interest for habitat mapping**

Stadel (1991) provides an overview of the climatic zones commonly applied to Central and South America, and links the climatic zones to different types of vegetation formations and human activities, summarised in **Figure 3**.

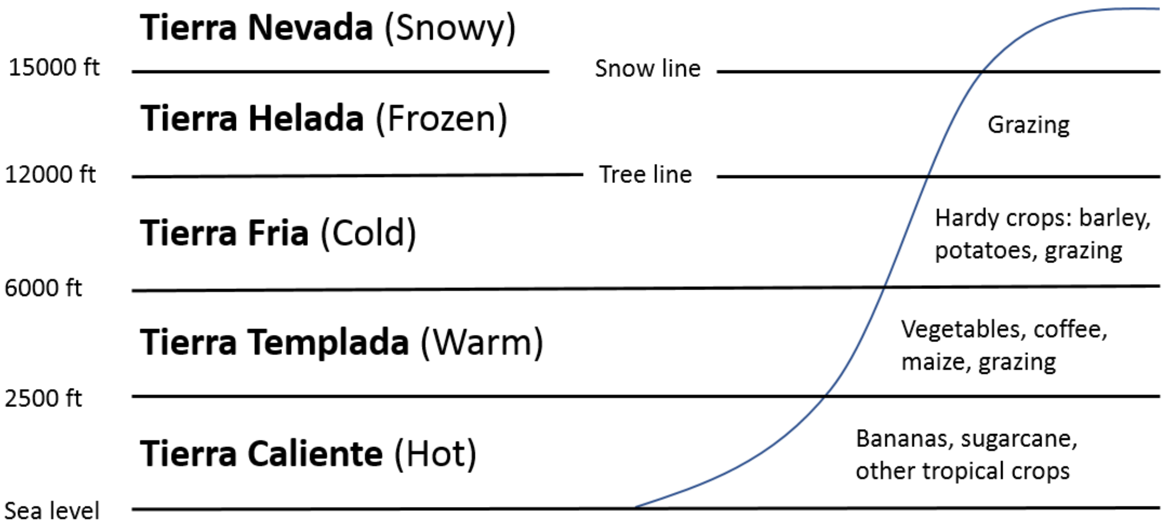


**Figure 3: Altitudinal zonation in Latin America (Stadel, 1991)**

In order to gain an overview of the area of interest, these broad altitude zones were visually checked against Sentinel-2 satellite imagery to establish their relevance for the habitat classification and subsequent ecosystem service analysis. The zones and their habitat characteristics as found in the case study region are described as follows:

- **Nevada**: Present with limited extent at the highest elevations within the case study region, characterised by permanent snow cover.
- **Helada**: Above the tree-line. Very low productivity paramo habitat which may be used for pastoral grazing. Numerous natural, high elevation lakes are visible within this zone.
- **Fria**: Characterised by extensive, almost continuous cover of dense primary forest. Pockets of land clearance for small-scale agriculture are visible in the lower reaches. The lower altitudinal threshold for this zone was defined by the frequency of agricultural activity and forest clearance.
- **Templada**: This zone was judged to begin at elevations where agricultural activity and forest clearance became more frequent. The zone was observed to consist of frequent, scattered, small-scale settlements and small agricultural holdings, with field visits confirming substantial coffee-growing in this area, particularly as an understorey crop. The combined cover of the small-scale agricultural activity was visually estimated to make up 50% of the land in this zone. The remaining forest cover is a mixture of large woodland blocks (particularly on steep, south east-facing slopes) and sections of fragmented or secondary forest surrounding the agricultural areas.
- **Caliente**: This zone was judged to begin in the foothills, at elevations where the primary forest becomes much more fragmented, with large areas of secondary woodland, which has regenerated following clearance. The foothills transition abruptly into a flat valley bottom; this is characterised by intensive palm and banana cultivation, and the wetlands of the Ciénaga, bordered by grazed fields. The valley bottom is distinguished by a lack of woodland habitat, although patches of shrub habitat occur in the less intensively managed areas.

# 3. Image Acquisition and Pre-Processing

Changes in vegetation characteristics in the region of interest were assessed as largely non-seasonal, therefore the main consideration when selecting suitable Sentinel-2 optical imagery was cloud cover. Two scenes were chosen that covered the entire region of interest and contained only low levels of cloud cover, which were captured on 2017-01-04 and 2018-02-08.

In addition, a time-series of Sentinel-1 radar images was chosen in order to provide monthly and annual temporal averages (mean) and standard deviation for three backscatter values: VV (vertical polarisation); VH (cross-polarisation); and VV/VH (ratio of VV to VH). The dense time-series of Sentinel-1 images available was particularly beneficial for identifying areas under intensive agriculture, by tracking the growth stages and harvest cycles of major crops. In addition, as Sentinel-1 is unaffected by cloud cover, this imagery assisted habitat classification in areas affected by cloud cover in the Sentinel-2 imagery.

Following a review of available datasets, the 2017-11 mean dataset (VV, VH and ratio values) and annual standard deviation dataset (VV, VH, ratio) were taken forward for inclusion in the habitat classification.

Images were sourced and automatically processed through Environment Systems Data Services; information on processing methods can be found in the associated WP6 documentation.  The input data were created using SNAP v4.0, GDAL v2.0 and RSGISLib 3.0 libraries. Processing included slice assembly, border and thermal noise removal, radiometric calibration, terrain correction, speckle filter and reprojection to EPSG 32618 (WGS 84 / UTM zone 18N).

SRTM elevation data tiles at 30m resolution were mosaicked and re-projected to EPSG 32618 (WGS 84 / UTM zone 18N).

A full list of datasets used is provided in Appendix A. An overview of the Copernicus Sentinel-1 and Sentinel-2 missions is provided in Appendix B.

# 4. Segmentation and Rule-Based Classification

The habitat map was produced by image analysis within eCognition 9.0.3. Due to the strength of influence on altitudinal zonation on habitat and land-use patterns, a hierarchal rule-based classification method was chosen, to enable existing knowledge on land-use patterns and physiological tolerances to be incorporated; it was foreseen that this would minimise the risk of the analysis classifying habitats within locations outside their physiological tolerance (e.g. crops within the Tierra Helada zone).

Furthermore, the rule-based approach provided the flexibility to apply different scales of segmentation (see section 4.1) to different zones as required; for example, a broader scale segmentation, resulting in larger image objects, was used in the Fria zone to facilitate classification of densely forested areas, and mitigate against the strong shadowing effects caused by the topography in this mountainous region. By contrast, a finer scale segmentation was applied in the Templada and Upper Caliente zones in order to define small land clearings and the thin strips of remnant and disturbed woodland, which differ from areas of primary woodland.

The rule-based approach provided flexibility for the dual purposes of habitat classification and ecosystem service assessment. It provided an straight forward method to record additional information in the output habitat classification dataset, required for the ecosystem services analysis. This additional information included attributes describing habitat position within the landscape and likely ‘naturalness’ of the habitat, which are important components of ecosystem service analyses (Bell, et.al. 2020).

## 4.1 Image segmentation

The process of image analysis began with image segmentation, to divide the landscape into ecologically-meaningful objects, by grouping together pixels with similar values (Figure 4) and creating a digital boundary around them (vector). OpenStreetMap urban and water features were included as information sources at this stage (Table 1).

**Table 1: Vector datasets used in the segmentation and rule-based classification**

| Vector | Description/Purpose |
|---|---|
| Infrastructure | OpenStreetMap urban features (urban mask) |
| Waterways | OpenStreetMap waterway features (river mask) |
| Waterbodies | OpenStreetMap waterbody features (lake/pond mask) |
| Catchment | AOI to define the land cover classification extent |

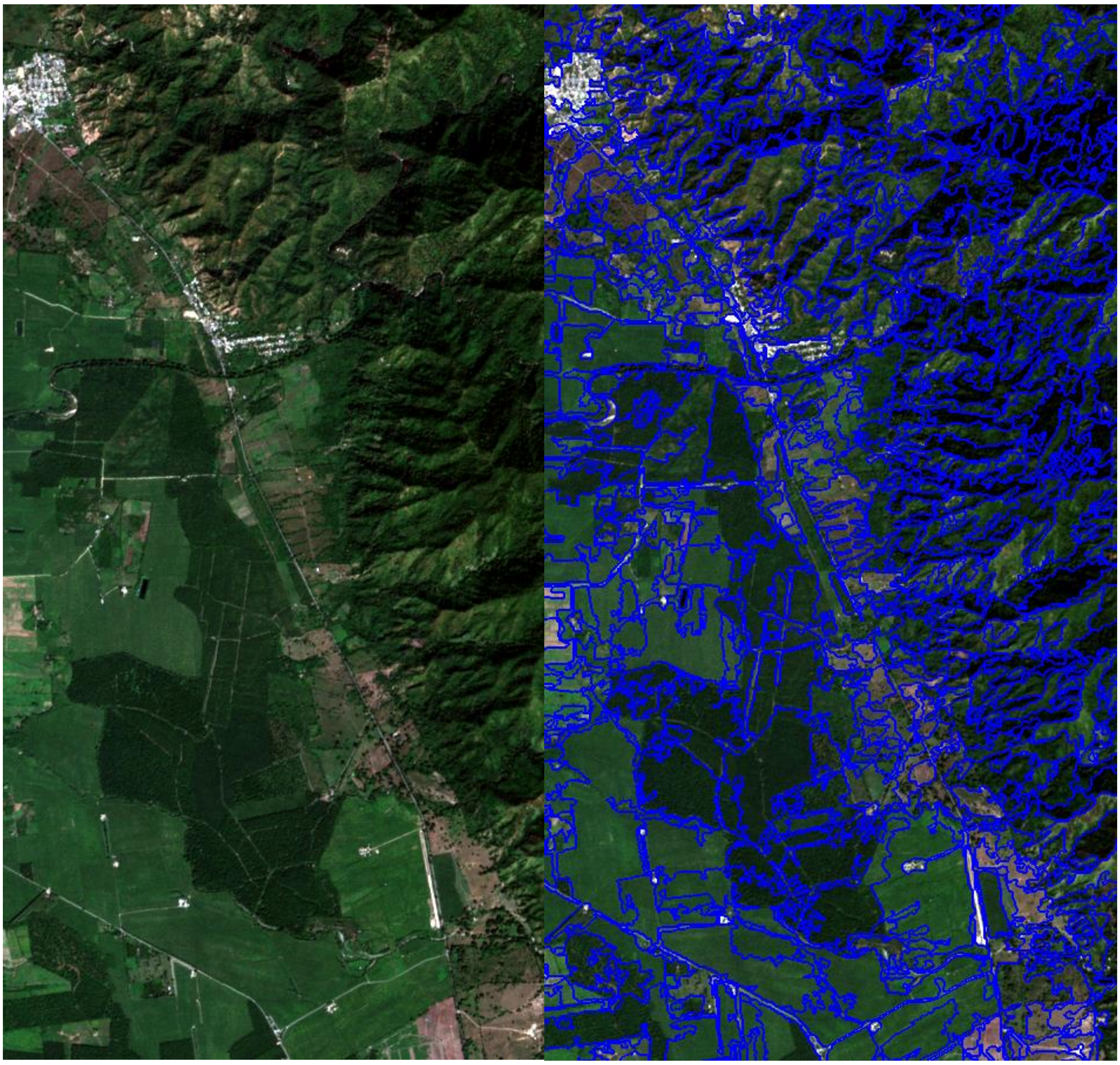

**Figure 4: Example of image segmentation outputs**

Following segmentation, the classification rule base was developed.

## 4.2 What is a rule-based classification?

The rule-based classification is an established, peer-reviewed methodology for separating one habitat type from another using their distinguishing characteristics in the satellite imagery – the data image object values in different image bands. For example, areas of bare ground are characterised by knowledge that the land has no, or very low, vegetation productivity measured as Normalised Difference Vegetation Index (NDVI) from the imagery. If the land remains bare, this NDVI measure is stable over time. By contrast, evergreen forests have very high vegetation productivity that is stable over time. Contextual information can also be built into the rule base; for example, mangrove forest cannot occur in the mountains. Combining knowledge of landscape ecology, plant communities and vegetation reflectance within the rule base, results in a hierarchal approach that first separates the major land cover types, and then, within these, classifies different habitats (Medcalf et. al, 2014) as shown illustratively in Figure 5.

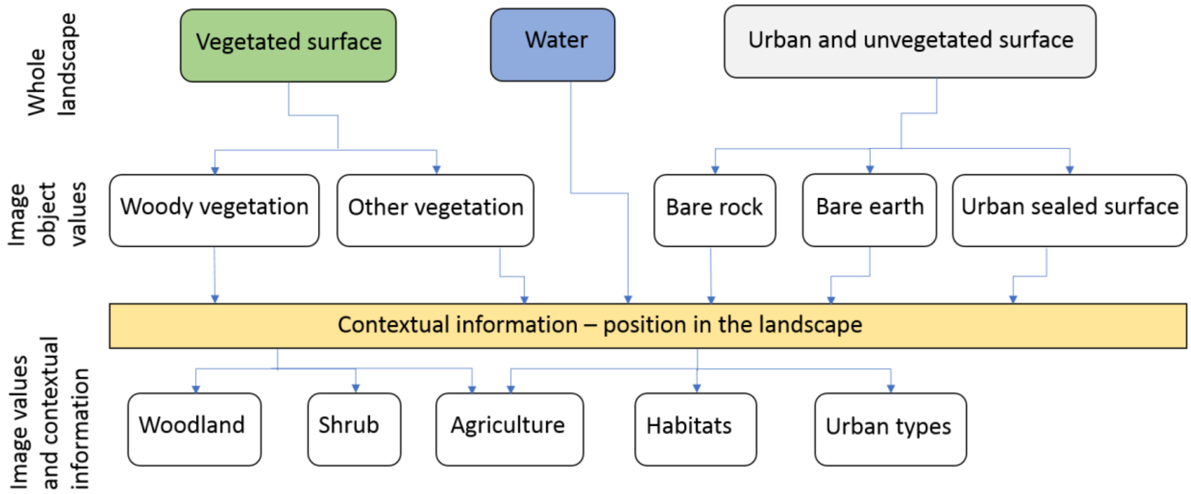


**Figure 5: Hierarchal landscape-splitting using a classification rule base**

## 4.3 Rule-Base Development

Development of the Zona Bananera rule base began with initial familiarisation with the case study area, including the geography, climate, ecology, phenology and farming practices of the region. These discussions were informed by fact-finding visits to the Zonana Bananera, which included site visits and discussions with stakeholders. This information was then fed back to the wider project team of ecological and image analysis specialists, and used to develop a broad plan of key habitat and land use classes to be mapped. A rule-base was then developed to meet these requirements, in an iterative process. The first-draft map was reviewed by the wider project team and presented to Colombian stakeholders; feedback from these meetings was incorporated into the final iteration of the map.

The initial image analysis defined key altitudinal zones in the study region (Figure 5) based upon the Altitudinal zonation in Latin America (Figure 3), by visually assessing the Sentinel-2 imagery to establish the location of the treeline (upper limit of tree growth) and permanent snow. These elevation values were used in combination with the Sentinel-2 imagery to classify the Nevada (> ~4500 m) and Helada (> 3750 m) zones. The Caliente zone was estimated to lie between 0 and 900 m, with the remaining are between 900-3700 m classed as Templada (900 – 2000 m) and Fria (2000 – 3700 m). Due to clear differences in the distribution of habitats and land use within the Caliente zone that were clearly related to topography, the region was split into two: an ‘Upper Caliente’ zone extending from the base of the mountains, and a ‘Valley Bottom’ zone, representing the flat valley plain.

Using the image characteristics, rules were developed to define nine broad habitat types; agriculture (excluding plantation), banana plantation, bare rock, grassland, palm plantation, waterbody, wetland, woodland and urban. These rules were then applied within each of the elevation zones, to identify and classify the habitats present.

Where it was known that a habitat could not be present in an elevation zone, the rules for that habitat were not applied (Table 2). For example, it is a known fact that mangroves are only present in coastal areas. There may be areas in the mountains with similar characteristics in the imagery to mangrove, but it would not make sense to allow mangrove to be mapped in the classification process in these areas. Where possible, the broad habitat types were then sub-divided into more detailed habitat classes (Table 3).

Urban areas and Waterbodies were first mapped using OpenStreetMap data, and additional urban and water features were then classified from rule-based image analysis.

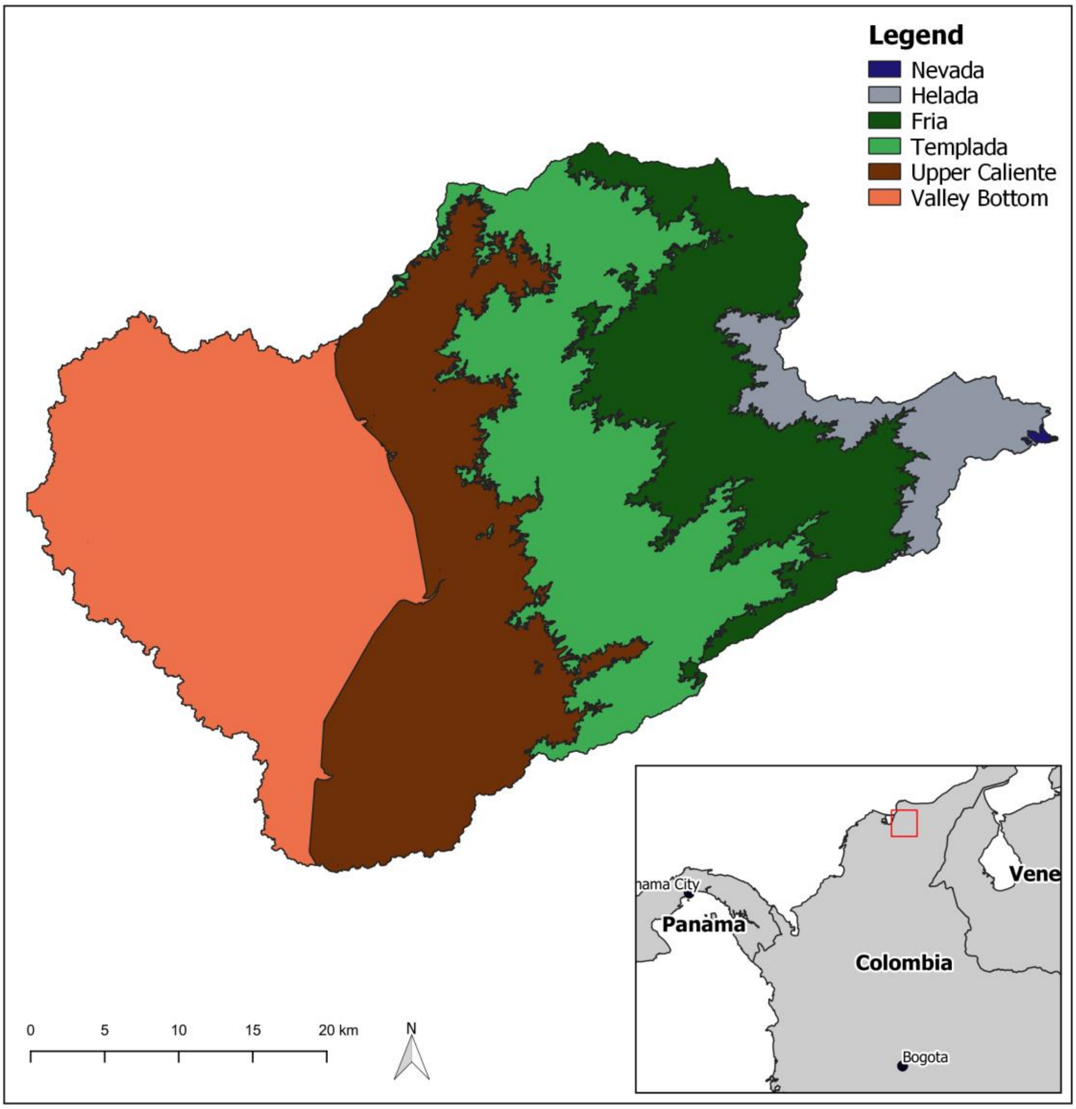


**Figure 5: Classification of altitude/land use zones within the study region**

**Table 2: Broad habitat classes for which zonal constraints were applied during the classification**

| Broad habitat type | Zone restrictions | Reason |
|---|---|---|
| Mangrove | Classified in Valley zone only | Mangroves are a coastal habitat not found in the mountains |
| Agriculture (all types) | Not classified in Helada zone | Intensive agriculture is not present in this zone.<br>Grasslands may be used as pasture; these are captured in the Grassland and Páramo classes. |
| Forest | Not classified in Helada zone | This zone is above the tree-line. |
| All (except Snow) | Not classified in Nevada zone | This zone is defined by permanent snow cover; therefore the entire zone is classed as Snow. |

### 4.4 Post-processing

The resulting classification was dissolved by habitat class and exported as a vector dataset. This was followed by manual quality assurance process which targeted wetlands, agriculture located around the fringe of the Ciénaga, and an assessment of naturalness of the waterbodies. Following initial stakeholder feedback, the Ciénaga wetland area was further subdivided by elevation in order to provide additional information for the ecosystem service mapping.

A subsequent stakeholder engagement event identified the importance of labelling páramo habitat as a distinct habitat class in the map. As the distribution of páramo is highly restricted, this was done by reclassifying all Grassland habitat polygons within the Helada zone. Additionally, lower-productivity grassland polygons in the Fria zone, whose centroids were located within an altitudinal limit of 3000m or above, were also reclassified as paramo. The resultant habitat map is shown in Figure 6, and class descriptions are provided in Table 3.

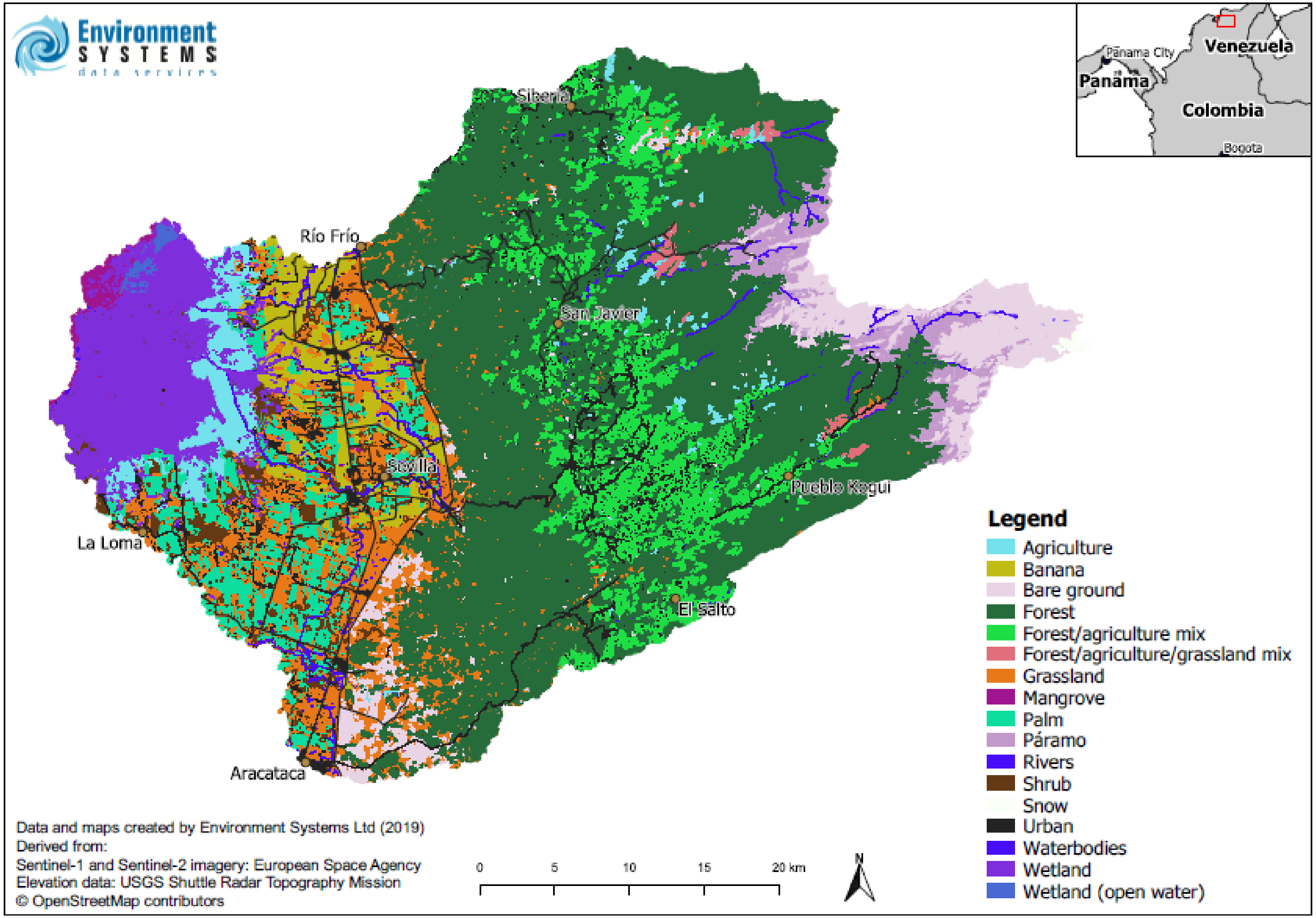


**Figure 6: Broad habitat classification map**

**Table 3: Habitat map class descriptions**

| Habitat | Description |
|---|---|
| Agriculture | Classifies agriculture of undetermined type; areas reclaimed from the Ciénaga, and areas resulting from forest clearance in upland zones. Excludes banana and palm plantations. |
| Banana | Areas of established banana plantation. |
| Bare ground | Includes areas of bare rock, scree and bare soil. Bare soil can be natural or induced by grazing pressure, or land clearance for agriculture. |
| Forest | Dense forest cover (includes both primary and secondary forest). |
| Forest / agriculture mix | Mosaic of forested area with pockets of land clearance for relatively low-intensity agriculture, including agroforestry (e.g. coffee-growing). |
| Forest /agriculture / grassland mix | Mosaic of forested area, agroforestry (e.g. coffee-growing) and regenerating grassland, with pockets of land clearance for relatively low-intensity agriculture. |
| Grassland | Includes more ‘natural’ grasslands above the treeline, and more intensively managed lowland grasslands. |
| Mangrove | Mangrove forests along the coastal fringe and channels of the Ciénaga wetland area. |
| Palm | Areas of established palm plantation. |
| Páramo | Montane vegetation above the continuous treeline, including areas under anthropogenic management (e.g. burning, grazing activities). |
| Rivers | Permanent watercourse - largely mapped from OpenStreetMap data. |
| Shrub | Scattered and dense shrub vegetation present within the wetland system and further inland. |
| Snow | Permanent snow cover. |
| Urban | Roads, buildings, hard standings and other built structures - partially mapped from OpenStreetMap data. |
| Waterbodies | Ponds and lakes - partially mapped from OpenStreetMap data). |
| Wetland | Coastal and inland wetlands; includes areas wet grassland, reedbed, marsh, swamp, mire, saltmarsh, and inundation grassland. |
| Wetland (open water) | Areas of open water within a wetland system. |

## 5. Field visits for validation and accuracy assessment

A field visit for the purpose of map validation and refinement was undertaken on 2018-04-23. However, due to accessibility and logistical constraints, only areas within the zona Bananera could be visited. Anecdotal information was obtained during the visit relating to grassland grazing pressure in the Valley zone, and the distribution of primary and secondary forest in the Upper Caliente and Templada zones. This was incorporated into the second iteration of the rule base, to produce the final habitat classification.

## 6. Next Steps

A habitat map has been produced for the study region within the Magdalena department of Colombia. This provides a baseline of type, extent and distribution of current land use and habitats. These natural assets are ecologically and hydrologically connected throughout the watershed within the area of interest. The map can be used to help inform catchment-scale planning for sustainable land-use, focused land management interventions, and subsequent policy decisions. The map was developed for use as an input dataset for ecosystem service, risk and opportunity analyses (Bell et.al., 2020).

When interpreting the habitat map it should be noted that the map classes were developed for the purpose of evaluating ecosystem service provision, which is often based on ecosystem functioning rather than species composition and habitat sub-categories. This habitat map does not fully capture the extent of agroforestry, due to a lack of ground data and the difficulties in identifying understorey activity (e.g. understorey crops such as coffee) that is hidden from the satellite view by the tree canopy above; therefore the extent of the Forest class could be over-estimated in places.

The current map is based on 20 m resolution Sentinel 1 and Sentinel 2 imagery and 30 m resolution elevation data. A more detailed habitat classification could be developed should higher-resolution imagery be available.

It is hoped that project stakeholders and other interested parties will take ownership of the habitat map and undertake a map validation and update exercise, incorporating field data and local knowledge to enhance the map, following a version control methodology. The existing map is suitable for use as a baseline for monitoring future changes, such as those resulting from management action or environmental events. Future map updates should be carried out periodically to facilitate monitoring of land use and habitats, change detection, and ensuring that land use policy and activity remains well-informed, and appropriate.

# References


Bell, G., Parker, N., Parker, J.A. and Smith, M.A.E., 2020. *EO4cultivar sustainable livelihoods case studies: Ecosystems services mapping in the Magdalena region, Colombia*. EO4cultivar Project Report. UK Space Agency International Partnership Programme, Project No 417000001416. Available at: https://jncc.gov.uk/eo4cultivar

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Stadel, C. (1991), Altitudinal Belts in the Tropical Andes: Their Ecology and Human Utilization. Yearbook (Conference of Latin Americanist Geographers, November 1991).

# Appendix A – Dataset Details

| Theme | Data set / capture date | Source | Coverage | Licensing |
|---|---|---|---|---|
| Base mapping | OpenStreetMap 2017-09-26T20:43:02z | OpenStreetMap | Partial mapping of roads, buildings and water features | Open Database 1.0 License |
| Landform | SRTM 30m | USGS | Complete | Open License |
| Sentinel 2 | S2A_2017-01-04 | ESA | Minor cloud cover | Open license CC BY-SA 3.0 IGO |
| Sentinel 2 | S2A_2018-02-08 | ESA | Minor cloud cover | Open license CC BY-SA 3.0 IGO |
| Sentinel 1 derivative (November 2017 temporal mean) | S1_2017_11_mean | Environment Systems Data Services | Complete | Open license CC BY-SA 4.0 |
| Sentinel 1 derivative (June 2017-May 2018 temporal standard deviation) | S1_2017_18_stdev | Environment Systems Data Services | Complete | Open license CC BY-SA 4.0 |
| Sentinel-1 images used to produce temporal mean (November 2017) and temporal standard deviation (June 2017-May 2018) | 20171111T230725 | ESA | Complete | Open license CC BY-SA 3.0 IGO |
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# Appendix B – Sentinel 1 and 2 Dataset Details

**Sentinel-1** is a polar-orbiting, all weather, day-and-night radar imaging mission for land and ocean services. The mission is part of the European Union (EU) Copernicus Programme and is operated by the European Space Agency (ESA). The mission consists of a two-satellite constellation providing orbit revisit times of six days. The radar instrument transmits and receives in C-band (5.405 GHz) at a resolution of 5 x 20 metres in interferometric wide-swath mode. This is the most common mode that is used over land masses. The data is processed and stored as Level 1 Single Look Complex (SLC) and Level 1 Ground Range Detected (GRD) products by the ground segment of ESA. The SLC product contains the intensity of returns and phase information, whereas the GRD product does not contain the phase information, due to the enhanced processing that it receives. This GRD data is multi-looked and projected to ground range using the earth ellipsoid model.

**Sentinel-2** is a polar-orbiting, multispectral high-resolution imaging mission for land monitoring. The mission is also part of the EU's Copernicus Programme and operated by ESA. The mission consists of a two-satellite constellation providing orbit revisit times 10 days at the equator with one satellite, and five days with two satellites under cloud free conditions which results in 2-3 days at mid-latitudes. The optical instrument payload samples 13 spectral bands: four bands at 10 metres six bands at 20 metre and three bands at 60 metre spatial resolution. The orbital swath width is 290 kilometres.