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Theobroma cacao L., land use conflict on the Ecuadorian coast

Theobroma cacao L., conflicto de uso de la tierra en el litoral del Ecuador

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Abstract

Cocoa cultivation is one of the sectors that most contributes to Ecuador's GDP. The aim of this study is to determine the Land-Use Conflict (UC) for cocoa in 71 cities on the coast of Ecuador. Photointerpretation has been applied to locate the crop and geospatial modeling has been used to analyze Land Use Capacity (LUC) criteria, agroecological requirements and LUC at 1:5,000. Of the total study surface area, 4.65% is occupied by cocoa crops and of this value 66.03% is in adequate use (AU) and 33.97% in LUC, and the category of UC over lightly used is the most frequent with 17.25% of the total surface in LUC. In the coastal region, the province of Guayas has the lowest LUC in contrast to Los Rios; the predominant LUC for the crop is Class III 34.32%. The findings show that the LUC of cocoa has a low concordance with the national Agroecological Zoning (AZ), since this model considers the crop in natural conditions, the main limiting factor is the vegetative wet period and does not take into account whether the crop is present in the territory. The use of national AZ information to establish crops could limit their production, since it has been demonstrated that there are cultivated areas that are not in conflict and that are exploited by farmers. This study is replicable to other crops and scalable to any area.

Keywords: cocoa; conflict; coast; Ecuador; land; GIS; use.

Resumen

El cultivo de la cacao es uno de los sectores importantes que contribuyen al PIB de Ecuador. El objetivo es determinar el Conflicto de Uso (UC) de la tierra para el cacao en 71 ciudades de la costa del Ecuador. Se aplicó fotointerpretación para localizar el cultivo y se utilizó modelación geoespacial para analizar los criterios de Capacidad de Uso de la Tierra (LUC), requerimientos agroecológicos y UC a 1:5.000. Del total del área de estudio, el 4,65 % está ocupada por cobertura de cacao y de este valor el 66,03 % se encuentra en uso adecuado (AU) y 33,97 % en UC, siendo la categoría de UC sobre utilizado ligero la más frecuente con un 17,25 % del total de la superficie en UC; en la región litoral la provincia de Guayas presenta el menor UC en contraste con Los Ríos; LUC predominante para el cultivo es de Clase III 34,32 %. Se encontró que el UC del cacao tiene una baja concordancia con la Zonificación Agroecológica (AZ) nacional, ya que este modelo considera al cultivo en condiciones naturales, el principal factor limitante es el periodo húmedo vegetativo y no toma en cuenta si el cultivo está presente en el territorio. El uso de la información de AZ nacional para establecer los cultivos, podrían limitar su producción, ya que se demostró que existen zonas cultivadas que no están en conflicto y que son aprovechadas por los agricultores. Este estudio es replicable a otros cultivos y escalable a cualquier superficie.

Palabras clave: cocoa; conflicto; costa; Ecuador; SIG; tierra; uso.

1. Introduction

Cocoa (*Theobroma cacao* L.) belongs to the Malvaceae family and is classified as a tropical tree as it's cultivated in the humid tropics of America and Africa; In Latin America, it is present in countries such as Brazil, Ecuador, Peru, Colombia, Venezuela, Trinidad and Tobago and among others (Moreno-Miranda et al., 2020; León-Villamar et al., 2016).

Cocoa, also called gold nugget or food of the gods, is one of the crops that has impacted the social and economic development of Ecuador, even before the establishment of the republic (Chávez Betancourt et al., 2019). There are records of Cocoa production and exportation dating back to 1770 and 1790, respectively, covering more than 253 years of its cultivation in the country; cocoa is used for the manufacture of chocolate and its fat is used for various industrial processes (Abad et al., 2020). In addition, it is relevant to note that agriculture is the second most profitable sector in the country's economy. Of importance, is the cultivation of bananas, flowers, and cocoa, the latter considered a crop with a long tradition in the country (Parada-Gutiérrez & Veloz-Cordero, 2021).

During the period between 1870 and 1930, Ecuador experienced what is known as the second period of the cocoa boom. The province of Los Ríos, characterized by the excellent environment and geographical conditions for the development of the crop, became the epicenter of the cocoa economy because of its quality product, achieving a better price for export (Abad et al., 2020). Briefly, the cocoa booms can be divided into two established stages. The first boom took place between the second half of the 1700s and the first half of 1800 (Acosta, 2006). Lasting almost a century, cocoa was positions as the economic engine of the time. The second boom occurred in 1870 until 1930, and during this period Ecuador became the world's leading producer of cocoa (Chávez Betancourt et al., 2019).

The volume of cocoa production in the country has experienced significant variations throughout the years due to various factors, such as agrarian transformations, the positioning of other crops in the market, the oil boom in 1972, among others (León-Villamar et al., 2016). However, cocoa has been and continues to be a reference in the productive matrix of the country; moreover, Ecuador contributes 65 % of the production of fine aroma cocoa worldwide, because of its unique flavor and aroma (Vargas Pérez et al., 2021).

In the period from 2019 to 2020, a production of 4.7 million tons of cocoa was registered worldwide; the three countries that contributed the most were Ivory Coast, Ghana, and Ecuador, with a production of 2.1, 0.8, and 0.32 million tons, respectively (García-Briones et al., 2021). At the end of 2020, the price of cocoa reached 2,100 dollars/ton in 2020, cocoa exports reached 60,965 million dollars; the agricultural gross added value (VAB) by 2021 was 7.95 %, and 370,931 t of exports of raw and roasted cocoa were registered by 2022, which corresponds to the highest value in the last four years (Vargas Pérez et al., 2021; Agricultural Public Information System [SIPA], 2023).

According to data from the Central Bank of Ecuador (BCE, 2023), the agriculture sector contributed to the country's economy 8,692,343 dollars in 2021, which corresponds to 8.187 % of the national GDP. By 2022, data from the Continuous Surface and Agricultural Production Survey (ESPAC) indicate that Ecuador has 4.66 million ha for agricultural use, of which 1,366,080 hectares are permanent crops, and 43.30 % (591,557 ha) of the total planted area corresponds to the cultivation of cocoa with a production of 337,149 Tm, and sales of 336,587 Tm; the province of Los Ríos accounts for 30.93 % of the cocoa production, followed by Guayas (20.45 %), and Manabí (14.82 %), among the main provinces (National Institute of Statistics and Censuses [INEC], 2022; García-Briones, et al., 2021).

The relevance of cocoa in Ecuador and globally has prompted research to identify the optimal production areas. Agroecological Zoning (AZ) is a methodology that consists of land evaluation on a continental scale through the characterization of land extensions using quantified information on climate, soils, and other physical factors, which are used to predict the potential productivity of various crops according to their specific environmental and management needs. Agroecological zones are defined as territorial units that have a similar combination of climatic and soil characteristics, and physical potential (Food and Agriculture Organization of the United Nations [FAO], 1996), which help characterize zones to determine their agricultural suitability (Merchán-Benavides et al., 2019).

At the national level, the Ministry of Agriculture and Livestock (MAG), as the governing body, has identified a series of environmental requirements and physical-chemical characteristics of the soil based on the method established by the FAO. This information allowed for the determination of zones with similar combinations of climate and soil, and for the prediction of the potential productivity of cocoa crops according to their agro-ecological requirements (FAO, 1996; MAG, 2020) (see Table 1).

Table 1. Agroecological zoning of cocoa

PARAMETER	AGROECOLOGICAL ZONING CATEGORIES OF THE CROP			
	OPTIMUM	MODERATE	MARGINAL	UNFIT
Slope (%)	Flat (0-2), very soft (2-5), soft (5-12), medium (12-25)	Medium to strong (25-40)	Strong (40-70), very strong (70-100), steep (100-150)	Very steep (150-200), abrupt (>200)
Soil surface texture	Loam, clay loam, sandy loam, sandy clay loam	Silt loam, sandy clay, silt clay, silt clay loam	Loamy, silty sand	Heavy clay, sand, clayey
Effective Depth (cm)	Deep (>100)	Moderately deep (51-100)	Shallow (21-50)	Superficial (11-20), very superficial (0-10)
Stoniness (%)	Null (does not have fragments), very few (<10)	Few (10-25)	Frequent (25-50)	Abundant (50-75), stony - rocky (>75)
Natural drainage	Well	Moderate	Well, Moderate	Excessive, poorly drained
Water table	Profound (>100), no evidence	Medium deep (51-100)	Shallow (21-50)	Superficial (11-20), very superficial (0-10)
pH	Medium acid (5.5-6.0), slightly acid (6.0-6.5)	Almost neutral (6.5-7.5), neutral (7)	Acid (4.5-5.5), slightly alkaline (7.5-8.0)	Very acid (8.5)
Toxicity (AC: Acids - meq/100 ml); (CAR: Carbonates - %)	Null	Light – AC	Average - AC (0.5-1.5), average - CAR (11-25)	High - AC (>1.5), High - CAR (>25)
Organic material (%)	High - Coast (>2), High - Highland (>5.0), High - Amazon (6.0)	Medium - Coast (1.0-2.0), Medium – Highland (3.0-5.0), Medium - Amazon (3.0-6.0)	Low - Coast (<1.0), Low - Highland (<3.0), Low - Amazon (1.5-3.0)	---
Salinity (ds/m)	Non-saline (<2.0)	Slightly saline (2.0- 4.0)	Saline (4.0-8.0)	Very saline (8.0-16.0), extremely saline (>16.0)
Soil Fertility Level	High	Half	Low, very low	---
Temperature range (°C)	24-26	21-24	18-21	<18 y >26
Vegetative Humid Period (Days)	210-270	180-210 / 270-300	160-180 / 300-365	<160
Precipitation (mm)	1,800-2,600	2,600-3,200 / 1,500-1,800	1,200-1,500 / 3,200-3,800	<1,200 y >3,800
Altitude (m.a.s.l.)	0-500	500-1,000	1,000-1,500	>1,500

Source: MAG, 2020. Own elaboration

In addition, since 2022 the Military Geographic Institute (IGM) has been carrying out the project "Determination of the reception capacity of the territory for urban development purposes through the generation of thematic geoinformation at a scale of 1: 5000" which has provided useful geospatial information about Ecuador, such as Land Use Land Cover (LULC), Land Use Capacity (LUC) and Land Use Conflict (UC). Based on these investigations, there is information about the location of cocoa crops and their limitations in the territory.

It is important to know how the aforementioned geospatial information is defined; LULC mapping and change detection allows us to evaluate the impact of human activities on the earth's surface; in this way, the Land Use (LU) map refers to the human activities that take place in a certain portion of the territory, such as agriculture, forestry, urbanization, transportation, and recreation (García-Álvarez et al., 2022). Land Cover (LC) indicates physical and biological cover, such as forests, grasslands, wetlands, bodies of water, and urban areas; LULC mapping allows us to understand the changes that occur on the earth's surface and their impacts on the environment and ecosystems (Amini et. al, 2022).

The development of timely and accurate LULC maps is important for a variety of applications such as urban and regional planning, risk and disaster monitoring, natural resources, environmental management, and food security. LULC mapping can help address several significant large-scale challenges, such as global warming, accelerating species habitat loss, unprecedented population migration, increasing urban sprawl, and growing inequality within and between nations (Szarek-Iwaniuk et al., 2022; Zhang & Li, 2022).

LUC refers to the ability of a portion of the territory of the earth's surface to support different uses, such as agriculture, forestry, and urban development, among others, based on its physical and chemical properties (García-Álvarez et al., 2022). The Land Capacity Classification (LCC) system, evaluates if the land is suitable for different uses, considering factors such as the type of soil, slope, drainage, and climate; this system assigns certain classes to the land according to the degree of specific soil limitations, such as erosion, excess moisture, problems in the area due to biotic factors, and climatic limitations (Quandt et al., 2020). It is also important to consider geology, hydrography, and topography, as these features limit the extent of land accessible for various purposes (Gebrehana et al., 2018).

UC can be defined as the phenomenon of spatial competition and conflict of interest between humans and land, that is, situations in which different land uses compete for the same space or resources, which generates tension, disputes, and negative impacts on the environment, the economy, and society. These conflicts can arise between different types of land uses, such as agriculture, forestry, fisheries, and urbanization, as well as between different stakeholders, such as farmers, developers, and environmentalists. Land use conflicts often arise from competing demands for limited resources, such as land, water, and energy, and are exacerbated by factors such as population growth, urbanization, and climate change (Zou et al., 2021).

According to Fienitz & Siebert (2022), land use conflicts often arise from competing claims over access to and control of land and natural resources, as well as conflicting perceptions of land use practices and their impacts on the environment and society. These conflicts can be complex, emotional, and challenging for the local stakeholders involved, and require effective communication, collaboration, and participatory processes to resolve them and achieve sustainable land use outcomes (Fienitz & Siebert, 2022). By way of example, consider population growth; the world population has grown from 2.6 billion in the 1950s to 7.7 billion, and is expected to reach approximately 9.7 billion by 2050 (Hemati et al., 2021). As a result, there is an increased demand for resources such as energy, food, housing provision, water supply, transportation, and health. Therefore, said demand entails the exploitation of natural resources and hence, the change of the earth's surface along with adverse effects on the environment and ecosystems.

For example, according to Amini et al., (2022), an abrupt change in urban structures was observed from 1985 to 1993, during that period, the built-up area extended from 18,595.7 to 41,538.94 ha, so urban growth has an annual average that oscillates between 0.51 % and 0.86 %. In an alternative example, it was observed that a disorderly agricultural production model that does not consider the physical, chemical, and biological characteristics of the soil results in low production, generating a conflict in land use and consequently a loss for the farmer (Flores Guzmán, 2018).

It is relevant to know the use of Geographic Information Systems (GIS) in the analysis and management of conflicts over land use. According to Jing et al. (2021), as well as Fienitz and Siebert (2022), a GIS can provide a platform to integrate and analyze various spatial data, such as land cover, land use, soil physicochemical characteristics and topography, which are important factors in assessing the suitability of the soil for different uses. By overlaying and analyzing these data layers, GIS can help identify areas where different land uses may compete for the same resources, such as water, land, or ecosystem services.

Thus, these systems can support the development of multi-criteria decision-making frameworks to assess the suitability of land for different uses, this involves weighing and combining different criteria, such as environmental, economic, and social factors to identify the most appropriate land use options for a particular area; GIS can help automate and streamline this process, enabling faster and more efficient decision-making (Jing et al., 2021).

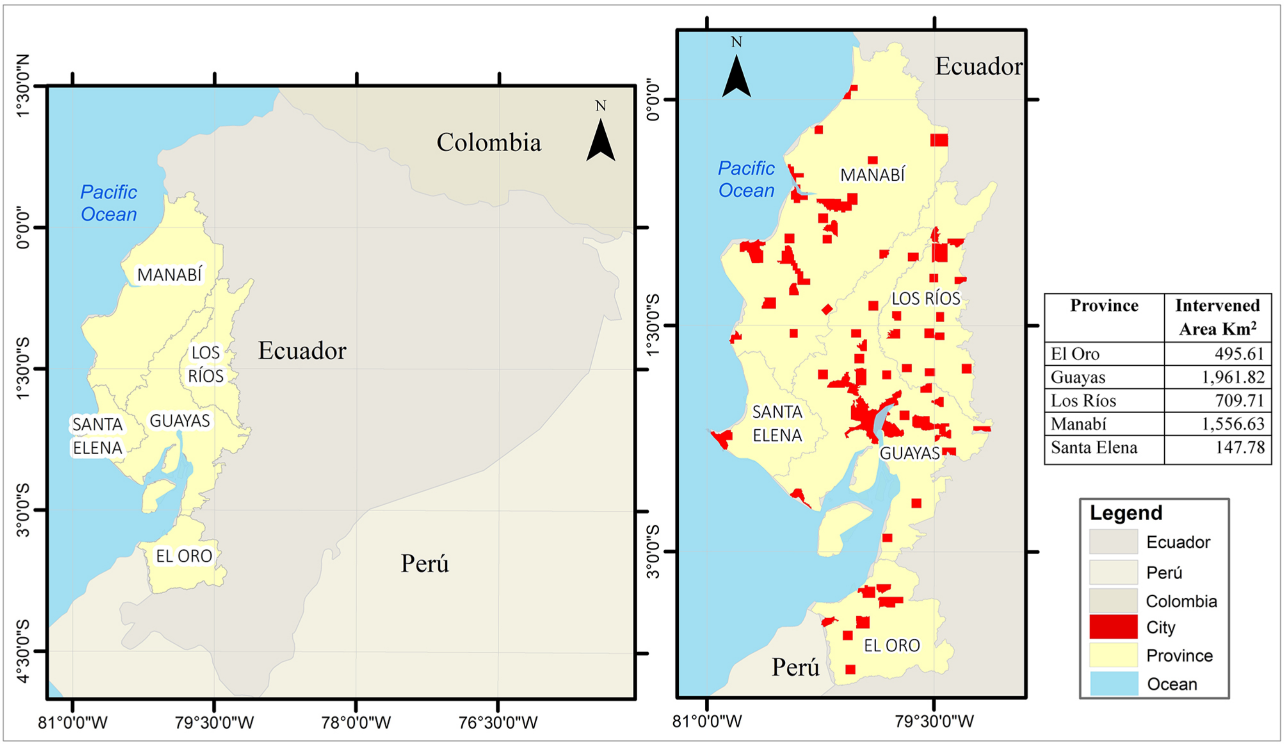
The AZ identifies potential or limited areas for cocoa production, but does not consider the use conflicts of already established crops; moreover, the detail of the cartography generalizes the information, which could imply the lack of use of areas suitable for the crop. In accordance with the preceding, the present work aims to determine the UC of the land for cocoa cultivation in 71 cities on the coast of Ecuador, using the LUC methodology, photo-interpretation, and agroecological requirements for production, trough geospatial technologies for the construction of geo-information at a scale of 1: 5,000 for informed decision-making by producers and authorities who manage and plan the territory.

2. Methodology

2.1. Study area

The study area is located in the country of Ecuador (continental platform) located between latitudes 1°30’ N and 5° S and longitudes 75° 2’ W and 81° W, the intervention areas are located in the coastal region, covering 71 cities belonging to the provinces of El Oro, Guayas, Los Ríos, Manabí and Santa Elena. The study surface includes 4,852.79 km² with an average of 43.07 km², a maximum of 416.79 km², and a minimum of 24.76 km², the area of interest starts from the consolidated area of each city and extends up to cover the average area that expanded or reduced according to the cantonal limits (see Figure 1).

Figure 1. Location map of the study areas



Province	Intervened Area Km²
El Oro	495.61
Guayas	1,961.82
Los Ríos	709.71
Manabí	1,556.63
Santa Elena	147.78

Source: IGM, 2023. Own elaboration

The coastal zone of Ecuador is made up of three climatic regions. The Tropical mega-thermal semi-arid region has rainfall of less than 500 mm/year and an average annual temperature of 23.4 °C; the tropical dry to semi-humid mega thermal region has rainfall ranging from 500 to 1,000 mm/year and an average annual temperature above 24°C; and the humid tropical mega thermal region has rainfall between 1,000 to 2,000 mm/year, the average annual temperature fluctuates around 25°C (Pourut, 1983; Cedeño & Donoso, 2010; Varela & Ron, 2018).

The intervened cities in the coastal region are characterized by a series of environmental variables that influence the formation of unique ecosystems. Climatic factors, such as temperature and precipitation, as well as proximity to the coastline and topography that varies from altitudes close to sea level to elevations above 910 m.a.s.l., play a fundamental role in determining the distribution and composition of the ecosystems, among them, we can mention the desert shrubland, the deciduous shrubland, the deciduous forest, the semideciduous forest, the seasonal evergreen forest, the piedmont evergreen forest, the riparian floodplain grassland, the flooded lake and mangrove (Ministry of Environment [MAE], 2013; Watkins, 2023).

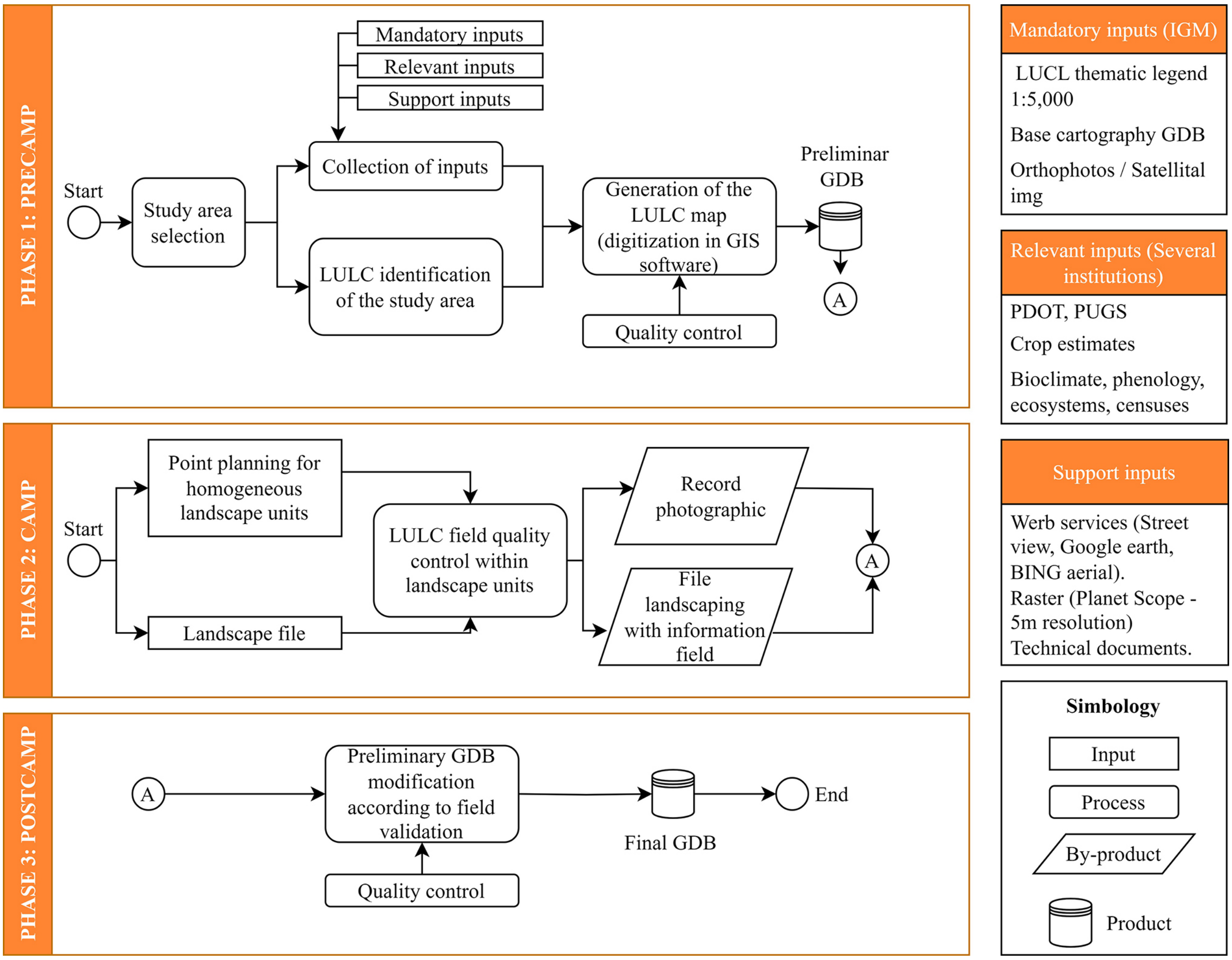
2.2. Supplies

The inputs used belong to the IGM and include orthophotos and satellite images collected with a spatial resolution that varies from 10 cm to 50 cm, and with an average pixel size of 30 cm. These range values allow for the construction of cartographic products at scale 1:5,000, where the required spatial resolution is 50 cm and with a minimum mappable area of 400 m² (IGM, 2016, 2022a). The 89.8 % of the inputs have a temporal resolution ranging from 2018 to 2022, and 10.2 % have a resolution earlier than 2018. Other inputs collected are the aforementioned LULC and LUC maps, which are part of the projects: Determination of the Reception Capacity of the Territory (CA) for urban development purposes through the generation of thematic geoinformation at a scale of 1:5,000 and Generation of geospatial information at a scale of 1:5,000 for the determination of the physical aptitude of the territory and urban development that are executed by IGM (2023).

2.3. Land cover and use flowchart

It is necessary to consider that the concept of LU and that of LC, although related, are technically different (Nedd et al., 2021). LC refers primarily to direct observation of terrestrial ecosystems, natural resources, and habitats on the earth's surface, while LU generally describes a certain type of soil produced, modified, or maintained by human arrangements, activities, and inputs. LU refers to the intended use of a portion of the land, but LC specifies its patterns and characteristics. It is important to note that most maps only provide information on land cover. In other cases, they focus on the land use of certain specific covers, such as artificial or agricultural areas, thus providing LULC data. This is the reason why information on land use and land cover is usually shown, as these two aspects tend to be combined within the same data sets (Figure 2) (García-Álvarez et al., 2022; Zhang & Li, 2022).

Figure 2. Land cover and use flowchart



Own elaboration

After the brief clarification of the LULC, it should be considered that in the present study, a map has been prepared that covers both land cover and land use; it was developed in three specific phases. The first phase begins with the collection of official and secondary inputs. According to the Agustín Codazzi Geographic Institute (IGAC) (2021), three types of information must be gathered: mandatory inputs (necessary for photointerpretation and digitization of coverage of interest), relevant inputs (provide context, criteria, and help in decision-making) and support inputs (complement or verify technical and thematic criteria). This collected data, contributes to the process of identifying specific crops and other coverages. Immediately afterward, the digitalization of the coverages is carried out according to the photointerpretation, a process that consists of the visual interpretation of shapes, colors, and textures that are associated with a particular coverage, with which a preliminary map is obtained.

After the first phase, there is the camp phase, in which validation is carried out in the territory of the study area. This process consists of capturing the coordinates of the coverage observed in the territory within a landscape unit. The latter, is delimited spatially by the geomorphological unit and qualitatively by characteristics of the phenosystem and cryptosystem. Lastly, in this phase, the digitized coverage is updated according to the observed change. The quality control process is carried out continuously in all phases, this process consists of control of completeness, omissions, logical consistency, and thematic, temporal, and spatial accuracy.

2.4. Land use capacity flowchart

The creation of the LUC map follows four phases: 1) identify the spatial analysis unit that corresponds to the geomorphological unit belonging to the geomorphology map of the CA project, a theme that stores the morphogenetic, morphological, morphodynamic characteristics, geology, type of deposits and geological factor; 2) correlate the physical, chemical and biological characteristics of the soil with the geomorphological unit; 3) classify the geomorphological units based on erosion, soil, humidity, and climate factors. These are detailed in ten parameters that can be limiting depending on the category; if the limitation is severe, it is enough to reclassify the unit into the next class with the lowest potential regardless of the degree of the other limitation, as described in Table 2 (IGM, 2022b).

Table 2. Criteria to determine the Land Use capacity

Variables	Classes of Capacity of Use							
	Agriculture and other arable uses				Little risk of erosion	Forest use or for conservation purposes - Non-arable		
	I	II	III	IV	V	VI	VII	VIII
Slope (%)	<5	≤ 12	≤ 25	≤ 40	≤ 12	≤ 70	≤ 100	Xi
Effective depth (cm)	>100	>50	>20	>20	Xi	>20	>20	Xi
Surface texture	Group 1	Group 1, 2	Group 1, 2	Group 1, 2	Xi	Xi	Xi	Xi
Stoniness (%)	≤ 10 (very few)	≤ 25 (few)	≤ 25 (few)	≤ 25 (few)	≤ 50 (up to frequent)	≤ 50 (up to frequent)	≤ 75 (until abundant)	Xi
Salinity (dS/m)	< 2 (not saline)	< 2 (not saline)	(slightly saline)	(slightly saline)	(until very saline)	(until very saline)	(until very saline)	Xi
Acidity or carbonate toxicity	without or null	None or none and light	None or none, light and medium	None or none, light and medium	Xi	Xi	Xi	Xi
Sewer system	Well	Good and moderate	Excessive, moderate and good	Excessive, moderate and good	Xi	Xi	Xi	Xi
Flood periods	Without or very short	Without or very short	Without or very short and short	Without or very short and short	Without or very short, short, medium and long	Without or very short and short	Without or very short, short and medium	Xi
Soil moisture regimes	Udic	Udic and Ustic	Udic and Ustic	Udic and Ustic	Xi	Udic, Ustic and Perudic	Udic, Ustic, Perudic and Aridic	Xi
Soil temperature regimes	rt1	rt1	rt1	rt1	rt2	rt2	Xi	Xi

Textures: Group 1: Loam, sandy clay loam, sandy loam, silt loam, silt clay loam, clay loam, and silt. Group 2: Loamy sand, sandy-clay, silty-clay and clayey. Group 3: Sand (very fine, fine, medium, and coarse). Group 4: Heavy clay. Soil temperature regimes: Isohyperthermic and isothermal (rt1), Isohyperthermic, isothermal and isomeric (rt2). Any Xi.

Categories I and II have slight to no limitations, classes III and IV have light to moderate limitations, category V has strong to very strong limitations, and categories VI, VII, and VIII have very strong limitations.

Source: IGM, 2022b

2.5. Land use conflict flowchart for Cocoa cultivation

To determine the UC for cocoa cultivation, geospatial technologies were applied together with a spatial analysis. This approach facilitated the evaluation of complex variables in a graphical and easily interpretable format. Overlapping the LULC and LUC coverage aids in determining the UC concerning the cocoa cultivated area and its agroecological requirement. In addition, it contributes in delimiting the area, quantifying the surface, and categorizing the type of conflict as underutilized, overutilized, or appropriately used. In order to characterize the UC, the following criteria are considered: 1) the biophysical offer expressed by the land use capability; 2) the current demand, expressed as current land cover and use; 3) the classes of conflicts according to their degree of intensity; and 4) the needs for land conservation and recovery (IGAC, 2014; Buzai & Baxendale, 2010).

Once the aforementioned processes were applied, a decision matrix was used to evaluate concordance, compatibility, or discrepancy about the land use through the process of orderly confronting each pair: the use capability - current use. Table 3 below presents the decision matrix created to determine the UC. This matrix is adapted from the decision matrix used to determine conflicts of use in expansion areas, as detailed in IGM (2022b); therefore, the coverage of interest is located in the OTMP column (object plus temporality). In this study case, the cocoa crop was determined as a permanent crop and from this premise, the LUC classes were obtained for the categories: Adequate Use (AU), Light overused (LO), Moderate Overused (MO), and Severe Overused (SO).

Table 3. Decision matrix extract to determine conflict of use

Decision matrix extract to determine UC									
Use and Cover	LUC Classes								
OTMP (Object + Temporality)	I	II	III	IV	V	VI	VII	VIII	Not apply
Native forest	U	U	U	U	AU	AU	AU	AU	NA
Annual crop	AU	AU	AU	LO	MO	MO	SO	SO	NA
Semi-permanent crop	AU	AU	AU	AU	LO	LO	SO	SO	NA
Permanent crop	AU	AU	AU	AU	LO	MO	MO	SO	NA
Adequate Use (AU), Light overused (LO), Moderate Overused (MO) and Severe Overused (SO), Underutilized (U), Not apply (NA).									

Source: IGM, 2022b

2.6. Data normalization

Data normalization is an information preprocessing task and one of the first to be performed during intellectual analysis, particularly in the case of tabular data. This process consists of scaling or transforming the data to ensure an equal contribution from each feature (Izonin, et al., 2022; Singh & Singh, 2020). In this case study, the data was normalized through the use of the maximum value within the range of the variables of interest (simple normalization as detailed in equation 1), which consisted of the area of the cities and the surface of cocoa present in each city; this resulted in two normalization factors that were multiplied by the LUC and UC values of each study area. This procedure prevented the comparison between cities with a large area of cocoa crops and minimal territorial size, and those cities with a smaller cocoa crop area but a larger territorial expanse.

$$Value_{normalized} = \frac{value}{maximun\ value} \quad (1)$$

2.7. Cross tabulation of LUC and AZ cartographic models

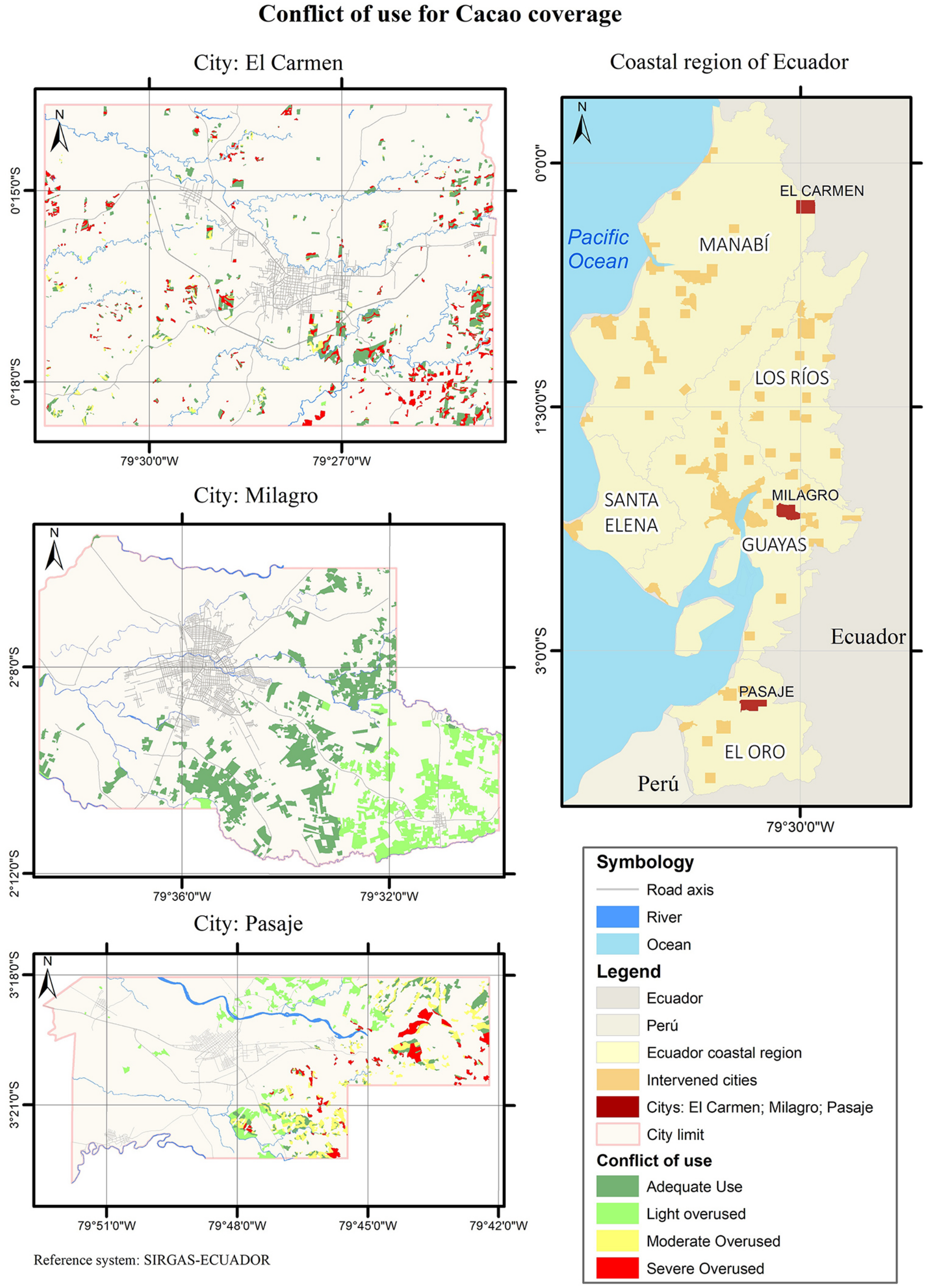
To make the comparison between LUC and AZ, a cross-tabulation was used. As detailed in Eastman (2012), this process facilitates the identification of changes between pairs of images, that is, it displays the frequencies within which the classes of each input have remained the same, thus providing detailed information about the changes between classes and their respective calculation of area. To carry out this process, the cities were grouped according to the province they belong. Consequently, raster with LUC and AZ datasets were used as inputs, both with the cities grouped at the level of administrative political division mentioned.

3. Results

Of the 100 % of the study area (4,852.79 km²), 4.65 % is occupied by the cultivation of cocoa (226.076 km²). Of the provinces of the Ecuadorian coast, Los Ríos stands out with 94.358 km² (41.74 %) of cocoa crops and, in second place, Guayas with 79.273 km² (35.06 %). Of the 71 cities identified, 13 cities do not have cocoa crops within the defined area, because they consider the built-up area as the epicenter and extend an average of 43.07 km², leaving out other areas that can be occupied for cultivation and can modify the results.

Of the cocoa cultivation area present in the 53 cities, it was identified that Naranjal (11.15 %, 2,522.24 ha), Milagro (9.28 %, 2,097.65 ha), Montalvo (8.35 %, 1,886.61 ha), San Jacinto de Buena Fe (8.19 %, 1,852.36 ha) and Quinsaloma (8.09 %, 1,829.46 ha) are the cities with the largest cocoa cultivation area identified in the territory in the area study.

Figure 3. Extract of cartographic models of the conflict of use of Cocoa in 71 cities of the coast of Ecuador



Source: IGM, 2023. Own elaboration

Of the 226,076 km² of cocoa cultivation based on land use capacity, it was identified that Class III (34.32 %, 77.6 km²), Class II (25.86 %, 58.46 km²), and Class V (17.25 %, 39.009 km²) are the most predominant.

The most representative values for each UC category, based on the normalization scale over 100 points (pts) and the analyzed provinces, resulted in the following classification: Class I (Los Rios 2.27 pts, 5.92 km²), Class II (Guayas 22.26 pts, 21.008 km²), Class III (Guayas 38.84 pts, 36.64 km²), Class IV (Guayas 1.30 pts, 3.38 km²), Class V (Guayas 17.75 pts, 16.74 km²), Class VI (Los Ríos 3.07 pts, 8 km²), Class VII (El Oro 0.82 pts, 3.06 km²), Class VIII (Los Ríos 4.76 pts, 12.4 km²).

Of the 53 cities with the presence of cocoa cultivation, it was identified that the most representative values for each TSA category based on the normalization scale over 100 pts are the following: Class I (Montalvo 2.29 pts, 4.82 km²), Class II (Naranjal 7.22 pts, 15.16 km²), Class III (Milagro 16.85 pts, 61.59 m²), Class IV (Quevedo 1.15 pts, 78.04 ha), Class V (Milagro 10.504 pts, 8.05 km²), Class VI (Quinsaloma 1.79 pts, 4.77 km²), Class VII (Passage 3.17 pts, 2.85 km²), Class VIII (El Carmen 2.802 pts, 2.45 km²).

Of the 226.076 km² of cocoa cultivation according to the UC, it was identified that: the area of adequate use corresponds to 14,928.73 ha (66.03 %), the area of the severe overused category is 2,230.31 ha (9.87 %), the area of moderate overuse is 1,547.28 ha (6.54 %) and the area of light overuse is 3,900.95 ha (17.25 %) (Index of cities see Annex 1, Annex 2, Annex 3, Annex 4).

The most representative values for each UC category, based on the normalization scale over 100 pts, and the provinces analyzed are: adequate use (Guayas; 63.34 pts; 5,973.84 ha), severe overuse (Los Ríos; 4.76 pts; 1,240.50 ha), moderately overused (Los Ríos; 3.08 pts; 803.47 ha) and slightly overused (Guayas; 17.75 pts; 1,674.70 ha).

Of the 53 cities with the presence of cocoa cultivation, it was identified that the most representative values for each category of UC, based on the normalization scale over 100 pts are the following: adequate use (Milagro; 16.85 pts; 1,292.11 ha), severe overuse (El Carmen; 2.80 pts; 245.84 ha), moderate overuse (Pasaje; 4.71 pts; 423.72 ha) and light overuse (Milagro; 10.50 pts; 805.40 ha) (See Figure 3).

4. Discussion

At the national level, Ecuador has an AZ at a scale of 1: 25,000 carried out in 2020. In this project, four types of zones are determined for the cultivation of cocoa, based on their specific climatic and edaphic requirements (FAO, 1996). They consist of optimal zones, which are comprised of surfaces where the natural conditions of soil, landforms, and climate are well-suited for the cultivation of cocoa; moderate zones, which are surfaces where the aforementioned conditions present slight limitations and could be improved with adequate management practices; marginal zones, which are areas that present considerable limitations in the conditions, which entails difficulties in the establishment and normal development of the crop in natural parameters; finally the unsuitable zones, where the crop cannot be established in the natural parameters (MAG, 2020).

By using the agroecological zoning map proposed by MAG (2020), it was possible to identify an area of 219.48 km² of agroecological zones for the cultivation of cocoa, which coincides with the study area. However, there is a difference of 6.59 km² which lacks information regarding the surface of the crop present in the territory, since the methodology applied by the MAG did not consider the areas delimited for protection and conservation purposes, such as Forests and Protective Vegetation (FPV), sites Ramsar, State Forest Heritage (SFH), State Natural Areas Heritage (SNAH), Intangible Zones, among others.

Of the 219.48 km² of cocoa cultivation according to MAG (2020), the following areas were identified: moderate (13.71 %; 30.09 km²), marginal (33.68 %, 73.93 km²), and unsuitable (51.13 %, 112.22 km²). The most representative values for the agroecological zone based on the normalization scale over 100 pts, and the provinces analyzed are: moderate (Los Ríos; 9.86 pts; 25.04 km²), marginal (Los Ríos; 20.93 pts; 53.18 km²), not suitable (Guayas; 64.37 pts; 60.66 km²).

To make a comparison between the results obtained by both methodologies, a cross-validation spatial analysis was carried out, which allows identifying the spatial relationship between the MAG (2020), products and the one proposed in this research, so that category changes are identified. For this process, the categories were normalized (see Table 4).

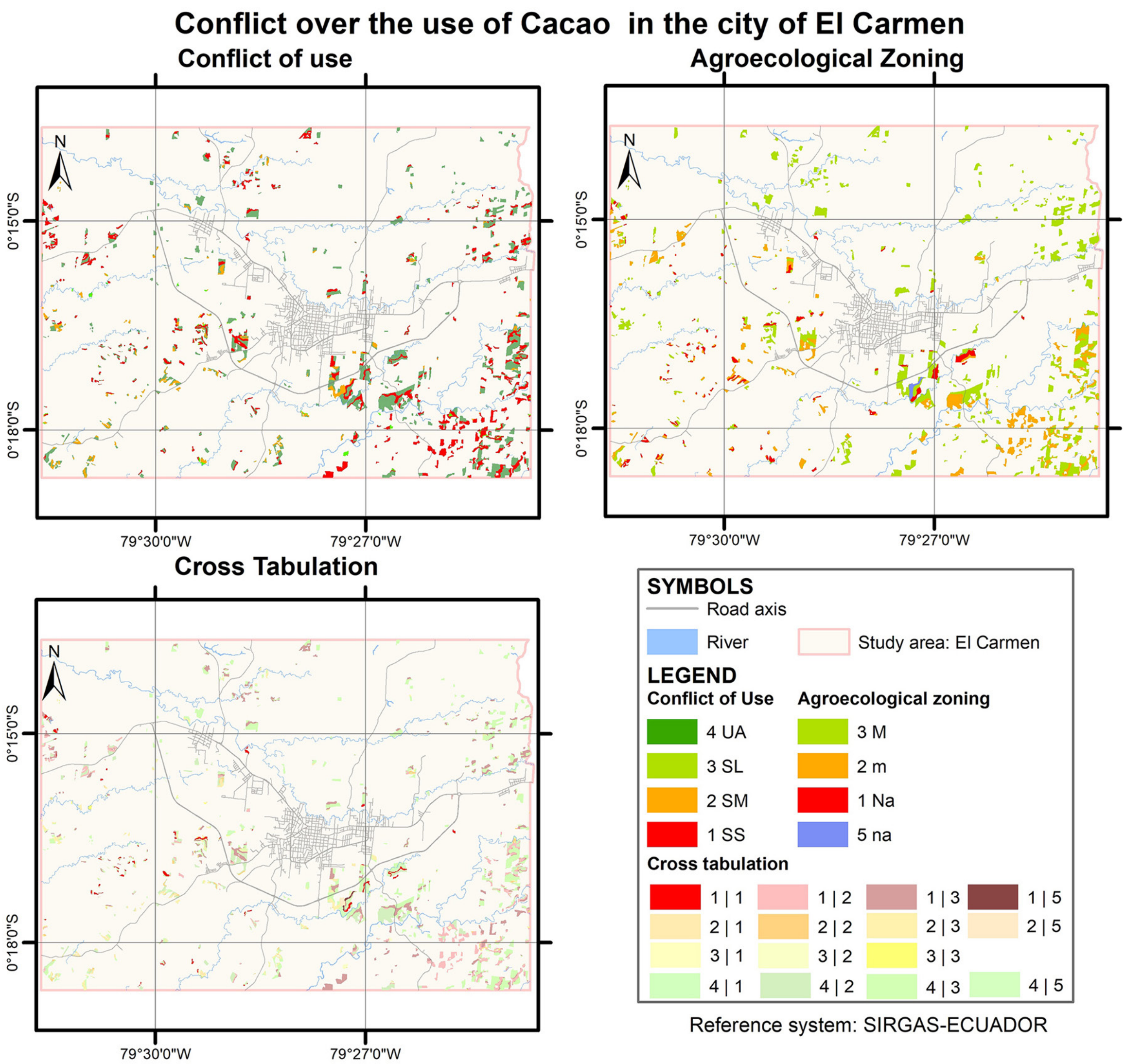
Table 4. Codes identifier

Code	UC	AZ
1	Severe Overused (SO)	Not suitable (NS)
2	Moderate Overused (MO)	Marginal (m)
3	Light Overused (LO)	Moderate (M)
4	Adequate Use (AU)	Optimum (Op)
5	Not Apply (NA)	Not apply (na)

Own elaboration

As a result of the spatial analysis, it was identified that there is a coincidence of code 1 (2.49 %; 520.32 ha), code 2 (2.35 %; 492.03 ha), and code 3 (0.66 %; 139,33 ha); and a variation of 94.48 % (19,737.68 ha). The most significant changes for each of the provinces are the following: El Oro (code 4 to 1; 57.24 %; 1,534.12 ha), Guayas (code 4 to 1; 55.56 %; 4,351.79 ha), Los Ríos (code 4 to 2; 41.701 %; 3,790.91 ha), Manabí (code 4 to 2; 19.99 %; 256.995 ha) and Santa Elena (code 3 to 1; 81.03 %; 1.05 ha).

Figure 4. Comparison of the conflict of use of cocoa, extract (El Carmen city)



Source: IGM, 2023. Own elaboration

Based on the results shown above, it is interpreted that the coincidences between both categories have a maximum of 2.49 %. This discrepancy may be the result of the difference between the scales of the products and the temporality of the inputs used for the elaboration of the ZA. The methodology developed by MAG (2020), predicts the optimal production areas of the crop at the national level under natural conditions, based on cartographic variables regardless of whether or not the crop is present. In contrast, this proposal determines the areas where the crops are already established, based on the interpretation of various inputs and by defining the type of conflict that the zones have. It is worth mentioning that while the ZA employs continuous data, the proposal presents a discrete characteristic. Nonetheless, it is crucial to have this comparison to identify the suitability of each product. Figure 4 shows an extract from a city (El Carmen) to exemplify the comparative spatial analysis between what was developed by the present investigation, and what was carried out by the Agroecological Zoning. It is observed that there is a coincidence between category 1|1 of 2.51 %, 2|2 of 1.30 %, 3|3 of 0.78 % and 95.41 % present some change between categories, the most significant is 4|3 with 36.82 % and it is followed by 1|3 with 19.11 %.

In general, a producer decides the use that he will give his land following parameters such as market demand, influence of the environment, experience, and they do not have defined long-term planting plans (Pedemonte et al., 2014). They are unaware that there is information indicating the areas with the optimal agroecological requirements for the development of each crop, which may be a consequence of the low coincidence between the optimal zones of the ZA and the CU, (Osty, 1978), mentions that agricultural exploitation comprises an organized whole that considers the objectives and opinions of the producers and that moves away from the simple and uniform criteria of optimization. Likewise, there are regulations in the country that define the use that should be given to rural land; it must be destined for agro-productive activities that are respectful of the environment as stipulated by the law *"Ley Orgánica de Ordenamiento Territorial, Uso y Gestión De Suelo"* (LOOTUGS) (LOOTUGS, 2016). Therefore, its use and occupation must be oriented through the cartographic information generated considering the capability of the soil and its suitability for the crop.

It is worth mentioning that the AZ considers cocoa production under natural conditions and the main factor that determines that the coincident zones in the study area are marginal and not optimal is the duration of the growth period (DGP) or vegetative period. This refers to the number of days where crop production is favorable under optimum humidity and temperature conditions (FAO, 1996). It is not exclusive; it is a guide where the areas that do not require any adaptation are indicated and the crop can be implemented. In the study area, these days are in different ranges that go from 50 to 290 days (Figure 5 and Figure 6), coinciding in the unsuitable areas with the lowest values. To correct this limitation, management practices can be carried out, such as irrigation, drainage, and shading systems.

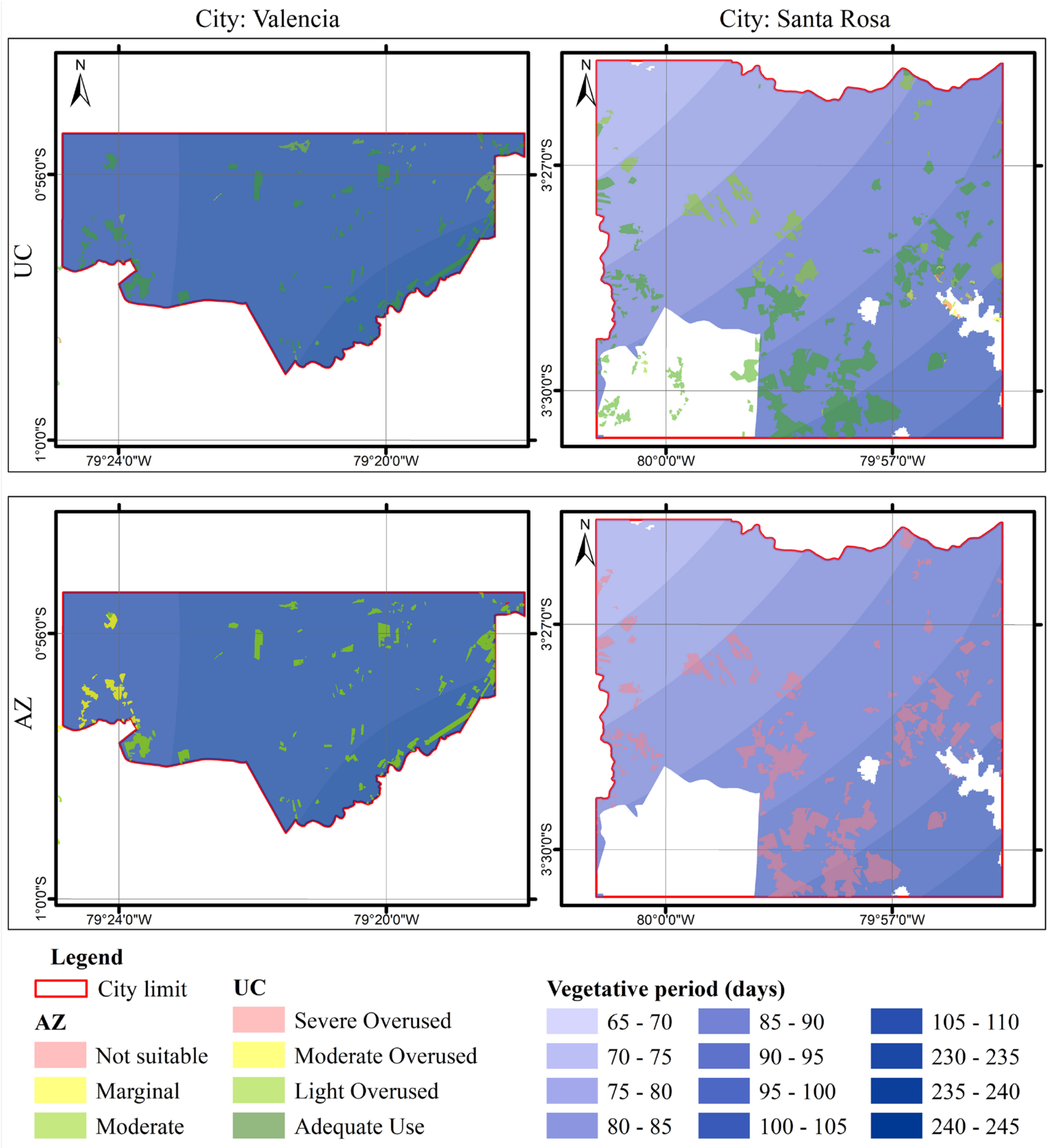
Figure 5. Comparison of cocoa crops in the cities of Valencia and Santa Rosa

a) Valencia [DGP > 230 days; visually favorable conditions for the plant, presence of weeds that indicate higher soil moisture] and b) Santa Rosa [DGP <160 days, less favorable conditions for the plant which makes it necessary to implement agricultural practices].

Authors' photograph

Likewise, there is another factor that influences the dilemma between AZ and our model. In the case of Naranjal, Milagro, and San Jacinto de Buena Fe, their biophysical conditions determine that the soil has an adequate use for the establishment of permanent crops, but in the specific case of cocoa, the effective depth (<1 m) is the limitation for its development in optimal conditions. This is due to the fact that in areas with high rainfall the roots need to give stability to the plant, and in areas with prolonged dry seasons the roots need to access soil moisture at depths greater than 1 m (Ibarra, 2019). Even though cocoa can adapt to various types of soils, it is recommended that these be light and with an effective depth of not less than 1.5 m that allows adequate development of the root system (Paredes et al., 2022; Suárez et al., 1994).

Figure 6. Comparison of the DGP of cocoa cultivation between the cities of Valencia and Santa Rosa



Source: IGM, 2023; MAG, 2020. Own elaboration

5. Conclusions

In the cities analyzed, there is a maximum of UC corresponding to the category of light overuse (3,900.95 ha; 17.25 %), in contrast to adequate use (14,928.73 ha; 66.03 %). The surfaces in proper use are concentrated in the LUC categories (Class I to IV) which are equivalent to 66.03 %. On the other hand, there is a conflict of 33.97 % that groups the crop surfaces in classes V to VIII that present severe agricultural limitations, mainly the effective depth, steep slopes, and stoniness.

In the study area according to the AZ, there is a maximum unsuitable area (112.22 ha; 51.13 %) followed by marginal areas (73.93 ha; 33.68 %). These categories are because, in the study area, there are biophysical and agroclimatic parameters, among others, that are not consistent with the agroecological needs for cocoa crop. The most influential is the humid vegetative period whose areas with values less than 160 days are considered unsuitable; likewise, the effective depth must be greater than 100 cm for the correct development of the crop. It is important to emphasize that marginal and unsuitable areas do not indicate the non-establishment of the crop, since agricultural or agroecological practices can be established, such as soil conservation, improvement of its physical parameters (pH, electrical conductivity, salinity, addition of nutrients), use of organic matter, and construction of terraces, among other processes.

From the cross-validation geospatial analysis, it is obtained that there is only a 5.51 % concordance between the categories of both products: code 1 (2.49 %; 520.32 ha), code 2 (2.35 %; 492.03 ha) and code 3 (0.66 %; 139.33 ha); therefore, there is a 94.49 % surface that varies between categories, so that the most representative is the change of appropriate use to areas considered marginal or unsuitable, and about the aforementioned, they are not necessarily areas in which the crop could not be established in a mandatory manner. Consequently, this research underscored the critical relevance of having detailed information about a territory to make decisions suitable to its characteristics. If the information were used at smaller scales, the expected result would not reflect the particularity of the territory.

If the farmers were to use the national AZ information to implement cocoa crops, they could limit their production, since this research showed that there are already cultivated areas that are not in conflict and that are used by farmers.

The present research is not limited to the study area, due to its flexibility and practicality, since the methodology is scalable to other surfaces not analyzed and replicable to other types of crops by modifying theirs agroecological requirements.

In order to improve the analysis and to adapt it to the farmer's reality, it is suggested to incorporate other criteria focused on the study of the characteristics of the variety of the cultivated species, other physical-chemical requirements necessary for its correct development, integrated management of important pests and diseases, and the farmer's capabilities. It is interesting to incorporate these criteria in future research in order to provide additional data for informed decision making.

Annexes

Annex 1 describes a table with the values of the intervened surface in the 71 cities of the coastal region, the total area of cocoa cultivation photo-interpreted for each study area and the amount of surface that is in conflict according to its category.

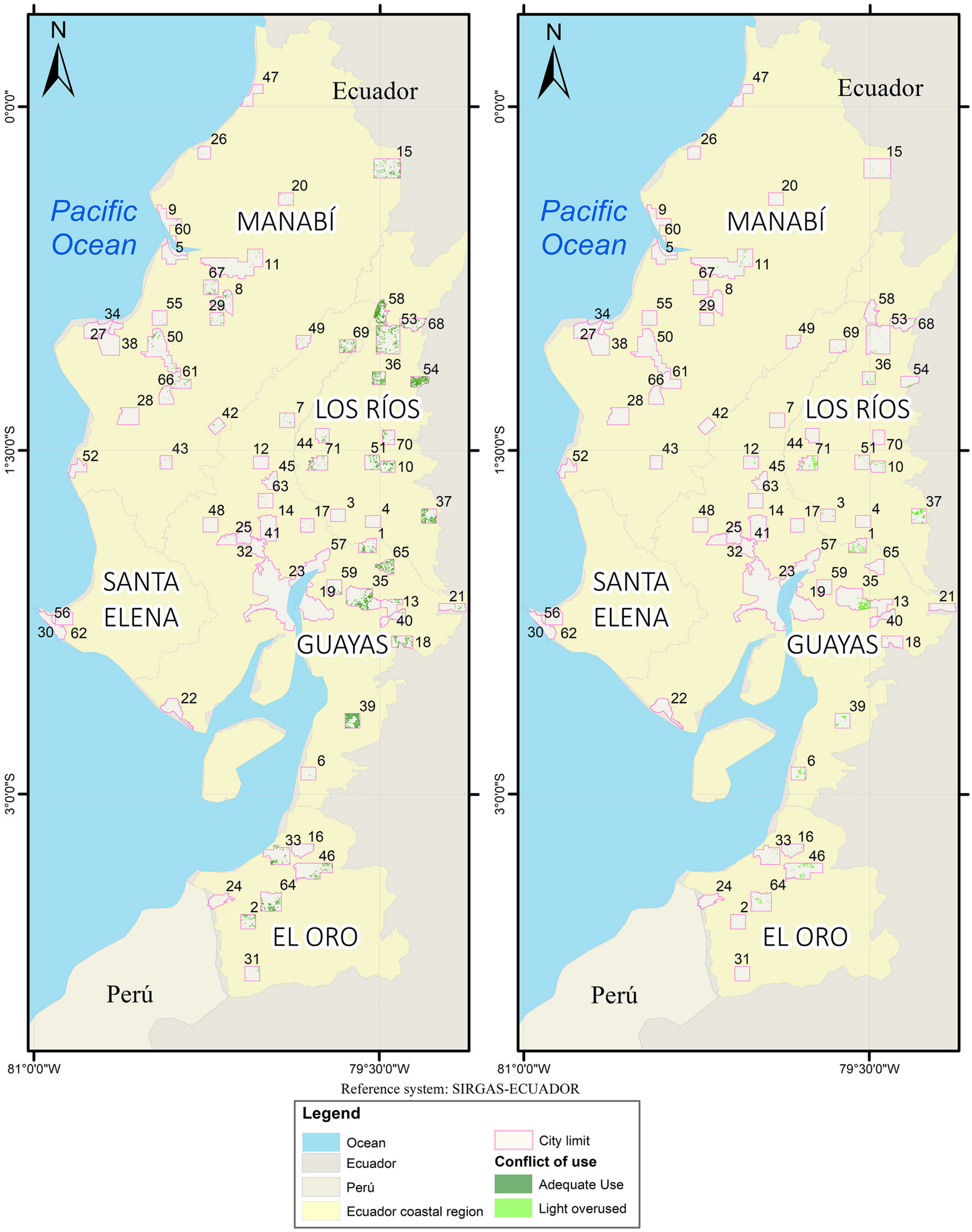
Annex 1. Cocoa area in Ecuador's coastal cities

Index	City	Area [ha]	Cocoa area [ha]	UC [ha]				
				LO	MO	SO	NA	AU
1	Alfredo Baquerizo Moreno (Jujan)	5,107.60	579.78	227.04	0.00	0.23	0.00	352.51
2	Arenillas	5,005.00	387.99	29.04	36.58	48.15	0.00	274.22
3	Baba	4,298.95	69.22	69.11	0.00	0.11	0.00	0.00
4	Babahoyo	4,370.76	5.43	5.36	0.00	0.00	0.07	0.00
5	Bahía De Caráquez	5,758.90	0.00	0.00	0.00	0.00	0.00	0.00
6	Balao	4,376.01	327.27	314.55	0.41	3.70	0.00	8.60
7	Balzar	5,005.00	32.06	0.00	2.28	0.52	0.00	29.25
8	Calceta	7,036.61	217.87	27.63	21.81	6.06	0.00	162.36
9	Canoa	6,732.70	22.98	2.11	0.00	0.01	0.00	20.86
10	Catarama	3,871.88	489.46	88.99	0.40	3.15	0.00	396.91
11	Chone	22,985.94	241.57	130.42	41.77	25.47	0.00	43.91
12	Colimes	4,319.31	42.41	41.53	0.00	0.00	0.00	0.88
13	Coronel Marcelino Maridueña	4,859.77	69.02	22.64	0.00	0.00	0.00	46.38
14	Daule	9,268.28	0.00	0.00	0.00	0.00	0.00	0.00
15	El Carmen	11,985.07	696.73	10.81	61.31	245.84	0.00	378.77
16	El Guabo	5,387.85	27.61	25.73	0.00	1.88	0.00	0.00
17	El Salitre (Las Ramas)	4,256.17	26.77	20.36	0.00	0.55	0.00	5.85
18	El Triunfo	5,181.30	667.31	21.89	34.50	0.30	0.00	610.62
19	Eloy Alfaro (Duran)	15,928.80	0.00	0.00	0.00	0.00	0.00	0.00
20	Flavio Alfaro	4,233.79	145.06	0.00	3.90	123.50	0.00	17.66
21	General Antonio Elizalde (Bucay)	4,397.27	82.93	2.69	2.97	22.58	0.00	54.69
22	General Villamil (Playas)	6,553.67	0.00	0.00	0.00	0.00	0.00	0.00
23	Guayaquil	41,679.26	0.86	0.00	0.00	0.06	0.00	0.80

24	Huaquillas	4,879.83	0.00	0.00	0.00	0.00	0.00	0.00
25	Isidro Ayora	4,463.51	27.60	0.45	9.89	0.00	0.00	17.26
26	Jama	3,697.21	4.85	1.24	0.00	0.00	0.00	3.61
27	Jaramijó	2,476.96	0.00	0.00	0.00	0.00	0.00	0.00
28	Jipijapa	7,669.12	1.24	0.00	0.14	0.25	0.00	0.85
29	Junín	4,126.49	91.71	4.33	7.24	6.48	0.00	73.66
30	La Libertad	2,527.52	0.00	0.00	0.00	0.00	0.00	0.00
31	La Victoria (Las Lajas)	5,005.00	37.41	0.12	5.90	2.99	0.00	28.40
32	Lomas De Sargentillo	5,885.12	0.00	0.00	0.00	0.00	0.00	0.00
33	Machala	8,844.69	455.59	46.75	0.00	0.00	0.33	408.50
34	Manta	7,691.56	0.00	0.00	0.00	0.00	0.00	0.00
35	Milagro	13,710.95	2,097.65	805.40	0.00	0.15	0.00	1,292.11
36	Mocache	3,988.89	818.06	78.00	25.99	282.63	0.00	431.45
37	Montalvo	5,005.00	1,886.61	619.63	38.57	43.51	0.00	1,184.90
38	Montecristi	10,091.84	5.87	1.88	3.99	0.00	0.00	0.00
39	Naranjal	5,005.00	2,522.25	168.06	0.96	132.19	0.00	2,221.04
40	Naranjito	5,176.78	166.72	6.88	0.00	0.00	0.00	159.84
41	Narcisa De Jesús (Nobol)	5,758.83	4.66	1.38	0.00	0.00	0.00	3.28
42	Olmedo	3,723.67	36.76	0.00	3.09	4.73	0.00	28.94
43	Pajan	3,694.20	20.22	1.07	0.00	1.58	0.00	17.56
44	Palenque	4,396.70	89.34	6.78	2.64	0.14	0.00	79.77
45	Palestina	4,198.05	19.88	10.33	0.00	0.00	0.00	9.55
46	Pasaje	11,687.51	1,260.66	374.11	423.72	210.18	0.00	252.65
47	Pedernales	5,118.94	4.49	0.00	0.44	0.00	0.00	4.05
48	Pedro Carbo	5,005.03	0.00	0.00	0.00	0.00	0.00	0.00
49	Pichincha	3,985.32	96.26	0.00	51.43	29.61	0.00	15.23
50	Portoviejo	14,710.79	242.64	2.91	7.29	18.56	0.00	213.88
51	Puebloviejo	5,020.92	333.50	30.21	0.15	0.01	0.00	303.12
52	Puerto López	4,263.03	0.00	0.00	0.00	0.00	0.00	0.00
53	Quevedo	15,512.14	1,052.14	38.36	91.89	107.31	0.00	814.58
54	Quinsaloma	3,938.73	1,829.46	50.56	477.90	270.25	0.00	1,030.76
55	Rocafuerte	5,005.00	17.93	6.02	4.49	1.09	0.00	6.33
56	Salinas	6,778.25	0.00	0.00	0.00	0.00	0.00	0.00
57	Samborondón	16,871.54	0.00	0.00	0.00	0.00	0.00	0.00
58	San Jacinto De Buena Fe	5,168.11	1,852.37	0.79	151.41	492.14	0.00	1,208.04
59	San Jacinto De Yaguachi	5,005.00	110.80	25.57	0.00	0.00	0.00	85.24
60	San Vicente	5,037.72	1.23	1.19	0.00	0.04	0.00	0.00
61	Santa Ana De Vuelta Larga	5,555.87	139.38	1.28	4.74	28.51	0.00	104.84
62	Santa Elena	5,472.32	1.30	1.30	0.00	0.00	0.00	0.00
63	Santa Lucia	5,005.00	8.59	0.79	0.00	0.00	0.00	7.79
64	Santa Rosa	8,751.48	898.35	165.13	10.48	5.57	0.00	717.17
65	Simón Bolívar	4,357.60	796.83	0.13	0.00	5.48	0.00	791.21
66	Sucre	5,077.94	51.78	1.48	2.51	1.48	0.00	46.31
67	Tosagua	5,004.35	136.95	0.27	1.95	0.00	0.00	134.73
68	Valencia	5,796.00	308.65	56.76	0.57	2.01	0.00	249.30
69	Velasco Ibarra (El Empalme)	4,807.46	343.96	5.01	0.00	62.04	0.00	276.92
70	Ventanas	4,099.01	173.81	5.32	13.94	33.11	0.00	121.44
71	Vinces	5,504.14	527.84	341.57	0.00	6.14	0.00	180.12

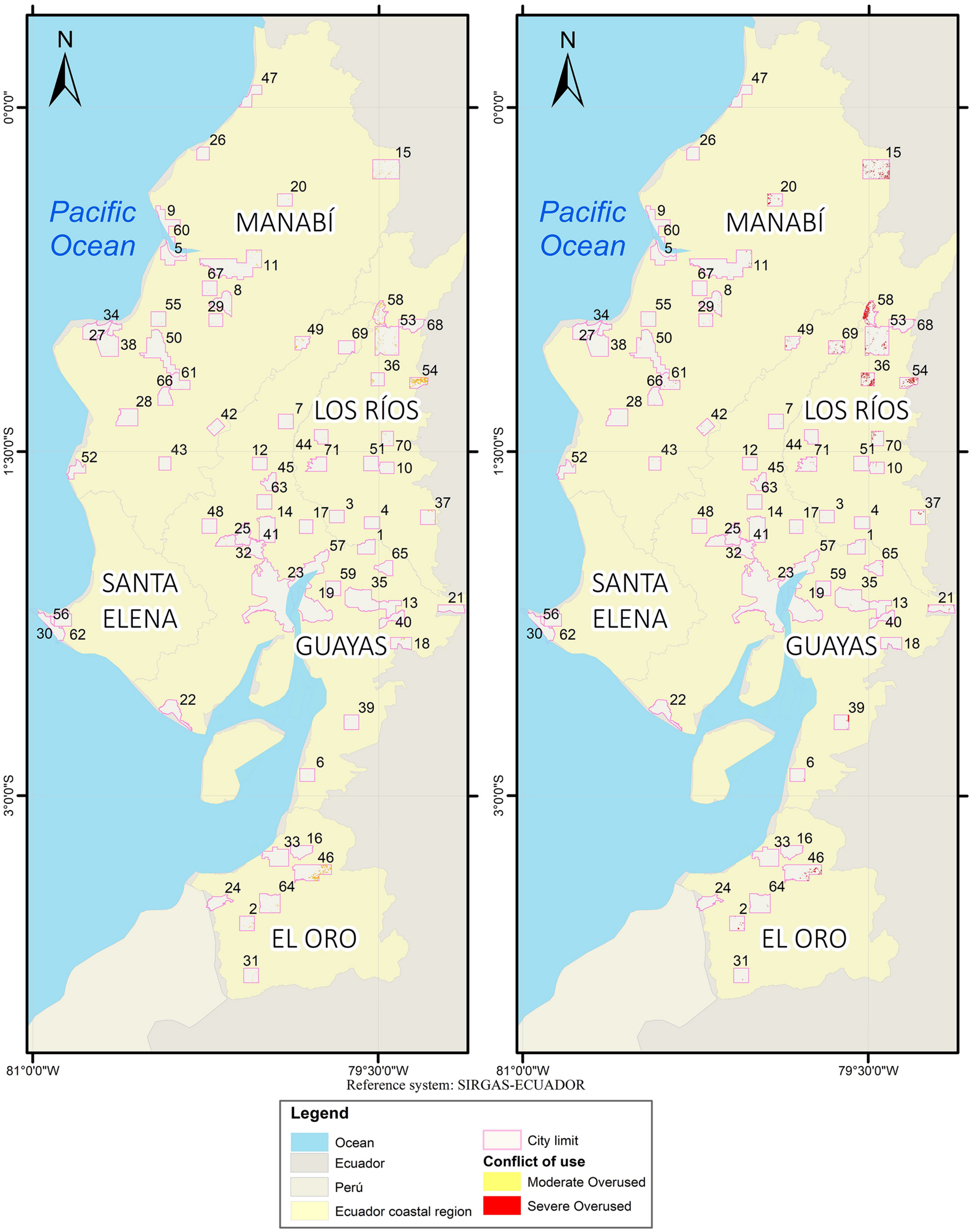
Own elaboration

Annex 2. Cartography of Cocoa Use Conflict Area (Appropriate Use; Light Overuse)



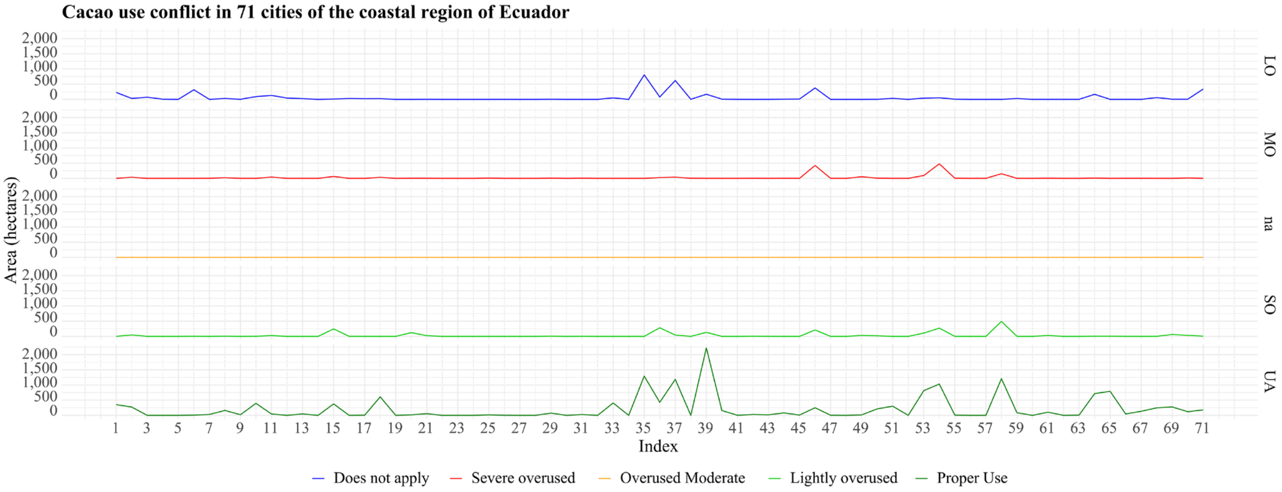
Own elaboration

Annex 3. Cartography of Cocoa Use Conflict Area (Moderate Overused; and Severe Overused)



Own elaboration

Annex 4. Conflict area of use of Cocoa



Own elaboration

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