Masters Program in Geospatial Technologies

LAND CHANGE IMPACTS ON ECOSYSTEM SERVICES THROUGH LANDSCAPE METRICS:

THE CASE OF MADEIRA ISLAND 1990-2040

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ABSTRACT

LULC changes from anthropogenic disturbance are a major impact-driven on ecosystems services and landscape metrics have been proposed for the assessment of impacts depicting spatial patterns determining the quality and state of interactions.

Madeira island possesses a rich unique ecosystem the Laurel forest, a World Heritage inscribed by UNESCO. Along with a considerable amount of endemic biodiversity, fertile volcanic soils and humanized terraced landscape. Economic development and natural disasters have been triggering changes. Yet, future projections regarding LULC change are missing.

In this study, the CORINE Land Cover from 1990 to 2012 is used to perform change analysis. The Multilayer Perceptron Neural Network implement in the TerrSet GIS software is applied to model four scenarios for the year 2040: Business as Usual, Conservation of Agricultural and Forests areas and Renaturation with the assessment of impacts using landscape metrics.

The results show a negative trend for ecosystem services in 2040 at different rates. A trend for the fragmentation of the landscape is found mainly in Renaturation scenario with 890 patches. A more significant decrease for biomass production in Scenario Renaturation and a loss of areas for food production of -32 km^2 in Scenario Conservation of Forests. Recreational and cultural areas with a loss of -32 km2 in Scenario Business as Usual followed by Conservation of Forest with -29 km^2.

This study contributes to Regional Planning Institutions improving monitoring and environmental resources management. Coupled with a practical application using landscape metrics for the assessment of ecosystem services accordingly with Burkhard and Maes (2017) in a context using future scenarios. Comparability from this study with other smalls islands can be performed.

KEYWORDS

CORINE Land Cover

Ecosystem services

Land use/ cover

Modelling

Landscape metrics

Scenarios

ACRONYMS

CLC – CORINE Land Cover

GIS – Geographic Information Systems

LCM - Land Change Modeler

LULC – Land Use Land Cover

MPL – Multiplayer perceptron

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1. Introduction

1.1 Theoretical Framework

Land use and cover changes are accounted for the most important anthropogenic disturbance to the environment (Mishra and Rai, 2016) with profound impacts at the global scale (Foley et al., 2005). The ability and capacity for a progressive appropriation along with manipulation of space by man has been increasing in intensity and rate (Hassan et al., 2016; Geist, 2006). Driven factors in the demand for lands, such as proximity and socio-economic variables change the state result and spatial patterns (Geist,2005; Seppelt et al., 2016).

This led to a degradation of the environment, altering its functions, structures and dynamics (MEA, 2005; Grimm et al., 2008; Singh et al., 2014; Brandt et al., 2017; Grimm et al., 2008; Dong et al., 2015) disrupting the ecosystem function (Geist, 2006).

To maintain integrity of ecosystems is fundamental to preserve biodiversity (Singh et al., 2014; Brandt et al., 2017; MEA, 2005) and the services provided to society (Palacios-Agúndez et al., 2015) in terms of products obtained, benefits from the regulation, aesthetic experiences and recreation (MEA, 2005).

These concerns brought the environment to international agendas (Agenda 21, Paris Agreement), intergenerational awareness and Ecosystem Services Assessment (Millennium Ecosystem Assessment in 2005, Mapping and Assessment of Ecosystem and their Services in 2018).

The sustainable development goals in the 2030 Agenda by United Nations, empathizes the increasing awareness of including planning and monitoring of the landscape. With integrating ecosystems values and biodiversity in the national, regional and local planning (Addis Abeba Action Agenda, 2015).

Managing ecosystem services requires spatial knowledge of the dynamic patterns and their present status, its interactions (Leh et al., 2013). Plus, the LULC changes studies has been contributing towards the decision-making of ecological management and

environmental planning for the future (Zhao et al., 2004; Erle and Pontius 2007; Fan et al., 2007).

Remote sensing derived products along with geographical information systems, can perform integrated modelling building future scenarios with the applicability of probabilistic matrices which have been part of a wide range of studies assisting to explore the future of landscape (Rounsevell et al., 2006; Araya and Cabral, 2010) and measure of potential impacts (Shrestha et al., 2019).

Scenarios allow accounting an amplitude of plausible situation for the future, with the identification of losses and gains. It has been applied in several studies. For forest areas (Armenteras et al., 2019; Gibson et al., 2018) soil erosion (Jazouli et al., 2019) land degradation (García et al., 2019). To Luck (2012) most prioritization analysis for ESs is being based on the present state of LULC, a limitation for maintenance of ESs across time and implementation of strategies to mitigate impacts of land use change (Verhagen et al., 2018).

The importance of producing a predictive model of changes scenarios is the development of human activities and the consequent impact on environmental quality and the potential state of this landscape features in a later state (Sing et al., 2004). Several studies have been applied in future land cover transitions (Shrestha et al., 2019; Eraso et al., 2013; Weber et al., 2014; Guzmán et al., 2019; Kundu et al., 2017).

It allows to helping decision-making and the establishment protection and recovery actions (Muller and Burhard, 2012 in Almeida et al., 2016). An urgent need to identify the synergies existing between ecosystem services and ecosystem condition linking human activities effects creating priorities guidelines towards restoration (Mae et al., 2015). Studies showing the relation between the impact on land cover change on Ecosystem services (Metzger et al., 2006; Polce et al., 2016; Sturck et al., 2015).

Landscape metrics allows to describe the size, shape, the number of landscape elements (Turners, 1989, Turner and Garden, 1991) integrated into the landscape ecology studies for decades to quantify landscape structures (Casimiro, 2002). The fundamental characteristics are accordingly with McGarigal (1995) the structure related to the spatial

relationship of the elements or ecosystems in terms of dimensions, shape, number, type and configuration.

The analysis and interpretation range from the class levels and the whole landscape measuring the complexity, spatial distribution, diversity and composition (Leitão et al., 2006).

Although some uncertainties can rise for the selection and significance of individual indices (Schindler et al., 2014) it has been applied to assess impacts on ecosystem services for social mapping (Vreese et al., 2016) agricultural landscape (Lee et al., 2015) for evaluation of the landscape structures impact on biodiversity (Walz, 2015) estimation cultural scenic attraction (Walz and Stein, 2014). Current landscape patterns create legacies for the future (Turner and Garden, 2015).

Understanding the current state of the natural resources from which future goals can derive (Botequilha Leitão et al., 2006) from the thematic map or images (Herold et al., 2005). The spatial patterns compared to past trends and future predictions. These indicators allow to improve the aesthetic value of the landscape, assessment of ecological functioning (Frank et al. 2012) and quantify terrestrial and coastal ecosystem in a different temporal analysis (Cegielska et al., 2018; Uuemaa et al., 2009; Norris et al., 2010; Herold et al., 2005). Investigation of connectivity, fragmentation, configuration and complexity of ecosystem have been studied (Plexida et al., 2014; Tran and Fischer, 2017).

Burkhard and Maes (2017) state that landscape metrics are applied in several ecosystem services mapping and assessment for the environmental scientist, decisions makers. Despite its recognized potentiality studies using future scenarios are missing.

Its importance derives from the fact that allows helping decision-making process establishing protection and recovery actions (Muller and Burkhard, 2012 in Almeida et al., 2016). An urgent need to identify the synergies existing between ecosystem services and ecosystem condition linking human activities effects creating priorities guidelines towards restoration (Mae et al., 2015). Studies showing the relation between the impact on land cover change on Ecosystem services (Metzger et al., 2006; Polce et al., 2016; Sturck et al., 2015).

Islands also called biodiversity “hot spots” (Mittermeier et al., 1998 in MEA, 2005), due to their historical and evolutionary isolation, a unique endemicity in the species is found (Whittaker and Fernández-Palacios, 2007) with a finite space and movement capacity response to human-induced or natural disasters (Whittaker et al., 2001; Gillespie et al., 2008; Euroisles, 2002).

A continuous linkage between human pressure on terrestrial and marine ecosystems services occurs (MEA, 2005) resulting in increased vulnerability and species diversity pressure (Baldacchino, 2004). Despite this, they have been on the margin of the planning literature (Fernandes, 2017).

Many extinctions have already occurred on such islands occurring in a higher rate than in mainland’s system (MEA, 2005) because of land use changes and an introduction of predators and competitors (Sadler, 1989).

These changes have also occurred in the Macaronesia islands. This biogeographical region holds a significant level of biodiversity worldwide (Medail and Quezel, 1997; Borges et al., 2008; Santos et al., 2014) and important ecological structure (Cropper, 2013; Sundseth, 2009). Despite the minor dimension 0.2% in the global EU territory, owns the most endangered and vulnerable flora (Sundseth, 2009). Land-change studies are important to this region (Doulgas, 1997).

Several studies in islands context show the importance of information LULC historical changes analysis and land use patterns depicting environment state and human-induced effects on ecosystems (Mwalusepo et al., 2017; Kim 2016; Kim 2013; Leh et al., 2013) spatial pattern (Chi et al., 2019).

Madeira island, endemic flora, Laurel Forest, a 40-million-year-old primary forest ecosystem, the evergreen broadleaf trees, led the United Nation to inscribed as World Heritage in 1999 due to its *“outstanding universal value”.*

The IUCN World Heritage Outlook report in 2014 classified the trend of value of the forests has: *“Good with some concerns”* but in 2017 states: *“High concern”* because of deteriorating with the risk of fire, expansion of invasive species the increase of human usage (tourism and infrastructure development). In terms of overall threats, *“a high*

threat for prospects of land-use changes might further exacerbate these threats if protection and management do not account for these".

A considerable amount of areas is part of the Natura 200 network, habitats directive and bird species directive (IFNC, 2019) along with a generous fertile soil for production of subtropical fruits and wine.

Tourism plays a major role in the regional economy, 25 to 30 % of its GDP (Neves, 2010) and its considered world's leading island destination since 2015 (World Travel Awards, 2018). With a centenary tradition and one of the "oldest tourist destination" (Ismeri Europa, 2011). Nature-based tourism (ACIF, 2014; PENT, 2014) along with the unique landscape heritage of humanized agricultural areas and walks across nature, part of the island identity and cultural value (Vieira, 2017; Santos et al., 2014; Silva, 2013; Quintal, 2010). The laboured terrace agriculture landscape in the fifteen and sixteenth century, a tremendous endeavour engraved from a physical conditioned terrain (Kiesow and Bork, 2017).

A revolution of accessibilities through the application of sectorial European Union funds aiming Regional Development, occurs in the island in 1989, not to mention, the applicability in the development of new information and transportation technologies. With its first highway (VR1) after this, a succession of infrastructures (tunnels, bridges, roadways) will boost effect within the landscape in terms of transformation and dispersion of the human activities (Leitão, 2012). Likewise, an expansion of tourism, regional economy and transformation in the society (Dantas, 2012) coupled with demographical changes and internal migration movements.

Climate change projections were produced for the island (See Santos et al., 2014; Gouveia, 2014; CLIMA-Madeira, 2015) and land development pressure from 1990 to 2006 (Rodrigues, 2016). Yet, projections regarding LULC are missing in Madeira Island (Gouveia, 2014).

The present study intends to contribute for the lack of information regarding future LULC with spatial explicit scenarios of change and respective assessment with the application of the Burkhard and Maes (2017) methodology using landscape metrics for the ecosystem services impacts.

1.2 Objectives

The aim of this dissertation is to model four different spatial land use/land cover scenarios for the year 2040 in Madeira Island, with the identification of impacts on ecosystem services.

To achieve the proposed aim, the following specific objectives were defined:

- Analyze and identify change on LULC from 1990, 2000, 2006 and 2012 with CORINE Land Cover data, legend level 2;
- Develop from the 1990 and 2012 CLC four LULC scenarios for 2040: A business as usual; conservation of agricultural areas; conservation of forests areas and renaturation;
- Assess and identify major terrestrial ecosystem services impacts from 1990 to 2012 and scenarios with the use of landscape statistical metrics analysis.

1.3 Dissertation structure

The present dissertation is organized into six chapters. The first characterized by introductory theoretical framework, aim and objectives. The second presents the contextual geographical location of the study area, namely the physical framework and population framework. The third chapter, data and methods used in the developing of the practical component of the dissertation. The fourth chapter presents the several outcomes of this study and the fifth a discussion of the these. The last chapter presents the conclusions.

2. Study area

2.1 Geographical context

Madeira Island is a Portuguese Autonomous Region located in the Atlantic Ocean, distancing approximately 968 Km from Lisbon (southwest) and 800 Km northwestern from the African coast (Brandão, 1991) in the latitude 32° 42′ 0″ North and longitude 17° 0′ 0″ West. It is 504 km north of the Canary Islands and 980 km southeast of the Azores (Ribeiro, 1985).

Madeira region concerns the main island which is the most populated having a rectangle-like physical configuration reaching above the 1800 m with a length of 58 Km direction East to West. The total width corresponds to 23 km direction North-South (Ribeiro, 1949). Located 40 Km northeast is the island of Porto Santo and it includes the uninhabited natural protected island of Desertas and Selvagens (southeast). The total area corresponds to 740.2 km^2 to Madeira and 42.5 km^2 Porto Santo.

Madeira Island is divided into 11 administrative municipalities (Figure 1): Funchal the capital, Santa Cruz, Câmara de Lobos, Machico, Ribeira Brava, Calheta in the South part of the island. Santana, São Vicente, Porto Moniz and Ponta do Sol in the North part and Porto Santo.

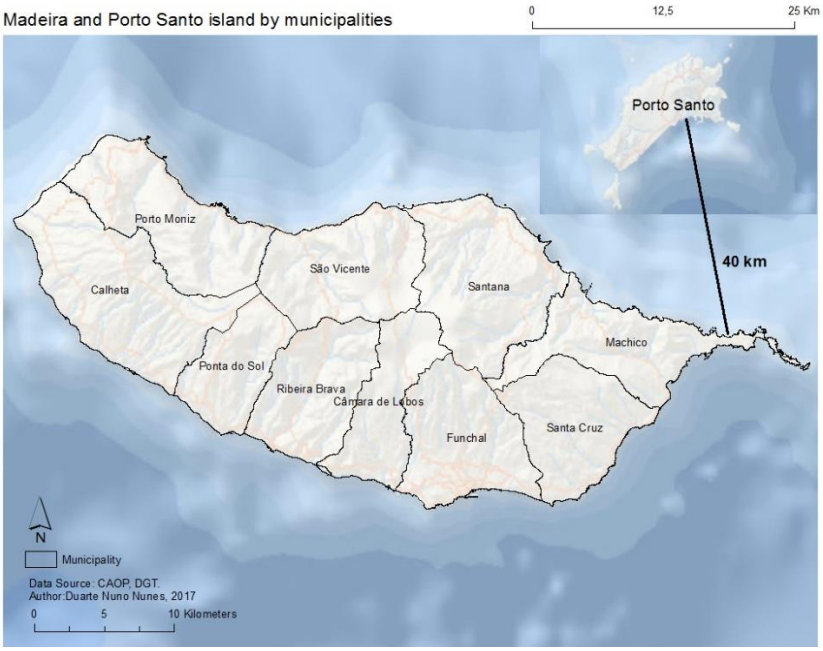

Figure 1: Geographic location of Madeira Island and municipalities.

2.2 Physical framework

Madeira island possesses a vigorous mountainous relief and consequently morphological declivity determinant in the whole landscape.

In terms of the elevation (Figure 2), higher points are in the central mountain range part appearing in a longitudinal backbone from East to West. Pico Ruivo with 1862 meters of altitude, Pico das Torres with 1851 meters and Pico do Areeiro with 1818 meters. There is a notorious division between the areas exposed to North and South in terms of its structure and climatic specificities. The north part of the island is characterized by the highest occurrence of sea cliffs drawn by polar winds, rain and a rough sea (Brito, 1997).

The south part is the opposite with less rain and a natural sheltered softer relief protected from the winds and possess higher temperatures. The climate condition of the island is influenced by its latitude and oceanic location, the proximity to African anticyclones and from Europe, the anticyclone of the Azores and the polar low atmospheric pressure at general scale (Quintal, 2007). The altitude and the exposure to solar radiation the global trade winds are the main local factors which influence the local climate.

The south part of the island is characterized by a higher number of hours exposed to the sun. The central backbone provokes the rapid rise of winds consequently, cloud formation and precipitation. The temperature is regular throughout the year decreasing with the altitude about 3°C by each 500 meters. The humidity and fog due to its orography constitute a high beneficial climatological factor in Madeiran vegetation (Pereira, 1989). Agricultural areas tend to be in the South part of the Island and East. Due to the climatic favourable conditions, in terms of higher temperature, fewer mists and fog (CLIMA-Madeira, 2015).

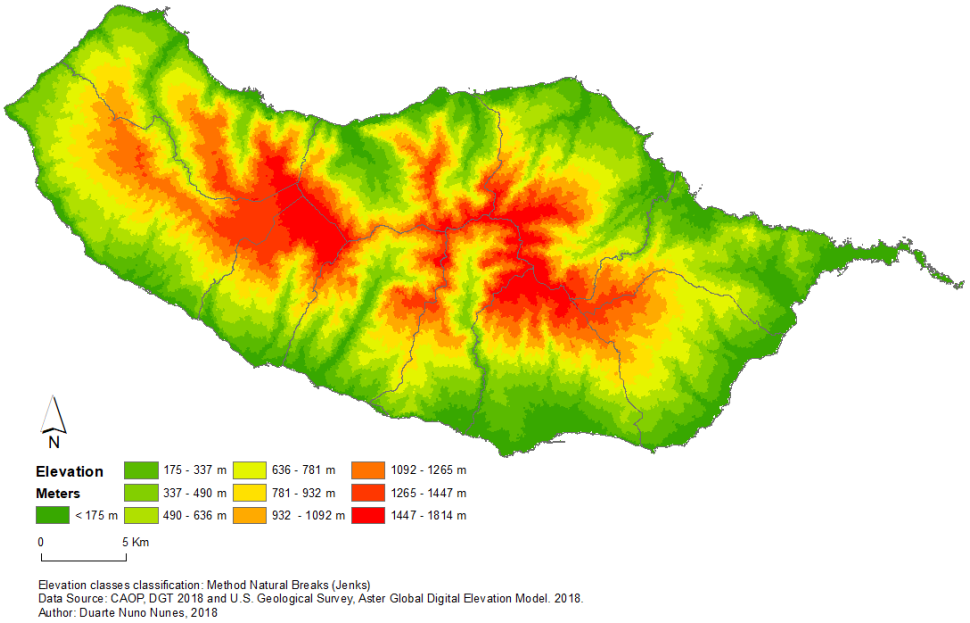

Figure 2:Elevation per meters in Madeira Island.

Approximately 7/10 of its surface area are higher than 25% of slope value being that 2/10 comprises between 25% and 16%. Only 1/10 of slope value equal or inferior to 16% (Brito, 1997).

The maximum value corresponds to 75%, its mean value 20% and the standard deviation is 12%. Natural factors print in the landscape irregular shapes due to physic and chemical interactions accelerating the erosive effects of wind, rain and sea (Ribeiro, 1999) in a continuous modelling of the topographical relief in terms of its structure and form (Abreu, 2008).

In Figure 3, visibly the South part of the island possess lower percentages of slopes as is the case of Funchal and Santa Cruz, although presents steep slopes in the form of valleys, which gives place in its end to streams with its origin in interior central areas. The central interior areas of the island are composed by high percentages of slopes due to its mountainous geomorphological structure.

The North part of the island possess a generally higher percentage of slopes comparatively with the South. The west-central part of the island is visibly composed by the largest plateau of Madeira with a total area of 24 Km^2 and an average altitude of 1500 m.

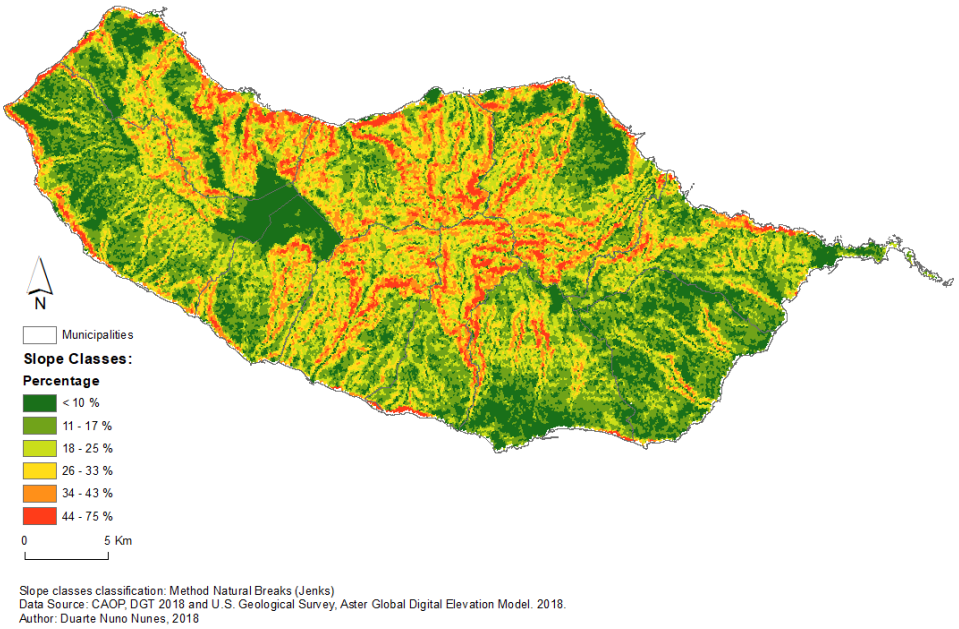

Figure 3: Slopes percentages.

2.3 Population framework

When analysing the population census data for the years 1991 to 2011, produced by the national institute of statistics (INE) some important information related to regional demographical trend can be extracted (Table 1).

The total population for the year 1991 corresponded to 253 476 inhabitants, in 2001 a decrease for 245 011 and for the year 2011 an increase to 267 785 inhabitants. In terms of population is mainly, concentrated in the city of Funchal with 111 892 in 2011, followed by Santa Cruz that presents 43 005, Câmara de Lobos with 35 666, Ribeira Brava with 13 375, Calheta with 11 521 and Ponta do Sol with 8 862. In the North part of the island, Santana holds 7 719 inhabitants.

Municipality	Population 1991	Population 2001	Population 2011	Variation rate 91-11 (%)
Calheta	13 055	11 946	11 521	-12 %
Câmara de Lobos	31 476	34 614	35 666	13 %
Funchal	115 403	103 961	111 892	-3 %
Machico	22 016	21 747	21 828	-1 %
Ponta do Sol	8 756	8 125	8 862	1 %
Porto Moniz	3 432	2 927	2 711	-21 %
Porto Santo	4 706	4 474	5 482	17 %
Ribeira Brava	13 170	12 494	13 375	2 %
Santa Cruz	23 465	29 721	43 005	83 %
Santana	10 302	8 804	7 719	-25 %
São Vicente	7 695	6 198	5 723	-25 %
Total	253 476	245 011	267 785	6 %

Table 1: Population and variation per municipalities Census 1991,2001 and 2011, in INE.

The population density is higher in Funchal followed by Câmara de Lobos, Santa Cruz and Machico (Figure 4) with the rest of the island ranging 35 to 191 inhabitants per km^2.

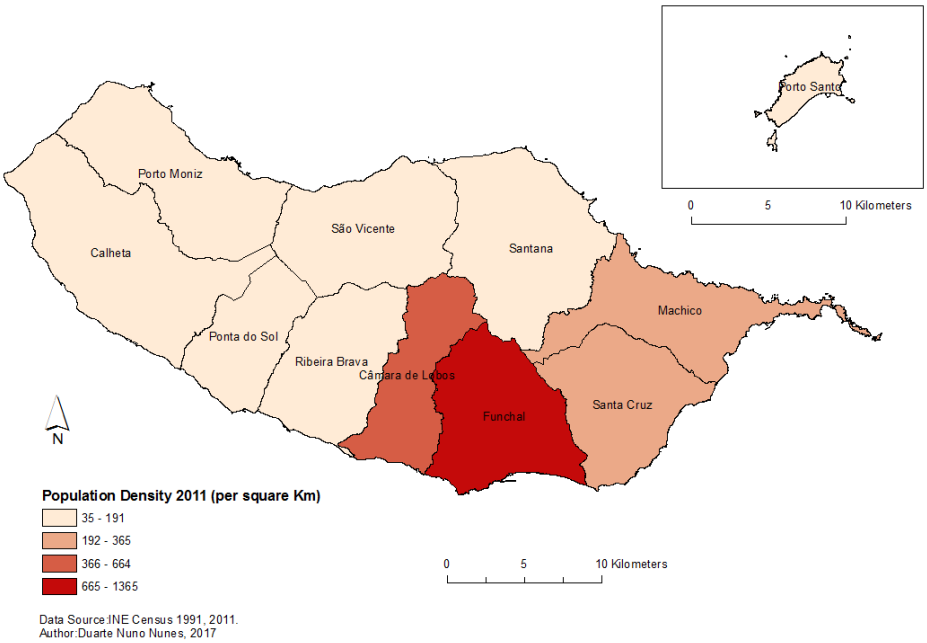

Figure 4: Population density in 2011 per km^2 and municipalities.

In terms of the population variation rate from 1991 to 2011 (Figure 5), a significantly higher percentage is found in Santa Cruz with 83% followed by the municipality of Câmara de Lobos with 13% and Ribeira Brava with 2%, meaning growth of population. On the contrary, the municipalities that lost a significant amount of population comprehends Santana with -25% and São Vicente with the same value. Followed by Porto Moniz with -21%. Calheta with -12%. Funchal with -3% and Machico with -1%.

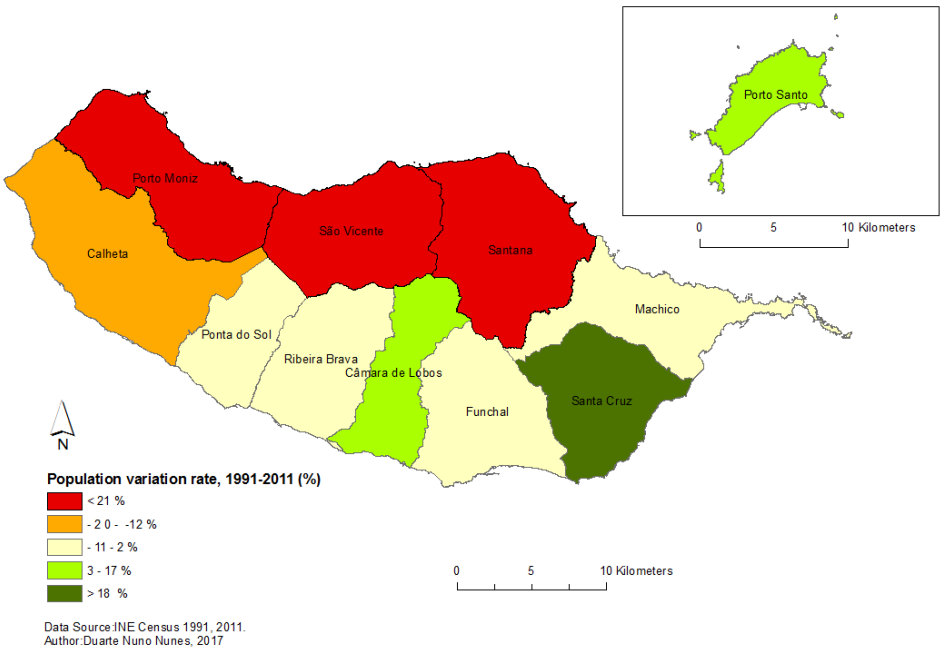

Figure 5:Population variation rate 1991-2011, INE Census.

3.Data and methods

3.1 Data and tools

During this study it was used data from several sources, the LULC from the CORINE Land Cover (Coordination of Information on the Environment) freely available (https://land.copernicus.eu/pan-european/corine-land-cover), providing information regarding LULC for many political directives (Water Framework Directive, Habitats Directive). Considered the most comprehensive dataset for terrestrial ecosystems at the EU level (Maes, 2018) and a major advance establishing a common methodology and classification in Europe (Geist, 2005).

It's a product derived from remote sensing technology in which it has been maintained the same framework and resolution from 1990 until 2012 enable comparisons among Europe (Table 2). The minimum mapping unit is 100 meters.

Specification	CLC 1990	CLC 2000	CLC 2006	CLC 2012
Satellite data	Landsat 5 MSS/TM single date	Landsat 7 ETM single date	SPOT 4/5 and IRS LISS III dual date	IRS LISS III and RapidEye dual date
Time consistency	1986-1998	2000 +/- 1 year	2006 +/- 1 year	2011-2012
Geometric accuracy	50 m	25 m	25 m	25 m
Minimum Mapping Unit	100 m	100 m	100 m	100 m
Geometric accuracy	100 m	Better than 100 m	Better than 100 m	Better than 100 m
Thematic accuracy	≥ 85% (probably not achieved)	≥ 85% (achieved)	≥ 85% (not checked)	≥ 85%
Production time	10 years	4 years	3 years	2 years
Documentation	Incomplete metadata	Standard metadata	Standard metadata	Standard metadata
Countries involved*	27	35	38	39

Table 2: Evolution of CORINE Land Cover (Buttner, 2014).

*Including late integration.

The Corine Land Cover is divided into three levels, the first level divided into 5 items with major categories the second level comprise 15 items and the third level with 44 items with a higher detailed categorization of the mapped features.

Table 3 presents the data and sources. Municipalities delimitation for a spatial explicit tool of analysis is used with the official government data of administrative limits. The digital elevation

model was used to derive elevation and slopes. Shapefiles from protected areas were provided by the official governmental institute of Madeira. The roads network was accessed with the Open Street Map information (https://www.geofabrik.de/data/download.html).

Data	Format	Source
Administrative Limits	Shapefile	General Directore of Territory
Corine Land Cover per year, 1990,2000, 2006,2012	Tiff	Copernicous Monitoring Services
Digital Elevation Model	Tiff	U.S. Geological Survey, Aster Digital Elevation Model
Madeira Protected areas: Natura 2000, Natural Park, Natural reserves	Shapefile	Institute of Forests and Nature Conservation, IP-Madeira
Roads network	Shapefile	Open Street Map

Table 3: Data and Sources.

The tools used during the execution of the present work was the GIS software ArcMap 10.5 and its Patch Analyst plugin by (Rempel, 2008) TerrSet with the Land Change Modeler (Eastman, 2016) and QuantumGIS 3.4.2.

3.2 Methods

The pre-processing part was done in the different Land Cover files, to extract the study area from the total raw extent included when using the CORINE Land Cover. The CORINE Land Cover of 1990, 2000, 2006, 2012, were reclassified from the legend level 3 to legend level 2. Where 12 classes are found in Madeira Island, and the class "burnt areas" was included in the "Open Spaces with little or no vegetation", since only in the year 2012 this category appeared due to forests fires. All the shapefiles are integrated into the TerrSet software with the same parameters (Table 4), namely: legend; categories sequence; backgrounds value of zero; spatial dimensions in terms of resolution and coordinates

Settings	
Columns:	558
Rows:	418
Resolution:	100 x and 100 y
No-data value:	0
Coordinate system:	ETRS 1989 LAEA
Extent:	Left: 1788904.1054 Top: 1544630.9392 Right: 1844704.1054 Bottom: 1592830.8392

Table 4: Shapefiles specifications used

The processing component was conducted in the Land Change Modeler an integrated LULC modelling and environmental assessment module (Eastman, 2016).

Exported to ArcMap 10.5 the application of the plugin Patch Analyst to calculate landscape metrics to assess impacts on ecosystem services. All the transitions below 1% of the total landscape was exclude from the analysis but presented in the annexes.

3.2.1 Modelling land use/cover change

The modelling was conducted in the Land Change Modeler of TerrSet. A stepwise process with the early map of CLC 1990 (time 1) and later map 2012 (time 2).

Fitted with the typical land change modelling process (Meyer and Turney 1992; Silva and Clarke 2002; Pontius and Chen, 2006), it was investigated quantitively land historical changes occurring in our study area and selected these transitions to build models for our scenarios.

With this step, we produce a change map, as an input for the transitions sub-model. In transition sub-model, the transitions are grouped since empirically we assumed to be affected by the same driven factors for the changes (Eastman, 2016). Meaning that for example: a transition of heterogeneous agricultural areas to Urban fabric and/or forests to urban fabric are driven by the same variables.

Using the Cramer's V measure, the assessment of driven variables is conducted to selected variables that possess a higher value of the measure which then explain the historical changes.

The driven variables are then integrated into the change prediction, the Multilayer perceptron is used to produce a potential of land for a transition. With the potential of land for transition, it is possible to predict a future scenario for a specific date.

The model will determine how the driven variables influence future change, how much change took place between time 1 and time 2, and then calculate a relative amount of transition using Multi-Layer Perceptron Neural Network a powerful modelling tool (Bishop, 1995) to the future date with Markov chain matrix.

After this, a LULC for the year 2040 is produced and the interactive process with remodelling in transitions sub-model to simulate four different scenarios the main outputs (Figure 6).

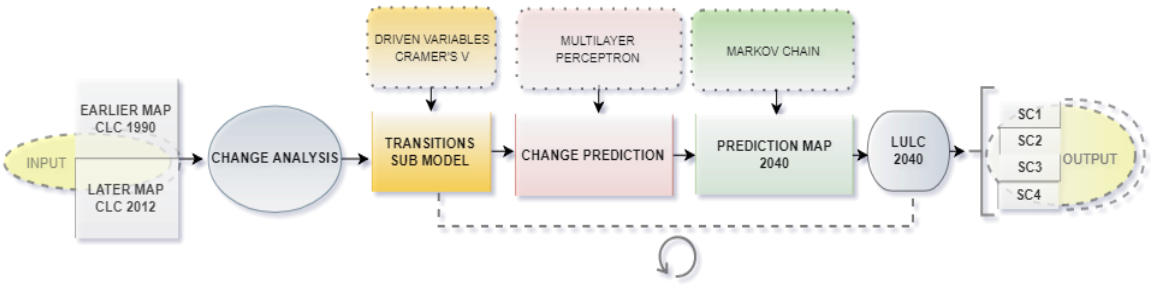

Figure 6: Land Change Modeler, workflow.

The output was then exported to ArcMap 10.5 and the plugin Patch Analysist is used to calculated landscape metrics at the landscape level and class level.

3.2.2 Change analysis 1990 to 2012

The Land cover transitions from 1990 to 2012, were grouped into a single sub-model since the underlying driver of change is assumed to be the same for each transition (Pérez-Vega et al., 2012).

Diverse physical and human geography specificities of Madeira Island were considered to predict future changes for the period of 2040. Factors that potentially explain and consists in the main actors for the changes occurred among the period of 1990 to 2012, within the landscape.

Drivers of changes can be seen related to proximity factors or driving forces from which an impulse occur and change the state result (Geist, 2005) consisting in a GIS datasets representation (Pérez-Vega et al., 2012).

The selection of the driven variables was accounted from the general literature review (Olmedo et al., 2018; Mas et al., 2014) studies in Madeira Island (CLIMA-Madeira, 2015) and information from Regional governmental institutions (Institute of Forest and Nature Conservation), since specificities of the location and physical context rise the need to explore variables, which evokes the land change process, accounting assertive regional context.

The usefulness of each variable selected is identified with the use of Cramer V's measures consisting in a product of a contingency table analysis (Eastman,2016) indicating the potential explanatory power of each selected variable. The variables consist of a separated shapefile. The measure ranges from 0.0 indicating no correlation to 1.0 corresponding to excellent explanatory power (Eastman, 2016; Megahed et al., 2015). In total it was created and tested 11 variables that were believed to drive the changes (Table 5).

Elevation of the island, since it ranges from 0 to 1862 meters, the assumption is that areas with a lower value of elevation are more susceptible to changes than higher values.

The slopes factor, since higher percentage of this variable, will be less suitable for changes.

The distance to the coastal areas due to the development of economic and political activities near the coast, where historical settlements took a step for this tendency.

The distance to urban areas in 1990, we assume that areas that were closer to these areas were more vulnerable and likely to have transitions, a neighbouring effect of urbanization in which surrounding areas will suffer changes.

The distance to disturbance were agricultural areas and urban fabric from 1990 can drive the changes occurred until 2012, due to the proximity.

In the distance to roads variables, two main procedure was taken since the raw shapefile from Open Street Map, contained 23.936 polyline features for our study area. But, our intend analysis is to depict the effect of roads on driving the changes, consulting auxiliary documentation of Open Street Map, to guide volunteers, when attributing the classification per each polyline, accordingly with the description of no roads features, it was then removed the polylines classified has: path (1069 km); bridleway (658 m); track (468.8 km); track grade (169 km); steps (69 m); footway (375.6 km) ; pedestrian (40.30 km) and cycleway (1 km).

Plus, the island possesses a significant number of tunnels, 452 with a total of 137 km. Not every tunnel is for traffic use, 160 features are integrated into paths a total of 29 km and

footways, with 37 features corresponding to 6.6 km. For traffic use, 249 features are integrated into highways with a total of 101 km. Being 2 of these tunnels with a length of 3 km, 7 with 2km and 16 with 1 km. It could not be assumed that the extension of the tunnel will affect changes, since they are underground passage way and enclosed, except the entrance and exit, then only the end and a start point of these features were considered. The distance to roads variables had a final value of 14.726 features.

Driven variable	Assumption	Source for selection:
Distance to capital	Attractiveness factor	Eastman (2016)
Distance to coastal areas	Change processes are increasing near coast	CLIMA-Madeira (2005)
Distance to disturbance	Agricultural and urban areas in 1990, closer areas will tend to be more vulnerable to change	Eastman (2016); Correia (2015)
Distance to interior	Change processes are increasing towards interior areas, due to previous settlements near coast	CLIMA-Madeira (2015) and CMF (2014)
Distance to Natura 2000 Network	Proximity to protected areas	Eastman (2016)
Distance to Natural park	Proximity to protected areas.	Eastman (2016)
Distance to roads	Areas closer to roads will be more likely affected by changes.	Eastman (2016); Leitão (2012); Cheng and Ding (2016)
Distance to South	Location of 85% of the island population	National Institute of Statistics Census 1991 and 2011.
Distance to urban centres in 1990	Areas closer to earlier urban centres have a higher change to be affected by urbanization	Eastman (2016)
Elevation	Areas of low elevation will tend to suffer a higher rate of changes (e.g.: better climatic conditions)	Quintal (2007); CLIMA-Madeira (2015); Chen and Ding (2016)
Slopes	Areas with lower values will be more likely to suffer change processes	Eastman (2016); Chen and Ding (2016)

Table 5: Driven variables.

3.2.3 Change prediction and validation

For the change prediction, it was applied the multilayer perceptron Neural network, a machine learning technique where the accuracy rate of the training should be achieved around 80% (Eastman, 2016). It consists of several interconnected nodes which are simple processing elements that respond to the weighted inputs received from other nodes (Atkinson and Tatnall, 1997). It uses several hidden layer nodes in which automatically evaluates and weights factor considering the correlations between the explanatory maps (Eastman, 2016). It flows unidirectionally from the input layer and the output layer (Du and Swamy, 2014; Bishop, 1995).

Its performance depends not only of the choice of the driven variables, number of hidden layers, nodes and training data but also the training parameters such as the learning rate value, momentum controlling the weight change and the number defined of iterations (Mas et al., 2014; Taud and Mas, 2018). As suggested by Eastman (2016) the default values were used during this process.

In the MLP half of the training data are randomly selected for the learning process and other half for the validation. Testing how well the model performed at predicting change with the skill measure, consisting of the accuracy of transition prediction minus the accuracy expected by chance (Mas et al., 2014), ranging from -1 to +1 and 0 indicating a skill no better than random allocation (Eastman, 2016; Cohen, 1960).

It can handle multiple transitions at once and the explanatory variables are the same (Abuelaish, 2018). A multivariate function predicting the potential for a pixel to transition based of the values of the driven variables for that pixel (Eastman, 2016) the output consists in transitions potentials maps for each transition modelled with a continuous value from 0 to 1 (Eastman, 2016).

With the transition potential map, the Markov chain method is applied consisting in a probability of a system being in a certain state at certain time (Kamusoko et al., 2019) commonly used in land change models (Olmedo and Mas, 2018; Ozturk, 2015) and environmental modelling (Paegelow and Camacho, 2008).

The time set for the application of the probabilistic method is the year 2040, producing the probabilistic matrix of change determining the amount quantity of land for transition from one category to another in 2040 (Olmedo and Mas, 2018; Eastman, 2016) with a simple power of

the base matrix (Kemeny and Snell, 1976). It is produced two future land cover maps: soft prediction and hard prediction. The soft prediction is only the probability for a cell to experience land cover change. On contrary, the hard prediction identifies the new land cover based on multi-objective land allocation module (Eastman, 2016; Houet and Hubert-Moy, 2006).

The change prediction process integrated constraints (Table 6) the shapefiles specifically created, will consists in a mask: a value of 0 on areas treated as absolute constraints on the and value of 1 are unconstrained and able to suffer changes (Eastman, 2016) incorporated in the planning tab from the LCM. Given the regional context with a significant specific geomorphological structure, two main constraints variables were selected.

Elevation, since higher values of this variable, will not be suitable for land change, due to natural conditions with lower temperatures, a higher percentage of humidity but also anthropogenic factors, with low infrastructures and anthropogenic activities. At the same time, although the main human-induced changes have occurred within lower elevation areas, there is a need to consider the Laurel forest and transition areas of agriculture. The defined elevation range for no consideration of changes was 800 meters based on IFNC (2013).

Another important factor to determine changes in the landscape is the variable of slopes. The assumption that lower values of slopes will be more likely to face changes.

The slope constraint selected was the value of 25%, based on Oliveira (2015) meaning that areas with this and higher value will not be considered to changes in our model and future scenarios.

The areas with these attributes will not be considered for future changes in our modelling process corresponding to 41.93% of our study area.

Constraints	Value	Percentage in landscape	Total constraint (%)	Source for selection:
Elevation	Equal or higher than 800 meters	38.18	41.93 %	Institute of Forests and Nature Conservation Madeira (2013)
Slopes	Equal or higher than 25 %	30.03		Oliveira (2015)

Table 6: Elevation and slopes constraint.

Four scenarios were modelled to 2040, with certain assumptions to explore plausible alternatives:

- Scenario Business as Usual (SC1): A continuation of the past changes; nature conservation is weak; little concern for biodiversity (Rounsevell et al.,2003); urban expansion; an increase of population.
- Scenario Conservation of Agriculture (SC2): Conservatives initiatives to protect these areas; Stimulation by European Union and Regional policies for production and integrity of agricultural activities.
- Scenario Conservation of Forests areas (SC3): Strict protection of areas with high biodiversity; Conservation policies and measures considered; Laurel forest protection.
- Scenario Renaturation (SC4): Assertive population decrease prospects (DREM, 2018); stationary urban expansion; abandonment of agricultural areas; natural transitions (Shrubs to Forests; Shrubs to Open Spaces).

Using the CLC of 1990 and 2000 it was simulated a prediction for the year 2012 and compared with the actual real CLC 2012 for validation (Table 7). With this comparison, we calculate the number of correct predictions (Hits), the predicted persistence of areas (Null success) and errors due to observed change predicted to persist (Misses) and observed persistence predict as change (False alarms). Moreover, the identification and quantification of the error in terms of allocation and quantity allows to depict an overestimation or underestimation of the prediction. The intensity analysis in applied to identify if different intensity rates of change are influencing the prediction and its performance.

Three main approaches are performed to do validation: Figure of merit and ratios (Hits, Misses and False alarms) by Pontius et al. (2008) the intensity analysis by Aldwaik and Pontius (2012) and quantity and allocation proposed by Pontius and Millones (2011).

Measure	Formula	Source:
Figure of merit	$FoM = \frac{H}{(H+M+F)} \times 100$	Pontius et al., 2007; Estoque and Murayama (2012)
Ratio of Hits	$HOC = \frac{H}{(H+M)}$	
Ratio of Misses	$MOC = \frac{M}{(H+M)}$	
Ratio of False alarms	$FOC = \frac{F}{(H+M)}$	
Quantity and allocation		Pontius et al., 2010
Error quantity	$\boldsymbol{Q} = \lvert(\boldsymbol{F}+\boldsymbol{H}) - (\boldsymbol{M}+\boldsymbol{H})\rvert$	
Error allocation	$\boldsymbol{A} = (\boldsymbol{F}+\boldsymbol{M}) - \boldsymbol{Q}$	

Table 7: Validation measures.

* H=Hits, M=Misses, F= False alarms

3.2.4 Impact of land change on ecosystems services

A considerable amount of metrics is available nowadays, as such the selection of variables that are appropriate to measure intending to achieve the desired ability to discriminate among different landscape types can be challenging. A further complication is to decide on an appropriate measurement scale. Spatial scale is known to affect observed patterns in landscapes (Wiens, 1989).

To assess the impact on ecosystem services it was used the landscape metrics referred in Burkhard and Maes (2017) in the CLC from 1990 to 2012 and from the predicted 2040 scenarios applied among the different classes accordingly with the author (Table 8). These metrics are applied in terms of the patch level and landscape level (McGarigal et al., 2002).

The dimension of biodiversity using the Shannon's Diversity Index in the landscape for all classes the patch density is represented with the number of patches since the landscape area is constant.

Provisioning services, with total patch area in km^2 for potential production of biomass in forest areas class and production of food for the class arable land, consisting in the aggregation of the classes: Arable land; Permanent crops; Pastures and Heterogeneous Agricultural areas.

The assumption: increase of areas will allow a higher production and performance of the service.

Regulating service with Shannon's Diversity index of agricultural areas to assess pest control and edge density of forests an effective tool for evaluating the effects of patch shape and area on the abundance of habitat edge (Hargis et al., 1998; Wallin et al., 1994) which is commonly used (Verhagen et al., 2018; Zulian et al., 2013; Bommarco, 2012).

Cultural services with a total of patch area of forest and arable land. Patch area for forest due to its touristic attractiveness factor and protected area (Van Berkel and Verburg, 2011) and agricultural areas represented by the same procedure has arable land. Limited information is available to assess cultural services in Europe (Maes et al., 2015). In our analysis we recognize the forest areas has a recreation opportunity (Maes et al., 2015), more land is protected and there is a positive trend in the opportunity for citizens and tourists to access these areas with significant recreation potential (Maes et al., 2015). Along with the laboured terrace agriculture landscape since in Madeira Island are part of the islander's identity (Vieira, 2017; Kiesow and Bork, 2017; Santos et al., 2014; Silva, 2013; Quintal, 2010). Mean shape index of forest contributes to aesthetic value (Dramstad et al., 2006; Herbst et al., 2009) Further explanation of landscape metrics (see McGarigal, 2015).

Metric name	Formula	Units	Description	Use in ES (Burkhard and Maes, 2017)
Edge density (ED)	$ED = \frac{E}{A}\ (10{,}000)$ E = total length (m) of edge in landscape A = total landscape area (m^2)	Meters per hectare	The total length of all edge segments per ha for the class or landscape of consideration (unit: m/ha).	Regulating services: Habitat provision for pollination.
Mean shape index (MSI)	$MN = \frac{\sum_{j=1}^{n} x_{ij}}{n_i}$ Sum all patches n_i = number patches same type	Meters per hectare	Average complexity of patch shape for a class (the index is 1 when square, and increases without limit as the patch becomes more irregular).	Cultural service: Landscape aesthetics
Patch area (PA)	Aij Aij =area (m^2) of patch ij.	Km^2	Area (m^2) of the patch.	Provisioning services: Production of food and biomass
Patch density (PD)	n_i Number of patches in the landscape of patch type (class) i	None	Number of patches of the corresponding patch type.	Dimension of biodiversity: Landscape diversity

Shannon's diversity index (SDI)	$SHDI = \sum_{i=1}^{m} (P_i * \ln P_i)$ P_i = proportion of the landscape occupied by patch type (class) i.	Information	A measure of patch diversity in a landscape that is determined by both the number of different patch types and the proportional distribution of area among patch types	Dimension of biodiversity: landscape diversity Regulating services: Pest control

Table 8: Metrics used for assessment of ecosystem services.

4. Results

4.1 Land change analysis 1990 to 2012

The most representative classes in Madeira's landscape in 1990 was forests with 43% (316 km^2), Shrubs/herbaceous vegetation with 25% corresponding to 188 km^2, agricultural areas with 18% an area of 130 km^2 and Urban fabric with 10% (72 km^2) and the remaining 4% distributed by 8 classes, 35 km^2.

The land change process in Madeira island is differentiated along the period analysed from the CORINE Land Cover, figure 7. From 1990 to 2000 the major change occurred in the urban fabric, with a total gain in percentage of the landscape being 3.92% representing 29 km^2. The heterogeneous agricultural areas decreased its representativeness by -3.11% approximately 23 km^2.

In the period 2000 to 2006, a percentage variation of 1.23% of Shrub class adding 9 km^2 to the landscape. The urban fabric had a growth of 4.8 km^2. Forest areas lost -4.41 km^2 and agricultural areas, -2.88 km^2.

From 2006 to 2012 a major loss of forest areas with -25.59 km^2. Followed by Shrub class with -21.59 km^2. The gains occurred mainly in the open spaces class with 46.83 km^2. The changes in urban fabric and heterogeneous agricultural areas are residual.

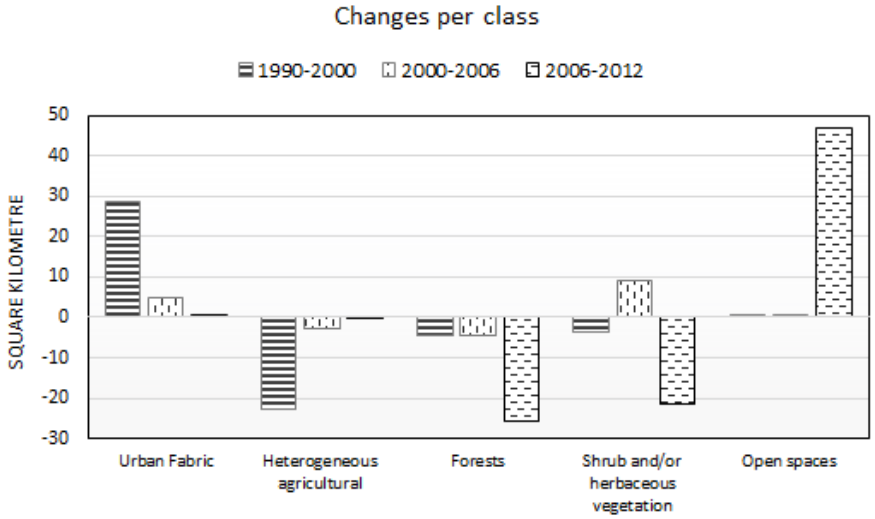

Figure 7: Land changes from 1990 to 2012, km^2.

The contributions for net change of the classes are: Heterogeneous agricultural areas to urban fabric with 26.9 km^2; Forests to Urban Fabric with 3.22 km^2; Forests to heterogeneous agricultural areas (3.34 km^2); Forests to open spaces with 22.54 km^2; Forests to Shrub with 4 km^2; Pastures to Shrubs with 4.41 km^2; Shrubs to Open spaces with 24.76 km^2; Shrubs to Forest with 4 km^2 and Heterogeneous agricultural areas to Shrub with 3.84 km^2.

Spatially (Figure 8) the change map depicts a tendency in the south part of the island concentrated along Câmara de Lobos, Funchal, Santa Cruz, Machico and Santana, a higher prevalence of transitions from heterogeneous agricultural areas to the Urban fabric. Forests to Urban fabric located in Santa Cruz, Funchal, Calheta and Santana.

Forest to Heterogenous agricultural areas located mainly in the northwest of Calheta and Santa Cruz.

In the higher altitude areas of Funchal, Câmara de Lobos, Calheta the transitions from Forests to Shrubs, Forests to Open spaces, Shrub to Open spaces gains significance.

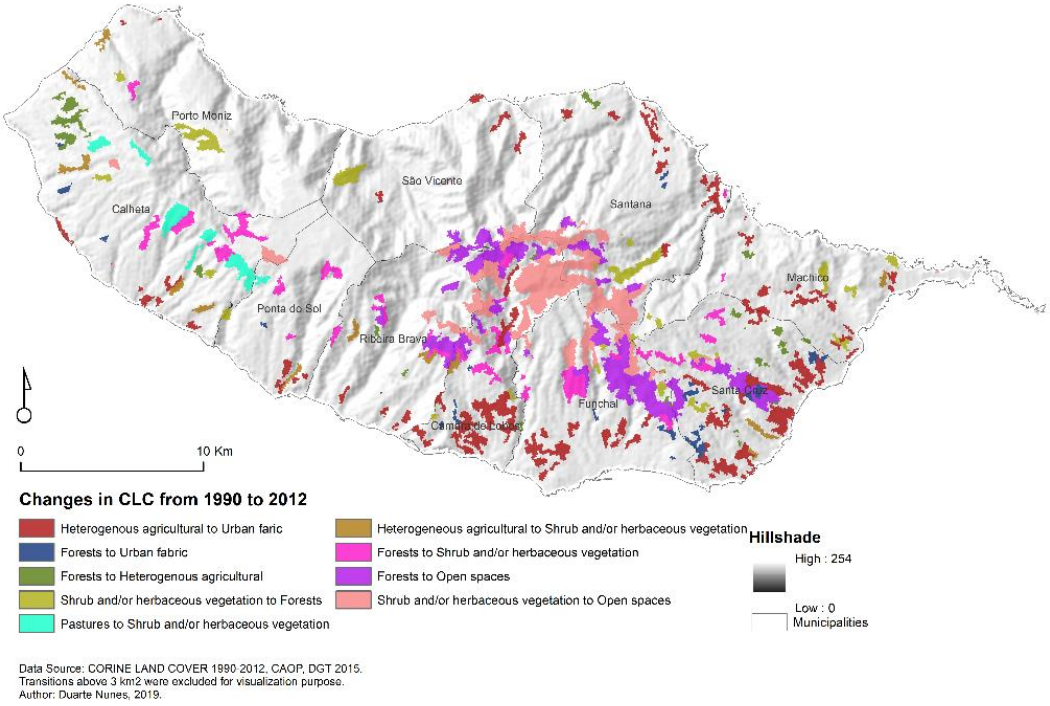

Figure 8: Change map 1990 to 2012.

In the explanatory driven variables, elevation possesses the higher Cramer's V measure meaning this natural variable is conditioning changes, followed by distance factors: to interior, urban centers in the year of 1990; to coastal areas; to south; to disturbance; to capital; to Natural 2000 Network; to roads, to natural park and finally slopes.

We can interpret that the changes and transitions that occurred in the period of 1990 to 2012 are being most influenced by these factors (Table 8).

Driven variable	Cramer's V
Elevation	0.2536
Distance to interior	0.2355
Distance to urban centers in 1990	0.2318
Distance to coastal areas	0.2088
Distance to south	0.2053
Distance to disturbance	0.1999
Distance to capital	0.1887
Distance to Natura 2000 Network	0.1778
Distance to roads	0.1628
Distance to Natural Park	0.1610
Slopes	0.1404

Table 8: Driven variable Cramer's V results.

4.2 Model validation

The accuracy rate for our models (Table 9), had a higher percentage in SC2 with 83.95% followed by SC3 with 75.5% and finally SC1 with 71.67%. The decreasing value of the accuracy is related to the complexity of the transitions that were modelled, plus the ability of each variable to explain these transitions. This represents a positive accuracy rate, meaning that the variables selected to possess a strong explanatory power for the changes occurring in our study area.

Model	Accuracy rate	Skill measure/Kappa
SC1	71.46 %	0.6789
SC2	83.95 %	0.7993
SC3	75.59 %	0.7071
SC4	71.67 %	0.6695

Table 9: Scenarios accuracy

Concerning the validation of our simulated LULC 2012 (Table 10)., a significantly low value of Figure of Merit is encountered 1.54% considered, a less than null model since the percentage is lower than 15% (Pontius et al., 2008).

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Measure	Result
Figure of Merit	1.54 %
Ratio of hits	0.02
Ratio of misses	0.98
Ratio of false alarms	0.29

Table 10: Validation measures results.

Since it was used the earlier CLC 1990 and CLC 2000, the remaining change a period from 2000 to 2012 is assumed to be the same.

As such the intensity analysis allow us to assess and depict the main trends on each period accordingly, with the intensity of land change (Pontius et al., 2013). Using the period rate (1990 to 2000) and comparing with 2000 to 2012, we can detect visually and quantitively, which pathway changes occurred more significantly (Figure 9).

It was used the percentage of variation, per category and the whole value of the landscape.

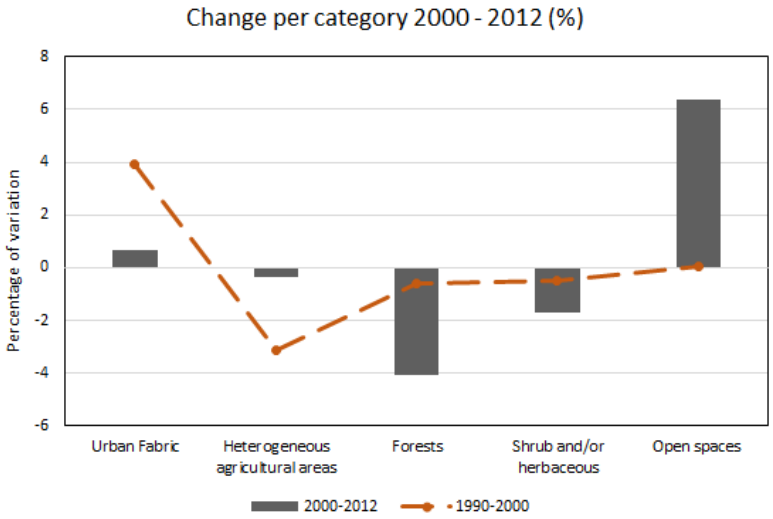

Figure 9: Intensity analysis percentage of variation.

As such, we can see that different trends are taking place in terms of its intensity and per category.

First period (1990 to 2000) the main gain occurred in the Urban Fabric with 3.92% and the losses in Heterogeneous agricultural areas -3.11% and less significance for the forest (-0.61%) and residual value for Shrubs (-0.05%) and Open Spaces (0.06%).

In comparison with the period 2000 to 2012, an opposite trend occurred, an expressive higher gain in Open Spaces with 6.35% followed by Urban fabric with 0.68%. The losses occurred mainly in Forests (-4.97%) and Shrub (-1.69%). This shows that model accuracy is highly dependent on the comparison interval selected.

Applying the error allocation and quantity validation procedure we can identify an 83% of null success of correct observed and predicted persistence of the total landscape (Figure 10)., only 0.42% of correct observed change predicted as changes, 15.31% of error due to observed change predicted as persistence and 1.15% of error due to observed persistence predict as change. Our model predicted 1.67% of change and, occurred 15.73% of observed change from the CLC 2000 to CLC 2012. Our simulated 2012 underestimated the changes.

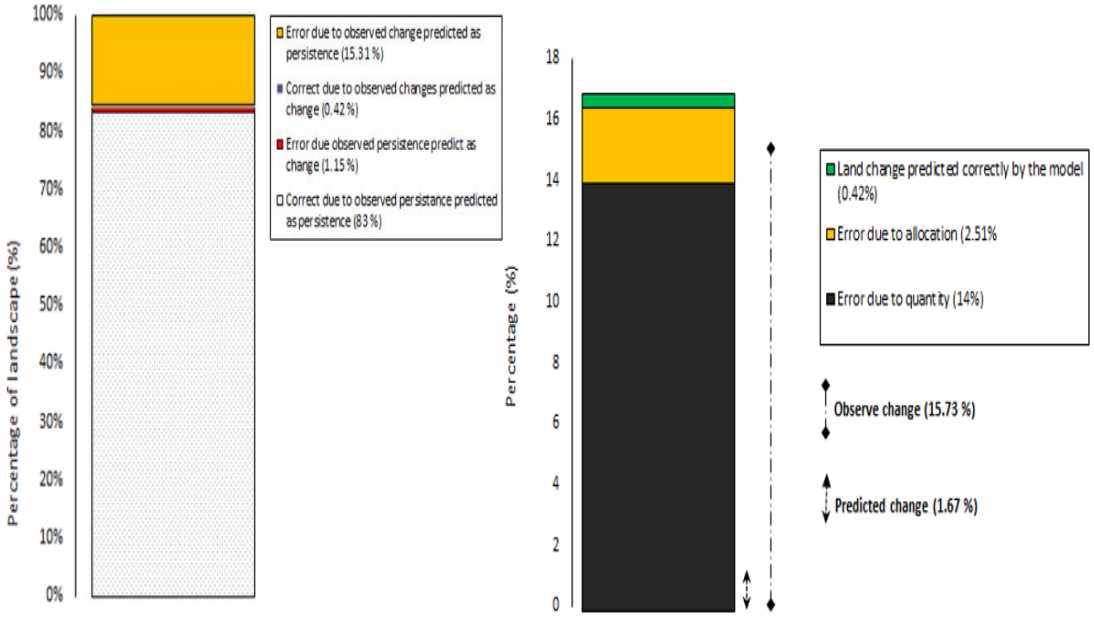

Figure 10: Error allocation and quantity.

Nonetheless, with intensity analysis and the good accuracy reached from the MLP and driven variables, it was decided to produce the scenarios for 2040 since it is intended to produce plausible scenarios for a distancing period of 28 years.

4. 3 Land change modelling 2040

In the urban fabric class, the SC1 present the higher value of variation with a growth of 33.62 km^2, followed by SC3 with 29.74 km^2, in lower value the SC2 with 0.49 km^2. This class is predicted to have a neutral change value for SC4. In terms of the results for the percentage of the total landscape in SC1, SC2, SC3 and SC4 it will represent 18.77%, 14.75%, 18.24% and 14.23%, respectively.

Heterogenous agricultural areas possess a decrease in every scenario except SC2, higher loss in SC3 with -37.24 km^2, followed by SC1 with -23.37 km^2 a value of -4.22 km^2 for SC4, and a growth of 4.92 km^2 in SC2. The percentage of the total landscape will correspond to 10.91 %, 14.72 %, 10.24 %, 13.49 % for SC1, SC2, SC3 and SC4.

Forests area predicted to decrease in the four scenarios being with higher intensity in SC4 with -5.62 km^2, followed by SC2 with -3.23 km^2 and SC1 with -1.24 km^2. In the scenario SC3 the change is residual. The total landscape percentage for each scenario will be 36.72 % in SC1, 36.69 % in SC2, 37.87 % in SC3 and 35.86 % in SC4.

The class Shrub and Open spaces are predicted to possess changes a negative value of -25.09 km^2 and a gain of 47.69 km^2, respectively with Open spaces.

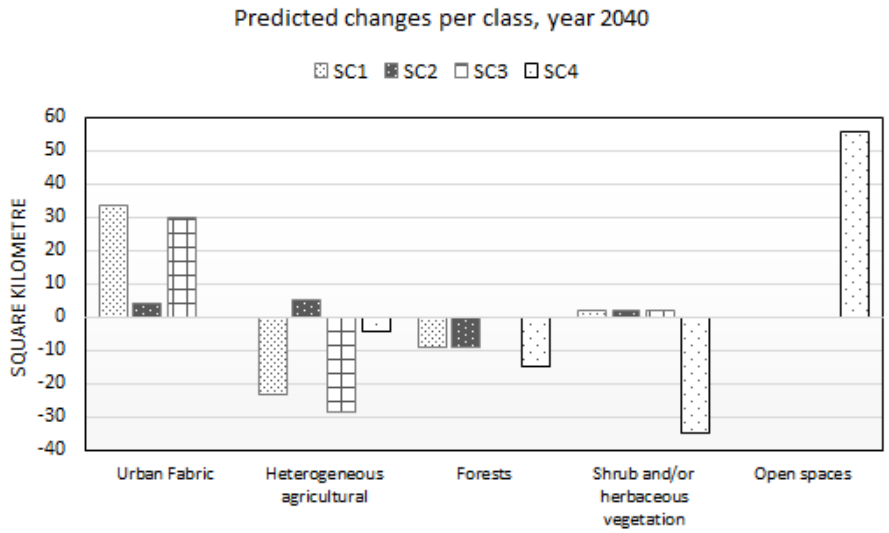

Figure 11: Predicted changes Scenarios 2040, km^2.

When analysing spatially (Figure 12), we can depict a tendency for a continuous transition in the south part of the island.

Five main transitions are expected to occur in the Business as usual scenario (SC1): Heterogenous agricultural areas to Urban fabric with -23.37 km^2, with significant transition in every municipality except Porto Moniz; Forest with a loss to Urban fabric and Heterogenous agricultural areas a total of -8.8 km^2; Pastures to Shrub with -1.82 km^2; Permanent crops to Urban fabric with -1.45 km^2. Calheta municipality is exclusively presenting the transition from Forests to Urban fabric and Forests to Heterogeneous agricultural area with São Vicente.

Concerning SC2, three main transitions are presented: Forests to Urban fabric with -3.88 km^2 in Porto Moniz, Calheta, Santana, Machico and Ribeira Brava. Forests to Heterogeneous agricultural areas with -8.8 km^2 in Calheta, Ponta do Sol, São Vicente. Pastures to Shrub with -1.82 km^2 in the neighbouring of Calheta and Porto Moniz.

In SC3 three main transitions occur: Heterogeneous agricultural areas to Urban fabric with -28.29 km^2 disperse across the island, higher areas of Santa Cruz, Câmara de Lobos, Ribeira Brava, Santana with lower expression in Machico and Funchal; Permanent crops to Urban fabric with -1.45 km^2 located in the neighbouring limits of Funchal and Câmara de Lobos; Pastures to Shrub with -1.82 km^2. On contrary to SC1, the north part of the island namely the municipalities of Porto Moniz and São Vicente presents the transitions from Heterogeneous agricultural areas to the Urban fabric.

For SC4, five transitions are predicted: Shrub to Forest and Open spaces with -34.58 km^2 located mainly in the higher areas of Funchal, Câmara de Lobos, Santa Cruz and Santana; Forest to Open spaces with -20.99 km^2 mainly in the south part of the island; Heterogenous agricultural areas to Shrub with -4.22 km^2 distributed in São Vicente, Santana, Calheta, Ponta do Sol and Ribeira Brava.

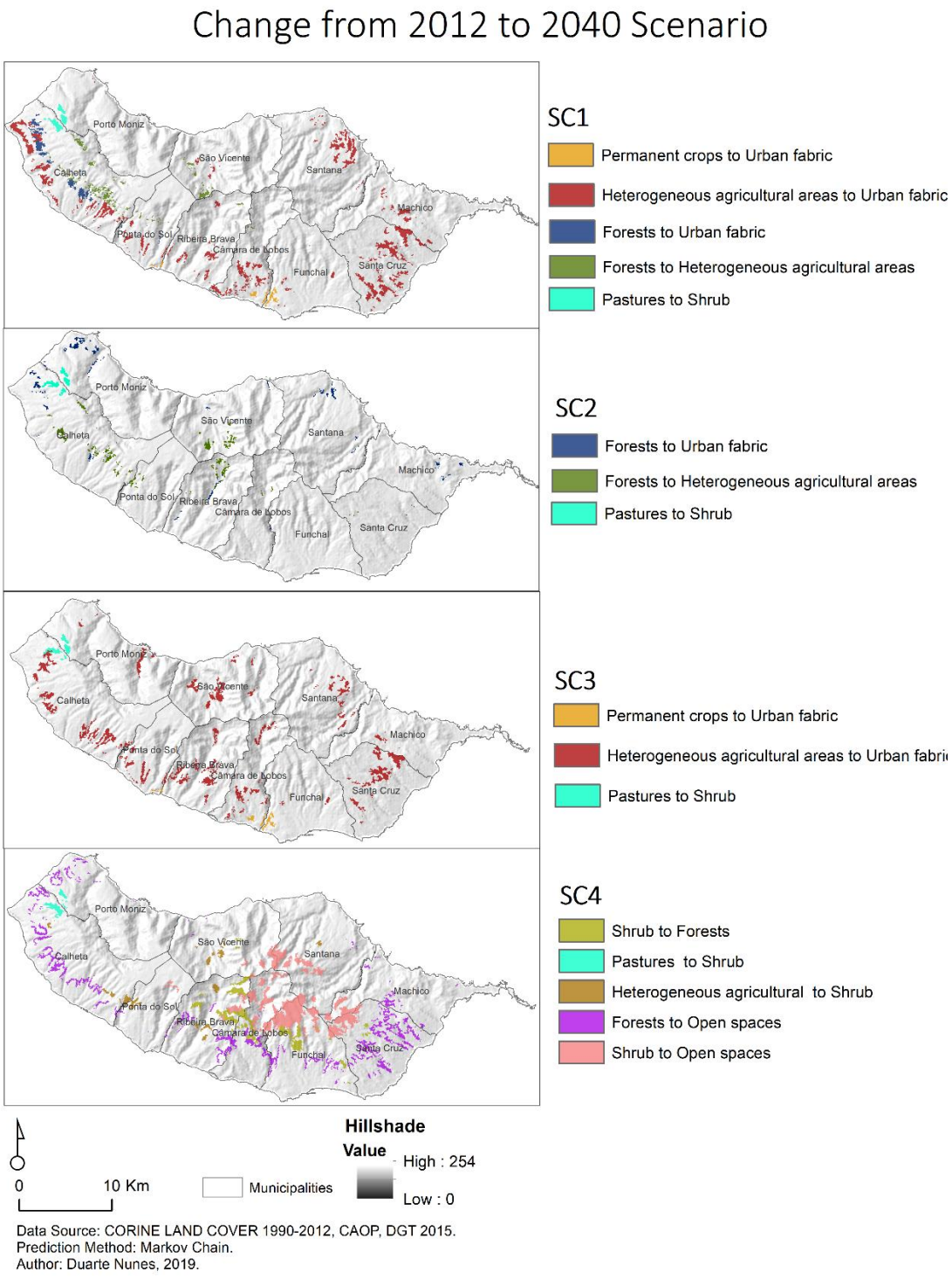

Figure 12: Transitions change map 2040 scenarios.

4.4 Impact of land change on ecosystems services

Impacts of the land change on ecosystem services can be identified in Figure 13, representing the past and present trends with the 2040 scenarios comparison. The change is accounted for the reference year 2012.

The dimension of biodiversity, Shannon's diversity measure in the landscape indicates a value of 1.47 in 1990, 2000 with 1.50, 2006 with 1.47 to 1.59 in 2012. Concerning the scenarios, the higher value is for SC4 with 1.64 followed by SC2 with 1.60 and SC1 with 1.58. The patch density is successively increasing from 381 in 1990 to 455 patches in 2012, with a significant increase for 2040 for all scenarios. A higher number is found in SC4 with 890 patches, followed by SC1 with 868, SC3 with 747 and finally the lower value, for SC2 with 660. In terms of the Forests patch numbers, it possesses 38 in 1990, 64 in 2012. For SC1 and SC2 a value of 123, 64 for SC3 and 153 for SC4.

For provisioning services, the patch area of arable land in the earlier year (1990) corresponded to 147 km^2, it had a higher decrease in 1990 to 2000 corresponding to -26 km^2, in which after had subtle variation until 2012, -11 km^2. For 2040, a more significant decrease is excepted in SC3 (-32 km^2) followed by SC1 (-27 km^2) and SC4 with -6 km^2, an increase of this area is expected in SC2 with 2 km^2. Regarding forests patch area from 316 km^2, a successive decreasing value is occurring from 1990 to 2012 a total of -36 km^2, the period 2006 and 2012 indicates a clear negative fluctuation of -26 km^2. A higher loss of this category is found in SC4 with -15 km^2, a decrease similar values for SC1 and SC2 with -8 km^2 and SC3 with a neutral value of 0.

Regulating services, Shannon's diversity index of agricultural areas shows the increase from 1990 (0.47) to 2000 (0.48) and higher significant decrease change in the period 2000 to 2006 (0.24) and a value of 0.25 for 2012. Our scenarios predict a continuation of decrease mainly in SC1 with 0.15, following a smooth increase to 0.16 for SC3, in SC2 the value of 0.17 and SC4 with 0.18. The edge density of forests in 1990 is 17.92 meters per hectares, 18.4 in 2000, decrease to 17.03 in 2012. A higher value in SC1 with 17.95, SC2 with 17.6, SC3 with 17.03 and SC4 with 16.42 meters per hectares.

Cultural services, the patch area of the Agricultural and Forests had a total of 445 km^2 in 1990. A higher decrease occurs in the first period to 2000 (-27 km^2), -8 km^2 to 2006, and -25 km^2 until 2012. In the Scenarios a continuation of loss is predicted, more significantly in SC1 with -33 km^2, followed by SC3 with -29 km^2, SC4 with -19 km^2 and -4 km^2 for SC2. The mean shape index of forests decreased from 1990 (2.61) to 2012 (2.38). The same value is found in SC3, then a decrease for SC1 with 1.92, followed by SC2 with 1.93 and the lowest value in SC4 with 1.70.

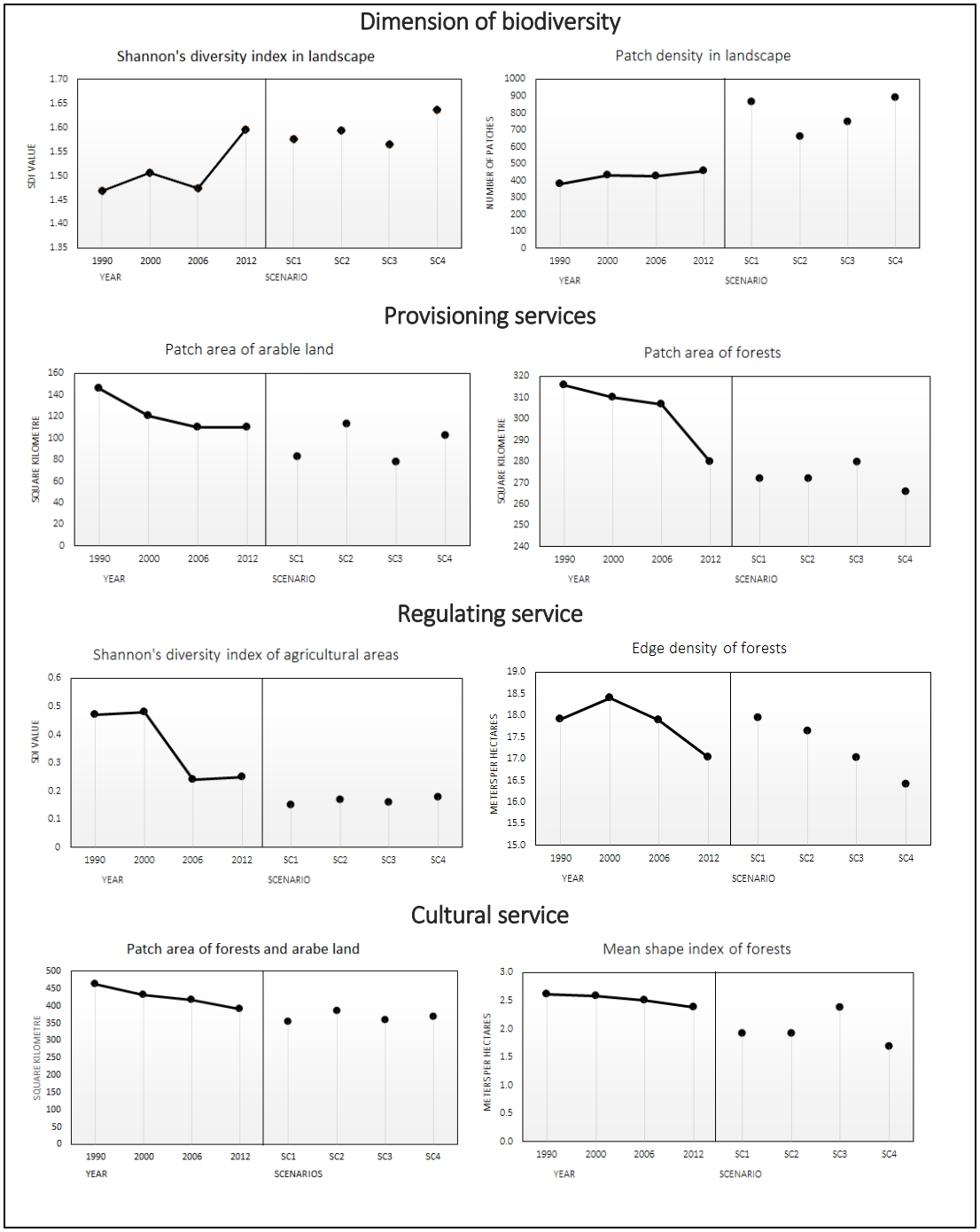

Figure 13: Impacts assessment per ecosystem services with landscape metrics.

5. Discussion

In this section it will be discussed the main outcomes from each step conducted in this study: historical land change analysis; land change modelling for the year 2040; assessment of the impacts on the different ecosystem services; limitations and recommendations for future work.

5. 1 Land change analysis 1990 to 2012

Identification of historical land changes in Madeira island from 1990 to 2012, assumes a clear opportunity to assess its implications while interpreting the dynamics driving the changes from human-induced and mix natural factors, a spatial informative source for intelligent regional planning application and intervention.

Our findings suggest that Madeira island had higher urban fabric growth, in the period of 1990 to 2000, with 3.92% of variation in the landscape in which after a stabilization occurred where, only 0.68% is found until 2012, probably explained by a low economic development and financial crises effects in Portugal (Carneiro et al., 2014; Rodrigues 2016).

This growth is spatially expressed in the south part of the island, mainly the neighbouring municipalities of Funchal. The establishment of new urban fabric towards higher elevation areas, in Santa Cruz and Câmara de Lobos, alike the population census variation rate, from 1991 to 2011, 83% and 13%, respectively (INE, 2011) and Leitão (2012). This tendency goes along with Azores islands (Gomes, 2013) and Europe trend from 2000 to 2010 (Maes et al., 2015) since the urban land had a growth of 0.35%. The urban fabric growth is occurring significantly from the heterogeneous agricultural areas (26.9 km^2) followed by forest areas (3.22 km^2) and permanent crops (2.97 km^2).

The decreased of agricultural land coincides with European (Cegieslska et al., 2018; Gingrich et al., 2015; Levers et al., 2016) and global trends (Meiyappan et al., 2014). The most representative period is 1990 to 2000 where is presented -22.70 km^2, after such the variation stabilize and turns to be residual (0.02%) due to the low expansion of urban areas. Nonetheless, new agricultural areas are emerging from forests areas (3.34 km^2) in higher areas of Santa Cruz, and extreme northwest of Calheta municipality, effects of a decreasing available area.

The transition of Heterogenous agricultural areas to Shrub and/herbaceous vegetation representing -3.84 km^2 is explained by the abandonment trend of these areas in the island (DREM,2011) along with Europe (Baumann et al., 2011) and Portugal mainland (Sturck et al., 2018; Eurostat, 2018). Furthermore, contrary to studies that show this abandonment trend contributing for growth of new Forest areas such as the island of Puerto Rico (Lugo and Helmer, 2004) and Quebec (Burton et al., 2003).

The forests areas which presented 42.64% of the total landscape in 1990, present a continuous significant decrease on contrary of Azores island (Gomes, 2013) and not meeting the European trend (except south) since studies indicate growth of these areas (Falcucci et al., 2007; Muchova and Tarnikova, 2018; Griffiths et al., 2013 in Cegieslaska et al., 2018; Mares et al., 2015) and even for future scenarios (Schroter et al., 2005). A variation of -4.68% for 1990 to 2012, but, significantly from 2006 and 2012 period, it presents a total loss of -3.46% (25.59 km^2). Due to forest fires that significantly occurred on the island in 2012 (Liberato et al., 2017). The loss of these areas to Urban fabric, was 3.22 km^2 with more spatial expression, in Santa Cruz.

A spatial dichotomy of the island manifests challenging fact to set planning instruments and protective actions of the natural heritage and convenient performance of conservation.

If the coastal areas are being continuously under urbanization with more expression in the South part rising the influence under anthropogenic pressure, impacting terrestrial and pressuring coastal natural areas.

On the other hand, a trend of change towards the higher points (interior) of the island will lead to a loss of agricultural areas and forest areas. One of this, in the end, will suffer inevitable changes, the finitude of space determines. Our driven variables indicate that the distance to the interior is influencing more these changes.

5.2 Land change modelling 2040

Our first land change future model for Madeira Island depicts four scenarios in which planning mechanism and be conducted at the regional and local level. Since real policy decisions require two or more options to choose to account its future consequences (Corona, 2016) and our scenarios depicts differentiations in the intensity of changes notwithstanding, its locations.

Nevertheless, Scenarios needs to be “a coherent, internally consistent, and plausible description of a possible future state of the world” (Houghton 1995). All the scenarios are subjected and sensitive to the course of upcoming decades and has defined by Geist (2005) exogenous factors or forces (e.g.: economical; political).

The potential modelling is higher within 5 classes of the island since it possesses more area that transitioned, meaning that a higher number of cells can be considered when applying the MLP.

A scenario Business as Usual will result in predominate changes in the South part of the island, with upper areas of Santa Cruz, Câmara de Lobos, Ribeira Brava, Ponta do Sol having the change of Heterogeneous agricultural areas to the Urban Fabric. The transition of permanent crops to Urban fabric in the south-west of Funchal. Calheta with a significant coastal areas transition. An intensification of the historical changes is observed. This scenario implies an island population growth which is not prospected for 2040 (DREM,2017) but recent Madeiran emigrants return flows from Venezuela (6.000 people) in two years, and thousands of others across the world more than 420.000 (CCME, 2018), might drive new dynamics depending of the global geopolitical stability of the destination countries. The signs of economic growth (EC, 2017) and tourism will also be determinant.

A scenario of conservation of forests and agricultural areas will be dependent on pollical guidelines from European Union and sectorial funds for its application, and governmental aspirations from national, regional to the local level. And affects differently the landscape the growth is more spread in SC3 with the north part being part of transitions to the Urban fabric from Heterogeneous agricultural areas, differently from SC1.

The Scenario Renaturation intends to predict a continuous stationary urban growth, with major natural factors and abandonment of agricultural areas, playing a major role of changes since the same process that affects abandonment are the ones that drive conversion of land (proximity factors). Constraints were not accounted in the model and it depicts certain areas more likely to face abandonment of agricultural land (Santana, São Vicente, Ponta do Sol and Ribeira Brava) an explorative modelling that can serve to mitigate location more likely to suffer negative impacts.

The change maps for the four scenarios indicate a variety of transitions and patterns except for Pastures to Shrubs that constantly presents the loss of -1.82 km^2 in all scenarios, due to the small area 2.4 km^2 (2012) of this class.

The transitions are more likely to continue to occur with changes in Heterogeneous agricultural areas, indicated by SC3 and SC4.

The assessment of the driven variables is classified has useful and good accuracy was reach in the Multilayer Perceptron represented by the skill measure. On the contrary, the simulated 2012 map, possess a low validation measure due to:

- Different intensity of changes in 1990 to 2000 and to the period predicted 2000 to 2012, in which the model did not experience has "learning process" for modelling, neither the driven variables selected, could explain the real change occurred (Transitions to Open Spaces; Stationary urban growth);
- A prediction changes from our model of 1.67 % for the landscape when the observed change was 15.73%;

The prediction changes and observed change is distinct from other authors where simulated change possess higher percentage (Aguejdad et al., 2017; Liu et al., 2014; Chen and Pontius, 2010).

These facts were derived from the intensity analysis and the quantification of the error, this was crucially important to understand our models' errors and produce a rigorous analysis (Pontius et al., 2008). In fact, has stated by (Paegelow, 2013) validations over short time periods are unreliable, the period used 1990 to 2000 was unrepresentative to account the transitions occurred from 2000 to 2012 and the learning modelling process, an idiosyncratic detail of the data (Brown et al., 2005).

5. 3 Impact of land change on ecosystems services

Using landscape metrics, we can identify several impacts on the terrestrial ecosystem's services in Madeira Island, resulting from the land change occurred and predicted for 2040 scenarios. Correlation with many more landscape metrics could have been tested, but it was decided to calculate this metrics which are readily explained that allow us to interpret and study hypothesis of a potential configuration of the landscape and effects on ecosystem services. The identification of this will allow conducting protective, restoration and

optimization measures on these different ecosystem services (Frank et al., 2012), and mitigation from predicted increased impacts across the landscape on the several land cover types. The different spatial explicit scenarios offer a range of alternatives for decision-making processes at the regional and local level and comparability with other regions, in contrast with the application of the same framework for the assessment of this study. These metrics should be considered a tool rather than a goal (Uuemaa et al., 2009) for the interpretations of the impacts. Important to keep in mind is the fact that ecosystems are linked, and they interact (Forman, 1983).

Dimension of biodiversity

Our findings suggest an increase of the landscape diversity for Madeira Island, depicted by Shannon's diversity index measure and a continuation to 2040 in the different scenarios. The patch density denotes an increase in the landscape. The use of landscape metrics for biodiversity has been used for decades (Morelli et al., 2018; Schindler et al., 2013) and allows to proceed with regional conservation measures. The main process of the landscape heterogeneity and variety suggests the following:

A continuation of the fragmentation of the landscape, is predicted with higher expression in SC1, followed by SC4, SC3 and SC2. A high fragmentation of the habitat is associated to a decrease in biodiversity (Fahrig et al., 2011). These results go along with global trends (Tittensor et al., 2014) and regional strategic plans (Madeira@2020) with a recognition of a fragmentation of the landscape is stated. New individualized areas are substantially occurring from our scenarios 2040, this will result in an overall fragmented habitat unable to support viable populations and for different sets of species since larger areas support more species (Shaffer and Samson 1985; Armbruster and Lande, 1993). Investigations show that insects respond strongly to different spatial patterns created by landscape change (Collinge and Forman, 1998). Plus, an increase of anthropogenic modification in the landscape results in an amount of intact habitat decrease, and habitat degradation increase (McIntyre and Hobbs, 2001) due to more sharply defined patch boundaries. (Lindenmayer and Fischer, 2007). The effects of the landscape changes in species population can a take long time to manifest (Tilman et al., 1994). Special attention should be given to the fact that a habitat isolation trough

fragmentation can affect special behaviour due to the adaption movements needed specially for birds (Wegner and Merriam, 1979; Graham, 2001).

Analysing the forest class that holds a considerable amount of biodiversity in the EU (Maes, 2018). In 1990 it had 38 patches and in 2012 a total of 64 this represent observed increase of a fragmented ecosystem for SC1 and SC2 123 patches are in the landscape SC4 with the higher number of 153 patches and SC3 with the same value than 2012. The wildfires occurred induced destruction of habitats for species (William and Gil, 1995; Bradstock et al., 2002) and the habitat loss and the habitat fragmentation is the recognized major modern cause induced by humans worldwide (Saunders et al., 1987; Kerr and Deguise, 2004).

But another interpretation can be considered, CLIMA-Madeira (2015) and Santos (2014) climatic future projections show a benefit for the Laurel Forest towards expansion to the higher altitude's areas due to the rise of temperature, in a longer-term contributing for attenuating the present loss.

Further research should be conducted to perceive species distribution pattern across Madeira landscape, considering the various requirements (habitats) that are fundamental for its life cycle (Lindenmayer and Fischer, 2006).

Provisioning services

Our findings through the patch area metric applied in the agricultural areas class and forests depict a future negative landscape structural capacity trend for food and biomass production.

The area available for production of agricultural products (arable land) is continuously decreasing from 1990 to 2012 (-37 km2) the projected scenarios accounts for a continuation of this trend. More negatively in SC3 (-32 km2) followed by SC1 (-27 km2) and SC4 with -6 km2. SC2 presents an increase in this area of 2 km2.

Regional agricultural census (1999, 2009) shows the agreement of these values, the decrease of the number of explorations and the used agricultural land by -3.85% (DREM, 2011).

Yet, the economic value of production shows a continuous increase from 1995 to 2012 meaning that productivity was not affected (INE, 2012). A deeper understanding of the relation between productivity, extensive use of actual agricultural areas, is needed. For a

quantitative assessment the impact of the decrease of arable land. For instance, in the EU although less arable is found from 2000 to 2010, more crops were produced (Maes, 2015). Geist (2005) state that in OECD countries land use for agriculture was falling but being more used intensively resulting in an increase in production.

Coupled with the spatial explicit maps, where the distribution of the agricultural areas currently located below 600 meters (Silva, 2013; Ribeiro, 1985) where more favourable conditions are found (CLIMA-Madeira, 2015) are being "pushed" to area with higher altitude areas in the South with more concern to Câmara de Lobos, the municipality with higher number of agricultural explorations (DREM, 2011) and Santa Cruz areas, which are predicted to suffer continuation of the loss of this areas to urban fabric (SC1,SC3).

The new locations of agricultural areas are predicted to be in the northwest of Calheta, where different climatic specificities, could affect the overall production quality. Rising the concern for the significant area protected in this municipality, 65% of its total area (ICNF, 2016). If the population increases a higher demand for production and consumption will occur.

The potential production of biomass from forests areas is continuously decreasing from 1990, with SC4 presenting the worst scenarios followed by SC1, SC2 and SC3. A contrary tendency of what is found in most EU members (Maes, 2015). The structural condition of forest area is accounted to be affected its potential biomass volume will also suffer from this and due to forest recovering process (forest fire), mineral nutrients, that can take decades (Trumbore et al., 2015).

Not only the decrease in these areas is negative, but also its spatial distribution. Since the higher conditions for available biomass is in the South of the island, mainly in Funchal, Santa Cruz, Calheta and Machico (Oliveira, 2005) in lower and medium altitudes. Precisely, where new urban fabric areas are predicted to continue to occur/expand. The impacts will potentially affect the Natural forest that ranges for 300 to 1300 meters (Menezes et al., 2004) but mainly the exotic forest since is in the south part of the island and lower altitude areas (Quintal, 1985). However, another interpretation of the increase of Shrubs is that might contribute positively to this service.

Regulating service

Agricultural areas function for pest control is decreasing, with a lower diversity in the landscape. Together with the fact that a more complex landscape is predicted to Madeira in which pest species tend to respond positively (Verhagen et al., 2016). Secondly, the abandonment of these areas will increase the settlements of Shrubs and herbaceous vegetations and increase the risk of wildfires in the urban-rural fringe (Correira and Santos, 2015) in the south due to the transitions from agricultural areas to the urban fabric. Thirdly, a risk for expansion of exotic invasive species for the forest. This species can induce a competition with the island endemic fauna and flora threatening ecologically (Vitousek et al., 1997) and the integrity of the ecosystem services.

The edge density of forests, confirms a habitat fragmentation with the increasing habitat edge for SC1 a higher irregular shape than SC2, SC3, SC4. Pollination can be limited in the forest areas, making the crop production dependent on insect pollination and benefiting from insect pollination (Zulian et al., 2013). Semi-natural and natural ecosystem have the potential to provide pollination services and rising the need to conserve and restored (Bommarco, 2012).

Further research producing information about species contribution of the forest's areas for pollination and agricultural areas functions, for pest control in Madeira, needs to be conducted. Since agricultural areas itself can produce negative impacts (Agrochemicals). To quantitively produce assessments and deeper analysis of linkage, the present scarce information, does not allow to identify precise impacts on these processes.

Cultural service

Through patch area metrics of forests and agricultural areas and mean shape index of forests the assessment of impact in terms of attraction and complexity; natural conditions were conducted.

Forest areas for the nature-based tourism, recreation and protection (Maes,2015) along with the agricultural areas part of the cultural landscape due to its characteristics and visual aesthetics (Kienast et al., in Schulp et al., 2019) especially in Madeira Island. Both these classes

are part of cultural services for attraction and complexity (Burkhard and Maes, 2017). Predicted to continue to decrease.

Together these areas had 444 km^2 in 1990 to 384 in km^2 in 2012. In our scenarios a higher decrease is excepted in SC1 (-32 km^2), followed by SC3 with -29 km^2, SC4 with -19 km^2 and SC2 with -3 km^2. The impacts in the landscape will be negative, not only in the cultural heritage and islander's identity but along with tourist appreciation, perception and expectations to have authentic contact with nature (ACIF, 2014) and potential recreation functions that will likely affect local communities and their economy (Sturck et al., 2018).

Despite this, the area suffering more changes in our scenarios, are located at south meaning that the north where the substantial part of Laurel is in then less likely to suffer from direct human-induced changes and the natural restoration of recently burnt areas, might increase these areas in upcoming decades. In comparison, a continuation of the abandonment of agricultural areas will affect negatively the cultural landscape along with, the European past and future trends (Schulp et al., 2019; Guipponi et al., 2006; Verburg et al., 2013; Tieskens et al., 2017). Maes (2015) states that in citizen in EU citizens are having access to areas with recreation function. In Madeira Island due to is substantial protected area and forest, a negative trend is found.

Mean shape index of forests assessing the complexity and natural conditions indicates compactness of the area with the decrease from 1990 with 2.61 to 2.38 in 2012 a tendency for a regular patch and a continuation for all Scenarios.

5.4 Limitations

The use of CORINE Land Cover allows us to make comparations across all EU countries (Buttner et al., 2004). With this data having an accuracy assessment at a minimum of 85% (Buttner et al., 2002). Relative reliability of this data is stated for analysing land-use dynamics at the national and regional level by Gutiérrez (2014). But some critical analysis of the data is advised (Teixeira et al., 2016) since input materials, comes from various sources and the production of the maps (Cegielska et al., 2018). If error comes from the input maps it will be propagated for the future scenarios output (Gibson et al., 2018).

Generalization occurred due to the spatial resolution of 25 ha, minimum mapping unit of 100 m (Buttner et al., 2002). But since Madeira Island possess a large and uniform landscape, with these conditions, the use is not problematic (Bielecka and Ciolkosz, 2004 in Cegielska et al., 2018). Likewise, most of the changes are occurring in the most representative and significant classes presented in the landscape, along with Azores island (Gomes et al., 2013) but water bodies were not considered since is composed by small streams not depicted from the resolution.

Limited information regarding the drivers for the transition of Forests to Shrubs and modelling of Pastures to Shrubs. The driven variables used during the present study are only classified has "Useful" 0.25 Cramer's V further identification of variables should be conducted to reach higher values. The fact that the variables are implemented as stable over time is one limitation (Kolb et al., 2013).

The fifth, Mapping and Assessment of Ecosystem and their services (MAES, 2018) report states that: *"CORINE Land Cover is the most comprehensive dataset for terrestrial ecosystems*". By contrast, Verhagen (2016) state that it should be carefully analysed findings for planning purpose the studies using this data set for ecosystem services analysis. Since it is a coarse land cover map, gives limited explanation patterns of biodiversity and ecosystems services for landscape management (Gimona, 2009 in Verhagen et al., 2016). Since it is limited to local scale studies, Burkhard (2009) advice supplementary case studies in terms of ecosystem services in relation to the CORINE Land Cover, integrated with expert judgement.

The land change modelling scenarios were conducted based on the information available from the historical changes and where an induced anthropogenic land change was interpreted in the transitions. Meaning that empirically natural factors and transitions with lower

representatives where to exclude and an oversimplification of more complex changes, this should be kept in mind (Sturck et al., 2018). Land ownership and changes in forests/agricultural policy cannot be quantified to our model.

The Markov chain assumes a constant proportion of the categories for transitions in each future date calculated resulting an equilibrium of the area of each category, which in a real situation is not found and constant rate change (Gibson et al., 2018; Petit et al., 2001) in our study area pasture to shrubs is continuously having the same amount of area of loss.

In ecosystem services assessment, the lack of data and studies regarding interactions of predators and natural endemic habitats. Together with scarce information regarding the ecology, the functioning of Laurel forest (SRA, 2012; Santos et al., 2014) did not allow to opt for different approaches during this study and. Scale properties and unit of analysis were then assumed for every ecosystem service like the case of Polce (2016). Despite this, the level 2 of the legend allows a more detailed explanation of the phenomena (Sertel et al., 2018).

Limited information of how configuration affects ES capacity (Verhagen et al., 2016) and the land cover diversity on landscape aesthetics potential, we applied the same weight value for forest and agricultural areas.

The number of studies that assess the linkage between landscape configuration and ecosystems services remains limited and empirical evidence are scarce (Mitchell and Gonzalez 2013; Verhagen et al., 2016), notably in the case of Madeira island. Further information regarding biotic information related to vegetation, fauna, habitats and abiotic information from soil types, climatic data needs to be accounted in further modelling approaches (See Burkhard et al., 2009)

Several ecosystem services impacts can rise not only with the location of the areas which the suffered change but also the neighbouring areas such as pollination (Verhagen et al., 2018). An analysis of the impacts per each single land cover type cannot account an integrated assessment of the regional ecosystem services interactions as stated by Furst et al., (2016) and Zurlini and Girardin (2007).

5.5 Future recommendations

To include in the future Madeira island modelling processes

- Conduct and consult informative expert knowledge and collaboration of regional governmental institutions, stakeholders in a form of interviews to select transitions and scenarios (Levrel et al., 2017; Voinov et al., 2016);
- The testing and exploration of new driven variables should be conducted that would present a Cramer's V measure of 0,40 or higher. Since it is considered a good value with higher explanatory power, which would affect the accuracy of our predictions and potentially, validation;
- Uncertainty of the variable slopes is presented since it had a value that could be neglected from our modelling process. Is really slopes not important in Madeira Island to drive changes or is due to the variable resolution?
- Reassess the roads variables to consider the tunnels with a certain margin to the potential impact of changes, assess the impact of the tunnels in regional and local roads;
- Explore and identify areas more likely to face renaturation processes, mainly the abandonment of agricultural areas to shrubs with relation to ancillary data, like ageing statistics of parishes and agricultural census. This is a process which could serve as a planning measure and protection against forest fires in the urban peripheric areas, and application of more "precise" in depth, landscape metrics. A question arises from the scenario, can really models predict abandonment of agricultural areas?;
- In this work we assume that the same driven variables are impacting the renaturation which needs to be reconsidered since wild renaturation processes are characterized by different factors than e.g.: conversion of heterogeneous agriculture areas to the urban fabric, specific variables that drives wild renaturation process must be investigated and included;
- Since each municipality possesses a legal instrument defined for a ten years period spatially guidelines and delineation of urbanization processes and areas predicted to host it. Yet economic development, the protection of agricultural areas and forests that legally cannot suffer changes, these areas, should then be considered a constraint or implementing a weighting factor, with suitability parameters.

In terms of applicability with the present work

- Develop regional and islands comparison like Macaronesia (e.g: Azores, Canary Island) using CORINE Land Cover, to identify land historical changes process, drivers of changes, threats and dimensions of changes on ecosystems, perceiving the dynamics, impacts state of the different ecosystem and its integrity;
- Cross the spatial information of CLIMA-Madeira project, the climate change scenarios map to assess vulnerability of exposure of the predicted change. Since the global system, affects the regional system (MEA,2005);
- Identification of habitats, protected areas, species, which are more sensitive towards anthropogenic disturbance in coastal areas and forest with the predicted changes (e.g: proximity ranking analysis);
- Identification of areas that possess higher touristic value to assess the potential impact of predicted changes;
- Identification of areas more susceptible to disasters occurrence: flash-foods, landslides locations, forest fires (combustibility) with ancillary information and CLIMA-Madeira data. Assessing if these areas are predicted to suffer changes by urbanization processes;
- Produce change analysis in CORINE Land Cover 2018, to inspect the trend of change of the classes spatially and quantitatively. The upcoming releases of CORINE Land Cover will allow producing a continuous comparability of the landscape;
- The use of Carbon Storage and Sequestration model from InVEST models, from the Natural Capital Project, adding carbon pools sources of carbon density aboveground biomass; carbon density belowground biomass; carbon density in soil; carbon density in dead matter. Allowing its estimation and quantification assessing its changes accordingly;
- Calculation and mapping of landscape metrics at the level of the patches providing per class dynamics (Frank, 2012; Burkhard and Maes, 2017).

6. Conclusion

This study presents findings that will be important to account in a range of regional environmental planning management policies, from four plausible LULC scenarios for the year 2040 in Madeira Island and mitigation of the negative impacts on ecosystem services. A clear trend of change is found for the south part of the island. The period of 1990 to 2000 a higher land change from agricultural areas to urban fabric. With a stationary growth until 2012 and the major changes occurring from wildfires in 2006 to 2012 with the loss of forest areas. Our scenarios provide a range of options with diverse spatial patterns of transitions and intensity which comprises the major landscape classes. Revealing different ecosystem capacities state. An integrated planning approach should be directed to balance potential loss in coastal areas and interior areas. Negative impacts on ecosystem services concern the biodiversity with a fragmentation of habitats, decrease of areas to produce food and biomass in 2040. Further research needs to assess the impact on regulating services for pollination and pest control. The cultural services provided by forests and agricultural areas is expected to continue to decrease impacting islander's identity and tourism expectations.

The outcomes represent the first land change prediction analysis for our study area along with a first practical application of assessment ecosystem services through landscape metrics for the future with spatial explicit patterns, using the methodology purposed by Burkhard and Maes (2017). It showed to be a promising effective tool to identify general tendencies coupled with capabilities of the landscape. Moreover, integration of indices related to ecological structure and detailed landscape properties is advice. Despite this, can serve has integrative information for LULC change studies. Further research includes comparability with small islands in EU. An urgent need is identified for the regional planning institutions to address mitigation mechanisms of potential negative impacts of land changes.

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APPENDICES

Change analysis

Net change per CLC period	1990-2000		2000-2006		2006-2012	
Class	sq km	cells	sq km	cells	sq km	cells
Urban Fabric	-24.52	2884	4.8	480	0.21	21
Industrial, commercial and transport units	-0.36	182	1.12	112	0.35	35
Mine, dump and constructions site	-0.32	97	1.11	111	-0.48	-48
Artificial, non-agricultural vegetated areas	-0.34	166	-0.08	-8	0	0
Arable land	0	0	-1.9	-190	0	0
Permanent crops	0	-235	-2.21	-221	0.22	22
Pastures	0.15	-21	-4.63	-463	0	0
Heterogeneous agricultural areas	0	-2270	-2.88	-288	0.05	5
Forests	2.64	-464	-4.41	-441	-25.59	-2559
Shrub and/or herbaceous vegetation association	0.07	-373	9.11	911	-21.59	-2159
Open spaces with little or no vegetation	-0.01	50	0.09	9	46.83	4683
Water Bodies	-0.01	-16	-0.12	-12	0	0

Net change 1990 - 2012				
Class	Sq km	Cells	% of area	% of change
Urban Fabric	33.85	3385	1.45	32.08
Industrial, commercial and transport units	3.29	329	0.14	66.73
Mine, dump and constructions site	1.6	160	0.07	75.47
Artificial, non-agricultural vegetated areas	1.58	158	0.07	81.44
Arable land	-1.9	-190	-0.08	-633.33
Permanent crops	-4.34	-434	-0.19	-147.62
Pastures	-4.84	-484	-0.21	-201.67
Heterogeneous agricultural areas	-25.53	-2553	-1.09	-24.49
Forests	-34.64	-3464	-1.49	-12.33
Shrub and/or herbaceous vegetation association	-16.21	-1621	-0.69	-9.41
Open spaces with little or no vegetation	47.42	4742	2.03	77.83

Contributions to Net Change in Urban Fabric 1990-2012	Sq km	Cells	% of area	% of change
Industrial, commercial and transport units	-0.52	-52	-0.02	-31.71
Mine, dump and constructions site	0	0	0	0
Artificial, non-agricultural vegetated areas	0.33	33	0.01	91.67
Arable land	0	0	0	0
Permanent crops	2.97	297	0.13	40.8
Pastures	0	0	0	0
Heterogeneous agricultural areas	26.9	2690	1.15	20.73
Forests	3.22	322	0.14	1.02
Shrub and/or herbaceous vegetation association	0.83	83	0.04	0.44
Open spaces with little or no vegetation	0	0	0	0
Water Bodies	0.12	12	0.01	6.49

Contributions to Net Change in Heterogeneous agricul. 1990-2012	Sq km	Cells	% of area	% of change
Urban Fabric	-26.9	-2690	-1.15	-37.53
Industrial, commercial and transport units	-0.54	-54	-0.02	-32.93
Mine, dump and constructions site	-0.13	-13	-0.01	-25
Artificial, non-agricultural vegetated areas	-0.34	-34	-0.01	-94.44
Arable land	1.77	177	0.08	80.45

Permanent crops	1.28	128	0.05	17.58
Pastures	0.15	15	0.01	2.07
Forests	3.34	334	0.14	1.06
Shrub and/or herbaceous vegetation association	-3.84	-384	-0.16	-2.04
Open spaces with little or no vegetation	-0.32	-32	-0.01	-2.37
Water Bodies	0	0	0	0

Contributions to Net Change in Forests 1990 - 2012	Sq km	Cells	% of area	% of change
Urban Fabric	-3.22	-322	-0.14	-4.49
Industrial, commercial and transport units	-0.22	-22	-0.01	-13.41
Mine, dump and constructions site	-0.27	-27	-0.01	-51.92
Artificial, non-agricultural vegetated areas	-0.88	-88	-0.04	-244.44
Arable land	0.13	13	0.01	5.91
Permanent crops	-0.18	-18	-0.01	-2.47
Pastures	-0.12	-12	-0.01	-1.66
Heterogeneous agricultural areas	-3.34	-334	-0.14	-2.57
Shrub and/or herbaceous vegetation association	-4	-400	-0.17	-2.12
Open spaces with little or no vegetation	-22.54	-2254	-0.97	-166.84
Water Bodies	0	0	0	0

Contributions to Net Change in Shrub 1990 -2012	Sq km	Cells	% of area	% of change
Urban Fabric	-0.83	-83	-0.04	-1.16
Industrial, commercial and transport units	-0.84	-84	-0.04	-51.22
Mine, dump and constructions site	-1.5	-150	-0.06	-288.46
Artificial, non-agricultural vegetated areas	-0.32	-32	-0.01	-88.89
Arable land	0	0	0	0
Permanent crops	-0.25	-25	-0.01	-3.43
Pastures	4.41	441	0.19	60.91
Heterogeneous agricultural areas	3.84	384	0.16	2.96
Forests	4	400	0.17	1.27
Open spaces with little or no vegetation	-24.76	-2476	-1.06	-183.27
Water Bodies	0.04	4	0	2.16

Contributions to Net Change in Open spaces 1990-2012	Sq km	Cells	% of area	% of change
Urban Fabric	0	0	0	0
Industrial, commercial and transport units	0	0	0	0
Mine, dump and constructions site	-0.2	-20	-0.01	-38.46
Artificial, non-agricultural vegetated areas	0	0	0	0
Arable land	0	0	0	0
Permanent crops	0	0	0	0
Pastures	0	0	0	0
Heterogeneous agricultural areas	0.32	32	0.01	0.25
Forests	22.54	2254	0.97	7.14
Shrub and/or herbaceous vegetation association	24.76	2476	1.06	13.13
Water Bodies	0	0	0	0

Class in landscape

Class	1990	2000	2006	2012	SC1	SC2	SC3	SC4
	Percentage (%)							
1	9,66	13,58	14,23	14,26	18,77	14,75	18,24	14,23
2	0,22	0,47	0,62	0,66	0,66	0,66	0,66	0,66
3	0,10	0,20	0,35	0,29	0,28	0,29	0,29	0,29
4	0,05	0,26	0,26	0,26	0,26	0,26	0,26	0,26
5	0,30	0,30	0,04	0,04	0,04	0,04	0,04	0,04
6	0,98	0,66	0,36	0,39	0,20	0,40	0,20	0,40
7	0,97	0,94	0,32	0,32	0,07	0,08	0,07	0,08
8	17,48	14,37	13,97	13,99	10,91	14,72	10,24	13,49
9	42,64	42,03	41,42	37,96	36,72	36,69	37,87	35,86
10	25,43	24,93	26,16	23,24	23,50	23,48	23,48	18,58
11	1,82	1,88	1,89	8,23	8,22	8,21	8,21	15,71

Scenarios MPL Results

SC1

Input file	Variable
1	Elevation
2	Distance to interior
3	Distance to urban centres 1990
4	Distance to Coast
5	Distance to South
6	Distance to 2000 Network
7	Distance to roads
8	Distance to Madeira Natural Park
9	Slopes
10	Distance to Funchal
11	Distance to disturbance

Input layer neurons	11
Hidden layer neurons	10
Output layer neurons	9
Requested samples per class	188
Final learning rate	0.0010
Momentum factor	0.5
Sigmoid constant	1
Acceptable RMS	0.01
Iterations	10000
Training RMS	0.1938
Testing RMS	0.2150
Accuracy rate	71.46%
Skill measure	0.6789

3) Model Skill Breakdown by Transition & Persistence

Class	Skill measure
Transition : Permanent crops to Urban Fabric	0.6566
Transition : Pastures to Shurb and/or herbaceous vegetation association	0.2354
Transition : Heterogeneous agricultural areas to Urban Fabric	0.9289
Transition : Forests to Urban Fabric	0.6133
Transition : Forests to Heterogeneous agricultural areas	0.9758

Persistence : Permanent crops	0.8105
Persistence : Pastures	1.0000
Persistence : Heterogeneous agricultural areas	0.3777
Persistence : Forests	0.5500

1) Forcing a Single Independent Variable to be Constant

Model	Accuracy (%)	Skill measure	Influence order
With all variables	71.46	0.6789	N/A
Var. 1 constant	51.93	0.4592	3
Var. 2 constant	61.40	0.5658	5
Var. 3 constant	60.00	0.5500	4
Var. 4 constant	69.71	0.6592	10
Var. 5 constant	50.29	0.4408	2
Var. 6 constant	41.99	0.3474	1 (most influential)
Var. 7 constant	68.65	0.6474	9
Var. 8 constant	67.02	0.6289	8
Var. 9 constant	70.64	0.6697	11 (least influential)
Var. 10 constant	61.64	0.5684	6
Var. 11 constant	63.51	0.5895	7

3) Backwards Stepwise Constant Forcing

Model	Variables included	Accuracy (%)	Skill measure
With all variables	All variables	71.46	0.6789
Step 1: var.[9] constant	[1,2,3,4,5,6,7,8,10,11]	70.64	0.6697
Step 2: var.[9,4] constant	[1,2,3,5,6,7,8,10,11]	67.84	0.6382
Step 3: var.[9,4,8] constant	[1,2,3,5,6,7,10,11]	64.91	0.6053
Step 4: var.[9,4,8,7] constant	[1,2,3,5,6,10,11]	60.58	0.5566
Step 5: var.[9,4,8,7,3] constant	[1,2,5,6,10,11]	54.04	0.4829
Step 6: var.[9,4,8,7,3,1] constant	[2,5,6,10,11]	52.05	0.4605
Step 7: var.[9,4,8,7,3,1,5] constant	[2,6,10,11]	42.92	0.3579
Step 8: var.[9,4,8,7,3,1,5,10] constant	[2,6,11]	41.40	0.3408
Step 9: var.[9,4,8,7,3,1,5,10,2] constant	[6,11]	39.42	0.3184
Step 10: var.[9,4,8,7,3,1,5,10,2,6] constant	[11]	27.60	0.1855

SC2

Input file	Variable
1	Elevation
2	Distance to interior
3	Distance to urban centres 1990
4	Distance to Coast
5	Distance to South
6	Distance to 2000 Network
7	Distance to roads
8	Distance to Madeira Natural Park
9	Slopes
10	Distance to Funchal
11	Distance to disturbance

2) Parameters and Performance

Input layer neurons	11
Hidden layer neurons	7
Output layer neurons	5
Requested samples per class	188
Final learning rate	0.0010
Momentum factor	0.5
Sigmoid constant	1
Acceptable RMS	0.01
Iterations	10000
Training RMS	0.1981
Testing RMS	0.2289
Accuracy rate	83.95%
Skill measure	0.7993

3) Model Skill Breakdown by Transition & Persistence

Class	Skill measure
Transition : Pastures to Shurb and/or herbaceous vegetation association	0.9138
Transition : Forests to Urban Fabric	0.6348
Transition : Forests to Heterogeneous agricultural areas	0.9728
Persistence : Pastures	0.9468
Persistence : Forests	0.5455

1) Forcing a Single Independent Variable to be Constant

Model	Accuracy (%)	Skill measure	Influence order
With all variables	83.95	0.7993	N/A
Var. 1 constant	77.87	0.7234	6
Var. 2 constant	75.92	0.6990	4
Var. 3 constant	57.27	0.4658	1 (most influential)
Var. 4 constant	83.51	0.7939	10
Var. 5 constant	82.65	0.7831	8
Var. 6 constant	66.16	0.5770	2
Var. 7 constant	78.96	0.7370	7
Var. 8 constant	82.65	0.7831	9
Var. 9 constant	83.73	0.7966	11 (least influential)
Var. 10 constant	73.97	0.6746	3
Var. 11 constant	77.01	0.7126	5

3) Backwards Stepwise Constant Forcing

Model	Variables included	Accuracy (%)	Skill measure
With all variables	All variables	83.95	0.7993
Step 1: var.[9] constant	[1,2,3,4,5,6,7,8,10,11]	83.73	0.7966
Step 2: var.[9,4] constant	[1,2,3,5,6,7,8,10,11]	83.30	0.7912
Step 3: var.[9,4,8] constant	[1,2,3,5,6,7,10,11]	82.21	0.7777
Step 4: var.[9,4,8,5] constant	[1,2,3,6,7,10,11]	82.00	0.7749
Step 5: var.[9,4,8,5,7] constant	[1,2,3,6,10,11]	79.83	0.7478
Step 6: var.[9,4,8,5,7,1] constant	[2,3,6,10,11]	76.14	0.7017
Step 7: var.[9,4,8,5,7,1,3] constant	[2,6,10,11]	77.87	0.7234
Step 8: var.[9,4,8,5,7,1,3,11] constant	[2,6,10]	63.77	0.5472
Step 9: var.[9,4,8,5,7,1,3,11,2] constant	[6,10]	57.27	0.4658
Step 10: var.[9,4,8,5,7,1,3,11,2,10] constant	[6]	27.33	0.0916

SC3

Input file	Variable
1	Elevation
2	Distance to interior
3	Distance to urban centres 1990
4	Distance to Coast
5	Distance to South
6	Distance to 2000 Network
7	Distance to roads
8	Distance to Madeira Natural Park
9	Slopes
10	Distance to Funchal
11	Distance to Disturbance

2) Parameters and Performance

Input layer neurons	11
Hidden layer neurons	7
Output layer neurons	6
Requested samples per class	188
Final learning rate	0.0010
Momentum factor	0.5
Sigmoid constant	1
Acceptable RMS	0.01
Iterations	10000
Training RMS	0.2183
Testing RMS	0.2387
Accuracy rate	75.59%
Skill measure	0.7071

3) Model Skill Breakdown by Transition & Persistence

Class	Skill measure
Transition : Permanent crops to Urban Fabric	0.5469
Transition : Pastures to Shurb and/or herbaceous vegetation association	0.4989
Transition : Heterogeneous agricultural areas to Urban Fabric	0.9581
Persistence : Permanent crops	0.7191
Persistence : Pastures	0.9872
Persistence : Heterogeneous agricultural areas	0.5467

1) Forcing a Single Independent Variable to be Constant

Model	Accuracy (%)	Skill measure	Influence order
With all variables	75.59	0.7071	N/A
Var. 1 constant	51.36	0.4163	1 (most influential)
Var. 2 constant	63.65	0.5638	6
Var. 3 constant	54.79	0.4575	2
Var. 4 constant	73.60	0.6832	8
Var. 5 constant	59.86	0.5183	4
Var. 6 constant	55.15	0.4618	3
Var. 7 constant	74.14	0.6897	9
Var. 8 constant	65.28	0.5834	7

Var. 9 constant	77.22	0.7266	11 (least influential)
Var. 10 constant	63.47	0.5617	5
Var. 11 constant	75.59	0.7071	10

3) Backwards Stepwise Constant Forcing

Model	Variables included	Accuracy (%)	Skill measure
With all variables	All variables	75.59	0.7071
Step 1: var.[9] constant	[1,2,3,4,5,6,7,8,10,11]	77.22	0.7266
Step 2: var.[9,11] constant	[1,2,3,4,5,6,7,8,10]	77.22	0.7266
Step 3: var.[9,11,4] constant	[1,2,3,5,6,7,8,10]	74.68	0.6962
Step 4: var.[9,11,4,7] constant	[1,2,3,5,6,8,10]	71.61	0.6593
Step 5: var.[9,11,4,7,5] constant	[1,2,3,6,8,10]	61.30	0.5356
Step 6: var.[9,11,4,7,5,8] constant	[1,2,3,6,10]	54.79	0.4575
Step 7: var.[9,11,4,7,5,8,1] constant	[2,3,6,10]	41.95	0.3034
Step 8: var.[9,11,4,7,5,8,1,3] constant	[2,6,10]	51.18	0.4141
Step 9: var.[9,11,4,7,5,8,1,3,2] constant	[6,10]	38.34	0.2600
Step 10: var.[9,11,4,7,5,8,1,3,2,10] constant	[6]	23.33	0.0799

SC4

Input file	Variable
1	Elevation
2	Distance to interior
3	Distance to coast
4	Distance to Urban centre 1990
5	Distance to South
6	Distance to Funchal
7	Distance 2000 Network
8	Distance to Roads
9	Distance to Madeira Natural Park
10	Slopes

2) Parameters and Performance

Input layer neurons	10
Hidden layer neurons	10
Output layer neurons	7
Requested samples per class	188
Final learning rate	0.0010
Momentum factor	0.5
Sigmoid constant	1
Acceptable RMS	0.01
Iterations	10000
Training RMS	0.2020
Testing RMS	0.2474
Accuracy rate	71.67%
Skill measure	0.6695

3) Model Skill Breakdown by Transition & Persistence

Class	Skill measure
Transition : Pastures to Shurb and/or herbaceous vegetation association	0.5333
Transition : Heterogeneous agricultural areas to Shurb and/or herbaceous vegetation association	0.9222
Transition : Shurb and/or herbaceous vegetation association to Forests	0.7640
Transition : Shurb and/or herbaceous vegetation association to Open spaces with little	0.7051

Persistence : Pastures	1.0000
Persistence : Heterogeneous agricultural areas	0.6241
Persistence : Shurb and/or herbaceous vegetation association	0.1315

1) Forcing a Single Independent Variable to be Constant

Model	Accuracy (%)	Skill measure	Influence order
With all variables	71.67	0.6695	N/A
Var. 1 constant	66.35	0.6075	7
Var. 2 constant	66.20	0.6056	6
Var. 3 constant	58.84	0.5198	3
Var. 4 constant	57.59	0.5052	2
Var. 5 constant	58.84	0.5198	4
Var. 6 constant	54.62	0.4705	1 (most influential)
Var. 7 constant	62.60	0.5636	5
Var. 8 constant	66.82	0.6129	8
Var. 9 constant	70.74	0.6586	9
Var. 10 constant	71.52	0.6677	10 (least influential)

3) Backwards Stepwise Constant Forcing

Model	Variables included	Accuracy (%)	Skill measure
With all variables	All variables	71.67	0.6695
Step 1: var.[10] constant	[1,2,3,4,5,6,7,8,9]	71.52	0.6677
Step 2: var.[10,9] constant	[1,2,3,4,5,6,7,8]	70.89	0.6604
Step 3: var.[10,9,2] constant	[1,3,4,5,6,7,8]	68.23	0.6294
Step 4: var.[10,9,2,8] constant	[1,3,4,5,6,7]	62.28	0.5600
Step 5: var.[10,9,2,8,1] constant	[3,4,5,6,7]	52.58	0.4468
Step 6: var.[10,9,2,8,1,7] constant	[3,4,5,6]	52.27	0.4431
Step 7: var.[10,9,2,8,1,7,4] constant	[3,5,6]	46.32	0.3738
Step 8: var.[10,9,2,8,1,7,4,5] constant	[3,6]	38.34	0.2806
Step 9: var.[10,9,2,8,1,7,4,5,3] constant	[6]	24.26	0.1163

Markov matrix

Coded values: Urban Fabric - UF; Industrial, commercial and transport units - ICT; Mine, dump and constructions sites - MDC; Artificial, non-agricultural vegetated areas - ANV; Arable land – AL; Permanent crops – PC; Pastures – PA; Heterogeneous agricultural areas – HEA; Forests – FO; Shrub and/or herbaceous vegetation associations – SHV; Open spaces with little or no vegetation - OPV

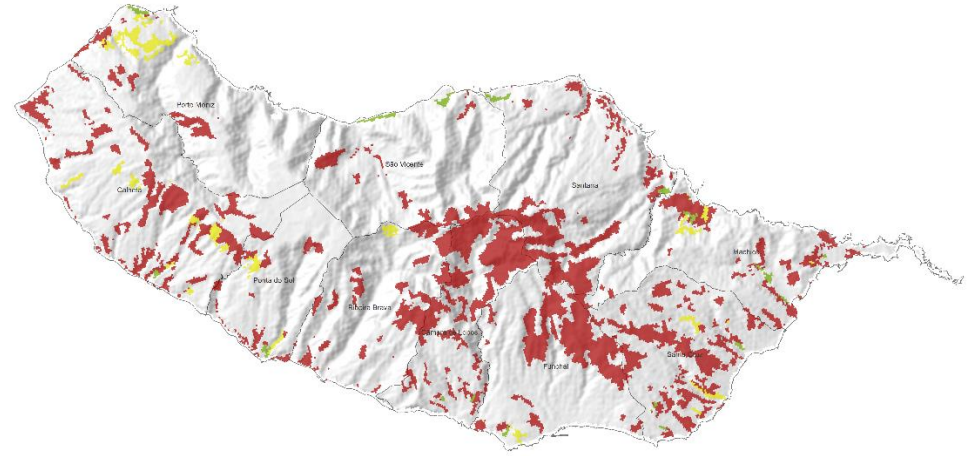
Markov probability matrix of land covers from 2012 to 2040											
From:	To:										
Class	UF	ICT	MDC	ANV	AL	PC	PA	HEA	FO	SHV	OPV
UF	0,97	0,01	0,00	0,00	0,00	0,00	0,02	0,00	0,00	0,00	0,00
ICT	0,08	0,90	0,00	0,00	0,00	0,00	0,00	0,00	0,02	0,00	0,00
MDC	0,02	0,94	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,03	0,00
ANV	0,91	0,08	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
AL	0,04	0,00	0,00	0,03	0,00	0,00	0,00	0,83	0,07	0,00	0,00
PC	0,50	0,09	0,00	0,00	0,00	0,19	0,00	0,23	0,01	0,00	0,00
PA	0,04	0,00	0,00	0,03	0,00	0,00	0,13	0,02	0,00	0,76	0,02
HEA	0,27	0,00	0,00	0,00	0,00	0,00	0,00	0,67	0,01	0,04	0,00
FO	0,01	0,00	0,00	0,00	0,00	0,00	0,00	0,02	0,82	0,05	0,09
SHV	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,06	0,73	0,18
OPV	0,00	0,00	0,01	0,00	0,00	0,00	0,00	0,00	0,00	0,17	0,80

Validation

Category	Cells	Legend
1	194	8 | 1 | 1 - Hits
2	1	2 | 2 | 1 - Misses
3	37	4 | 4 | 1 - Misses
4	114	6 | 6 | 1 - Misses
5	211	8 | 8 | 1 - Misses
6	135	9 | 9 | 1 - Misses
7	36	10 | 10 | 1 - Misses
8	14	12 | 12 | 1 - Misses
9	46	1 | 1 | 2 - Misses
10	3	4 | 4 | 2 - Misses
11	4	8 | 8 | 2 - Misses
12	32	9 | 9 | 2 - Misses
13	32	10 | 10 | 2 - Misses
14	7	8 | 1 | 3 - False Alarms
15	41	9 | 9 | 3 - Misses
16	32	10 | 10 | 3 - Misses
17	20	11 | 11 | 3 - Misses
18	32	10 | 10 | 4 - Misses
19	10	8 | 1 | 6 - False Alarms
20	23	8 | 8 | 6 - Misses
21	1	9 | 9 | 6 - Misses
22	25	10 | 10 | 6 - Misses

23	12	9 | 9 | 7 - Misses
24	40	10 | 10 | 7 - Misses
25	186	1 | 1 | 8 - Misses
26	2111	8 | 1 | 8 - False Alarms
27	177	5 | 5 | 8 - Misses
28	140	6 | 6 | 8 - Misses
29	2	9 | 8 | 8 - Hits
30	157	9 | 9 | 8 - Misses
31	25	10 | 10 | 8 - Misses
32	1	12 | 12 | 8 - Misses
33	1	1 | 1 | 9 - Misses
34	4	8 | 1 | 9 - False Alarms
35	136	9 | 1 | 9 - False Alarms
36	3	2 | 2 | 9 - Misses
37	13	5 | 5 | 9 - Misses
38	4	6 | 6 | 9 - Misses
39	69	8 | 8 | 9 - Misses
40	368	9 | 8 | 9 - False Alarms
41	786	10 | 10 | 9 - Misses
42	43	9 | 11 | 9 - False Alarms
43	40	11 | 11 | 9 - Misses
44	4	1 | 1 | 10 - Misses
45	93	8 | 1 | 10 - False Alarms
46	75	9 | 1 | 10 - False Alarms
47	2	2 | 2 | 10 - Misses
48	515	7 | 7 | 10 - Misses
49	325	8 | 8 | 10 - Misses
50	1186	9 | 9 | 10 - Misses
51	16	9 | 11 | 10 - False Alarms
52	198	11 | 11 | 10 - Misses
53	1	12 | 12 | 10 - Misses
54	31	8 | 8 | 11 - Misses
55	2263	9 | 9 | 11 - Misses
56	2656	10 | 10 | 11 - Misses

Table: Net change 1990 to 2012.



0 7 Km

Municipalities

Data Source: CORINE LAND COVER 1990-2012, CAOP, DGT 2015.
Prediction Method: Markov Chain.
Author: Duarte Nunes, 2019.

Correct due to observed persistance predicted as persistence

Correct due to observed change predicted as change

Error due observed persistence predict as change

Error due to observed change predicted as persistence

Change analysis Scenarios

SC1 net change from 2012				
Class	sq km	Cells	% area	% change
Urban Fabric	33.62	3362	1.44	24.16
Industrial, commercial and transport units	0	0	0	0
Mine, dump and constructions site	0	0	0	0
Artificial, non-agricultural vegetated areas	0	0	0	0
Arable land	0	0	0	0
Permanent crops	-1.45	-145	-0.06	-97.32
Pastures	-1.82	-182	-0.08	-313.79
Heterogeneous agricultural areas	-23.37	-2337	-1	-28.89
Forests	-8.8	-880	-0.38	-3.23
Shrub and/or herbaceous vegetation association	1.82	182	0.08	1.04
Open spaces with little or no vegetation	0	0	0	0
Water Bodies	0	0	0	0

SC2 net change from 2012				
Class	Sq km	Cells	% area	% change
Urban Fabric	3.88	388	0.17	3.55
Industrial, commercial and transport units	0	0	0	0
Mine, dump and constructions site	0	0	0	0
Artificial, non-agricultural vegetated areas	0	0	0	0
Arable land	0	0	0	0
Permanent crops	0	0	0	0
Pastures	-1.82	-182	-0.08	-313.79
Heterogeneous agricultural areas	4.92	492	0.21	4.51
Forests	-8.8	-880	-0.38	-3.23
Shrub and/or herbaceous vegetation association	1.82	182	0.08	1.04
Open spaces with little or no vegetation	0	0	0	0
Water Bodies	0	0	0	0

SC3 net change from 2012				
Class	Sq km	Cells	% area	% change
Urban Fabric	29.74	2974	1.28	21.99
Industrial, commercial and transport units	0	0	0	0
Mine, dump and constructions site	0	0	0	0
Artificial, non-agricultural vegetated areas	0	0	0	0
Arable land	0	0	0	0
Permanent crops	-1.45	-145	-0.06	-97.32
Pastures	-1.82	-182	-0.08	-313.79
Heterogeneous agricultural areas	-28.29	-2829	-1.21	-37.24
Forests	0	0	0	0
Shrub and/or herbaceous vegetation association	1.82	182	0.08	1.04
Open spaces with little or no vegetation	0	0	0	0
Water Bodies	0	0	0	0

SC4 net change from 2012				
Class	Sq km	Cells	% area	% change
Urban Fabric	0	0	0	0
Industrial, commercial and transport units	0	0	0	0
Mine, dump and constructions site	0	0	0	0
Artificial, non-agricultural vegetated areas	0	0	0	0
Arable land	0	0	0	0
Permanent crops	0	0	0	0
Pastures	-1.82	-182	-0.08	-313.79
Heterogeneous agricultural areas	-4.22	-422	-0.18	-4.22
Forests	-14.95	-1495	-0.64	-5.62
Shrub and/or herbaceous vegetation association	-34.58	-3458	-1.48	-25.1
Open spaces with little or no vegetation	55.57	5557	2.38	47.7
Water Bodies	0	0	0	0

Landscape metrics

Coded values

Code	Class
1	Urban fabric
2	Industrial, commercial and transport units
3	Mine, dump and constructions sites
4	Artificial, non-agricultural vegetated area
5	Arable land
6	Permanent crops
7	Pastures
8	Heterogeneous agricultural areas
9	Forests
10	Shrub and/or herbaceous vegetation associations
11	Open spaces with little or no vegetation
12	Water Bodies

	1990	2000	2006	2012	SC1	SC2	SC3	SC4
	Class level							
Class	Number of patches/ Patch density							
1	78	92	89	90	189	161	220	90
2	4	7	8	9	9	9	9	9
3	1	4	8	6	6	6	6	6
4	1	3	3	3	3	3	3	3
5	6	6	2	2	2	2	2	2
6	13	13	10	10	12	10	13	10
7	11	11	3	3	2	5	3	8
8	119	141	145	142	397	216	302	142
9	38	47	51	64	123	123	64	153
10	89	84	89	101	100	100	100	193

11	21	22	17	25	25	25	25	274
12	0	0	0	0	0	0	0	0
Total	381	430	425	455	868	660	747	890

Landscape level – Shannon's Diversity index								
	1990	**2000**	**2006**	**2012**	**SC1**	**SC2**	**SC3**	**SC4**
SDI	1.469	1.507	1.475	1.596	1.577	1.595	1.565	1.637

	1990	**2000**	**2006**	**2012**	**SC1**	**SC2**	**SC3**	**SC4**
				Class level				
Class				Total Patch area				
1	7169	10053	10537	10558	13920	10946	13532	10558
2	166	349	461	496	496	496	496	496
3	52	149	260	212	212	212	212	212
4	36	202	194	194	194	194	194	194
5	220	220	30	30	30	30	30	30
6	728	493	272	294	149	294	149	294
7	724	703	240	240	58	58	58	58
8	12978	10708	10420	10425	8088	10917	7596	10003
9	31556	31092	30651	28092	27212	27212	28092	26597
10	18860	18488	19399	17240	17422	17422	17422	13782
11	1354	1404	1413	6096	6096	6096	6096	11653
12	313	295	279	279	279	279	279	279
Total	74156	74156	74156	74156	74156	74156	74156	74156

	1990	**2000**	**2006**	**2012**	**SC1**	**SC2**	**SC3**	**SC4**
				Class level				
Class				Mean Shape Index				
1	2.20684	2.23701	2.23259	2.22188	1.70149	1.79454	1.68498	2.22188
2	1.98809	2.20923	2.18498	2.15141	2.15141	2.15141	2.15141	2.15141
3	1.643302	1.94194	1.93512	1.96379	1.96379	1.96379	1.96379	1.96379
4	1.41047	1.91435	2.21696	2.21696	2.21696	2.21696	2.21696	2.21696
5	1.89141	1.89141	1.40233	1.40233	1.140233	1.40233	1.40233	1.40233
6	2.14516	2.0616	1.97902	2.06793	1.63263	2.06793	1.5692	2.06793
7	1.92079	1.90829	1.97432	1.97432	2.09177	1.53079	1.44756	1.36741
8	2.27236	2.21065	2.17801	2.18509	1.50877	1.88693	1.59717	2.18284
9	2.60706	2.58756	2.50782	2.38287	1.92216	1.93059	2.38287	1.69888
10	2.01922	2.04921	2.04285	2.0212	2.02131	2.0232	2.02241	1.6113
11	2.05685	2.03975	2.08729	2.26077	2.26077	2.26077	2.26077	1.52279
12	1.14807	1.14524	1.14371	1.14371	1.14371	1.14371	1.14371	1.14371

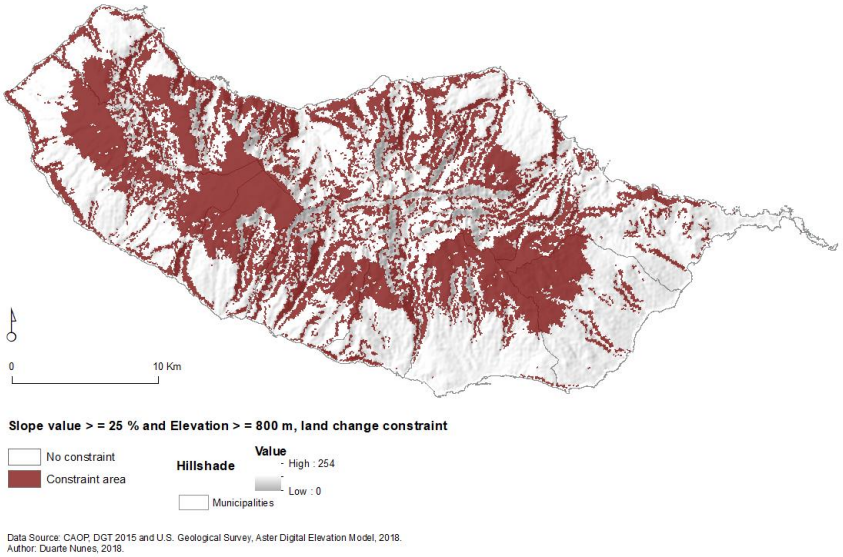
	1990	2000	2006	2012	SC1	SC2	SC3	SC4
				Class level				
Class				Edge Density				
1	7.82674	10.0464	10.1731	10.1705	12.2768	11.0146	13.1453	10.1705
2	0.231943	0.501645	0.609526	0.663466	0.663466	0.663466	0.663466	0.663466
3	0.056637	0.231943	0.420735	0.331733	0.331733	0.331733	0.331733	0.331733
4	0.040455	0.229246	0.248126	0.248126	0.248126	0.248126	0.248126	0.248126
5	0.342521	0.342521	0.048546	0.048546	0.048546	0.048546	0.048546	0.048546
6	0.970926	0.782135	0.507039	0.550191	0.33443	0.550191	0.33443	0.550191
7	0.803711	0.784832	0.261611	0.261611	0.110578	0.118669	0.086305	0.129457
8	13.9112	13.2612	12.8971	12.8216	12.1555	13.9031	11.0982	12.5276
9	17.9217	18.4125	17.8947	17.0344	17.9486	17.6385	17.0344	16.4194
10	11.9909	11.8723	12.0611	12.1905	12.1501	12.2337	12.1986	11.0227
11	1.62091	1.67754	1.48336	4.35299	4.35299	4.35299	4.35299	10.575
12	1.49684	1.4483	1.37818	1.37818	1.37818	1.37818	1.37818	1.37818

	1990	2000	2006	2012	SC1	SC2	SC3	SC4
				Class level				
Class				Shannon's diversity index				
Agricultural areas	0.4682	0.477779	0.239737	0.246495	0.154939	0.170985	0.1628	0.182875

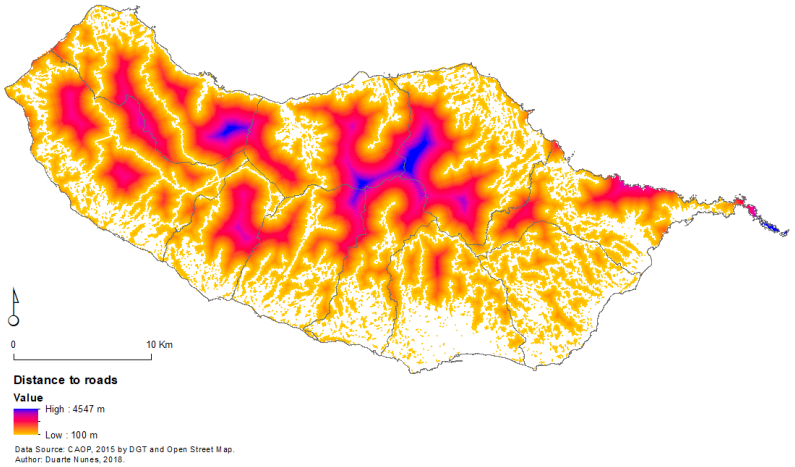
.

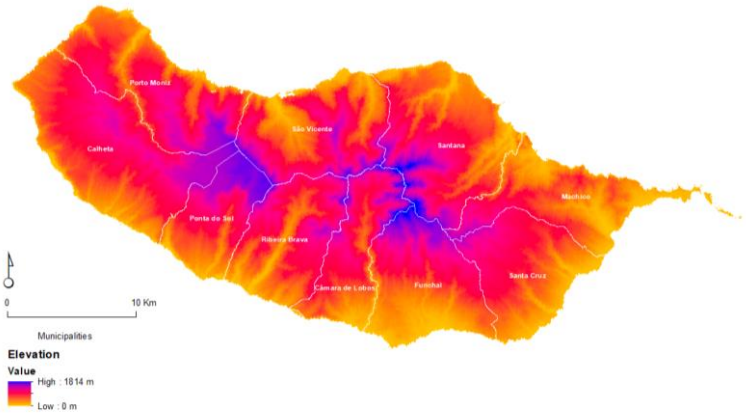
Municipality	Area Hectares (ha)	Protected areas Hectares (ha)	Natura 2000 Hectares (ha)	Surface area (%) Protected areas
Calheta	11 150	7 258	3 835	65, 1%
Câmara de Lobos	5 214	3 228	1 016	61,9 %
Funchal	7 625	2 936	2 243	38,5 %
Machico	6 833	3 529	3 080	51, 7 %
Ponta do Sol	4 619	2 978	1 271	64,4 %
Porto Moniz	8 293	6 953	11 320	83, 8 %
Porto Santo	4 217	230	328	5,3 %
Ribeira Brava	6 541	5 007	652	76, 5 %
Santa Cruz	8 152	2 558	3 119	31,4 %
Santana	9 556	6 400	8 675	67 %
São Vicente	7 820	5 229	10 201	66,3 %
Total Island	74 100	46 306	45 740	57, 8 %

Constraints map

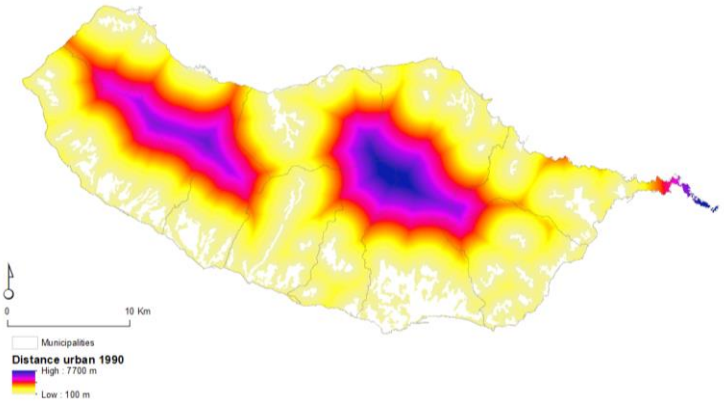


Driven variables

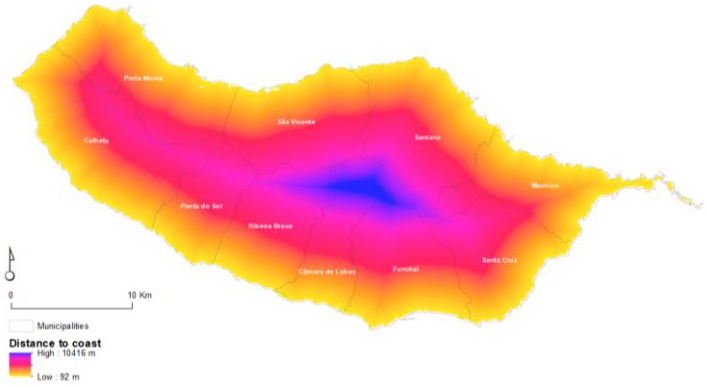




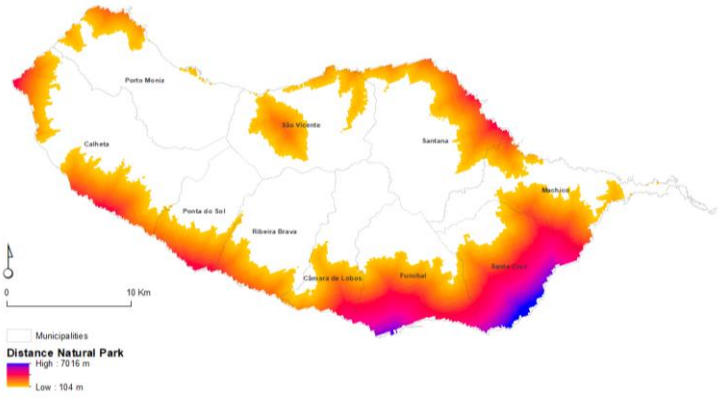
Data Source: CAOP 2015, DGT and U.S. Geological Survey, Aster Global Digital Elevation Model, 2018.
Author: Duarte Nunes, 2018.



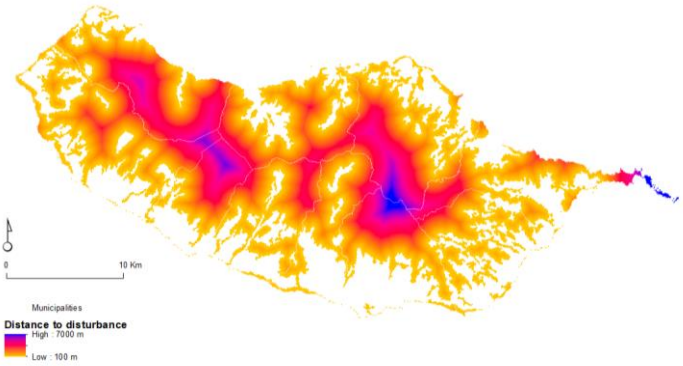
Data Source: CAOP 2015, DGT and Corine Land Cover 1990.
Author: Duarte Nunes, 2018.



Data Source: DGT, CAOP 2015.
Author: Duarte Nunes, 2018.



Data Source: Provided by Institute for Nature Conservation and Forests, IP-RAM.
Author: Duarte Nunes, 2018.



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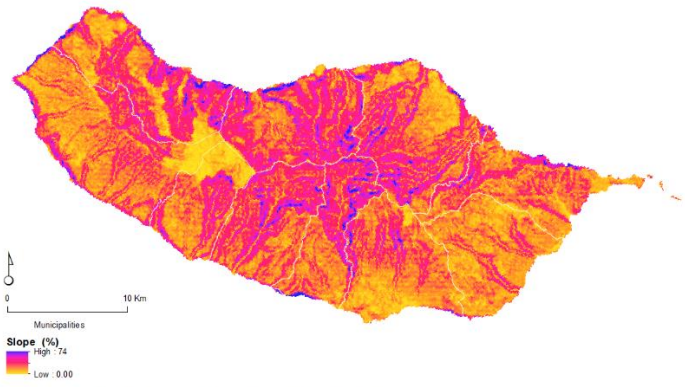
Author: Duarte Nunes, 2018.



Data Source: CAOP 2015, DGT and U.S. Geological Survey, Aster Global Digital Elevation Model, 2018.
Author: Duarte Nunes, 2018.

Data Source: DGT, CAOP, 2015 used for Administrative limits.
Author: Duarte Nunes, 2018.

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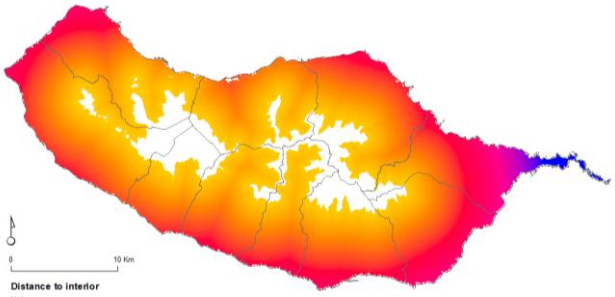

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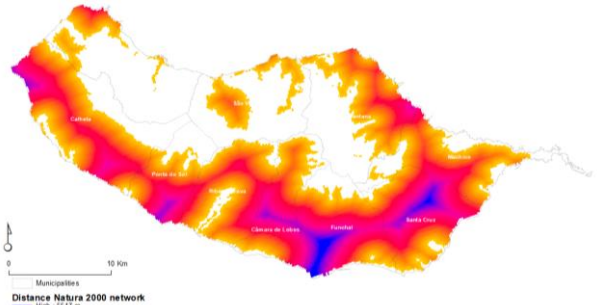
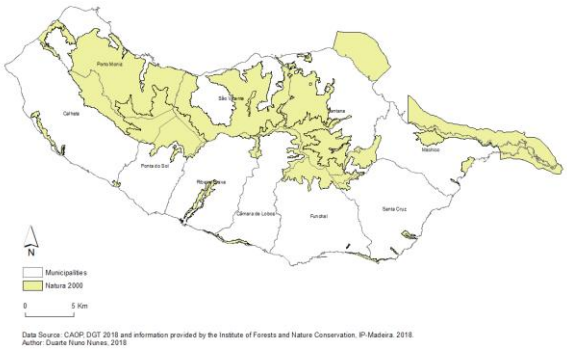
Author: Duarte Nunes, 2018.

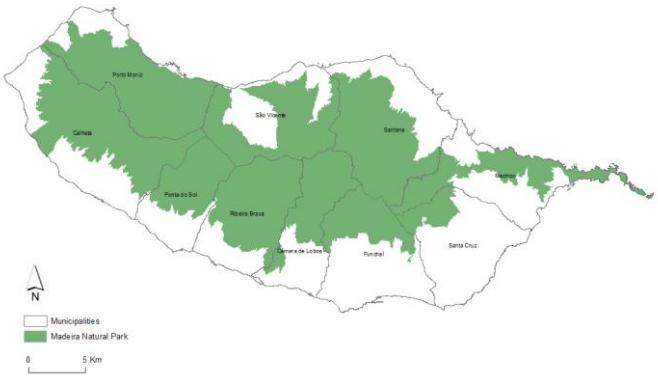


Data Source: Provided by Institute for Nature Conservation and Forests, IP-RAM.
Author: Duarte Nunes, 2018.

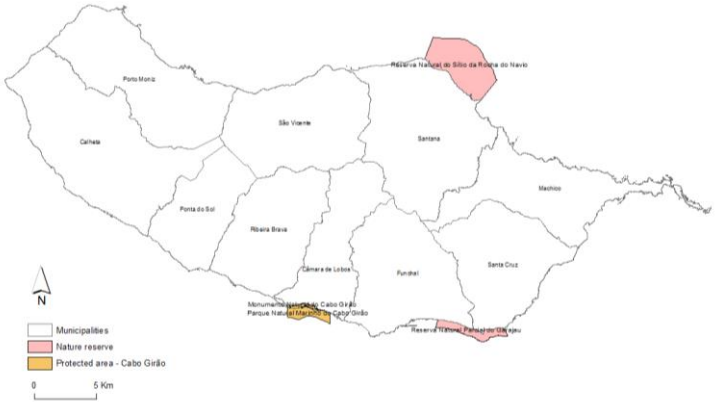
Protected areas – Provided by Institute of Forests and Nature Conservation, IP-Madeira, 2018.



Data Source: CAOP, DGT 2018 and information provided by the Institute of Forests and Nature Conservation, IP-Madeira. 2018.
Author: Duarte Nuno Nunes, 2018

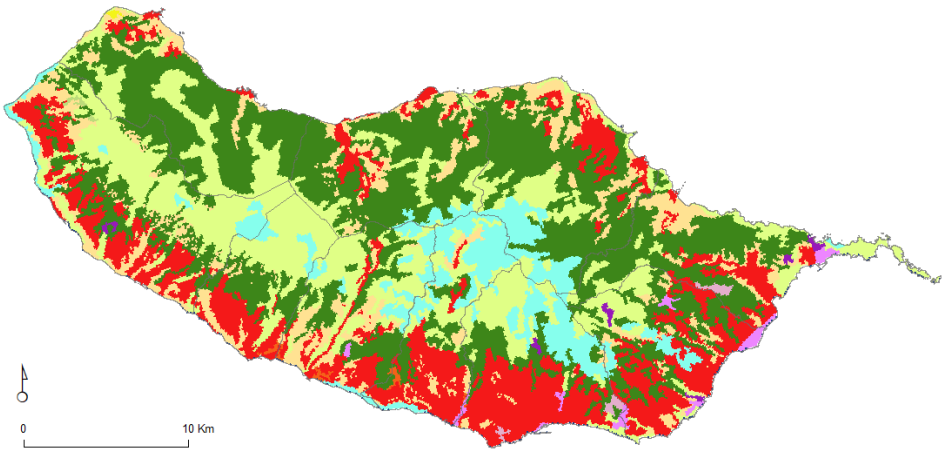


Data Source: CAOP, DGT 2018 and information provided by the Institute of Forests and Nature Conservation, IP-Madeira. 2018.
Author: Duarte Nuno Nunes, 2018



Data Source: CAOP, DGT 2018 and information provided by the Institute of Forests and Nature Conservation, IP-Madeira. 2018.
Author: Duarte Nuno Nunes, 2018

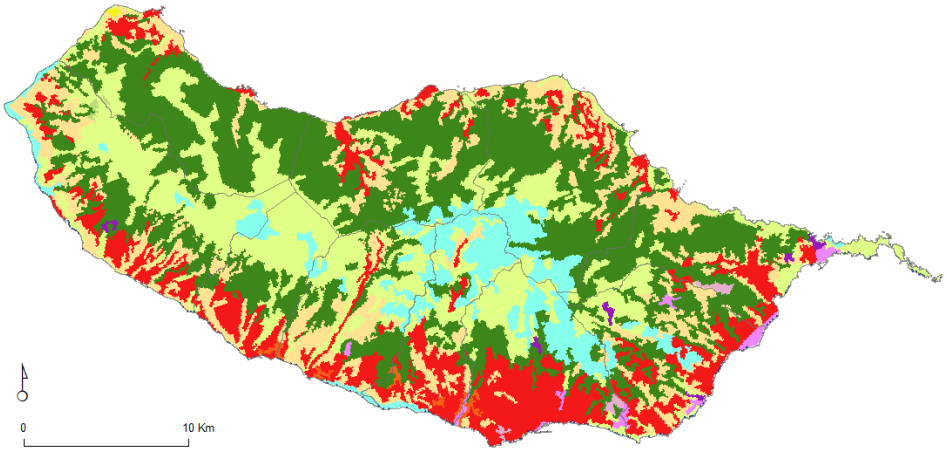
Predict LULC 2040



Scenario business as usual (SC1), 2040

- Urban fabric
- Industrial, commercial and transport units
- Mine, dump and constructions sites
- Artificial, non-agricultural vegetated areas
- Arable land
- Permanent crops
- Pastures
- Heterogeneous agricultural areas
- Forests
- Shurb and/ or herbaceous vegetation associations
- Open spaces with little or no vegetation
- Water Bodies
- Municipalities

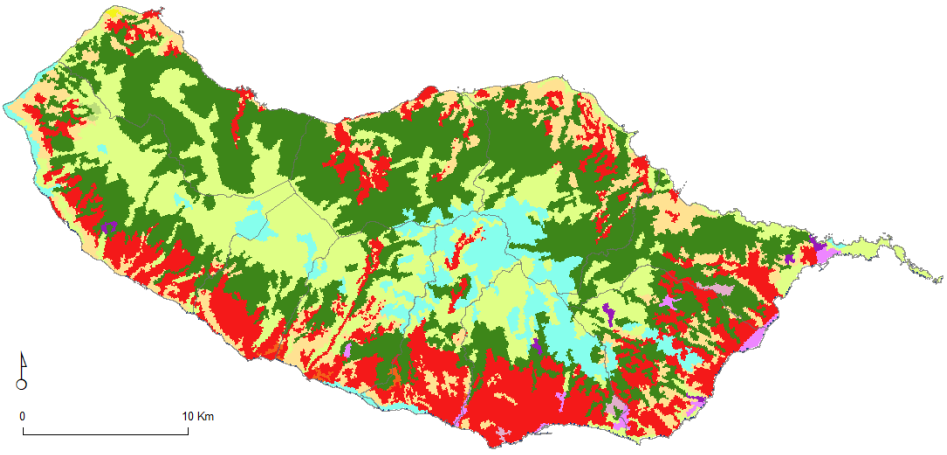
Data Source: CORINE LAND COVER, 1990-2012, CAOP, DGT 2015.
Prediction method: Markov Chain.
Author: Duarte Nunes, 2018.



Scenario protection of agricultural areas (SC2), 2040.

- Urban fabric
- Industrial, commercial and transport units
- Mine, dump and constructions sites
- Artificial, non-agricultural vegetated areas
- Arable land
- Permanent crops
- Pastures
- Heterogeneous agricultural areas
- Forests
- Shurb and/ or herbaceous vegetation associations
- Open spaces with little or no vegetation
- Water Bodies
- Municipalities

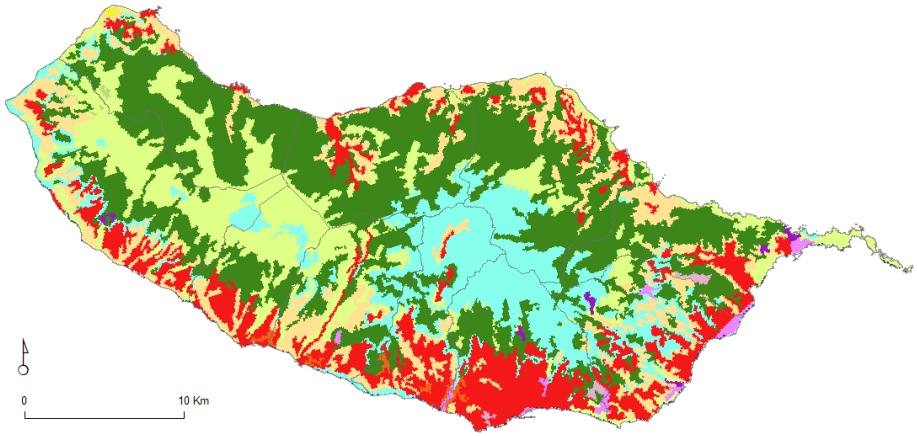
Data Source: CORINE LAND COVER, 1990-2012, CAOP, DGT 2015.
Prediction method: Markov Chain.
Author: Duarte Nunes, 2018.



Scenario protection of forests areas (SC3), 2040.

- Urban fabric
- Industrial, commercial and transport units
- Mine, dump and constructions sites
- Artificial, non-agricultural vegetated areas
- Arable land
- Permanent crops
- Pastures
- Heterogeneous agricultural areas
- Forests
- Shurb and/ or herbaceous vegetation associations
- Open spaces with little or no vegetation
- Water Bodies
- Municipalities

Data Source: CORINE LAND COVER, 1990-2012, CAOP, DGT 2015.
Prediction method: Markov Chain.
Author: Duarte Nunes, 2018.



Scenario renaturation (SC4), 2040.

- Municipalities
- Urban fabric
- Industrial, commercial and transport units
- Mine, dump and constructions sites
- Artificial, non-agricultural vegetated areas
- Arable land
- Permanent crops
- Pastures
- Heterogeneous agricultural areas
- Forests
- Shurb and/ or herbaceous vegetation associations
- Open spaces with little or no vegetation
- Water Bodies

Data Source: CORINE LAND COVER, 1990-2012, CAOP, DGT 2015.
Prediction method: Markov Chain.
Author: Duarte Nunes, 2018.

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