Action Plan for the Habitat Type
9360 Macaronesian laurel forests

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BACKGROUND AND INTRODUCTION

This habitat action plan aims to guide the measures required to maintain and restore the laurel forest habitat to a favourable conservation status throughout its range.

Under the framework of the Biogeographical Process Natura 2000, the initial Seminar of the Macaronesian Biogeographic Region was held in September 2018, in Funchal (Madeira, Portugal). One of the conclusions of this Seminar was the need to promote the preparation of a pilot action plan for a habitat type of of community interest in the Macaronesian region. To this end, the creation of a working group in the Macaronesian region was proposed. The group agreed to focus the action plan on a habitat type that is endemic to the biogeographical region, and is present in all three of the constituting archipelagos (Azores, Madeira and the Canary Islands) of the region: the Macaronesian laurel forests (9360)

A group formed of scientific experts and regional authority representatives (from Azores, Madeira and the Canary Islands) collaborated to elaborate this action plan. The Spanish Ministry for Ecological Transition and the Demographic Challenge provided the necessary support for the drafting of this action plan.

This exercise has also served to identify information gaps and future needs for addressing the conservation of this habitat type and its implementation. The pilot exercise will also be useful in the preparation of future habitat action plans in the framework of the Natura 2000 Biogeographical Process.

1. OBJECTIVES AND SCOPE OF THE ACTION PLAN

Overall aim of the action plan:

To promote the necessary actions to achieve a favourable conservation status of the habitat type in the Macaronesian region.

Specific objectives:

i) To share knowledge and experiences on the assessment and monitoring of the status of the habitat and its main pressures and threats, and

ii) To promote harmonised and consistent approaches to address the conservation of the habitat type at the biogeographical level, based on scientific knowledge and the ecosystem approach.

Scope:

Biogeographical region and the MS where the type is present.

2. HABITAT TYPE DEFINITION AND ECOLOGICAL CHARACTERIZATION

2.1 Habitat type name and definition

The Interpretation Manual of European Union habitats (European Commission, 2013) defines the habitat type as follows:

“Humid to hyper-humid, mist-bound, luxuriant, evergreen, lauriphyllous forests of the cloud belt of the Macaronesian islands, extremely rich in floral and faunal species, among which many are restricted to these communities (*Pruno-Lauretalia*). Genera such as *Picconia, Semele, Gesnouinia, Lactucosonchus, Ixanthus* are entirely endemic to these communities, while others, such as *Isoplexis, Visnea* and *Phyllis*, reach in them their maximum development; in addition, each of the formations of the various archipelagos harbours distinctive endemic species. This habitat type includes:

- lauriphyllous forests of the Azores (45.61 *Ericetalia azorica* p.), where the humid forests of the coastal areas (*Myrico-Pittosporietum undulati* p.) have been totally or almost totally degraded, largely invaded by the introduced Australian *Pittosporum undulatum;* a better representation survives of the hyper-humid forests (*Culcito-Juniperion brevifoliae* p.) of higher elevations;

- lauriphyllous forests of Madeira (45.62 *Pruno-Lauretalia azorica*) still occupying a relatively large surface, of the order of 10,000 ha;

- lauriphyllous forests of the Canary Islands (45.63 *Ixantho-Laurion azoricae)*; the laurel forests of each island harbour a distinctive set of endemic plants and animals, as exemplified by the species of the composite genus *Pericallis*, the well-marked races of the chaffinch *Fringilla coelebs* or the carabid fauna”.

Revised definition proposal

Proposed new definition: HCI 9360 Macaronesian Laurisilva (*Laurus, Picconia*)*

The Macaronesian laurisilva is a frost-free, humid to hyper-humid, tropical-like, multi-stratified lauriphyllous evergreen forest, characteristic, but not exclusive, of the mountain cloud belt, distributed exclusively in the NE Atlantic volcanic archipelagos of Azores, Madeira and the Canary Islands. It is considered to be a relic of the former Paleo and Neogene European and Tethys Sea Basin Palaeotropical Geoflora.

The height of the canopy varies depending on the archipelago and environmental conditions of the site, and the habitat can hold an important amount of biomass (> 500 t/ha) both above and below the soil surface. It is extremely species-rich, with ca. 30 canopy palaeoendemic tree species in its distribution area. It displays several tropical-like characters (extended real or functional dioecy, entomophily, ornithochory, recalcitrant seeds, seedling and sucker banks, etc.) and belongs to botanical families not well represented in the European mainland, such as Clethraceae, Lauraceae, Myrsinaceae, Pentaphylacaceae, Pittosporaceae or Sapotaceae.

Other taxonomic groups present with high endemicity include shrubs, lianas, birds, arthropods or molluscs, and with high species richness include fungi, ferns, mosses and lichens, many of them epiphytes. Besides its biodiversity and historical value, this habitat type provides the local community with important ecosystem services, such as: capture of carbon, capture and retention of water, and soil formation and retention.

Rationale for the proposed changes:

- Laurisilva instead of laurel forest, because this is the way it is named in Macaronesia.
- *Picconia* instead of *Ocotea*, because *Picconia* is an endemic genus of Macaronesia existing in the three archipelagos, whereas *Ocotea* is neither endemic nor native in Azores.
- The definition intends to be as concise and representative of the 9360 of the three archipelagos as much as possible.
- The main abiotic characteristics of the HCI have been included.
- The relic character of the HCI has been highlighted.
- Phytosociological and taxonomical names have been omitted, with exception of some botanical family names. The idea is to include the names of the more representative taxa (trees, birds, arthropods, molluscs) in its characterization.
- Important ecosystem services have been added.

2.2. Ecological characterization

2.2.1 Main habitat characteristics and ecological requirements

(based in Fernández-Palacios *et al.*, 2017)

The term 'laurisilva' was first introduced by Brockmann-Jerosch & Rübel in 1912. It is commonly applied to the laurisilva of Macaronesia, but covers all types of multistoried forests that are largely made up of trees and shrubs with broad, coriaceous, glossy evergreen leaves (laurophylls = leaves similar to those of the laurel). However, the tree composition is highly varied including, in some cases, conifers and deciduous species (Santos-Guerra, 1990). These laurophyll forests evolve under tropical or subtropical climates with high relative humidity and moderate temperatures, and are accompanied by epiphytes and lianas that give a 'tropical' character. This vegetation formation does not have as many species as tropical forests, but looks very similar to them in physiognomy, structure, diversity, complexity and in the specialised adaptations that their species possess.

The Macaronesian laurisilva is home to several botanical families absent, or almost absent, in the European continent, despite having been abundant there in the past. Examples include Clethraceae, Lauraceae, Myrsinaceae, Pentaphyllacaeae, Pittosporaceae or Sapotaceae. The whole Macaronesia counts with ca. 30 exclusive canopy tree species, the vast majority of them palaeoendemics, and a very high neoendemic biodiversity in other forest dweller groups, such as birds, arthropods or molluscs, which implies an outstanding species richness and endemicity rate.

Additional interesting 9360 tropical-like community or species attributes include: i) the recalcitrant nature of the arboreal seeds, meaning that they either germinate or die, thus forming seedling banks; ii) the absence of marked flowering periods, which in some species can last the whole year long; iii) the caulifloria, present in Myrsinaceae and Sapotaceae; iv) the perennial habit of all the tree species (except *Sambucus* spp.); v) a dominance of sexual dimorphism, i.e. dioecy in *Ilex, Laurus, Morella, Pittosporum, Rhamnus*; or androdioecy in *Picconia*) or vi) a generalized entomogamy and ornithochory, among others (Fernández-Palacios *et al.*, 2017).

Finally, the Macaronesian laurisilva capacity for capturing carbon is outstanding (see Appendix I) and levels as high as 350-370 t/ha C have been measured in mature laurisilva stands in La Gomera (and very likely have similar values in Madeiran 9360 mature stands), to which we should add 230-430 t/ha C in the 9360 soils, so that the total C captured can reach in mature forests as much as 400-800 t/ha. Furthermore, community Basal Areas can reach in mature forest stands > 60 m^2/ha and the canopy height on flat terrain can reach up to 30-40 m.

Laurisilva is fundamentally a relict biome. The once extensive Paleotropical Geoflora was found throughout the middle latitudes during the Tertiary, when conditions were much warmer and wetter than today. This biome has persisted in unique geographic settings characterized by relict climates that have been maintained without great change since the Tertiary. As a result of the climate deterioration experienced in high to middle latitudes during the Neogene and, especially, from the beginning of the Plio-Pleistocene glaciations, these laurisilvas occur in just a few areas.

At present, we find different versions of this biome throughout the world, generally between latitudes 25° and 40° north and south, on the eastern and western edges of continents (where it has its greatest extent), and on scattered islands. Therefore, it presents a clearly disjunct distribution of fragmented forests distant from one another and with a small total area relative to other biomes, but present in all the major plant kingdoms. The different laurisilvas in the world have distinctive evolutionary histories and scarcely share any species between them. However, they share forest structures that demonstrate similar responses to similar environmental conditions. As a group, the flora of these forests belongs mostly to the floristic region in which they are found, but always includes species of tropical origin. This fact, which implies a common tropical-subtropical origin, can be interpreted as implying that all laurisilva formations are derived in some way or another from the primitive tropical rainforest. In fact, the laurisilvas represent tropical forests in extratropical regions (Schroeder, 1998).

In general, the climate under which the various laurisilvas of the world develop are characterised by abundant precipitation throughout the year and by mild temperatures. They are also associated with some degree of contrast between summer and winter, which differentiates them from tropical rainforests. This climate, through the lack of hydrological or thermal stress in the course of the year, resembles the Tertiary climates. Because of this, it can only exist in humid subtropical zones, or occasionally in rainy temperate zones exposed to west wind flow. These zones are preferentially located on the eastern or western edges of the continents depending on which hemisphere they are in. A common denominator that we always find in this type of forest biome, independent of its location, is lack of a marked dry season at any point in the year and a low frequency of frosts. Moreover, the laurisilvas are found in regions that were less affected by the Quaternary glaciations than most, which has undoubtedly favoured retention of some very ancient species.

However, in regions subjected to Mediterranean-type climate, the laurisilva can also survive as a type of mountain cloud forest under the shelter of orographic cloud banks generated by dominant winds. In these conditions, laurisilva distribution is limited to the altitudinal band under cloud influence, which allows it to overcome the moisture stress that prevails above and below. As the cloud shelter exists only on mountain flanks and escarpments, the laurisilva then becomes, as in Macaronesia, a cloud forest similar in structure to tropical forests, but much poorer in species (Ohsawa *et al.*, 2010).

In general, as we will see, the laurisilvas have a high arboreal diversity. The benign climate and the evergreen character of most of the species means a certain level of photosynthesis occurs nearly year-round. When rainfall and temperature are adequate, the laurisilva structure rivals that of the tropical rainforest, with canopies that can reach 30-50 m high, under which other tree and shrub strata as well as climbers and epiphytes occur.

Many laurisilva tree species can resprout from the base of the trunk or from the roots, perhaps an adaptation to overcome storm damage, and individual trees may have multiple trunks forming cage-like structures. Much the same as tropical forest, the laurisilva is dark and essentially without seasonality, so that flowering and fruiting is not synchronised as in temperate forests. As a result, depending very much on the species involved, there are flowers and fruits all year round.

The mountainous volcanic character of the Atlantic archipelagos means that these islands support a nearly permanent, humid, trade wind belt on their flanks. The steady flow of the trade winds together with the moderating effect of the Atlantic Ocean, and the fact that it could move towards the mountain peaks, or down to the coast as the climate warmed or cooled, has protected the Macaronesian laurisilva from the repeated cold climate crises. Such crises eliminated laurisilva in the course of the Quaternary from nearby Europe and North Africa (Mai, 1989). The Atlantic laurisilva forest is a mountain cloud forest whose principal characteristic, considerin gits latitude, is an elevated arboreal richness of about thirty species- mostly endemic. In broad terms, the forest is made up of evergreen trees dominated by those with lauroid leaves, which are medium-sized, glossy leaves reminiscent of or easily confused with those of laurel, a result of their adaptation to the relatively even yearly climate with moderate temperatures and high humidity.

The laurisilva forest ecosystem is not homogeneous, presenting, a great range of forest types. Variations in altitude, exposure or relief bring with them very different temperatures, rainfall, wind intensity, cloudiness, sunshine etc., creating distinctive environments to which the species have differing sensitivities. Finally, the laurisilva forest has played and plays a critically important role both for soil development and retention, as well as for the capture and retention of carbon and water from both rainfall and trapping of cloud moisture (Fig. 1).

Appendix I summarizes the ecological characterization of the 9360 in the three different archipelagos. This provides data about abiotic characteristics (climate and soil properties), as well as biotic characteristics including floristic and faunistic species richness and composition, structure and function parameters, regeneration and dynamicity.

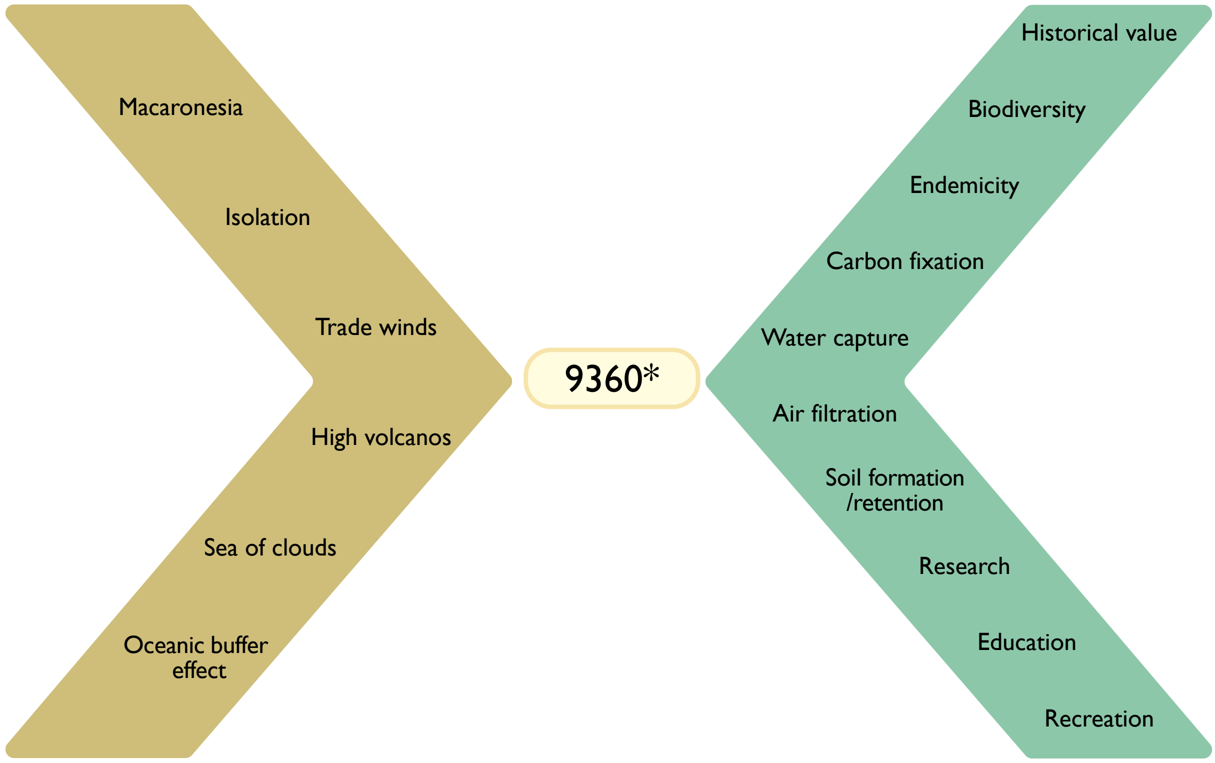


Figure 1: Flow chart of 9360 compiling the biogeographical-ecological grounds of its existence and the ecosystem services being provided.

Selection of typical species

Following European Commission documents, candidates to be selected as **typical species** should include one or more of the following characteristics: 1) A species in which the identification of the habitat is based; 2) A species that is inseparable of this habitat; 3) A species that is regularly present in the habitat, but no restricted to it; 4) A species characteristic of the habitat; 5) A species that is an integral part of the habitat's structure or 6) A key species with significant influence over the habitat' structure and/or function. To avoid overlapping with the evaluation of habitat's structure and function, the document suggests defining typical species as those that are inseparable of the habitat where they are present, but different from those used for defining this habitat type. Following these indications, it has been considered that **typical species** could be defined as those relevant to maintain the habitat type in a favourable conservation status, either due to their frequency or dominancy (structural value) or due to their key influence in the habitat's ecological functioning (functional value). One should also consider the geographical reference level or scale for which this species is typical, a habitat subtype, a zone of a given island, a whole island, an archipelago, or the biogeographical region. If the selected species has a reduced distribution area, it would be interesting to mention in which Special Area of Conservation (hereafter SAC) it is present and to give genetic and demographic parameters that permit the analysis of its conservation status. In these cases, it would be relevant to indicate its IUCN threat category (European Commission, 2017).

Following these indications for Macaronesian laurisilva, one should not designate the constituent canopy trees as typical species because they will be evaluated periodically in the habitat's structure and function. Due to their isolation, the 9360 that exists on different islands used to have different endemic species-usually single island endemic species. It seems reasonable to consider these island endemisms as suitable typical species to monitor and evaluate each insular version of the 9360 HCI. Table 1 compiles a preliminary approximation towards this goal, but the identification of these 9360 typical species should be one of the tasks carried out by experts in the near future.

Laurisilva gap caused by Storm Delta in Anaga (Tenerife). Photo: Nélida Rodríguez

Typical species	Taxonomic group	Endemicity	Island	IUCN status
Echium pininana	Vascular plant	SIE	La Palma	EN
Echium acanthocarpum	Vascular plant	MAE	La Gomera	EN
Euphorbia mellifera	Vascular plant	SIE	Tenerife, La Gomera, Madeira	LC
Isoplexis chalcantha	Vascular plant	SIE	Gran Canaria	CR
Euphorbia santamariae	Vascular plant	MIE	Santa Maria	CR
Euphorbia stygiana	Vascular plant	SIE	São Miguel, Terceira, Pico, Faial, Flores	?
Musschia wollastonii	Vascular plant	SIE	Madeira	EN
Laurobasidium lauri	Fungi	MAE	Macaronesia	NT
Tremella ssp.	Fungi	Non-endemic	Macaronesia	NE
Clavaria vermicularis	Fungi	MAE	Madeira, Canaries	NE
Sacrocsypha macaronesica	Fungi	MAE	Madeira, Canaries	NE
Plagiochila maderensis	Bryophyte	MAE	Madeira, Tenerife, La Gomera	NE
Cryptolentodon longisetus	Bryophyte	MAE	Macaronesia	NE
Homalothecium mandonii	Bryophyte	MAE	Macaronesia	NE
Exerthotheca intermedia	Bryophyte	MAE	Macaronesia	NE
Nephroma ssp.	Lichen	MAE	Macaronesia	NE
Lobaria ssp.	Lichen	MAE	Macaronesia	NE
Pseudocyphellaria ssp.	Lichen	MAE	Macaronesia	NE
Sticta ssp.	Lichen	MAE		NE
Columba bollii	Aves	MIE	Tenerife, La Palma, La Gomera, El Hierro	LC
Columba trocaz	Aves	SIE	Madeira	LC
Scolopax rusticola	Aves	MAE	Macaronesia	
Phyrrula murina	Aves	SIE	São Miguel	VU
Fringilla ssp.	Aves	MIE	Macaronesia	
Erithacus ssp.	Aves	SIE/MIE	Macaronesia	
Regulus ssp.	Aves	SIE/MIE	Macaronesia	
Pipistrellus maderensis	Chiroptera	MAE	Madeira, Canaries	EN
Nyctalus azoreum	Chiroptera	MIE	All except, Flores and Corvo	VU
Plecotus tenerifae	Chiroptera	Canaries	Tenerife, La Palma, El Hierro	CR
Carabus faustus	Insecta	Canaries	Tenerife	NT
Dysdera spp.	Aranae	SIE	Canaries	
Leiostyla spp.	Mollusca		Madeira	
Madeirovitrina ssp.	Mollusca		Madeira	
Insulivitrina ssp.	Mollusca		Canaries	
Plutonia ssp.	Mollusca		Azores	

Table 1: Preliminary list of candidate typical species for monitoring in the evaluation of the 9360 condition (extracted from Fernández-Palacios *et al*., 2017). Endemicity stands as SIE: single island endemics; MIE: multiple island endemics; MAE: multiple archipelago endemics; IUCN threat categories stand as CR: Critically endangered; EN. Endangered; VU: Vulnerable; LC: Less concern; NT: Near threatened; NE: Not evaluated.

2.2.2 Dynamics (spatial and temporal) of the habitat type throughout the region

Macaronesian laurisilva can exist where the proper climatic conditions occur permitting this peculiar ecosystem to withstand the intense summer drought of the Mediterranean type climate. This is possible in the Canaries and Madeira because of the existence of the sea of clouds originated by the NE trade winds that create in the volcanic islands a climatic refugium at the mid elevations of the windward island slopes (ca. 100-1,500 m in Madeira and ca. 500-1,200 m in the Canaries). In Azores, it is the year-round humidity and mild temperatures of the Gulf-Stream driven oceanic climate, which permits the existence of 9360 from the coasts to the summit of all the islands (except Pico). Beyond this climatic refugium, the 9360 can only appear in these particular climatic circumstances in the leeward slopes of the islands (profound ravines or cliffs exposed to the North).

This is to say that 9360 has been reiteratively ascending to the islands' summit and descending to the coast following the sea of clouds' vertical migration related with the onset of the Pleistocene glaciations. The future of this habitat is strongly bound to the sea of clouds produced by the trade winds. If ongoing climate change were to affect the sea of clouds with an altitudinal redistribution (either upwards or downwards), the 9360 would respond. Additionally, if the ongoing climate change were to dissipate the sea of clouds, it would also result in the disappearance of the laurisilva, at least, as we know it today.

2.2.3 Ecological diversity and variability: habitat subtypes

Knowledge of the 9360 internal ecological diversity stems from the vegetation classification and vegetation mapping (both potential or pre-human, and current or present existing vegetation) that has been elaborated by the scholars working in these areas. An example of such knowledge is the recognized habitat subtypes in the different archipelagos of the Macaronesian Biogeographical Region and their main characteristics. The production of these vegetation classifications and consequent maps mainly follows a bioclimatic-phytosociological approach. The bioclimate of a given area can be analyzed, using several parameters dealing with temperature (annual, monthly, seasonal, maxima and minima, etc.), precipitation (annual, monthly, seasonal, etc.), frost events, evapotranspiration, cloudiness, sun hours, and relative humidity. One can also ascribe the vegetation to a specific phytosociological entity

Seedling bank, Anaga (Tenerife). Photo: Nélida Rodríguez.

(either associations, alliances, orders, classes) characterized by the presence/abundance of different vascular plant species.

This classical approach to vegetation analysis and characterization should be complemented in the near future with a more ecologically-based classification of habitats types and subtypes, that pays more attention, besides bioclimatic and floristic characteristics, to crucial ecological characteristics, that can be more informative about the habitat structure, function and dynamics. These can include: aerial and subterranean biomass allocation, litter quantity and composition, Net Primary Productivity, decomposition rate, distribution of Diameter at Breast Height (DBH) and height classes, regeneration type and effectiveness, soil and leaves C/N ratios, and several plant functional traits (leaf size, specific leaf area, individual height, stem density, seed weight, sexual expression, pollination and dispersal modes, etc.) and so on. Actually, many of these characteristics are considered indispensable variables to evaluate the condition of the 9360 forest stands.

The most recent classifications based on the bioclimatic-phytosociological approach of laurel forest subtypes for the Azores (Dias, 1996; Dias *et al.*, 2004, 2007, 2012; 2021; Elias *et al.*, 2016), Madeira (Capelo *et al.*, 2004, 2005, 2007, 2021; Mesquita *et al.*, 2004, 2007) and the Canaries (del Arco, 2006, del Arco *et al.*, 2010), recognize the following subtypes (see maps in the Appendix 4):

In Azores, two or three different communities (depending on the authors consulted) have been recognized within 9360, which would occupy the lowlands of the islands, whereas the Juniper montane forests (HCI 9560 and 91D0) would occupy the higher zones.

- **Lowland forest of *Picconia-Morella*** (Elias *et al.*, 2016) (= Supramediterranean evergreen forest from Dias *et al.*, 2012).

- **Submontane *Laurus* forest** (Elias *et al.*, 2016), subdivided by Dias *et al.*, (2012) in: a) **subtropical broadleaf forest (*Laurus-Frangula*)** and b) **oceanic broadleaf forest (*Laurus-Ilex*).**

Furthermore, sensu Elias *et al.*, (2016) between the *Picconia-Morella* lowland forest and the island's coasts a heather of *Erica azorica* (4050) (not recognized by Dias *et al.*, 2012) would be distributed.

In Madeira, three laurel forest subtypes have been recognized by Capelo *et al.*, (2004, 2005, 2007, 2021):

- **Barbusano laurel forest (*Apollonias-Ilex*),** more thermophylic and located at lower altitudes.

- **Til laurel forest (*Ocotea-Clethra*),** more tolerant to cold and located at higher altitudes.

- **Stream laurel forest (*Persea*),** more exigent of hydric resources linked to water streams.

Moreover, a community of pioneer cauli-rosette species (*Musschia, Isoplexis, Sonchus*) playing a very important role in the recuperation of the laurel forest gaps is also recognized, Finally, the marmolano (*Sideroxylon*) scrublands have been included in the laurel forest by Capelo *et al.*, (2007). Above the laurel forest, an altitudinal heath (dominated by *Erica arborea*) (4050) would dominate.

Finally, in the Canaries, del Arco (2006) recognized the existence of five different subtypes of laurel forests, besides the (*Erica-Morella* Woody heath) (4050). The subtypes are:

- **Dry laurel forest,** community developed on more xeric and thermophylic environments, dominated by *Apollonias, Arbutus, Visnea* and *Picconia*

- **Humid laurel forest,** found in zones that are more humid and dominated by *Laurus, Ilex* and *Heberdenia*

- **Cold Laurel forest** or altitudinal fayal, ruling in the cooler sited and dominated by *Morella* and *Erica arborea* (although elements characterizing the *Erica-Morella* woody heath (4070)), here belong to the mature laurel forest.

- **Crests laurel forest,** dominated by *Erica platycodon, E. arborea* and *Morella*

• **Hygrophillic laurel forest,** located in the ravine beds, and dominated by *Ocotea, Persea and Ilex perado*.

2.2.4 Relations with other habitat types

9360 has a profound and complex relation with the HCI 4050 (Macaronesian endemic heaths), based on that both habitats are related through the dynamicity of the ecological succession, being 4050 an immature version, and 9360 a mature version, of the same vegetation series.

The spontaneous transition from 4050 to 9360 is frequent in locations that have been subject to human exploitation in the past (for instance, for agriculture, pasturages, wood extraction, soil extraction, etc.) and have been subsequently abandoned. After its abandonment the vegetation spontaneously recovers, so that the *Erica-Morella* woody heath (4050) existing today is being transformed into a community dominated by Lauraceae, *Ilex or Picconia,* i.e. 9360. There where spontaneous ecological restoration is ongoing, and disturbances have ceased permanently, for instance in the *medianías* (mid-altitude zones) of some Canary Islands, we should expect for the future a diminution of the 4050 extension, balanced with an increase of the 9360 extension.

Nevertheless, in some very special locations (i.e. very windy zones, colder zones at higher altitudes or locations with very poor soils), even in the absence of disturbance, several authors (Santos-Guerra, 1990; del Arco, 2006; Capelo *et al*., 2007; Fernández-López & Gómez-González, 2016; Fernández-Palacios *et al*., 2017) consider that 4050 can indeed be a mature community. In these cases, a transition to 9360 will not happen.

The proper way to discern if a given community is 4050 or 9360 is thus a matter of species composition, because both HCIs can grow in the same places. Our proposal here is to use the **basal area** of the canopy tree species participating in the community (BA, m^2/ha) to decide its adscription. If *Erica's* BA is larger than the 50% of the total community's BA, it will be a 4050, whereas if the sum of Lauraceae-*Picconia-Ilex-Morella* BA is larger than 50%, the community should be catalogued a 9360. Another option, would be to use the NDVI index (see Appendix 3) to discern between 4050 and 9360 HCI. The transition from HCI 4050 to 9360 should be evaluated accordingly.

Although not officially recognized by the EU, Azorean specialists (Dias *et al*., 2012; Elias *et al*., 2016) adscribe the **Azorean forests dominated by *Juniperus brevifolia*** in HCI 9560 (Forest of endemic *Juniperus*), with the exception of the **Azorean woody (with *Juniperus*) bogs,** which the same authors adscribe to the HCI 91D0.

2.2.5 Gap analysis and future needs

Although the existing knowledge on the 9360 functionality is undoubtedly important (see paragraph 4.2 and references therein), more knowledge is still needed in specific fields if we aspire to achieve a rigorous 9360 condition evaluation and ecological restoration/conservation plans.

For instance, knowledge about the structural and functional reference values or rank of values of the plots representing the best-conserved communities of the different 9360 subtypes is needed. This information is crucial for evaluating the condition of the surveyed forest stands. For the calculation of biomass, necromass and carbon stored above and below the soil surface, allometric equations for many tree species that still do not count with one (all, except *Erica arborea, Ilex canariensis, Laurus novocanariensis,* and *Morella faya*) are needed (Montero *et al*., 2005). If this is unapproachable, at the very least a laurisilva general allometric equation that can be used for all the canopy tree species would be needed. In addition, the final election of the proper typical species per 9360 islands and subtypes is a pending task to be done by experts, departing from the preliminary list above offered.

There are as well large gaps in our knowledge about the sexual expression, pollination and dispersal networks of the 9360 vascular plant species, or about the diversity and functional role of earthworms, slugs, snails, and arthropods. In addition, we lack the knowledge about the threat status of the invertebrate dwellers of the 9360, the big majority of them being single island endemics. For those islands where the original 9360 has almost disappeared (Corvo, Graciosa, Santa Maria, Porto Santo, Desertas, Fuerteventura, Gran Canaria), we would need palaeoecological information about original extension and species composition that could drive future restoration projects.

Moreover, as above-mentioned, it is necessary to work on the identification of the habitat typical species that can be used to assess its condition.

Regulus regulus inermis, Terceira Island (Azores). Photo: Eduardo Dias

3. CONSERVATION STATUS AND TRENDS

The conservation status assessement under article 17 considers the following parameters: range, area, structure and functions, and future prospects. The results from the last reporting (2013-2018) are shown below (Table 2). According to these reports, the range, area and structure and function were of a favourable status in Portugal and Spain. Therefore the conservation status of the habitat is favourable in both countries.

However, as discussed below, the assessment requires harmonisation and could be revised and improved for the next reporting period taking into account the proposed methodologies in this action plan.

Legend: FV Favourable XX Unknown U1 Unfavourable-Inadequate U2 Unfavourable-Bad

Current selection: 2013-2018, Forests, 9360 Macaronesian laurel forests (Laurus, Ocotea), Macaronesian. Show all Forests

Member States reports

MS	Range (km²)				Area (km²)							
	Surface	Status (% MS)	Trend	FRR	Min	Max	Best value	Type est.	Method	Status (% MS)	Trend	FRA
ES	676	11.50	=	≈	N/A	N/A	102.94	estimate	a	17.07	=	≈
PT	5200	88.50	+	≈	420	530	500	estimate	a	82.93	=	≈

MS	Structure and functions (km²)					Future prospects			
	Good	Not good	Not known	Status	Trend	Range prosp.	Area prosp.	S & f prosp.	Status
ES	95.83 - 95.83	N/A - N/A	7.10 - 7.10	FV	=	good	good	good	FV
PT	202 - 230	140 - 172	68 - 122	FV	=	good	good	good	FV

MS	Overall assessment						Distribution area(km²)		
	Curr. CS	Curr. CS trend	Prev. CS	Prev. CS trend	Status Nat. of ch.	CS trend Nat. of ch.	Distrib.	Method	% MS
ES	FV	=	FV	N/A	noChange	method	3200	a	40
PT	FV	=	U1	=	noChange	genuine	4800	a	60

Table 2: Results of the last article 17 reporting (2013-2018) of the two MS (Portugal and Spain) harbouring the habitat 9360.

3.1 Current distribution, range and area estimate

3.1.1 Current distribution/mapping of the habitat type and all its subtypes

Table 3 presents the current distribution of the different 9360 subtypes in the different Macaronesian Biogeographical Region constituent islands and archipelagos. Although we count 9360 potential and current data for each island, unfortunately data for current the distribution of the different 9360 subtypes in Azores is lacking. Even so, and while waiting for that data to be obtained, a preliminary analysis and diagnosis of the current 9360 situation in the different islands, archipelagos and the whole Macaronesia can be done.

The current situation of this HCI is worrying; with the exceptions of Madeira (25.33 %) and La Gomera (37.14 %), the present 9360 distribution is < 20% of the original extension of this habitat. Places with more than 10% of the original 9360 distribution, include some islands in the Azores, such as Faial (17.66%) and Flores (15.54%), or in the Canaries, such as La Palma (19.26%), and El Hierro (12.63%). The rest of the islands have < 10% of the original distribution, and this habitat has already almost vanished (< 1%) from Corvo, Graciosa, São Miguel and Santa Maria (Azores), Porto Santo and Desertas (Madeira) and Gran Canaria (Canaries).

At an archipelagic level, the situation is critical in the Azores, with only 3.30% of the original distribution still existing. In the Canaries, the situation is clearly unfavourable with slightly more than a tenth (11.68%) of the original 9360 distribution. Finally, only in Madeira, although 9360 has vanished from two islands (Porto Santo and Desertas), the situation can be considered as adequate, with 25% of the pre-anthropogenic extension. Finally, Macaronesia as a whole, with a value < 10% (9.73%), evidences the urgent need of restoring/conserving this unique, invaluable habitat.

Fruits of *Morella faya*, Anaga (Tenerife). Photo: Nélida Rodríguez.

Island/ 9360 subtypes potential/current extension in ha (% remaining)	Lowland forest (*Picconia-Morella*)	Submontane *Laurus* forest (*Laurus-Ilex*)	Total 9360
Corvo	400/0 (0)	1100/0 (0)	1500/0 (0)
Flores	4000/? (?)	6100/? (?)	10 100/1571 (15.54)
Graciosa	3000/0 (0)	800/0 (0)	3800/0 (0)
Faial	4300/? (?)	8500/? (?)	12 800/226 (17.66)
Pico	6700/? (?)	22000/? (?)	28 700/952 (3.31)
São Jorge	7800/? (?)	9500/? (?)	17 300/293 (1.69)
Terceira	15 300/? (?)	17 100/? (?)	32 400/2345 (7.23)
São Miguel	27 500/? (?)	30 700/? (?)	58 200/331 (0.57)
Santa Maria	6700/? (?)	1800/? (?)	9 500/9 (0.1)
Azores	75 700/? (?)	97 600/? (?)	173 300/5727 (3.30)

Island/ 9360 subtypes potential/ current extension in ha (% remaining)	Barbusano laurel forest (*Apollonias-Ilex*)	Til laurel forest (*Ocotea*-Clethra)	Total 9360
Madeira	22 908/1392 (6.07)	38 331/14 125 (36.85)	61 239/ 15 517 (25.33)
Porto Santo	1032.2/0 (0)	0	1032.2/0 (0)
Desertas	324.6/0 (0)	0	324.6/0 (0)
Madeira arch.	24 264.8/1392 (5.74)	38 331/14 125 (36.85)	62 595.8/15 517 (24.79)

Island/ 9360 subtypes potential/current extension in ha (% remaining)	Dry laurel forest (*Apollonias. Picconia*)	Humid laurel forest (*Laurus, Ilex*)	Cold laurel forest (*Morella, Erica arborea*)	Crests laurel forest (*E. platycodon*	Hygrophillic (Wet) laurel forest (*Ocotea*)	Total 9360
Fuerteventura	5/5 (100)	0	0	0	0	5/5 (100)
Gran Canaria	10 000/17 (0.2)	7500/145 (1.93)	1600/0 (0)		200/3 (1.5)	19 300/165 (0.85)
Tenerife	12 600/671 (5.3)	16 900/860 (5.09)	1800/85 (4.72)	400/363 (90.75)	1000/17 (1.7)	32 700/1996 (6.10)
La Gomera	4000/487 (12.18)	4300/2621 (60.95)	900/295 (32.78)	100/100 (100)	300/62 (20.67)	9600/3565 (37.14)
La Palma	4100/321 (7.83)	11 700/3074 (26.27)	2500/156 (6.24)		600/90 (15.00)	18 900/3641 (19.26)
El Hierro	2600/499 (19.19)	3000/3 (0.10)	700/296 (42.29)		20/0 (0)	6320/798 (12.63)
Canaries	33 305/2000 (6.06)	43 200 /6703 (15.52)	7500/831 (11.08)	500/463 (92.6)	2120/173 (8.16)	87 100 /10 170 (11.68)

Archipelago	Potential distribution (ha)	Current distribution (ha)	% remaining
Azores	173 300	5727	3.30
Madeira	62 595	15 517	24.79
Canaries	87 100	10 170	11.68
Macaronesia	322 995	31 414	9.73

Table 3: 9360 (subtypes) potential and actual distribution per island, archipelago and biogeographical region. a) Azorean data (Elias *et al.*, 2016; Triantis *et al.*, 2010); b) Madeiran data (Capelo, 2004; Mesquita *et al.*, 2007); c) Canarian data (del Arco *et al.*, 2010); d) Data summary for the different archipelagos.

3.1.2 Spatial structure

A very important issue in Conservation Biology deals with the fragmentation degree that the human activity (i.e., deforestation, agriculture, grazing, infrastructures, settlements, forest fires, etc.) has created on the original forest patch. It is important to stress that the fragmentation existing on oceanic islands is intrinsic, so that even without human impact, oceanic island forest communities are fragmented and isolated from other islands or archipelagos. A direct consequence of this is that to a large extent only the structuring tree species (those constituting the forest canopy) are shared among island or archipelagos, whereas an important fraction of the vascular plants, and floor-soil invertebrates (arthropods and molluscs) are single-island endemics (SIEs).

Nevertheless, humans have also altered profoundly the 9360 original forest distribution in many islands, and Macaronesia is not an exception. For instance, in the Canaries the current number of 9360 patches existing is greater, being them on average smaller, more isolated, species impoverished and having a larger edge effect (i.e., the fraction of the patch influenced by the matrix separating the remaining forest patches) than the original ones (Table 4).

Island	4050 + 9360 area (km²)	Fragments no.	Mean fragment size ± SD (km²)	Mean distance to the nearest fragment ± SD (km)
Gran Canaria	8.36	15	0.56 ± 0.62	1.10 ± 1.12
Tenerife	108.5	22	4.91 ± 11.33	0.86 ± 1.09
La Gomera	55.81	2	27.91 ± 39.07	-
La Palma	108.26	58	1.87 ± 8.02	0.31 ± 0.34
El Hierro	23.36	14	1.67 ± 4.40	0.68 ± 1.28
Canaries	304.19	111	2.74 ± 7.77	-

Table 4: Number of fragments, mean size and isolation existing in the distribution of the HCI 4050 and 9360 in the different Canary Islands. Source: Delgado *et al.*, 2001.

It is remarkable that the island with the largest relative extent of these habitat types (La Gomera) counts with just two large fragments (almost a continuous habitat), whereas La Palma, also with a relatively large distribution of 4050 and 9360, has 58 fragments. According to the Species-Area Relationship (SAR) (see below), the smaller the fragments the less species they contain. Isolation also plays a certain role and the larger the isolation the lower the patches' probabilities of being colonized from similar ones. Gran Canaria has the smaller and more isolated patches, whereas in Tenerife or La Palma, the patches are larger and better communicated. El Hierro occupies an intermediate position. Within this context, one priority objective of the ecological restoration of 9360 would be the creation of corridors that help to connect the fragmented patches, as in La Palma, or to enlarge them as would be needed for Gran Canaria.

It would be preferential to complete these types of fragmentation analyses for all the islands where 9360 is present.

3.1.3 Distribution and area in Natura 2000 sites

In both Madeira and the Canaries, almost all the 9360 still existing is included in the Natura 2000 Network (see table 5 and Appendices 2, 5). However, in the Azores, a significant fraction of the existing 9360 on different islands (such as Terceira, Pico, São Jorge, Faial or Flores) is still outside the Natura 2000 Network, although part of it may be protected in the regional/ insular network. It is thus a crucial goal of this Action Plan for the Azores to incorporate all, or the big majority, of the 9360 still outside to the Natura 2000 Network (either protected or not by the regional /insular network) in the Natura 2000 Network.

Island/archipelago	Current 9360 area (ha)	Inside Natura 2000 (ha) (%)	Outside Natura 2000 (ha) (%)
Flores	143.1	45.72 (31.95 %)	97.38 (68.05 %)
Faial	959.1	328.87 (34.29 %)	630.22 (65.71 %)
Pico	2 960	1 258 (42.5 %)	1 702 (57.5 %)
São Jorge	663.8	302.96 (45.64 %)	360.84 (54.36 %)
Terceira	847.27	436.85 (51.56 %)	410.42 (48.44 %)
São Miguel	195.1	185.36 (95.01 %)	9.73 (4.99 %)
Santa Maria	112.4	0 (0 %)	112.4 (100 %)
Azores	5 880.8	2 557.12 (43.49 %)	3 323.68 (56.51%)
Madeira	17 008	15 462 (90.91%)	1 546 (9.09 %)
Portugal	22 888.9	18 019.12 (78.72 %)	4 869.68 (21.28 %)
Fuerteventura	4.50	4.50 (100 %)	0 (0%)
Gran Canaria	165.05	75.42 (45.70 %)	89.63 (54.30 %)
Tenerife	2025.68	1880.45 (92.83 %)	145.23 (7.17 %)
La Gomera	3667.55	3595.55 (98.04%)	72 (1.96 %)
La Palma	3633.60	3239.13 (89.15 %)	394.47 (10.85 %)
El Hierro	797.89	788.30 (98.80 %)	9.59 (1.20%)
Canary Islands	10 294.28	9 583.35 (93.09 %)	710.93 (6.93 %)
Spain	10 294.28	9 583.35 (93.09 %)	710.93 (6.93 %)
Macaronesia	33 183.08	27 602.47 (83.18 %)	5 580.61 (16.82 %)

Table 5: Proportion of the 9360 inside and outside the Natura 2000 Network per island, archipelago and Biogeographic Region. Source: The different regional administrations.

3.1.4 Area estimate

The procedures that the different regional administrations have used for the determination of the 9360 range and area, as well as of its structure and function are clearly different, as we have been able to recognize form a questionnaire (see Appendix 6). We suggest a methodological harmonization approach so that results obtained across the different archipelagos within the biogeographical region and across time within the same archipelago can be comparable.

Proposal for harmonisation of the assessment of range and occupied area in the Macaronesian Region

The departure point has to be a complete current vegetation map, with a phytosociological or bioclimatological base, combined with many vegetation inventories, of the different subtypes of laurel forest. These maps do exist for all the archipelagos: Azores (Dias *et al*., 2007; Elias *et al*., 2016), Madeira (Capelo, 2004; Mesquita *et al*., 2007) and the Canaries (del Arco, 2006; del Arco *et al*., 2010), although some are yet to be published.

The next step is to gather ESA Sentinel satellites imagery (which is free of charge), taking a flight each 8-10 days over the archipelagos with 10 x 10 m square pixels four spectral bands (visible plus infrared) and 20 x 20 m pixels up to 10-14 spectral bands. From these spectral bands, vegetation development indexes such as NDVI or EVI, may be calculated. There is ample flexibility for the acquisition of georeferenced, corrected and applicable spectral information in different environments, such as Copernicus, SEN 2R and SCP. The methodology is replicable and scalable and the information is public, costless and based on free software.

Satellite imagery cannot just provide qualitative information of the condition state, but quantitative as well through a procedure called thresholding, a process of finding threshold values intended to discretize continuous rasters. It is the key and critical step for calculating surfaces or categorizing rasters. Its'more frequent use is distinguishing pixels with and without vegetation (Ibarrola *et al*., 2019). With that aim different statistics criteria (such as mean, median, first quartile, etc.) are used. It can vary depending on season and location.

The Normalized Difference Vegetation Index (NDVI) is especially adequate for estimating the chlorophyll quantity, the photosynthetic performance and/or the Leaf Area Index (LAI). Varies from -1 (ice, asphalt, lava flows) to 1 (tropical forests, growth peak of cultures, etc.). It is calculated as the response of the spectral reflectance of a surface, using this quotient. For an application of this method on real 9360 data see the examples provided in Appendix 3.

3.1.5 Favourable reference area

Favourable Reference Area is defined as the surface area in a given biogeographical region considered the minimum necessary to ensure the long-term viability of the habitat type.

Proposal for determining FRA based on species-area relationship

The core concepts of the Equilibrium Theory of Island Biogeography (ETIB) (MacArthur & Wilson, 1967) have been widely used since its formulation for the design of natural reserves (Whittaker & Fernández-Palacios, 2007). The main contribution of the ETIB to Protected Areas managers and Conservation Biology practitioners is the use of the species-area and species-isolation relationships, that can be further extrapolated to habitat islands, product of the fragmentation of original continuous habitat extensions, and that control the species richness that such fragments can harbour.

The species–area relationship (SAR) describes the relationship between the species number and the habitat area (Rosenzweig, 1995). It is a curvilinear relationship usually described by the power function.

$$S = A^z$$

where *S* is species number, *A* is habitat area and z is the slope of the relationship.

The shape of the species–area curve depends on body size and life history, and therefore differs for different biotic groups (e.g. vertebrates, arthropods, vascular plants, etc.). It also varies across habitats, ecosystems and landscapes, but the general shape of the curve remains always the same (Fig. 2).

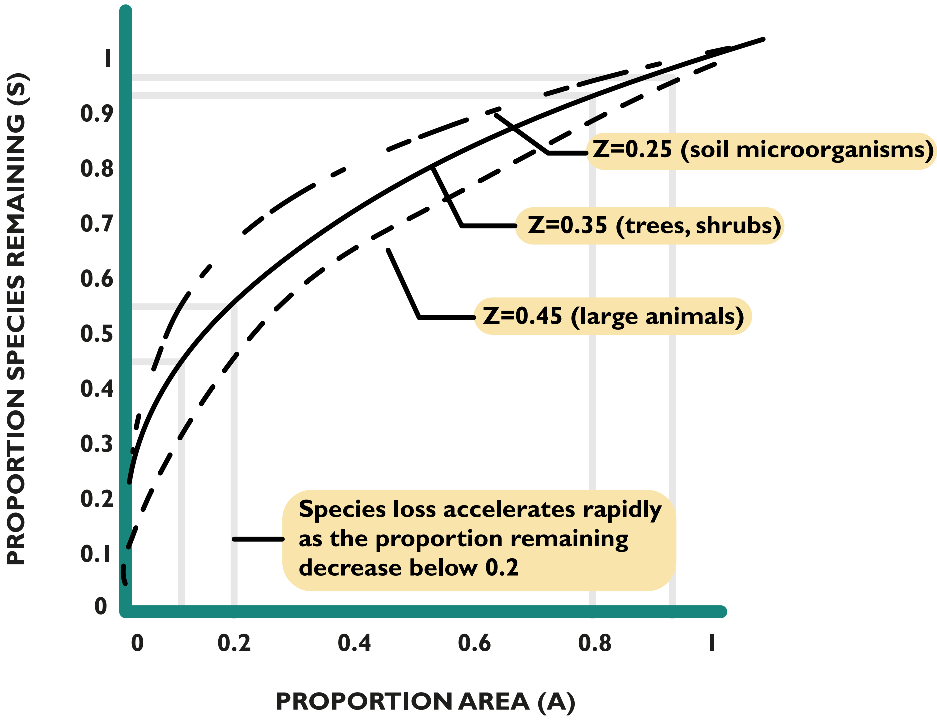


Figure 2: Species-area relationship (SAR) of the proportion of species (S) remaining in a given habitat in respect to the proportion of habitat area (A) remaining for taxa of different body size (z = 0.25, 0.35 and 0.45). Source: Walker *et al.*, 2005. New Zealand's remaining indigenous cover: recent changes and biodiversity protection needs (doc.govt.nz). DOC (Crown) copyright. CC BY 4.0 Deed | Attribution 4.0 International | Creative Commons).

Because larger areas are always able to support more species, the SAR predicts that any loss of a fraction of the area occupied by an ecosystem, habitat or community will lead to the loss of some species associated with it. With initial decreases in area, the rate of species loss may be relatively low (Fig. 2). Large-bodied, host-dependent, narrow-range and/or habitat-specialist biota and those dependent on large contiguous habitats tend to be most affected at this stage. However, as habitat area is further reduced, it results in a greater magnitude of loss of remaining biodiversity (Fig. 2). However, because of the shape of the relationship between area and species richness, even the last habitat remnants are predicted to still contain a significant proportion of the biodiversity associated with that environment.

A species–area relationship with an exponent of 0.35 (i.e. the curve z = 0.35 in Fig. 2) may be an appropriate 'average' to apply to biodiversity protection, since it approximates the curve that could be expected for prominent vegetation components. An example are the trees structuring the laurisilva, which are readily recognised (including by remote sensing) and often pragmatically used as surrogates for other elements of the native biodiversity.

SAR predicts an increasing rate of biodiversity loss as habitat area decreases. For example, the curve z = 0.35 predicts that a change from 90 to 80% remaining habitat will remove 3.9% of the original full complement of species and 4.0% of those remaining in an area, but reduction from 20 to 10% remaining habitat removes 12.3% of the original full complement of species and 21.5% of the species remaining (Walker *et al*., 2005).

Higher habitat fragmentation implies usually smaller and more isolated habitat patches, and two main conservation consequences. On the one hand, the emergence of the edge effect (the penetration of the matrix's properties and/or biota in the habitat fragment), which may affect the whole patch if it has an elongated shape, decreases the survivorship of species that can only thrive in non-altered habitat patches. On the other hand, the populations thriving in the habitat fragment will have smaller population sizes and, if no genetic flow happens among patches (what will depend on the dispersiveness of the target species), inbreeding depression will emerge forcing genetic loss, which will progressively depauperate the genetic heritage of the population, bringing it to the brink of extirpation/extinction.

In Australia and other British Commonwealth nations, the threshold of the proportion of the original habitat area to maintain (or to recover, if the habitat destruction has already surpassed it) has been set at 15% of the original habitat area. Whereas in New Zealand it was incremented up to 20% due to their isolation and, consequent, high endemicity levels, (Walker *et al*., 2005).

Our proposal is to define the Favourable Reference Area as **25%** of the potential distribution of the HCI 9360 (Fig. 3) because:

1) 9360 is a priority habitat endemic to Macaronesia

2) 9360 possesses a very important historical value as remnant of the European Palaeotropical Geoflora.

3) 9360 embraces a very high biodiversity, including a huge number of endemisms, among them canopy trees, herbs, birds, insects, spiders and molluscs, the majority of them distributed in a single island.

4) 9360 provides very important ecosystems services, such as carbon fixation, fog capture, air filtration or soil creation and retention.

The 25% threshold has already been achieved in Madeira and La Gomera

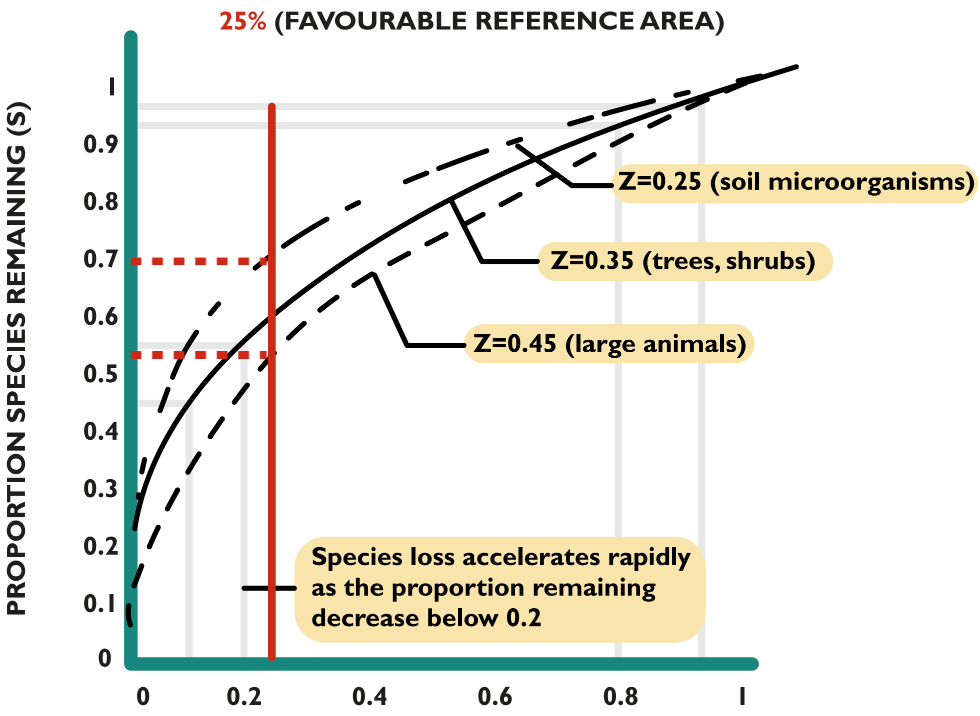


Figure 3: According to the SAR, the proportion of species that will persist conserving or restoring a 25% of the original habitat distribution (red dot lines) will embrace, depending on the taxa, between 50-70%, what is a more than acceptable proportion (Adapted from Walker *et al.*, 2005.New Zealand's remaining indigenous cover: recent changes and biodiversity protection needs (doc.govt.nz). DOC (Crown) copyright. CC BY 4.0 Deed | Attribution 4.0 International | Creative Commons).

Jorge Capelo (2023) has recently proposed a graphical and very helpful schematic form to understand the meaning of Favourable Reference Range (FRR) and Favourable Reference Area (FRA), as well as the Minimum Restoration Deficit (MRD) and the Extended Restoration Deficit (ERD) needed for 9360 adequate conservation. Figure 4 shows the spatial relationships among these parameters, and Figure 5 plots them against their conservation values.

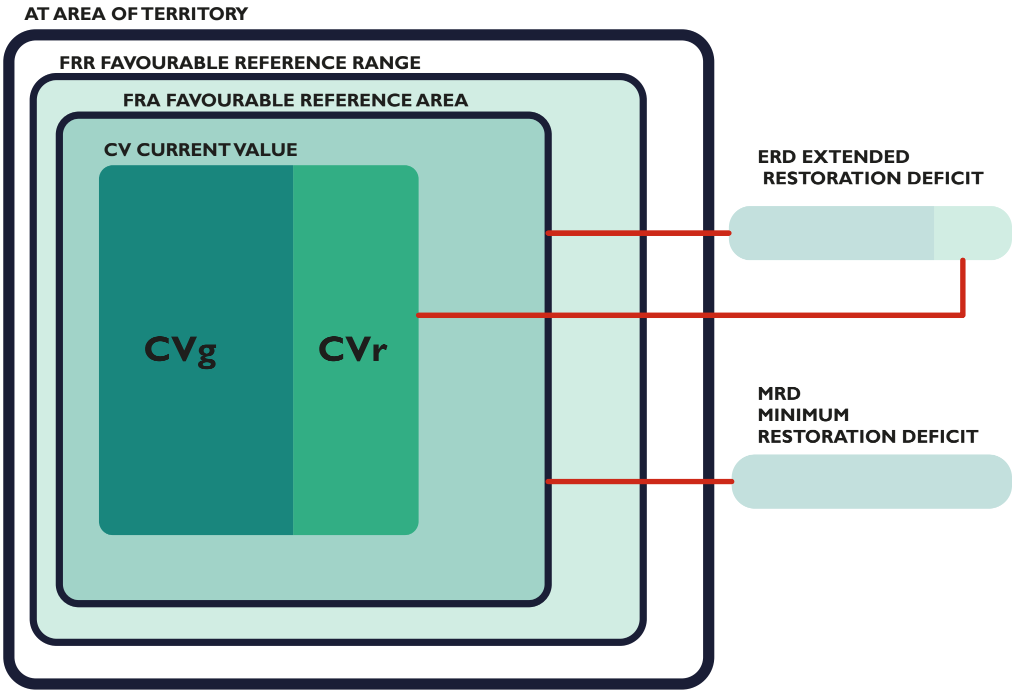


Figure 4: Nested spatial distribution of the different Favourable Reference Values (FRV) for a given habitat type. Source: Capelo (2023), unpublished document.

where:

AT: Area of the Territory (ha), depending on the scope and scale can refer to a given island, archipelago or the whole Macaronesian Biogeographic Region.

FRR: Favourable Reference Range (ha), is the potential, pre-human distribution of the 9360 in a given island, archipelago or the whole Macaronesian Biogeographic Region.

FRA: Favourable Reference Area (ha), is the minimum viable area for maintaining the 9360 habitat and constituting species in a long-term Favourable Condition in a given island, archipelago or the whole Macaronesian Biogeographic Region. We suggest here that for achieving this goal this FRA has to be (at least) the 25% of the FRR of the 9360.

CV: Current Value (ha) is the extension of the 9360 distribution, independent of its quality and conservation value.

CVg: Current value in good conservation status (ha), is the current distribution of 9360 in good conservation status.

CVr: Current value in bad conservation status, but restorable (ha), is the current distribution of 9360 in bad conservation status, but susceptible of being ecologically restored.

MRD: Minimum Restoration Deficit, [FRA – CV], is the minimal area of 9360 to be restored to achieve the FRA.

ERD: Extended Restoration Deficit, [MRD + CVr], is the area to be restored to achieve the FRA in a good conservation status.

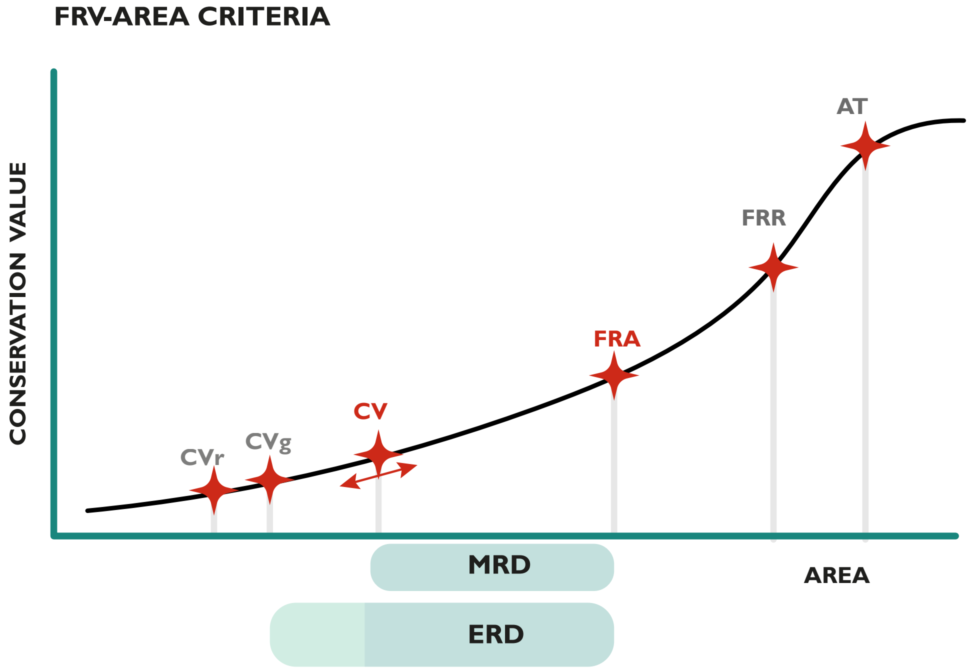


Figure 5: Distribution of the different Favourable Reference Values (FRV) in the plot defined by area (abscises) and conservation value (ordinates). Source: Capelo (2023), unpublished document.

The sources for the calculation of the Favourable Reference Range (9360 Potential Distribution) and of the Current Value (9360 Actual Distribution) in a given island, archipelago or the whole Macaronesian region have to be the potential and current vegetation maps of the different archipelagos based in bioclimatic information and in satellite imagery and/or aerial photographs, respectively. The condition (quality) of the current distribution of the habitat, and thus the calculation of CVg and CVR has to be based on field inventories about their species composition, structure and function, where the different variables listed above must be used. Within this context, we can illustrate with a simple exercise, which is the restoration effort to be carried out on different islands or archipelagos to meet the Favourable Reference Area (Table 6).

Parameter (ha)	Pico	Tenerife	La Gomera	Azores	Madeira	Canaries	Macaronesia
AT	44 480	203 400	36 976	233 300	75 070	745 000	1 063 900
FRR	28 700	32 700	9 600	173 000	61 239	87 100	322 995
FRA (25% FRR)	7 175	8 175	2 400	43 250	15 310	21 175	80 749
CV	952	1 996	3 565	5 727	15 517	10 170	31 414
MRD	6 223	6 179	0*	37 523	0*	11 605	49 335

Table 6: Examples of the 9360-restoration effort needed to meet the proposed FRA for selected islands, the three archipelagos and Macaronesia as a whole. * In La Gomera and Madeira, as the current extension value of 9360 is > than the FRA, only conservation, but no restoration efforts are needed, unless the quality of these remaining areas, or of a fraction of them, is inadequate. Parameter names and definitions are given in the text.

3.1.6 Trends analysis

Before the arrival of the Castilians, the Guanche people (Canarian aborigines) had already disturbed the pristine distribution and conditions of the 9360 with the use of fire, gathering fruits and, especially, through the introduction of pigs and ovicaprids that roamed free there for more than one millennium (de Nascimento *et al*., 2020). However, the main impacts on the 9360 came after the conquest of the Canaries by Castilians, and after the colonization of Azores and Madeira (archipelagos not previously inhabited) by the Portuguese (Fernández-Palacios *et al*., 2017). The European colonizers transformed progressively the Macaronesian islands first towards sugar cane exportation hubs, cutting the forests for matching the needs of space for its cultivation and of wood for fueling the sugar mills. The result was the beginning of a rapid deforestation of the islands (Santana, 2001; Triantis *et al*., 2010; Otto *et al*., 2017). This has lasted with different rhythms and intensities, depending on the land use change (mainly towards agriculture in Canaries and Madeira, and towards cattle grazing and forestry in Azores), until the 1960's, when mass tourism substituted exportation agriculture as the economic fuel of the islands, especially in Madeira and the Canaries.

Since then, and because the shift of the economic model of the islands' development from mid-lands towards the coasts, the abandonment of the cultivated and grazed zones permitted a slow, but unstoppable, spontaneously recovery of the 9360 HCI there where the ecological conditions permitted it (i.e. existence of 9360 patches), recovery that is still ongoing. This is to say that, at least for Madeira and the western Canaries, the current laurel forest extension and condition is perhaps the best of the last centuries. Nevertheless, where such land use changes (Azores), or ecological conditions (Gran Canaria) did not happen, the status of 9360 remains precarious (Fernández-Palacios *et al*., 2017).

Pyrrhula murina, São Miguel Island (Azores). Photo: Eduardo Dias

3.2 Structure and functions

3.2.1 Current assessment of structure and function parameter (under article 17 reporting)

Despite the existence of some common aspects, the methodologies used for the assessment of habitat condition structure and function in each archipelago are different. There is a need to have harmonized procedures, in particular for the filed surveys so that results obtained across the different archipelagos within the biogeographical region and over time within the same archipelago could be comparable. Below we suggest a methodological harmonization approach.

3.2.2 Proposal for harmonisation of the methodology for assessment and monitoring

A methodology for assessment and monitoring of habitat condition (structure and functions) shall include the following main items:

- Variables to assess the relevant habitat characteristics, metrics and measurement methods, including the possible use of existing data sources:
  - abiotic: physical, chemical
  - biotic: composition, structure and functions
  - other: pressure-based variables
  - landscape
- Reference values and thresholds for each variable to determine their condition
- Methods for the aggregation of variables at local and supra-local scale.
- Monitoring methods and protocols, selection of monitoring localities.

3.2.2.1 Proposal of variables and indexes for assessment of structure and function (condition) of habitat 9360 condition:

The variables and the indexes for determining the condition status of the 9360 have to be clearly defined, their measurement procedure unambiguously explained, and they have to be easy to measure by non-experts, as well as informative and diagnostic of the conservation status of the habitat stand.

A first proposal for a set of variables to evaluate and diagnose the structure and function of the habitat, based on its ecological characterization, is presented below and summarized in Table 7.

ABIOTIC VARIABLES

a) Climatic indexes (in need of measurements over several years)

1. Days without cloud sea protection (n° days/y)

2. Fog drip amount (mm/y)

b) Edaphic indexes

1. Soil pH

2. Soil Organic Matter Content (mg/g soil)

3. Soil C/N ratio

BIOTIC VARIABLES

a) Structural indexes

1. Canopy Height (m)

Measurement procedure: In each plot the canopy height will be measured at five points (the four corners and the plot center) using a Blume-Leiss or a similar device.

Condition assessment: definition of thresholds for good, inadequate and bad condition shall be developed based on reference values.

2. Number of height (or DBH) classes represented

Measurement procedure: In each plot the number of height (or DBH) classes existing (using standardized criteria, i.e. one height class each 5 m, and a final one of > 30 m) or one DBH class each 10 cm and a final one of > 1 m) are calculated.

Condition assessment: definition of thresholds for good, inadequate and bad condition shall be developed based on reference values

3. Community Basal Area (m^2/ha)

Measurement procedure: In each plot, the Diameter at Breast Height (DBH, in cm) for all the individuals higher than 2 m should be measured, and this DBH transformed in the BA of the species existing within the plot and, by adding them, of the community.

Condition:

- Favorable: Basal area > 30 m^2/ha
- Unfavorable-inadequate: Basal area 15-30 m^2/ha
- Unfavorable-bad: Basal area < 15 m^2/ha

4. Mean plot DBH (cm)

Measurement procedure: In each plot, the Diameter at Breast Height (DBH, in cm) for all the individuals higher than 2 m should be measured, and its mean value across species calculated.

Condition:

- Favorable: mean DBH > 20 cm
- Unfavorable-inadequate: mean DBH 10-20 cm
- Unfavorable-bad: mean DBH < 10 cm

5. Density of large trees (> 40 cm DBH) (ind./ha)

Measurement procedure: Within the plot, the number of individuals of native species with DBH > 40 cm should be counted. If the individuals are multi-stemmed, the DBH of each stem has to be measured and considered if the basal area sum of the stems equals 1/8 m^2.

Condition:

- Favorable: > 10 ind. (> 40 cm DBH) /ha
- Unfavorable-inadequate: 5-10 ind. (> 40 cm DBH) /ha
- Unfavorable-bad: < 5 ind. (> 40 cm DBH) /ha

6. *Biomass (t/ha)* (optional)

Measurement procedure: calculate the biomass of the community using available allometric equations for each tree species.

Condition assessment: definition of thresholds for good, inadequate and bad condition shall be developed based on reference values.

Note: As this parameter is strongly correlated with basal area, perhaps we should keep just one of both. Much easier to measure the basal area, because allometric equations may not exist for all the species.

7. Leaf Area Index (LAI) (adimensional)

Measurement procedure: In each plot the LAI will be measured at five points (the four corners and the plot centre) using a LAI-meter.

Condition assessment: definition of thresholds for good, inadequate and bad condition shall be developed based on reference values.

8. Litter (t/ha)

Measurement procedure: In each plot the litter will be collected until reaching the mineral soil in 1 x 1 m subplots located in five points (the four corners and the plot centre). The litter will be fresh- (in situ) and dry- (lab) weighted and the results will be expressed in dry weight per area.

Condition assessment: definition of thresholds for good, inadequate and bad condition shall be developed based on reference values.

9. Amount of standing and lying deadwood (t/ha) (optional)

Measurement procedure: in each plot the standing and lying deadwood will be evaluated in 1 x 1 m subplots located in five points (the four corners and the plot centre). The deadwood will be fresh- (in situ) and dry- (lab) weighted and the results will be expressed in dry weight per area.

Condition assessment: definition of thresholds for good, inadequate and bad condition shall be developed based on reference values.

b) Compositional indexes

10. Canopy richness

Measurement procedure: calculate the richness of the canopy counting the number of native tree species participating in the forest canopy.

Condition assessment: definition of thresholds for good, inadequate and bad condition shall be developed based on reference values.

NOTE: Species richness comparisons could only be made if the areas compared are similar!

11. Canopy species composition

Measurement procedure: make the list of the canopy species within a plot,

Condition:

- Favorable: high presence of characteristics species and absence of exotic species.
- Unfavorable-inadequate: medium presence of characteristic species, presence de exotic species (*Pinus spp., Eucalyptus spp., Castanea sativa, Pittosporum undulatum, Cryptomeria japonica, Acacia mearnsi, Robinia pseudoacacia,* etc.).
- Unfavorable-bad: low presence of characteristic species, dominance (basal area) of exotic species.

12. Composition of the avian community

Measurement procedure: carry out line transects (with transects number, length, width, and duration to be fixed by experts) across the evaluated area to determine the frequency and/or abundance of the different species integrating the 9360 avifauna community.

Condition:

- Favorable: Absence of exotic bird species
- Unfavorable-inadequate: Presence of exotic bird species
- Unfavorable-bad: Dominance of exotic bird species

13. Composition of the soil invertebrate (arthropods and molluscs) community

Measurement procedure: carry out a sample procedure (to be fixed by experts) across the evaluated area to determine the frequency/abundance of the different species integrating the soil invertebrate fauna community.

Condition:

- Favorable: Absence of exotic invertebrate (athropods/molluscs) species
- Unfavorable-inadequate: Presence of exotic invertebrate (athropods/molluscs) species
- Unfavorable-bad: Dominance of exotic invertebrate (athropods/molluscs) species

c) Functional indexes:

14. Regeneration composition

Measurement procedure: At five 1 x 1 m subplots (four corners and plot centre), evaluate the regeneration (seedlings community) composition.

Condition:

- Favorable: absence of seedlings of exotic species
- Unfavorable-inadequate: presence of seedlings of exotic species
- Unfavorable-bad: dominance of seedlings of exotic species

The monitoring of two further indexes of the habitat function (*15. Net Primary Productivity and 16. Litter Decomposition rate*) would be very interesting, but their evaluation would need several (at least three) years, which makes them more problematic. They can be considered as ***optional.***

Abiotic variables		
Climatic variables	Measurement procedure	Condition evaluation
Days without sea of clouds protection (n° d/y)	Gather reliable data from the nearest meteorological station(s)	based on reference values
Fog drip amount (mm/y)	Gather reliable data from the nearest meteorological station(s)	based on reference values
Edaphic variables		
Soil pH	In five plot locations (four corners and plot centre), take soil samples and evaluate the soil pH with a pH-meter	based on reference values
Soil Organic Matter (SOM) Content	In five plot locations (four corners and plot centre), take soil samples and evaluate the SOM via Loss on Ignition (LOI)	based on reference values
Soil C/N ratio	In five plot locations (four corners and plot centre), take soil samples and evaluate the soil C/N ratio	based on reference values

Biotic variables		
Structural variables	Measurement procedure	Condition
Canopy height (m)	In each plot the canopy height will be measured in five points (the four corners and the plot center) using a Blume-Leiss.	based on reference values
Number of height (or DBH) classes present	In each plot the number of height (or DBH) classes existing (one height class each 5 m, and a final one of > 30 m) or one DBH class each 10 cm and a final one of > 1 m) are calculated.	based on reference values
Basal Area (BA) (m^2/ha)	In each plot, the DBH (cm) for all the individuals higher than 2 m should be measured, and transformed in the BA of the species existing within the plot and, by adding them, of the community.	Favorable: BA > 30 m^2/ha Inadequate: BA 15-30 m^2/ha Bad: BA < 15 m^2/ha
Mean plot DBH (cm)	In each plot, the DBH (cm) for all the individuals > 2 m should be measured, and its mean value across species calculated.	Favorable: mean DBH > 20 cm Inadequate: mean DBH 10-20 cm Bad: mean DBH < 10 cm
Density of large trees (> 40 cm DBH) (ind./ha)	Within the plot, the number of individuals of native species with DBH > 40 cm should be counted. With multi-stemmed trees, each stem DBH should be measured and considered if the tree BA > 1/8 m^2.	Favorable: > 10 ind. /ha Inadequate: 5-10 ind. /ha Bad: < 5 ind. /ha
Biomass (t/ha) (optional)	In/for each plot calculate the biomass of the community using available allometric equations for each tree species	based on reference values
Leaf Area Index	In/for each plot the LAI will be measured in five points (the four corners and the plot centre) using a LAI-meter.	based on reference values
Litter (t/ha)	In each plot the litter will be collected until reaching the mineral soil in 1 x 1 m subplots located in five points (the four corners and the plot centre). The litter will be expressed in dry weight per area.	based on reference values
Amount of deadwood (t/ha) (optional)	in each plot the standing and lying deadwood will be evaluated in 1 x 1 m subplots located in five points (the four corners and the plot centre). The deadwood will be fresh- (in situ) and dry- (lab) weighted and the results will be expressed in dry weight per area.	based on reference values

Compositional variables		
Canopy richness	Calculate the richness of the canopy counting the number of native tree species participating in the plot's forest canopy.	based on reference values
Canopy species composition	Make a list of the canopy species within a plot	Favorable: absence of exotic species. Inadequate: presence de exotic species Bad: dominance (basal area) of exotic species.
Composition of the avian community	Carry out transects across the evaluated area to determine the frequency and/or abundance of the different species integrating the bird community.	Favorable: Absence of exotic bird species Inadequate: Presence of exotic bird species Bad: Dominance of exotic bird species.
Composition of the soil invertebrate (arthropods and molluscs) community	Carry out a sample procedure across the evaluated area to determine the frequency/abundance of the different species integrating the soil invertebrate fauna community.	Favorable: Absence of exotic invertebrate (arthropods/ molluscs) species Inadequate: Presence of exotic invertebrate (arthropods/ molluscs) species Bad: Dominance of exotic invertebrate (arthropods/ molluscs) species.
Functional variables		
Regeneration composition	In five 1 x 1 m subplots (four corners and plot centre), evaluate the regeneration composition	Favorable: absence of exotic species' seedlings Inadequate: presence of exotic seedlings Bad: dominance of seedlings of exotic species
Net Primary Productivity (t/ha y) (optional)	Using five litter traps per plot the monitoring of the litter rain across time will be measured and the NPP calculated	based on reference values
Litter decomposition rate (k value) (optional)	Using several litter bags with a known content of soil litter, the decrease over time in litter weight will be measured and the decomposition rate (k) calcuated	based on reference values

Table 7: Proposal of the abiotic (climatic and edaphic) and biotic (structural, compositional and functional) variables to be monitored for the diagnosis of the 9360 HCI condition.

3.2.2.2 Proposal for defining reference values and thresholds to assess structure and function from measured variables

In the search of indexes for assessing the condition of the HCI 9360 it should be considered that for many indexes we will need **reference values,** i.e. the values of the searched parameters existing in the **best-preserved stands of the current distribution of the 9360 habitat type or subtypes.** The reference value for each parameter **will not be a mean value, but a range of values.** This will depend on the archipelago, island, exposition, inclination, habitat subtype, etc. Each stand has to be compared with the reference value of one or more well preserved stand(s) with similar conservation conditions and locations.

Reference locations

The evaluation and diagnosis of the condition of the different 9360 subtypes will need from the designation of well-preserved locations where to analyse the different abiotic and biotic variables which will serve as a reference for the ulterior comparison with the variables measured in the rest of the locations. With that aim, we have asked the 9360 experts on each island and archipelago to make a selection of such privileged sites. These data are compiled in Table 8.

9360 Subtype	Flores	Faial	Pico	S. Jorge	Terceira	S. Miguel	S. Maria
Lowland forest (*Picconia-Morella*) (sensu Elias *et al.*, 2016) Supramediterranean evergreen forest (*Picconia-Morella*) (sensu Dias *et al.*, 2012)	Ponta do Ilhéu (Ponta Delgada)	Varadouro	Ponta da Ilha; Piedade	–	Fajã da Serreta	-	Barreiro da Faneca-Baía do Raposo; Malbusca
Subtropical broadleaf forest (*Laurus-Frangula*) (sensu Dias *et al.*, 2012) [not recognized by Elias *et al.*, 2016]		Ribeira do Cabo	Mistério da Prainha	Fajã do Castelhano	Dorsal de Serreta;	Achadinha	
Submontane *Laurus* forest (*Laurus*-Ilex) (sensu Elias *et al.*, 2016) Oceanic broadleaf forest (*Laurus-Ilex*) (sensu Dias *et al.*, 2012)	Vale da Ribeira das Aguinhas	Base da Caldeira	Mistério da Prainha; Caminho dos Burros; Norte das Lajes; Cabecinhos; entre São João e Pico da Urze	A Norte do Pico Pinheiro; Ponta dos Rosais; Ribeira Seca;	Biscoito da Ferraria e Pico Alto; Terra Brava; Quatro Ribeiras; Caldera de Santa Bárbara	Ribeira do Guilherme; Tronqueira	–

9360 Subtype	Madeira
Barbusano laurel forest (*Apollonias-Ilex*)	Ribeira Funda
Til laurel forest (*Ocotea*-Clethra)	Levada do Folhadal; Montado dos Pessegueiros; Galhano; Boaventura - Achada do Touco; Fajã da Nogueira - Rochão dos Vinháticos; Seixal - Chão da Ribeira; Ribeira Grande de São Vicente

9360 Subtype	Gran Canaria	Tenerife	La Gomera	La Palma	El Hierro
Dry laurel forest (Apollonias, *Picconia*)		Aguirre; Barranco de Badajoz	Aceviños	Breña Alta	Mencáfete
Humid laurel forest (*Laurus, Ilex*)	Los Tiles de Moya	Nieto; Monte del Agua; Las Palomas; Vueltas de Taganana	Meriga; Noruegos	Los Tilos; La Galga	
Cold laurel forest (*Morella, Erica arborea*)		Erjos	Altos del Garajonay	Roque Faro	Las Jayas
Crests laurel forest (Erica *platycodon*)		Chinobre	Inchereda		
Hygrophillic (wet) laurel forest (*Ocotea*)		Ijuana; El Pijaral	El Cedro; La Meseta	Marcos y Cordero	Garoé

Table 8: Experts' proposal of the reference sites location of 9360 subtypes for estimating the habitat condition. For the Azores (a), the experts have been Rui Elias and Eduardo Dias. For Madeira (b) the experts have been Miguel Menezes de Sequeira, Jorge Capelo, and Carlos Lobo, and finally, for the Canaries (c) the experts have been Ángel Fernández and José María Fernández-Palacios.

Additional items for assessment and monitoring of habitat condition

Once defined and agreed the variables, and set the reference levels and thresholds to assess their condition, it will be necessary to define aggregation methods to calculate composite indexes to determine when the habitat is in good or bad condition. This is firstly done at the local scale, i.e. at the level of the plot or location where the variables are measured, and then at supra-local scale, i.e. at the level of the island, archipelago or biogeographical region.

According to the guidelines for reporting under article 17 of the Habitats Directive, the habitat structure and function is in favourable status in the biogeographical region when it has been assessed as in good condition for 90% of its area. On the other hand, if 25% of habitat surface is assessed as in bad condition, the overall assessment of structure and function in the biogeographical region is unfavourable.

Moreover, harmonisation of monitoring methods and protocols, including the criteria for the selection of monitoring localities will also be necessary.

3.2.2.3 Sampling strategy for evaluating the 9360-habitat condition

The assessment and monitoring of the 9360 condition (structure and function) needs the design of a **network of permanent plots**. This network has to be large enough to correctly represent the 9360 geographic distribution and ecological diversity (all subtypes should be adequately represented) and contain plots distributed both inside and outside the Natura 2000 Network and the reference plot.

The plots should be permanently marked (with iron bars in their corners) **squares of 50 m length (area = 0.25 ha)** when possible (Fig. 6), and monitored with the same frequency (six years) as needed to be reported to the European Union. Sentinel satellite imagery from the European Space Agency works with a resolution of either 10 m x 10 m (four spectral bands: visible + infrared), or 20 m x 20 m (up to 10-14 spectral bands). Consequentially, it could be favourable to work with plots measuring multiples of such sizes, such as 20 m x 20 m (0.04 ha) or better 40 m x 40 m (0.16 ha). In this case, the already installed 50 m x 50 m plots could be easily downscaled.

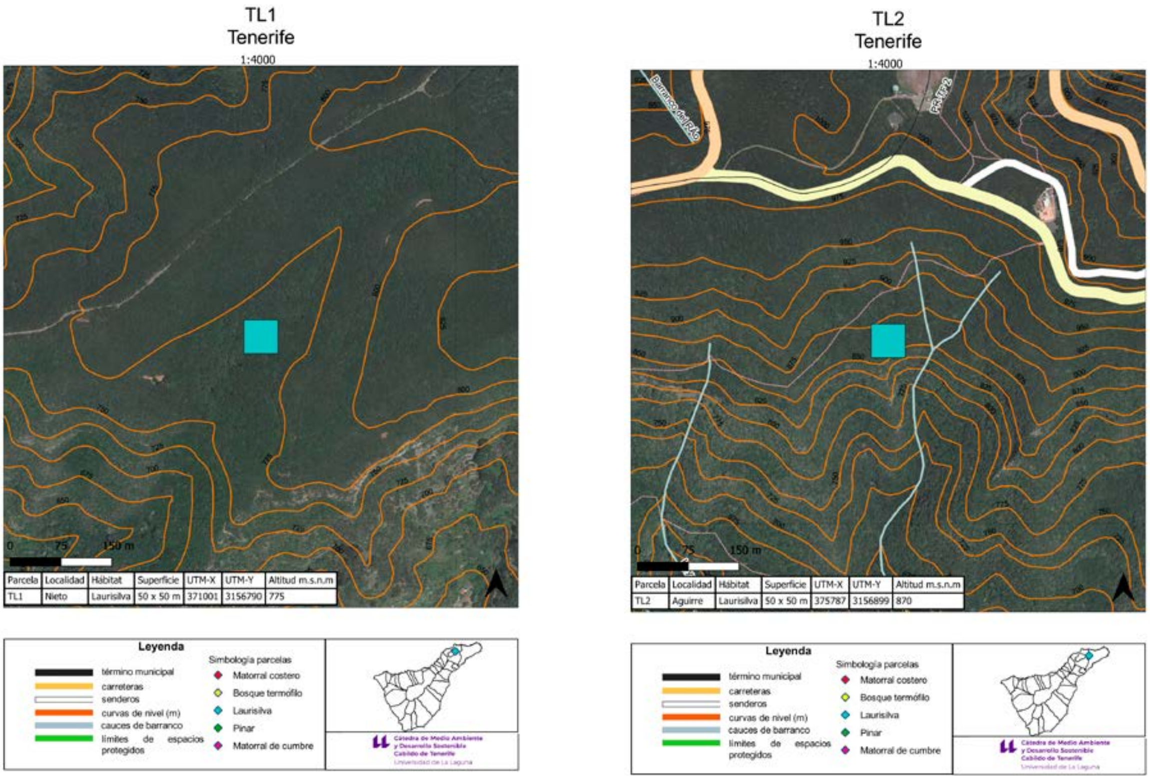


Figure 6: Examples of two 9360 HCI 50 x 50 m permanent plots installed in Anaga Rural Park (Tenerife) (Nieto and Aguirre, respectively) for the monitoring and acquisition of data for comparison from reference plots.

In this endeavour, the already existing and actively surveyed permanent plots of the different countries' **National Forest Inventories** may add to match these objectives and contribute with needed information on the monitored variables (Alberdi *et al.*, 2017, 2019). It will be useful to know to what extent existing forest inventories can cover these needs and provide the necessary information for the selected variables (Pescador *et al.*, 2022). Another option would be to integrate the necessary variables in such National Forest Inventories. The optimal situation would have been if the different archipelagos had monitored permanent plots in 9360 distribution areas, so that we could incorporate function, condition, and its temporal variation in the evaluation of the 9360 structure. Currently, the three archipelagos count with National Forest Inventories (see Table 9) (IFRAA 1; IFRAM 1, 2; IFN 1, 2, 3, 4), where a variable number of permanent plots have been fixed systematically (depending on the island area) and inventoried in different time slots (see Table 9).

Archipelago/Island	Forest Inventories sampling plots	From them in 9360	Source
Azores	?	?	IFRAA 1 (2007-?)
Madeira	385	?	IFRAM 1 (2004-2008) IFRAM 2 (2008-2015)
Canaries	1737 (IFN 2) 2470 (IFN 3) 1971 (IFN 4)	Gran Canaria: ? Tenerife: 26 (IFN 3) La Gomera: 27 (IFN 3) La Palma: 30 (IFN 3) El Hierro: ?	IFN 1 (1965-1974) IFN 2 (1986-1996) IFN 3 (1997-2007) IFN 4 (2008-today)

Table 9: Number of Inventories plots per island and archipelago, and how many of them represent 9360. ?: lack of knowledge.

As these permanent plots have been located systematically, they can be either inside or outside the Natura 2000 web, and can represent the 9360 habitat, other forested habitats, or even plantations. Due to their quality, it is expected that the reference plots all belong to Natura 2000 protected areas (see Fig. 7).

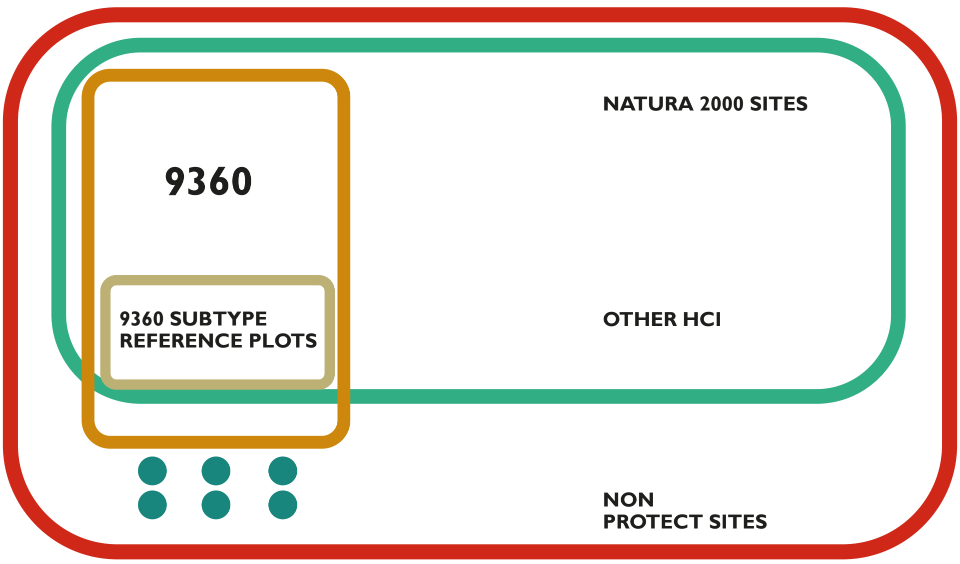


Figure 7: Sampling strategy for the evaluation of 9360 habitat condition, using different permanent plots inside or outside the Natura 2000 Network representing the 9360 for assessing their condition and for comparing it with the reference plots in the different islands and archipelagos.

Unfortunately, the permanent plots' density, location, size, shape, sampling procedures, and monitoring period do not coincide across archipelagos. For instance, they are more focused on the forest plantations with exotic timber in Azores, not paying that much attention to natural laurel forest stands. In the Canaries, the plots are located in each 500 x 500 m UTM grids interception, and the plots are circles with r = 25 m, meaning an area = 0.19625 ha, which is located between the area of a 40 x 40 m plot (0.16 ha) and that of a 50 x 50 m plot (0.25 ha).

Figure 8 shows that for the island of La Gomera, the location of the 27 9360 permanent plots of IFN 3, are all within the Garajonay National Park. The approach would imply that only some of these plots (4-6) would be used as references of excellent habitat condition of the different subtypes (see Table 8), whereas the rest of La Gomera permanent plots would permit the temporal evaluation of 9360 condition.

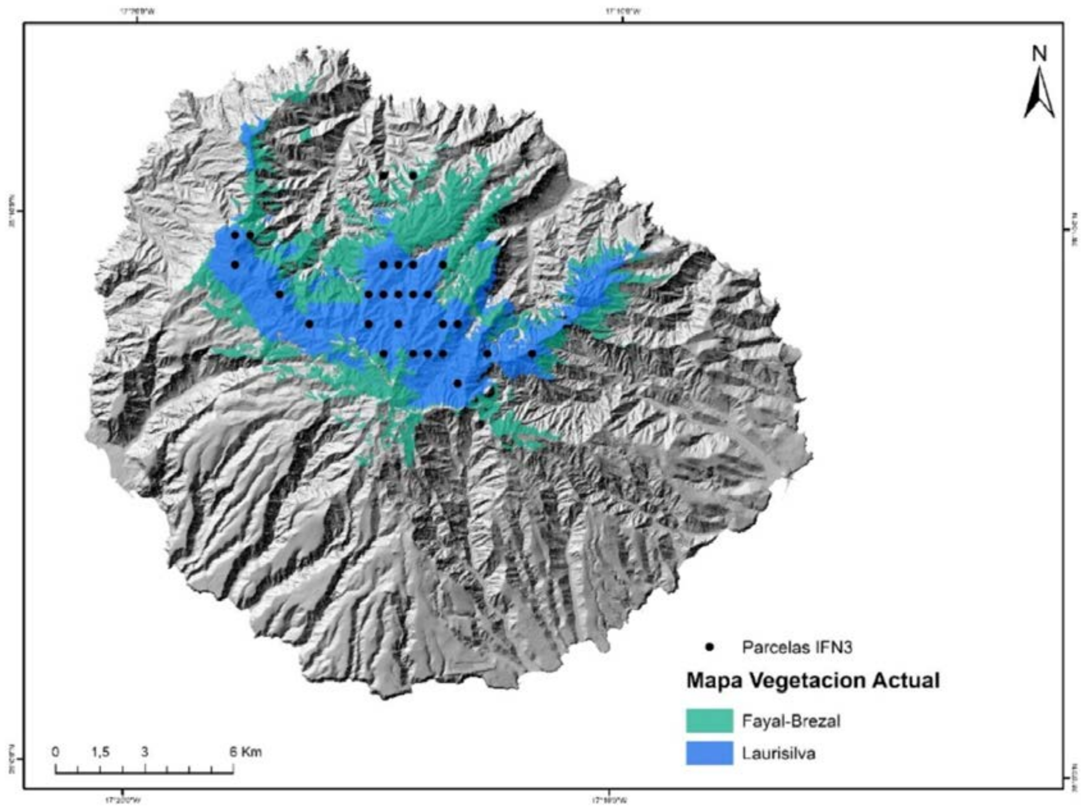


Figure 8: Distribution of the 27 9360 IFN 3 permanent plots (blue) in La Gomera. Source: Otto et al. (2022), unpublished.

It is clear that, only a fraction of the data needed to evaluate the stand condition (see above the parameters to be gathered), especially the structural fraction (basal area, density, mean DBH, canopy height, height and DBH classes, etc.) of the 9360 would be possible to be obtained from the different National Forest Inventories related to these permanent plots. The rest of them, especially those concerning understory and faunistic (both, vertebrates and invertebrates) species composition, should be obtained through further sampling efforts in the same plots.

3.2.2.4 Selection of localities and monitoring plots

Criteria for the selection of monitoring localities and plots

The selection of localities and monitoring plots should take into account the following criteria:

- Statistical significance considering the habitat extent/area
- Representativeness of the ecological diversity, i.e. representation of all subtypes
- Reference ecosystems included

Statistical significance of the sample

The first step is the determination of the number of plots to evaluate taking into account the total area of the habitat type in the geographical area in which the monitoring network is going to be established. To do this, it would be needed to establish a minimum number of plots for **each of the existing 9360 subtypes**, so as to ensure the statistical significance of the sample and the representativeness of the total area.

Methodological proposal for 9360 sample size election

Rationale: The evaluation of the 9360 condition is focused on knowing if habitat type structure and function are in an **unfavourable condition in > 25% of its current distribution** (if this happens, the habitat as a whole is considered having an **unfavourable condition**). As a result, we need to establish a **sample size** for estimating a **proportion** (i.e. the proportion of the habitat type that is in an unfavourable condition and the one that is in a favourable condition).

According to Thompson (2012) the sample size needed for estimating a proportion can be calculated using this formula:

$$n_0 = [(z^2) \cdot (1-p) \cdot p] / (d^2)$$

where n_0 is the sample size (number of plots to install); z is the z-score of the desired *alpha/2 error* (usually 1.96, if *alpha standard error* = 0.05); d is the precision required, and ***p*** and ***1-p*** are the estimations of both proportions (favourable and unfavourable conditions). As ***p*** cannot be known a priori, we substitute this value for the worst possible one: 0.5

For example, according to Table 10, to know the appropriate sample size for estimating the proportion of unfavourable structure and function in a given habitat, with a **5%** precision, we would need to sample **384** plots. With this number of plots installed, the **estimated proportion** would be **± 5%** of the real value, meaning that you can theoretically confound a **real value** of 28% of the habitat's plots in **unfavourable bad** condition with an estimated 23%. This would result in the decision of determining the habitat as a whole as being in an **unfavourable, bad** condition, when it actually is not!

Precision	Number of plots needed
0.20	24
0.15	42
0.10	96
0.05	384
0.01	9604

Table 10: Plots needed for a given precision for a *z-score* = 1.96 and *Alpha error* = 0.05. Sources: Pescador *et al.*, 2019; Thompson, 2012.

On the other hand, you can consider a **real value** of 23% of habitat plots in an **unfavourable bad** condition as an estimated 28%, which would result in thinking that it is in **unfavourable**, **inadequate** condition, when it actually is not. Obviously, working with less precision (i.e**. 10% =** ± 10%, from 15 to 35%) will enlarge the likelihood of these errors to a certain extent.

We consider that it would be preferable to work on the 9360 condition's evaluation with **5% instead of 10% precision** (i.e. locating **384 non-reference plots** across Macaronesia). This is because 9360 is a peculiar Habitat Type of Community Interest, meaning that although its global extension is not very large (potential distribution = 323 000 ha; current distribution = 31 414 ha) (Table 3), it is naturally fragmented across **three archipelagos** (Azores, Madeira and Canaries) and ca. **15 islands**. Each one has its own biogeographic characteristics and endemic species. It also contains **10 habitats subtypes**, each of them with their own characteristic climatic values, species, structure and function. **This implies that all subtype/ island combinations will show differences and, thus, should be sampled.**

There are currently **ca. 35 different 9360 subtype/island combinations**, meaning that this is the minimum number of reference plots we would need for having all of them represented. If the decision is made to **replicate the reference plots** (something desirable that will improve the comparisons), at least, **70 plots (for two replicates) or 105 plots (for three replicates) per subtype/ island combination will be needed**, figures that have to be **added** to the **non-reference plot** surveys.

An interesting working procedure would be to sample each year 1/6 of the total plots installed for obtaining the information needed for the preparation of the 6-years interval article 17 report on the 9360's condition.

Summary of the steps for evaluating the 9360's condition:

1) Analyze the values of the NDVI index to differentiate 9360 from 4050 following the protocol prepared (see appendix 3) and evaluate if the 9360's distribution range and area are increasing, stable or decreasing with time.

2) Fix the sample size for a **5% precision (384 plots).**

3) Delimit and permanently mark the reference plots in the locations already agreed upon by experts, at least one per island and subtype (35 plots) and, preferably, two (70 plots) or three (105 plots) replicates per combination.

4) Locate the non-reference plots, comprising both protected and (only in Azores) non-protected Natura 2000 sites. A proper strategy would be a **systematic sampling** (such as IFN, in each coordinates' crosses) within each island and subtype.

5) Establish the plot dimensions (either 50 or 40 m side squares) and **mark them to create permanent plots** (for instance, putting iron bars in their corners), because they will be surveyed indefinitely.

6) Measure the agreed structure and function variables in the reference and non-reference plots.

7) Compare the variables measured in the non-reference plots with the ones of the reference plots, following the protocol set, for **taking a decision about each plot condition.**

8) Apply the calculated condition for each plot at different geographical scales, using a proper metric: i) a given subtype in a given island; ii) a given island (embracing all the subtypes present); iii) a given subtype (embracing all the islands where present); iv) a given archipelago (embracing all the islands); v) the 9360

HCI in the whole Biogeographical Region (Macaronesia) (embracing all the archipelagos). **Important:** In this procedure the reference plots **will not be included**, because they have been subjectively located.

3.2.3 Trends analysis

An analysis of the surface area variation over time could be made based on available information: i.e. the area has been reduced, maintained or increased over a given period (e.g. since the Directive was approved (1992) or from previous periods as far as possible). For structure and function we only have the assessments done under article 17 (Table 11).

According to the article 17 reports provided by Portugal and Spain, the 9360 the assessment of structure and function seems to have improved between the first and the third period. The overall assessment has passed from unfavourable bad in 2001-2206 to favourable in 2013-2018 (Table 11).

Current selection: 2001-2006, Forests, 9360 Macaronesian laurel forests (Laurus, Ocotea), All bioregions. Show all Forests

ETC/BD treated member states' data

MS	Reg	Range (km²)				Area				Struct & func.	Future prosp.	Overall asses.	Areas from gridded maps(km²)				Quality	
		Surface	% MS	Trend	Ref.	Surface	% MS	Trend	Ref.				Range	% MS	Distrib.	% MS	Range	Area
ES	MAC	949.75	50.2	-	N/A	235.50	42.7	-	N/A	U1	N/A	U2	N/A	N/A	3100	51.7	G (2006)	G (2006)
PT	MAC	942.20	49.8	=	>942.20	316.50	57.3	-	>>316.50	U1	N/A	U2	3100	100	2900	48.3	M (2003-2006)	M (2003-2006)

Current selection: 2007-2012, Forests, 9360 Macaronesian laurel forests (Laurus, Ocotea), All bioregions. Show all Forests

Treated data from Member States reports

MS	Reg	Range (km²)				Area				Struct & func.	Future prosp.	Overall asses.				Areas from gridded maps(km²)			
		Surface	% MS	Trend	Ref.	Surface	% MS	Trend	Ref.			Curr. CS	Qualifier	Prev. CS	Nat. of ch.	Range	% MS	Distrib.	% MS
ES	MAC	118.55	2.7	0	≈118.55	102.94	20	0	≈102.94	XX	N/A	FV		U2	c1	4000	48.2	3200	48.5
PT	MAC	4300	97.3	0	≈4300	413	80	0	>413	FV	N/A	U1	=	U2	c1	4300	51.8	3400	51.5

Current selection: 2013-2018, Forests, 9360 Macaronesian laurel forests (Laurus, Ocotea), Macaronesian. Show all Forests

Member States reports

MS	Range (km²)				Area (km²)								Structure and functions (km²)					Future prospects				Overall assessment					
	Surface	Status (% MS)	Trend	FRR	Min	Max	Best value	Type est.	Method	Status (% MS)	Trend	FRA	Good	Not good	Not known	Status	Trend	Range prosp.	Area prosp.	S & f prosp.	Status	Curr. CS	Curr. CS trend	Prev. CS	Prev. CS trend	Status Nat. of ch.	CS trend Nat. of ch.
ES	675	11.50	+	=	N/A	N/A	102.94	estimate	a	17.07	+	=	95.83 - 95.83	N/A - N/A	7.10 - 7.10	FV	+	good	good	good	FV	FV	+	FV	N/A	noChange	method
PT	5200	88.50	+	=	420	530	500	estimate	a	82.93	+	=	202 - 239	140 - 172	68 - 122	FV	+	good	good	good	FV	FV	+	U1	+	noChange	genuine

Table 11: Source: EEA. EIONET Portal. https://www.eionet.europa.eu/etcs/etc-be/activities/reporting/article-17

3.3 Future prospects: analysis of pressures and threats

3.3.1 Identification and assessment of current pressures and threats under article 17 reporting)

The pressures and threats reported for the 9360 HCI in the last article 17 reports by Portugal (Azores and Madeira) (Table 12) and Spain (Canary Islands), were the following:

7. Main pressures and threats	
7.1 Characterisation of pressures/threats	
a) Pressure	b) Ranking
A09-Intensive grazing or overgrazing by livestock	H-High importance/impact
A01 - Conversion into agricultural land (excluding drainage and burning)	H-High importance/impact
102-Other invasive alien species (other then species of Union concern)	H-High importance/impact
A03-Conversion from mixed farming and agroforestry systems to specialised (e.g. single crop) production	H-High importance/impact
A05-Removal of small landscape features for agricultural land parcel consolidation (hedges, stone walls, rushes, open ditches,springs, solitary trees, etc.)	H-High importance/impact
A33-Modification of hydrological flow or physical alteration of water bodies for agriculture (excluding development and operation of dams)	M-Medium importance/impact
K04 - Modification of hydrological flow	M-Medium importance/impact
F07-Sports, tourism and leisure activities	M-Medium importance/impact
F01 - Conversion from other land uses to housing, settlement or recreational areas (excluding drainage and modification of coastline, estuary and coastal conditions)	M-Medium importance/impact
E01 - Roads, paths, railroads and related infrastructure (e.g. bridges, viaducts, tunnels)	M-Medium importance/impact
a) Threat	a) Ranking
A09 - Intensive grazing or overgrazing by livestock	H-High importance/impact
A01-Conversion into agricultural land (excluding drainage and burning)	H-High importance/impact
102-Other invasive alien species (other than species of Union concern)	H-High importance/impact
A03-Conversion from mixed farming and agroforestry systems to specialised (e.g. single crop) production	H-High importance/impact
A05 - Removal of small landscape features for agricultural land parcel consolidation (hedges, stone walls, rushes, open ditches, springs, solitary trees, etc.)	H-High importance/impact
NO2-Droughts and decreases in precipitation due to climate change	M-Medium importance/impact
K04 - Modification of hydrological flow	M-Medium importance/impact
F07 - Sports, tourism and leisure activities	M-Medium importance/impact

Table 12: Main pressures & threats recognized on 9360 in Portugal. Source: article 17 (2013-2018) report.

Conversely, Spain just reported in the same period about:

Pressure: H04. Vandalism or arson: Medium importance impact, and

Threat: N01. Rise of temperature due to climate change: Medium importance impact

Preliminary list of main pressures identified in this action plan:

Due to very different reasons, the main pressures exerted by human activity to the 9360 HCI do not coincide in the different archipelagos. The situation in the Canaries and Madeira, both with an economy based on tourism is very similar, and their pressures as well, perhaps with the exception of a higher pressure of invasive exotic species in Madeira. In Azores, the main pressures derive from their economic development model, centred in the first economical sector (agriculture, livestock raising and forestry). On the other hand, the climate change threat is ubiquitous across the biogeographical region. Table 13 and Figure 9 summarize the main pressures and threats recognized acting on 9360 in the different archipelagos.

Pressures/Threats	Azores	Madeira	Canaries
Climate change (shifts in temperature and precipitation)	+	+++	+++
Climate change (Altitudinal redistribution/ Dissipation of the sea of clouds)	-	+	++
Climate change (Tropical storms incidence)	+	+	+
Increment of Forest fires (due to climate change or anthropogenic pressure)	-	+	+
Invasive alien species	+++ (*Pittosporum undulatum, Hedychium gardnerianum, Clethra arborea)*	++ (*Ailanthus, Cytisus, Ulex, Acacia, Eucalipto, Passiflora, Pittosporum, Hortensia*)	+ (*Tradescantia, Crassa, Ailanthus*)
Conversion of the 9360 existing out of Natura 2000 Network in plantations or rangeland	+/++	-	-
Fragmentation and low connectivity	+		
Illegal grazing and herbivory	+/++		
Road infrastructure	+	+	+
Stream channelization	-	-	+
Water table unsustainable exploitation	-	-	+
Tracks /Mountain bikes	-	-	+
Volcanic activity	+	-	+

Table 13: Preliminary list of threats and pressures acting in the different archipelagos on 9360 recognized by the authors of this Action Plan. **Note**: The number of crosses is proportional to the importance of pressures and/or threats.

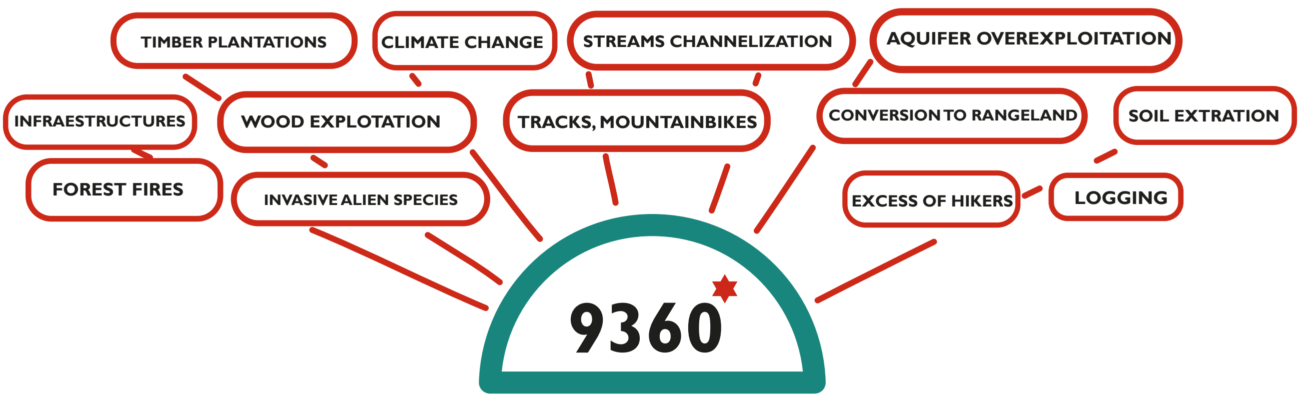


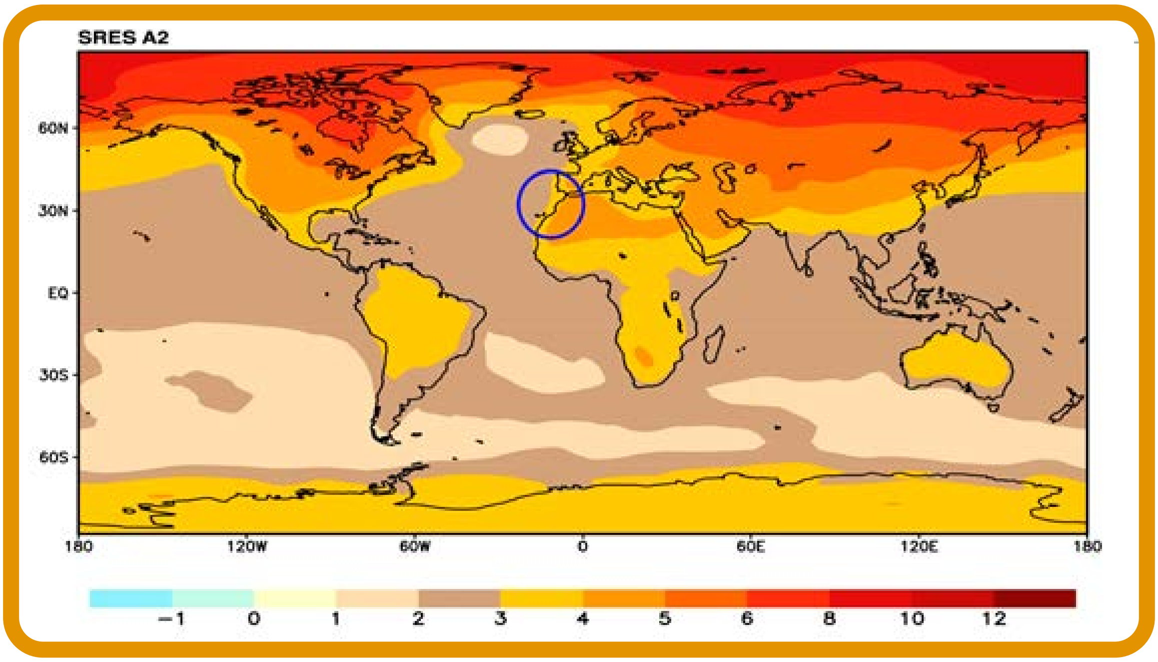
Figure 9: Main pressures and threats exerted by human activity on the Macaronesian laurisilva.

3.3.2 Main drivers for identified pressures and threats

The drivers affecting the pressures and threats exerted on 9360 habitat type on different archipelagos of Macaronesia can be divided in two groups: i) those that have an extrinsic origin, thus being the same for the different archipelagos; and ii) those that have an intrinsic origin, and will depend on the economic development model of each archipelago, the latter being necessarily distinct.

Firstly, the main common driver for all archipelagos, but from which we expected different results according to the archipelagic location and vulnerability is climate change. Climate change projections determine an increase of temperatures between 2-4 °C for the end of this century for all the Macaronesian Region (Fig. 10a), but the response to precipitation varies among archipelagos (Fig. 10b), with similar or slight increases (+ 5 mm/y) of precipitations projected for Azores. Madeira and the Canaries could see a decrease in precipitation of up to 20 mm/y.

Temperature is quantitatively much more important than precipitation, and among other consequences, we may expect an altitudinal shift of the habitat, which may be a serious problem on islands where it is already occupying the summits (Ferreira *et al*., 2016, 2019; Renner *et al*., 2022).



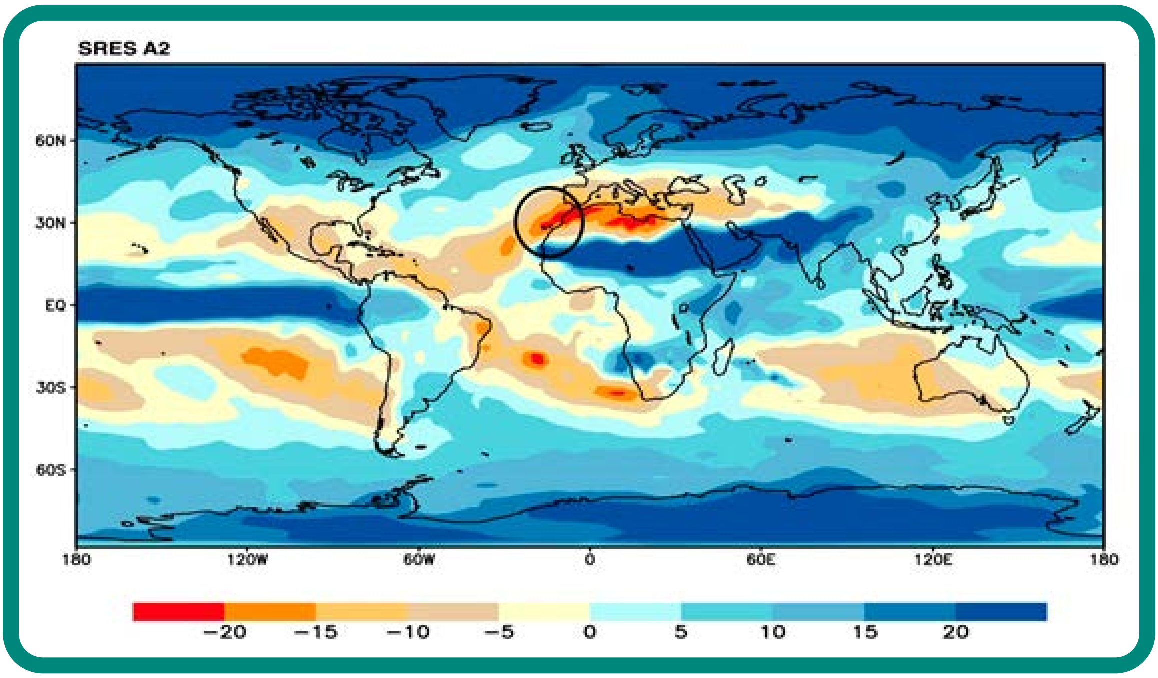


Figure 10: Change of a) Mean Annual Temperature (ºC) and b) Annual Precipitation (mm) projected for the SRES scenario A2 for the end of this century for the globe and Macaronesia (encircled). The figure shows the period 2071–2100 relative to the period 1961–1990. Source: Gitay *et al.,* 2002.

Another concern related to climate change is how it will affect the orographic cloud layers which are of great importance for 9360. Orographic cloud layers create humid refugia where forested ecosystems can withstand the year-long or seasonal aridity of the macroclimate. The altitudinal location, frequency and depth of the cloud layer are also expected to be affected by climate change, though cloud layer projections are still uncertain, with some postulating its altitudinal ascent (Still *et al.*, 1999) and others its descent (Sperling *et al.*, 2004). The increase in elevation may pose serious risks on islands that only have the cloud layer around their summits, because they may lose it. On the other hand, the descent of the cloud layer's base means that it will occupy areas in large part already transformed for agriculture or settlements, thus impeding the relocation of the communities for which the cloud layer serves as a climatic refugium.

Also, the increasing incidence of hurricanes and tropical storms in the Macaronesian archipelagos, traditionally out of the hurricanes' route, is an important consequence of climate change, consequence that already began to leave signals on 9360 structure and dynamics with events such as Delta (2005) in Madeira and the Canaries, Vince (2005) in Madeira or Lorenzo (2019) affecting Azores. These winds create gaps of a previously unknown size, which can alter the 9360 natural recovery dynamics (Fernández-Palacios *et al.*, 2017).

The second group of drivers are intrinsic to the archipelagos, i.e. dependent on their economic development model, which in Azores is mainly focused on cattle grazing and forestry, and on mass tourism in Madeira and the Canaries. On the one hand, pressures and threats on Azores should be related to land use change (i.e., wood exploitation, timber plantations, conversion to rangeland, etc.). On the other hand, on Madeira and the Canaries pressures and threats on 9360 should be more related to human density (aquifer overexploitation) or natural areas visitors (excess of hikers, tracks, mountain bikes, roads infrastructure, noise, anthropogenic fires), but also with agriculture (aquifer overexploitation, streams channelization).

3.3.3 Proposal for harmonisation of the assessment of pressures and threats

It is necessary to establish a methodology, as objective as possible, to evaluate the pressures and threats that affect or will affect the habitat conservation. Standard procedures for assessing the impact of each pressure/threat on the area, structure and functions of the habitat type should be developed. A conceptual framework for assessment of pressures and threats on forests has recently been developed within the framework of the system for monitoring conservation status of habitat types in Spain (Chacón-Labella *et al.*, 2019[1]).

The characterization of each of the pressures and threats will allow establishing a procedure to evaluate the 'Future perspectives' parameter for the habitat type at the scale of the biogeographical region. In this regard, it is necessary to formalize procedures to estimate the intensity of each pressure and threat in the short or medium term (Cardoso *et al.*, 2013), and for each of the three parameters that make up the conservation status of the habitat type:

- Range
- Occupied area
- Structure and function.

The evaluation of the degree of intensity on each of these parameters will allow, through its combination with an appropriate decision matrix, to characterize the 'Future perspectives' of the habitat as favourable, unfavourable-inadequate, unfavourable-bad or unknown. In this way, a habitat type in a biogeographic region will have good future prospects if, in the foreseeable future (12 years) the geographical range and the area of the type of habitat remains stable or expands and the parameter 'Structure and function' is maintained as favourable.
As a first step, using the reference list available for reporting pressures and threats for habitat types under the Habitats Directive, those relevant pressures and threats that can cause a change in the conservation status at the biogeographical regional level shall be identified and briefly described for each of the three parameters: 'Range', 'Occupied area', 'Structure and function'.

The analysis of intensity and impact of pressures and threats on the area and condition (structure and function) of the habitat could address the following main steps:

1) Compilation of information sources and databases: GIS Layers, inventories of pressures and threats available, statistical models, considering appropriate scales, frequency, extent, etc.

2) Determine the overlapping of pressures and threats with habitat distribution

3) Evaluate the sensitivity of the habitat type to each pressure and define critical thresholds that determine the categories H (high), M (medium) and L (low), e.g. considering regulations, bibliography, etc.

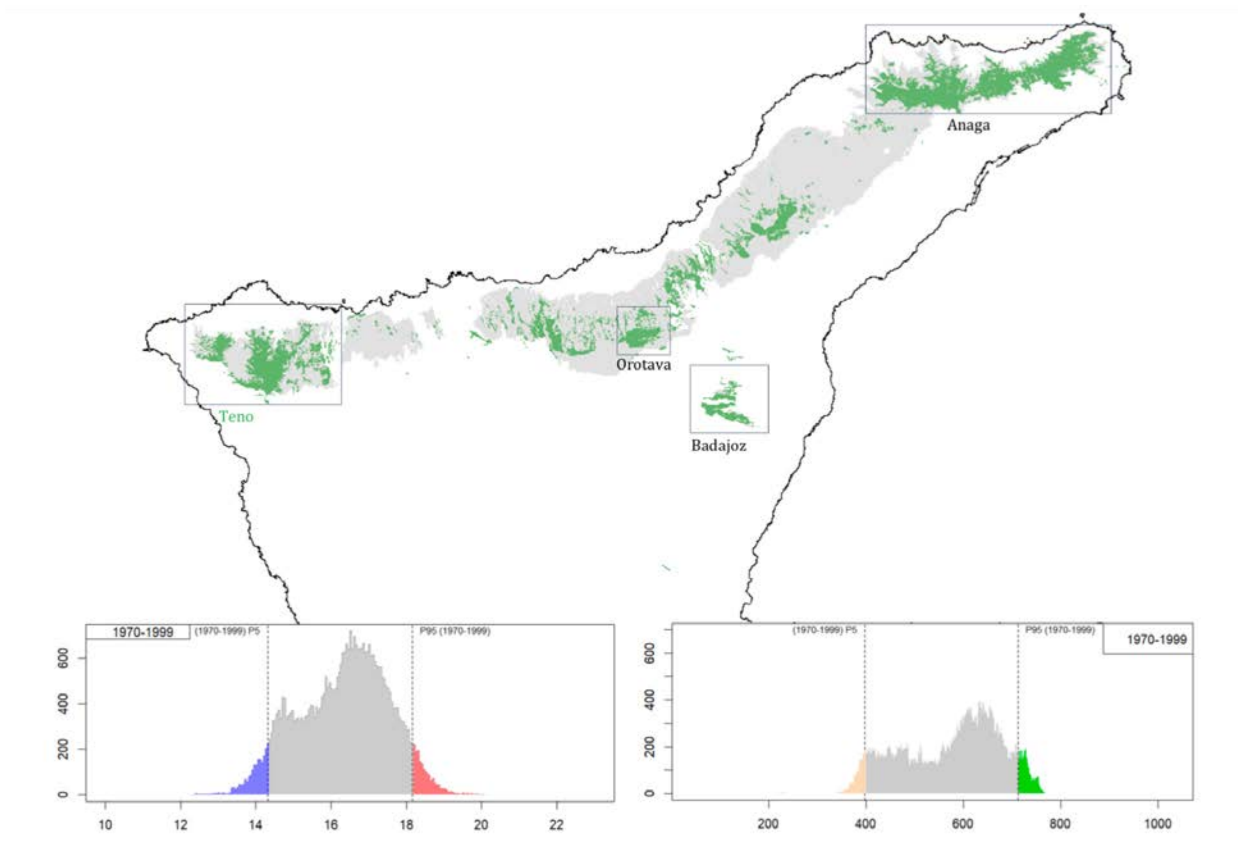
1 https://www.miteco.gob.es/content/dam/miteco/es/biodiversidad/temas/ecosistemas-y-conectividad/bosquesymatorrales-nofluviales_8_metodospresionesyamenazas_tcm30-508583.pdf

BOX 1: Worked example of the analysis of a pressure Climate change impact on laurel forests in Tenerife
(Martín Esquivel (2022) unpublished)

The Canarian Government has recently carried out an unpublished analysis to assess the effect of climate change on the habitats 4060 (Endemic Macaronesian heaths) and 9360 in Tenerife. The aim of the work was to assess how the current anthropogenic climate change has affected already the 4060-9360 distribution area in the island, and thus, to obtain insights in how it will be affected in the future.

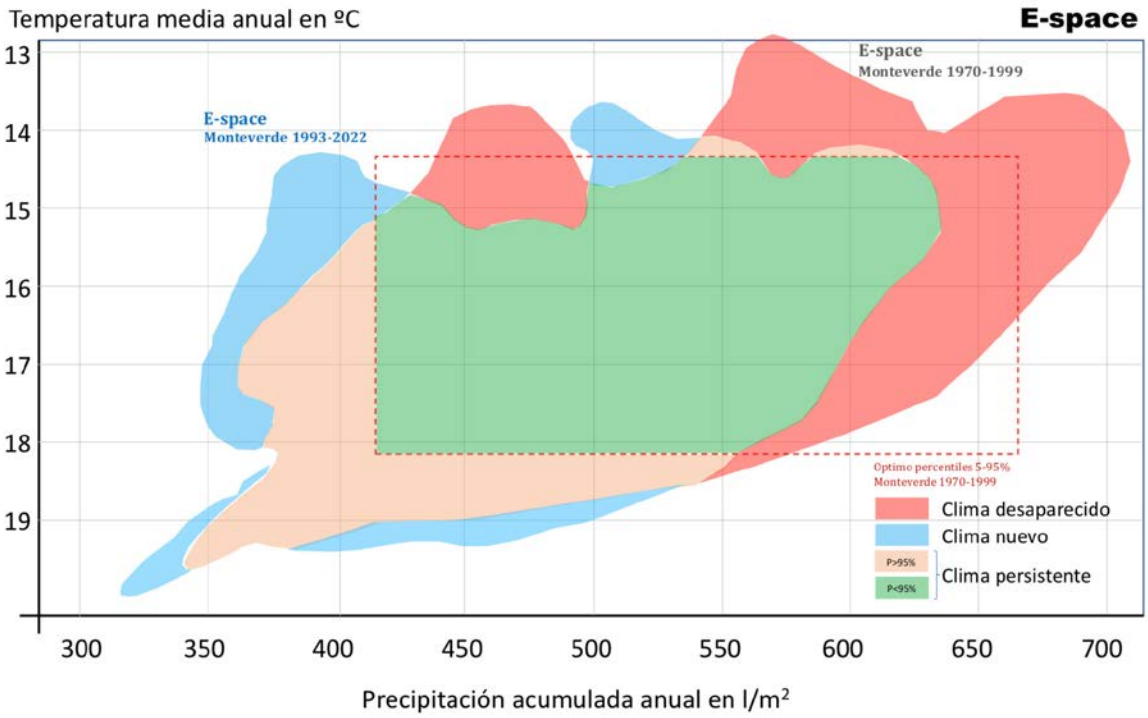
Methodology: The authors gathered existing meteorological information for the 4050-9360 main distribution areas in the island (Anaga, La Orotava, Teno and Güímar) (Box Fig. 1) for the periods 1970-1999 and 1993-2022 and make a comparison. Knowing the climate requirements of the 9360 in Tenerife and using the raw data for modelling the temperature (T) and precipitation (P) of both habitats' distribution zones, they were able to construct a climatic space (T versus P) (Box Fig. 2) where the climatic distribution during these time frames was plotted.

Climatic areas of the Monteverde of Tenerife



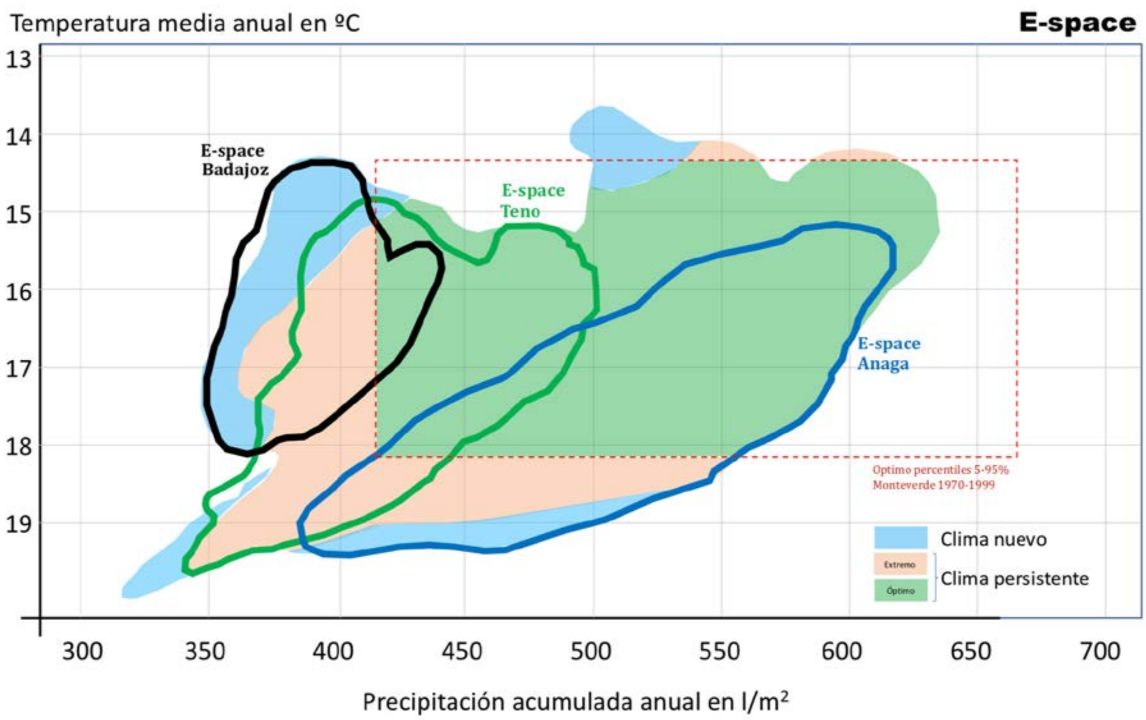
Box Figure 1: Above, pristine (grey) and current (green) geographic distribution of 4060 and 9360 HCI on Tenerife. Below, mean annual temperature (left) and annual precipitation (right) distributions in periods (1970-1999, white) and (1993-2022, grey). In blue (5 percentile) and in red (95 percentile) overlapping of both curves for temperature and orange (5 percentile) precipitation overlapping. No overlapping exists for the 95 percentile of precipitation values.

Climatic areas of the Monteverde of Tenerife



Box Figure 2: Extension occupied by 4060 and 9360 in the Temperature-Precipitation climatic space. In red, 1970-1999 climatic space already vanished, and in blue, new climatic space emerged between 1993-2020. Green (P< 95%) and orange (P>95%) areas indicate persistent climatic space.

Climatic areas of the Monteverde of Tenerife



Box Figure 3: Distribution of the 4060 and 9360 habitats of specific insular regions (Anaga, Teno and Badajoz (Güímar)), in the climate space.

Results: The dominant climate since the 1970-1992 time period in Tenerife 4060-9360's geographical distribution has shifted in these last 50 years towards warmer and dryer conditions, so that a significant fraction of its climatic space has vanished (red in Box Fig. 2). Conversely, a new climatic space has emerged (light blue in Box Fig. 2), although its climatic area, is smaller than the one that has disappeared.

The shift towards a warmer and drier climate in areas where these habitats are now distributed may result in an altitudinal redistribution of both habitats towards the island summit, for tracking its original climatic requirements. Nevertheless, this altitudinal redistribution may be hindered by the inability of the ecosystem to track the climatic shift due to dispersal failure or by the inexistence of higher terrain to colonise. This is the case of Anaga and Teno massives, whose summits are already occupied by these vegetation types (Box Fig. 3). On the other hand, the lower distribution areas 4060 and 9360 may be replaced by other ecosystems' altitudinal redistributions, such as the thermophilous woodlands (as can happen in Badajoz, Güímar Valley).

Summarizing, there is certainty about the climatic shift happening in the 9360 distribution areas to warmer and drier conditions during the last half century, but uncertainty about the 9360 capacity of tracking its climatic envelope, there where it is still possible because the existence of higher altitude zones to colonize (La Orotava).

Insulivitrina lamarckii, a Tenerife endemic slug species. Photo: Nélida Rodríguez.

3.4 Conclusions on the assessment of conservation status and trends, gaps and future needs

The diagnosis of the habitat should be based on a rigorous assessment of conservation status, including area, structure and function and future prospects based on the analysis of pressures and threats. This also requires harmonised approaches in order to obtain more accurate and comparable results across the Macaronesian region.

Area:

- There is a need to apply a common protocol to evaluate the area occupied by the laurisilva in every island, e.g. using a methodology based on the NDVI as proposed in this action plan (see Appendix 3).

- There is also a need to improve knowledge on potential distribution area, especially in Azores, in order to be able to estimate the Favourable Reference Area of the habitat, which is required to address possible restoration efforts.

Structure and function (habitat condition)

- Develop and apply a standard procedure for the assessment and monitoring of 9360 habitat condition (structure and function) in the Macaronesian entire region. This will require an agreement on the use of a common set of variables and the development of thresholds, aggregation methods, monitoring and sampling protocols, etc. for their implementation in the whole biogeographical level.

- Explore the use of information from forest inventories for the assessment and monitoring of habitat condition.

- Explore possible use of other information sources and technologies ways to measure the habitat condition (considering the necessary variables), e.g. by remote sensing, aerial LiDAR, terrestrial LiDAR, etc.

Future prospects: analysis of pressures

- Develop standard procedures to quantify the intensity (high, medium, low) of pressures and threats on habitat surface and structure and function.

Fringilla coelebs moreletii, Terceira Island (Azores). Photo: Eduardo Dias

4. CONSERVATION OBJECTIVES AND MEASURES

4.1 Restoration and conservation objectives

4.1.1 Recovery of the favourable reference area by 2050

This Action Plan advocates for the recovery of the FRA, i.e. increasing the area to **reach the 25% of the potential area the habitat 9360 by 2050**, and as far as possible apply this target to each habitat sub-type. For now, only Madeira and La Gomera (and not for all the 9360 subtypes) reach globally this objective (25%), whereas other islands, such as Tenerife, La Palma or El Hierro, reach the threshold for some subtypes, but not globally (see Table 3). On islands where the 9360 HCI is not well preserved (Gran Canaria, and many Azorean islands), achieving this objective will need important efforts in restoring the original laurisilva masses.

Justification

This objective is based on the determination of Favourable Reference Area explained in the previous section. If we considered the outstanding endemicity of Macaronesia and the fact that this habitat type is endemic to this biogeographical region, the objective of restoring the habitat to reach 25% of its potential distribution area seems appropriate. This would imply (depending on the taxonomic groups) that at least a fraction of varying between ca. 60-75% of the original biota of the 9360 would survive. This is especially transcendent if we consider that the large majority of the endemic species living on oceanic islands are single island endemics (SIEs) (Fernández-Palacios *et al*., 2021), and that the large majority of them are as well single habitat endemics (SHEs), meaning that their loss in their inhabited island and habitat will imply the species extinction. This objective can be particularly challenging for some regions, as the Azores, or in Gran Canaria, which currently hold < 3% of the potential laurisilva distribution.

Necessary measures to achieve this objective

- Determine the potential distribution area of laurisilva in in all the Macaronesian islands to **define and quantify the favourable reference area.**

- Identify potential restoration areas on all the islands, as required, and **prepare restoration plans to carry out the necessary restoration actions.** These restoration plans shall consider the feasibility and the means required to carry out of the restoration actions.

- The implementation of restoration action should be carefully planned. For instance, some potential restoration areas can be in private lands and the **implementation of restoration actions** will require land purchase or the establishment of stewardship agreements with landowners. Agreements with local authorities can also be used to carry out some restoration actions in public lands. The costs and financial resources to carry out the planned actions shall be estimated in the best possible detail and the necessary permits and agreements shall be envisaged.

4.1.2 Maintain in good condition at least 90% of the habitat surface

Justification

According to the guidelines for conservation status assessment, at least 90% of the habitat surface must be in good condition to consider the habitat structure and function in favourable status. This requires improving the conditions in some areas where the habitat may be currently present, but degraded or not in good condition.

Necessary measures to achieve this objective

- Identify degraded areas with recovery potential and identify the main pressures and threats that cause their degradation, in order to prepare recovery plans based on that information, considering the necessary resources for their implementation.

- Develop recovery actions by the removal and reduction of the relevant pressures and implement recovery/restoration measures as required to improve the condition in the selected areas.

4.1.3 Improve protection and management inside and outside Natura 2000

Justification

Currently, the percentage of the habitat area included in Natura 2000 is 78.72 % in Portugal and 93% in Spain of the habitat area. Although in the Canaries and Madeira the large majority of the current 9360 habitat distribution is included in the Natura 2000 Network existing in the archipelagos (see Table 5), being exceptional the fragments not included, this is not the case for the Azorean archipelago, where a significant part of the 9360 (56.51 %) is outside the Natura 2000 Network. Irrespective of their conservation condition, this Action Plan considers that the protection of those 9360 fragments still existing outside the EU Natura 2000 Network (wherever archipelago this happens) is urgently needed, because its present status without official European protection can be extremely risky for the long-term survival of those fragments and of the species inhabiting them.

Considering the uniqueness and priority for conservation of this habitat type in the Macaronesian regions, it is proposed to include 100% of the habitat surface in Natura 2000.

The elaboration, update and implementation of management plans for Natura 2000 sites with 9360 will also be necessary to ensure proper management of all these sites (Guimaraes & Olmeda, 2008).

Considering the fragmentation of laurisilva across its distribution area, there is also a need to improve coherence and connectivity of the Natura 2000 Network for 9360 to ensure long-term conservation and viability of the habitat (Aparício *et al.*, 2018). This could be done though the development of plans to improve the coherence of the laurisilva network.

Finally, in order to improve management and implement in a coordinated manner the necessary conservation measures, it is considered appropriate to establish coordination mechanisms between regional and local administrations and relevant stakeholders for the management and conservation of laurisilva areas.

Necessary measures to achieve this objective

- In order **to improve the protection of laurisilva** under Natura 2000, it will be necessary to identify all current areas with laurisilva outside Natura 2000 and designate the corresponding SCIs. The designation of new Natura 2000 sites shall also include all the areas subjected to the restoration of laurisilva.

- To **improve coherence and connectivity of the Natura 2000 Network for laurisilva**, it is proposed to analyse the coherence (representativeness, connectivity, resilience, rarity and redundancy) of the Natura 2000 Network for this habitat. This will be a first step elaborate and implement plans for improving coherence at different scales: site, island, archipelago, biogeographical region.

- Improving **coordination for management and conservation of laurisilva** would require the **creation of an interregional group** with representatives from the three archipelagos and support from national authorities. This group would coordinate and follow up conservation, knowledge and monitoring activities.

4.1.4 Ensure adaptation to climate change

Justification

Considering the future climate change scenarios and the impact they can have on the conservation of laurisilva in the Macaronesian region (see Figure 14), this action plan aims to promote the conservation and restoration of laurel forests in favourable areas expected in the new climate conditions.

Necessary measures to achieve this objective

- To prepare the measures required to ensure adaptation of laurisilva to climate change, it is considered necessary to **analyse and forecast changes in the laurel forest area in the climate change scenarios**, via modelling techniques, in order to **identify favourable areas** for the occurrence of the laurisilva in those scenarios. An example of this type of analysis has been carried on the Tenerife islands and shown in this action plan (see Box 1 in section 3.3.3).

- Based on the predictive analysis of changes in laurel forest areas resulting from new climate conditions, and **adaptation plan** shall be prepared to **implement the necessary adaptation, conservation and restoration actions in the new favourable areas** identified in the plan. The costs, financial resources and means to carry out the planned actions shall be estimated and envisaged in detail.

Laurisilva leaf litter, Anaga (Tenerife). Photo: Nélida Rodríguez

4.2 Objectives and measures to improve knowledge and monitoring

One of the first obstacles faced by managers and practitioners for the development of appropriate conservation actions towards the achievement of the favourable conservation status of any habitat is the lack of knowledge. The last decades have contributed to the accumulation of outstanding knowledge about the 9360 HCI (Santos-Guerra, 1990; Gandullo, 1991; Costa Neves *et al*., 1996, 1997; Ohsawa *et al*., 1999; Fernández López & Moreno, 2004; Sande Silva, 2004; Meneses *et al*., 2006; Fernández López & Gómez González, 2016; Arozena *et al*., 2017; Fernández-Palacios *et al*., 2017) and more than one hundred papers published in scientific journals (see Fernández-Palacios *et al*., 2017 and references therein). Despite these developments, there is still an important knowledge gap for this habitat type in respect to several issues, mainly related to the conservation status, pressures and threats. The following objectives and measures are proposed in this action plan.

4.2.1 Improve knowledge about diversity and ecological requirements of laurisilva

Justification

The laurisilva forests show an outstanding diversity across their distribution, with a significant number of sub-types identified in the different islands across their range. Improving knowledge about the different laurisilva types, their distribution and ecological requirements is necessary to properly address their conservation. Better knowledge is also required on the key ecological processes for maintaining laurisilva in good condition.

Necessary measures to improve knowledge about ecological diversity and requirements

- The **analysis of the ecological diversity** of laurisilva across its distribution area would involve defining the criteria to **identify the various sub-types**, as well as elaborating a **full description** and **accurate maps** of the identified subtypes.

- The **study and analysis of key characteristics, ecological requirements and processes** for maintaining laurisilva in a favourable conservation status, considering all the subtypes identified, is a necessary measure to properly identify and address the conservation needs of this habitat type across its range.

4.2.2 Improve assessment and monitoring of laurisilva conservation status, including improving knowledge about pressures and their impacts on laurisilva

Justification

The diagnosis of the habitat carried out in this action plan has revealed that the knowledge on the status of the key parameters of laurisilva (area, structure and function and future perspectives) is incomplete and inaccurate. The lack of harmonized methodologies used for assessment of the conservation status in the three archipelagos harbouring laurisilva, prevents obtaining comparable results across the Macaronesian region.

Collecting detailed knowledge about current pressure affecting laurisilva in its distribution areas and foreseeable threats in the future is also essential to be able to identify the areas where actions are needed to address those threats that put the habitat conservation at risk.

Necessary measures to achieve the objective

• The **development and implementation of harmonised, standard methods and protocols to evaluate conservation status** of laurisilva is essential for a proper assessment of the main parameters: area, structure and function, and future prospects based on the analysis of pressures and threats.

• A **common protocol to evaluate the area occupied by the laurisilva** should be developed and applied on every island and archipelago across Macaronesia. This could be done, for instance using a methodology based on the NDVI as proposed in this action plan (see Appendix 3).

• There is also a need to **quantify the Favourable Reference Area** of the habitat. This requires improving knowledge on potential distribution area, especially in Azores.

• It is also necessary to **develop and apply a common standard procedure for the assessment and monitoring of laurisilva habitat condition** (structure and function) in the Macaronesian region. This will require an agreement on the use of a common set of variables and the development of thresholds, aggregation methods, monitoring and sampling protocols, etc. for their implementation in the entire Macaronesian region.

• Exploring the **use of information from forest inventories** and other information sources and technologies (e.g. remote sensing, LiDAR, etc.) for assessment and monitoring of habitat condition is also proposed.

• The **study, analysis and mapping of pressures and threats** that affect laurisilva across its range requires developing standard procedures to quantify the intensity and impacts (high, medium, low) of pressures and threats on habitat surface, structure and function.

• The **creation of a joint working group to develop the standard methodologies** that are considered necessary to improve assessment and monitoring of the habitat conservation status is thus essential and awareness-raising.

Sea of clouds overflowing over Encumeada in Madeira. Photo: Nélida Rodríguez.

4.3 Dissemination and awareness-raising objectives and measures

4.3.1 Increase awareness about the importance of laurisilva conservation

Justification

The dissemination of information about the originality of laurisilva and its importance for the conservation of biodiversity in the Macaronesian region is considered necessary to raise awareness about its value among the population, local administrations and stakeholders, that can support the conservation of this unique forest habitat.

Necessary measures to achieve the objective

- The **elaboration and dissemination of information and awareness raising materials** on the importance of laurisilva is necessary to support its conservation. These materials should be designed and targeted to local population and visitors, local administrations and relevant stakeholders that can contribute to the implementation of the necessary conservation measures.

- The dissemination of information on the current status and conservation needs of laurisilva is essential to **promote and support the implementation of the action plan** by regional and local Administrations, relevant stakeholders and NGOs.

Viburnum rigidum, Anaga (Tenerife). Photo: Nélida Rodríguez.

5. RESOURCES AND TOOLS FOR IMPLEMENTATION

5.1 Costs of measures and funding sources

The estimate of costs of the measures proposed in this action plan could not be carried out during its preparation but will need to be addressed before its implementation. A number of studies and analyses are proposed to improve knowledge as well as to guide and support the implementation of the necessary actions, which can be budgeted considering similar studies carried out on other habitats and contexts. A precise quantification of the needs in terms of restoration and conservation measures will be necessary to estimate their costs, which can also be based on the unit costs of other similar experiences and projects. The final budget will also depend on the ambition in the implementation of the planned actions throughout the execution of the action plan.

Regarding the potential sources of financing, in general, the main funds that can be used for restoration, conservation management and monitoring of the habitat and to raise public awareness are the Common Agricultural Policy (CAP) funds and other European funding such as LIFE and the Regional Development Fund, as well as national funds.

The CAP provides financial support to rural areas and EU countries can choose to fund forestry interventions through their CAP Strategic Plans. These interventions are aimed at protecting forests, making them more resilient to climate change, safeguarding their multiple functions, including the provision of environmental services. These interventions can support both investments and specific forest management actions as the following:

- afforestation or creation of woodland, both their establishment as investments and their maintenance;
- prevention of forest damage caused by fires, natural disasters or catastrophic events, and restoring damaged forests;
- investments in improving climate resilience and environmental value of forest ecosystems;
- land management contracts for forest-environment-climate services and forest conservation.

The LIFE programme provides support for integrated approaches, pilot, demonstration and best practice projects that contribute to the implementation of biodiversity objectives, climate change mitigation strategies, and action plans at regional or national level. This includes projects combining the restoration and promotion of ecosystem services with the establishment of innovative financing tools. The LIFE programme can also finance land purchase under strict conditions, e.g. when required to implement priority restoration actions.

The European Commission has published a Guidance to help public and private entities, and forest owners and managers, to develop and implement payment schemes for forest ecosystem services.

5.2 Implementation tools and supportive measures

Possible measures to enable and support the implementation of the action plan can include legal and administrative measures, incentives, communication, stakeholders' involvement, etc.

Legal and administrative measures will be necessary to improve protection and support the implementation of management plans in Natura 2000 sites.

Agreements with private owners and public authorities can be useful for the implementation of restoration and conservation measures in some laurisilva areas.

Private forest reserves established through and stewardship agreements have been financed by the public administration and environmental foundations in some Spanish regions, like Catalonia, to allow the conservation of mature forests and valuable ecosystems.

6. MONITORING AND REVIEW OF THE ACTION PLAN

A monitoring plan should be designed before the implementation of the action plan to assess the implementation and effectiveness of the planned actions, including relevant indicators and time frames for the assessment.

To assess the effectiveness of the planned measures, it would be useful to carry out a scientifically supervised monitoring of the results on the habitat. Some possible indicators to assess the effectiveness of the implemented measures could include the following:

- Area of habitat in favourable condition.
- Increase of managed areas, increase or maintenance of favourable status in managed areas, improving status of typical species, regression of problematic species.
- Diversity of typical, endangered or rare species.
- Vegetation structure, bioindicator species (both positive and negative and from different groups of organisms, including soil biota), umbrella species.
- Faunistic composition. High species diversity, especially invertebrate well represented and in good status.

Regarding the review of the action plan, it would seem appropriate to review and update the action plan every twelve years, to cover two reporting cycles (under Article 17 of the Habitats Directive), given the slow time for habitats to react to changes. Nevertheless, the implementation of the actions could be reviewed every six years in order to check the activities implemented and intermediate results, detect possible gaps, difficulties and constraints that would need to be resolved, and revise and adjust the actions as required.

Picconia azorica, São Jorge Island (Azores). Photo: Eduardo Dias

7. GOVERNANCE FOR IMPLEMENTATION OF THE ACTION PLAN

To make the action plan operational at national, archipelagic and insular level, it is necessary to agree on the responsibilities for implementation. The relevant bodies and people responsible for the implementation and monitoring of the action plan should be clearly identified.

The national and regional authorities should identify and designate those responsible for the implementation of the actions. A specific body or a steering committee could be in charge of the plan. Regular exchange of information about the implementation of the actions and a yearly meeting for its review could be foreseen to monitor the implementation of the action plan.

This governance system should be defined and established at the start of the action plan. The following steps could be considered:

- Set up a governance system for the action plan implementation: identify the relevant bodies and people responsible for implementation and monitoring of the action plan. MS should designate those responsible for the implementation of the planned actions.

- Define a decision-making process.

- Set up the procedures and responsibilities for monitoring, evaluation and review of the action plan (e.g. yearly exchange and review of the action plan implementation).

8. FRAMEWORK FOR ACTION

An operational framework including the objectives, actions, geographical scope, responsibilities, and timescales is included in following pages.

Conservation and restoration objectives				
Key actions	**Activities, means and input required**	**Geographical scope**	**Responsibilities**	**Timescale**
Objective 1: Recovery of the Favourable Reference Area by 2050				
Increase the area to reach the 25% of the potential area of habitat 9360	Identify potential restoration areas and prepare a restoration plan	All Macaronesian islands with recovery potential	Regional Administrations, Scientific experts	2027
	Develop restoration actions		Regional and local Administrations, relevant stakeholders and NGOs	2036
Objective 2: Maintain in good condition at least 90% of the habitat surface, to reach a favourable conservation status				
Recovery of areas in bad condition (degraded)	Identify potential recovery areas and main pressures and threats that cause their degradation, and prepare a recovery plan	All Macaronesian islands with recovery potential	Regional Administrations Scientific experts	2027
	Develop recovery actions: remove/reduce pressures and implement recovery/restoration measures		Regional and local Administrations	2036
Objective 3: Improve protection and management inside and outside Natura 2000				
Include 100% of the habitat surface in Natura 2000 (currently 79% in Portugal & 93% in Spain)	Identify current areas outside Natura 2000 and designate the corresponding SCIs	All Macaronesian islands with laurisilva areas outside Natura 2000	Regional Administrations	2027
	Include all the restored areas in Natura 2000	All restored areas	Regional Administrations	2028
Elaboration, update and implementation of management plans for Natura 2000 sites with laurisilva	Update and adopt management plans for Natura 2000 sites with laurisilva.	All Macaronesian islands	Regional Administrations	2030
	Implement conservation measures, including measures to reduce/remove main pressures and threats		Regional and local Administrations, relevant stakeholders and NGOs	2036
Develop plans to improve the coherence of the laurisilva network	Analyse the coherence (representativeness, connectivity, resilience, rarity and redundancy) of the Natura 2000 Network for the laurel forest	Natura 2000 Network in the Macaronesian region	Regional and local Administrations, scientific experts, relevant stakeholders and NGOs	2027
	Elaborate and implement plans for improving coherence (multilevel: space, island, region)			2028
Establish coordination mechanisms between administrations for management of laurisilva	Creation of an interregional group with representatives from the three archipelagos and support from national authorities to coordinate conservation, knowledge and monitoring activities			2024

Objective 4: Adaptation to climate change				
Promote the conservation and restoration of laurel forests in favourable areas, considering the new climate conditions	Analyse and forecast changes in the laurel forest area in the climate change scenarios, identify favourable areas and develop an adaptation plan.	All Macaronesian islands	Regional Administrations Scientific experts	2030
	Develop adaptation, conservation and restoration actions in the new favourable areas identified in the plan	All Macaronesian islands	Regional and local Administrations, relevant stakeholders and NGOs	2036
Knowledge improvement objectives				
Key actions	Activities, means and input required	Geographical scope	Responsibilities	Timescale
Objective 5: Improve knowledge about eco-diversity and ecological requirements of laurisilva				
Study the different laurisilva types, their distribution and ecological requirements	Analyse the ecological diversity, determine criteria to identify the various sub-types, describe and map the identified subtypes	All Macaronesian islands with laurisilva	Regional Administrations, Scientific experts	2027
Study the key ecological processes for maintaining laurisilva in good condition	Analyse and determine the key ecological requirements and processes for maintaining laurisilva in a favourable conservation status (incl. ratio between 4050 and 9360, trophic relations (pollination, dispersal, herbivory, predation, parasitism), soil…)	All Macaronesian islands with laurisilva	Regional Administrations, Scientific experts	2030
Objective 6: Improve knowledge about pressures and their impacts on laurisilva				
Study the pressures and threats that affect the laurel forest	Analysis, description and mapping of pressures and threats on laurisilva in all its distribution	All Macaronesian islands with laurisilva	Regional Administrations, Scientific experts	2027
Monitoring of laurisilva conservation status				
Objective 7: Improve assessment and monitoring of laurisilva conservation status				
Develop and apply standard methods and protocols to evaluate conservation status of laurisilva	Creation of a joint working group to develop the standard methodology	Macaronesian region	Regional Administrations, Scientific experts	2024
	Definition and implementation of a standard methodology for assessment and monitoring of the area, structure and functions, pressures and threats and future perspectives of laurisilva		Regional Administrations, Scientific experts	2026

Dissemination and awareness-raising				
Objective 8: Increase awareness about the importance of laurisilva's conservation and monitoring				
Disseminate the originality of laurisilva and the importance of its conservation	Elaborate and disseminate awareness raising materials on the importance of laurisilva for conservation	All Macaronesian islands	Regional and local Administrations, relevant stakeholders and NGOs	2024
	Disseminate the current status and conservation needs of laurisilva, and the action plan			2024

ABBREVIATIONS

BR: Biogeographical Region

CS: Conservation Status

FCS: Favourable Conservation Status

FRV: Favourable Reference Values

HCI: Habitat type of Community interest

MS: Member States

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APPENDIXES

Appendix 1. 9360 Ecological characterization.

Appendix 2. 9360 inside Natura 2000 Network.

Appendix 3. A protocol for the spatial monitoring of habitat 9360 (Macaronesian laurel forests: Laurus, Ocotea*) using the Normalized Difference Vegetation Index (NDVI) and different remote sensing techniques. Written by Juan José García Alvarado, in collaboration with Esperanza Sánchez Rodríguez and José María Fernández-Palacios.

Appendix 4. Maps of the 9360's potential distribution in Macaronesia (Source: Fernández-Palacios *et al*., 2017).

Appendix 5. Maps of the current 9360 distribution and limits of the Natura 2000 protected areas in Macaronesia.

Appendix 6. Regional Administrations answer to the questionnaire about how 9360 area, structure and function were assessed for the art. 17 report.

Appendix 7. Regional Administrations answers to the questionnaire about how 9360 pressures and threats were assessed for the art. 17 report.

Appendix 1. 9360 Ecological characterization

Relevant characteristics		Elements (mean value and range in brackets when known, including references).	Canaries (9360 subtypes) Dry Laurisilva (*Apollonias-Picconia*) Wet Laurisilva (*Laurus-Ilex*) Cold Laurisilva (*Morella-Erica arborea*) Crests Laurisilva (*Erica platycodon*) Hygrophilous laurisilva (*Ocotea*)	Madeira (9360 subtypes) Barbusano Laurisilva (*Apollonias-Ilex*) Til Laurisilva (*Ocotea-Clethra*)	Azores (9360 subtypes) Lowland laurisilva (*Morella-Picconia*) Submontane laurisilva (*Laurus*)
Abiotic Characteristics					
Physical	Climate	Annual Precipitation (mm)	ca. 800-1000 mm + fog drip (which depending on the site can be unimportant or twice the vertical precipitation amount) (4)	1500 – 3000 mm (17, 18, 19, 20) Laurissilva do Barbusano: 600 – 1400 mm (24, 17, 43, 20) Laurissilva do Til: 1200 - 2500 mm + fog precipitation in this forest, registered in stations at around 1000 m in altitude, is estimated to increase water input by 20% (24, 17, 43, 19, 20).	1618 ± 356 a 2203 ± 306 mm (41)
		Sea of clouds belt: altitudinal range (m) and seasonality incidence	ca. 500-600 to 1200-1500 m on the windward (NE) slopes, being in winter higher, thicker and less frequent and in summer lower, thinner and more frequent (4)	800-1600m on the N slope, > 200 days/y (18, 19) Sea of clouds persists for more than 200 days a year, between 800-1600m on the north coast of the island of Madeira. These are a result of adiabatic cooling of the northeastern trade winds that are intercepted and forced upward by the islands´ east–west oriented and steep relif mountain range. (44, 19, 21)	
		Mean Annual Temperature (°C)	14-16°C (4)	6-20°C (17-20) Laurissilva do Barbusano: Between 15°C and 20°C (24,17, 43, 20) Laurissilva do Til: Between 9-18°C (24; 17, 43, 20).	16.9 ± 0.8 - 14.9 ± 0.4 °C (41)
		Wind incidence	Usually affected by light trade winds, with infrequent Atlantic storms (4)	Predominantly from the NE resulting from an eastern branch of the Azores anticyclone (17, 20) Predominantly trade winds from the northeast, resulting from an eastern branch of the Azores anticyclone. Ocasional SE dry and hot winds, with a strong north african influence and southwestern subtropical stroms, with high rainfall (17, 20)	Prevailing winds from SW, W and NW
	Distribution	Altitude (m)	Restricted to the influence area of the sea of clouds (see above) in the windward slope and only occassionally represented (deep ravines, north facing mountainsides) in the leeward slope. On mid elevation islands (La Gomera) or island regions (Teno, Anaga) occupying the summits (4)	800-1450 m on the S slope and 300-1400 m on the N slope (17, 18, 21) Laurissilva do barbusano: Between 300-800 m on the south coast of Madeira Island and between 50-400 (600) m on the north coast of Madeira Island (24, 17, 43) Laurissilva do til: Between 800-1450 m on the south coast of Madeira Island and between 300-1400 m on the north coast of Madeira Island (24, 17, 21, 43)	Lowland laurel forest: 100 - 300 m; submontane laurel forest: 300 to 600 m (41)
		Slope	Vary variable, but dominating sloping terrain	Mostly > 30° (20) Mostly > 30° (20)	
		Exposure	Windward (NE)	Almost exclusively on the N slope. Small portion on the S slope (18)	

Relevant characteristics		Elements (mean value and range in brackets when known, including references).	Canaries (9360 subtypes) Dry Laurisilva (*Apollonias-Picconia*) Wet Laurisilva (*Laurus-Ilex*) Cold Laurisilva (*Morella-Erica arborea*) Crests Laurisilva (*Erica platycodon*) Hygrophilous laurisilva (*Ocotea*)	Madeira (9360 subtypes) Barbusano Laurisilva (*Apollonias-Ilex*) Til Laurisilva (*Ocotea-Clethra*)	Azores (9360 subtypes) Lowland laurisilva (*Morella-Picconia*) Submontane laurisilva (*Laurus*)
	Soils	Type	Andosols	Mostly umbric andosols and rough terrain. Cambisols to a lesser extent, mainly at lower altitudes (22) Laurissilva do barbusano: Mostly on the north side of the island of Madeira, exposed to the dominant north trade winds. Small dispersed portions on the southwestern slope of the island of Madeira (24, 44) Laurissilva do til: Almost exclusively on the north side of the island of Madeira, exposed to the dominant north trade winds. Small portion on the southern slope of the island of Madeira (24, 44) Laurissilva do vinhático: Almost exclusively on the north side of the island of Madeira (24, 44)	Andosols
		Organic Matter content (%)	[ANAGA, TF] 3.64-6.57 (15)	Umbric andosols: 7-15% (20)	311.9 g/kg (= 31 %) (14)
		Carbon content (%)	[ANAGA, TF] 2.12-3.82 (15)	Depth (0-30 cm) Cambisols: 7.5 kg/m^2 (mean); Andosols: 12.1 kg/m^2 (mean). Depth (0-100 cm) Cambisols: 15.6 kg/m^2 (mean); Andosols: 26.7 kg/m^2 (mean) (23)	34.2 t/ha (14)
		C/N	[ANAGA, TF] 11.15-13.64 (15); 13.76-16.85 (8.10)		
		Depth (m)	1.5 – 3 m (15)	Andosols > 0.5m (20) Andosols deeper than 0.5m (20)	
Chemical	Soils	Soil pH	[ANAGA, TF] 5.4-5.9 (8, 10)	Umbric andosols 4,5-5,5; Cambisols 5,6-7,2 (20)	5.2 (14)
		Soil salinity			
		Main soil anions (μg/g)	N-NO_3- (9.30-12.88); (10)		
		Main soil cations (mEq/100 g)	[ANAGA, TF] Mg (5.71-7.78), Ca (2.76-4.81), K (1.85-2.03), Na (0.59-1.82) (8.10)		
Biogeographical characteristics					

Relevant characteristics		Elements (mean value and range in brackets when known, including references).	Canaries (9360 subtypes) Dry Laurisilva (*Apollonias-Picconia*) Wet Laurisilva (*Laurus-Ilex*) Cold Laurisilva (*Morella-Erica arborea*) Crests Laurisilva (*Erica platycodon*) Hygrophilous laurisilva (*Ocotea*)	Madeira (9360 subtypes) Barbusano Laurisilva (*Apollonias-Ilex*) Til Laurisilva (*Ocotea-Clethra*)	Azores (9360 subtypes) Lowland laurisilva (*Morella-Picconia*) Submontane laurisilva (*Laurus*)
Characteristic species com-position: main species defining the habitat 9360	Flora	Habitat canopy tree species richness	ca. 20 tree species in a few hectares (4)	ca. 20 tree species in a few hectares (4, 18) Total of 20 tree species (24, 44, 4)	7 spp. (*Laurus azorica, Picconia azorica, Morella faya, Ilex azorica, Juniperus brevifolia, Frangula azorica, Erica azorica*) (41)
		Most characteristic canopy tree species	*Ilex, Laurus, Morella, Persea, Picconia*	*Apollonias, Clethra, Ilex, Laurus, Morella, Ocotea, Persea, Picconia* (24) Laurissilva do barbusano: *Apollonias barbujana* subsp. *barbujana, Ilex canariensis, Laurus novocanriensis, Morella faya* Laurissilva do til: *Ocotea foetens, Laurus novocanriensis, Clethra arborea, Heberdenia excelsa, Persea indica, lex perado* subsp. *perado, Morella faya, Picconia excelsa* (24, 44, 4)	*Picconia azorica* and *Morella faya* in lowland laurel forests; *Laurus azorica* in submontane laurel forests (41)
		Main understory spermatophytes species	*Cedronella, Isoplexis, Ixanthus, Pericallis, Phyllis, Ranunculus*	*Vaccinium padifolium, Cedronella canariensis, Phyllis nobla,* Laurissilva de barbusano: *Woodwardia radicans, Asplenium onopteris, Dryopteris aitoniana, Davallia canariensis, Polypodium macaronesicum, Selaginella kraussiana, Selaginella denticulata, Pteris incompleta* (24). Laurissilva de til: *Pteris incompleta, Asplenium onopteris, Stgenogramma pozoi, Diplazium caudatum, Woodwardia radicans, Dryopteris aemula, Dryopteris maderensis, Dryopteris aitoniana, Arachnioides webbianum, Blechnum spicant, Culcita macrocarpa* (24).	*Vaccinium cylindraceum, Myrsine retusa, Lysimachia azorica, Luzula purpurea-splendens* (41)
		Main fern species	*Asplenium, Culcita, Davallia, Diplazium, Dryopteris, Polystichon, Vandenboschia, Woodwardia*	*Arachnioides webbianum Asplenium onopteris, Blechnum spicant, Culcita macrocarpa, Diplazium caudatum, Dryopteris aitoniana, D. maderensis, Pteris incompleta, Woodwardia radicans* (24)	*Dryopteris azorica, Culcita macrocarpa, Blechnum spicant, Dryopteris aemula* (41)
		Main bryophyte species	*Cryptoleptodon, Exerthotheca, Homalothecium*	*Plagiochila maderensis, Cryptolentodon longisetus, Homalothecium mando-nii, Exerthotheca intermedia*	*Alophosia azorica; Andoa berthelotiana; Breutelia azorica; Echinodium renauldii; Hypnum curpressiforme; Myurium hochstetteri; Thuidium tamariscinum; Metzgeria furcata; Drepanolejeunea hamtifolia; Lejeunea lamarecina; Lepidozia cupressina*

Relevant characteristics		Elements (mean value and range in brackets when known, including references).	Canaries (9360 subtypes) Dry Laurisilva (*Apollonias-Picconia*) Wet Laurisilva (*Laurus-Ilex*) Cold Laurisilva (*Morella-Erica arborea*) Crests Laurisilva (*Erica platycodon*) Hygrophilous laurisilva (*Ocotea*)	Madeira (9360 subtypes) Barbusano Laurisilva (*Apollonias-Ilex*) Til Laurisilva (*Ocotea-Clethra*)	Azores (9360 subtypes) Lowland laurisilva (*Morella-Picconia*) Submontane laurisilva (*Laurus*)
		Main lichen species	*Cladonia, Hypogymnia, Lobularia, Nephroma, Pseudocyphellaria, Sticta, Usnea*	*Nephroma, Usnea, Lobaria, Sticta, Pseudocyphellaria, Hypogymnia, Degelia, Leptogium, Cladonia, Peltigera, Teloschistes, Lethariella, Ramalina*	*Usnea flamea, Degelia atlantica, Sticta canariensis, Cladonia spp., Bacidia rosella*
		Main fungi species	*Armillaria, Ganoderma, Gymnopilus, Laurobasidium, Hypholloma, Scutelinia, Phellinus, Stereum, Trametes, Tremella, Botryobasium, Hyphoderma, Hyphodontia, Peniophora, Phlebia, Sistotrema,*	*Flammula angulatispora; Marasmus amaryllidis, Phalus maderensis, Botryobasium, Hyphoderma, Hyphodontia, Peniophora, Phlebia, Sistotrema,*	*Calycellina lauri, Clitocybula wildpretii, Coccomyces ericae, Hygrophorus cavipies, Lagarobasicius calongei, Lambertella myricae, Moellerodiscus hederae, Repetopbasidium azoricum, Skeletocutis azorica, Botryobasium, Hyphoderma, Hyphodontia, Peniophora, Phlebia, Sistotrema*
		% vascular plants endemicity in the habitat	High to very high (mainly Macaronesian) endemicity (< 80%) (4)	High to very high (mainly Macaronesian) endemicity (> 80%) (4)	50-60% (41)
		% non-vascular plant endemicity in the habitat	Low to very low (< 10%) (4)	< 5%; occurring 7 Madeiran endemic bryophyte species: *Acrobolbus maderensis, Echinodium setigerum Fissidens nobreganus, Hedenisiastrum percurrens, Nobregae laetinervis, Porella inaequalis, Thamnobryum fernandesii*	
	Fauna	Habitat bird species richness	10-15	10-15	11-12
		Habitat main bird species	*Columba bollii, C. junionae, Fringilla canariensis, Erythacus, Turdus merula, Regulus*	*Buteo buteo buteo, Columba trocaz, Regulus ignicapillus madeirensis, Erithacus rubecula rubecula, Falco tinnunculus canariensis, Fringilla coelebs maderensis, Turdus merula cabrerae,* (4, 25).	*Regulus regulus spp.; Sylvia atricapilla gularis; Motacilla cinerea patriciae; Buteo buteo rothschildi; Columba palumbus azorica; Erithacus rubecula; Fringilla coelebs moreletti; Turdus merula azorensis*
		Habitat bat species richness	3-5	3-5 (26, 27)	1

Relevant characteristics	Elements (mean value and range in brackets when known, including references).	Canaries (9360 subtypes) Dry Laurisilva (*Apollonias-Picconia*) Wet Laurisilva (*Laurus-Ilex*) Cold Laurisilva (*Morella-Erica arborea*) Crests Laurisilva (*Erica platycodon*) Hygrophilous laurisilva (*Ocotea*)	Madeira (9360 subtypes) Barbusano Laurisilva (*Apollonias-Ilex*) Til Laurisilva (*Ocotea-Clethra*)	Azores (9360 subtypes) Lowland laurisilva (*Morella-Picconia*) Submontane laurisilva (*Laurus*)
	Main bat species	*Plecotus teneriffae, Pipistrellus maderenssis, Tadarida teniotis (4)*	*Pipistrellus maderensis, Nyctalus leisleri verrucosus, Plecotus austriacus* (4, 26, 28) Laurissilva de barbusano: *Pipistrellus maderensis, Nyctalus leisleri verrucosus, Plecotus austriacus* (28, 4, 26) Laurissilva de til: *Pipistrellus maderensis, Nyctalus leisleri verrucosus, Plecotus austriacus* (28, 4, 26). Laurissilva do til: *Pipistrellus maderensis, Nyctalus leisleri verrucosus, Plecotus austriacus* (28, 4, 26).	*Nyctalus azoreum*
	Main arthropod species	*Laparocerus, Carabus, Calathus, Dysdera, Tarphius*	750 - 1000 endemic species are referenced (28 and expert opinion).	*Trigoniophthalmus borgesi; Calacalles subcarinatus; Calathus* spp., *Drouetius borgesi; Notothecta dryochares; Tarphius* spp.; *Cixius* spp.; *Pinalitus oromii; Argyresthia atlanticella; Pseudophloeophagus tenax borgesi*
	Main mollusc species	*Insulivitrina, Hemicycla, Napaeus, Canariaella*	54 especies endémicas referenciadas (30, 31, 32), con especial atención a *Leiostyla* (22 especies) y *Plutonia* (4 especies).	*Craspedopoma hespericum; Lauria fasciolata; Leiostyla fuscidula; Acanthinula azorica; Spermodea monas; Napaeus delibutus; Punctum azoricum; Plutonia atlantica*
	% endemicity vertebrate fauna	Middle (*Columba, Fringilla, Erythacus, Plecotus, Pipistrellum*) (aprox. 50%)		60 %
	% endemicity invertebrate fauna	Very high (insects, spiders, molluscs, etc.) (> 80%)		50 %
Ecological (structure and function) characteristics				

Relevant characteristics	Elements (mean value and range in brackets when known, including references).	Canaries (9360 subtypes) Dry Laurisilva (*Apollonias-Picconia*) Wet Laurisilva (*Laurus-Ilex*) Cold Laurisilva (*Morella-Erica arborea*) Crests Laurisilva (*Erica platycodon*) Hygrophilous laurisilva (*Ocotea*)	Madeira (9360 subtypes) Barbusano Laurisilva (*Apollonias-Ilex*) Til Laurisilva (*Ocotea-Clethra*)	Azores (9360 subtypes) Lowland laurisilva (*Morella-Picconia*) Submontane laurisilva (*Laurus*)
Habitat structure	Height of the canopy range and mean (m)	ca. 10-40 m range and 20 m mean value in flat places. Much lower in sloping terrains (4). Higher canopy values only obtained in mature laurel forest stands, such as Garajonay NP.	Between 20-40 m (*Ocotea, Persea and Laurus* as the tallest tree species) (4, 21)	5 - 15 m (mean 7.70 m) (41)
	Number of vegetation strata	2-3 depending on locality and its preservation status	4; Tree strata, Shrub strata, Herb strata and forest floor	4 vertical layers + climbers + epiphytic (41)
	Basal areal (m^2/ha)	[LG] 64.0 m^2/ha (4) (mature forest) [ANAGA, TF] 39.0-58.0 m^2/ha (4,8)	Data available in BA classes (13): < 5 m^2/ha: 3205 ha 5-10 m^2/ha: 4407 ha 10-15 m^2/ha: 1602 ha 15-20 m^2/ha: 2003 ha 20-25 m^2/ha: 401 ha 25-30 m^2/ha: 1602 ha >30 m^2/ha: 2003 ha	[TER] 14.0-47.0 m^2/ha (15) (trophic data mainly referred to submontane laurel forest) 37.1 m^2/ha (considering all stems > 2,5 cm DBH) (14)
	Mean DBH (cm)	[LG] 31.3 cm (4) (mature forest) [ANAGA, TF] 22.2-25.5 cm (4)		[TER] 13.74-18.81 cm (15) 7.7 cm (min 2.5 cm; max 36.9 cm) (considering all stems > 2.5 cm DBH) (14)
	Stems density (no. of stems/ha)	[LG] 832.50 stems/ha (4) (mature forest) [ANAGA, TF] 1100-1400 stems/ha (4) [LP]?	Community: 740 ind. /ha (13) *Laurus:* 140 ind./ha; *Ocotea:* 90 ind./ha; *Morella:* 74 ind./ha; *Clethra:* 50 ind./ha; *Persea:* 18 ind./ha. (33) Area sensu density (13) < 300 ind./ha: 3605 ha 300 to 600 ind./ha: 3205 ha 600 to 900 ind./ha: 2804 ha 900 to 1200 ind./ha: 2804 ha >1200 ind./ha: 2804 ha 3100-3770 stems/ha (14)	[TER] 720-1800 stems/ha (15) 1373 stems/ha (considering stems > 10 cm) (source?)
	Tree density (or % of the trees) per DBH class	Mid (*Columba, Fringilla, Erythacus, Plecotus, Pipistrellum*) (aprox. 50%)		60 %

Relevant characteristics	**Elements (mean value and range in brackets when known, including references).**	**Canaries (9360 subtypes) Dry Laurisilva (*Apollonias-Picconia*) Wet Laurisilva (*Laurus-Ilex*) Cold Laurisilva (*Morella-Erica arborea*) Crests Laurisilva (*Erica platycodon*) Hygrophilous laurisilva (*Ocotea*)**	**Madeira (9360 subtypes) Barbusano Laurisilva (*Apollonias-Ilex*) Til Laurisilva (*Ocotea-Clethra*)**	**Azores (9360 subtypes) Lowland laurisilva (*Morella-Picconia*) Submontane laurisilva (*Laurus*)**
	Dominance/codominance (no. of individuals per tree species and/or per basal area)	[LG] *Morella, Laurus, Persea, Ilex* (1) [LP] *Persea, Laurus, Morella* (1) [TF] *Laurus, Morella, others* (1)	*Laurus, Clethra, Morella, Erica, Ocotea* (4) In % de frecuencia (13) *Laurus*: 84 %; *Clethra*: 71 %; *Morella*: 61%; *Erica arborea*: 47%; *Ocotea*: 18%; *Persea*: 5%; *Juniperus cedrus*: 5%; *Picconia*: 3 %	[TER] *Erica, Laurus, Juniperus, Ilex, Frangula, Picconia* (15) *Laurus azorica* (18.9 m^2/ha)
	Above ground biomass (t/ha)	[LG] 300-450 t/ha (1) [LP y TF] 180-300 t/ha (1) Obs: in LG mature forest plots: 450-500 t/ha (1)	103 t/ha (13)	162.4 t/ha (14)
	Below ground biomass (t/ha)	[LG] 170-240 t/ha (1) [LP,TF] 100-150 t/ha (1) Obs: in LG mature forest plots: 230-250 t/h (1)	25 t/ha (13)	71.4 t/ha (14)
	Total biomass (t/ha)	[LG] 500-700 t/ha (1) [LP,TF] 200-450 t/ha (1) Obs: in LG mature forest plots: 700-750 t/ha (1)	128 t/ha (13)	233.8 t/ha (14)
	Deadwood (t/ha)	[LG] 3-60 t/ha (2,6) [LP] 3-30 t/ha (2,6) [TF] 5-20 t/ha (2,6)	310 m^3/ha deadwood, 3% of dead trees (13); 11.3 t/ha (13)	?
	Litter (t/ha)	[ANAGA,TF] 7,2-14,7 t/ha (3)	7.3 t/ha (13)	1.34 t/ha (14)
	Total necromass (t/ha)	[LG] 10-75 t/ha [LP] 10-40 t/ha [TF] 12-35 t/ha	18.6 t/ha (13)	?
	Total biomass + necromass (t/ha)	[LG] 510-775 t/ha [LP,TF] 210-500 t/ha	136.6 t/ha (13)	233.8 t/ha (14)
	C content in the biomass + necromass (t/ha)	[LG] 250-380 t/ha (1) [PL y TF] 100-250 t/ha (1) Obs: in LG mature forest plots: 350-370 t/ha (1)	68.3 t/ha (13)	133.6 t/ha (14)
	C content in soil Carbon (t/ha)	[LG] 223-430 t/ha (5)	18.4 kg/m^2 (= 184 t/ha) (23)	25.8-76.1 t/ha (14)

Relevant characteristics		Elements (mean value and range in brackets when known, including references).	Canaries (9360 subtypes) Dry Laurisilva (*Apollonias-Picconia*) Wet Laurisilva (*Laurus-Ilex*) Cold Laurisilva (*Morella-Erica arborea*) Crests Laurisilva (*Erica platycodon*) Hygrophilous laurisilva (*Ocotea*)	Madeira (9360 subtypes) Barbusano Laurisilva (*Apollonias-Ilex*) Til Laurisilva (*Ocotea-Clethra*)	Azores (9360 subtypes) Lowland laurisilva (*Morella-Picconia*) Submontane laurisilva (*Laurus*)
		Total C (t/ha)	[LG] 480-800 t/ha (1.5)	Data in t/ha not available; Only in 1000 t (= Gg) for the whole Madeiran laurisilva area (15 354 ha) (13) Aboveground biomass: 783 Gg (51 t/ha) Total tree biomass: 974 Gg (63.4 t/ha) Aboveground in shrubs: 128 Gg (8 t/ha) Litter: 56 Gg (3.6 t/ha) Deadwood: 9 Gg (0.6 t/ha)	160-225 t/ha (14)
		NPP (t/ha · year)	[ANAGA, TF] 8.6 t/ha año (7)	600-650 g C/ m^2 year) (17) = 12-13 t/ha year	
		Decomposition rate (k)			
		Leaf index AREA (LAI)	[ANAGA, TF] 4.80-5.49 (8)		
		Abundance of epiphytes (t/ha)	Ephyphitic bryophytes: 5 t/ha (12)		
		Abundance of bryophytes		High abundance of lichens and mosses in 92% of Madeira's area (13)	High abundance of bryophytes especially in the submontane laurel forest (Gabriel, pers. com.)
		Abundance of invertebrates	High percentage of endemicity in the following taxa: Coleoptera, Isopoda, Millipeda, Arachnida and Molluscs, among others (4)		
Habitat function	Habitat matureness	Age of mature stands	> 500 years (11)		
		% mature stands	[Canaries] 3.5% (3000 ha) (11)		
		Stands mean age	9360 forests with low conservation value occupy 21300 ha, with medium 6500 ha, and with high, only 3000 ha, of 87000 potential ha in the Canaries (11)		
	Reproductive strategies	Main sexual expressions present with examples	Extended real (*Ilex, Laurus, Morella*) or functional (*Apollonias, Persea, Ocotea*) dioecy (4), with unbalanced towards male sex ratios (16)	Idem	Dioecy (*Laurus, Morella, Ilex, Juniperus*); Androdioecy (*Picconia*); Hermaphroditism (*Frangula, Erica*) (4)

Relevant characteristics		Elements (mean value and range in brackets when known, including references).	Canaries (9360 subtypes) Dry Laurisilva (*Apollonias-Picconia*) Wet Laurisilva (*Laurus-Ilex*) Cold Laurisilva (*Morella-Erica arborea*) Crests Laurisilva (*Erica platycodon*) Hygrophilous laurisilva (*Ocotea*)	Madeira (9360 subtypes) Barbusano Laurisilva (*Apollonias-Ilex*) Til Laurisilva (*Ocotea-Clethra*)	Azores (9360 subtypes) Lowland laurisilva (*Morella-Picconia*) Submontane laurisilva (*Laurus*)
		Main reproduction mechanisms (seed-, seedling- or sucker-banks) with examples	Existence of seedling (instead of seed) banks (with few exceptions, such as Erica). Prevalence of asexual reproduction via resprouting (sucker banks) *(Lauraceae, Aquifoliaceae, Prunus, Morella*) (4)	Seedling banks for most Lauraceae (*Laurus, Ocotea, Persea, Apollonias*) and other dominant tree species (*Clethra, Ilex, Picconia*) in the forest; Resprouting (sucker banks) for some Lauraceae species (*Laurus, Ocotea, Persea*) as well as *Clethra, Pittosporum, Morella and Salix;* Seed banks for other tree, shrub and herbaceous species in the forest (4)	Seedling bank and resprouting (*Laurus*); Seed bank and resprouting (*Morella*); Seedlings grow under the canopy (*Picconia, Ilex and Frangula*); seed bank (*Juniperus and Erica*) (source?)
		Seedlings per ha	[ANAGA, TF] 12300-16400 seedlings/ha (9)		844 seedlings/ha (*Laurus, Ilex*); 2089 saplings/ha (*Laurus*), 1911 saplings/ha (*Ilex*); 533 seedlings/ha and 1377 saplings/ha (*Frangula*) (42)
		Seedlings survival rate (%)	[ANAGA, TF] 5.68- 12.28 % (9)		
		Seedlings survival rate (%)	Generalized entomogamy (*Halictinae and Lasioglosum chalcodes bees; Pieris cheiranthi, Gonepteryx cleobule butterflies, Heringia adpropinquans and Tachina* spp. flies) (16, 37)		Insects (*Laurus, Picconia, Ilex, Frangula*); Wind (*Morella, Juniperus*); Wind and insects (*Erica*) (4)
		Dispersal types (%)	Generalized ornithochory (*Columba, Erithacus, Turdus*)	Generalized ornithochory (mostly *Columba trocaz, Fringilla coelebs madeirensis, Turdus merula cabrerae, Regulus ignicarpillus mmadeirensis; Erithacus rubecula rubecula*). Most of the dominant plant species of the Laurisilva produce fleshy fruits. Fruit size determines the bird agent (4, 34, 35, 36).	Generalized ornithochory (*Fringilla, Turdus*), except for *Erica* (wind) (4)
	Relations with other HCI	Spatial relation (ecotones)	HCI 9360 form ecotones in mountain crests with HCI 4050 (4)	Relation to HCI Endemic Macaronesian heaths (4050), to Siliceous rocky slopes with chasmophytic vegetations (8220) and Siliceous rock with pioneer vegetation of the Sedo-Scleranthion or of the Sedo albi-Veronicion dillenii (8230)	
		Dynamic relations (succession)	The HCI 4050 is the secondary, substitution formation after disturbance on HCI 9360 (4)		

NOTE: unfilled boxes are due to lack of knowledge.

REFERENCES IN APPENDIX I

1. Otto, R. *et al*. (2021) Memoria parcial del año 2021 del proyecto de investigación "*Cuantificación de la potencialidad de los ecosistemas terrestres canarios para la captura de carbono*". Universidad de La Laguna, inédito.

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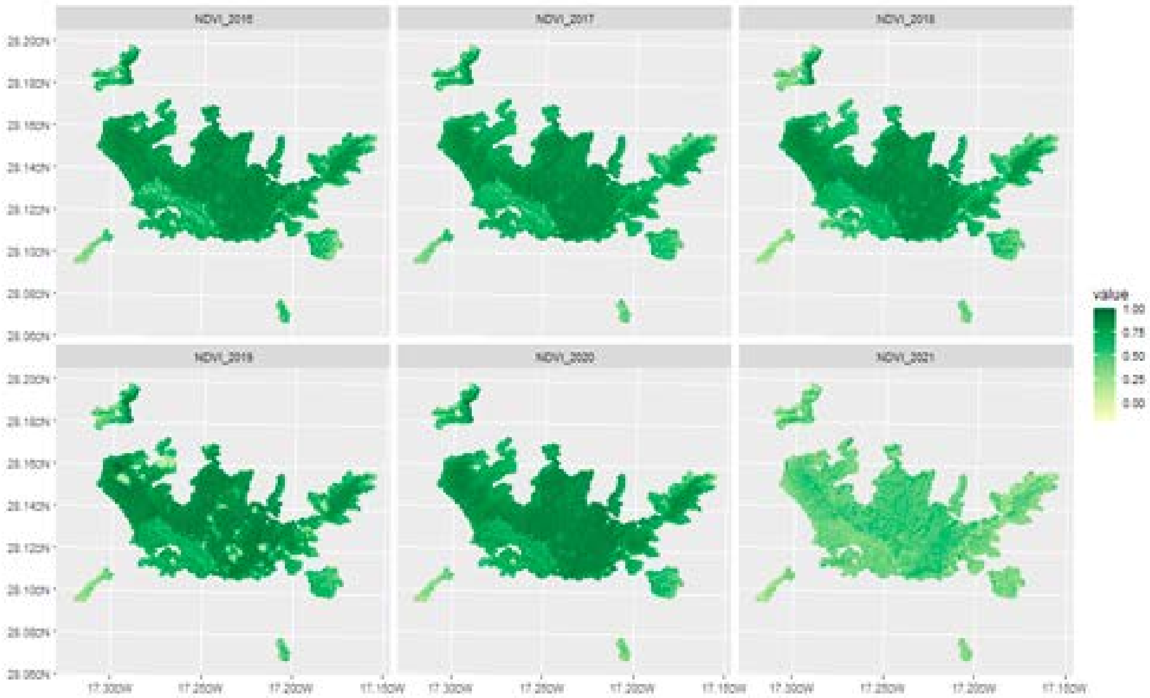
Appendix 2. 9360 Inside Natura 2000 Network

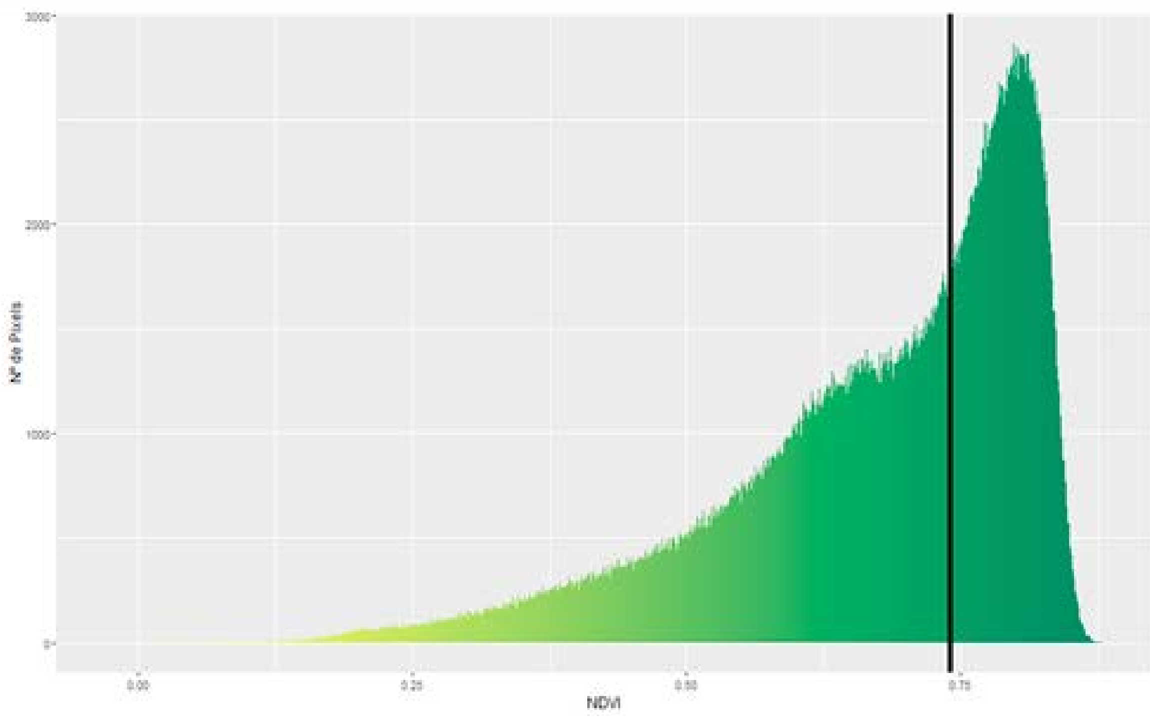
Site code	Site Name	Island	Space area (ha)	9360 area (ha)	% 9360
ES0000044	Garajonay	La Gomera	3 785.4	2 991.83	79
ES7010002	Barranco Oscuro	Gran Canaria	33.4	12.38	37
ES7010004	Azuaje	Gran Canaria	456.3	6.16	1
ES7010005	Los Tilos de Moya	Gran Canaria	89	62.04	70
ES7010033	Jandía	Fuerteventura	14 972.5	4.5	0.03
ES7010038	Barranco de La Virgen	Gran Canaria	559.4	39.48	7
ES7020001	Mencáfete	El Hierro	454.6	36.91	8
ES7020009	Guelguén	La Palma	1 062.4	67.49	6
ES7020010	Las Nieves	La Palma	5 114.6	1 520.94	30
ES7020011	Cumbre Vieja	La Palma	7 522.1	2.63	0.03
ES7020020	Tablado	La Palma	223.6	33.55	15
ES7020024	Juan Mayor	La Palma	28.3	10.02	35
ES7020025	Barranco del Agua	La Palma	74.2	11.38	15
ES7020028	Benchijigua	La Gomera	483.2	6.23	1
ES7020030	Majona	La Gomera	1 975.7	313.34	16
ES7020033	Roque Blanco	La Gomera	29.8	8.42	28
ES7020037	Lomo del Carretón	La Gomera	248.5	1.33	0.5
ES7020044	Ijuana	Tenerife	901.8	1.52	0.1
ES7020045	Pijaral	Tenerife	295.7	90.96	31
ES7020047	Pinoleris	Tenerife	178.4	3.97	2
ES7020052	Chinyero	Tenerife	2 380	1.57	0.01
ES7020053	Las Palomas	Tenerife	582.7	68.45	12
ES7020054	Corona Forestal	Tenerife	41 067.7	517.47	1
ES7020069	Las Lagunetas	Tenerife	3 568.3	36.46	1
ES7020072	Montaña de la Breña	La Palma	26.1	19.95	76
ES7020073	Los Acantilados de la Culata	Tenerife	440.9	40.87	9
ES7020074	Los Campeches, Tigaiga y Ruiz	Tenerife	543.5	3.98	1
ES7020075	La Resbala	Tenerife	590.6	50.98	9
ES7020081	Interián	Tenerife	100.2	0.13	0.1
ES7020082	Barranco de Ruiz	Tenerife	95.3	2.5	3
ES7020084	Barlovento, Garafía, El Paso y Tijarafe	La Palma	5 561.7	327.33	6
ES7020085	El Paso y Santa Cruz de La Palma	La Palma	1 390.5	85.96	6
ES7020089	Sabinar de La Galga	La Palma	81	39.72	49
ES7020091	Monteverde de Gallegos-Franceses	La Palma	1 408.6	179.11	13
ES7020092	Monteverde de Lomo Grande	La Palma	494.9	269.5	54
ES7020093	Monteverde de Barranco Seco-Barranco del Agua	La Palma	1 939.1	653.6	34
ES7020094	Monteverde de Breña Alta	La Palma	823.2	16.73	2

Site code	Site Name	Island	Space area (ha)	9360 area (ha)	% 9360
ES7020095	Anaga	Tenerife	10 340.6	578.47	6
ES7020096	Teno	Tenerife	6 119.7	448.31	7
ES7020097	Teselinde-Cabecera de Vallehermoso	La Gomera	2 340.9	111.84	5
ES7020099	Frontera	El Hierro	8 807.4	751.76	9
ES7020101	Laderas de Enchereda	La Gomera	682.6	73.18	11
ES7020109	Barrancos del Cedro y Liria	La Gomera	584.18	90.07	15
PTFAI0004	Caldeira e Capelinhos	Faial	2 086.21	11.0	1
PTFAI0006	Ponta do Varadouro	Faial	17.61	8	45
PTFLO0002	Zona Central - Morro Alto	Flores	2 938.89	40.16	1
PTJOR0014	Costa NE e Ponta do Topo	São Jorge	3 965.08	8.84	0.2
PTMAD0001	Laurissilva da Madeira	Madeira	15 462	15462	100
PTMIG0024	Serra da Tronqueira / Planalto dos Graminhais	São MIguel	2 010.63	265.04	13
PTPIC0009	Montanha do Pico, Prainha e Caveiro	Pico	8 462.65	487.82	6
PTTER0017	Serra Santa Bárbara e Pico Alto	Terceira	4 730.93	498.63	11

Appendix 3. A protocol for the spatial monitoring of habitat 9360 (Macaronesian laurel forests: Laurus, Ocotea*) using the Normalized Difference Vegetation Index (NDVI) and different remote sensing techniques.

Written by Juan José García Alvarado, in collaboration with Esperanza Sánchez Rodríguez and José María Fernández-Palacios





CONTENTS

1. INTRODUCTION AND JUSTIFICATION

1.1 Brief introduction to environmental remote sensing

Remote sensing is the technical discipline of acquiring images of the Earth's surface from airborne or space-based sensors (Chuvieco, 2008). This definition encompasses the full range of processes involved in obtaining a satellite image, including the pre-treatment of the information, its manipulation, processing, and the creation of workflows, up to its post-processing. This latter stage is concerned with the interpretation and meaning assigned to the satellite and spectral information obtained. This is a technique known as remote sensing of the Earth's surface. This discipline has been extensively employed in the environmental and ecological field, primarily for the monitoring of natural phenomena across extensive study areas, the analysis of pre- and post-fire evolution and comparison, as well as vegetation monitoring, among other applications. The vast array of satellite information providers, both free and private, has also contributed to the application of these methods, as well as to the exponential growth in scientific and technical publications that use satellite data. The free providers include Landsat (Landsat 8 and 9 being the most recent) and its various missions (operational since the 1980s) and Sentinel, whose satellite constellations covers the Earth's surface and has been providing spectral products since 2016. In addition, the definition of remote sensing posits an energetic interaction between the land cover and its various forms of modelling and cover, as well as the sensor responsible for acquiring and storing the information in an appropriate manner.

In studies involving the use of remote sensing, it is of particular importance to consider both spatial and temporal resolution, as well as the availability of spectral products. In some cases, the latter can become a limitation. This is particularly the case when analyses are applied to very specific ecosystems or geographic regions, and when the scale of the work is required to be as detailed as possible. Similarly, it is logical to conclude that the monitoring of natural phenomena that imply spatio-temporal changes (phenological cycles, productivity blooms, forest fires, etc.) not only requires the satellite information provider to provide a comprehensive spatial coverage, but also necessitates a significant temporal amplitude to allow robust conclusions to be drawn, especially if they are to be applied directly in management of species, ecosystems or territorial administration. In this area, it is also imperative to validate the results with information obtained directly from the ground (referred to as ground truth data), parallel mapping resources, or other calibration sources of the results obtained, such as systematic sampling or information at expert level.

Because of this, the Canary Islands, and indeed any other island environment, present a significant challenge for this type of study. This is since satellite observation must be capable of coping with an atmosphere that is frequently affected by episodes of suspended dust, in addition to the frequent cloud accumulation on the northern and north-eastern sides of the central and western islands.

1.2 Objective and target habitat

This report's objective is to develop and apply a replicable, reproducible and scalable methodology for the spatial monitoring of habitat 9360 (Macaronesian laurel forests). The objective is to quantify the possible spatial extent or contraction of this ecosystem. This will be achieved by using the normalised vegetation index (hereafter NDVI), its difference between dates/images (hereafter dNDVI), as well as a set of other spatial and remote sensing techniques that inherently employ a spectral background. The objective is to:

- Establish the methodological foundations for the remote sensing-based spatial monitoring of habitat 9360.

- Quantify and delimit its current fragments.

- Study and evaluate the spatial change of the same over a specific period of years.

Furthermore, several examples of direct application in island environments will be presented, all of which use freely available software and products, thereby enhancing the value of the methodology presented. The course introduces the fundamental definitions and concepts of remote vegetation monitoring, with the objective of facilitating familiarity with the technology.

The study's subject is the Macaronesian Laurisilva, which is classified under the code 9360 within the habitats of Community interest (further details can be found in [1] and [2]). This is classified in the Natura 2000 habitats as Mediterranean sclerophyllous forests, in accordance with the European Community hierarchy. The term in question refers to "evergreen, subtropical, humid forests, dominated by laurel-leaved trees (coriaceous and lustrous), typical of the Canary Islands". However, habitat 4050 [3], which refers to the endemic Macaronesian heathlands, which include the Canarian fayal-brezal communities, is not included in the analysis. These communities have been identified by several authors as degradation series of the Macaronesian laurel forest itself (del Arco & Rodríguez 2018) and other heather or yew formations present on the islands.

1.3 Tools to be used

This section will provide an overview of the set of essential geoinformatics tools, as well as other complementary tools, which are necessary for the implementation of the spectral and spatial operations described in this report. Table 1 presents an overview of these tools, along with their typology and function. Furthermore, alternative solutions can be implemented to facilitate operations in environments other than a desktop Geographic Information System (hereafter GIS).

Tool	Type	Use
QGIS (Version 3.26.1-Buenos Aires)	Software SIG	Layers and Geoprocessing Handling
SCP Plugin (Semi-Automatic Classification Plugin)	QGIS Plugin	Band management, pre-processing operations, satellite image classification, post-classification treatments. Generation of spectral signatures
GRASS	QGIS Complement	High-performance geographic operations
Orfeo Tool Box (*)	QGIS Plugin	Banding and post-processing operations of remotely sensed data
Raster Calculator	QGIS Complement	Inter-band operations, index generation.
Dzetsaka (*)	QGIS Plugin	Supervised classifications using machine learning techniques.
	Alternatives in R	
R	Programming Language	
raster/terrace	R Library	Manipulation and management of Raster geographic objects
sf	R Library	Manipulation and management of vector geographic objects
RSToolbox	R Library	Operations on bands pre-processing, post-processing of remotely sensed information
caret	R Library	Supervised rankings with a multitude of algorithms and tuning options
sen2r	R Library	Downloading, corrections and working with Sentinel-2 bands
ggplot2	R Library	Generation of scientific graphs

Table 1. Software used in this report and alternative options. (*) Tools not used in the methodology, nevertheless complementary in the QGIS environment.

1.4 Cartographic bases

The cartographic base used as a reference for the report's write up was the European Land Use and Land Cover (LULC) mapping (2018) [4][5], which is common to all European countries and the French Overseas Territories. The methodology employed is based on the interpretation of both Landsat and Sentinel satellite images, with the objective of collecting and cataloguing all land cover types and their respective characteristics. This information is available for download in vector format (geopackage) at a resolution of 100 m, with a minimum mapping unit of 25 hectares (García-Álvarez *et al.*, 2022). It can be read in QGIS [6] without difficulty. The reference patches corresponding to the desired habitat can be further filtered by the code 311 (broad-leaved forest) (Figure 1). In certain instances, these may be represented by patches at a relatively coarse scale. However, they serve to provide a **common and homogeneous** reference mapping, which is freely accessible to any user of a habitat that is highly correlated with 9360.

As an alternative, should more detailed mapping be available, this may prove an efficacious method to validate the methodology. To achieve this objective, the cartography present in the *Mapa de Vegetación de Canarias* (del Arco *et al.*, 2006) is employed to identify and quantify the current laurel forest remnants on the various islands with greater precision, as well as other secondary formations associated with them. **This dataset is for the exclusive use of the Canary Islands.**

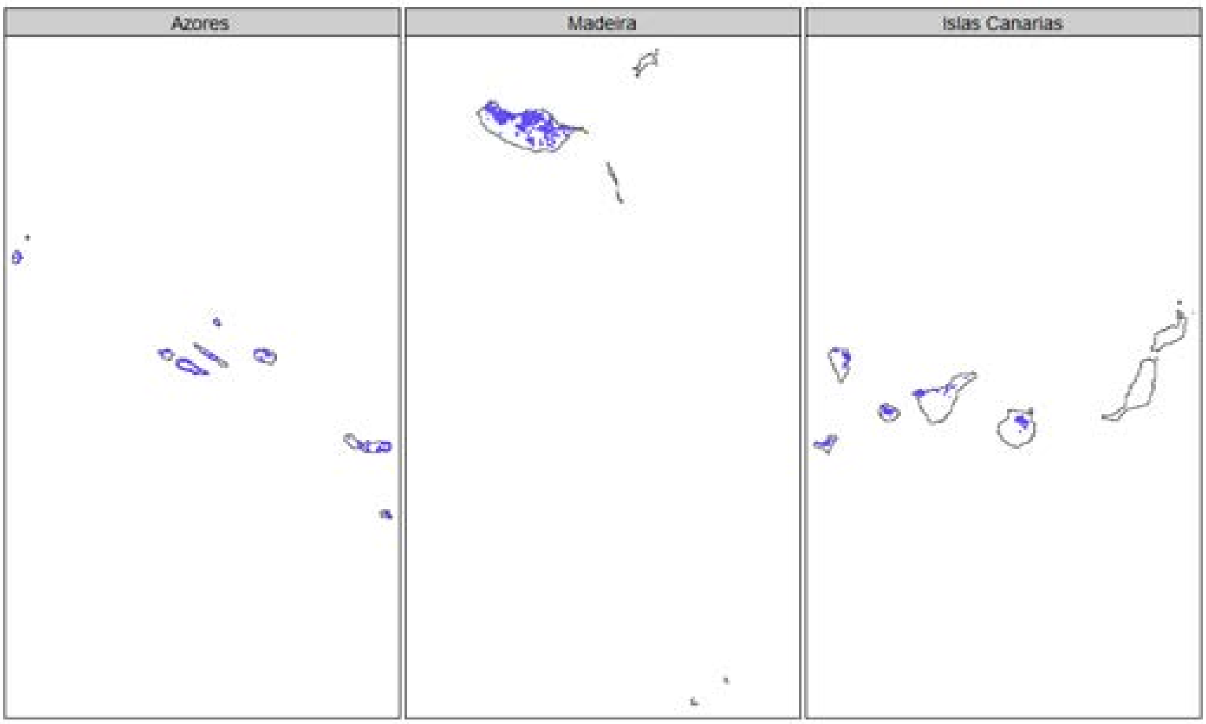


Figure 1. The following illustration depicts the distribution of patches corresponding to use code 311 (broad-leaved forest) for the Macaronesian archipelagos, arranged latitudinally.

In this instance, the cartographic base has been employed to substantiate the delineation of vegetation patches and to construct the ultimate working mask. This process enables the exclusion of land uses that may potentially compromise the analytical outcomes, including agricultural zones, pastures, and other tree formations that do not align with the habitat under investigation.

The cartographic criteria employed were the WGS 84 coordinate reference system with the UTM 28N projection (EPSG: 32628), with all areas quantified in hectares and in a real number format.

2. THE COPERNICUS DATA ECOSYSTEM. SENTINEL-2 AND THE GENERATION OF VEGETATION INDICES

2.1 Copernicus and Sentinel-2

The Copernicus is a European Union initiative whose core mission is the observation of the Earth and the dissemination of the information obtained to any user through an open data ecosystem. In the context of environmental remote sensing, it is necessary to consider Sentinel-2 as a satellite constellation that is responsible for the capture, storage and processing of spectral information. The current satellite configuration comprises the twin satellites Sentinel-2A and Sentinel-2B, which are equipped with sensors that orbit at a 180° offset from each other. This configuration allows the satellites to sweep the globe from opposite ends, thereby providing greater spatial coverage. It is beneficial to provide a concise overview of the key concepts related to a sensor's resolution:

- Spectral Resolution: number of bands of the sensor considering the full spectrum. In the case of Sentinel-2, there would be twelve, which are summarised in Figure 2.

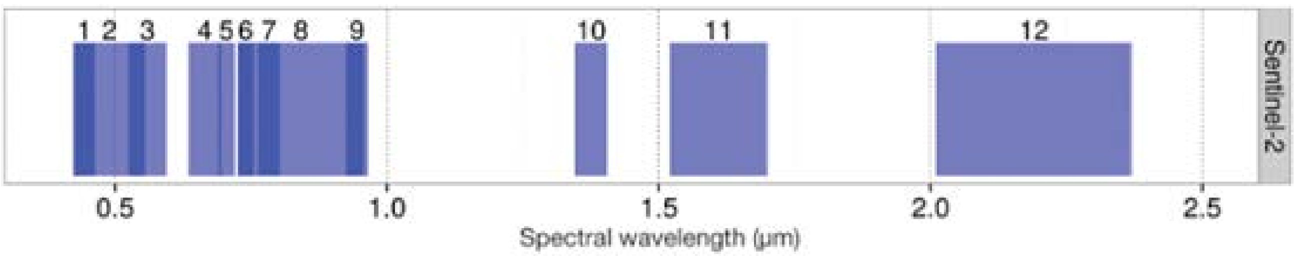


Figure 2. Each band's wavelengths and the widths of the wavelengths across the entire spectrum are presented. Sourced from Leutner *et al*., (2016).

- Spatial Resolution: pixel size or spatial granularity of the bands [7].

- Temporary Resolution: Time interval between the image captures by the satellite sensor. In a similar manner, the satellite revisit time over the same point or the maximum theoretical time rate of product availability may be considered.

The Copernicus satellite products are available for purchase directly and free of charge within the data ecosystem. This ecosystem features a searchable user interface [8] that facilitates the purchase procedure and allows for immediate access to the bands. Upon completion of the registration process, users are presented with the option of downloading images that align with their specified region of interest (ROI), as identified through the application of pre-defined search criteria. Additionally, users are able to digitise their ROI by using a polygon selector. Furthermore, the level of correction may be selected, either level 1 (acronym L1C), which pertains to products for which no revision or correction has been carried out and with a reflectance level above the atmosphere (TOA), or level 2 (acronym L2A), ortho-rectified products with reflectance levels below the atmosphere (BOA), with an in-built atmospheric correction that brings the reflectance data closer to reality.

In addition to the factors, the search encompasses the percentage of cloud cover and the temporal range, which extends from 2015 to the present (Figure 3).

In the case of the Sentinel-2 satellites, the spectral resolution is sufficient to accommodate a total of 12 bands: 4 bands at 10 metres, 6 bands at 20 metres and 2 bands at 60 metres spatial resolution. The revisit time is five days, commencing from the launch of the Sentinel-2B satellite in 2017. However, between the years 2015 and 2017, the temporal resolution was ten days, with all satellite information exclusively derived from the 2A satellite.

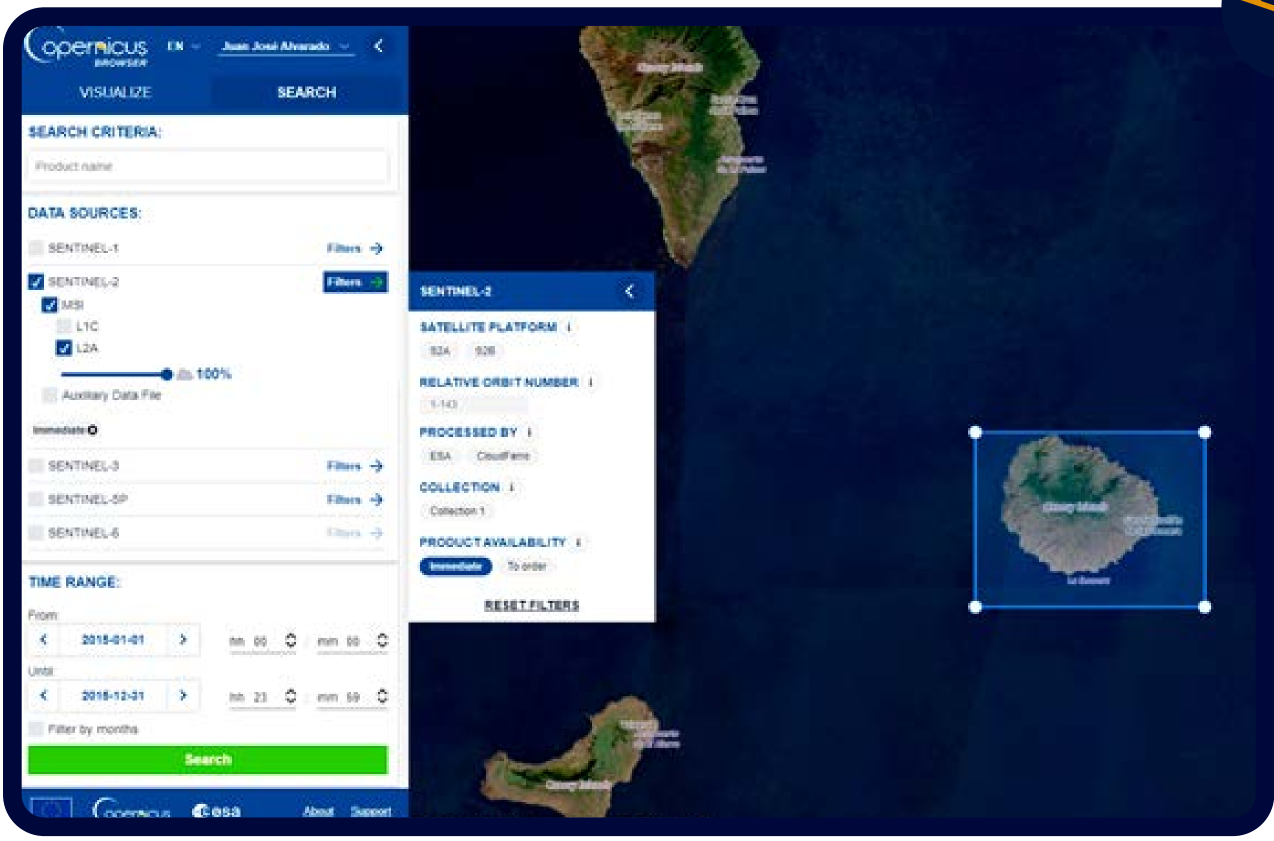


Figure 3. User interface for downloading Sentinel-2 products.

Conversely, the use of Sentinel-2 derived products at processing level 2A represents the most compelling alternative for this specific type of work, not only in terms of coverage and spectral and spatial resolution. The satellite images in this set have been subjected to radiometric and atmospheric correction. Furthermore, they also benefit from effective additional topographic correction, which obviates the necessity to resort to external programmes or programmatic resources.

- **Access and Use of Sentinel-2 Products**

  Once the file has been downloaded from the Copernicus data ecosystem and subsequently decompressed, a file with the '.SAFE' extension will be generated. This file's nomenclature is as follows:

- S2A_MSIL2A_20160117T115312_N0201_R123_T28RBS_20160117T115314.SAFE

- **S2A:** Satellite that captured the image either S2A or its twin, S2B.

- **MSIL2A:** MSI is the multispectral instrument that operates on board the satellite device. L2A indicates that the product has undergone surface, radiometric and atmospheric reflectance correction. This correction pertains to the transformation of reflectance from top-of-atmosphere (TOA) to surface reflectance (BOA) values.

- **20160117T115312:** The date is written in the format ymd (year/month/day) and the day in UTC time.

The remaining fragments of the nomenclature serve to identify specific moments of image validation, as well as the relative orbits and territorial coverage of the image.

To access the bands individually, one must navigate to the **GRANULE/IMG_DATA** directory. There, the bands will be separated by resolution: 10, 20 and 60 metres (Figure 4), respectively; in '.jp2' format, perfectly legible in QGIS desktop software thanks to GDAL drivers [9].

It is possible to obtain all available bands at a resolution of 10 metres. This step is superfluous for the NDVI calculation, as the red (4) and near-infrared (NIR) bands (8) have already been resampled to this resolution. The R Library 'sen2r' (Ranghetti *et al.*, 2020) permits the remaining bands at 20-metre resolution to be de-scaled to 10 metres through the application of brightness and pixel interpolation, facilitated by the s2_translate function, which acts upon a corrected product at level 2A, resulting in the generation of a raster packet (stack) with the bands at the desired resolution. This represents an intriguing alternative for those seeking to calculate other vegetation or spectral combination indices with one of the newly de-scaled bands, with greater detail. This includes numerous indices related to charring and post-fire effects, which typically use the shortwave infrared (bands 11 and 12).

Spatial Resolution (m)	Band Number	S2A		S2B	
		Central Wavelength (nm)	Bandwidth (nm)	Central Wavelength (nm)	Bandwidth(nm)
10	2	492.4	66	492.1	66
	3	559.8	36	559.0	36
	4	664.6	31	664.9	31
	8	832.8	106	832.9	106
20	5	704.1	15	703.8	16
	6	740.5	15	739.1	15
	7	728.8	20	779.7	20
	8a	864.7	21	864.0	22
	11	1613.7	91	1610.4	94
	12	2202.4	175	2185.7	185
60	1	442.7	21	442.2	21
	9	945.1	20	943.2	21
	10	1373.5	31	1376.9	30

Figure 4. Arrangement of the bands is based on their spatial and spectral resolution, as well as the Sentinel-2 satellite. Sourced from [10].

2.2 Vegetation indices

The information interpretation derived from satellite and spectral analysis represents a fundamental aspect of environmental remote sensing and spatial ecology. Furthermore, this analysis type is a direct application in the conservation of biodiversity and ecosystems. The most studied phenomena in natural sciences are those that can be observed in the natural environment, such as photosynthetic activity, water or vegetative stress, phenological episodes and pulses, forest fires, and so forth. The application of vegetation indices has been instrumental in facilitating the study of these phenomena. In these cases, the near-infrared (NIR) and visible spectral regions are the primary regions of interest.

The principal advantages of using this specific index are as follows:

- Capacity to enhance ground cover and its separability from the ground.
- Inter-band arithmetic operations serve to normalise the equations, thereby accounting for distortions caused by illumination from terrain or cloud cover, both intra- and inter-image.
- Measurements of the Earth's surface are employed extensively in ecological studies. With direct interpretations of the vegetation's state, for example.
- Not limited to ecological and predictive analysis.

One of the most frequently employed indices, which serves as the primary axis of this methodology, is the **NDVI**. This index has been linked to various parameters, including vegetation cover, primary productivity, and biomass. As is the case with numerous other devices, it employs the properties of red reflectance and NIR, specifically the contrast observed in the range of the spectrum commonly referred to as the "red edge". In essence, the spectral path of healthy vegetation exhibits a high reflectance in the near-infrared (NIR) region and a low reflectance/high absorption in the red. This phenomenon is commonly attributed to the photosynthetic machinery of the leaf and its activity. As photosynthetic activity declines, the differences in reflectivity between near-infrared (NIR) and red wavelengths also diminish.

The arithmetic combination of bands allows the value of this index for each pixel of our ROI to be calculated using the following formula:

$$\textbf{NDVI} = \text{NIR} - \text{Red} / \text{NIR} + \text{Red} \qquad (1)$$

The values in question exhibit a continuous range from -1 to 1. Values approaching 1 indicate a notable divergence in the red edge, which is indicative of a high photosynthetic yield or greenness. Areas with values approaching or below zero are characterised by a very low vegetation cover. In terms of its use, the Normalized Difference Vegetation Index (NDVI) offers a number of benefits that encourage its use to the detriment of other indices.

- The simplicity of mathematical concepts and their interpretation.
- Minimises topographical effects.
- The application of band ratios results in a process of normalisation, which subsequently reduces the impact of sensor calibration degradation and the influence of atmospheric effects.
- The application of continuous numerical values allows for the implementation of thresholding.

The comparative component of the Normalized Difference Vegetation Index (NDVI) is the dNDVI, which compares the values of the index between two images, typically corresponding to the same period but different years. This allows for the study of changes that have occurred in the territory, with an approximation of the differences in greenness.

$$\mathbf{dNDVI} = NDVI_{t2} - NDVI_{t1} \qquad (2)$$

In the notation employed in equation 2, $NDVI_{t2}$ represents the later NDVI, while $NDVI_{t1}$ denotes the NDVI of the earlier date.

A positive value of dNDVI is indicative of an increase in photosynthetic activity, whereas a negative value is indicative of a reduction in photosynthetic activity. Values close to zero indicate a lack of change. The analysis of time series of dNDVI can inform the drawing of conclusions regarding the existence of a discernible trend in the reduction of NDVI, thereby indicating the potential for a decline in the forest stand. In the absence of a clear temporal pattern, the observed failure to obtain a clear temporal pattern could be indicative of inherent fluctuations associated with wetter or drier years in greening, or the absence of greening in the vegetation.

Important Note: It is of paramount importance to be familiar with the band notation to perform arithmetic operations between rasters. In the Sentinel-2 satellite imagery, the NIR band (band 8) while band 4 corresponds to the red band. In the event that Landsat data is employed, it is imperative that the information provided by the vendor of the product be utilized for the accurate designation of the bands.

It should be noted that there are other vegetation indices that can be employed in ecological analyses, including the enhanced vegetation index (EVI) and the vegetation index with soil correction applied (MSAVI). The latter may be a suitable alternative in ecosystems where the soil fraction plays a significant role, such as in natural and open Canary Island pine forest formations, summit scrub (Ibarrola *et al*., 2019), or junipers, where red and infrared reflectivity is strongly influenced by the soil fraction.

3. USE OF REMOTE SENSING TECHNIQUES APPLIED TO HABITAT 9360

CASE STUDY 1: First approach to NDVI calculation: quantification of forest condition and different spatial change analysis techniques: the case of the Garajonay National Park and La Gomera.

Introduction

La Gomera's laurel forest represents one of the most notable examples of this habitat type in the Macaronesian region. Its patches exhibit notable spatial continuity, and it is home to a variety of different types of laurel forest, which have reached a high degree of maturity. This is largely due to the fact that almost all of them are located under the protection and management of the Garajonay National Park. The diversity of environments is considerable, encompassing a range of habitats from the classic humid laurel and vineyard laurel forest, through the drier laurel forest of barbusan facies, cloud forests, to the laurel forest of the bottom of the til ravine. This represents an optimal scenario for the testing of this methodology.

As previously stated in section 2.1, NDVI is one of the most employed vegetation indices in ecological studies. It can be employed as an indicator of several functional aspects of the ecosystem, including productivity, ecophysiological state, and stress.

In the first example, the objective is to delineate and quantify the extent of the current laurel forest fragments by establishing appropriate thresholds. Subsequently, the spatio-temporal dynamics will be compared between the first Sentinel-2 imaging available for the island of La Gomera (2016) and the last one in 2024, with January imaging chosen for analysis. The objective is not merely to quantify the area and its delimitation, but also to ascertain the current vital state of the subject matter by comparing images and dates. The objective is to identify spatial and spectral changes that have occurred, using dNDVI and temporal regression between images. This approach will enable the identification of areas at risk of laurel forest loss and deterioration, as well as areas where the laurel forest may be recovering, given the significant fire that occurred in 2012.

Methodology

- **Change Detection**

One of the most common applications of remote sensing is change detection. This involves the identification of pixels that have undergone a change in their spectral characteristics or digital levels between two or more images. These images are typically captured on different dates, allowing for the comparison of changes over time. It is therefore a tool that should be considered when monitoring a specific dynamic phenomenon that can be observed in space and time.

In this context, supervised classifications may be employed, whereby the pixels of each observed coverage or class within the study region are grouped according to their physical, topographical, vegetational, spatial, and other relevant characteristics. This necessitates prior knowledge of the region and the application of various classification algorithms, many of which are based on machine learning. These algorithms often require a certain level of programming expertise and may involve a high computational cost. Furthermore, the replication and validation of the results are essential. Once the optimal classifier algorithm has been identified, it is then possible to use the spectral data for as many areas of interest and dates as required.

Another common practice is to apply a linear regression between two images or bands corresponding to two different dates. This technique is based on the mathematical model of simple linear regression in space, whereby the digital levels of one image are dependent on the digital levels of another, whose values are strongly associated.

$$ND_{t2} = a + b * ND_{t1} \qquad (3)$$

As demonstrated by equation 3, the digital levels of the second date are estimated from those of the first date. In this context, a and b represent the regression coefficients for the intercept and the first date, respectively. These digital values between the two dates will be very similar if no change has occurred, a situation characterised by stability in the vegetation cover studied. In the absence of this information, the estimated values for the second date will be significantly divergent from the actual values, exhibiting a high degree of discrepancy in the form of residual values (discrepant pixels).

To elaborate the vector mask, the LULC polygons corresponding to use 311 have been selected, as this is the only method of applying a consistent and replicable methodology to all the Macaronesian archipelagos with the presence of laurel forests, while also masking as much as possible other forest formations that are not the subject of the study. A 100-metre buffer operation (QGIS native geoprocessing algorithm) has been applied to these patches to accommodate the maximum possible variability and the possibility of habitat expansion as a result of possible recovery. The mask has been saved as a shapefile (.shp) for subsequent use in the QGIS SCP plugin

Satellite products used	Suplier
S2A_MSIL2A_20160117T115312_N0201_R123_T28RBS_20160117T115314	Sentinel-2
S2B_MSIL2A_20240110T115219_N0510_R123_T28RBS_20240110T125311	Sentinel-2

- **Satellite product clipping for the desired study area**

In the context of this particular methodology, it is strongly advised that working masks be developed. Firstly, the area to be studied must be delimited and any cover that may cause noise, such as crops, pastures, grasslands and even unwanted forest formations, must be eliminated. Furthermore, in terms of processing speed and the consumption of machine resources, this is also a compelling argument. This considered, it is recommended that the SCP Plugin, a QGIS add-on, be employed to facilitate the management and manipulation of the bands in question. The procedure for cutting multiple rasters is as follows: firstly, load the selected bands into the band set; secondly, select the option "cut multiple rasters"; thirdly, either use a vector file in exclusively shapefile (.shp) format or an extension, if the upper left and lower right UTM coordinates are known.

The clipped bands will be incorporated into the QGIS layer panel with the prefix "clip_" or other user-defined prefix and stored in the corresponding selected directory. Moreover, the add-on enables the raster output to be organised as a stack of stacked strips. Figure 5 shows all these first steps.

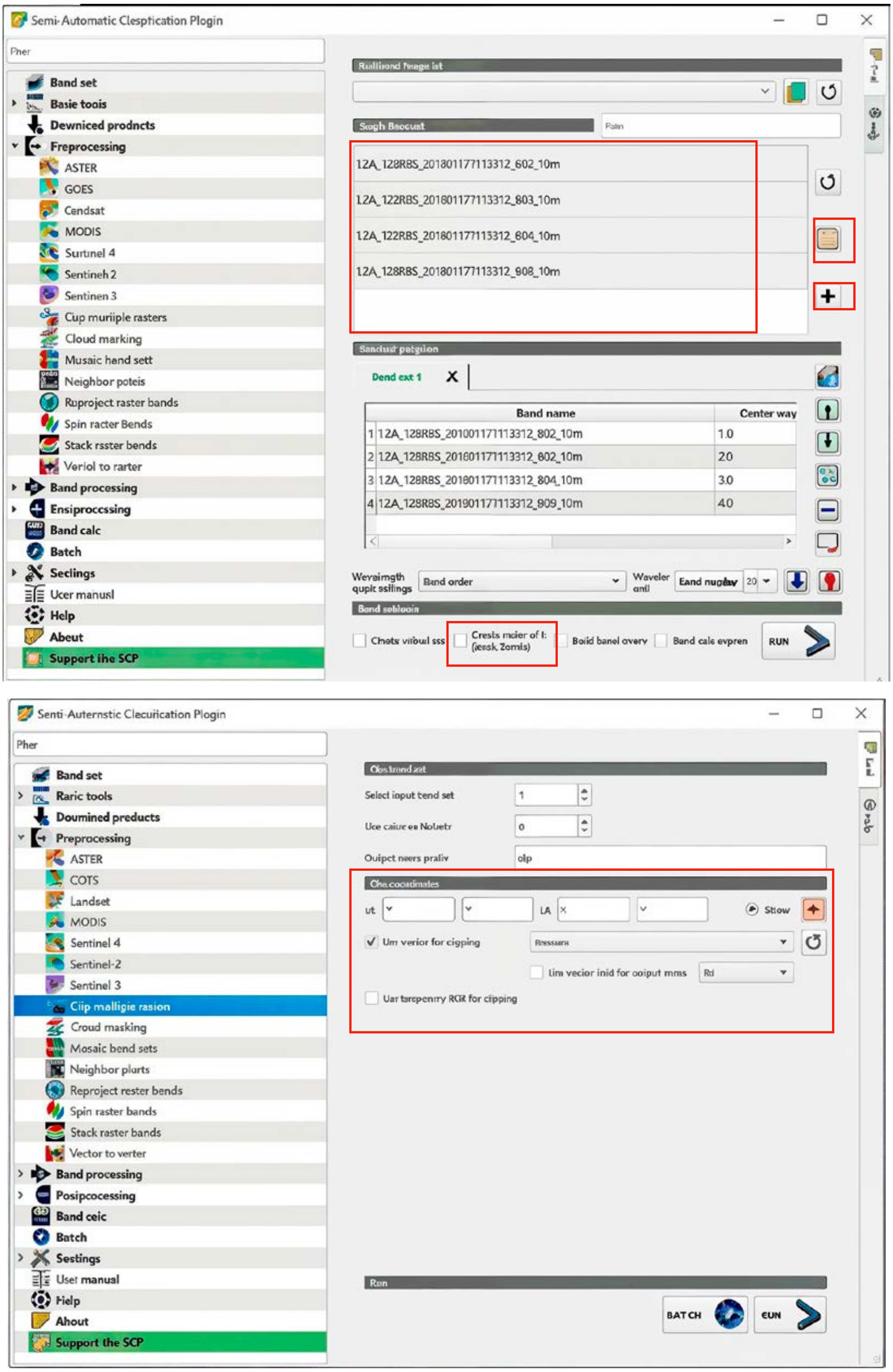


Figure 5. SCP Plugin user interface. The red rectangles indicate the different options described in the methodology.

Once the bands have been correctly adjusted to the study area, the calculation is made by map algebra, using the raster calculator in accordance with the following expression:

NDVI 2016 = ("clip_L2A_T28RBS_20160117T115312_B08_10m@1"-"clip_L2A_T28RBS_20160117T115312_B04_10m@1") / ("clip_L2A_T28RBS_20160117T115312_B08_10m@1" + "clip_L2A_T28RBS_20160117T115312_B04_10m@1")

The expression's outcome is a continuous raster of NDVI values, as illustrated in Figure 6. It can be observed that the NDVI value within the generated study mask is not homogeneous. The index's highest values coincide with the territorial scope of the Garajonay National Park, as well as the Vallehermoso ridge and Majona Natural Park, which are representative samples of laurel forest in La Gomera.

Figure 7 illustrates that the entire island of La Gomera exhibits a bimodal distribution of NDVI values. The values below 0.5 are more frequent and fall within the first mode of the distribution. The second mode would be the highest NDVI values, which directly overlap with the histogram of the area delimited for this study. This distribution of values is notably skewed towards the right tail, where high NDVI values are particularly prevalent. Conversely, regions with NDVI values below 0.5 remain in a residual position. The final region of the distribution is where the secondary formations are situated (jarales, retamonares), as well as serial formations of degradation of the laurel forest, including fayal-brezal. Additionally, this area was affected by the fire that occurred in 2012.

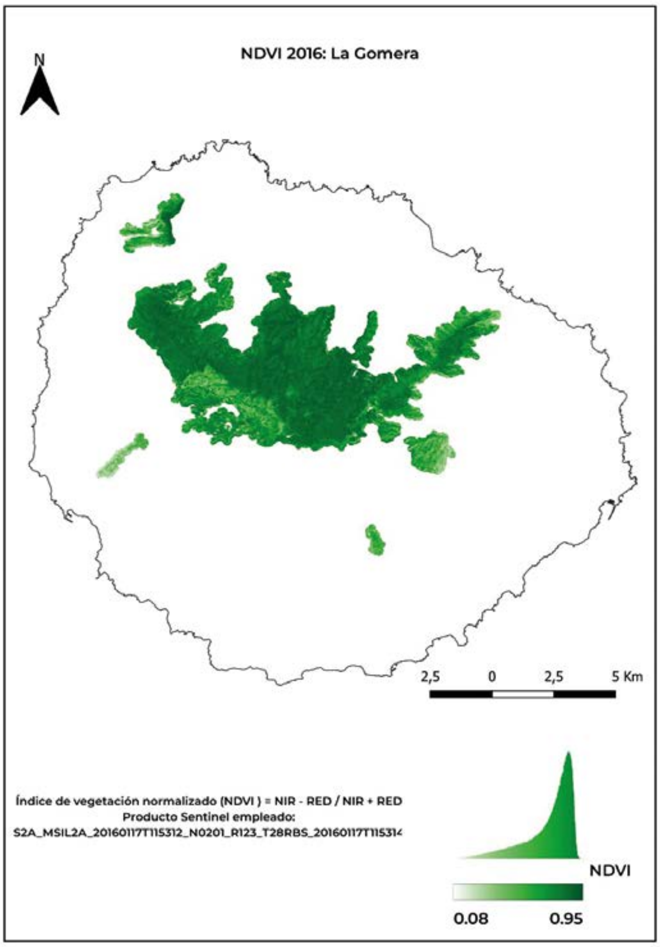


Figure 6. The Normalized Difference Vegetation Index (NDVI) was calculated for the study area based on data from January 2016.

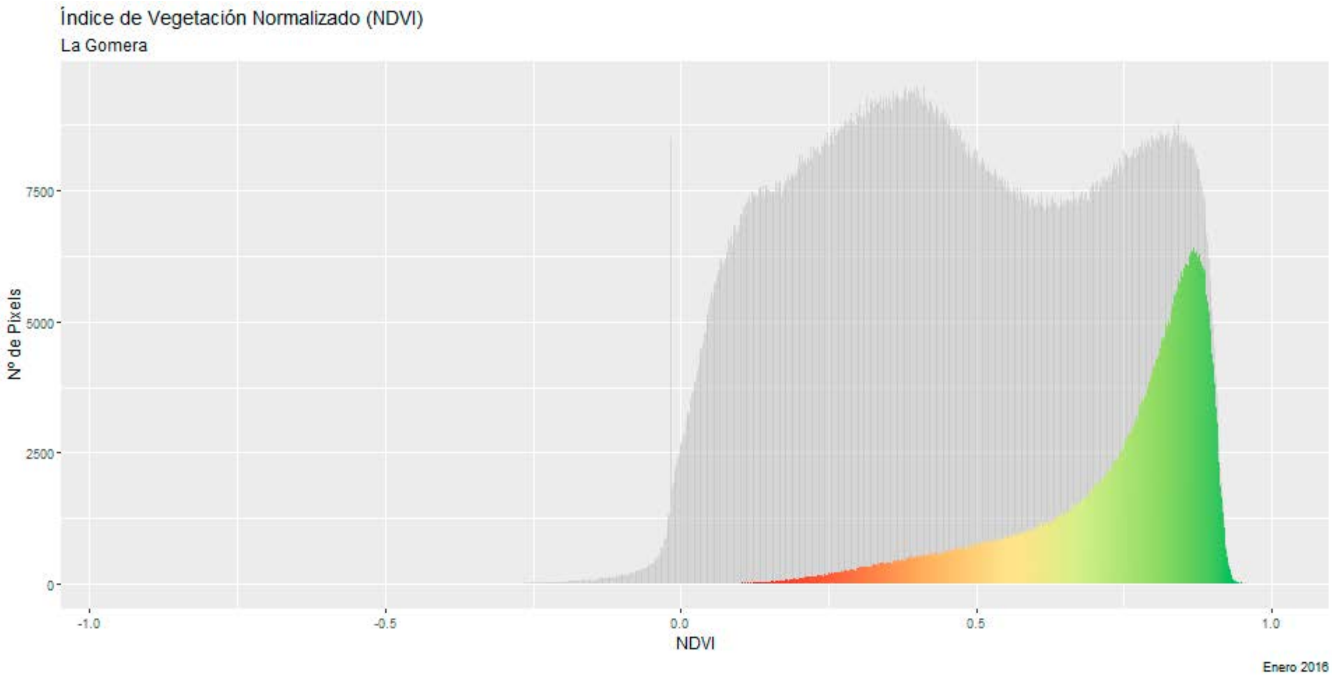


Figure 7. The NDVI values of the selected study area are represented by a gradual ramp from warm tones for the lowest values to green tones in areas where the maximum of the index is reached. In contrast, the complete histogram of NDVI values of the total extension of La Gomera is located in grey tones in the graph's background. The x-axis displays the Normalized Difference Vegetation Index (NDVI) values, which range from -1 to 1. The y-axis represents the frequency of occurrence of these values, expressed as pixel counts. The total number of pixels measuring 100 m² that were analysed on La Gomera is 3,679,269 (equivalent to 36792.69 hectares), while the study area encompasses 629,996 pixels (6299.96 hectares).

- **Change Detection: dNDVI and Linear Regression Between Images**

The study of the differences in the coverage of the different ranges of natural breaks represents a preliminary approach to the spatial estimation of changes in the spectral index. The study's objective is to identify areas where there has been a change in the habitat's conservation status by incorporating dNDVI and linear regression between images. The dNDVI is calculated by subtracting the oldest NDVI value from the most recent one, using map algebra with the raster calculator.

A detailed analysis of the dNDVI (Figure 8) reveals that the orange and yellow tones represent areas that have remained stable, with the majority of pixels in the central sector exhibiting this behaviour. However, there is a bias towards negative values. The darker orange and red tones indicate areas where the difference in the Normalized Difference Vegetation Index (NDVI) is particularly pronounced, suggesting a decline in the NDVI value. It would be in those locations where fieldwork would be necessary to study the causes and manifestations of this phenomenon in the ecosystem. The blue tones, which represent an increase in the Normalized Difference Vegetation Index (NDVI), are in the minority and are almost all located in the area affected by the 2012 fire. This suggests that the laurel forest is recovering.

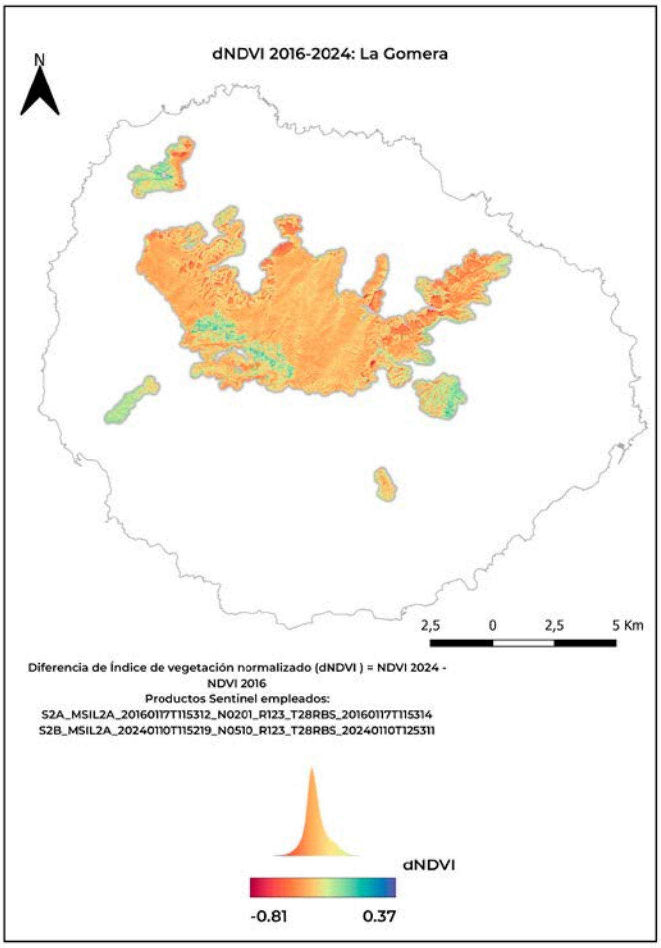


Figure 8. Difference in the normalised vegetation index between 2024 and 2016.

An alternative approach to the analysis of temporal changes is through the use of linear regression between images. If possible, between images captured at the same time of the year, thus isolating any topographical shadowing effects. The procedure, which was previously discussed in the methodology in its theoretical scope, employs the 'r.regression.multi' algorithm of GRASS [11] within the QGIS environment. The NDVI of 2024 serves as the y coefficient (variable to be predicted), while the NDVI of 2016 serves as the independent variable (x coefficient). The output comprises two raster files, one containing the predicted values and the other the residuals. As well, a text file is generated, containing the various regression values (see Figure 9).

$$\text{Residuals} = \text{Observed} - \text{Predicted} \qquad (4)$$

The predicted values (Figure 9, left) represent the fraction of 2024 pixels that can be linearly combined with the NDVI values of the 2016 pixels. Consequently, the estimates represent an approximation of the NDVI in 2024, derived exclusively through the application of a linear relationship between the values observed in that year and the index values recorded in 2016. This continuous area of predicted values is isolated from potential interferences due to drought, post-fire recovery, or any other factor not reflected in the 2016 values.

Conversely, the residuals (obtained via equation 4) (Figure 9, right) represent the proportion of the regression that indicates the discrepancy between images. Low residuals (approximately 0) indicate a high degree of stability, as evidenced by the similarity between observed NDVI values in 2024 and those predicted based on the 2016 values. This suggests that the forest stand would have been less disturbed or would be less severely affected by the drought's effects. The presence of both positive and negative residuals indicates alterations between the images. The indicator is bidirectional in its reading, with excessively negative residuals indicating a detriment in the habitat conditions under study. This is evidenced by regions of the forest that have been subjected to significant water stress and are related to negative values of dNDVI. Conversely, higher residuals are associated with an increase in NDVI favourability and are closely correlated with high values of dNDVI. Most of these pixels are concentrated in the south-western sector, which coincides with the area affected by the 2012 forest fire. The area is currently undergoing a nascent and natural process of recovery.

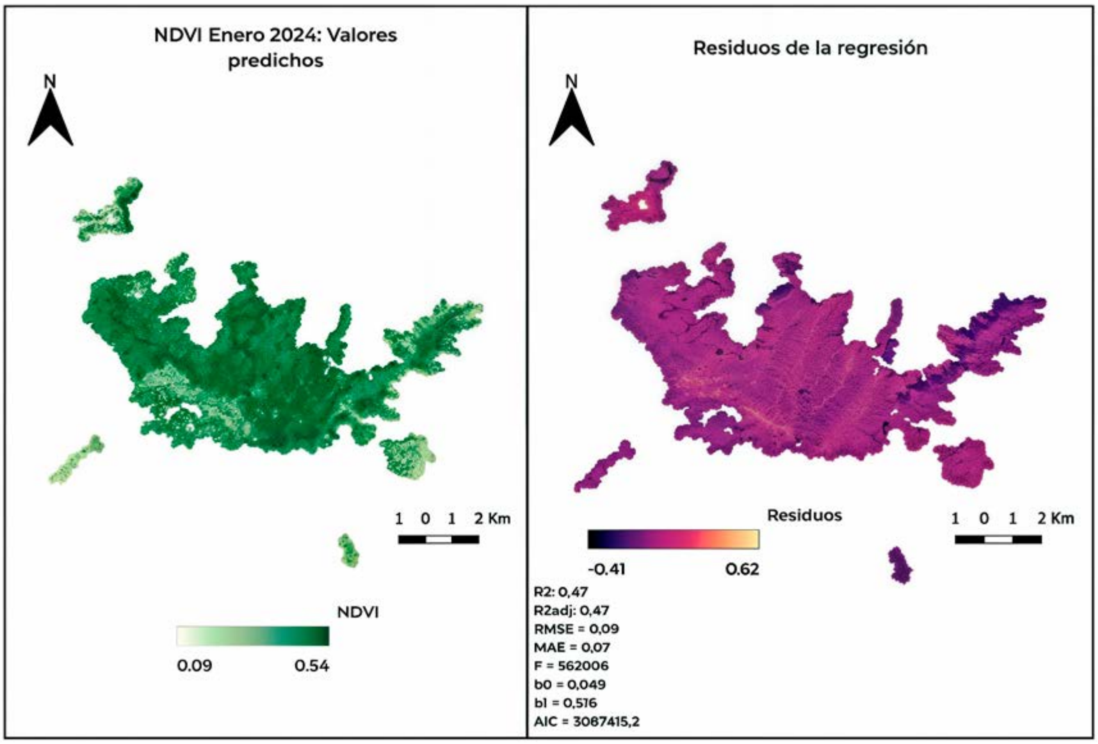


Figure 9. (Left) Linear regression predicted values. (Right) Regression residuals. R2 = coefficient of determinationR2; R2adj = adjusted coefficient of determination; RMSE = root mean square error; MAE = mean absolute error; F = F-statistic; b0 = regression coefficient of the intercept; b1 = regression coefficient of the NDVI 2016; AIC = *Akaike Information Criterion.*

CASE STUDY 2: *Thresholding*. The objective is to identify the optimal threshold for discerning the constituent patches of habitat 9360 using NDVI. The maxSSS methodology to the time series data from laurisilva gomera for the six-year period 2016-2021 and 2018-2023.

One of the fundamental objectives of this methodology is the delimitation and quantification of habitat patches 9360. To achieve this objective, a thresholding procedure, designated as thresholding, will be employed to transform the continuous surface of the index or probability of a phenomenon into a binary map representing the existence or non-existence of the phenomenon in question. To achieve this objective, a threshold designated as maxSSS will be employed in conjunction with a six-year time series, as this is the period encompassed by the Action Plan. Furthermore, this approach aims to minimise the impact of seasonal variations, drought and other external factors on the fluctuations of NDVI values by utilising the largest possible data set.

Once the raster surfaces have been obtained, together with the information on the regions that do or do not constitute the habitat under study, it is possible to compute the surfaces of each one separately. This allows for the identification of areas of habitat loss, gain and stability.

In remote sensing, a time series is defined as a collection of repeated observations of a specific region, the revisit data of which is directly dependent on the sensor's temporal resolution (Verbesselt *et al*., 2016). The methodology employed for this study incorporates all the steps included in cases 1 and 2, with the exception that it will be applied to NDVI time periods. Initially, it will be applied to the series between 2016-2019 (4 years), and subsequently to the series between 2020-2023 (4 years). January is a month that will always be considered, due to the availability of Sentinel-2 products and to follow the coherent thread that has been developing.

The only difference between this case study and the first is that we will work with the average NDVI value of the six-year series 2016-2021 and the series 2018-2023, rather than individual dates. The process will proceed in a similar manner to that described for the thresholding process and the subsequent production of the mapping.

This procedure is recommended for studies that involve evaluations with a fixed, established periodicity and in the face of phenomena of marked seasonality. It is much less sensitive to anomalous episodes, i.e. extraordinarily wet or dry years, a fact inherent to an ecosystem as heterogeneous as the laurel forest, which inevitably affects the stability of the NDVI and therefore the conclusions that can be drawn from its use (Caparrós-Santiago *et al*., 2023). Consequently, it enables trend observation, thereby enhancing the process's numerical robustness.

Once the NDVI has been calculated for each year that forms part of the study period, the average raster can be calculated in a similar manner to that described in the first case study. This involves finding the arithmetic mean between the rasters that make up that period, using map algebra (Figure 10).

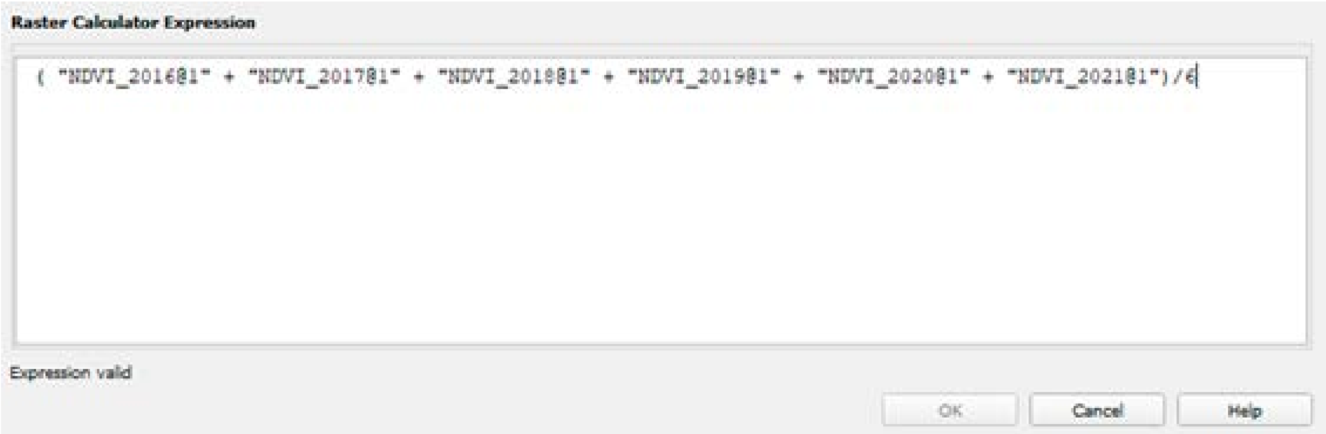


Figure 10. Calculation of the average NDVI for the six-year period 2016-2021.

- **maxSSS**

To define the maxSSS, it is first necessary to draw on some classical concepts of spatial ecology or species distribution modelling, which are assembled in this section (Fletcher & Fortin 2019):

- **Omission Errors:** False positive rate. In other words, values predicted as present are, in fact, absent.

- **Commission Errors:** False negative rate. In contrast, omission errors occur when values are predicted as absences, yet they represent actual presences.

- **Sensitivity:** True positives ratio.

- **Specificity:** True negatives ratio

- ***True Skill Statistic* (TSS):** Sensitivity + Specificity - 1. This classic discrimination metric already incorporates the sum of sensitivity and specificity, and thus it is common in the literature to synonymise maxSSS and maxTSSS.

A principal feature of this methodology is the necessity for polygons belonging to patches of current well-consolidated laurel forest, which will constitute the fraction of true positives. Conversely, polygons that do not correspond to laurel forest are required, which will constitute the portion of true negatives. This will be employed to generate a binary raster file representing a laurel forest/non-laurel forest classification, with a value of 1 assigned to pixels representing laurel forest and a value of 0 assigned to pixels representing non-laurel forest. Furthermore, the previously calculated NDVI will be employed.

The NDVI value that maximises the sum of specificity and sensitivity (hereafter maxSSS), that is to say, that maximises the TSS, will be used as the threshold. This numerical value has the capacity to more effectively accommodate and balance the NDVI values that constitute habitat 9360, as well as to discriminate those pixels that do not form part of the habitat. It is therefore the value that most effectively balances and minimises both errors of omission and errors of commission.

A series of random points will be generated on the binary and NDVI raster to collect the values of NDVI and the presence/absence of laurel forest (0 or 1), forming a data frame of predicted and observed values, respectively. A threshold optimisation function based on specificity and sensitivity will be applied to the data, returning a numerical value attributable to the maxSSS. The process will be repeated 10 times, with the average value serving as the threshold for reclassifying the averaged NDVI and the binary raster that separates the laurisilva from the non-laurisilva vegetation. The complete workflow for acquiring an understanding of maxSSS is presented in Figure 11.

The following R libraries are required for this project: 'raster' (Hijmans 2023), 'modEvA' (Barbosa *et al.*, 2013), 'dismo' (Hijmans *et al.*, 2023) and 'ggplot2' (Wickham 2016).

To facilitate the methodology and ensure reproducibility, the R **script ndvi_maxSSS.R,** which forms part of this report, has been incorporated. In all calculations, regardless of the period under consideration, the prevailing water stress conditions during that period, and so forth, are taken into account. Consequently, the potential occurrence of dry years and the vulnerability of the NDVI to such conditions are already accounted for.

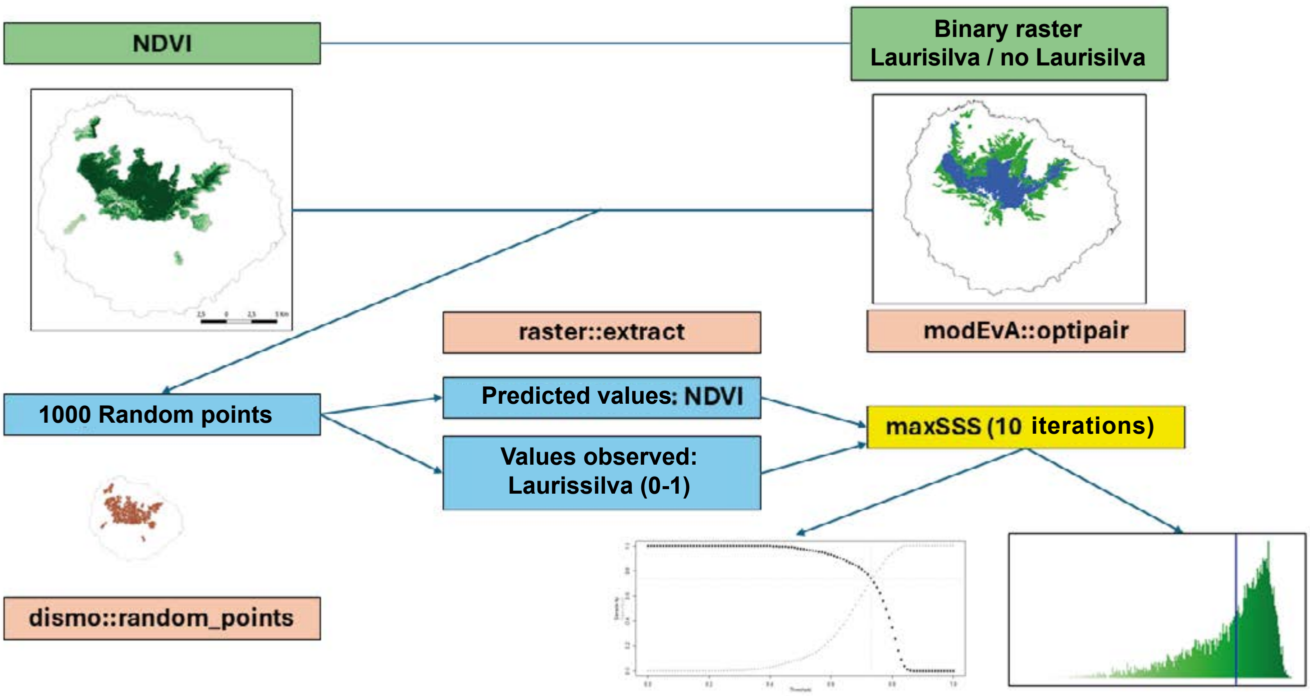


Figure 11. The workflow was implemented in order to obtain the maximum SSS threshold. The source raster files, which constitute the input data for the procedure, are represented in green. The files in vector format, which constitute the points with NDVI and presence/absence values of Habitat 9360, are represented in blue. The functions of the corresponding R libraries are performed in salmon colour. The final threshold is represented by the NDVI reclassifying threshold, which is indicated in yellow.

The previously described workflow results in the generation of a value averaged over 10 iterations of NDVI, which serves as the cut-off threshold that differentiates laurel forest from the remaining habitats in the study area over the two six-year periods considered (Table 2). This threshold value has been calibrated to reflect the distribution of NDVI values for the period under consideration and to align with the distribution of previous laurel forest patches. This ensures that the threshold is relatively insensitive to seasonal fluctuations or irregularities in humidity conditions. In addition, it minimises allocation errors (maximising the TSS).

Six-year Period	Threshold (10 iterations)
2016-2021	0.741 ± 0.01
2018-2023	0.691 ± 0.01

Table 2. Value of maxSSS for each six-year period considered together with its deviation.

Satellite products used	Supplier
S2A_MSIL2A_20160117T115312_N0201_R123_T28RBS_20160117T115314	Sentinel-2
S2A_MSIL2A_20170101T115212_N0204_R123_T28RBS_20170101T115212	Sentinel-2
S2B_MSIL2A_20180121T115209_N9999_R123_T28RBS_20221107T125726	Sentinel-2
S2B_MSIL2A_20190116T115219_N0211_R123_T28RBS_20190116T141038	Sentinel-2
S2A_MSIL2A_20200116T115211_N0213_R123_T28RBS_20200116T125318	Sentinel-2
S2A_MSIL2A_20210130T115221_N0500_R123_T28RBS_20230522T093800	Sentinel-2
S2A_MSIL2A_20220115T115221_N0301_R123_T28RBS_20220115T141122	Sentinel-2
S2B_MSIL2A_20230105T115219_N0509_R123_T28RBS_20230105T135146	Sentinel-2
S2B_MSIL2A_20240110T115219_N0510_R123_T28RBS_20240110T125311	Sentinel-2

Figure 12 illustrates the histograms of raster values for each six-year period of NDVI considered in this section, along with the thresholds calculated above for each period. In general, the distributions are skewed to the right. The NDVI regions with the highest accumulation of cells correspond to the highest NDVI values for the study area under consideration. In terms of the threshold value for both distributions, the value for the six-year period 2016-2021 is slightly higher than for the six-year period 2018-2023. This is also true of the maximum NDVI value (0.88 and 0.86, respectively) and the median (0.71 and 0.66). These values are more robust indicators to use in distributions with an evident bias towards one of the tails of the distribution. They have also been suggested in the literature as threshold values on many occasions. In this instance, using the median would result in a notable increase in the number of false positives, i.e. pixels without habitat 9360 that the thresholding process would incorrectly identify as such.

It is worth noting the emerging trend in intermediate NDVI values over the past six years, particularly in areas around 0.6, which coincides with the recovery of burned areas. However, these values have not yet been incorporated into the forest matrix, nor are they currently present in the laurel forest, as they fall below the established threshold.

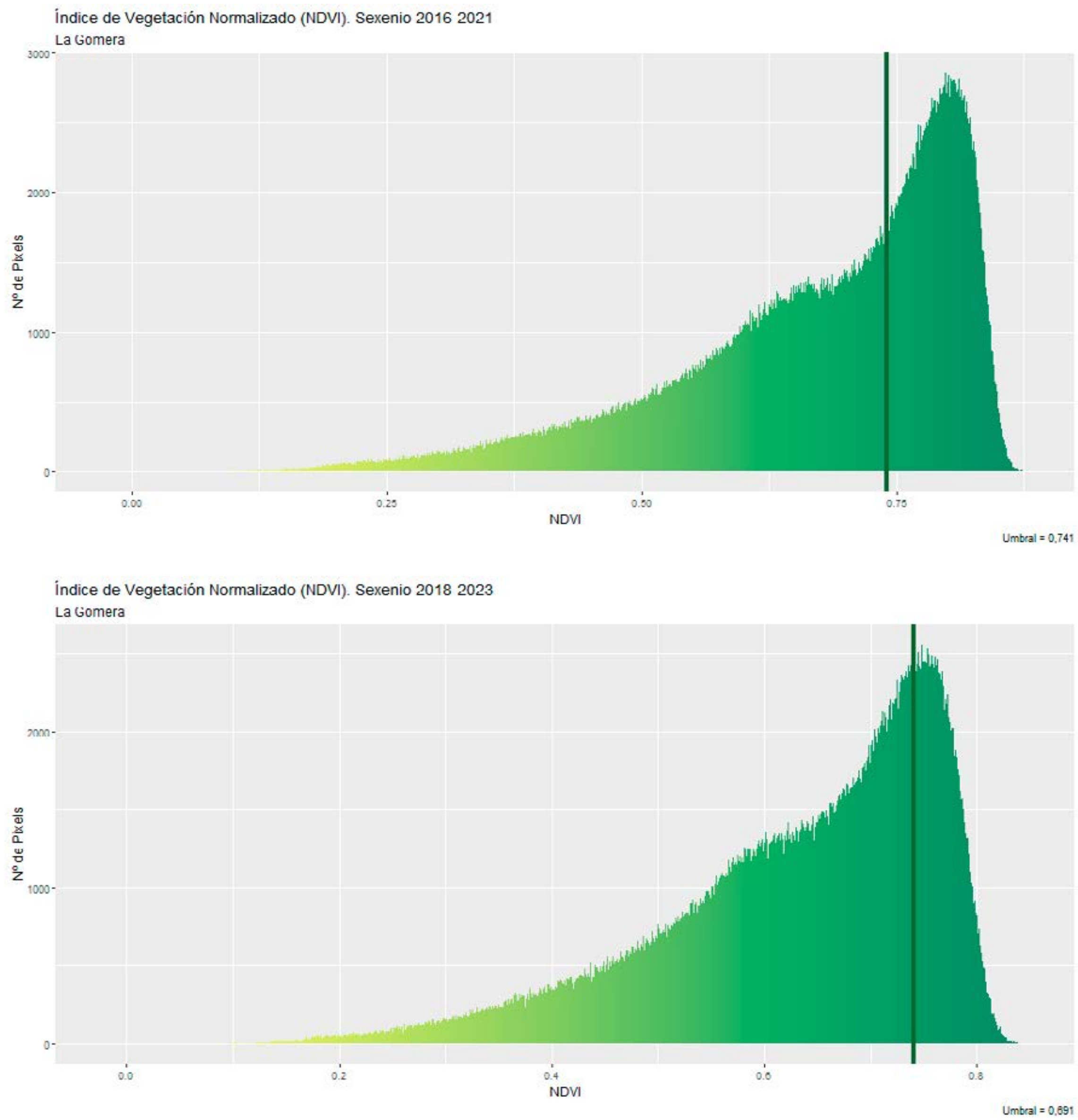


Figure 12. The following graphs show the NDVI for the six-year period 2016-2021 (top graph) and for the six-year period 2018-2023 (bottom graph). The green vertical asymptote represents the threshold value within the distribution of NDVI values. The x-axis displays the Normalized Difference Vegetation Index (NDVI) values, which range from -1 to 1. The y-axis represents the frequency of occurrence of these values, expressed as pixel counts.

The threshold value will be applied to the averaged NDVI rasters using a reclassification carried out with the raster calculator and map algebra (Figure 13). This will result in a binary raster, with value 1 representing the habitat of interest and value 0 representing cells not considered to be part of the habitat (Figure 14).

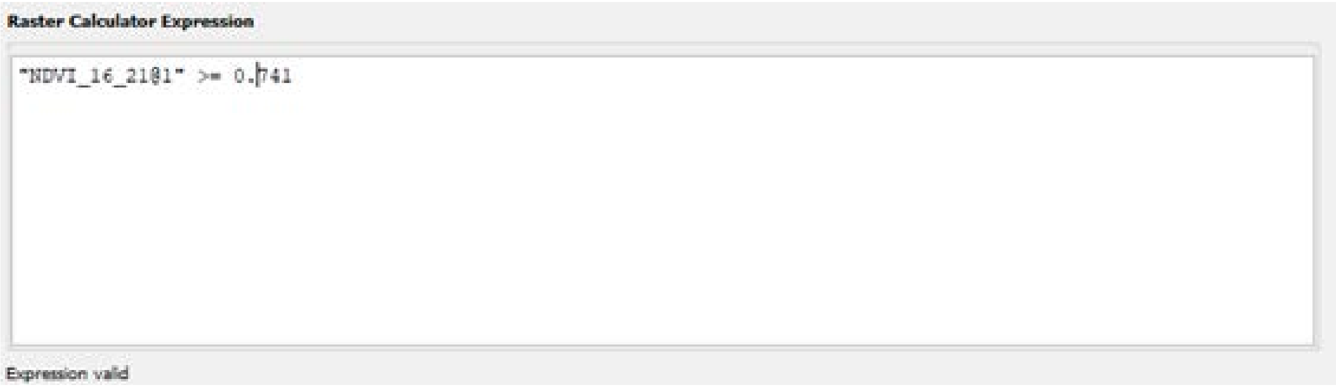
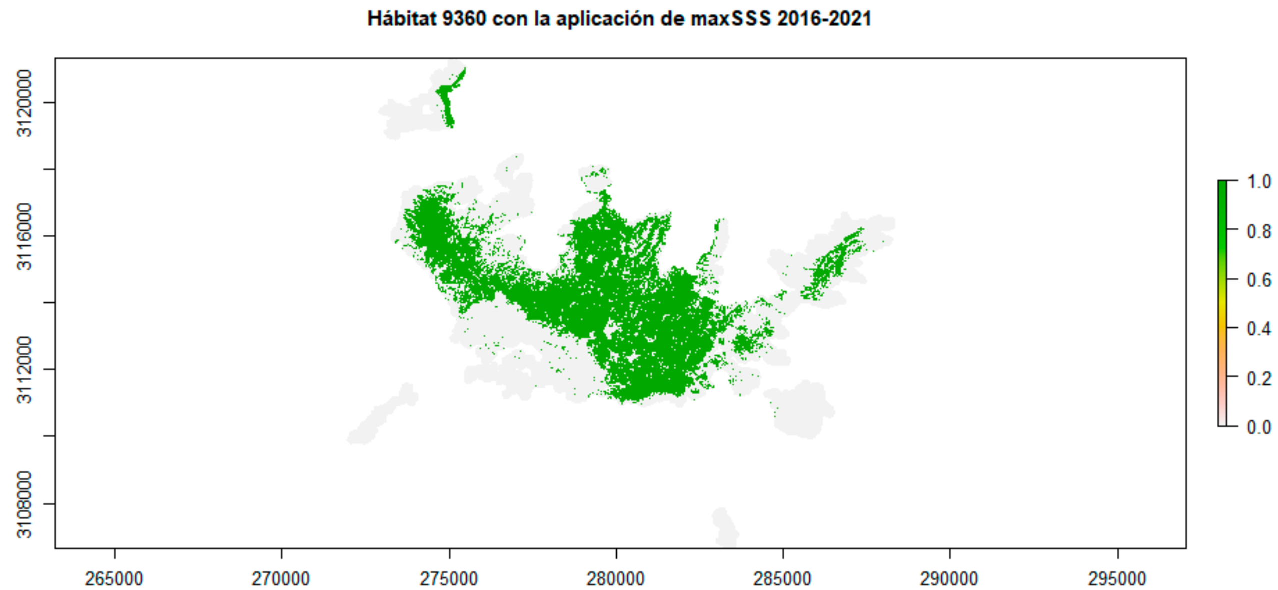


Figure 13. Reclassify the averaged NDVI raster from the maxSSS threshold obtained above.



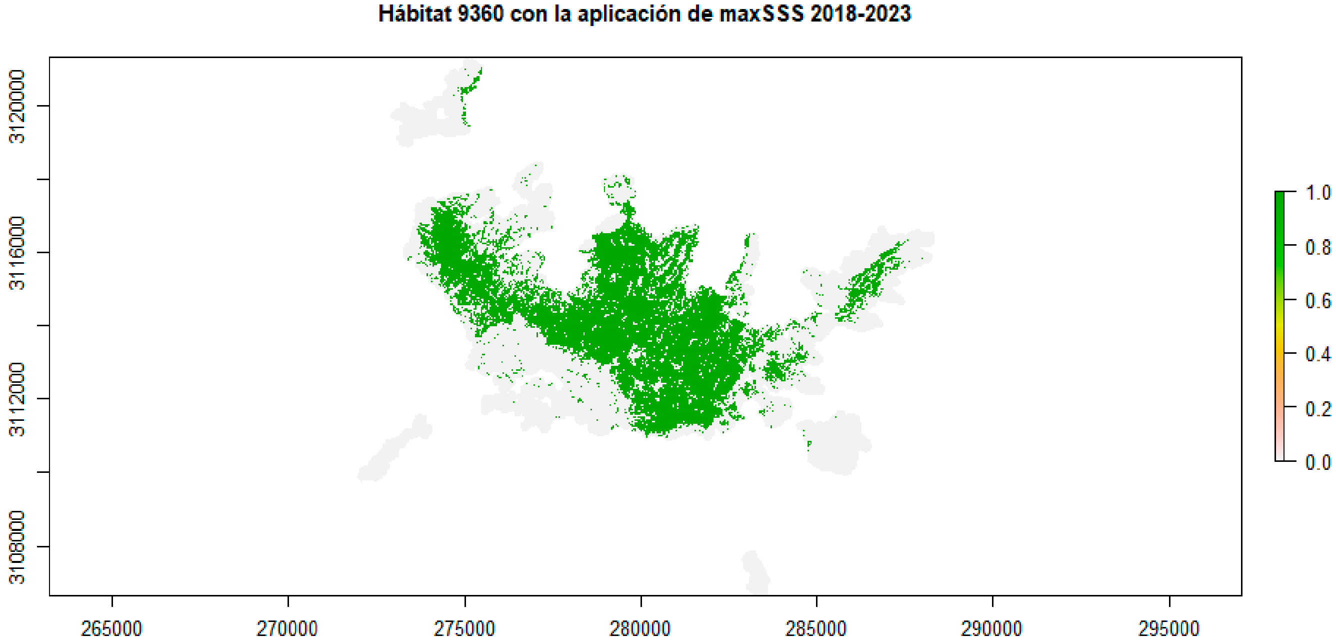


Figure 14. Binary maps of Habitat 9360 created following the application of maxSSS to the NDVI of each time series.

- **Computation of statistics from a binary raster.**

The QGIS native algorithm 'raster layer unique values report' generates a summary table with the number of pixels (Figure 15) and the corresponding area in m^2 for each of the two binary classes we have been working with so far: habitat 9360 and the areas excluded from it. The geoprocessing operation requires only a categorical raster for the habitat of interest, previously generated during the thresholding process. This solution offers an efficient and highly useful alternative for calculating areas and surfaces of change, avoiding the need for costly conversions to points or polygons. Please refer to Table 3 for the area computations for the binary classes and NDVI periods under consideration.

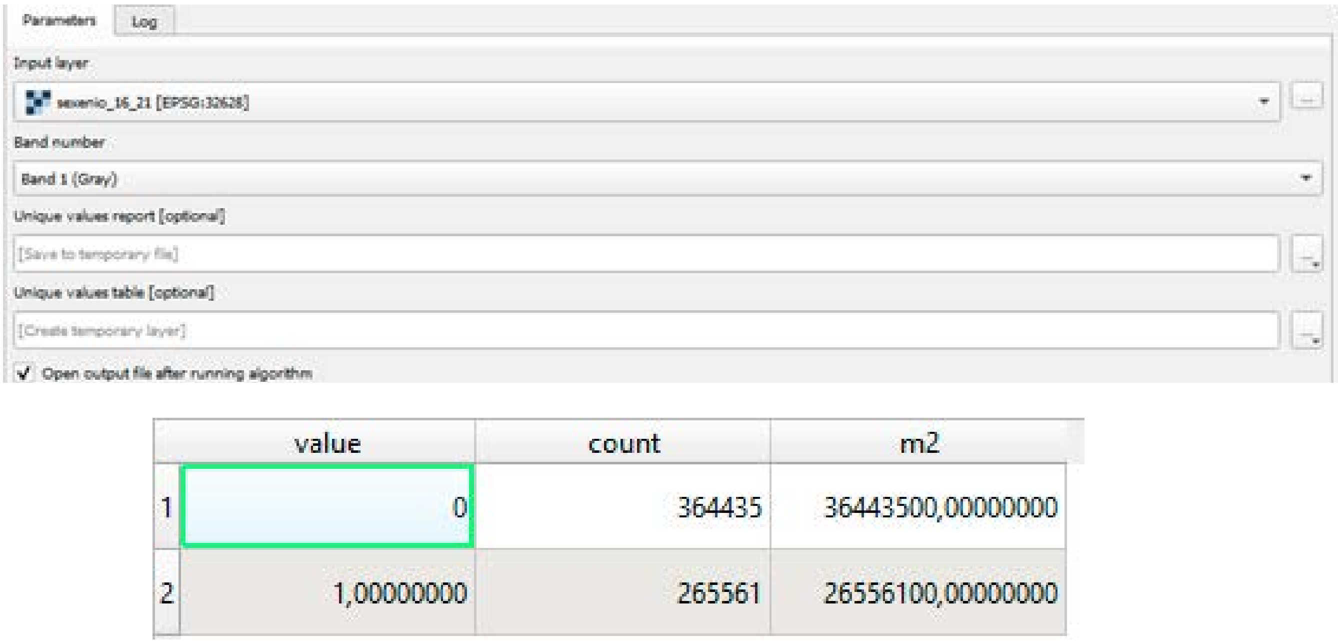


Figure 15. The application and output of the 'raster layer unique values' algorithm.

Period NDVI	Laurel Forest (Ha)	Other habitats (Ha)
2016-2021	2655.6	3644.4
2018-2023	2612.3	3687.7

Table 3. Summary of the areas attributable to Habitat 9360, based on an analysis of the NDVI time series.

- **A comparison of the spatial stability of laurel forests over two six-year periods.**

This final section forms part of the spatial monitoring of habitat 9360 but is applied to the comparison of the two six-year periods as a whole. In summary, the objective is to identify and quantify the areas where stability would be promoted, as well as to identify the regions where there is a possibility of loss or contraction, and expansion or gain of laurel forest area. This identification can be a highly beneficial tool from a managerial perspective, particularly insofar as it would necessitate the implementation of coordinated surveys in the identified areas of loss or gain.

By employing the process of subtraction, as illustrated in Figure 16, through the use of map algebra, two binary rasters (each comprising values of 1 and 0) yield three potential cell values.

- 1: The cells of value 1 in the initial six-year period and of value 0 in the subsequent six-year period are as follows: Pixels involving loss of laurel forest.
- 0: The cells of value 1 in six-year periods are as follows: The objective of the maintenance pixels is to promote the stability of the forest stand.
- 1: The cells with a value of 0 in the initial six-year period and a value of 1 in the subsequent six-year period are as follows: The assumption is that the cells in question are part of the laurel forest

Figure 16. A raster calculator calculation was performed to determine the pixel dynamics between six-year periods.

Figure 17 illustrates the dynamics of the study habitat over the six-year comparison period. The general trend across the surface of the study area is towards stability (Table 4), particularly in the central sector, where most the habitat's constituent pixels are maintained. The areas of loss are marginally greater than the areas where the habitat could have been subjected to further surveys. It is noteworthy that the most significant events occurred in Alto Garajonay and the Vallehermoso ridge, as well as in the Majona Natural Park. The latter two locations are situated beyond the boundaries of the Garajonay National Park. The gains are based on single pixels, many of which are embedded in a matrix of pixels that are either current habitat or located in the southwest, where the forest formation is recovering after the 2012 fire.

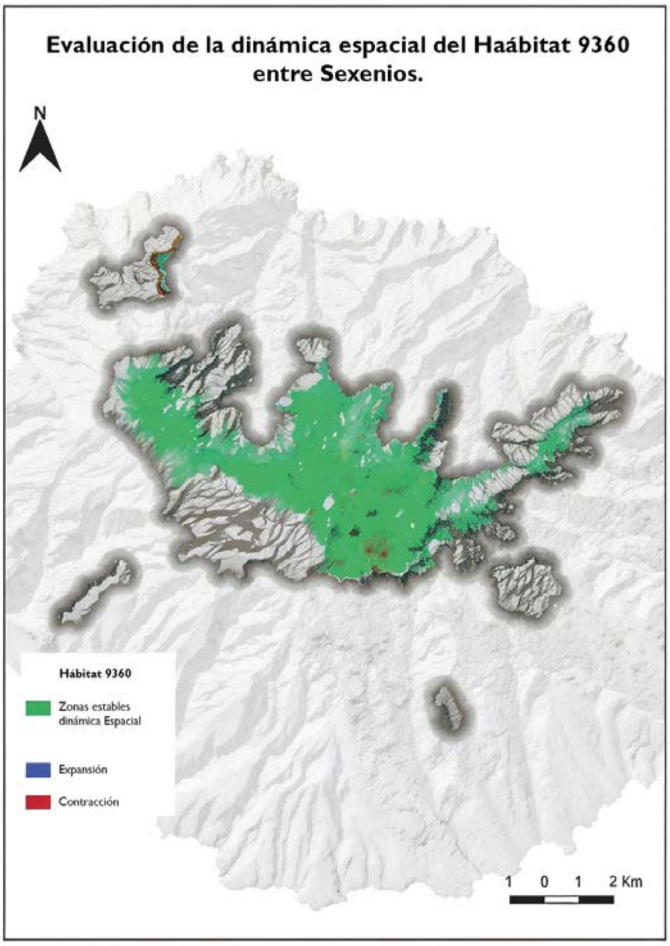


Figure 17. A map illustrating the dynamics of the laurel forest over the six-year periods under consideration. The map illustrates the common areas between the two six-year periods (shades of green), areas of loss of suitable pixels (cells in red) and new areas of expansion of the habitat (blue pixels).

Dynamic	Area (Ha)
Profit	42.32
Stability	5411.7
Loss	84.6

Table 4. A comparison of the number of laurel forests maintained, or lost or gained, over a six-year period.

- **Conclusion**

The application of maxSSS as a threshold is a promising alternative for *thresholding* six-year NDVI time series, with several advantages and disadvantages that are detailed below. These should be weighed against the baseline data when determining the most appropriate thresholding method.

Advantages:

- The numerical robustness of this method is high, and it is also relatively insensitive to irregularities in NDVI.
- Replicable for any NDVI date and any location. High reproducibility thanks to the code.
- Computational agility when working with resampling.

Inconveniences:

- It is not possible to perform detailed range computations due to the potential impact of hypothetical natural breaks. This represents a clear example of pure binarization.
- Requires programming.
- The initial step is to conduct a comprehensive or at least partial mapping of the Habitat 9360 patches to optimise the training of the method.

CASE STUDY 3: Use NDVI for the detection of invasive species in laurel forests. the case study concerns the chestnut tree (*Castanea sativa* Mill.) on La Palma.

Introduction

The presence of the chestnut tree (*Castanea sativa*) has been widely reported in the westernmost Canary Islands, with the island of La Palma (Figure 20, left) representing the most conspicuous example. This species has been the subject of discussion regarding its ability to colonise potential laurel forest space for many years (Santos-Guerra, 1983), as evidenced by Figure 20 (right). The figure illustrates the relationship between chestnut and potential laurel forest pixels in a bivariate space. It demonstrates that chestnut patches exhibit similar values of ombrothermal index (Io) and compensated thermicity index (Itc) as a specific fraction of potential laurel forest. These bioclimatic variables represent two of the principal bioclimatic descriptors of the Canarian laurel forest, in addition to the presence of fog. Further details on the bioclimatology of La Palma can be found in Garzón-Machado *et al.,* (2013). This process of spatial occupation of the laurel forest has even materialised in the form of scientific publications with a different approach (e.g. Devkota *et al*., 2020; González-Montelongo & Pérez-Vargas 2021).

The possibility of detecting chestnut patches is contingent upon the species' deciduous nature, which allows for the observation of leaf loss between January and February. Conversely, there are invasive tree species with a similar greenness to the elements of the laurel forest, including *Pittosporum undulatum* and *Cryptomeria japonica* (widely distributed in the Azores and Madeira). Furthermore, *Ulex europaeus*, which presents a more challenging identification due to the absence of a distinctive leaf phenology, also exhibits a similar greenness.

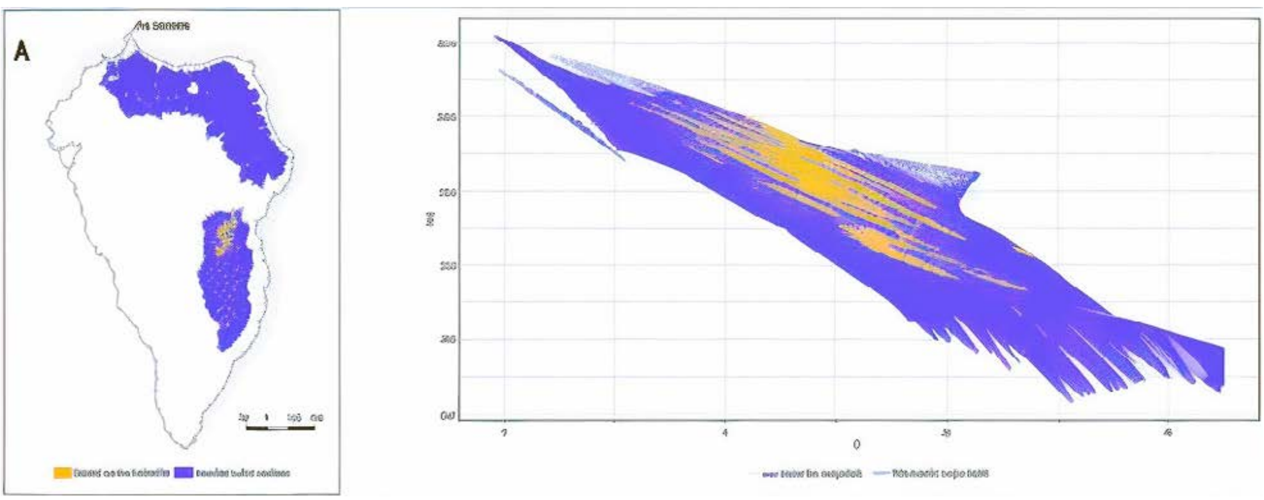


Figure 20. Left: Chestnut patches present in the potential area attributable to laurel forest on the island of La Palma according to del Arco *et al*., 2006. Right: Bioclimatic space mapping of both plant formations.

Methodology

In the preceding examples, several studies have been presented which demonstrate the efficacy of the methodology in detecting and evaluating changes. In this case, the studies concern the laurel forest of La Gomera and the Garajonay National Park. In this instance, a number of additional techniques will be integrated for the purpose of detecting the spread of a potentially invasive species within the area of 9360.

The **time vector** procedure **or change vector analysis (CVA)** is another classical method to detect spectral variations between two images. The modification of the digital level between the bands of the image also implies a change in their spectral location. It encompasses both the significance and the magnitude of the change. The magnitude is defined by the length of the vector separating the digital level of the pixel in images 1 and 2 according to the corresponding band/index. To illustrate, a pixel that reduces its plant vigor value exhibits a decrease in its digital level in the near infrared (lower reflectance) and an increase in the red (higher reflectance; lower red absorption capacity, reduced photosynthetic machinery, senescence, etc.). Consequently, the vector will have a downward and rightward direction on the NIR-RED bivariate axis. The analysis generates two outputs in raster format. The first is a representation of the angle of change in space, while the second is a representation of the magnitude of change in space.

The results obtained from the linear regression (predicted raster and residuals), the NDVI of the two images, their difference between dates (dNDVI) and the magnitude and angle of change obtained from CVA, all variables in raster format and with a high level of autocorrelation and multicollinearity (Leutner & Wegmann 2016), are introduced into a **raster principal component analysis** (hereafter RPCA) after scaling and normalising them, to obtain dimensionless raster variables, uncorrelated and linear combination of those previously introduced, which try to accommodate the maximum variability of the space's spectral characteristics.

The resulting principal components are then subjected to k-means clustering, an unsupervised method that requires the establishment of an '*a priori*' number of clusters. This method is commonly applied to remotely sensed data to distinguish homogeneous groups from each other and heterogeneous groups from each other in the field, plant communities (Hoffman *et al*., 2018), and other contexts. This method randomly distributes several seed points in the spectral space. A substantial number of pixels are subsequently grouped together in accordance with their nearest seed, with the mean spectral value of this cluster then being calculated. This average value can be considered to represent a centre of mass of the points and is therefore known as the centroid. At each iteration, the class means are recalculated, and the pixels are reclassified in accordance with the new means. This process is repeated until the centroids remain relatively stable and only a few pixels change class in subsequent iterations (Puzzi *et al*., 2024). To achieve this objective, 100 replicates were conducted, considering the five types of land cover considered in the study mask: fayal-brezal/laurel forest, humid pine forest, chestnut grove, crops and recent landslides. The procedure is dependent on the nature of the study territory and the researcher's knowledge of it. The scheme of work for this case study is presented in Figure 21.

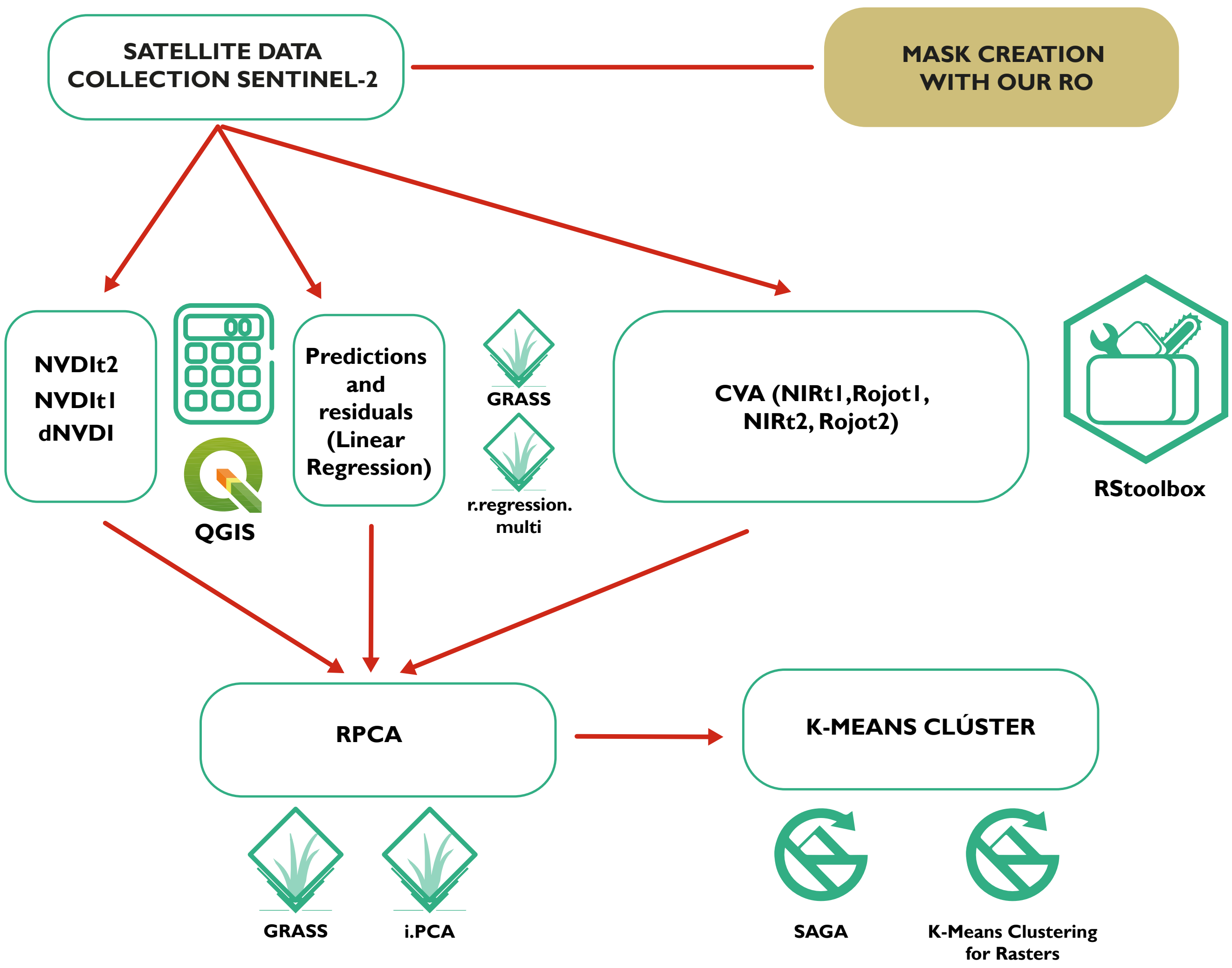


Figure 21. Workflow used in the methodology. The processes are represented in blue for those involving raster output and in green for those involving vector output. Each process is accompanied by a dedicated application tool in both the QGIS and R environments.

The result of this change detection procedure is a set of clusters or spatial groupings, which are distinguished from the rest of the clusters formed by the intracluster pixels that exhibit common characteristics of greenness and change. The clusters will be subjected to screening and validation procedures, employing thematic information and other high-resolution digital sources, with the objective of filtering and removing any residual pixels.

Satellite products used	Supplier
S2A_MSIL2A_20180708T120331_N0208_R023_T28RBS_20180708T141805	Sentinel-2
S2A_MSIL2A_20190213T120321_N0211_R023_T28RBS_20190213T172742	Sentinel-2

Results

One potential method for evaluating the reflectance characteristics of vegetative coverings is through the analysis of their spectral signatures. This entails plotting the reflectance path in the different regions of the spectrum or wavelengths of the chosen classes. In this example, the chestnut grove, the fayal-brezal and the laurel forest are the respective regions. As illustrated in the spectral signature of the fayal-brezal, laurel forest and chestnut patches for the February 2019 band set (Figure 22), a higher reflectivity of chestnut can be inferred in the red and shortwave infrared (SWIR1 and SWIR 2, bands 11 and 12, respectively). This is precisely the region of the spectrum where the absence of vegetation (in this case, the absence of leaves and leaf structure) is most noticeable, with higher values. This dynamic is typical of deciduous formations, a fact that is even more evident in a context of mostly perennial vegetation (Caparrós-Santiago *et al.*, 2023). As anticipated, the reflectance is lower for fayal-brezal and laurel forest patches, which are typically evergreen vegetation and whose machinery and photosynthetic yield is more stable throughout the year.

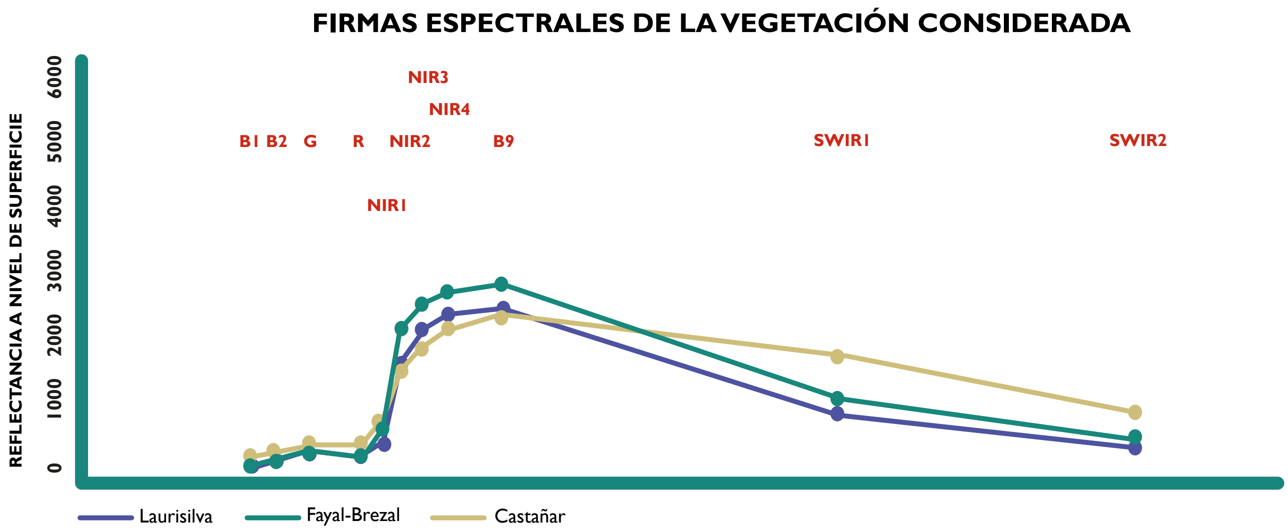


Figure 22. Spectral path of the canopies under consideration for February 2019

Figure 23 illustrates the detection of chestnut patches, which are a conspicuous feature of the study area. Furthermore, it can be observed that these formations have expanded their spatial distribution towards the south, in Breña Baja, situated on the spurs of the Cumbre Nueva ridge facing east. This area is currently classified as a potential laurel forest domain and is characterised by fayal-brezal vegetation. In the north-eastern sector of the island, the identified patches of chestnut are of lesser importance, as are those located in humid pine forest.

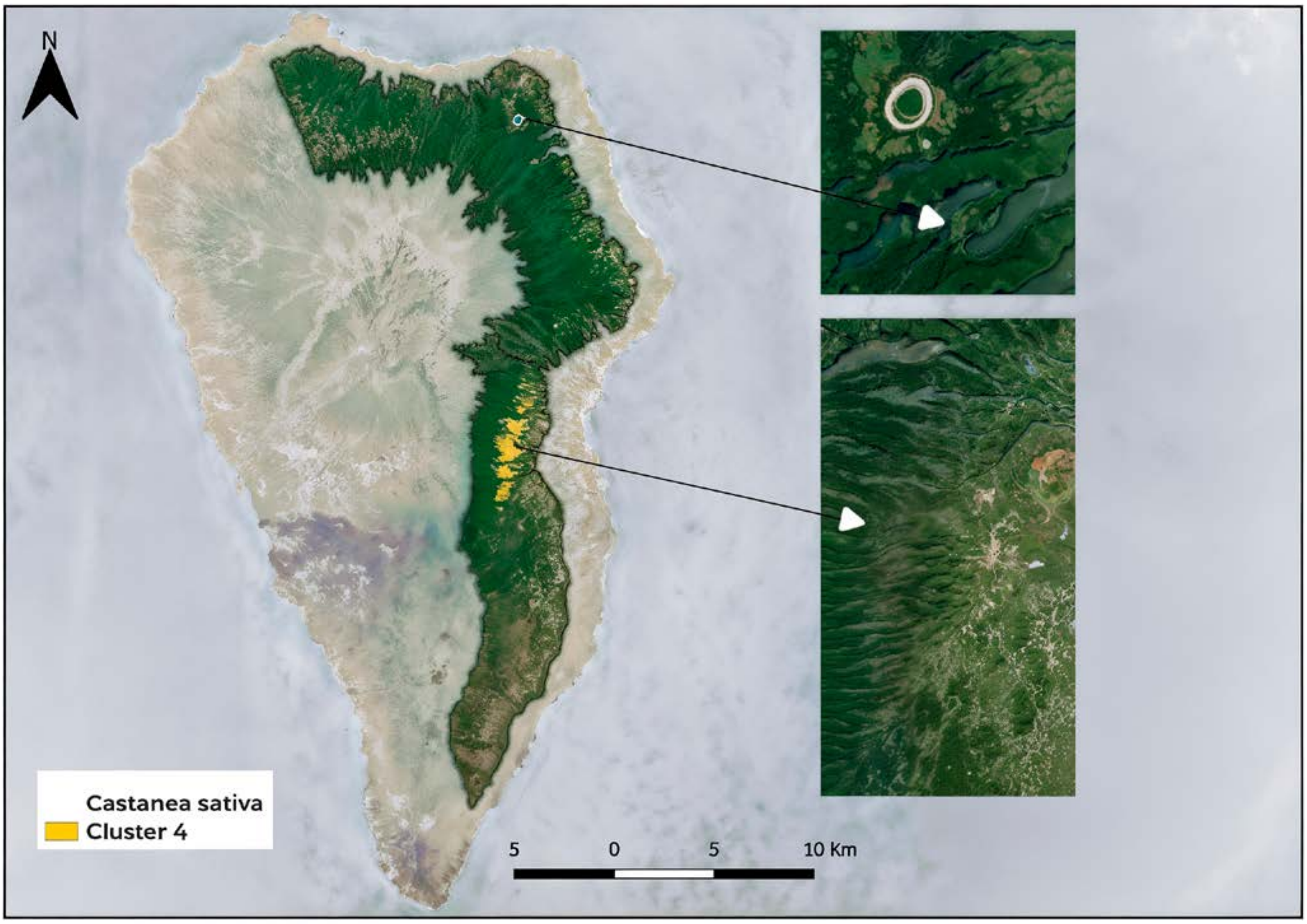


Figure 23. Localised chestnut patches using PCA + K-means.

Table 4 presents a comparison between the surface area obtained through the methodology described above and that established by del Arco and colleagues in 2006 in the Vegetation Map of the Canary Islands. The area corresponding to chestnut patches has increased by 16 hectares in the study area in 2019. This expansion has occurred primarily at the expense of the fayal-brezal, although it has also occurred in areas belonging to the humid laurel forest.

Chestnut Patches	Área (ha)
del Arco *et al.*, (2006)	384
Clúster 4 (2019)	400

Table 4. The study area was characterised by a high degree of chestnut tree cover, which was then compared with the real vegetation of La Palma as presented in the work of Del Arco *et al.*, (2006).

This methodology enables the invasion process of a deciduous species in the habitat of interest to be quantified and monitored in real time, obviating the need for complex supervised classifications. These typically entail the selection of a substantial number of training areas, the application of an appropriate classifier algorithm and its calibration, a validation process and a post-classification correction of the result. It is important to note that a background knowledge of remote sensing and classification techniques is inherent to this process, as is an understanding of the study area and its land cover.

4. OTHER REMARKS

In this last section, a number of additional points are made about the different remote sensing techniques, the aspects they cover, their limitations, special cases to be considered and complementary resources.

- **Notes on the granularity of analysis**

The study of classical spectral information provides valuable insights into the quantity of biomass, the physiological state of the vegetation, its yield and photosynthetic activity. It can even assist in distinguishing important vegetation units within a given territory. Furthermore, it represents a fundamental technique for supervised classifications, with information derived from satellites and subsequent calculation of vegetation indices. Conversely, hyperspectral devices (UAVs) or very high resolution imagery (e.g., RapidEye or Quickbird) can assist in the delineation of spectral signatures by species, thereby reducing the granularity of the analysis from large vegetation units to the mapping and study of communities and even taxa and their distribution in space (Massetti *et al.*, 2016). Conversely, if the objective of the study is to draw inferences about other ecosystem characteristics, such as maturity, structure, vertical complexity, and plant stratum classification for fuel modelling, the available technology options are limited to LiDAR (Laser Imaging Detection and Ranging) and SAR (Synthetic Aperture Radar) (Parada-Díaz *et al.*, 2022).

- **Topographical Effect**

Topography can occasionally present challenges when utilising satellite imagery and remote sensing techniques. This is a limiting factor that is assumed by the very principles on which these techniques are based. The sun's position (solar elevation) at the time of sensor capture is a differential factor. It is possible that certain unexposed and topographically complex areas may not be covered, resulting in the absence of reflectance and the creation of absolute shadows.

In certain instances, the necessity of the studio necessitates the utilisation of specific images on a designated date. Consequently, these types of issues must be addressed. Some experts propose the utilisation of images captured during the summer months, as this is the season of the year when the incidence of solar radiation is more vertical, thereby neutralising the effect of certain shadows. However, due to the disposition of the sea of clouds during this period, where it reaches its highest frequency and accumulation on the slopes exposed to the trade winds, there may be a reduction in the availability of satellite images without cloud interference. The implementation of topographical corrections has been demonstrated to enhance the efficacy of both supervised and semi-automated classification processes. The solution to such situations may lie partly in comparisons between bands acquired on similar dates but in different years, which have the same solar position. This will neutralise the effect of topography. Conversely, for images acquired during different times of the year, lighting differences represent a limiting factor.

- **Threshold-Based Methods**

As Chuvieco (2008) notes, most change detection techniques return continuous value surfaces, where modifications between images are presented as a gradual scale of change rather than with the desired binary categories of change/stability. In many cases, it is the responsibility of the interpreter to distinguish between areas of change and non-change and to corroborate through fieldwork the meaning and significance of change. It is possible to evaluate changes between images using alternative methods, such as the segmentation of the resulting images or the nature and shape of the histogram of values. In theory, bimodal profiling involves the classification of pixels into two distinct categories: stable and dynamic. While the distinction between these two modes is typically gradual and not abrupt, the interpretation of this categorisation is often subjective and open to interpretation.

One of the key points reiterated in this document is the necessity for a scientific and quantitative approach to this issue. Consequently, the significance of comprehensive vegetation mapping as a preliminary step has been emphasised. The selection of a threshold value must encompass both the capacity to accommodate the considerable variability of values associated with the proposed vegetation index and the ability to distinguish the desired land cover, ensuring an equilibrium between the ratio of errors of omission and commission. The latter issue is challenging to address without the accurate identification of areas that correspond to habitat and areas that do not.

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Online Resources

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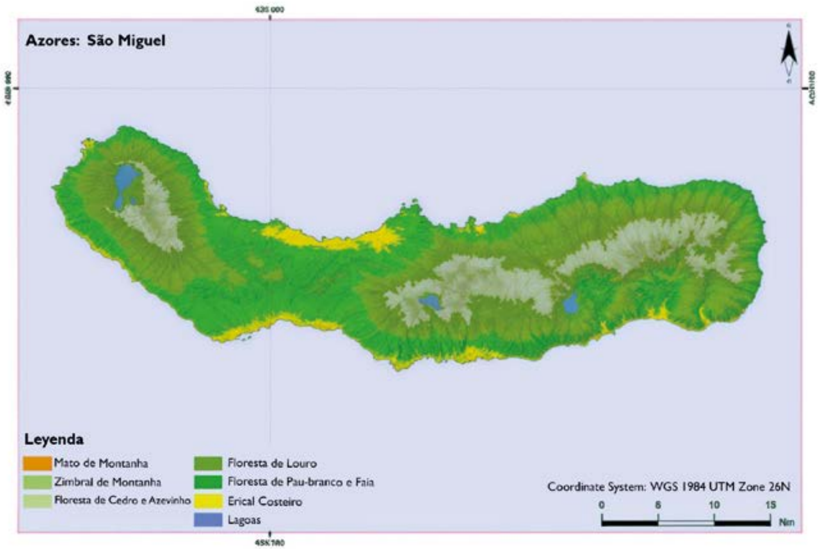
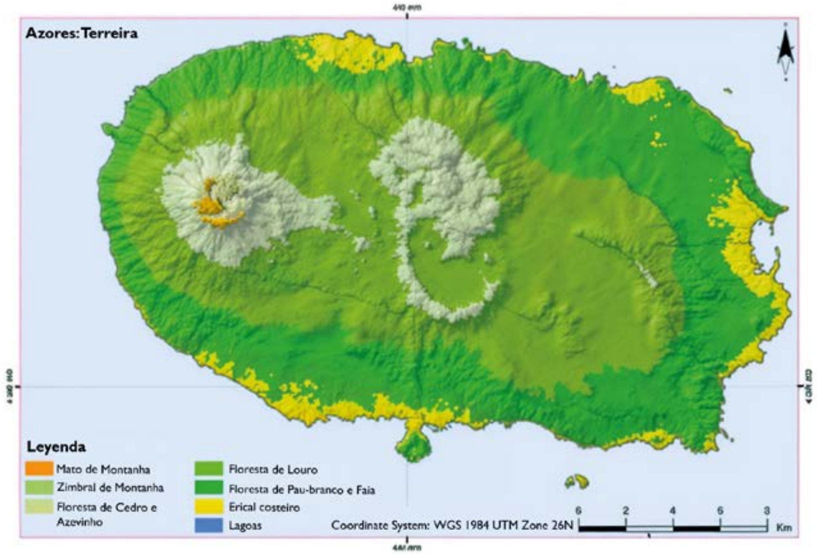
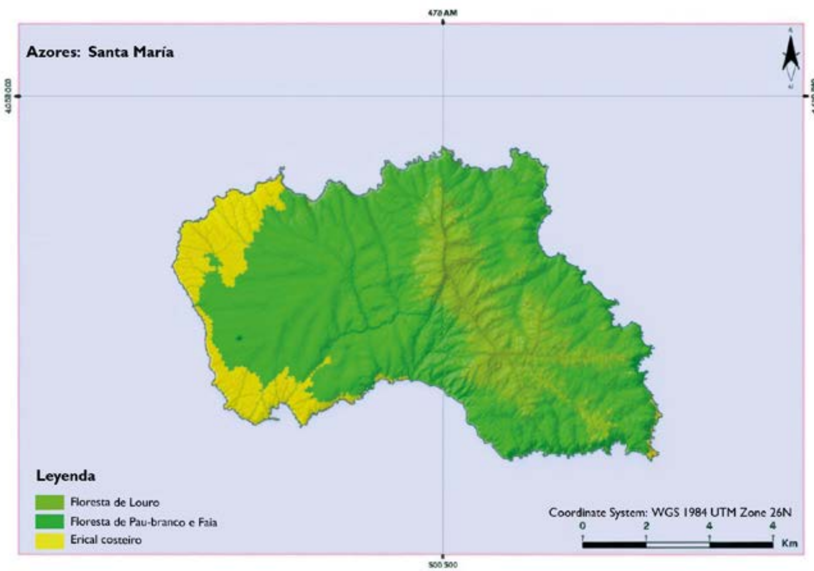
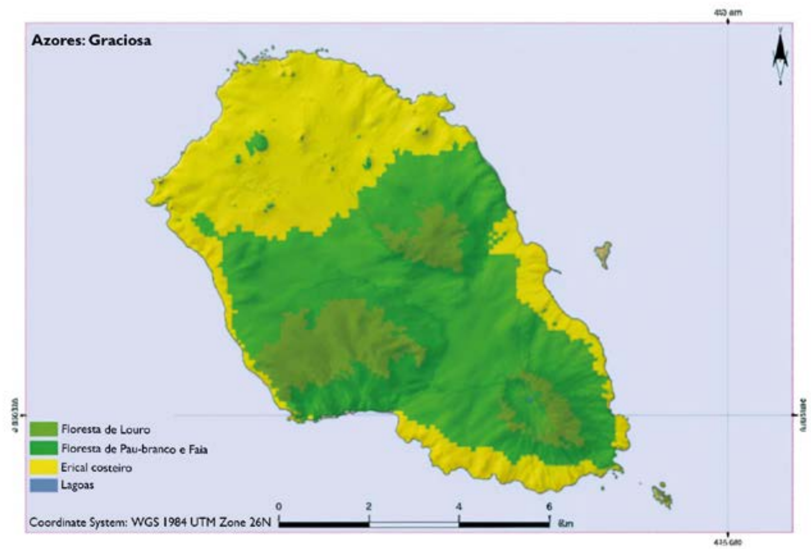
Appendix 4. Potential distribution of the different 9360 subtypes in the different islands of the Macaronesian Biogeographical Region

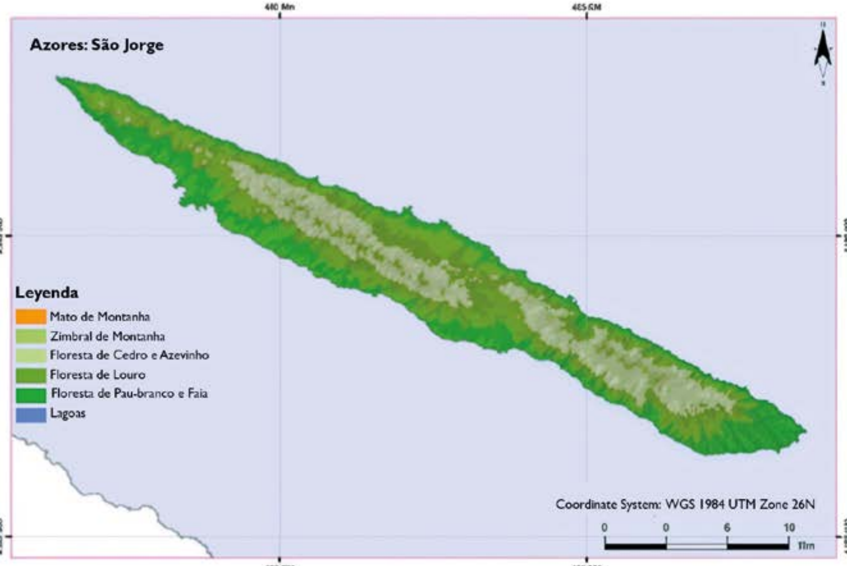
(Source: Fernández-Palacios *et al.*, 2017 and references therein)







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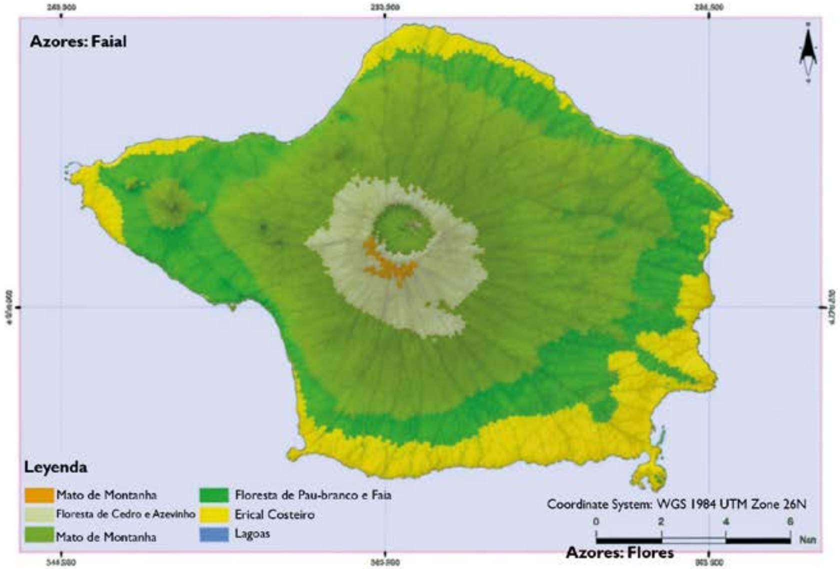
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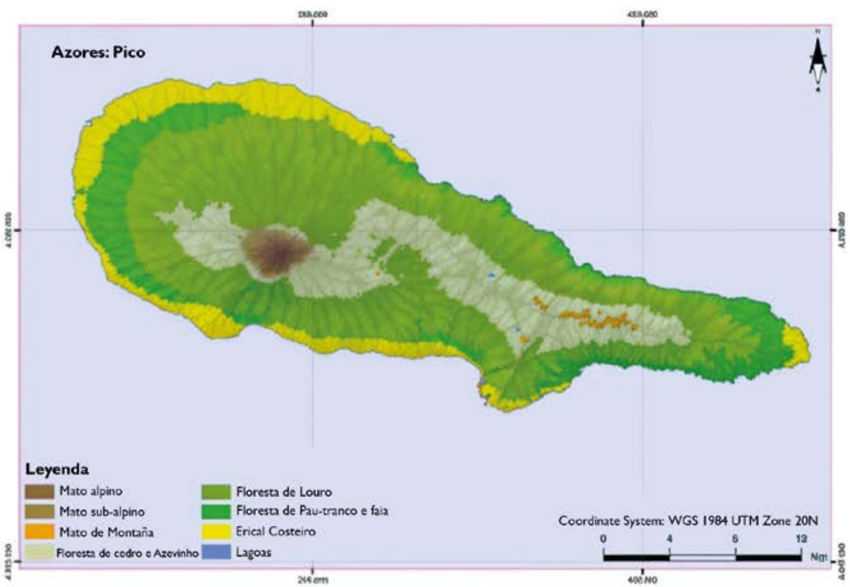
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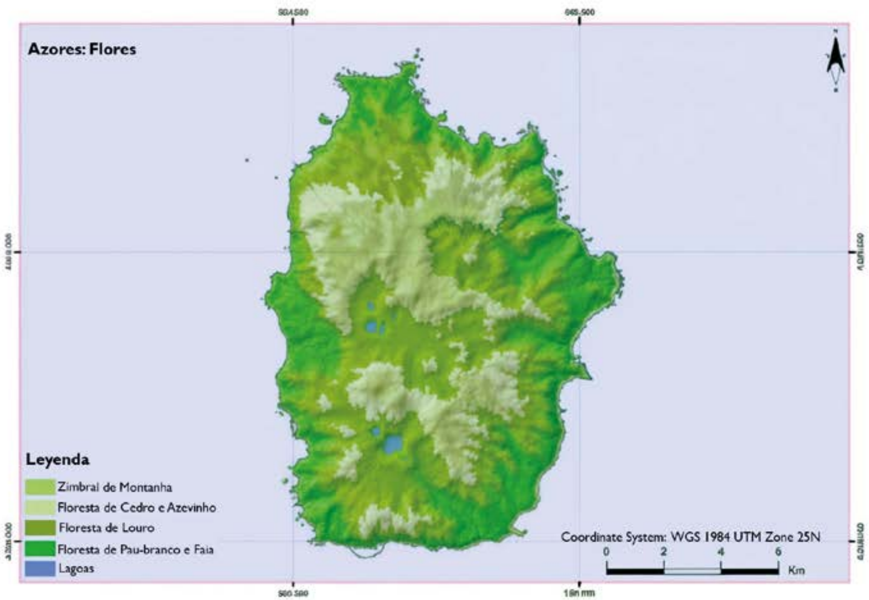
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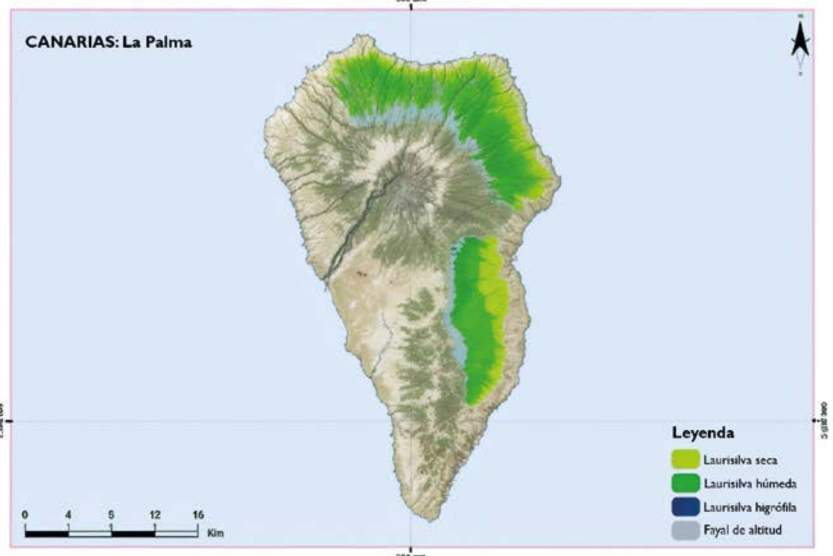
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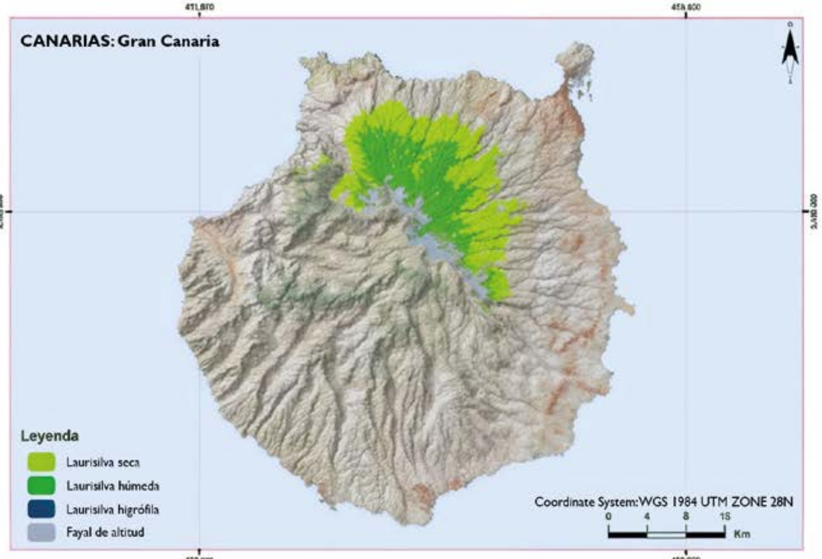
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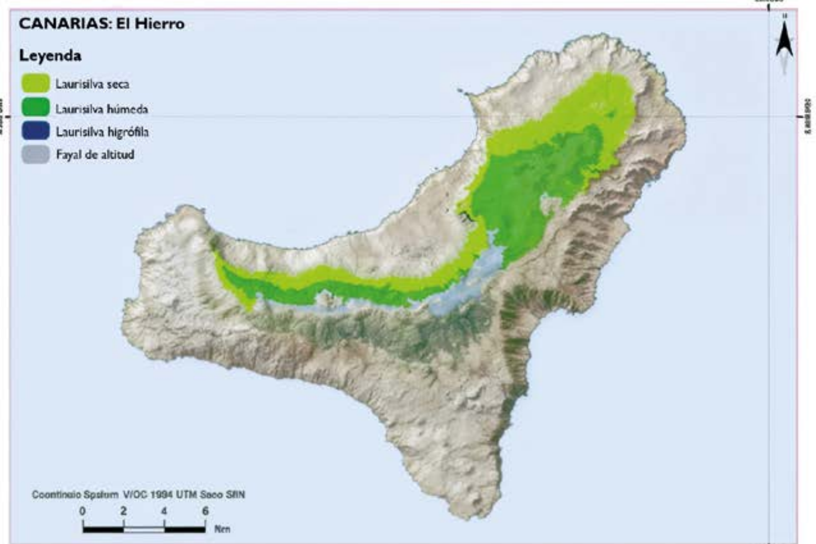
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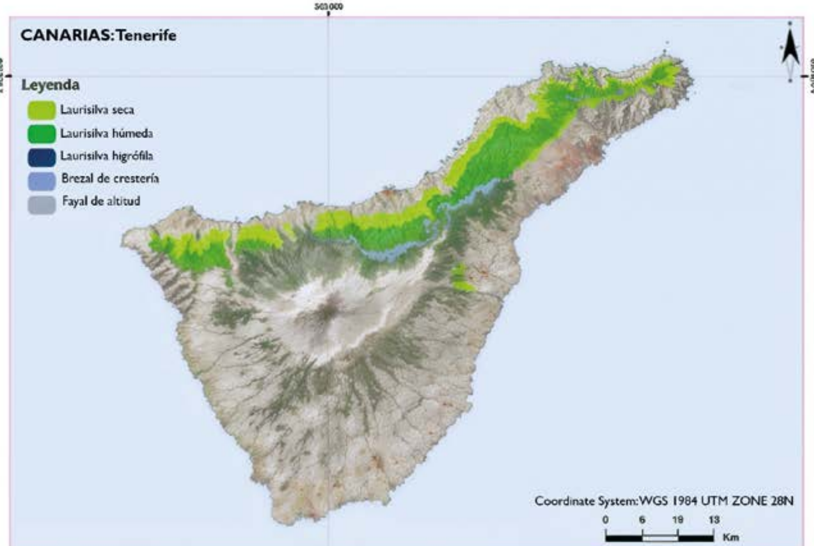
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Leyenda
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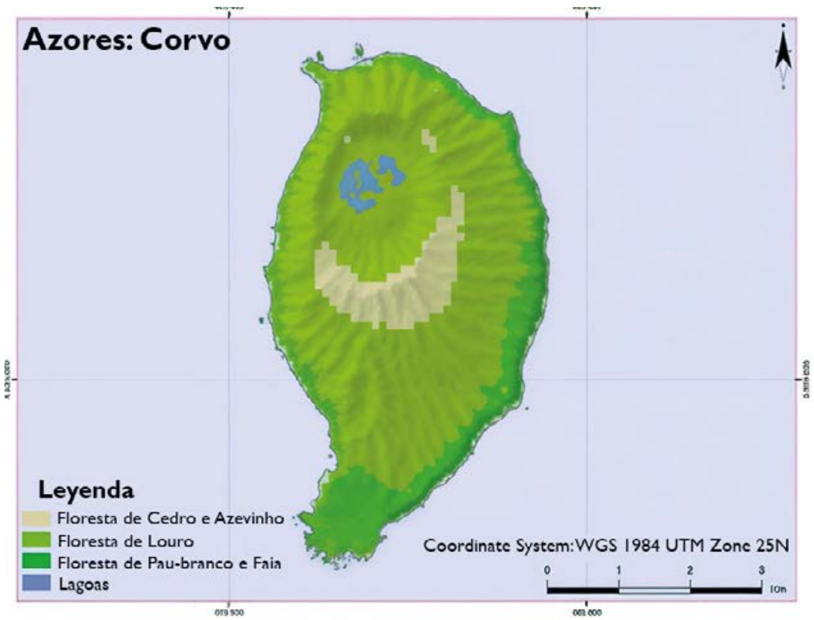
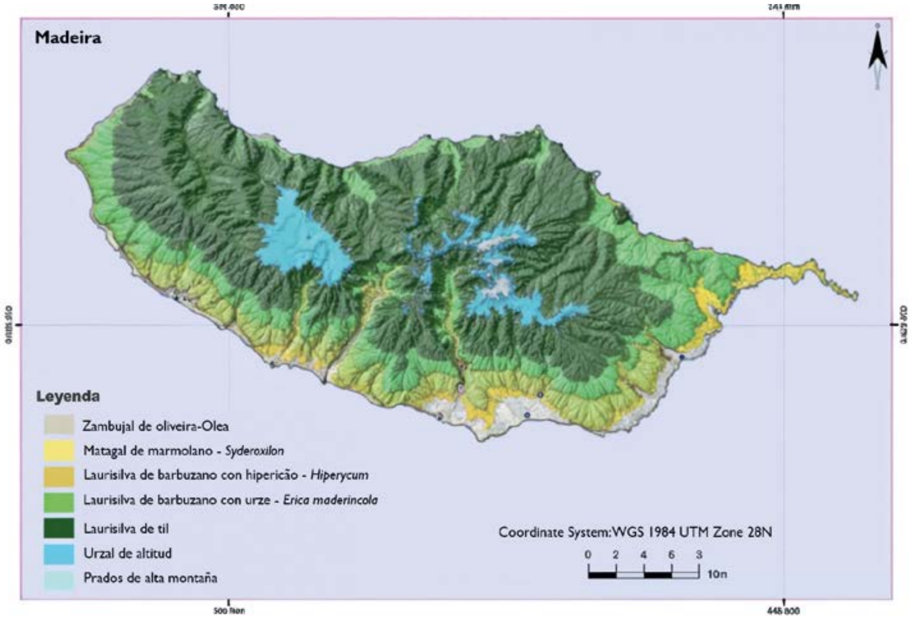
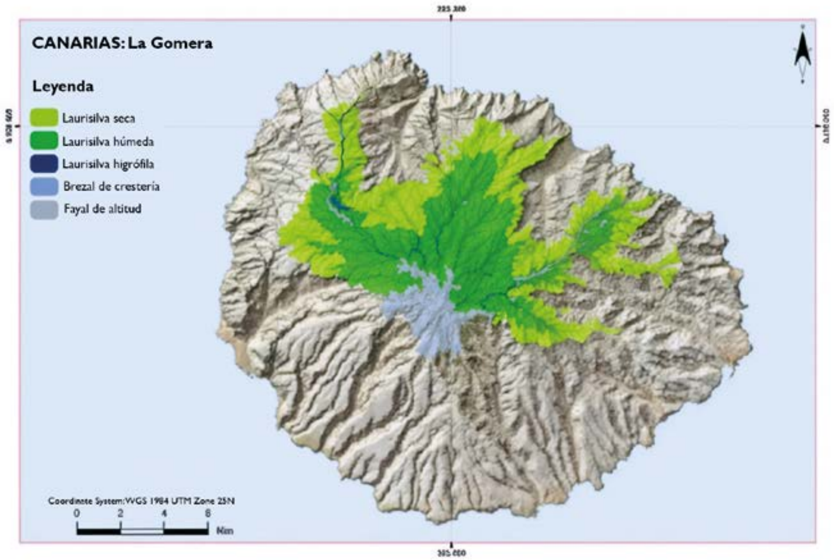
Brezal de crestería
Fayal de altitud
Coordinate System: WGS 1984 UTM ZONE 28N
Km

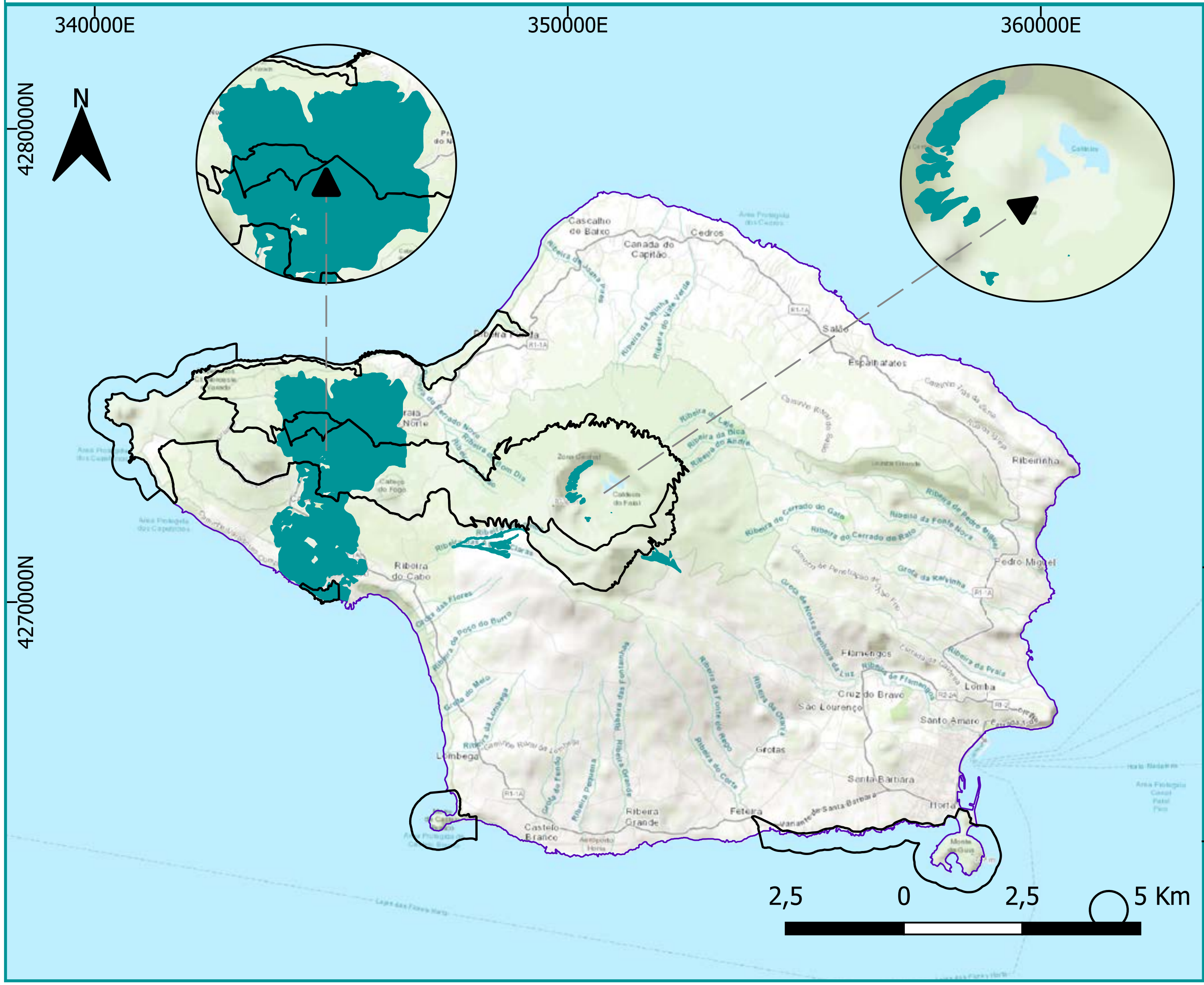

Azores: Corvo
Leyenda
Floresta de Cedro e Azevinho
Floresta de Louro
Floresta de Pau-branco e Faia
Lagoas
Coordinate System: WGS 1984 UTM Zone 25N
0
1
2
3

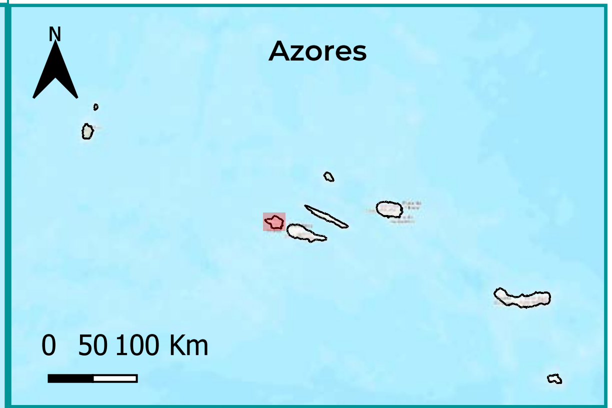

Madeira
Leyenda
Zambujal de oliveira-Olea
Matagal de marmolano - Syderoxilon
Laurisilva de barbuzano con hipericão - Hiperycum
Laurisilva de barbuzano con urze - Erica maderincola
Laurisilva de til
Urzal de altitud
Prados de alta montaña
Coordinate System: WGS 1984 UTM Zone 28N
0
2
4
6
3


CANARIAS: La Gomera
Leyenda
Laurisilva seca
Laurisilva húmeda
Laurisilva higrófila
Brezal de crestería
Fayal de altitud
Coordinate System:WGS 1984 UTM Zone 25N
0
2
4
6
Km

Appendix 5. Maps of the current 9360 distribution and limits of the Natura 2000 protected areas in Macaronesia.

Faial (Azores)





Projection: PTRA08 / UTM zone 26N

Name : Faial

Total Area (ha): 17305.53

Natura 2000 Network

NATURA 2000

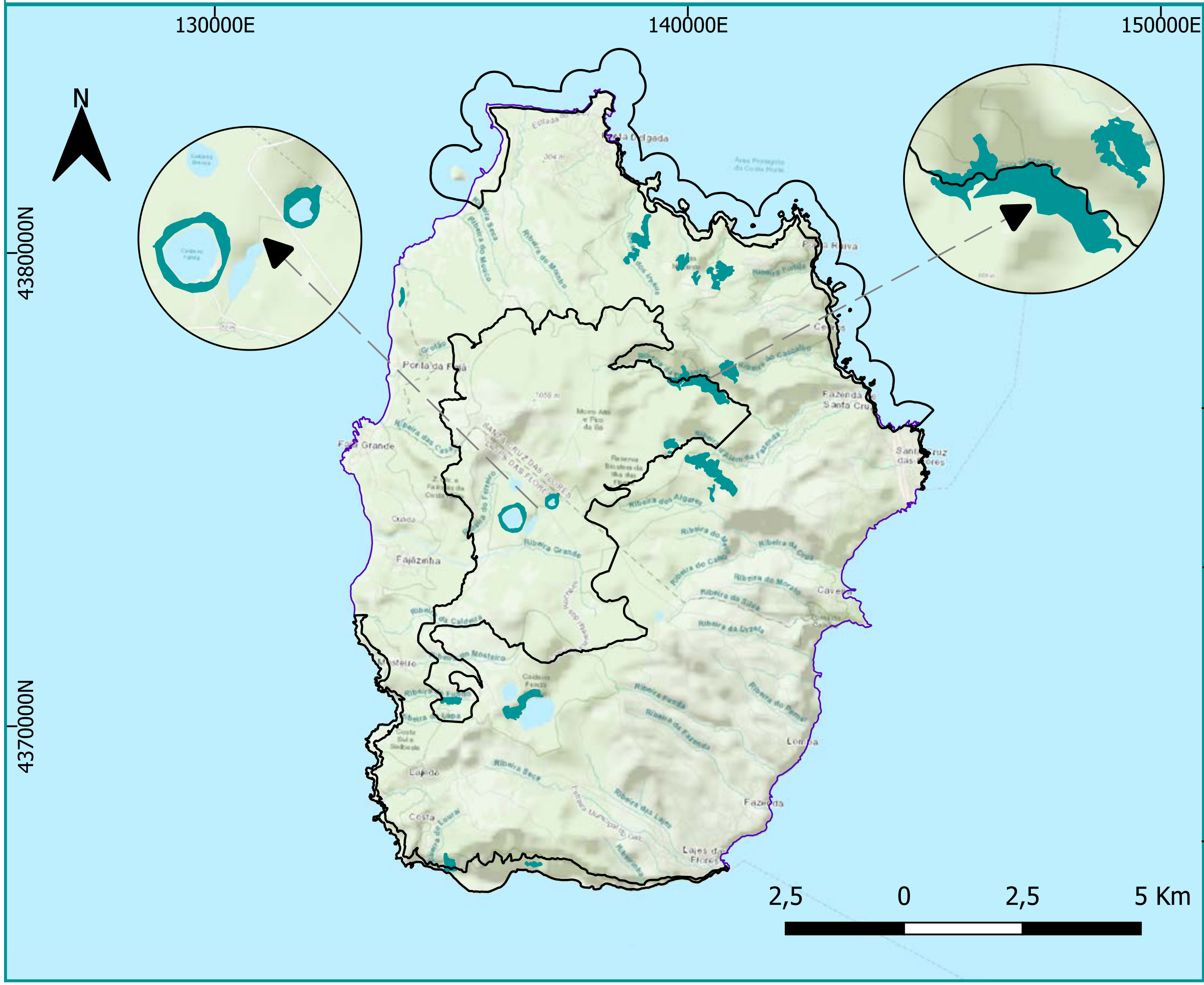
https://natura2000.eea.europa.eu/sitecode=PTFAI0004

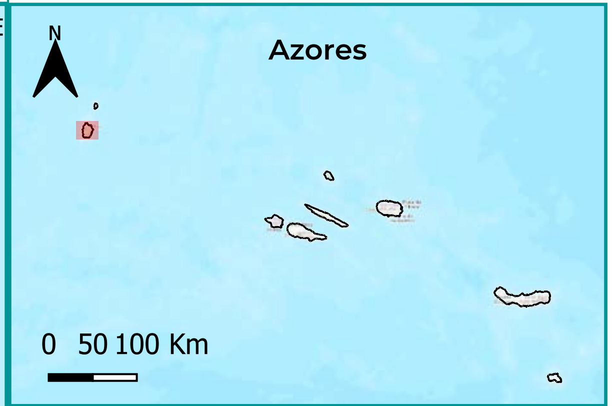
Natura 2000

9360* - Macaronesian laurel forests

9360 area protected (ha) in N2000	Percentage of island 9360 protected	Contribution (%) to archipelago 9360 protected area
300,89	34,38	5,3

Flores (Azores)





Projection: PTRA08 / UTM zone 26N

Name : Flores

Total Area (ha): 14096.22

Natura 2000 Network

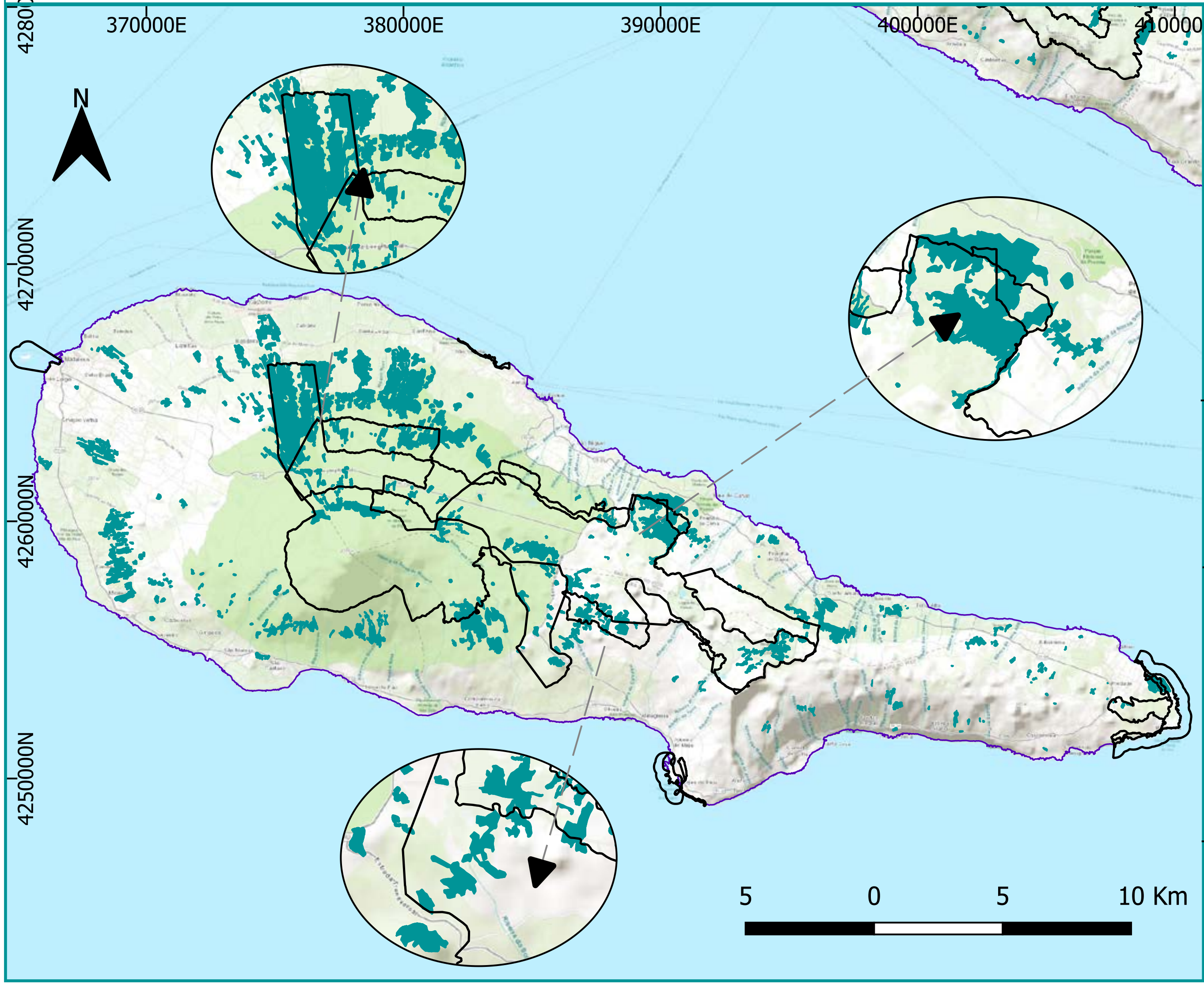
https://natura2000.eea.europa.eu/sitecode=PTFLO0002

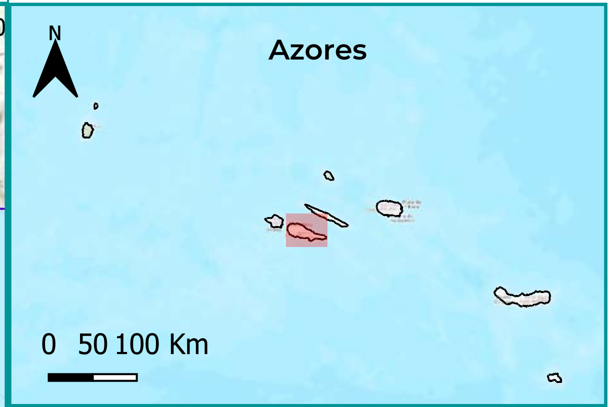
Natura 2000

9360* - Macaronesian laurel forests

9360 area protected (ha) in N2000	Percentage of island 9360 protected	Contribution (%) to archipelago 9360 protected area
45,73	31,95	0,81

Pico (Azores)





Projection: PTRA08 / UTM zone 26N

Name : Pico

Total Area (ha): 44479.53

Natura 2000 Network

NATURA 2000

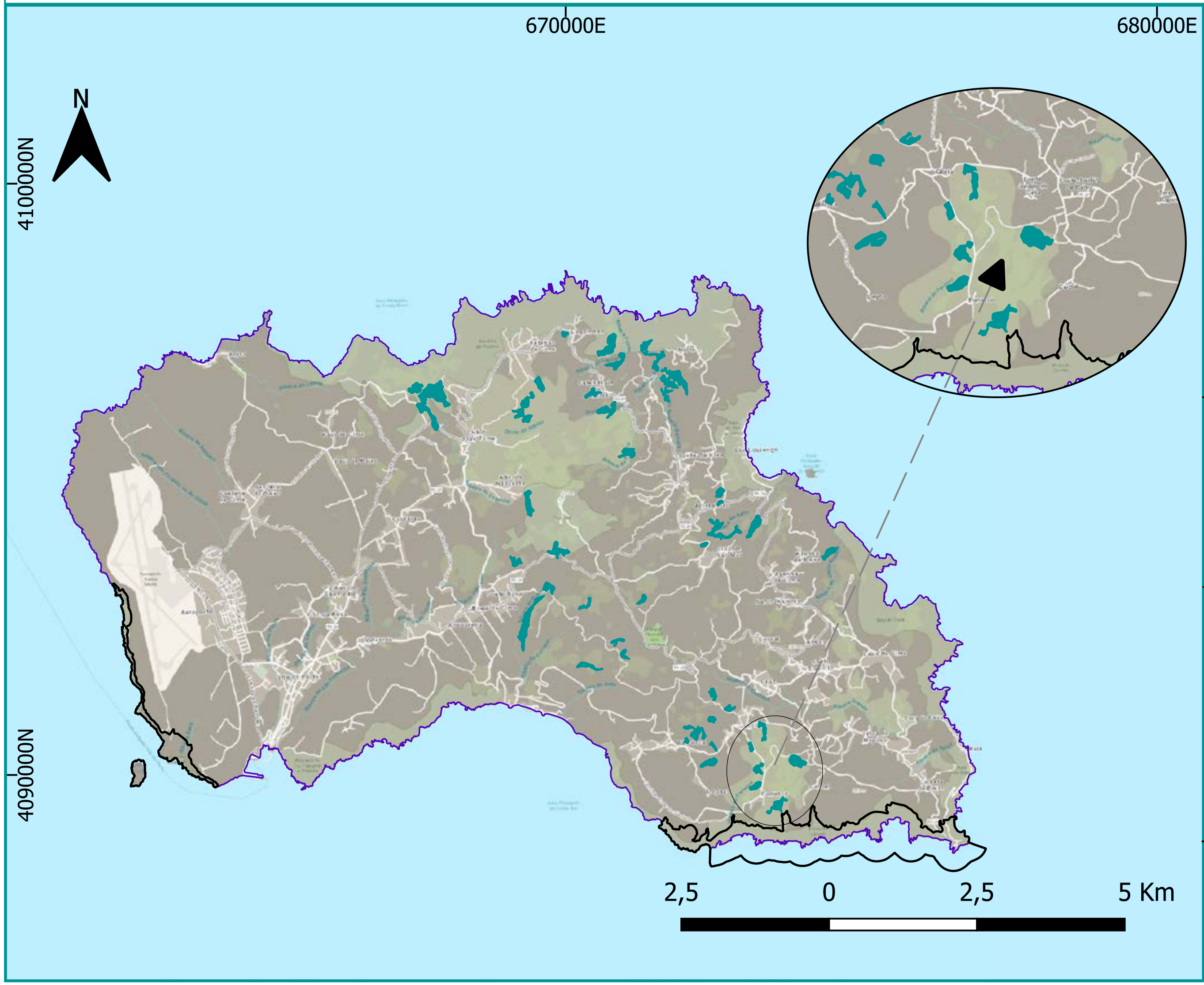
https://natura2000.eea.europa.eu/sitecode=PTPIC0009

Natura 2000

9360* - Macaronesian laurel forests

9360 area protected (ha) in N2000	Percentage of island 9360 protected	Contribution (%) to archipelago 9360 protected area
1250,49	42,97	22,02

Santa Maria (Azores)



Projection: PTRA08 / UTM zone 26N

Name : Santa Maria

Total Area (ha): 9688.74

Natura 2000 Network

NATURA 2000

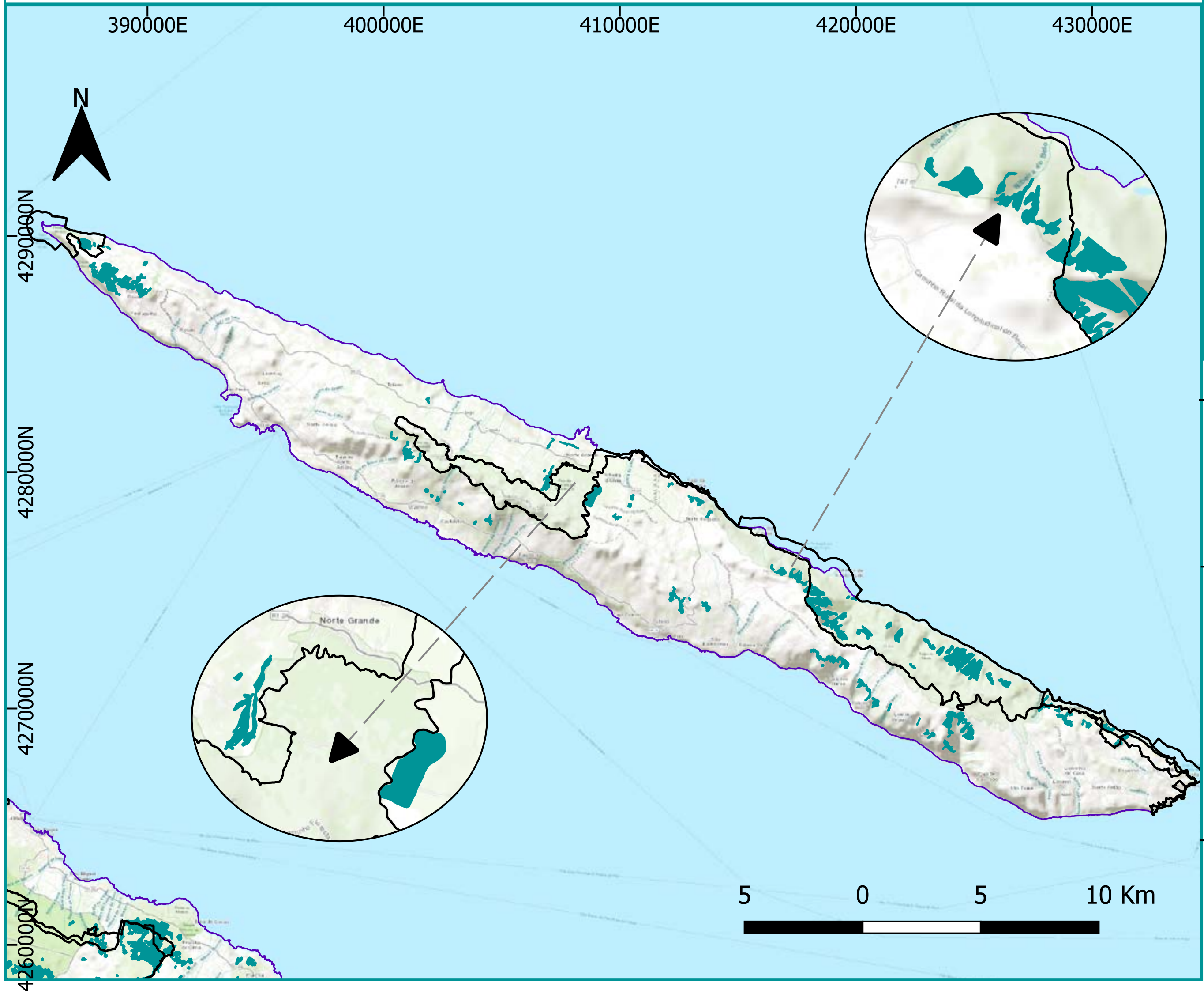
https://natura2000.eea.europa.e
sitecode=PTSMA0022

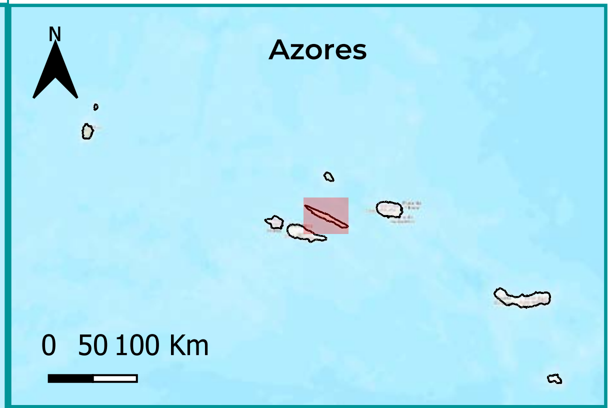
Natura 2000

9360* - Macaronesian laurel forests

9360 area protected (ha) in N2000	Percentage of island 9360 protected	Contribution (%) to archipelago 9360 protected area
0	0	0

São Jorge (Azores)





Projection: PTRA08 / UTM zone 26N

Name : São Jorge

Total Area (ha): 24364.78

Natura 2000 Network

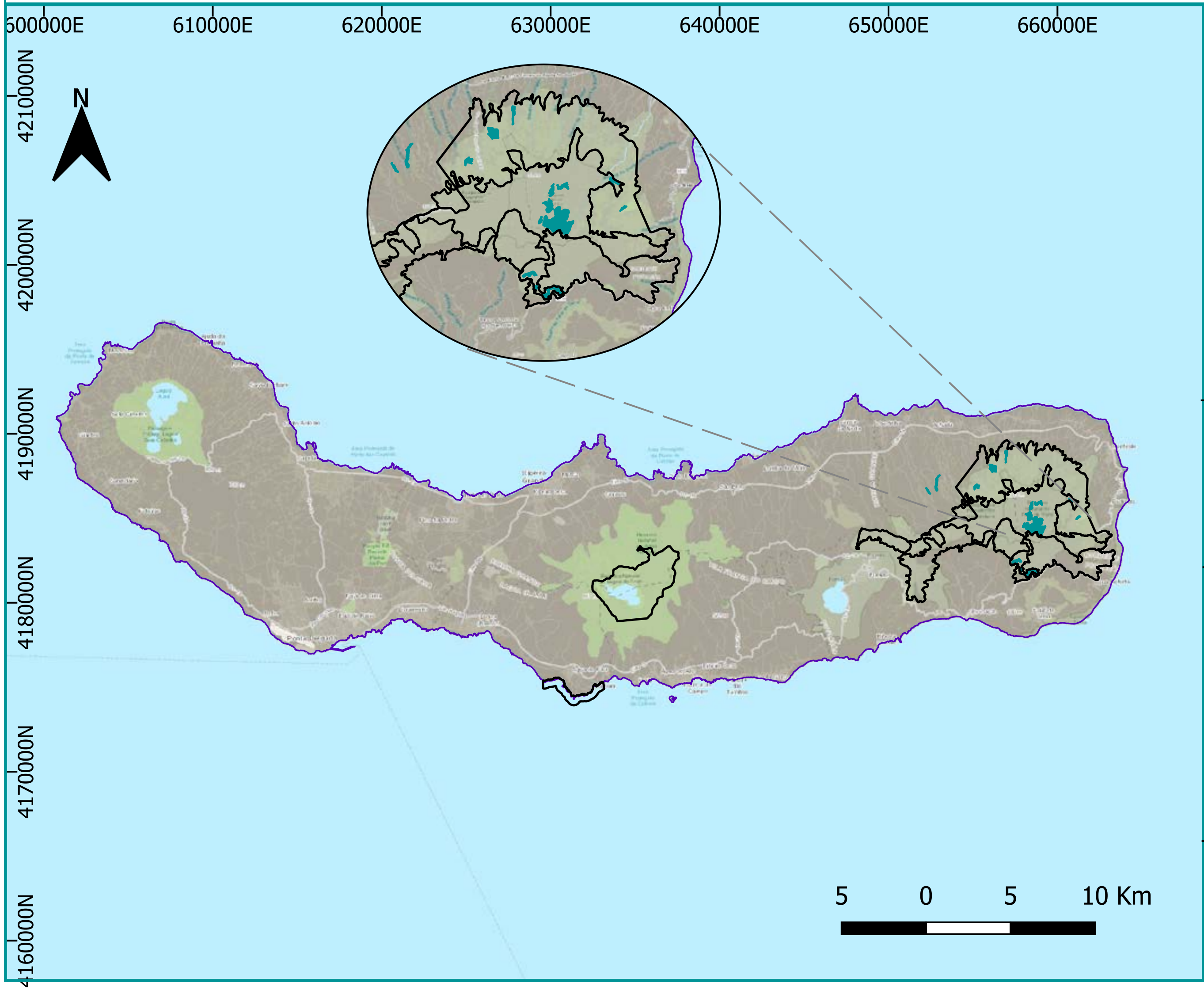
https://natura2000.eea.europa.e
sitecode=PTJOR0014

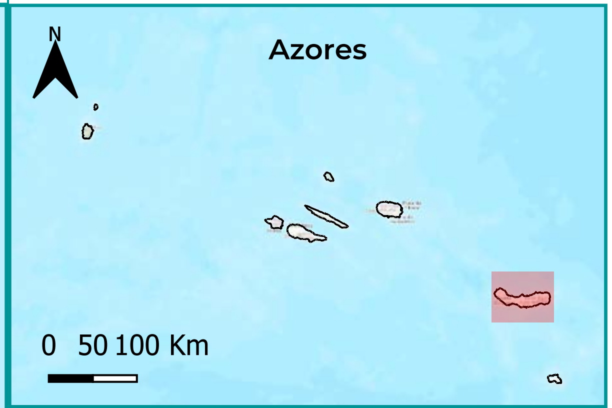
Natura 2000

9360* - Macaronesian laurel forests

9360 area protected (ha) in N2000	Percentage of island 9360 protected	Contribution (%) to archipelago 9360 protected area
278,06	42,77	4,9

São Miguel (Azores)





Projection: PTRA08 / UTM zone 26N

Name : São Miguel

Total Area (ha): 74457.5

Natura 2000 Network

NATURA 2000

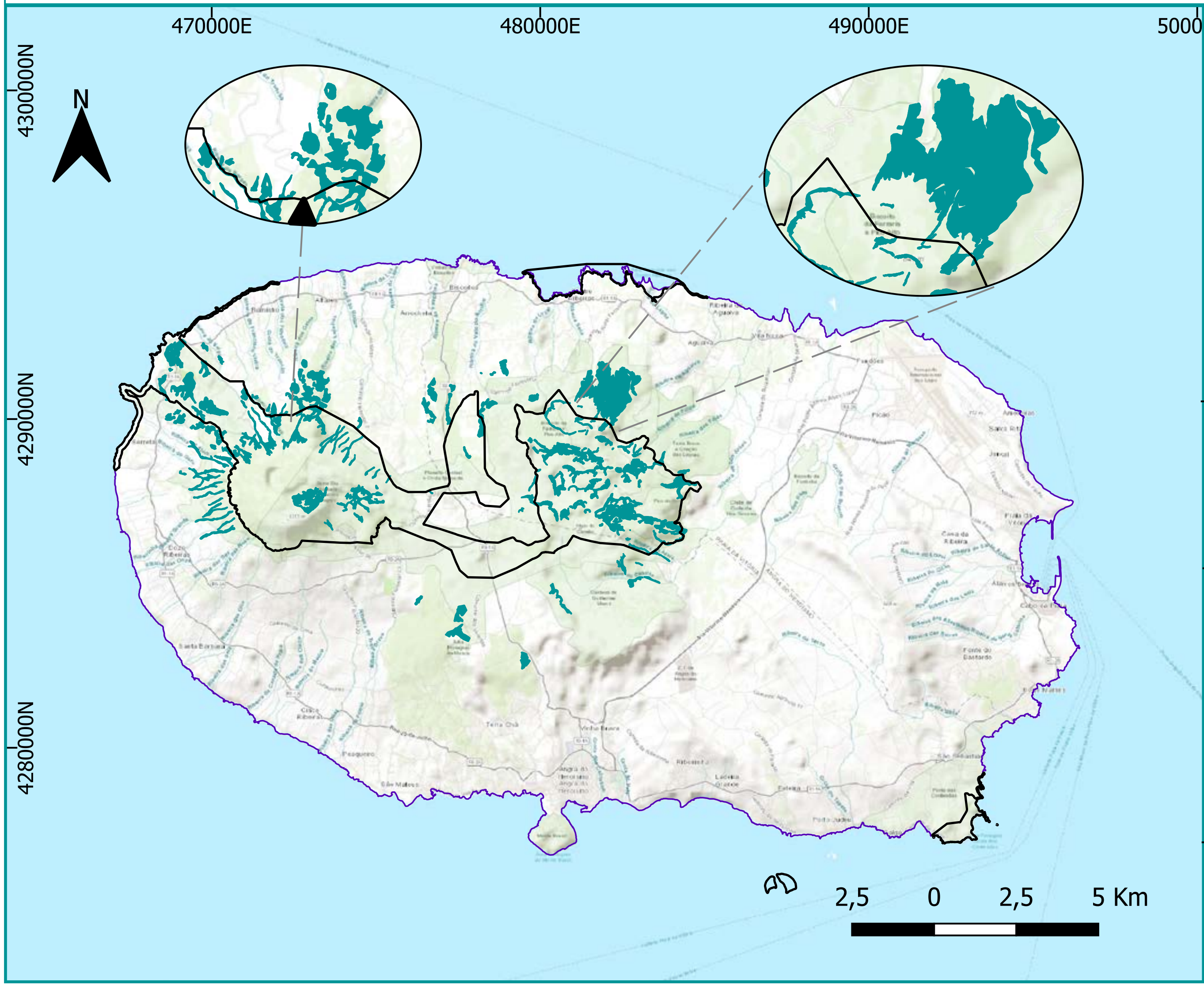
https://natura2000.eea.europa.eu sitecode=PTMIG0024

Natura 2000

9360* - Macaronesian laurel forests

9360 area protected (ha) in N2000	Percentage of island 9360 protected	Contribution (%) to archipelago 9360 protected area
132,6	93,14	2,33

Terceira (Azores)



Projection: PTRA08 / UTM zone 26N

Name : Terceira

Total Area (ha): 40026.72

Natura 2000 Network

NATURA 2000

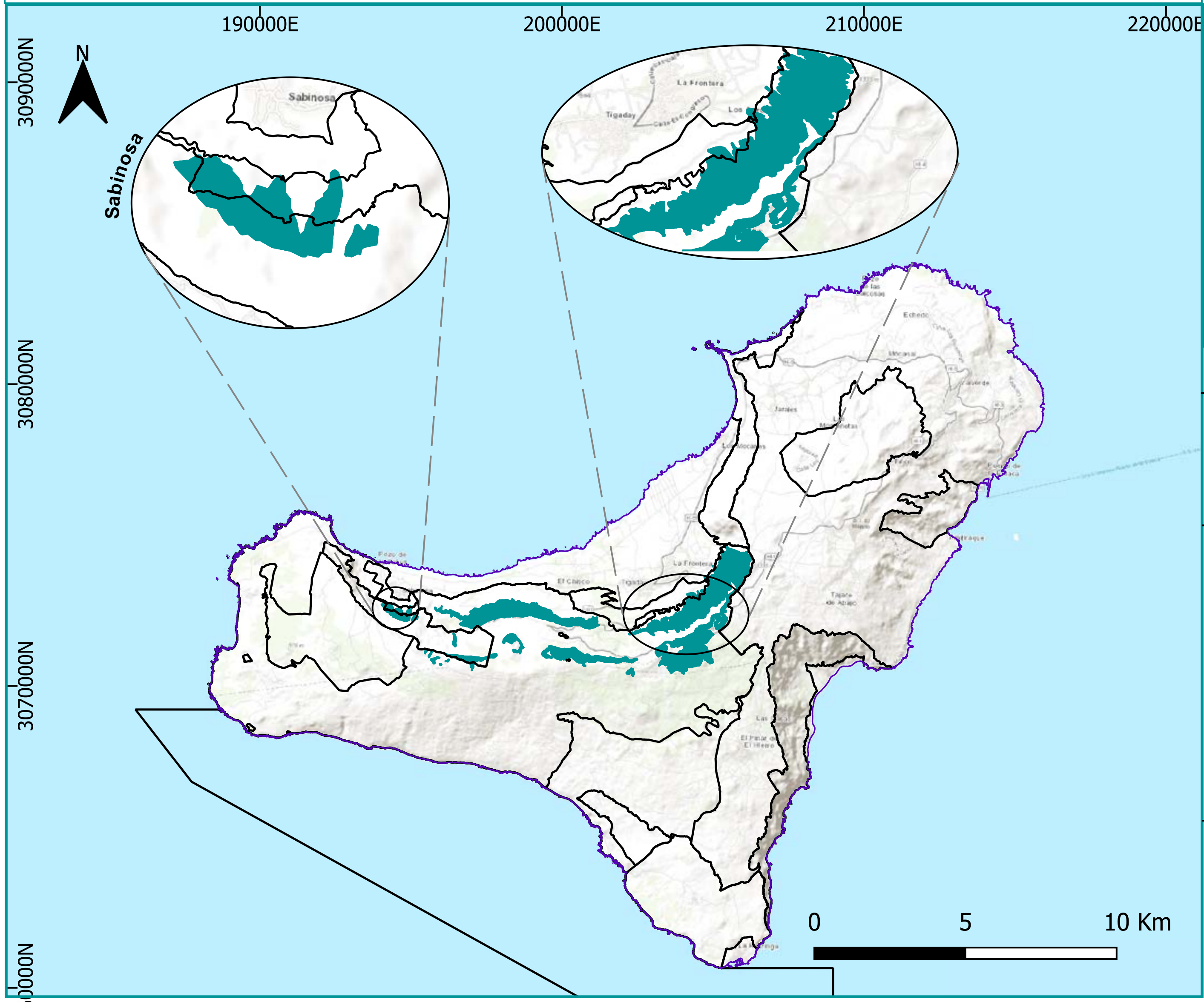
https://natura2000.eea.europa.eu/sitecode=PTTER0017

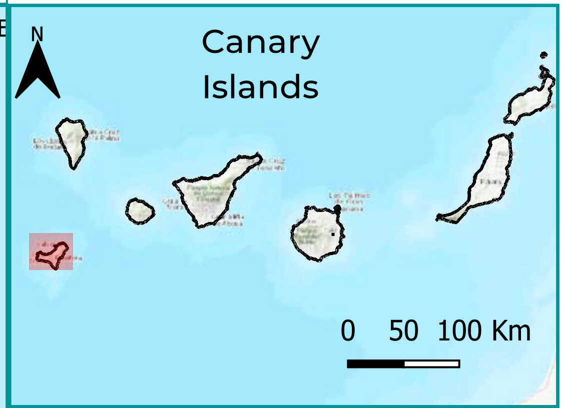
Natura 2000

9360* - Macaronesian laurel forests

9360 area protected (ha) in N2000	Percentage of island 9360 protected	Contribution (%) to archipelago 9360 protected area
436,08	51,4	7,68

El Hierro (Canary Islands)





Projection: WGS 84 / UTM zone 28N

Island name : El Hierro

Total Area (ha): 27800

Natura 2000 Network

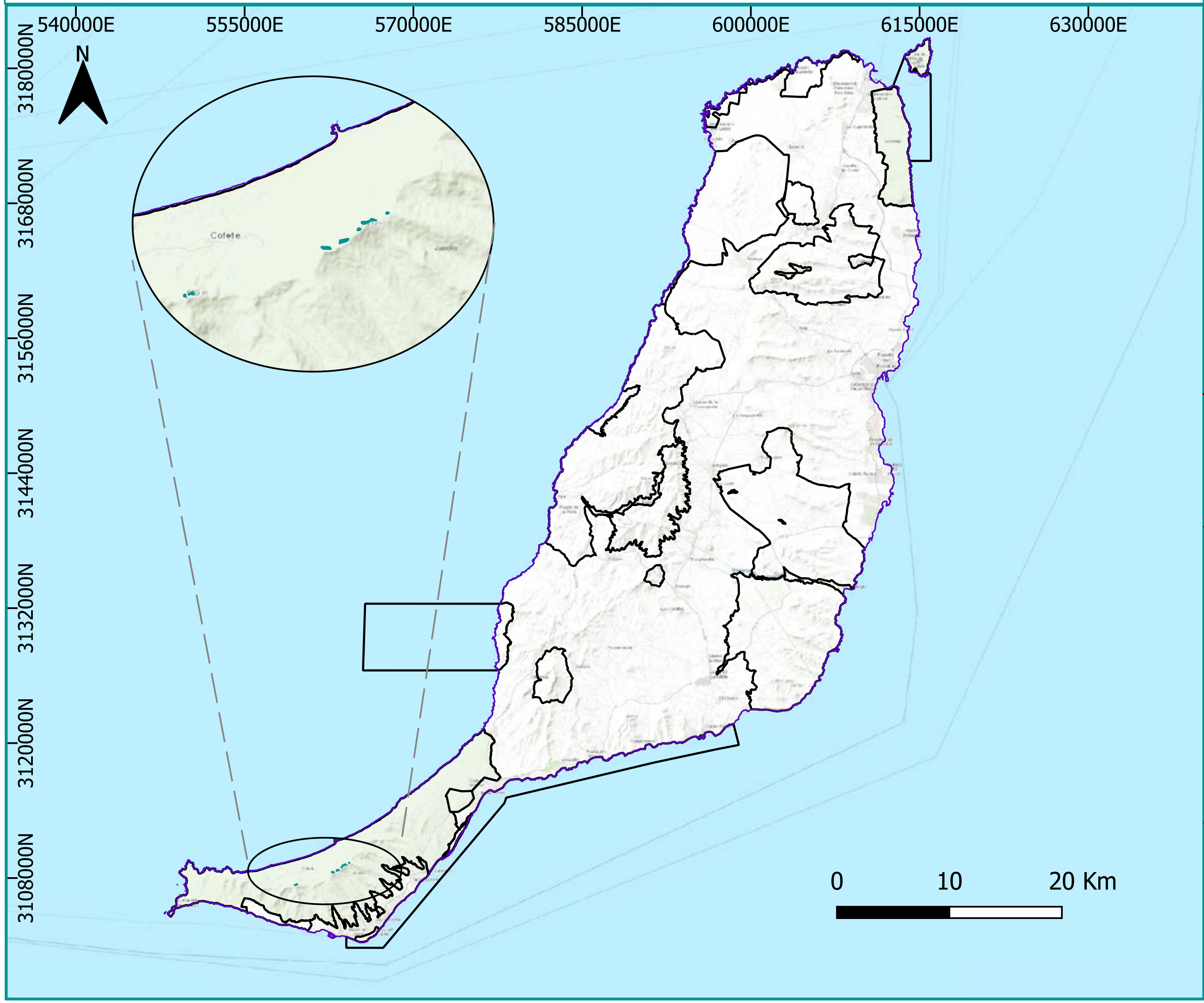
https://natura2000.eea.europa.eu/?sitecode=ES7020001

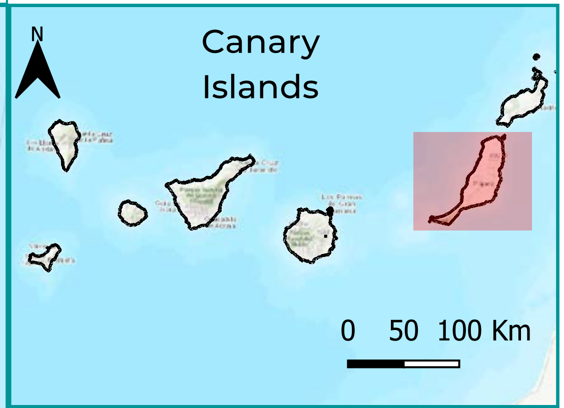
Natura 2000

9360 * Macaronesian laurel forests

9360 area protected (ha) in N2000	Percentage of island 9360 protected	Contribution (%) to archipelago 9360 protected area
794,52	99,72	7,72

Fuerteventura (Canary Islands)





Projection: WGS 84 / UTM zone 28N

Island name : Fuerteventura

Total Area (ha): 166000

Natura 2000 Network

NATURA 2000

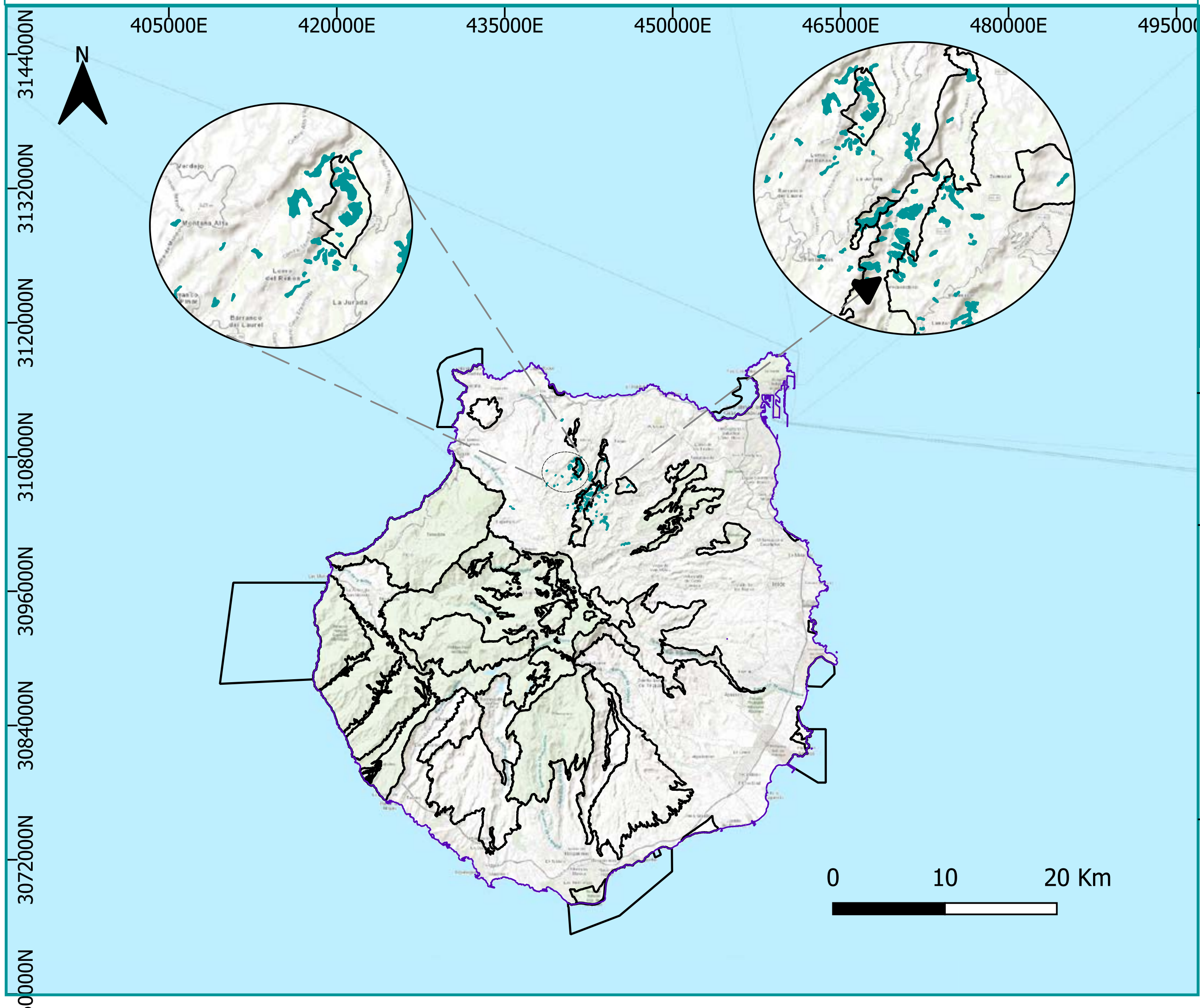
https://natura2000.eea.europa.eu/?sitecode=ES0000039

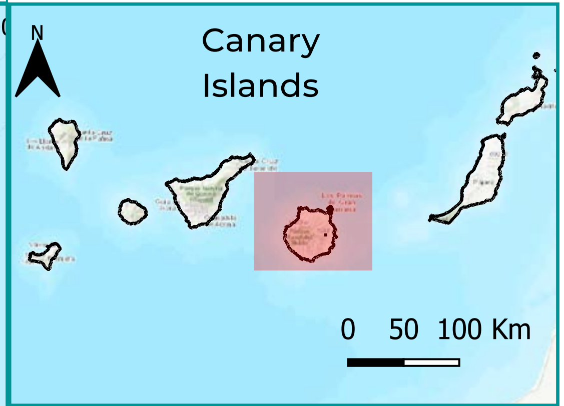
Natura 2000

9360 * Macaronesian laurel forests

9360 area protected (ha) in N2000	Percentage of island 9360 protected	Contribution (%) to archipelago 9360 protected area
4,51	100	0,04

Gran Canaria (Canary Islands)





Projection: WGS 84 / UTM zone 28N

Island name : Gran Canaria

Total Area (ha): 156000

Natura 2000 Network

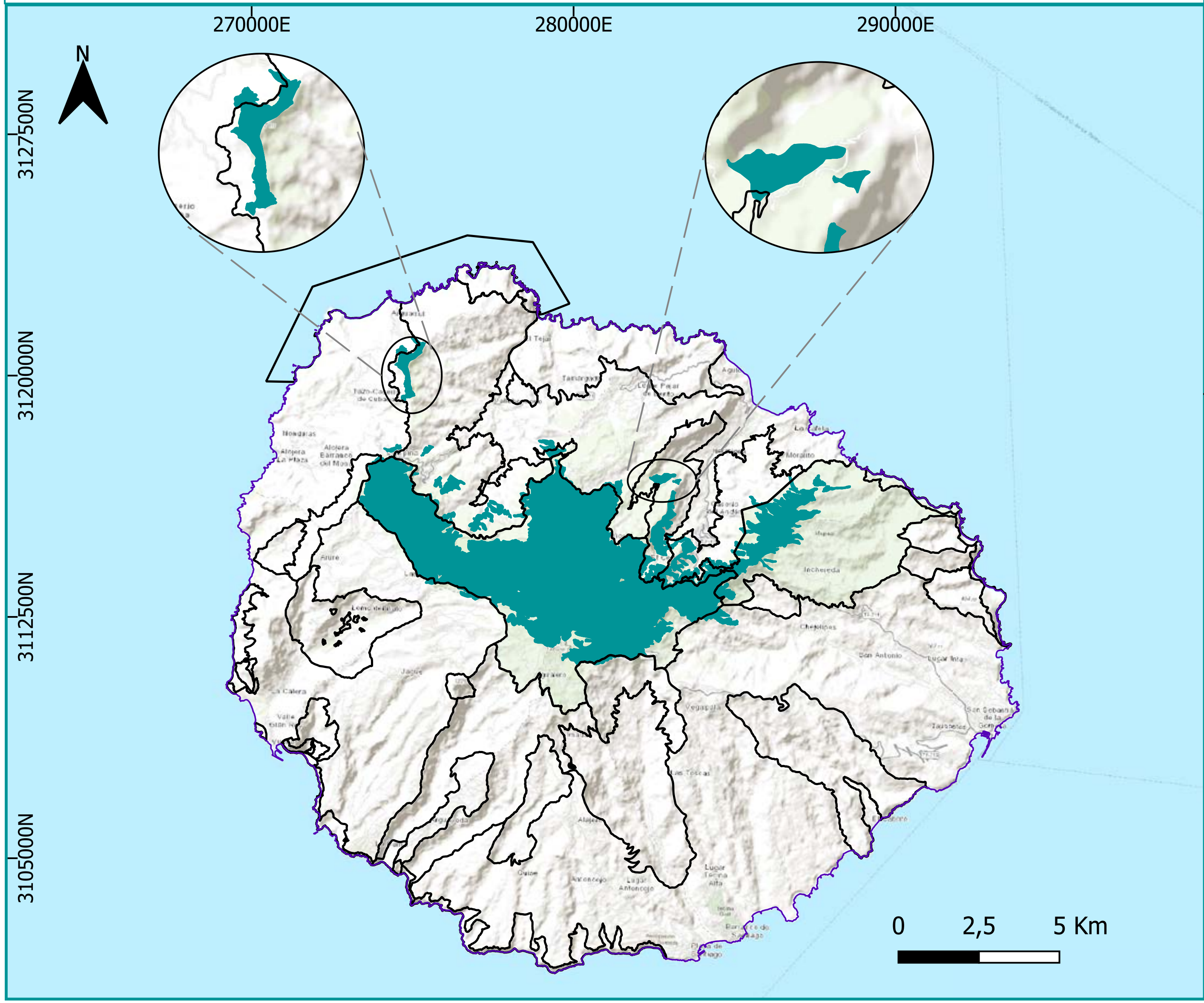
https://natura2000.eea.europa.eu/?sitecode=ES7010004

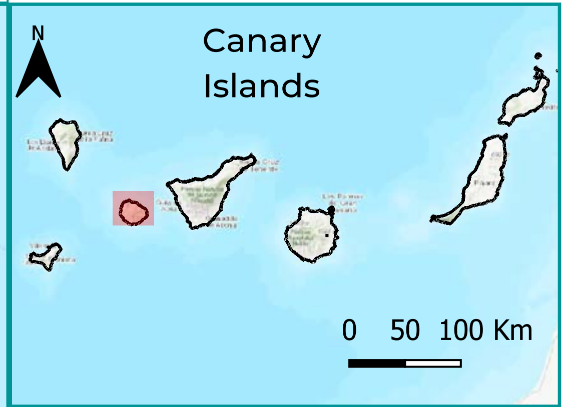
Natura 2000

9360 * Macaronesian laurel forests

9360 area protected (ha) in N2000	Percentage of island 9360 protected	Contribution (%) to archipelago 9360 protected area
75,49	45,7	0,73

La Gomera (Canary Islands)





Projection: WGS 84 / UTM zone 28N

Island name : La Gomera

Total Area (ha): 36980

Natura 2000 Network

https://natura2000.eea.europa.eu/?sitecode=ES0000044

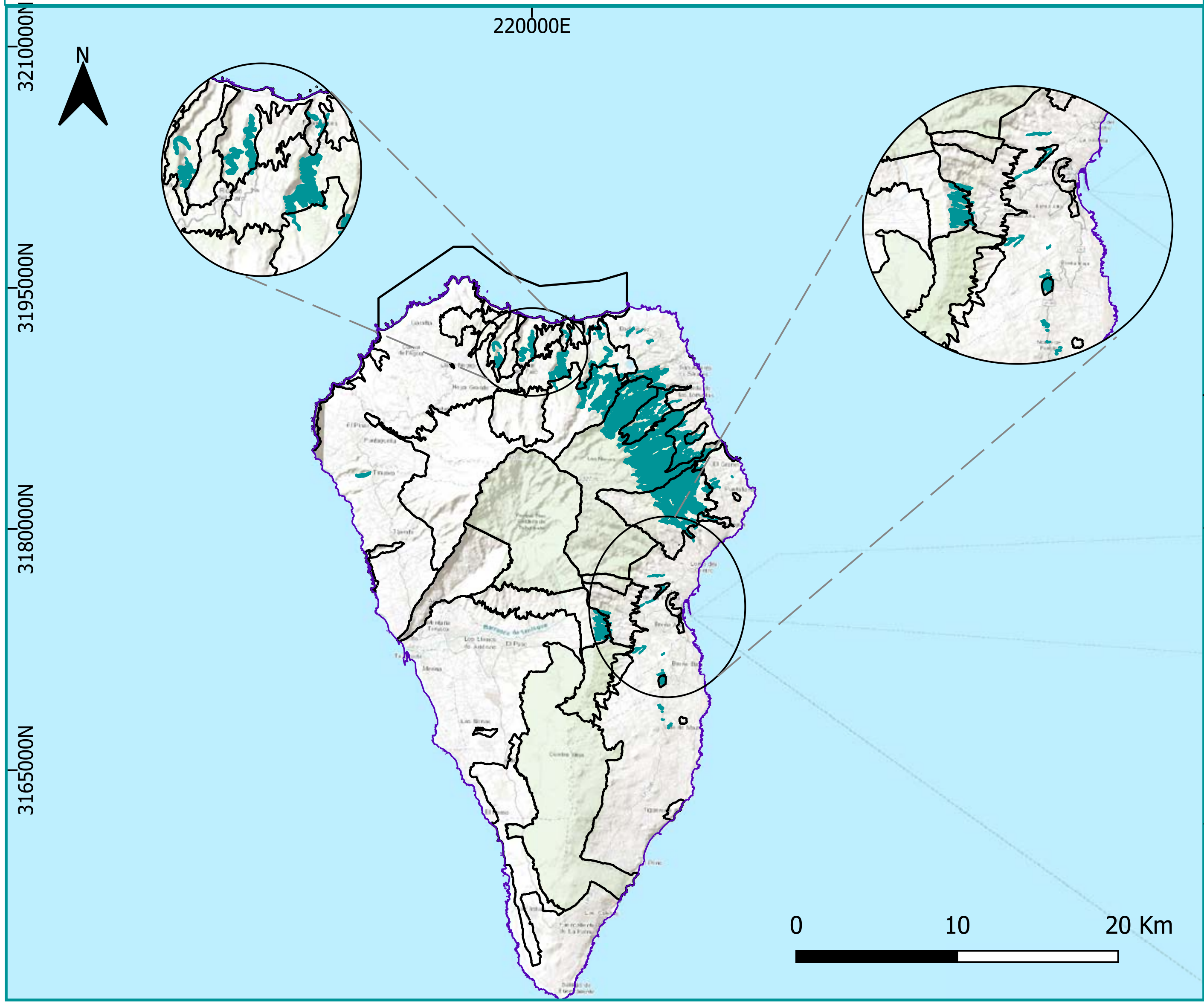
NATURA 2000

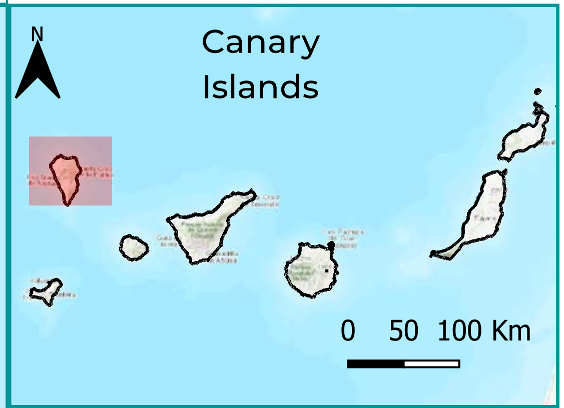
Natura 2000

9360 * Macaronesian laurel forests

9360 area protected (ha) in N2000	Percentage of island 9360 protected	Contribution (%) to achipelago 9360 protected area
3594,12	98,04	34,93

La Palma (Canary Islands)





Projection: WGS 84 / UTM zone 28N

Island name : La Palma

Total Area (ha): 70600

Natura 2000 Network

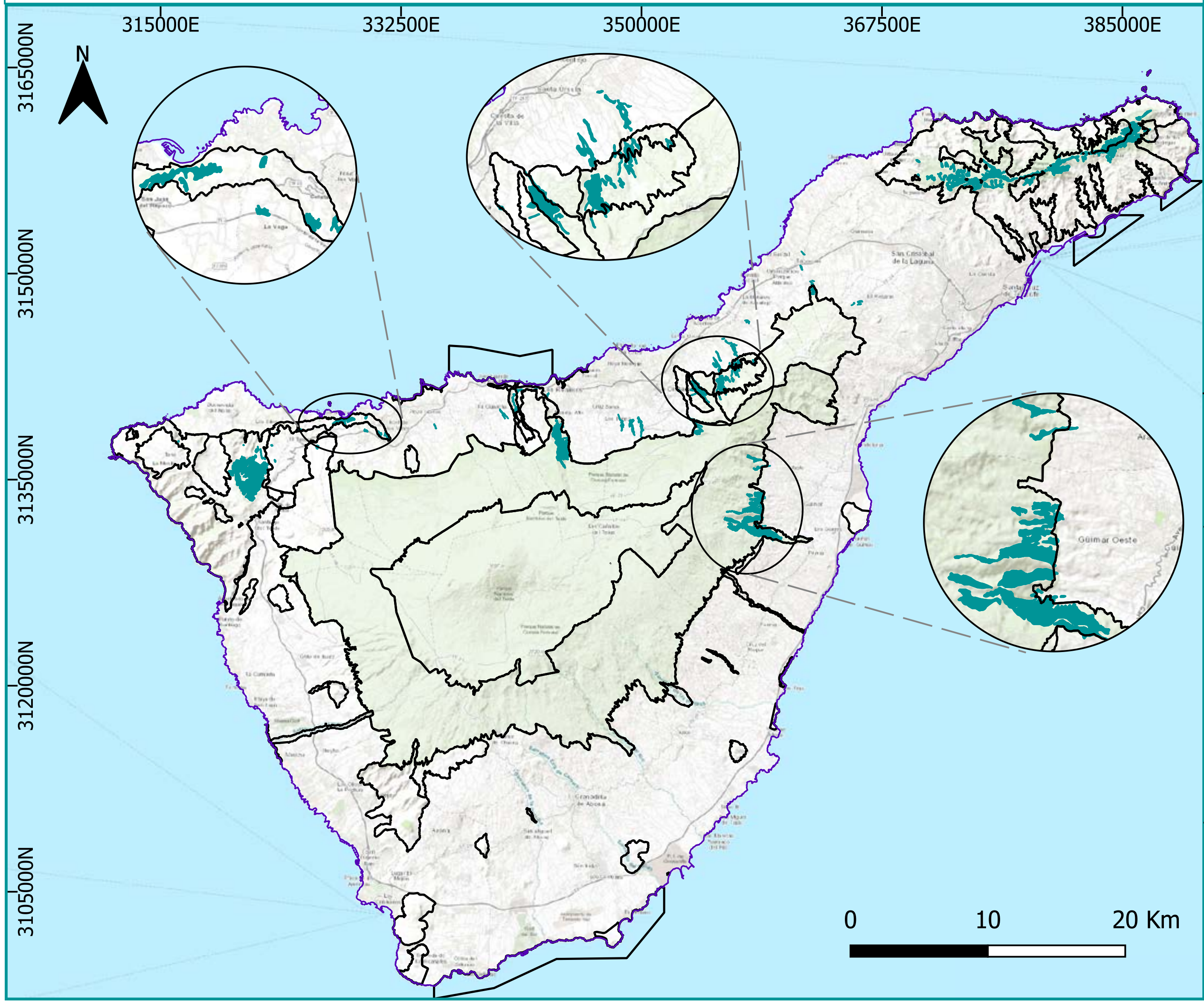
https://natura2000.eea.europa.eu/?sitecode=ES0000114

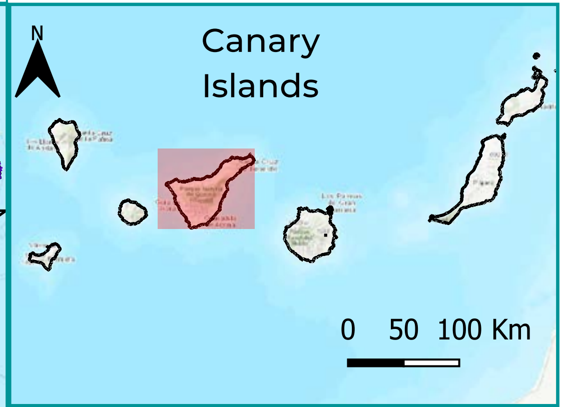
Natura 2000

9360 * Macaronesian laurel forests

9360 area protected (ha) in N2000	Percentage of island 9360 protected	Contribution (%) to archipelago 9360 protected area
3235,73	89,14	31,45

Tenerife (Canary Islands)





Projection: WGS 84 / UTM zone 28N

Island name : Tenerife

Total Area (ha): 203400

Natura 2000 Network

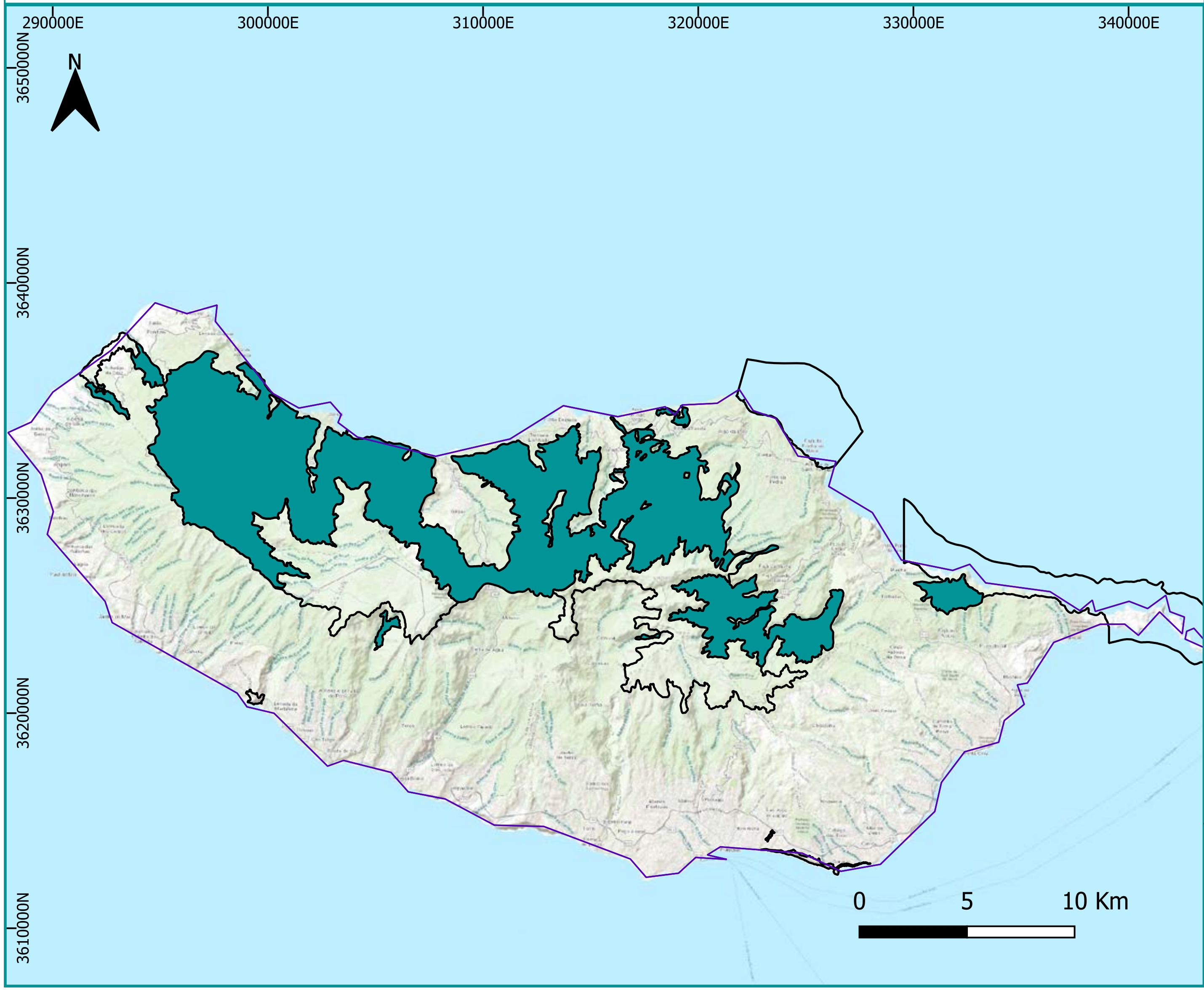
https://natura2000.eea.europa.eu/?sitecode=ES0000109

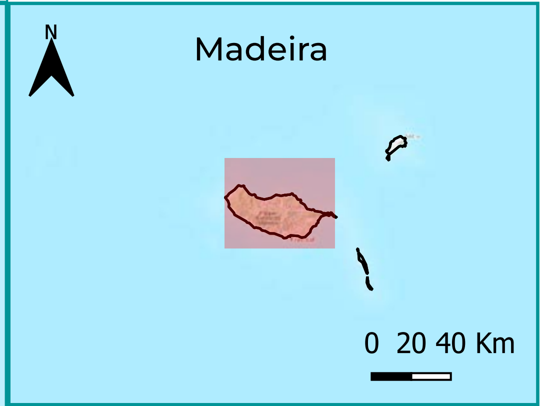
Natura 2000

9360 * Macaronesian laurel forests

9360 area protected (ha) in N2000	Percentage of island 9360 protected	Contribution (%) to archipelago 9360 protected area
1904,95	94,01	18,52

Madeira (Madeira)





Projection: WGS 84 / UTM zone 28N

Island name : Madeira

Total Area (ha): 15462

Natura 2000 Network

https://natura2000.eea.europa.eu/?sitecode=PTMAD0001

Natura 2000

9360* - Macaronesian laurel forests

9360 area protected (ha) in N2000	Percentage of island 9360 protected	Contribution (%) to archipelago 9360 protected area
15456,1	99,96	99,96

Appendix 6. Administrations answer to questionnaire about how area, structure and function were assesed for the art. 17 report

Question	Azorean administration	Madeira administration	Canarian administration
Who answered	Prof. Eduardo Dias	Carlos Lobo	Ángel Vera
Which methodology was used for mapping the areas occupied by 9360 habitat?	The mapping methodology used for the three last reports was based in the ATLÂNTIDA©GEVA data base and its respective GIS project, which collects field data geolocated inventories and field cartography since the beginning of 1990. This historical information, although not coherent across the whole territory, works as a comparative basis for recent mapping. That way the known stands are revisited, the field data and maps updated, but now with more detail using remote sensing. Similarly, this accumulative database permits the development of distribution patterns and models that indicate new areas that deserve being mapped. The recent evolution of technical media has permitted the mapping of new areas of difficult access, with an increase in the detail through the use of satellite and drone images, confirming new distribution areas that were later subject to field work and inventories. That way and considering the typical working flow, a new area was first inventoried according to a standard field form that answers the criteria needed for filling the art. 17 annex report, and that gives us information about floristics, structure and conservation status of the HCI. The limits of the 9360 distribution are based on the information given by drone or satellite images that are later transformed in a first local mapping. The distribution and degree of naturalization are later confirmed by vegetation indexes. Changes in the informative matrix that may imply changes in the habitat typology or naturalization degree and later confirmed by new field inventories.	The official Madeiran cartography of 9360 was created in 1997 following a Costa Neves *et al.,* (1996) work, who made an exhaustive field work between 1992-1995, gathering data of density, dominance, frequency and importance of the different elements integrating the floristic composition of Madeiran laurisilva. The information gathered during the fieldwork were transposed to maps by the Serviço do Atlas do Ambiente de Portugal of the Direção Geral do Ambiente (Costa Neves *et al.*, 1997). This cartopgarphy has been used for representing the laurisilva distribution in several projects, including the Art. 17 reports from the Habitat directive. Mesquita *et al.*, (2007) maps the present vegetation of Madeira island, where two types of laurisilva are distinguished: Barbusano- and Til-laurisilva. Nevertheless, the authors recognized that the maps delivered are based in Madeiran (ombrotype and thermotype) climatic models and on other information available, but without additional fieldwork, what the authors highlighted as indispensable for obtaining a more precise mapping. The laurisilva distribution proposed by these authors is, in general terms, similar to the Costa Neves *et al.,* (1997) one, although with a larger area and range, what could be explained because if the introduction of the Erica platycodon communities in the Barbusano-laurisilva type and of the Erica *platycodon maderincola* and *Vaccinium padifolium* in the Til-laurisilva type.	The cartography used is based on the Vegetation Map of the Canaries. Relations between phytosociological associations and types of habitats of community interests have been made. These relations have been revised according to anomalous situations (i.e. the case of Gran Canarian legume communities in area of potential pine forest distribution, because it has no sense to establish these substitution communities as 9360 habitat, for later being converted in 9550 habitat).
Which was the working scale?	According to the methodology commented the working scale is very detailed. If the area is covered by drone photography, it will be of 100 m^2, or even smaller if covered by satellite (Sentinel 2). Currently, given the fragmentation if the territory, is the fragments size what limits the mapping, because many patches are too small to de considered.	Departing from quali- and quantitative data from Madeiran laurisilva produced by Costa Neves *et al.*, (1996), the scale used was 1:100 000 (Costa Neves *et al.*, 1997).	The scale used was the reference scale of the Vegetation of the Canaries Map which is officially 1: 20 000, but worked at ca. 1: 18 000.

Question	Azorean administration	Madeira administration	Canarian administration
Have you considered reference values for the occupied range and area?	For Art. 17 reports Azores have always used the option of an operator for the reference values, both for range and for area occupancy, leaving clear that the reference values should be larger or much larger than the current area. The high diversity of forest types, its distribution along nine islands (currently just seven), the inexistence of laurel forest reference value models and the difficulty in founding well preserved sampling points, especially for the lowland types, creates a very complex scenario for obtaining these reference values.	The work developed by Costa Neves *et al.*, (1996) permitted infer the conservation status of the Madeiran laurisilva. With few exceptions, the reference values of this work are still being used. For the Art. 17 from the Habitat directive reports, the favorable reference values (FRV) for range and area are defined based in the existing cartography base in Costa Neves *et al.,* (1996) work. It is important to note that due to the antiquity of these data is important to reevaluate the habitat area with more modern and precise methods, and it is assumed that the range and area FRV are based in extrapolations of limited data.	The value of the occurrence area, corresponding to this cartography is of 102.94 km^2. It has been considered that the favorable reference value (FRV) for the 9360 HCI is this area, and that way has been informed in the 2013-2018 report. This surface corresponds to the current distribution of the 9360 HCI in the Canaries, and considering its importance and priority character, it should not be considered an inferior area as FRV. Nevertheless, it should be considered that the estimation of the distribution area at a resolution of 1 km side grid, produces a surface of 438 km^2, meaning that the FRV has to be correlated with a specific resolution.

Question	Azorean administration	Madeira administration	Canarian administration
About structure and function			
Which methodologies are you currently using for the evaluation of the 9360 structure and function and which have been used for the Art. 17 2018 report?	The vertical structure and the spatial organization were established through quantitative measurements for each 9360 identified, using Dias (1996) 45 inventories of biovolume per species and establishing a pattern for each Azorean forest type. In more recent inventories we have used the height of the canopy tree species. The horizontal structure, which has been measured in some stands as way to monitor the conservation status, was estimated via photogrammetry in permanent plots. Dynamic processes have been mainly studied in mountain laurisilva (Elias & Dias, 2008, 2009), associated with natural climatic or volcanic processes. In the lowlands, the advance of invasive woody species such as Pittosporum undulatum or Clethra arborea due to the destruction of the natural forest are the biggest threats to the patches existing at this elevation. In this context, for the Art 17 report, an identification model based on its spectral signature using remote sensing methods was used for analyzing the advance of Pittosporum that permit the quantification of the cover of this species in 9360 forests. Similarly, different vegetation indexes (especially the NDVI) have been used comparing their values with values for well-preserved reference stands. Considering these parameters and those of the next point (dominant species), the field inventories have been classified according to their naturalness degree with an index that tries to evaluate the conservation status based in the Ecology studies of reference communities. For the first reports we used the natureness index (IN), developed with this aim that use the threat typologies detected for the Azorean forests, varying from 0 (less natural) to 4 (more natural). Recently, this index has been improved introducing a quantitative evaluation of some parameters and picking some older ones suggested by Machado (2004), varying in a scale from 1 (less natural) to 10 (most natural). The mapped forest spots are classified using the NI from field inventories or from invasive species (satellite or drone images) when its cover is so important the dominate over other community attributes	In the last Art. 17 report the parameters Structure and Function were data-less submitted	In 2018, there was no new information available for this parameter, so we decided the keep the previous values. Currently new tasks are being carried out to obtain, through teledetection, indirect indicators of the functional status of the habitats. This work is focused on the use of vegetation indexes (such as NDVI, EVI, etc.) and especially how they vary with time (both monthly and yearly). We expect to be able to count on a system that contributes each time with analyses that generate and detect abrupt trend changes (alerts). This methodology is under construction. Referring to structure, fieldwork inventories have been carried out that give information about cover per strata and number of individuals of the present species in the analyzed communities. In the case of 9360, we have also carried out a preliminary fragmentation analysis that can be a pilot project for other natural habitats with community interest.

Question	Azorean administration	Madeira administration	Canarian administration
Have you selected typical species? If so, which have been the criteria for such selection?	The selection of typical species is a complex problem, especially in such forest with very diverse typology. Classically, we have to choose between the two big phytosociological schools that differ using either dominant or indicative species. However, islands used to have generalistic species with low indicative value. On the other hand, the high typological diversity of these forests impedes choosing a group of species. That way, for the Art. 17 report, we have used the dominant species as the typical ones, defining the Azorean subtypes of 9360. The reference scenarios are based on the Azorean forest typologies determined with quantitative data (Dias, 1996) and on the syntaxonomic tables that hold them with a floristic base, that are updated with the field work done on the different spots. As said, these inventories count with a normalized file that include a floristic inventory (relevé). Following the methodology just described, their analysis permits the extraction of the typical species.	In the last Art. 17 report the parameters Structure and Function were submitted data-less.	No typical species have been selected by the regional administration because of the lack of criteria with solid scientific background

Appendix 7. Administrations answer to questionnaire about 9360 pressures and threats

Question	Azorean administration	Madeira administration	Canarian administration
Who answered	Prof. Eduardo Dias & Prof. Paulo Borges	Carlos Lobo	Ángel Vera
What methodology have you used in the latest Article 17 report to detect and measure pressures and threats to laurel forests?	Regarding the Azores, we have a publication that determines the level of "DISTURBANCE" for the various islands. We follow a methodology that uses multiple sources of information, adjusted for the various potential pressures, which are collected into a central database over the monitoring period and then reconciled and synthesized for the final report. These collection programs are adjusted for each parameter, which in some cases may result in quantifying the intensity in each vegetation patch, or at least, assessing its frequency across the Azores. These values, weighted by area, are then reconciled with those of Madeira to provide the final results, as the National Report of Portugal includes both archipelagos, and this habitat is common to both. Some of the pressures are well known, so there are dedicated methodologies to assess their extent, but an open program is maintained to evaluate and consider new possible pressures. Pressure on the size of forest areas, such as land use change, either by mechanized means or tree felling, is monitored using cartography based on remote sensing. The overall state of habitat quality is monitored through remote sensing for each patch, where the standard state has been established for different indices such as the NDVI of each patch. Variations in this state are potential indicators of changes to be investigated on the ground. Remote sensing, such as the spectral signature associated with some dominant species like Laurus, is used to assess changes in the canopy. Similarly, the spectral signature of some invasive species that reach the outer canopy (such as Pittosporum) is used to evaluate their presence and evolution over time. At the local scale, new information is collected in standardized forms about the pressures, following the baseline discrimination of the pressures listed in the Article 17 report database: a quantitative inventory of invasive species is made, a structural analysis to assess structural changes (generally due to the presence of cattle) is conducted, and signs of animal presence—such as cows, goats, rabbits—are evaluated by counting droppings and collecting leaves to check for pests. At each inventory site, changes in the hydrological regime are also assessed by evaluating dead wood and signs of flooding along watercourse margins.	The selection of pressures and threats to Laurissilva was not based on a specific methodology, but on the field knowledge of specialists and technicians, combined with information from various publications. This knowledge was fundamental to list the main pressures and threats affecting Laurissilva in the report.	The Autonomous Community of the Canary Islands has not yet developed a general and systematic registry of the pressures and threats affecting natural habitats and species in the archipelago. This situation represents a weakness for public administration in terms of the potential use and exploitation of information on this subject, particularly regarding how it could support the planning and management of the areas that make up Natura 2000 in the archipelago. There is some information on this topic, obtained from various methodologies, referring to different geographical areas, related to diverse sources, and with heterogeneous chronological references. However, a systematization of this information and homogeneity in the mentioned aspects—method, areas, and periodicity—have not yet been addressed. Currently, this situation greatly hinders the management and exploitation of the existing information.

	Functional issues and the general state of conservation—clues for the presence of unidentified pressures—are sought in particularly sensitive communities, such as the structure and distribution of epiphylls. Evidently, detectable changes are noted, such as the opening of paths or trails, construction of structures, or tree felling, through an inventory dedicated to these pressures. For more global impacts and less perceptible changes, such as climate change, 9 permanent plots have been maintained for 15 years on 3 islands, which are monitored every 6 years to compare results with the reference situation (2006), with quantification of floristic structure, soil structure, advancement of invasive species, and canopy structure through branch fall..		
Is there any document or bibliographic reference that reflects this methodology?	All the periods for which we were contracted to implement the methodology resulted in the delivery of descriptive reports on the methodologies applied to the Regional Directorate of the Environment. Cardoso, P., Rigal, F., Fattorini, S., Terzopoulou, S. & Borges, P.A.V. (2013). Integrating Landscape Disturbance and Indicator Species in Conservation Studies. PLoS ONE, 8: e63294. DOI:10.1371/journal.pone.0063294	No	No

Do you know of any other methodology or experience of assessing pressures and threats that would be useful for laurel forests?	No work was done in this regard due to the uniqueness and specificity of this habitat in the Azores. Some of the pressures identified as having a greater impact, such as the presence of large vertebrates or rabbit herbivory in these forests, are not considered negative in continental areas.Fragmentação, Espécies Invasoras e Alterações climáticas.	Although the Laurissilva of Madeira has not yet been the subject of a specific study to classify and map its pressures and threats, there are some studies that make it possible to assess the importance of certain circumstances as pressures and threats: • Rodrigues, A. A. F. (2013). Assessing Impacts from Future Climatic Scenarios on the Distribution of Flora and Vegetation at Madeira Island (Doctoral dissertation, Universidade de Coimbra (Portugal)) // • Gouveia, C. S. A. (2014). Predicting the impacts of climate change on the distribution and conservation of endemic forest land snails of Madeira Island (Master's thesis). //• CLIMAAT, I. (2006). Estudo Detalhado Sobre o Clima do Arquipélago da Madeira, Produção de Cartografia Climática, Construção de Cenários Climáticos Futuros e Realização de Estudos de Impacte e Medidas de Adaptação às Alterações Climáticas em Vários Sectores de Actividade.[FD Santos e R. Aguiar, Eds.]. Projecto CLIMAAT II–Clima e Meteorologia dos Arquipélagos Atlânticos II, Programa de Iniciativa Comunitária INTERREG III B, Espaço Açores–Madeira–Canárias. ICAT, Lisboa. // • Agrela, S. A. M. D. (2017). Carta de risco de incêndio florestal para o Parque Natural na Ilha da Madeira (Master's thesis). // • PROF-RAM (2015).	MANAGEMENT PLANS FOR THE SPECIAL AREAS OF CONSERVATION (SAC) Among these sources, the information from the management plans stands out. At the time of their drafting, the set of pressures and threats affecting each habitat or species subject to conservation in each SAC was collected and assessed. The management plans approved so far have included a section on "Assessment and conservation status of habitat types of community interest and Natura 2000 species." This section addresses each habitat and species separately, listing the pressures and threats and their significance in each area covered by these management plans. To facilitate standardization, the classification of pressures and threats is in accordance with the Commission Implementing Decision 2011/484/EU of 11 July 2011 on a Natura 2000 site information form [OJ L 198, 30 July 2011]. The drawback of the information collected in the management plans is its age, as it dates back to when these plans were drafted, around 2015. It requires updating. PUBLIC USE IN COASTAL AREAS To analyze the impact of public use on protected species and habitats of community interest in the coastal areas of the Canary Islands, a project co-financed with FEDER funds was launched. It gathered information on user influx, activities, and impacts detected in 20 coastal localities on each island (10 in the case of El Hierro, La Gomera, and La Palma). The work was carried out along three lines of action: field data collection, analysis of the conservation status of habitats and species, and finally, the proposal of management measures.

	Plano Regional de Ordenamento Florestal da Região Autónoma da Madeira. Direção Regional de Florestas e Conservação da Natureza, Funchal, Madeira. // • Mota, L., Franco, M., & Santos, R. (2021). Island tourism carrying capacity in the UNESCO Site Laurisilva of Madeira. Island Studies Journal, 16(2), 255-269. //• Vasconcelos, F. R. E. V. D. (2015). Avaliação da vulnerabilidade da biodiversidade terrestre às alterações climáticas e proposta de medidas de adaptação para o Arquipélago da Madeira (Master's thesis).	For data collection, 640 visits of two hours each were made to each locality, at morning, afternoon, and night hours. Using a software application, general data of the study areas, presence of species and habitats of community interest, activities conducted (fishing, sports, camping, vehicles, etc.), detected users, as well as photographic records and georeferenced impacts (waste, discharges, exotic species, trampling, etc.) were recorded. The study of the collected data allowed for a detailed analysis of the conservation status of the habitats of community interest present, by locality and island. Based on this, management measures and proposals were developed for each study area, prioritized according to the issues, aimed at reversing unfavorable situations. The project began in 2018 with the islands of Tenerife, Gran Canaria, and Fuerteventura, Lanzarote was added in 2019, and the work for El Hierro, La Gomera, and La Palma was carried out in the 2020-2021 period.

What are the most important pressures and threats affecting laurel forests on your islands/ archipelago?	"Fragmentation, invasive species and climate change. (Ferreira, M.T., Cardoso, P., Borges, P.A.V., Gabriel, R., Azevedo, E.B., Reis, F., Araújo, M.B. & Elias, R.B. (2016). Effects of climate change on the distribution of indigenous species in oceanic islands (Azores). Climatic Change, 138: 603-615. DOI:10.1007/s10584-016-1754-6 // Ferreira, M.T., Cardoso, P., Borges, P.A.V., Gabriel, R., Azevedo, E.B. & Elias, R.B. (2019). Implications of climate change to the design of protected areas: the case of small islands (Azores). PlosOne, 14(6): e0218168. DOI: 10.1371/journal.pone.0218168 // Aparício, B.A., Cascalho, J., Cruz, M.J., Borges, P.A.V., Azevedo, E.B., Elias, R.B. & Ascensão, F. (2018). Assessing the landscape functional connectivity using movement maps: a case study with endemic Azorean insects. Journal of Insect Conservation, 22: 257-265. DOI:10.1007/s10841-018-0059-7) // Obviously, the greatest pressure that continues to be observed is the occupation of natural forest areas by agricultural land. The second major pressure and threat, which will probably lead to the destruction of all patches in the future, is the advance of invasive tree species such as Pittosporum. The third, with strong impacts on biodiversity and forest structure, is the presence of rabbits and their impact on palatable species. The pressures resulting from the above, such as fragmentation, loss of biodiversity and even extinction of typologies, are also important."	According to the latest Article 17 report, the pressures and threats that most affect Laurissilva are the following: Pressures HIGH: o Invasive alien species of Union concern (I01) / o Interspecific relations (competition, predation, parasitism, pathogens) (L06); MEDIUM: o Modification of hydrological flow or physical alteration of water bodies for agriculture (excluding development and operation of dams) (A33) / o Development and operation of dams for agriculture (A32) / o Active abstractions from groundwater, surface water or mixed water for agriculture (A30); Threats HIGH: o Invasive alien species of Union concern (I01); / o Modification of hydrological flow or physical alteration of water bodies for agriculture (excluding development and operation of dams) (A33); / o Active abstractions from groundwater, surface water or mixed water for agriculture (A30). / o Droughts and decreases in precipitation due to climate change (N02); MEDIUM: o Development and operation of dams for agriculture (A32); / o Interspecific relations (competition, predation, parasitism, pathogens) (L06); / o Temperature changes (e.g. rise of temperature & extremes) due to climate change (N01).	MONITORING THE CONSERVATION STATUS Based on the methodology used in the previous initiative, the "Experimental Project for Monitoring and Recording Information on the Conservation Status of Habitats of Community Interest and Habitats of Species of Community Interest, with Special Attention to the Natura 2000 Network" was launched in 2020. This project is also framed within the FEDER Operational Program for the Canary Islands (2014-2020). This time, the objective was not only to understand the impacts associated with human activities on the natural environment but also to detect changes occurring in habitats and species as a consequence of climate change. Field surveys were conducted using georeferenced transects and inventories in 20x20 meter plots that are repeated periodically to track their evolution over time. The project aims to cover not only coastal areas but as much of each island's surface as possible, from coast to summit and across all slopes, both inside and outside the Natura 2000 Network. With this data collection initiated in the peripheral islands and continued in 2023 with the incorporation of Tenerife and Gran Canaria, a baseline of knowledge is established that will serve as a reference for future monitoring.

Do you have any mapping related to existing pressures and threats?	Mappings have been produced for some variables, such as land use change and the distribution of some invasive species. In other cases, the distribution is ad hoc, although their occurrence has been mapped. In other cases, this has not been done, or they are not mappable.	Laurissilva has not yet been the subject of a specific study to classify and map its pressures and threats. Therefore, no mapping is available. However, the Regional Forest Management Plan of the Autonomous Region of Madeira (PROF-RAM), a sectoral policy instrument that aims to ensure the sustainable management of Madeira's forest areas, includes several characterisation and framework maps of Madeira's forest areas, some of which allow us to infer the importance of certain pressures or threats to the Laurissilva.	TRENDS IN ARBOREAL AND SHRUB HABITATS In recent years, a parallel process has been developing to analyze the trends of natural plant-type habitats using remote indicators, specifically the Enhanced Vegetation Index (EVI). This will facilitate the detection of changes in the vegetative activity of certain arboreal and shrub habitats, and consequently, the possible effects of pressures and threats on them. To address this detection capability, the mean values and variation of this index have been analyzed by habitat subtypes, seasonal periods, and groups of years for reference areas. This way, each analyzed habitat subtype has thresholds that distinguish values corresponding to normal situations from those of anomalous situations. Although quite advanced, this process is still under development. The intention of the Government of the Canary Islands is to implement and develop these systems under standardization, following the reference list of threats, pressures, and activities available on the Natura 2000 Reference Portal (in accordance with the Commission Implementing Decision of July 11, 2011, on a Natura 2000 site information form). The participation of all Natura 2000 site managers (island councils and non-delegated national parks) and the implementation of detection systems outside the European Network that affect natural values of community interest should be promoted. This way, there would be a standardized collection of pressures and threats with cartographic expression and associated alphanumeric information that would be openly available.

GOBIERNO DE ESPAÑA

MINISTERIO PARA LA TRANSICIÓN ECOLÓGICA Y EL RETO DEMOGRÁFICO