INVESTIGATING RELATIONSHIPS BETWEEN ENDEMIC PLANT SPECIES AND ENVIRONMENTAL VARIABLES TO INDICATE ECOLOGICAL DROUGHT VARIATIONS WITHIN REGIONS OF ITALY

by

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ABSTRACT

Investigating relationships between endemic plant species and environmental variables to indicate ecological drought variations within regions of Italy

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The present study focuses on the country of Italy, which is uniquely situated as an elongated peninsula extending into the central Mediterranean and where drought is intensifying under climate change. A Mediterranean climate has long persisted with two shared components of aridity fluctuation and human activity. Endemic plants are adapted to the Mediterranean climate in Italy and are considered in this thesis as an indicator of "ecological drought". Endemic, endemic exclusive, and total vascular plant species categories are investigated as indicators of drought with eleven environmental variables consisting of climate, land use type, and human population in each of the twenty regions of Italian territory. Using correlation analysis the present research analyzes associations between the three plant categories and eleven environmental variables including precipitation, temperature, soil anomaly, fAPAR, human population, and land use types. Though precipitation receives the greatest amount of attention with regard to explaining drought, the findings of this work show that precipitation was not statistically associated with the plant indicators of drought. Conversely, drought is associated with ecological state-change land-use-changes, which function as a mechanism that redirects water supply. Endemic exclusive plants show the most adaptability to climate change intensity where other plant indicators are variable in their need for moisture dependent upon other factors. The results suggest that ecological drought is determined through a combination of variables and the relationships between those conditions, not singly through changes in precipitation, temperature, or generalized vegetation cover. Furthermore, the results suggest that land use change should be more seriously considered as a contributor of drought conditions.

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I. Introduction

A. Predicting drought

Under climate change temperature warming and the amount of water available to meet human need is a main indicator of drought. Drought as a growing concern for both public and private land management focuses attention to precipitation quantity in making determinations of drought conditions. Standard precipitation is used as the predominant indicator to measure ground drying. This drying leads to the need for climate prediction where water shortage is a concern. Subsequently water shortage impacts crop management and thus focus excludes other conditions that contribute to predicting drought.

There are three types of drought commonly analyzed: meteorological, hydrological, and agricultural. A state of drought is identified for meteorological drought by measures of precipitation, hydrological drought by a lack of groundwater recharge, and for agricultural drought by a lack of soil moisture for crops. However, these measures exclude a fourth condition: ecological drought. Unlike, the first three categories of drought, which rely on precipitation to supply direct moisture, ecological drought is considered as an episodic event but includes the distinction that feedbacks occur as part of a cycle that produces drought. As such ecological drought may be determined by more than simply precipitation and created through improper and/or uninformed management of resources instead. Predicting the fourth category of drought must account for anthropogenic and climatically induced activity and needs to be investigated together for the potential contributions towards drought.

A fifth type of drought is designated by the Italian environmental agency as "socio-economic drought", which relates to human use of the water resources for both social and economically sustaining needs (ISPRA, 2018b) in an unspecified manner. By recognizing this category of drought the Italian environmental agency provides a more cognizant idea behind drought as a complex phenomena that is difficult to pinpoint in its antecedent contributions. In this sense it becomes increasingly important to consider drought as an ecological event. The present study can assist in understanding some of the complexities behind drought in Italy as socio-economic drought contained within ecological drought since predictor variables are expected to parallel these two latter definitions of drought. Similarly how the first three definitions of drought are related under the theme of precipitation, the latter two are related under the theme of a series of interacting mechanisms that traverse one another to limit water resources and create dry bare ground.

The purpose of the present study is to widen the scope of understanding as to what constitutes drought and provide an association of the drought tools available to researchers. By combining those tools with other factors known to contribute to environmental degradation, such as land use, drought can become better predicted. Choices of what and how to monitor selections in the satellite tool that rest solely on the ability of the user to implement can become improved through additional knowledge provided in the present study. The present study is important because it intends to capture conditions that contribute to drought as an ecological event within the total environment instead of another type of drought that depends of rainfall, groundwater recharge, or the ability of agriculture to resist decreased water. Thus, drought must include other conditions necessary to develop a combined ecological indicator for determining true drought, not simply the use of climatic conditions.

The present study includes those other conditions that may contribute to ecological drought in the form of land use types, climate signals from both ground and atmosphere, the influence of human population on the landscape, and endemic plants as part of the circulatory shape of drought (acting as a more holistic cyclic system) whereas the other three types of drought are exclusively vertical or horizontal (acting in one way up or down such as rainfall and evapotranspiration, or side to side such as source to sink hydrological flow as in a stream or river emptying to a water body).

The utilization of correlation analysis is intended to measure the relationships between the suspected components of ecological drought. The overall expected findings of the analysis is that precipitation quantity is not the only or most highly relevant factor of drought, but that instead anthropogenic activity is also relevant for drought conditions. The main reasoning behind this expected outcome is that endemic plants are expected to thrive in drought conditions (Sadori, 2013), yet they are unable to do so if anthropogenic land use change has significantly altered the natural environment to which they have evolved.

The discussion presented in this study considers the wide variability throughout Italy’s twenty regions, providing the needed evidence to broaden the assessment of drought. An ecological drought predictor could be formulated within the existing theoretical drought framework by adopting methods from this study.

B. Research problem

Government agencies that advise both public and private management provide research updates to government managed satellite tools and are beginning to include other components to some drought predictors such as soil and vegetation conditions. However, these measures make no distinctions about specific ground conditions such as the category of the vegetation, for example whether the vegetation is an endemic plant group or a patch of agricultural area.

This study seeks to learn how environmental variables correlate with local plant species as determinants of drought conditions. Specifically this research asks the following questions: Are different indicators of land use, climatic factors and human population correlated with the endemic plant species counts, and what can this tell us about drought in Italy? Does one variable impact dry conditions more than another and if so for which plant category? Has decreasing precipitation impacted local plant quantity between 2005 and 2018 since counts were updated?

C. Geography of Italy

The environmental variability over the twenty regions of Italy offers some insight as to why ecological considerations are important in a location already exposed to naturally moderate aridity and where drought is predicted to become extreme more rapidly than other parts of the westernized world.

Italy is uniquely located as an elongated peninsula in the central Mediterranean basin. In the far north Italy is bounded by the Alps and Dolomites mountain ranges running west to east. Lying at the base of the mountains is the Po River. As Italy's longest and arguably most important river the Po River plain traverses the landscape in the north also running west to east and draining into the Adriatic. The prominent Apennines mountain range begins just south west of the plain connecting the northern Ligurian Alps and continues as a spine of mountains for 190 kilometers that tails from the north through central into southern Italy ending in Calabria. Over 1,000 rivers drain into the seas on either side of the parallel strips of the Apennines mountain chain into the countryside where hilly areas are intermingled with plains until reaching coastal areas (see Figures 1 and 2).

Figure 1. Generalized map of Italian territory (base image from ISPRA (2018c) Geoviewer [Terra interactive map tool]

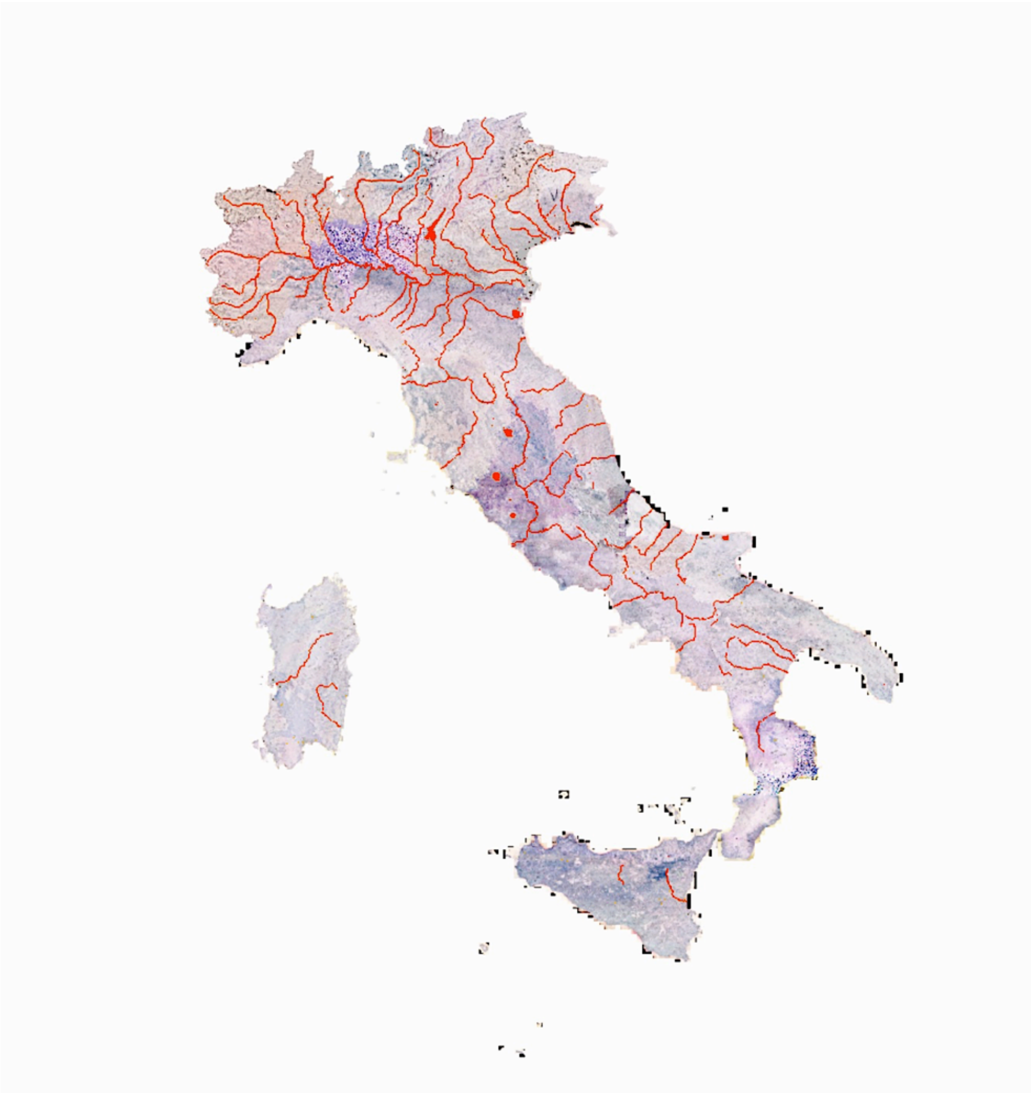

Figure 2. Map of water bodies and rivers within the Italian territory

The mountains of Italy are cut by circulatory wind patterns where Diodato (2007) explains these winds are opposite; in wintertime cyclonic depressions bring rain, then summertime hemispheric meridional circulation in the form of an anti-cyclone intensifies drought. This seasonal pattern induces greater extremes in wet-dry periods under climate change.

The forces of sporadic wetter and drier climatic conditions are stronger in Italy over the last decade, affecting more people and resources. Additionally climatic extremes are becoming more noticeable. As climate related events are projected to intensify, resource management strategies are a high priority.

D. A variety of scientific voices

According to Buttafuoco et al. (2015) standard precipitation is easiest to calculate for drought prediction and is best utilized in meteorological and hydrological water management. Researchers in Italy such as Peruzzi et al. (2015) and Bartolucci et al. (2018) point to a long history of failing to accurately identify and classify endemic and non-endemic plant species and thus organize endemic plant species into their respective taxonomy. Researchers such as Fenu et al. (2015) and Brundu et al. (2015) who use other tools (such as Geographic Information Systems) to determine vegetation distribution point out that work to conserve endemic plants is underfunded, while authors such as Vergni et al. (2015) whose main applications are in adjusting standard precipitation methods shift their focus to agriculture as the main beneficiary of standardized drought prediction tools. A lack of classifying and identifying non-agricultural endemic plants has posed a problem for ecological management despite current updates in classification efforts. Further complicating land management in Italy is the prediction of drought predominantly applied to economic and agricultural uses that disrupts efforts to manage vegetation for ecological and/or ethical reasons (e.g., ecosystem services, species conservation, nature preserve management).

When endemic species lack identification they may become extinct before their role in the environment is studied. Vegetation is classified into units by genera, species, and family to improve conservation (Peruzzi et al., 2015). Plant identification informs land management from an ecological perspective when the variety of plant species is included in decision-making.

Environmental classifications and indices are helpful for organizing land, vegetation, and climatic relationships into categories for contextual background. The present research attempts to capture decadal change using eleven indicators of drought (including precipitation as modeled in previous papers for agricultural drought with soil anomaly added) and three different plant count variables to supplement comparisons between native plants and environmental indicators as an additional indicator of drought. Analysis of variables from two years, 2005 and 2018, supplements ongoing development and use of drought indicators. As such, this method can be applied to ecological drought management.

Researchers use a wide range of methods for evaluating climatic conditions. Some include measuring vegetation such as a forest patch using incremental intervals of time (growth) that include remodeling precipitation (time series) and vegetation. For example, Cramer et al. (2018) use narrow time series moments to obtain clearer indicator timing, then apply this to forest existence and drought prediction: in this way the researcher attempts to precisely assess through strict technological means the directness of relationship between climate and vegetation without in field experimentation.

Other researchers focus exclusively on flaws in standard precipitation indices and offer new calculation methods for use in global prediction (Vergni et al., 2017). Still others focus on land use changes as environmental degradation (Salvati et al., 2015) without specifying plant categories, while others specialize in documenting endemic plant threats by species only (Médail and Baumel, 2018). Last, some researchers focus on extreme soil conditions and plant types for phytoremediation or evolutionary biology (Rajakaruna and Boyd, 2019). In this thesis, I propose an intermediate between the sets of extreme methods, which I argue is best applied to site-specific land management from an ecological perspective. The resulting analysis reveals that the dynamics of specific environmental variables reflect uncertainty in how different plant species might adapt under climate change.

Analyses performed by many authors adapt standard precipitation from meteorological to hydrological to drought types and the extent thereof (Vergni et al., 2015) under the view that drought is the action that reduces available water from one of the precipitation based sources (rain, snow, groundwater, streamflow) (Vergni and Todisco, 2011) and thus fail to include a wider variety of indicators in determining drought. This paper continues analysis of drought after the 1951-2009 (ISPRA 2005-2018a; ISTAT 2000-2018) available data sets for the standard precipitation index by analyzing data sets from the 2005 to 2018 time period. Additionally, I utilize a wider variety of variables than previous research. Instead of focusing on precipitation alone, or adding temperature and evapotranspiration as the combined predictors of drought, I analyze additional variables and also focus on three different endemic plant categories as the indicators of drought. The objective of my study is to provide a wider understanding of drought that could help land managers address changes at the ecosystem level by considering additional variables that may impact land and water resources in relation to climatic conditions and for whom/what (e.g., humans/vegetation type). Shifting from precipitation alone to include wider applicable variables aides in ecological drought prediction and supports ecosystem services while protecting ecosystems instead of single species.

Several authors in endemic plant species conservation stress the importance of coordinated management to protect “Red Listed” (policy protected species) and other potentially unidentified threatened species (Médail and Baumel, 2018; Fenu et al., 2015; Peruzzi et al., 2015) citing 2020-2040 as the most vulnerable time period for extinction risk (Casazza et al., 2014). My research infers extinction has already taken place with a loss of species over time evident and decreased habitat and range through land use conversion as of 2018. The present short-term study aids identifying immediate needs and also suggests further research should improve strategies for preserving natural habitat.

While precipitation is used as a main indicator in predicting drought in most studies and land management, plants in truth receive their moisture from soils, not directly from the sky, and streams may pass many endemic species without providing moisture. Endemic vegetation cover may behave differently from cultivated crops depending on specific plant features such as leaf area, stem shape, branching, height, and other morphological features and thus redirect water. Soil properties act as a significant factor in species endemism due to unique local soil characteristics derived from the geological structure of the local environment (Rajakaruna and Boyd, 2019). Specialized endemic plants can behave differently from cultivated species and adapt to unique chemical changes (soil type, offsite disturbance, CO2 or other changes) in the environment. Available water, the amount of sunlight received, soil chemistry and soil properties such as texture and acidity will also factor into plant adaptation.

E. Plants as markers

While soil types are important and often critical for particular plant species especially some of the most specialized, soil types in Italy will not be discussed in this paper. Instead, plant variables will be used as markers of potential soil problems due to the fact that plants are adapted to soil types and species will rise or decline in relation to soil changes. Changes can become induced through natural disturbance and/or intentional land use. Agricultural homogenization through tillage and other soil modifications are known to be responsible for habitat alterations and changes to soil physical and chemical properties. However, it is expected that a high level of adaptation is probable in the biodiverse regions of Italy due to the unique geology of the territory. As Italy hosts high counts of endemic species compared to other parts of the world it is expected a higher level of adaptation exists over time and other variables must factor into endemic species vegetation cover. Thus, climatic and land use variables along with human population are the focus of the present investigation and serve as a comparison of indicators to gain a clearer understanding of vegetation response across regions.

Since vegetation cover is also know to reduce drought it is important to distinguish land use types to determine which land use most affects which group of vegetation. Land units in Italy are divided in three categories of Mediterranean, temperate, and transitional

(Smiraglia et al., 2013). In the worldwide bioclimatic classification systems the Italian territory is divided into two macroclimate groups: Mediterranean and temperate with four identified bioclimates and two subcategories of sub-Mediterranean and steppe (Pesaresi et al., 2017). These broader classifications do not accurately account for localized features by region and thus are not as helpful in understanding how variables constrain vegetation categories. Mediterranean plant species may have generalized adaptations to climate but are affected by local micro-site variables where the global region is acting as a micro-site for specialized plants to exist relative to soil properties while climate is an agent of slow adaptive change.

F. Separating endemic plants into groups

The present research utilizes three categories of plants as indicators of ecological drought, namely endemic exclusive highly specialized, endemic moderately specialized, or total vascular plants as the most generalist plants of the categories. The separation of plant groups into endemic, endemic exclusive, and total vascular (Bartolucci et al., 2018) breaks apart generic inferences of "vegetation cover" within an area, region, or territory. These distinctions organize taxonomy to identify species groups that represent relationships of specialization and vulnerability in the environment. Endemic plants are generally defined as plants that are native to an area and are not found in any other area (Bartolucci et al., 2018), whether it is an area within a region, a region itself, or a national territory. Endemic exclusive plants are species that represent the highest specialization in their respective biomes (and could even be represented exclusively in a small neighborhood within a region or territory) (Bartolucci et al., 2018) and are those most suited to the unique characteristics of their habitat (Rajakaruna and Boyd, 2019). Thus, endemic exclusive species may be found only in a distinctive localized area dependent upon a unique soil composition, genetics, and/or adaptations to geological climate. Total vascular plants represent species that could share distinctive features and requirements (e.g., shade, moisture, soil type) with plants from outside a local area (Bartolucci et al., 2018). Plants in this category may have better dispersal and generalist features than endemic exclusive species that may be otherwise isolated to specific soil attributes (e.g., dolomite or limestone parent material, soil metal content).

It is likely each plant category contains species and subspecies with varying specializations and represents hybridization characteristics that make it possible for plants to adapt and survive changes in the environment. Across regions in Italy plant species are grouped distinctly following taxonomic classifications developed by the Italian Botanical Society (Peruzzi et al., 2015) for purposes of identifying the collection of endemic and non-endemic vegetation within the territory.

G. Plant counts

Though climatic variables have been recognized as the primary important factors affecting vegetation cover and leading to drought, endemic plant species are also an important indicator. Yet, endemic plant counts in several Mediterranean regions remain undersampled due to a lack of research in some locations (e.g., North Africa, Greece, Turkey, eastern Mediterranean) (Médail and Baumel, 2018) and conservation priorities are hindered by a lack of identification (Bartolucci et al., 2018). Further, as species are identified many species in Italy are new to science as a result of past inactivity in taxonomic classification (Bartolucci et al., 2018) and may account for increases in species counts. Given the previous lack of attention to the identification of endemic species climatic variables may have been recognized as the only important factors affecting vegetation cover and leading to drought.

H. Evapotranspiration and aridity

A study by Moonen et al. (2002) of the last 122 years found temperature and moisture absorption through direct heating by sunlight did not make a significant impact on evapotranspiration. Though the study was related to agriculture and precipitation across Italy, their finding was contrary to the established belief in science that the Mediterranean is subject to high evapotranspiration rates because of typical higher temperature and aridity. The study further cited similar high temperature and aridity conditions in Russia and China as failing to coincide with high evapotranspiration or drought proneness (Moonen et al., 2002).

What is interesting from the study is the focus on agriculture and water resources. Findings showed that irrigation needs remained unchanged, potentially preventing conditions of aridity while climate had little or no impact on crop production. Climatic episodes were momentary or short-lived and not spread over time as previous modeling predicted based on the Moonen et al. (2002) study, concluding that evapotranspiration is limited even when temperatures are high and climate had no noticeable effect on inducing drought. Further that study determined the ability of agricultural vegetation to survive climatic extremes is dependent upon the type of crop planted.

I. Reordering water distribution

Of concern is a continual management practice of redirecting water resources and altering land where available water resources may be subject to fast runoff. For example, water lost during climate extremes when downpours occur is water that will exit the system as runoff and thus reduces water potential collection by wetlands or other moisture habitat. A reduction of wetlands leads to a reduction of soil moisture and reduces the colonization by certain types of endemic plants, supporting that alterations to the land change vegetation community composition and lead to bare ground and drying.

The reordering of streams over more than 1000 years across all of Italy for traditional high agricultural and other uses (e.g., urbanization) is also responsible for land and water system (Mensing et al., 2015) changes. Water redistribution to meet climatic changes across the territory instead spreads drought through modification of the landscape.

J. Potentiality of agricultural adaptation

Vergni et al. (2015) studied the effects of moisture retention on agricultural vegetation and finds low precipitation and soil moisture does not necessarily result in lower crop yields. Torrential downpours and storm events as a water source have not changed in the past +120 years (Moonen et al., 2002) and is an historical characteristic of climate that is left unmanaged ecologically. Collected rainfall downpours could support plants in need of wetlands and moisture rich environments while endemic exclusive species have space to colonize more drought prone or arid areas that favor their needs.

K. Attention to endemic exclusive plants

Since endemic exclusive plant species are the ones most adapted to climatic and soil changes over time it is this category of plants that is important in terms of drought indicators because these species are the most environmentally specialized. Endemic plants, and endemic exclusive plants, which may be distinguished from each other through identification and occurrence, and/or specific genetic traits and habitat requirements are most resilient in the native habitat and thus survive climatic pressures. Select economic or agricultural vegetation categories may serve as the variable impacted by the standard precipitation index if those particular plants happen to be the ones prone to adaptation in dryland biomes or not. Further, in this instance standard precipitation fails to account for other moisture sources or other plants.

L. A loss of plant species translates to drought

In the present study, it is expected that redirection of water supply based on population pressures, conversion to urban, loss of forests, conversion in semi-natural and wildlands, and even loss of agricultural land for certain species are more important contributors to drought than the quantity of precipitation and extremity of temperature.

While this study uses some of the variables from indices (precipitation, temperature, evapotranspiration), it also includes non-indices variables hypothesized as important in understanding drought (agriculture, urban, water bodies, human population). What is unique about this study is the utilization of various plant categories and their relation to various environmental land use variables.

Plants serve as identifiers to ecological health in their respective biomes. Insights gained from investigation and research on the wide variety of existing and remaining plant species is useful to manage desertification spread and local ecology. Additionally, informing which environmental conditions are most related to endemic species proliferation aids clarification for research, planning, and policy direction. Alterations in local environmental chemistry are pronounced by land use, climatic, and anthropogenic changes within an area. Failing to identify gains and losses in species is detrimental when considering the consequences of drought onset and species extinction. Thus, the relationships between environmental changes and plant species proliferation advance the organization of studies to support species protection and prevent desertification.

II. Literature review

A. Investigating drought in Italy

The significance of this research is to discover information about drought increase in Italy and to answer the larger question of drought proneness and its natural and induced contribution to desertification. Much of the literature referencing regions within the Italian territory points to faulty land use practices and increased disparity in water usage and availability, disrupting ecosystem services regimes and facilitating drying conditions that transition to a land use state-change exacerbated by climate change.

The theoretical seat of this research is related to the process of desertification. The United Nations uses a broad statement to describe desertification as “land degradation in arid, semi-arid, and dry sub-humid areas resulting from various factors, including climatic variations and human activities" (Boschetto et al., 2010). In ecology desertification is recognized as a response-specific process that changes the state of the land itself. State changes create limits to plant production (Bestelmeyer et al., 2015) where observed reductions in existing vegetation are first indicators of the desertification process (Zanella et al., 2018; Bestelmeyer et al., 2015). An example of this state change is land cultivated for crops that continually require water resources. If precipitation (or irrigation water) is lacking in the forced land conversion state, drought can occur.

A precursor to desertification is deforestation and agriculture that enhances climate change (Ruddiman, 2003). Agricultural land use converts large-scale swaths of landscape, which alters environmental chemistry at the molecular level to increase greenhouse gases (Ruddiman, 2017). Climate change therefore is not only an effect of increased CO2 and CH4 from industrial emissions but an effect of human land use alterations largely associated with the arrival of large scale agriculture. While pre-industrial forest clearing for agriculture added 24 ppm to the atmosphere, this change accounts for 60% of the climate anomaly in the paleo-records (8,000 years ago) (Ruddiman, 2003) showing that small changes can cause environmental disturbance.

As human land use activity increased with affluence throughout time, resource demand simultaneously increased to alter the chemical composition of the land, air, and water, thereby increasing desertification mechanisms that now threaten human settlements with increased drought (Zanella et al., 2018; Ruddiman, 2003). In recent times, human civilization has decreased the area of farmland and increased the output of agricultural production compared to paleo-agricultural times (Ruddiman, 2017).

Spreading urbanization and modification of the landscape contributes to other ways in which land use changes continue to move forward the desertification process. Landscape modifications and land management are common features related to human settlement in Mediterranean Italy and are especially important over historical time (Brock, 2018) and into modern times (Viero et al., 2019) when considering climate.

This study is centralized on the country of Italy as a one of the Mediterranean territories expected to suffer from increasing drought under climate change. General climatic characteristics of the Mediterranean basin and the process of ongoing climate change raise concerns as drought is expected to last longer at recurring intervals into the coming decades (Appiotti et al., 2014; Dieter et al., 2011; Diadato et al., 2007). Precipitation is projected to decrease as summer temperatures warm and temperature-precipitation extremes become a typical scenario for the Mediterranean territories (Longobardi et al., 2016).

B. Mediterranean climate

The geographic Mediterranean is a physical place bounded in the southernmost part of the European continent, northern outskirts of the African continent, and the edges of the Asian continent to the east. The Mediterranean Sea between the two continents of Europe and Africa is narrowly accessed by through-flow water from the strait of Gibraltar at its westernmost point and the Suez Canal to the easternmost point (Bergamasco and Malanotte-Rizzoli, 2010).

It is known that the Mediterranean represents a unique region of the world because of its closed basin sea characteristics combined with unique bathymetrical features such as peaks, troughs, shelves, gulfs, and other geomorphology. (Lionello et al., 2006). The "conveyer belt" activity typical of ocean circulation within long stretches of open ocean such as in the North Atlantic or Southern Oceans is condensed within the many sub-basins and smaller margins of the Mediterranean Sea (Bergamasco and Malanotte-Rizzoli, 2010) where the basin's features (such as land forms) constrain small and medium trails of surface eddies. These movements interact with the atmosphere above and deeper layers of sea below while cut by vertical and horizontal warm-cold transitions accompanied by varying salinity concentrations. In this way the Mediterranean Sea represents a transition zone of differences that can bring about unusual and sudden storms in the region (Bergamasco and Malanotte-Rizzoli, 2010). A closer proximity to the equator contributes to sub-humid to dry climatic patterns that clash between the mid-latitude and Hadley cell (sub-tropical) circulations (Lionello et al., 2006) that affect precipitation patterns between winter and summer.

Due to the limited amount of precipitation the Mediterranean region is defined as an arid land area divided into bands of sub-climatic systems (Pesaresi et al., 2017), i.e., areas of climatic diversity yield uncertainty within the overarching definition of aridity as a typical Mediterranean climatic characteristic. A Mediterranean climate in its most general sense is one that exhibits periods of wet precipitation episodes in autumn-winter and contrasted periods of dry evaporate episodes in spring-summer that creates a dichotomy in the precipitation pattern over winter to summer seasons. Mild temperatures will exist in winter with hot temperatures carrying over summer (Lionello et al., 2006).

While the Mediterranean ecosystem is prone to drying and increased aridity since the Holocene (last 12,500 years before present) it is the documented human presence that facilitates the speed at which drying and drought occurs (Sadori, 2013) to cause ecological drought. What is unclear in the literature is whether or not drying would continually increase until drought and ultimately desertification consumes the landscape without humans present (Tietjen et al., 2017; Sadori, 2013).

It is anticipated that regular climatic regimes will consist of peaks and troughs, for example sudden storms, temperature spikes or drops, and/or cyclonic direction clashing with topographic features. These characteristics amplify climatic intensity and as triggers that expose surface soils to sunlight, wind, temperature, and organisms. Sadori (2013) summarizes how over time vegetation and organism adaptation to the land will result in environmental changes to climate. Depending on the interaction of organisms for example, plant composition, grazing animals, and vegetation will respond to the pressures from other organisms. Adaptations or extinctions depend on the traits and characteristics of the environment and the organism itself, which is also dependent upon the rate at which adaptation may be possible or threats to a species may occur. As a basis for extinction, which in some instances is normal over geologic time, other factors can speed the process of land degradation to create extinctions. Drought as an antecedent to desertification is one of the processes and vegetation, water, and human activity are some of the factors.

C. Types of drought

Types of drought are predominantly considered in the literature as either hydrological or meteorological (Diodato, 2007); hydrological drought means that the source of flow is lacking where flow is common, as in streams and rivers, and meteorological drought means that the source of flow in the form of precipitation is lacking, such as fog, rain, or snow. Agricultural drought is more loosely defined as the lack of soil moisture to sustain crop production (Vergni et al., 2015). The United States Geological Survey offers these following definitions of drought from the literature:

1. Meteorological drought: “A period of abnormally dry weather sufficiently prolonged for the lack of water to cause serious hydrologic imbalance in the affected area,” (Huschke, 1959).

2. Agricultural drought: “A climatic excursion involving a shortage of precipitation sufficient to adversely affect crop production or range production,” (Rosenberg, N.J., ed., 1979).

3. Hydrologic drought: “A period of below average water content in streams, reservoirs, groundwater aquifers, lakes and soils,” (Hall and Salas, 1977).

As already mentioned a fourth type of drought is highly relevant for understanding drought in general: ecological drought. A potential definition for ecological drought is provided in the literature as a response by organisms to climatic extremes where fitness and survival are traits of causality associated with climate and species survival (Smith, 2011). A more current and inclusive definition in this same theme of response describes ecological drought as “an episodic deficit in water availability that drives ecosystems beyond thresholds of vulnerability, impacts ecosystem services, and triggers feedbacks in natural and/or human systems" (Crausbay et al., 2017). The current definition attempts to capture a fuller range of conditions, similarly as additions to definitions of drought types of meteorological, agricultural, and hydrological. While scientific and governmental definitions of drought are becoming more inclusive of the various facets of drought, single definitions lack an ability to fully explain what drought is at its source, especially under climatic diversity. One or more of the definitions can be truly dependent upon the unique characteristics of the area under question as being affected by one or more types of drought.

Drought is typically predicted using temperature and precipitation indicators. The standard precipitation index (SPI) has been predominantly used worldwide and as a method to indicate drought in the European Union and in Italy by region (Diadato, 2007). Spatial extent, peak or minimum precipitation is modeled into a distribution to determine hydrological, meteorological, and agricultural drought through indices that rank severity of the precipitation distribution with parameters added, such as soil moisture conditions, to update the indices (Vergni et al., 2015). Though scientific methodology to assess drought remains causally related to rainfall (Boschetto et al., 2010) it lacks a relationship between drought and environment as an ecological relationship.

In the Mediterranean precipitation can oscillate unpredictably over time between wet and dry periods even when drying periods last longer, meaning proximal regions within Italy can experience differing levels of drought dependent upon a local microclimate (Longobardi et al., 2016). Within dry conditions drought can vary intermittently and increase in severity with dramatic differences between short three to six month periods and long-term drying periods of one to two years. SPI can also be measured at selected one month, three, six, nine, twelve, or 24-month intervals. Within the literature a concerning trend that drying conditions extend over longer periods is already evident in Italy (Buttafuoco et al., 2015) from short term to severe long term drying episodes. Included in this drying are streams originating in the mountains (from snowpack or springs) that fail to return at their regular intervals lasting over the two-year drying period (Pinna et al., 2016).

While snowpack will decline with increased temperature, expected snow will fall as rain dependent upon elevation, topography, and temperature where antecedent conditions will exist in mountain regions differently (Penna et al., 2011). Water delivery by streams from the mountains to the hills, plains, and valleys is altered regionally by extremes in flow that originate from varying levels of snowpack and rainfall, available mountain lake storage, and local climate variability (Oueslati et al., 2010). Water delivered downslope is dependent upon soil (specifically the amount of organic horizon), vegetation, and existing moisture saturation conditions (Penna et al., 2011). Variability between locations within the same mountain chain and within the Mediterranean itself can produce divergence from the expected effects of predicted (precipitation) flow quantity (Oueslati et al., 2010). Variability due to mountain geomorphology within a centralized location such as a local Italian region can also vary. Precipitation recharge to mountain springs and aquifers providing flow to river systems as well as water for urban, natural (e.g., woodlands), and agricultural uses can change because of elevation, thus local topography may be more important than precipitation in determining groundwater recharge (Allocca et al., 2013) as a water source.

Given these variabilities, researchers develop multiple indices to explain and report meteorologic and hydrologic variability. Similar to SPI, multiple variables are continually added to create new indices and enhance existing indices and improve prediction of streamflow and water resource delivery. Since the multiplicity of indices has become confusing and may pose difficulties for users, Oueslati et al. (2010) proposed a method to adjust prediction. They suggest matching local conditions to newer classifications that describe flow based on findings that measures differed within geographic regions depending on directionality and positioning either east, west, north, or south in the Mediterranean basin. Locally important predictors are important since global predictors often fail to match water source availability and predict flow quantity. They further explain classification and indices creation relying on global standardized predictors confuses local flow variability because flow was distributed by geographic location and not solely on precipitation quantity. In other words, understanding local conditions appears better suited to determining predictions instead of applying global standardized indices.

To manage ecological drought local conditions must be taken into consideration. In Italy local storms as a product of atmosphere provide for seasonal flow with high runoff (i.e., water lost to usage) (Penna et al., 2011) and identifying and developing local indicators could help manage those water resources. Italy shows an increase in warming double the global temperature (ISPRA, 2016) where an ecological assessment of local conditions would better manage drought. Studies are needed to determine locally what differences from global standard indices exist in a region. Local management purposes are intended to meet the needs of local inhabitants (Appiotti et al., 2014) and may not reflect global patterns.

D. Aridity and Mediterranean vegetation

In addition to human presence and water needs, within the Mediterranean climatic regime are biomes supporting specialized plants that are adapted to dryer conditions and that represent a high biodiverse collection of flora compared to other sites worldwide. Tietjen et al. (2017) claim dryland vegetation is highly sensitive to changes in climate, however, in the Mediterranean, studies show resilience to climate change and increased aridity over geologic time (Sadori, 2013) revealing resilience to dry conditions. In fact aridity may increase but downpours or other moisture sources (e.g., snowmelt, mountain springs) are present to provide moisture while plant adaptation may sustain species for longer periods of dry episodes.

The Mediterranean is divided into many zones of temperate and arid lands, where even in the same region a hillslope may provide moisture on one side where the opposite side of the hill may be prone to drying. Thus one side may host endemic exclusive species while the other side is bare or hosting sparse tree species that may be found elsewhere (Wellstein et al., 2014). Thus, adaptation may not be exclusive but part of the total vascular plant community adapted to the overarching geographic Mediterranean climate of collective lower precipitation.

While Tietjen et al. (2017) analyze global precipitation and vegetation data in several regional (South America, United States, Mediterranean Basin) dryland biomes, they fail to account for the adaptability of localized vegetation and human impact. Soil moisture is found as the limiting factor for ecosystem services success and is in line with findings from other authors (Zanella et al., 2018). Moist soils tend to support vegetation where dry soils were found to have less vegetation cover and faster drying (Tietjen et al., 2017). Is this wet-dry phenomena with or without human influence? Where Tietjen et al. (2017) determine that increasing aridity is an act of climate change alone does not support ecological management. The findings by Tietjen et al. (2017) that drying will increase regardless of the increased vegetation to cover bare ground were based off the reasoning that increased vegetation will result in higher water needs and still lead to drought conditions. Local plants are thus a category to study further to determine their resilience during increasing aridity, especially since drought tolerant plants have been around for thousands of years.

In contrast to the idea of ecological drought, the Tietjen et al. (2017) paper focused on climate modeling of vegetation and aridity and did not account for factors of local conditions. To address their use of vegetation related to climate, species found in the Holocene (Sadori, 2013) are still present in the Mediterranean today (Bartolucci et al., 2018). Additionally, studies of paleo-climate reveal evidence that human influence alters the composition of vegetation communities more than climate (Sadori, 2003) and thus future climate modeling should also account for this variable.

In the literature importance is placed on high aridity and evapotranspiration as a characteristic of the Mediterranean climate. In terms of Mediterranean climate a logical feedback response is represented as an exchange between vegetation and transpiration. An increase in vegetation should balance the amount of evaporation between ground vegetation and atmosphere as part of natural feedback, thus questioning the global generalized climatic modeling. In other words the amount of water on earth is fixed and is only exchanged through feedbacks in the various systems (e.g., hydrological, vegetation-climate, and flux between the many types of natural systems) with location also an important drought prediction component. Precipitation patterns may be more important than precipitation quantity in terms of relating this moisture variable to a local region.

Italy as generalized in topographic representation by a mountainous (center), hilly (mid-way), and coastal area (edge line) bioclimate transition and its smaller land area create a proneness to dynamic fluctuations from the already dynamic Mediterranean sea-atmosphere system. Depending on the region and factors specific to a particular region, human settlement, vegetation, land use, and climate will vary in wet-dry intensity. The findings by Tietjen et al. (2017) that vegetation will respond to precipitation is not correct in every case, especially when smaller regions are focused on as part of contents within a larger region (e.g., regions inside Italy as existing in the central Mediterranean basin). In fact dryland vegetation responds to drought, not precipitation as explained by the longevity of Mediterranean plant species and global increasing aridity since the last glaciation ended and began the Holocene (Sadori, 2013).

Soil moisture as a source of water for life is necessary, yet moisture refuges coincide with organic cover, thus protecting soil microhabitats from the drying (Rossetti et al., 2015; Bagella et al., 2014) and degenerative effects of solar radiation (Dieter et al., 2011) and allowing a basis for vegetation cover (Zanella et al., 2018). Can we know for certain that solar absorption indices and soil moisture indices will predict drought in this case? Why are soil refugia locations often referred to in the literature such small and limited areas? What are the potential correlations to discover how the dynamic properties of the environment predict drought or not in regions of Italy?

E. Effects of human presence on land

Human land use practices are factors contributing to rapid deterioration of the landscape that causes agricultural and endemic plant productivity to change and results in drought. This behavior need not be direct either. As alterations to the land increase, such as spreading agricultural lands, conversion of natural areas to urbanization, and redirection of waterways, moisture for vegetation is reduced and speeds the drying process. The state-change land-use-change framework proposed in ecology allows for analysis of multiple variables to assist in determining the factors causing the state change (Bestelmeyer et al., 2015). The scale of degradation often extends to lands other than those directly under conversion, causing one unproductive state to interact with other land use states (Bestelmeyer et al., 2015) and thus extending the range of drought penetrability.

Landscape modification, especially land morphological changes - such as engineering to natural water delivery channels, floodplains for agricultural production, and mountain dynamiting for tunnels or other uses and other surface degradations such as deforestation are all sources of water loss. Population density and water management have rearranged the natural water resource flow regimes in addition to threatening existing natural infrastructure and natural areas (Viero et al., 2019; Bocchi et al., 2012). Ruddiman (2017) further stresses the relationship between decreased agricultural area, ongoing deforestation, and coinciding exponential growth of human population as facilitating climatic change. This action is leading to generalized global drought.

Exploitation of land for agriculture forces the natural distribution of river channels to change because of human occupation of the area. Erosional modifications occur as a result of land area bounded by agricultural use whether intentional or not. Rivers may flow but humans on the land prevent the expansion or directionality of the river flow channel path by placing constraints (e.g., building a barrier, filling, clearing an area for agricultural use). Modification aids in producing erosional features which push successive modifications and/or collapse (Magliulo and Cusano, 2016) of the natural water delivery system and cyclically inducing more human modification. Modification on-site can over draw aquifers offsite and disrupt the natural floodplain.

Both on and offsite modifications to natural processes are common across the Italian territory, where many land use types sit (e.g., the city of Rome in a major floodplain). A floodplain is altered to establish an urban center, modifications support the type of habitat humans create, thus additional utilization of offsite resources, such as a spring fed mountain aquifer depletes water resources in both locations and creates land degradation that impacts local vegetation. This and other common scenarios of land use modification to supply resources for human communities disrupt natural processes and redistribute water. Alterations to river channels, catchments, and floodplains in this way throughout Italy are an additional ecological problem for water management and have been an occurrence over thousands of years (Scorpio et al., 2018; Brock, 2017; Mensing et al, 2015). The redirection of water resources exemplifies how human modification of the landscape moves resources from one site to another where the phenomena of flooding in urbanized areas (Sofia et al., 2017) can distort society's view of drought occurrence.

Agriculture is another source of landscape modification resulting is redistribution of water resources. Agriculture is also an historical cultural heritage in Italy (Costantini and L'Abate, 2009). Agriculture over thousands of years has also been extremely important to the Italian economy. Yet land degradation from intensive agricultural usage is widespread (Costantini and Lorenzetti, 2013) and results in landscape modifications that can lead to water shortages, erosion, contamination, and state-changes. These problems are worsened by a lack of management (Salvati et al., 2015) coupled to the practice of land abandonment after it has been exploited (Bajocco et al., 2018).

Abandoned (agricultural) lands that are degraded and no longer managed add to the lack of equilibrium over Italian territory by increasing the risk of sensitivity to desertification (Boschetto et al., 2010; Marchetti et al., 2012). Alternative land use practices out of sync with natural ecosystem processes act as a low to medium desertification risk presenting an increased degradation threat to a higher sensitivity under climate change (Boschetto et al., 2010). Thus, soil sensitivity increases stepwise towards aridity intensifying drought into desertification.

While this study focuses on the Italian territory due to its unique floral assemblages, globally the pattern of land modification has similar results and is commonly documented in the literature. Drought related incidents and drought severity depend upon local characteristics. The United States for example has an equal if not worse water shortage problem across the country due to agricultural management, land use and abandonment, and land modification over time (Montgomery, 2012) with varying severities worsened by climate change.

Land use conversion compromises soil quality and the ability of native plants to establish and abate desertification processes in Italy (Salvati et al, 2015). The reduction of naturally adapted vegetation limits the potential of soils to retain moisture and spreads desertification as soils are also altered by environmental variables (Sadori, 2013; Montgomery, 2012). Vegetation is also introduced, removed, reintroduced, and redistributed due to human influence. These changes in surface responses consisting of soil quality and vegetation cover may be included in modeling indices to predict drought along with rainfall and temperature (Vergni et al., 2017). Indexes are generally converted to desertification prediction maps to simplify application, but maps are a static snapshot and may not capture dynamic properties related to drought. Drought is then indicated by a lack of soil moisture and reduced vegetation relative to climate (Boschetto et al., 2010).

Levels of desertification should be measured through several variables or indexes categorizing the amount of rain, vegetation, soil health, and temperature (Boschetto et al., 2010) to better predict drought. The quantity of expected precipitation is mainly applied to certain types of plant production for agricultural purposes as the main cue for drought prediction (Vergni et al., 2017). Despite updates in science to include soils, vegetation cover, evapotranspiration, solar absorption, temperature, and hydrological modeling for purposes of a better drought indicator, ecological drought is neglected, yet its importance is overlooked in the methods of drought prediction.

Practically, understanding localized behaviors related to the spread of drought is important for managing land use because people depend on desertifying lands for both their livelihoods and ecosystem services. Management plans are lacking and drought related response is defaulted to emergency systems (Appiotti et al., 2014). It is important to investigate drought conditions and identify areas where behavior changes or land use practices can prevent the need for reactive emergency response.

In summary, drought as usually measured by precipitation and other climatic indices are only somewhat useful in predicting drought and do not take into account locally important factors, such as land use, human population, and endemic flora. Land use modification is a leading cause of drought and impacts endemic vegetation along with people within the climate system. The present study includes the variables from drought prediction indices (precipitation, temperature, evapotranspiration) but adds non-standard indices variables (agriculture, urban, water bodies, human population) as important in understanding drought. Unique in this study is the utilization of various plant categories and their relation to various environmental land use variables for a better understanding of drought. By incorporating the particular variable types, a wider view of drought is gained which enables a more holistic view of drought that captures more than climatic variation.

III. Methods

Land use, including area, human population, vegetation, and climatic numerical data from twenty administrative regions comprising the Italian territory are investigated to better understand ecological drought as opposed to single drought types directed by standard precipitation. These secondary data were collected from governmental and scientific sources (see Table 1) and assembled in a Microsoft Excel worksheet by region and year for 2005 and 2018 for eleven independent variables and three dependent variables.

A. Variables by name

Land Area

1. Total land area of each region

Vegetation

2. Endemic plant taxa in each region
3. Endemic plant taxa exclusive to each region
4. Total vascular plant taxa in each region

Climatic

5. Precipitation
6. fAPAR
7. Soil anomaly
8. Temperature

Land Use

9. Urban
10. Agricultural

11. Forest and semi-natural/wildlands

12. Wetlands

13. Water bodies

Population

14. Human population

B. Variables by definition

This section introduces the plant species variables and hypothesized variables related to ecological drought. Species-area relationship is explained at the end of the following variables definitions.

1. Vegetation

Data representing vegetation counts by region are derived from Istituto Superiore per la Protezione e la Ricerca Ambientale, (ISPRA; Italian Environmental Protection and Research Agency, Rome, Italy) and Bartolucci's updated plant list (2018). **Endemic plant taxa** represent the count of endemic species and subspecies by family per region that are found only in Italy. There are approximately 8,195 plant units found in Italy but of that count about 7,483 are only found in Italy (Bartolucci et al., 2018) and are the endemic vascular plant species representing this (y) variable. **Endemic plant taxa exclusive to each region** (or regionally exclusive and/or endemic exclusive) represents the count of endemic species found only in a respective region adding up to about 1,708 of exclusive plant species in all regions combined (Bartolucci et al., 2018, Peruzzi et al., 2015). **Total vascular plants** are the 8,195 total vascular plant species count per region that are also inclusive of plant families found outside of Italy (Bartolucci et al., 2018).

Since species counts are likely a function of area (Wagner, 2013), all three dependent variables were transformed into a new variable that accounts for the species-area relationship. This was accomplished by logn (natural log) transforming regional area as well as the three plant species variables mentioned above. Next, ordinary least squares regression models were estimated with the logged area as the x and each of the three logged species variables as three y variables. The residuals from these three regression models were then saved as three new dependent variables to represent the species-area relationship.

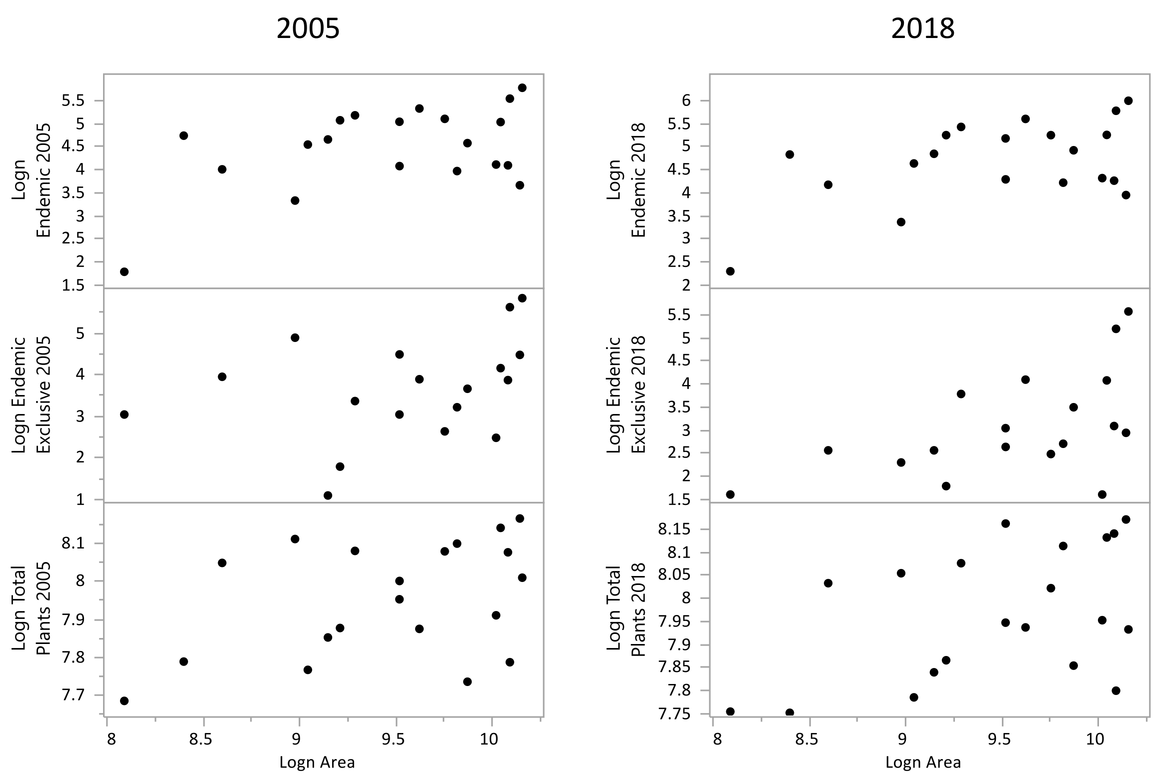

Figure 3. Logn dependent variables scatterplots shows natural log (y) plant categories of endemic, endemic exclusive, and total vascular plants against (x) area variable

2. Climatic

Climatic data excluding temperature (described below) are derived from the European Union Copernicus Earth Observation and Monitoring (EUCEOM) program satellite data. To calculate yearly values for each climatic variable (differences in temperature data calculations are explained separately) daily measurement values per day are added over the twelve-month (January and July months for temperature) time period for 2005 and 2018 then the mean taken over the year for each respective region.

Precipitation is the amount in millimeters of daily rainfall collected from gauge stations in each region. Daily rainfall measurements were averaged to obtain the annual measure over the time period investigated.

Fraction of absorbed photosynthetically active radiation (fAPAR) is the amount of solar energy absorption by plants and plant water stress measured by solar energy wave reflection using satellite observation collected values. The fAPAR is the daily satellite collected surface reflectance of solar radiation. The fAPAR output is generally used as a predictor of agricultural drought stress on plants for human consumption. The fAPAR is also used for detecting plant water stress in non-agricultural vegetation by generally measuring canopy cover (regardless of plant size) to detect plant sunlight absorption over area. Vegetation patches are then recognized by satellite through fAPAR to determine areas where plants may be clustered in patches. Thus, fAPAR measures where solar radiation is absorbed and where it is reflected. The range of absorption for this variable is -4 to +4. Negative fAPAR anomalies reveal levels of plant water stress associated with drought conditions. Positive values represent the intensity of absorption and zero no absorption or reflectance is detected by satellite.

Precipitation and temperature as drought indicators and meteorological drought predictors lack capturing the amount of solar absorption and feedback by plants, thus fAPAR is used as an additional variable to account for part of the changes in solar radiation absorption and evapotranspiration.

Soil anomaly is calculated by hydrological modeling using existing topographic, meteorologic, and land cover data sets. The anomaly is representative of the amount of soil water moisture available to plants and includes water availability from rainfall runoff, streamflow, and groundwater sources plus incident moisture sources (e.g., leaching, snowmelt) and is used as a proxy of water availability for plants to absorb. The range for this variable is -7 to +7. Differences in soil moisture above zero represent the level of soil drying and below zero the level of soil saturation, with ranges from zero to two representative of drought conditions. A value of four is considered an extreme and up to seven representative of the worst drying. The soil anomaly variable is used as a measure of other potential water source factors on land besides precipitation and/or fAPAR alone as a factor of plant water stress.

Soil moisture is included as a variable due to its importance as part of the earth-atmosphere interaction in the hydrological cycle. Soil moisture data presents a weakness due to the method of calculation (linear modeling). A benefit however to using modeled soil anomaly is its applicability to account for water availability over topographic diversity, useful for the high variation of the Italian landscape (mountainous, plains, and coasts).

Temperature is measured in degrees Celsius (°C). Data were calculated for two separate months (January and July) to represent the lowest wintertime and highest summertime temperatures for 2005 and 2018 for all twenty regions. Daily temperature data per region was obtained from Il Meteo (The Weather, Padova, Italy) archived weather data.

3. Land Use

The following land use data in this analysis comes from ISPRA environmental data (ISPRA, 2005-2018a). Land use variables were included because plant richness was not included in the satellite data. Raw data values for land use variables are used as factors against potential space available for vegetation as natural systems modification (e.g., river channel alteration, wetlands conversion) through environmental engineering or other means affects habitat.

Urban area land use is the percent of each regions' area occupied by urbanization and artificial uses per region. Artificial areas represent any built, structural, or non-natural land use, (e.g., cities, monuments, bridges, garbage dumps, etc.).

Agricultural area land use is the percent of each regions' area occupied by cultivated plants for human consumption for each region. **Forest and semi-natural/wildland area** is the percent of a region's area occupied by trees and uncultivated land. **Wetlands area** represent the percent of region's area occupied by lowland moisture rich conditions per region. **Water bodies** are the represented amount of each regions' area occupied by permanent lakes and ponds.

4. Population

Human population data is collected from census information counted by region. Total population for the territory is calculated by adding each regional population count to arrive at the total population for years 2005 and 2018. Human population data counts are taken from Istituto nazionale di statistica, ISTAT, (Italian National Institute of Statistics, Rome, Italy) environmental data. Population data is used to better understand the relationship between the amount of human presence and the quantity of each plant indicator variable.

Table 1. Variables with data origin/source coded

Variable	**Data Source**
Total Area (km^2)	ISPRA
Plant (drought indicator) Variables	
Endemic plants	ISPRA, Bartolucci et al. (2018)
Endemic plants regionally exclusive	ISPRA, Bartolucci et al. (2018)
Total vascular (taxa)	ISPRA, Bartolucci et al. (2018)
Environmental Variables	
Precipitation (mm)	EUCEOM
fAPAR	EUCEOM

Soil anomaly	EUCEOM
Temperature (°C)	
January Annual Average	Il Meteo
July Annual Average	Il Meteo
Land Use Type (km^2)	
Urban	ISPRA
Agricultural	ISPRA
Forests/semi-natural/wildlands	ISPRA
Wetlands	ISPRA
Water bodies	ISPRA
Human Population	ISTAT

C. Analytical strategy

Correlation analysis was performed to test the association between each of the three residuals species-area dependent variable against eleven environmental variables. This was done for years 2005 and 2018 (See Results section IV for correlation tables).

Kendall's Tau nonparametric correlation tests were performed since the urban, population, water bodies, and wetlands data remained non-normally distributed even after transformation. Kendall's especially was also chosen due to the small sample size of 20 regions (Pearson's r correlation has been identified as inappropriate for small sample sizes) (Vergni et al., 2017). Kendall's as unaffected by outliers, zero values, or missing data points is chosen due to its ranking of data, non-assumptive nature in detecting patterns in the data, and preservation of the original variation in variables. Applicable to the small sample size the analysis is based on conditions that the test makes no assumptions about the normality of the variables' frequency distributions. Kendall's as a rank-based parameter of the sample and narrows the confidence interval on the available sample and therefore can yield a more accurate picture of correlation between variables of small sample sizes (Brossart et al., 2018).

Scatterplots of correlations are produced for both years (2005 and 2018) to graphically illustrate relationships between variables and are provided in Appendix II. The correlation analyses help determine if there is a statistically significant association between the plant variables (with species-area relationship accounted for) and human population, land use, and climatic variables for 2005 and 2018.

D. Research hypotheses

Several factors impact the distribution of drought, not only climate. Land use modifications are prone to change the interactions between plant species and the environment thus altering vegetation cover. Similarly, humans will have a greater or lessor impact to the three plant categories in terms of natural areas, water bodies and wetlands depending on how decisions are made to utilize the landscape. In general, the main hypothesis behind the present study is that climatic variables, especially the quantity of precipitation will have little effect on plant categories. In terms of climate change and the higher warming in Italy, temperature is expected to have positive associations to the plant categories. The relationships between environment and plant variables will change as humans modify land and water area by redistributing specific resources (e.g., water, natural habitat). It is expected that plants will relocate according to the type of available land area, water availability, and available space. In spite of ongoing climatic and land use variability precipitation standards are well defined and used to predict drought. Thus, to offer an association between drought and the selected variables to build an alternative form of clarity for predicting drought, correlation analyses are used to test the following hypothesis:

H_1. Three plant categories of endemic, regionally exclusive, and total vascular plant species (accounting for species-area relationship) in the twenty regions of Italian territory are not positively associated with the standard meteorological drought indicator of precipitation, (i.e., as precipitation decreases endemic plants decrease), but are positively associated with the availability of natural areas such as forests, semi-natural and wildlands, and wetlands areas while negative associations are expected to exist between plant categories and anthropogenic factors of land use type (i.e., as anthropogenic modification increases endemic plant species will decline).

i. Expectations of main inter-relationships of variables under the research hypothesis

Anthropogenic variables of land use are anticipated as those more strongly influencing the three plant variable indicators of drought than precipitation or other climate-related variables. However, other variables are expected to be associated with the three plant categories dependent upon natural seasonal conditions as a response to environmental changes from the entire set of variables working between each other. In general terms, it is expected that the three plant categories will not be as impacted by the recent changes to climate given their adaptive history to the territory.

ii. fAPAR

The fAPAR as important in the relationship between precipitation, sunlight absorption and solar radiation is expected to positively associate with the three plant categories. Plants generally do not photosynthesize under cloud cover (although it is does occur) and are expected to negatively associate as precipitation increases. Meanwhile, the fAPAR variable accounts for evapotranspiration and increases the amount of ground moisture lost under radiative solar bombardment.

iii. Soil anomaly

As fAPAR either increases or decreases and acts on soil anomaly it is expected to be not statistically associated with the three plant categories (as soils dry plants do not decline). To replenish soil moisture precipitation availability is assumed to be a deciding factor in the soil anomaly. In the present study soil anomaly is expected as not positively associated with precipitation (i.e., as precipitation decreases soils dry). Soil anomaly in this case is expected to positively associate instead with the three plant categories (as soils dry plants will not decline) because of adaptations to the Mediterranean climate.

iv. Temperature

January annual average temperature is expected to be positively associated with the three plant categories because sub-climates should contain endemic species requiring humidity and warm-wet conditions. It is expected that both cases of January warming and January precipitation will benefit plants in the Mediterranean sub-climates. As the temperature variables increase plants will not decline. July annual average temperature is positively associated with the three plant categories and is positively associated. Higher temperatures imply increased solar radiation penetration to the ground where soil anomaly is expected to trend towards drying. As July annual average temperature increases plants will not decline if soil moisture decreases and are negatively associated with precipitation to again reveal adaptation in wet-dry climate by endemic plant species.

v. Urban and agricultural land use

In anthropogenic terms urban area is expected to be negatively associated with the three plant categories. An anticipated negative association with precipitation is expected to represent both a reduction of available space and water lost to usage due to soil sealing by materials used in urban environments. Agricultural area is anticipated to be negatively associated with the three plant categories. Since both land use and water redirection is expected to take available resources away from endemic plant species urban and agricultural area are expected to be negatively associated with plant species counts.

vi. Forests/semi-natural/wildlands, wetlands, and water bodies

Forests/semi-natural/wildlands are anticipated to be positively associated with the three plant categories due to habitat requirements mainly in higher organic layering in soil types and ground moisture availability. A positive association is expected with the precipitation variable because natural lands are expected to retain moisture spread in the ground differently than human modification that may channel water in a path instead and prevent infiltration. Similarly, wetlands areas are expected to be positively associated with the three plant categories because of the spreading capacity of ground moisture in these types of lands. Water bodies are expected to have no association with the three plant categories as lacking in ability for terrestrial plants to take root and where water is collected into existing reservoirs.

vii. Human population

Lastly, human population is expected to be negatively associated with the three plant categories (i.e., where population increases plants decline) because the potentiality of on-site or off-site activity can result in plant decline. While space is reduced for the three plant categories as human population increases population may not be sprawled and thus show mostly as an impact on surface water availability.

In summary, precipitation as the main indicator of drought is expected to not be significant for the three plant categories since other factors can contribute to a decrease of plants. Although alterations to land contribute to climate change and alter the availability of precipitation, that precipitation is expected to be fixed yet differently distributed and affected by other variables such as urban and agricultural land use and human population in this study.

IV. Results

A. Summary of descriptive statistics for the Italian territory

The mean, frequency, range, and standard deviation basic features of the data for 2005 and 2018 are displayed in Tables 2 and 3 below as a territory-wide report. The following descriptive statistics contain the highest and lowest value differences presented as by variable regional data. Detailed tables reporting variable values by region are provided separately in Appendix I. Land use type occurrences for the given sample are represented in percent.

Table 2. Mean, range, and standard deviation of all variables combined, year 2005 (n = 20 regions)

All Variables	**2005**		
	Mean/ Freq.	**Range**	**(SD)**
Total Area (km^2)	301,397.25	-	-
Dependent Variables			
Endemic plants	117.90	6 - 321	80.60
Endemic plants regionally exclusive	65.70	0 - 344	91.14
Total vascular (taxa)	2,872	2,174 - 3,521	420.11
Independent Variables			
Precipitation (mm)	863.26	551.09 - 1324.32	175.02
fAPAR	0.0898	-0.2569 - 0.5755	0.1890
Soil anomaly	-0.0204	-0.6858 - 0.4516	0.3299
Temperature (°C)			
January Annual Average	4.72	0.5 - 8.9	2.74
July Annual Average	24.98	22.8 - 28.9	1.38
Land Use Type (km^2)			
Urban	779.47, 5.17	45.18 - 2,658.80	612.35
Agricultural	7869.21, 52.22	259.43 - 17,423.99	4916.83
Forests/semi-natural/wildlands	6222.59, 41.29	1,610.03 - 12,927.30	3342.58
Wetlands	35.77, 0.24	0 - 276.76	64.48
Water bodies	157.07, 1.04	3.41 - 681.43	201.19
Human Population	2,849,787	119,548 - 9,032,554	2,251,527.80

Table 3. Mean, range, and standard deviation of all variables combined, year 2018 (n = 20 regions)

All Variables	**2018**		
	Mean/ Freq.	**Range**	**(SD)**
Total Area (km^2)	301,397.25	-	-

Dependent Variables			
Endemic plants	145.10	10 - 400	101.73
Endemic plants regionally exclusive	39.65	0 - 262	65.72
Total vascular (taxa)	2,909.2	2,333 - 3,535	407.72
Independent Variables			
Precipitation (mm)	885.46	579.36 - 1427.75	187.64
fAPAR	0.4340	-0.0016 - 0.9469	0.2713
Soil anomaly	-0.2497	-1.0913 - 0.7238	0.3806
Temperature (°C)			
January Annual Average	8.42	5 - 12.4	2.66
July Annual Average	25.87	24.5 - 27.2	0.82
Land Use Type (km^2)			
Urban	2038.16, 13.5	158.53 - 5,889.66	1486.89
Agricultural	6613.06, 43.88	146.08 - 15,105.12	4248.37
Forests/semi-natural/wildlands	6219.29, 41.27	1,609.70 - 12,904.31	3339.83
Wetlands	36.12, 0.24	0 - 282.59	65.61
Water bodies	157.46, 1.05	3.41 - 684.99	200.43
Human Population	2,979,676	126,883 - 9,951,442	2,477,039.10

B. Summary of change in variables, 2005-2018

Differences for each region are representative of the variety in variable values over time beginning 2005 and ending 2018. The lowest and highest values between regions are reported below.

i. Endemic plants

Endemic plants range from six species in 2005 to ten species in 2018 in the northern region of Valle d'Aosta representing the smallest number of endemic species throughout all regions. The highest counts of endemic species are found in the farthest southern region of Sicilia and range between 321 and 400. All twenty regions show increases in endemic species counts with the region of Friuli-Venezia Giulia only increasing by one species count over the 2005 to 2018 time period.

ii. Endemic plants regionally exclusive

Endemic plant species that are exclusive to a respective region decreased differently across regions between 2005 and 2018. Thirteen regions show a decrease in endemic exclusive plant species. The lowest decrease occurs in Lazio (-2 species) and the highest decrease in Friuli-Venezia Giulia (-123 species). Four regions show no change; Umbria and Molise: 0, Campania: 21, Basilicata: 6, and three regions increase, Marche (+10), Abruzzo (+15), and Calabria (+11). Thus, the majority of regions show a decrease in endemic exclusive plant species with seven exceptions. Zero as the lowest value is found in only two of the twenty regions, Umbria and Molise. In Sicilia where the end range highest counts of endemic regionally exclusive plant species are found have declined from 344 in 2005 to 262 in 2018.

iii. Total vascular plants

Total vascular plant species counts for each region shows a decrease in eleven of the twenty regions. The smallest range of decrease was found in Abruzzo (-16) and Marche (-31). The greatest decrease occurred in Friuli-Venezia Giulia (-188) and Lazio (-181). Out of the nine regions to increase total vascular plant species the smallest increase is found in Piemonte (+14) and highest count in Trentino-Alto Adige (+519).

iv. Precipitation

Nine regions received an increase in precipitation while eleven decreased in precipitation. Precipitation increased from 2005 to 2018 in the northern regions while a decrease occurred in the central to southern regions on the peninsula with Liguria (+393.08mm) experiencing the greatest increase in rainfall and Abruzzo (-338.31mm) the least. The islands of Sicilia (+39.88mm) and Sardegna (+192.76mm) both received increased rainfall.

v. fAPAR

An increase in fAPAR occurred in eighteen regions. Liguria (-0.0828) and Marche (-0.2553) show a decrease. Solar radiation absorption and evapotranspiration above zero was at its lowest in Trentino-Alto Adige (+0.0167) and highest in Emilia-Romagna (+0.6745).

vi. Soil anomaly

Soil moisture anomaly occurs over all twenty regions. Fifteen regions represent an increase in soil saturation and five regions a decrease in soil saturation. The lowest level of soil saturation occurred in Friuli-Venezia Giulia (-0.0153) and the highest in Sicilia (+0.7338).

vii. Temperature

Temperature over January increased in all twenty regions from 2005 to 2018 with Liguria measuring the least change at 2.2°C and Molise the highest at 6.6°C. July temperatures over eighteen regions increased between 0.2°C (Basilicata) and by 4.4°C

(Molise). July temperatures decreased in the two regions of Umbria by 2.8 °C and Lazio by 0.6 °C.

viii. Urban

All twenty regions experienced an increase in urban land use between 2005 and 2018. Six regions show less than 5% increase, eight show between 5% and 10%, and six increased by more than 10% urban area land use. The lowest percent increase occurred in Liguria with a 3.05% increase and the highest in Veneto at 16.32%.

ix. Agricultural

Agricultural land use decreased in all twenty regions with the least percentage of decline occurring in Liguria at 3.05% and the largest in Veneto by 16.3%. Five regions decreased agricultural land use by less than 5%, eight between 5% and 10% and five regions by over 10%.

x. Forests

Forests, semi-natural, and wildlands show no change in the three regions of Valle d'Aosta, Umbria, and Sardegna. The remaining seventeen regions show decreases between 0.007% and 0.1% as essentially no change. Forest cover is above 50% in six regions, between 25% and 50% in thirteen regions and less than 25% in one region.

xi. Wetlands

Wetlands show no change over fourteen regions. Three regions show a slight increase as essentially no change, Piemonte (0.001%), Valle d'Aosta (0.0165%), and

Veneto (0.031%). A slight decrease in values occurred as essentially no change in Basilicata (0.0007%), Campania (0.007%), and Toscana (0.008%).

xii. Water Bodies

Water bodies increased as essentially no change over Sardegna (0.003%), Calabria and Campania (0.02%), Basilicata (0.005%), Puglia and Molise (0.009%), and Lombardia (0.018%). Two regions show low decreasing values of 0.009% (Emilia-Romagna) and Veneto (0.035%) as essentially no change. The remaining eleven regions have no percent change in permanent water bodies.

xiii. Human Population

Human population increased over fifteen regions. Five regions decreased in human population with Liguria by -7,036, Molise -10,152, Basilicata -27,403, Calabria -56,451, and Sardegna -551,324. The region with the highest increase in human population over 2005 to 2018 is Lombardia by +918,888. The region with the smallest increase is Valle d'Aosta with +7,335.

To visually summarize the period 2005 to 2018 Table 4 below shows the number of regions that experienced an increase, decrease, or no change in variable values.

Table 4. Variables summary showing number of regions with an increase, decrease, or no change in data values for 2005 to 2018

	Increase	**Decrease**	**No change**
Dependent Variables			
Endemic plants	20	0	0
Endemic plants regionally exclusive	3	13	4
Total vascular (taxa)	9	11	0

Independent Variables			
Precipitation (mm)	9	11	0
fAPAR	19	1	0
Soil anomaly	15	5	0
Temperature (°C)			
January Annual Average	20	0	0
July Annual Average	18	2	0
Land Use Type (km^2)			
Urban	20	0	0
Agricultural	0	20	0
Forests/semi-natural/wildlands	0	0	20*
Wetlands	0	0	20*
Water bodies	0	0	20*
Human Population	15	5	0

* Values between 2005 and 2018 are too small to be considered significant change but small changes may be prevalent and are discussed in section V. Discussion, part 3. Total vascular plants

C. Correlation summary

As mentioned previously, Kendall's τ was calculated for each pairing of the three plant variables with the climate, land use, and human population variables. Kendall's coefficients describe the strength of association between variables, as well as the direction of the relationship. Seven correlation results are found to be statistically significant. These are discussed below.

i. Endemic plants

Table 5 shows nonparametric correlation results for endemic vascular plant species. Results indicate that the amount of endemic plant species is statistically associated with soil anomaly for 2005, January annual average temperature for 2005 and 2018, and human population for 2005 and 2018.

Table 5. Correlation for endemic plant species

Endemic plants	**2005**	**2018**
Variables	**Endemic plants**	**Endemic plants**
Precipitation (mm)	0.211	-0.253
fAPAR	0.221	-0.052
Soil anomaly	-0.400◆	-0.326
January Annual Average Temp	0.349◆	0.431◆◆
July Annual Average Temp	0.016	0.258
Urban	-0.242	-0.168
Agricultural	-0.052	0.031
Forests/semi-natural/wildlands	-0.094	-0.073
Wetlands	-0.185	-0.237
Water bodies	-0.273	-0.273
Human Population	-0.126◆	-0.147◆◆

n = 20, ◆Prob>|τ| < .05, ◆◆Prob>|τ| < .01

The correlation coefficient for endemic plants and soil anomaly at Prob>|τ| < .05 is -0.400 in 2005. The type of relationship is moderately weak negative.

The strength in positive association increased between January temperature and endemic plant species over 2005 and 2018. The correlation coefficient for January annual average temperature at Prob>|τ| < .05 is 0.349 weak positive association in 2005. In 2018 the correlation coefficient for January annual average temperature at Prob>|τ| < .01 is 0.431 weak to moderate positive association. Likewise the probability of relationship increased with the percent chance of randomness in association decreasing from 0.05 to 0.01.

The correlation coefficient for endemic vascular plant species and human population at Prob>|τ| < .05 is -0.126 for 2005 and at Prob>|τ| < .01 is -0.147 for 2018.

ii. Endemic plants regionally exclusive

Table 6 presents the associations between endemic vascular plant species that are regionally exclusive in the twenty regions of Italian territory and other variables. January temperature is the only statistically significant variable and it trends in a positive direction for the year 2018. Endemic exclusive plant species are negatively associated with the meteorological and/or agricultural drought indicator of precipitation in 2005 and 2018. Neither are these two precipitation values statistically significant with the probability greater than α at both .05 and .01. There is not enough evidence to reject the null hypothesis that endemic vascular plants exclusive to a region will increase with increased rainfall or decrease with decreased rainfall and thus fail to reject the null. No other variables showed as statistically significant in relationship to endemic regionally exclusive plants.

Table 6. Correlation for endemic exclusive plants species

Endemic plants regionally exclusive	**2005**	**2018**
Variables	**Endemic plants regionally exclusive**	**Endemic plants regionally exclusive**
Precipitation (mm)	-0.262	-0.065
fAPAR	-0.111	-0.084
Soil anomaly	0.202	-0.333
January Annual Average Temp	0.190	0.464◆◆
July Annual Average Temp	0.093	0.313
Urban	-0.071	-0.098
Agricultural	-0.084	0.019

Forests/semi-natural/wildlands	0.254	0.032
Wetlands	-0.066	-0.183
Water bodies	-0.058	-0.281
Human Population	-0.124	-0.111

n = 20, ◆Prob>|τ| < .05, ◆◆Prob>|τ| < .01

A statistically significant relationship exists between endemic vascular plant species that are regionally exclusive and January annual average temperature for 2018. The correlation coefficient in 2018 for endemic plants regionally exclusive and January annual average temperature at Prob>|τ| < .01 is 0.464 with a moderate positive association.

iii. Total vascular plants

Table 7 displays the associations between total vascular plant species in the twenty regions of Italian territory. Agricultural land use is the only statistically significant variable to total vascular plants. The coefficient trends in a negatively increasing direction from 2005 to 2018 with 2018 showing significance. No other variables are statistically significant with total vascular plant species. The total vascular plant variable is positively associated with the meteorological and/or agricultural drought indicator of precipitation in 2005 and 2018. Coefficient values lack statistical significance with the probability greater than α at both .05 and .01. There is not enough evidence to reject the null hypothesis that total vascular plants will increase with increased rainfall or decrease with decreased rainfall and thus fail to reject the null.

Table 7. Correlation for total vascular plant species

Total vascular plants	**2005**	**2018**
Variables	**Total vascular plants**	**Total vascular plants**

Precipitation (mm)	0.095	0.222
fAPAR	0.094	-0.073
Soil anomaly	0.168	0.200
January Annual Average Temp	-0.052	-0.305
July Annual Average Temp	-0.240	-0.311
Urban	0.136	-0.021
Agricultural	-0.136	-0.242◆
Forests/semi-natural/wildlands	0.178	0.263
Wetlands	-0.058	-0.110
Water bodies	0.084	0.000
Human Population	0.084	0.084

n = 20, ◆Prob>|τ| < .05, ◆◆Prob>|τ| < .01

A statistically significant relationship exists between agricultural land use and total vascular plants for 2018. The correlation coefficient in 2018 for agricultural land use and total vascular plants at Prob>|τ| < .05 is -0.242 with a weak negative association.

V. Discussion

A. Contributions of the present study

This paper provides three main contributions to the current research on climate and vegetation related to drought in Italy. One, it provides a framework by which to investigate three non-agricultural plant variables. Two, it provides some alternative explanations of drought. Three, it compares important features of the descriptive statistics by region to better understand the parallels to socio-economic and ecological drought as having shared commonalities. The latter is important since the methodology to develop an ecological indicator in high variability environments is undeveloped (Boschetto et al., 2010).

Lacking in other studies such as those performed by Abbate et al. (2015) or Salvati et al. (2015) is analysis of the distinction between land use types and how they might be related to plant species counts. Previous studies that did count land use collapsed several types of agricultural land use (Salvati et al., 2015), but these are not necessarily widely applicable to drought prediction. In discussing land degradation Bajocca et al. (2018) generalized vegetation as one type of cover and land management the ratio to population and agriculture (without specifying land use types), and climate as simply rainfall (no other climatic variable used), thus failing to account for differences in agricultural and other land use percentages or other factors of climate such as temperature. These studies analyzed environmental conditions as one variable, whereas the present study does not. Last, other studies tend to analyze generalized vegetation rather than different plant species categories. One important study by Casazza et al. (2014) explained climatic and endemic exclusive plant relationships without testing land use or any other variables. Other authors, such as research by Capra and Scicolone (2012) only compare meteorological variables and fail to include vegetation at all. Finally, in an attempt to determine all four types of drought in global terms some authors such as Vicente-Serrano et al. (2012) use only precipitation, tree ring archives, and wheat crops to predict drought. As a corollary to existing literature, authors such as Vergni et al., (2015; 2017) and Vergni and Todisco (2011) continued to focus on standard precipitation and agriculture to build on previous work where other authors mentioned leave out elements to build the ecology behind drought.

In terms of drought many studies have exclusively and predominantly focused on testing relationships between temperature, precipitation, and crop production, which excludes categories of endemic, endemic exclusive, and total plant species. As far as the author can tell no study has used the complete set of variables used in this analysis in the context of drought or impacts on plant species.

Although previous work by authors such as Abbate et al. (2015) has performed statistical and correlative analyses by regions comparing variables by region, those studies lack identifying specific environmental variables (such as land use type and climate) and the impact to non-agricultural plant variables. While these studies elude to land degradation or connect land degradation with environment variables, the relationship between the set of environmental variables used in the present and the relationship to those variables and the three categories of plants are absent. Thus, the present study accounts for species-area relationship across regions to examine drought occurrence, offering a more complete picture.

Studies that included human population and vegetation relationships (i.e., namely forests and agricultural lands) in their analyses mainly occur in social science and economics literature but do not include climate (Ferrara et al., 2017). Those studies working off of authors such as Salvati et al. (2015) and Bajocca et al. (2018) essentially connected forest cover to human activity as a form of land degradation in the socio-economic environment as an influence of human activity but neglected to specify land use types, climatic variables, water availability, and do not relate their results to drought occurrence.

B. Findings

The main finding of the present research in terms of standard precipitation is that precipitation is not statistically associated with the prevalence of plant species within any of the three plant categories analyzed. In terms of the environmental variables that show statistically significant relationships with the three plant species-area variables, those that were statistically related to the endemic plant species-area variable were January annual average temperature (2005 and 2018), soil anomaly (2005), and human population (2005 and 2018). Just January annual average temperature (2018) had a statistically significant association with the species-area variable of endemic regionally exclusive plants and agricultural land use in 2018 with the species-area variable of total vascular plants.

That precipitation was not significant is important in terms of connecting ecological drought to the remaining variables. Therefore the following discussion will address the statistically significant findings, and will then discuss other variables that were notable in the descriptive statistics when comparing between regions. Thus, every variable detail may not be discussed except where connections in the data can be made to modifications or some way of addressing water supply. Since the following discussion will focus largely on regional variation between variables, for reference a map pointing to the location of each region is provided below.

Region Code	Region
1	Piemonte
2	Valle d'Aosta
3	Lombardia
4	Trentino-Alto Adige
5	Veneto
6	Friuli-Venezia Giulia
7	Liguria
8	Emilia-Romagna
9	Toscana
10	Umbria
11	Marche
12	Lazio
13	Abruzzo
14	Molise
15	Campania
16	Puglia
17	Basilicata
18	Calabria
19	Sicilia
20	Sardegna

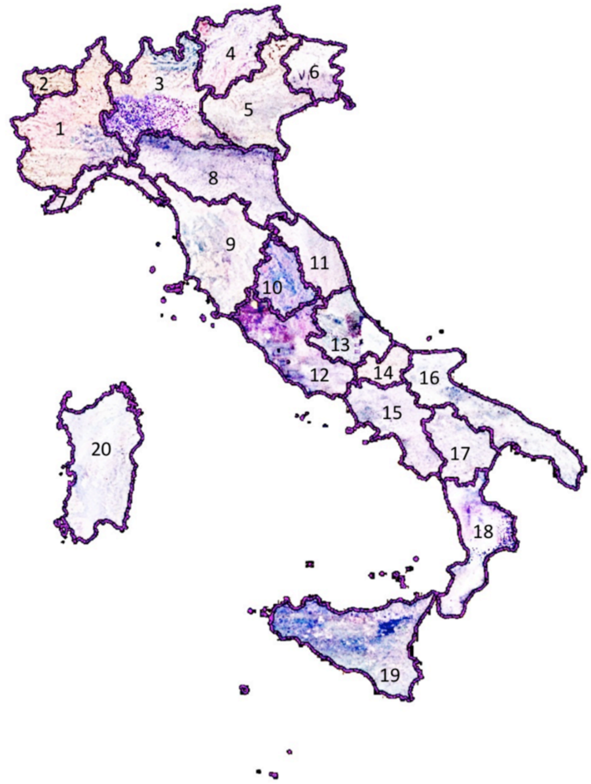

Figure 4. Map outlining the different regional boundaries within the Italian territory.

1. Endemic plants

i. Endemic plants and precipitation

Precipitation was not found to be statistically associated with endemic species frequencies. While 2018 precipitation is 444mm higher over the entire Italian territory a decrease in precipitation occurs over 55% of the regions. The increase of endemic plant species across all regions is at least partly due to identification, classification, and count coordinated across researchers as observed in the author’s review of the updated plant list compiled by Bartolucci et al., 2018 and continually updated by Peruzzi et al., 2015, and less likely a result of the increased precipitation or fluctuations of drought. The fact that there is little or no consistent documentation on previous existence or stationing of endemic plant species by location over time makes analysis of how these variables change over time challenging.

To compare the disparate relationship between plants and precipitation across the territory, in Veneto for example endemic plants increased by 15 species while precipitation deficit is -148mm. Contrast this with the adjacent region of Friuli-Venezia Giulia with a gain of one species and a simultaneous increase of +103mm of precipitation. Further south Abruzzo counted +50 endemic species while -338mm precipitation registered in 2018. The precipitation quantity in Liguria of +393mm coincided with an addition of +10 endemic plant species. The variation in precipitation does not strictly coincide with increases or decreases in species despite identification increasing across all 20 regions.

As part of collective environmentally associated variables the coefficient for precipitation is positive (2005) then becomes negative (2018) while endemic plants are counted higher. Other non-significant findings show that when drier conditions exist endemic plants adapt. The case more likely exists that endemic plants tolerate dry conditions well, which statistically compliments the fixed number of endemic plants identified by region in 2005. As precipitation surges, moisture is retained in ground sources and plants use available moisture before evaporation occurs and temperatures and solar radiation rise.

ii. Endemic plants and soil moisture

Soil anomaly is statistically significant and associated with endemic plants in 2005 when counts are lower, there is less precipitation, and soils are drier. Otherwise, endemic plants appear to do well in saturated soils confirming their need for ground moisture. While soil anomaly though is significant in 2005 when overall soil conditions are drier and though not significant in 2018 the coefficient tends towards no relationship to support that increased precipitation can oversaturate soils. Downpour precipitation from sudden storms due to sustained temperature rise from climate change can explain part of the soil anomaly. Where torrential downpours and storms were not as frequent under past climate endemic plant species today may drown as a result of excess water availability from these precipitation events.

Precipitation as an indicator for feeding soil moisture may have its impediments due to anthropogenic land use factors. As human population also rises with the temperature land use must provide a place for water storage in the form of habitat to prolong soil moisture conditions as climatically drying becomes long-term. Wetlands can serve as an on-site refuge for endemic water tolerant plants to colonize, allow excess stormwater to collect, and off-site create potential space where dry ground endemic plants can assemble, avoid drowning, and cover bare soils to reduce drought. Wetlands area have not increased and future conservation of endemic species may depend on the availability of these moisture refuges.

Supporting the above findings is that soil moisture in relation to endemic plant species in 2018 was greater in 75% of regions. The association lacks significance although there were more plant species that year. An example of this is the region of

Sicilia with already saturated soils in 2005 and the highest soil saturation of all regions in 2018 at -1.0913 and only +39mm of rainfall. As stated earlier, precipitation quantity is not a factor for endemic plants but ground moisture is. Soil moisture environmental conditions in Sicilia coincide with the highest endemic species count of any region at +79.

If slight changes in latitude are considered as affecting climate and vegetation, Sardegna had the next highest increase in endemic species at +68 with the island region situated at around a three-degree higher latitude than Sicilia. However, soils were dry in 2005 and saturated in 2018 when precipitation was +192mm greater, only +39 more than Sicilia. Additionally, Calabria (which is situated on the southernmost tip of the peninsula to the west between Sicilia and Sardegna) is only one-degree difference in latitude and had the third greatest increase in endemic species. While Calabria experienced a decrease in precipitation by -22mm, the region shares the characteristic with Sicilia of sustained soil moisture saturation in both years.

As latitude changes the generalized temperate climate may be predicted but soil moisture is a factor associated with endemic species. Toscana further north with a six-degree difference in latitude also had saturated soils in both years and increased endemic species by +38 while receiving -114mm in precipitation in 2018 than in 2005.

However, endemic species can be found even when soil saturation is sustained at a low level. Abruzzo registers no soil saturation in 2005 and minimal soil saturation in 2018 yet has a high endemic addition to the region. Commonalities among regions are that continual ground saturation is important for endemic plants although variation and anomalies exist. Soils may retain groundwater saturation even when there is reduced precipitation but this would depend on other variables such as existing vegetation cover, other available moisture, and environmental conditions.

iii. Endemic plants and human population

An attribute of change that impacts available moisture is human population. A statistically significant association was found between endemic plants and human population in both 2005 and 2018, which could explain some of the saturation-desertification process as humans shift water distribution according to the type of transfer (e.g., pipes for urban use, irrigation ditches for agriculture). Thus quantity of human population change is an example of offsite or indirect pressure sources that coincide with changes in endemic plants. The human population increase of 2,597,776 inhabitants across the territory by 2018 is not uniform across regions, neither are the added +544 endemic species found to increase or decrease proportionally to the human population differences across regions. Regions that decreased human populations simultaneously increased in endemic species but population is not a strict regionally specific factor for higher or lesser numbers of endemic plant species. Emilia-Romagna with an additional +378,336 people and 59% agricultural use had dry soils in 2005 that became drier in 2018 while receiving higher precipitation. The region added +14 endemic species despite changes.

iv. Human population pressure as a land use change affecting endemic plants

The differences between regional variability depend on contributors to on-site and off-site state as previously mentioned (e.g., environmental conditions, topography, modifications) where human population size does not determine direct causal relationships between endemic plants and environment but can alter pressures or opportunities for endemic plant species. For example, Molise and Lombardia are widely variable in human population. Molise's decline in population of -10,152 and Lombardia's increase of +918,888 fails to account for changes in endemic plants as each region gained +11 endemic species.

Regions with high agricultural use (at or above 50%) sustain soil moisture over 2005 and 2018 with anomalies. Basilicata (+31 endemic species) and Molise (+11 endemic species) both sustain soil saturation over 2005 and 2018 while precipitation decreases yet neither region increased in human population.

The fluctuating soil anomaly is likely human-induced in both drying (urbanization) and saturation (agriculture). Molise converted 4% of their 61% agricultural area over the region to urban use while Lombardia converted 13% of their 47% agricultural area to urban use. Veneto had an increase in urbanization by 16% and loses its soil saturation to dry ground in 2018 and counts an additional +15 endemic plant species coinciding with drying and high urbanization. Puglia and Lombardia are two regions with high agricultural land use conversion to urbanization at ~13% after Veneto. Both also experience soil drying in 2018 coinciding with urban land use conversion despite differences in precipitation and population. The region of Puglia has the highest agricultural use at 70% while human population pressure added +43,181 and counted an additional +40 endemic plant species. Again, the same soil saturation pattern appears where in 2005 was a wet ground year and then 2018 was a dry ground year with -90mm of precipitation. However, land use conversion is central to the wet-dry process.

Endemic plants may colonize on moist ground where intentional watering from irrigation provides endemic plants with soil moisture. While these regions add endemic plant species soil moisture is reduced by land use conversion contributing to drought. A change in land use from agriculture to urbanization redistributes water as a modification of natural ecosystems leading to drier conditions. When precipitation, groundwater, and streamflow are reduced, water is redirected to where it is most needed for particular use (e.g., agriculture, urban water supply).

Human population indirectly influences the location where plants tend to root. When population increases the alteration in water availability changes the way endemic plant species are spread over the territory due to creating available soil moisture elsewhere. Human population drives the rearrangement of the ecosystem and explains indirect changes in ground moisture that result in a state-change of the land due to use choices.

v. Endemic plants and temperature

January annual average temperature is statistically significant for endemic plants in 2005 and 2018 such that warmer wintertime temperatures relate to greater counts of endemic plant species, aside from moisture and plant identification updates. Findings in the short-term data for 2005 to 2018 over the entire territory show a mean temperature rise of 3.7 °C in January and 0.89 °C in July. Warmer January temperatures occurred in 100% of the regions while July (the hottest month) temperature increased in 80% of the regions in 2018.

Temperatures too hot or too cold may inhibit or promote growth depending upon the location, timing of temperature change, and species type where endemic plants generally tend to adapt to the warming climate (Tardella et al., 2016; Alma et al., 2014). Future proliferation from seeds will depend upon hot and cold temperature fluctuations that vary depending on the species type and duration of temperature extremes. While increased wintertime temperatures appear favorable to endemic plants, a lack of specialization may occur if plants are unable to adapt to rapid environmental alterations that affect their habitat. Under this scenario distortion of the true number of endemic species or subspecies makes identification and conservation strategies difficult (Fenu et al., 2015) where it may complicate distinguishing genetically distinct species from known species. Temperature may instead present as an increase in endemic plant count as endemic plant communities change and adapt to warming temperatures.

vi. Disparity for endemic plants

While soil saturation remains low for Italian regions according to the soil anomaly scale, drier soils were not problematic. In this study variations such as in Umbria where the region is found to have received -187mm less rainfall in 2018 than in 2005 occurs while rainfall increases over the territory (as part of overarching climate). There, nine endemic species were identified while soil saturation increased. Thus, by standard drought prediction moisture is not a strict coincider of plant proliferation. In Abruzzo, where drought is patchy (Di Lena et al., 2014) and difficult to interpret, there is a +50 increase of endemic species. Hydrological drought and the relationship between other forms of soil moisture must be considered because soil saturation conditions are present.

However, precipitation and climatic variables may not contribute as severely as some of the literature proposes, for example Tietjen et al. (2017).

Neighboring Marche, north of Abruzzo increased by +22 endemic plant species as solar absorption declined, soil saturation declined and precipitation declined indicating drought tolerance, thus defying generalized predictions of drought and plant response, and thus supports findings by researchers such as Moonen et al. (2002). When a decrease in precipitation occurs endemic plant species appear to adapt and thus precipitation lacks usefulness as a drought indicator.

vii. Endemic plants as a response in determining drought

From the above examples, determining drought appears to have more to do with response specific uses of the land than precipitation quantity. The descriptive data over the territory is perhaps somewhat counterintuitive in that its shows slight climatic variation by year in contrast to the wide variation between regions. While territory wide climate generalizations hold true over time, such as hotter sustained temperatures and reduced precipitation, in this regard indicators based on climate variables may not be useful for predicting drought without ongoing attention to local on-site conditions such as land use and anthropogenic water distribution disturbances. Regionally endemic plants are finding ways to adapt and survive climatic pressures differently with some apparent commonalities, such as tolerating reduced precipitation and wet-dry soil moisture anomaly. It appears from territory wide descriptive statistics that increased precipitation and soil moisture coincide with increased endemic plants. The results of the correlation analysis, however, indicates that soil moisture, human population, and wintertime temperature, are the significant variables to give attention to when assessing endemic plants as an indicator of ecological drought.

2. Endemic plants regionally exclusive

viii. Endemic plants regionally exclusive and temperature

The most important finding for the endemic plants regionally exclusive is that the only significant association was with January annual average temperature, with a positive association. Contrary to the finding where warmer wintertime temperatures support plant growth (Tardella et al., 2016) Molise as the only region to experience exceptionally high (+6.6 °C change) increases in January annual average temperature by 2018 may possibly indicate an increase too high for endemic regionally exclusive plant species. The average January temperature in Molise is 1.5°C to 4.5°C higher than other regions but there is no change in the zero count of endemic regionally exclusive plant species from 2005 to 2018. Thus temperature increase does not strictly coincide with plant count either, supporting regional variation and regional plant count differences.

Abruzzo borders Molise to the north with a less severe 3.9 °C wintertime temperature increase and an addition of +15 endemic exclusive plants identified. As the other two regions to have zero change in endemic regionally exclusive plants, Campania (+3.7 °C, 21 endemic regionally exclusive plant species) and Basilicata (+2.4 °C, 6 endemic regionally exclusive plant species) did not lose endemic regionally exclusive plant species despite changes in climate, land use, and human population. Temperature increase fluctuates between these neighboring regions indicating that temperature increases alone is not a cause of decline or increase in endemic regionally exclusive plants. Thus together precipitation and temperature are not consistent indicators of plant stress when predicting drought for this plant category, at least not for the territory at large. Conversely, extremely high temperatures may represent a threshold at which most vegetation will perish, and in that instance it may be too late for drought prevention. Thus, other contributors to drought should be identified and used in prediction.

ix. Endemic plants regionally exclusive and precipitation

Similarly to endemic plants, precipitation is not statistically related to endemic regionally exclusive plants. Endemic regionally exclusive plant species decreased by 70% from 2005 to 2018 failing to strictly coincide with higher 2018 precipitation levels. The endemic regionally exclusive plant counts appear relatively stable in 2005 when precipitation was less. Even as plant counts have increased from 2005 as of 2018, less endemic regionally exclusive plants are found despite improved identification.

x. Endemic regionally exclusive plants and wet-dry trend

For years 2005 and 2018 endemic regionally exclusive plants exemplify response to the wet-dry climate behavior within global climate change as those plant species most adapted and tolerant of the Mediterranean aridity. The region of Marche, which experienced the worst regional drought in 2017, shows endemic regionally exclusive plant species increased from counts of three to thirteen while following the same decreasing precipitation trend as endemic species. The same simultaneous trends of drying and frequency of endemic regionally exclusive plant species is also found in

Abruzzo (recalling patchy drought conditions). Calabria also increased endemic regionally exclusive species while precipitation decreased by -22mm.

Soil anomaly alters differently between these three regions as the only three regions to have added endemic regionally exclusive plants. Calabria maintains saturated soils in 2005 and 2018, Abruzzo has dry soils in 2005 and slightly saturated soils in 2018, and Marche has slightly saturated soils in 2005 and dry soils in 2018. Marche is the only region to experience no soil saturation with a simultaneous decrease in precipitation in 2018. With that observation also comes the increase in endemic regionally exclusive plants (and endemic) thus questioning precipitation as an indicator of drought. It is also a region with high agricultural use at 64% in 2005 declining to 54% in 2018 and converting that area from 4% to 14% urban use, thus increasing drying conditions. Too much drying from urbanization influence may be detrimental for endemic regionally exclusive plants and thus the above examples support the need for ecological balance to manage drought.

xi. Endemic regionally exclusive plants and soil anomaly

Sicilia with the largest decrease in endemic regionally exclusive plant species counts maintained soil saturation in 2005 and 2018 in accordance with high agricultural land use at 67% declining to 58%. Soil saturation in Sicilia is the highest of all regions. While solar absorption increases with precipitation the region loses a large number of endemic regionally exclusive plant species since 2005. These particular trend results suggest that drought and drier ground is in fact more hospitable for the least generalist of the plant categories. Ideally if we could reduce and manage land modification in an ecological manner where land use is more restorative we could prevent increased species loss. Additionally greater attention to and proper management of land use and water distribution could prevent drought.

xii. Moisture as unfavorable for endemic regionally exclusive plants

Soil saturation and increased rainfall may result as a factor of unpredictable climate and impact specialized plants. Increased storms and climatic changes in the form of severe weather events may factor in some of the changes between regions. However, a review of changes in Lazio reveals that soil saturation is present across both years with decreased precipitation. Forests and agriculture together utilize 80% of land use while urbanization increases from 6% to 17%. Soil saturation remained in 2005 and 2018 coinciding with decreased July temperature and high increase in January temperature. These overly wet and minimally dry climatic and moisture conditions are not ideal for endemic regionally exclusive plant species.

As land conversion continues endemic regionally exclusive species lose parts of their native habitat range and suffer extinction (Casazza et al., 2014). Thus, precipitation without counting impacts of land use fails to predict vegetation for the most vulnerable of endemic plant species, especially since endemic exclusive plant species are revealed in this study as highly drought tolerant, indicating that precipitation does not predict drought for the endemic regionally exclusive vegetation type.

Regions where precipitation rise appears for both 2005 and 2018 suffer a loss of endemic regionally exclusive plant species. Comparing the variables between regions, it is the drier environmental conditions that coincide with the increase of endemic regionally exclusive plant species over three regions. Further, precipitation and moisture appear as conditions that endemic exclusive plant species avoid. In this case, when adding endemic regionally exclusive plants an ecological picture of drought begins to emerge.

3. Total vascular plants

xiii. Total vascular plants and association with agriculture

Although the only statistically significant coefficient for total vascular plants is agricultural land use in 2018, total vascular plants do not necessarily increase or decrease with specific agricultural area. Total vascular plants were 1.3% higher in 2018 than 2005 but as agriculture declines total vascular plant species are spread across regions non-uniformly with highs and lows varying across regions. In 2005 when agricultural land use was higher more regions retained total vascular plant species. As agriculture declined across all regions in 2018 only a few of those regions experienced a high change in total vascular plant species.

xiv. Total vascular plants and precipitation

Precipitation is also non-significant for the total vascular plant category variable. While nine out of eleven regions increased in total vascular plant species, and nine out of eleven regions increased in precipitation, these are not necessarily the same regions experiencing simultaneous increases of both total vascular plants and precipitation. Friuli-Venezia Giulia (-188 total vascular plant species) and Calabria (+169 total vascular plant species) are the only two regions to sustain precipitation above 1000mm over both 2005 and 2018 while other regions fluctuate between precipitation quantities below

1000mm. Calabria though has less precipitation in 2018. Liguria (-51 total vascular plant species) where the precipitation increase peaks higher than any of the regions at +393mm the quantity is not above 1000mm. Thus increasing precipitation may act negatively for total vascular plants.

xv. Total vascular plants anomaly in Trentino-Alto Adige

The region of Trentino-Alto Adige stands out as an anomaly with a high total of vascular plant species at +519 in 2018. The region contained 2,985 total vascular plant species in 2005 and in 2018 contains 3,504. At the same time soil drying increased to soil saturation while precipitation increased (but still below 1000mm) and solar radiation went from negative to positive with minimal temperature changes for January and July, implying ground moisture. Forests and semi-natural/wildlands are high at 83% with only Valle d'Aosta having a higher forest cover at 94.5%. Valle d'Aosta however loses total vascular plants while soil saturation and precipitation is greater (over 1000mm by 2018) despite forest and semi-natural/wildlands cover.

While Trentino-Alto Adige has 7.4% urbanization and 8.4% agriculture, human population pressure is +60,890 to total 1,004,906 inhabitants. Precipitation there is higher than 13 of the 20 regions (yet under 1000mm) with a simultaneous rise in soil moisture conditions that may favor particular plant species, eluding to an abundance in total vascular plant cover retaining moisture as a drought prevention despite precipitation quantity.

xvi. Total vascular plants and regional variation with agricultural land use

A central cluster increase of total vascular plants is found in bordering regions (surrounding Trentino-Alto Adige) of Lombardia (+209) and Veneto (+43) then Emilia-Romagna (+117) with medium to high agricultural use (Lombardia 34%; Veneto 40%; Emilia-Romagna 59% in 2018). Trentino-Alto Adige maintains the lowest agricultural use of the clustered regions (8% in 2018) validating that lower agricultural use yields higher total vascular plants. This finding appears in line with a study by Ferrara et al. (2017) that confirmed forests tend to cover abandoned agricultural lands. Thus coinciding with significant findings in the present study that shows as agricultural lands decline total vascular plants tend to increase, suggesting total vascular plants utilize available space.

A counter finding in the present study to this idea of agricultural land use dictating available space for total vascular plant species is in the southern region of Puglia. The dry region uses land at 70% agriculture and contains +290 total vascular plant species. Calabria a little further south on the western coast with nearly twice the precipitation and ongoing soil saturation has 42% agriculture and +169 total vascular plant species. These anomalies could represent specialization within the total vascular plant category of varying moisture requirements, adaptations, movement, and constraints of specific land use in addition to climate and topography. Thus precipitation quantity cannot predict these changes or the contribution to drought for the total vascular plant category either.

xvii. Total vascular plants and population contribution to water redistribution

Carrying capacity in terms of population effect on water supply relative to the land use type may coincide more with urban or agricultural water redistribution where human population, although non-significant could represent an indirect source of water redistribution for total vascular plant species. In the territory wide descriptive statistics both wetlands and water bodies appear to increase, but regionally amounts may be small and represent as no change. Sicilia for example, recalling the highest soil saturation uses more area for agriculture (58%) while adding +87,650 (5,056,641 total) inhabitants and declined in total vascular plant species by -224 (the highest). Human occupancy and land use may contribute more than climatic variables in determining the number of total vascular plants there.

Puglia, although a lower human population increase (+43,181) and the second highest increase in total vascular plants coincides with additional water bodies and high agriculture, implying water redistribution. Lombardia contrasts to other regions by its increase in total vascular plant species adding +209. Recalling its +918,888 (9,951,442 total) inhabitants human population may coincide with an increase in water bodies (+0.63%). Lombardia though has a higher long-term percentage of permanent water bodies over other regions. What these variations show are how moisture fluctuations throughout regions act as factors related to land use providing a means of moisture sources for total vascular plant species.

xviii. Total vascular plants, wetlands, and water bodies as moisture sources

The aridity of the Mediterranean climate is cause to give attention to available water within regions, especially since precipitation is also non-significant Although water bodies are found as non-significant for total vascular plant species the small changes occurring may play a role in moisture distribution complimentary to land use modification.

Permanent water bodies across regions are relatively stable with little to no change although there were some gains. Puglia with less than one percent of its land area in permanent water bodies has an increase of +1.29% from 2005 to 2018. Other regions have a similar trend; Calabria by +50% and the northern cluster where Lombardia gained permanent water bodies by +0.63%, Veneto by -0.86%, and Emilia-Romagna +0.95% of existing permanent water body coverage.

In attempting to further explain total vascular plant increase wetlands area in Veneto rose by 2% and gained +43 total vascular plants. Other regions that gained total vascular plant species did not necessarily experience an increase of moisture in the form of wetlands or water bodies. Umbria with +46 total vascular plants decreased precipitation moisture and had no change in wetlands or water bodies in either 2005 or 2018 while Sardegna added +0.37% water bodies and +33 total vascular plant species. Even though the amount of water bodies across the territory is limited in percentage of land cover, there is a tendency for total vascular plants to increase where small changes in water body moisture in the form of wetlands or even agricultural lands may have an impact on total vascular plant species counts.

Upholding the regional variation extremes is that the change in water bodies does not completely explain the expansion of total vascular plant species, as Trentino-Aldo Adige had no change in water bodies, nor was there any increase in wetlands. Lazio (1.47%) and Friuli-Venezia Giuli (1.98%) had no change in permanent water bodies but maintains the highest amount of water and loses the most total vascular plant species (-

188). While Veneto has 4% of its area as permanent water bodies compared to Lombardia's 2.8% Trentino-Alto Adige's 0.4% coverage difference fails to explain the change in total vascular plants. These findings coincide with the trend in endemic plants and endemic regionally exclusive plant species needing moisture but not too much moisture as an adaptation to the Mediterranean geo-climatic conditions.

VI. Concluding Remarks

A. Defining ecological drought

The present study showed that temperature rise, drier grounds, and reduced precipitation were favorable for all three plant categories with an emphasis on endemic and especially endemic regionally exclusive plants needing drier conditions. Thus, areas where plants are declining tend to experience higher land use and this is where attention needs direction. Water redistributed by humans and land changes made by humans coincide with plant counts more than a lack of precipitation. Further, the ecological definition of drought proposed by the American Meteorologic Society still assumes a perpetual condition of climatic mystery acting upon society as a causal event in the occurrence of drought, implying the need for standard precipitation monitoring as a main indicator of drought. Thus the present study offers an insight to drought as a natural hazard that is created by a state-change derived from a combination of antecedent environmental conditions that affect vegetation responses.

The present study determines ecological drought in Italy as a multi-directional systems-oriented phenomena based on multiple environmental conditions where an event, anthropogenic, climatic, or otherwise working in dynamic action together has the capacity to reduce available moisture. The meaning behind this definition is such that "multi-directional" infers moisture sources are interchangeable and that a vertical or horizontal condition of meteorological or hydrological drought does not suffice to prevent drought from occurring. Agricultural drought also limits ecological drought prediction, and in the present study a lack of agricultural drought may also affect endemic, endemic regionally exclusive plant species and total vascular plant species as part of the collective Italian ecosystem.

Importantly, endemic plant species counts appear to have increased due to identification and these plants tend to prefer drier habitats. Only a small fraction of the most specialized (endemic regionally exclusive plant species) can survive agricultural or other land use. The total vascular plants are not exclusively endemic or highly specialized and capitalize on human activity to survive the already drought prone conditions. Either way, the three plant categories appear to redistribute according to Mediterranean aridity, not precipitation, thus relying on varying degrees of soil moisture sources. Therefore, the three plant categories, if given appropriate space and habitat to sustain plant species biodiversity in other land uses besides protected areas may be the real indicators of drought. These plant categories may prevent drought by providing vegetation cover when precipitation is limited because these tend to tolerate the drying and warming climatic changes. Once local plant interactions are understood and incorporated in assessing ecological drought then drought can become better predicted. When combined with the use of satellite tools, organization, and dissemination of national data for the many drought indicators the non-agricultural (endemic) plant categories can aide in determining ecological drought. In summary, the ecological factors are best suited to predict drought when they are combined to reduce the drying that is undesirable by not simply focusing on precipitation or the remaining climatic variables.

B. Future study

What would further enhance this study is branching the Italian plant classification list into the three existing plant categories that include the names of specific species belonging to endemic, endemic regionally exclusive, and total vascular categories. Then, identifying those species that are affected under the Italian Red List vulnerable species designation to better administer habitat, land, and water use from an ecological perspective is suggested. Investigation as to which species in each of the categories benefits from which moisture source, such as ground source type, or additional precipitation or reduced precipitation, and how those species are affected by which variables is useful as an application of the taxonomic list to ecology. To preserve species otherwise overlooked when focusing on meteorological drought prediction precipitation indices should be adapted to an ecological picture in this manner.

C. Recommendations

Beyond standard precipitation a main attention should be given to storm events as part of the interactions within the global hydrological-meteorological system. Results from the present study imply other unexplained water sources where storms are also part of preventing drought and are in fact undistinguished by standard precipitation and thus may not be counted in gauge measurements. In this sense land use choices will become more important as a means to provide space for not only species but for water collection. When precipitation does occur local regions need advanced preparation ahead of time in terms of restoring degraded lands, addressing erosion and vegetation homogenization, and limiting the redirection of water resources in order to prevent drought. To abate future drought the main recommendation from this study is that each region develop a drought hazard prevention plan based on their region, and even within their municipalities.

D. Closing summary

This research has been an initial investigation into the understudied area of drought. While satellite data and documentation can provide information leading to drought prediction, drought prediction is an ecological problem encompassing many factors such as conservation, water resources, human use and modification of the landscape as much as it is a climate related event.

Thus, meteorological, hydrological, and agricultural droughts are antecedent ecological features that help identify the phenomena of a water resource deficit. Here ecological drought prediction and management is the overarching drought scenario while the other types of drought are embedded within the local to global ecology. Precipitation quantity as an indicator makes sense when considering that water is redistributed around the world by precipitation events, yet this should be a tool that is combined with the other factors of drought (as shown in this study by use of the three plant categories, climate, land use, and human population) to capture environmental conditions. The selected variables, however, are not limited to those examined in this study but are a framework to adapt drought prediction by location within the available tools.

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Appendices

VIII. Appendix I: Regional descriptive statistics

The data in the tables below shows dependent and independent variables for all twenty administrative regions of the Italian territory. Area for each region is provided as context. Dependent plants variables are the count of species in each respective region. Independent climatic variables of precipitation, fAPAR, soil anomaly, and temperature list the averages over each year for each respective region. Land use is shown in percentages representing the amount of area used for each type. Human population variable lists total counts in each region.

Table 8. Piemonte

1. Piemonte	**2005**	**2018**
Area (km^2)	25,400.63	25,400.63
Dependent Variables		
Endemic plants	39	52
Endemic plants regionally exclusive	88	19
Total vascular (taxa)	3,521	3,535
Independent Variables		
Precipitation Annual Average (mm)	712.66	1028.92
fAPAR	-0.0822	0.2786
Soil anomaly	0.3538	-0.1988
Temperature (°C)		
January Average	1.3	5.3
July Average	24.0	24.5

Land Use Types (km^2)		
Urban	4.5%	10.23%
Agricultural	43.65%	38.10%
Forests/semi-natural/wildlands	50.89%	50.80%
Wetlands	0.003%	0.004%
Water bodies	0.85%	0.85%
Human Population	4,214,677	4,384,109

Table 9. Valle d' Aosta

2. Valle d'Aosta	**2005**	**2018**
Area (km^2)	3262.03	3262.03
Dependent Variables		
Endemic plants	6	10
Endemic plants regionally exclusive	21	5
Total vascular (taxa)	2,174	2,133
Independent Variables		
Precipitation Annual Average (mm)	712.66	1028.92
fAPAR	0.0202	0.1002
Soil anomaly	0.2897	-0.2747
Temperature (°C)		
January Average	2.9	5.7
July Average	26.7	27.2
Land Use Types (km^2)		
Urban	1.385%	4.859%

Agricultural	7.95%	4.478%
Forests/semi-natural/wildlands	90.54%	90.54%
Wetlands	0	0.0165%
Water bodies	0.104%	0.104%
Human Population	119,548	126,883

Table 10. Lombardia

3. Lombardia	**2005**	**2018**
Area (km^2)	23,878.52	23,878.52
Dependent Variables		
Endemic plants	60	71
Endemic plants regionally exclusive	48	22
Total vascular (taxa)	3,220	3,429
Independent Variables		
Precipitation Annual Average (mm)	747.18	1035.47
fAPAR	0.1591	0.6513
Soil anomaly	0.5925	-0.0188
Temperature (°C)		
January Average	0.5	5.0
July Average	24.1	24.8
Land Use Types (km^2)		
Urban	11.13%	24.66%
Agricultural	47.587%	34.08%
Forests/semi-natural/wildlands	38.317%	38.274%

Wetlands	0.096%	0.096%
Water bodies	2.85%	2.868%
Human Population	9,032,554	9,951,442

Table 11. Trentino-Alto Adige

4. Trentino-Alto Adige	**2005**	**2018**
Area (km^2)	13,604.9552	13,604.9552
Dependent Variables		
Endemic plants	59	73
Endemic plants regionally exclusive	89	14
Total vascular (taxa)	2,985	3,504
Independent Variables		
Precipitation Annual Average (mm)	731.32	917.96
fAPAR	-0.1283	0.1450
Soil anomaly	0.3683	-0.2455
Temperature (°C)		
January Average	0.5	2.9
July Average	23.4	25.9
Land Use Types (km^2)		
Urban	2.145%	7.45%
Agricultural	13.759%	8.44%
Forests/semi-natural/wildlands	83.655%	83.654%
Wetlands	0.0214%	0.0214%
Water bodies	0.425%	0.425%

Human Population	940,016	1,004,906

Table 12. Veneto

5. Veneto	**2005**	**2018**
Area (km^2)	18,336.55	18,336.55
Dependent Variables		
Endemic plants	53	68
Endemic plants regionally exclusive	25	15
Total vascular (taxa)	3,295	3,338
Independent Variables		
Precipitation Annual Average (mm)	911.03	762.45
fAPAR	0.2969	0.9469
Soil anomaly	-0.1508	0.0741
Temperature (°C)		
January Average	2.2	6.1
July Average	23.9	25.0
Land Use Types (km^2)		
Urban	8.55%	24.87%
Agricultural	57.22%	40.92%
Forests/semi-natural/wildlands	28.975%	28.96%
Wetlands	1.509%	1.54%
Water bodies	4.05%	4.015%
Human Population	4,527,694	4,884,534

Table 13. Friuli-Venezia Giulia

6. Friuli-Venezia Giulia	**2005**	**2018**
Area (km^2)	7,911.33	7,911.33
Dependent Variables		
Endemic plants	28	29
Endemic plants regionally exclusive	133	10
Total vascular (taxa)	3,335	3,147
Independent Variables		
Precipitation Annual Average (mm)	1324.32	1427.75
fAPAR	-0.2125	0.7833
Soil anomaly	0.0755	-0.0908
Temperature (°C)		
January Average	5.3	9.0
July Average	24.8	25.3
Land Use Types (km^2)		
Urban	7.168%	17.65%
Agricultural	38.59%	28.16%
Forests/semi-natural/wildlands	51.12%	51.069%
Wetlands	0.327%	0.327%
Water bodies	1.98%	1.98%
Human Population	1,183,764	1,207,589

Table 14. Liguria

7. Liguria	**2005**	**2018**

Area (km^2)	5,419.79	5,419.79
Dependent Variables		
Endemic plants	55	65
Endemic plants regionally exclusive	52	13
Total vascular (taxa)	3,131	3,080
Independent Variables		
Precipitation Annual Average (mm)	551.09	944.17
fAPAR	0.0908	0.0080
Soil anomaly	0.0494	-0.5522
Temperature (°C)		
January Average	8.9	11.1
July Average	24.5	25.6
Land Use Types (km^2)		
Urban	5.11%	8.16%
Agricultural	16.48%	13.425%
Forests/semi-natural/wildlands	78.20%	78.22%
Wetlands	0.01%	0.01%
Water bodies	0.08%	0.08%
Human Population	1,571,783	1,564,747

Table 15. Emilia-Romagna

8. Emilia-Romagna	**2005**	**2018**
Area (km^2)	22,452.90	22,452.90
Dependent Variables		

Endemic plants	61	75
Endemic plants regionally exclusive	12	5
Total vascular (taxa)	2,726	2,843
Independent Variables		
Precipitation Annual Average (mm)	883.33	905.07
fAPAR	0.1013	0.7758
Soil anomaly	0.4516	0.7238
Temperature (°C)		
January Average	1.7	5.6
July Average	25.1	25.9
Land Use Types (km^2)		
Urban	5.13%	13.22%
Agricultural	67.24%	59.19%
Forests/semi-natural/wildlands	26.08%	26.03%
Wetlands	0.53%	0.53%
Water bodies	0.947%	0.956%
Human Population	3,983,346	4,361,682

Table 16. Toscana

9. Toscana	**2005**	**2018**
Area (km^2)	22,987.45	22,987.45
Dependent Variables		
Endemic plants	153	191
Endemic plants regionally exclusive	64	59

Total vascular (taxa)	3,435	3,400
Independent Variables		
Precipitation Annual Average (mm)	895.3	780.82
fAPAR	0.2061	0.4816
Soil anomaly	-0.0166	-0.1508
Temperature (°C)		
January Average	5.3	8.8
July Average	25.2	26.3
Land Use Types (km^2)		
Urban	4.66%	8.75%
Agricultural	45.43%	41.35%
Forests/semi-natural/wildlands	49.25%	49.23%
Wetlands	0.24%	0.248%
Water bodies	0.38%	0.38%
Human Population	3,497,806	3,645,472

Table 17. Umbria

10. Umbria	**2005**	**2018**
Area (km^2)	8,454.165	8,454.165
Dependent Variables		
Endemic plants	94	103
Endemic plants regionally exclusive	0	0
Total vascular (taxa)	2,360	2,406
Independent Variables		

Precipitation Annual Average (mm)	954.23	767.25
fAPAR	0.0680	0.1655
Soil anomaly	-0.1558	-0.4738
Temperature (°C)		
January Average	3.8	8.2
July Average	28.9	26.1
Land Use Types (km^2)		
Urban	3.426%	10.385%
Agricultural	51.03%	44.075%
Forests/semi-natural/wildlands	43.67%	43.67%
Wetlands	0.106%	0.106%
Water bodies	1.755%	1.755%
Human Population	843,183	888,908

Table 18. Marche

11. Marche	**2005**	**2018**
Area (km^2)	9,382.67	9,382.67
Dependent Variables		
Endemic plants	105	127
Endemic plants regionally exclusive	3	13
Total vascular (taxa)	2,571	2,540
Independent Variables		
Precipitation Annual Average (mm)	970.12	827.18
fAPAR	-0.2569	-0.0016

Soil anomaly	-0.2583	0.0091
Temperature (°C)		
January Average	4.3	8.1
July Average	24.2	25.8
Land Use Types (km^2)		
Urban	4.71%	14.296%
Agricultural	64.32%	54.749%
Forests/semi-natural/wildlands	30.81%	30.809%
Wetlands	0	0
Water bodies	0.1146%	0.1146%
Human Population	1,453,224	1,496,619

Table 19. Lazio

12. Lazio	**2005**	**2018**
Area (km^2)	17,203.2069	17,203.2069
Dependent Variables		
Endemic plants	164	190
Endemic plants regionally exclusive	14	12
Total vascular (taxa)	3,228	3,047
Independent Variables		
Precipitation Annual Average (mm)	971.97	791.17
fAPAR	0.2052	0.5494
Soil anomaly	-0.4708	-0.2444
Temperature (°C)		

January Average	6.0	10.6
July Average	26.7	26.1
Land Use Types (km^2)		
Urban	6.22%	17.72%
Agricultural	56.519%	45.016%
Forests/semi-natural/wildlands	35.72%	35.725%
Wetlands	0.0376%	0.0376%
Water bodies	1.47%	1.47%
Human Population	5,112,413	5,898,124

Table 20. Abruzzo

13. Abruzzo	**2005**	**2018**
Area (km^2)	10,797.38	10,797.38
Dependent Variables		
Endemic plants	177	227
Endemic plants regionally exclusive	29	44
Total vascular (taxa)	3,232	3,216
Independent Variables		
Precipitation Annual Average (mm)	943.64	605.33
fAPAR	0.1744	0.2727
Soil anomaly	0.0350	-0.1258
Temperature (°C)		
January Average	4.4	8.3
July Average	24.1	25.3

Land Use Types (km^2)		
Urban	2.95%	8.35%
Agricultural	44.90%	39.52%
Forests/semi-natural/wildlands	51.91%	51.90%
Wetlands	0	0
Water bodies	0.19%	0.19%
Human Population	1,262,392	1,322,247

Table 21. Molise

14. Molise	**2005**	**2018**
Area (km^2)	4,440.16	4,440.16
Dependent Variables		
Endemic plants	114	125
Endemic plants regionally exclusive	0	0
Total vascular (taxa)	2,412	2,327
Independent Variables		
Precipitation Annual Average (mm)	971.87	958.39
fAPAR	0.1205	0.4200
Soil anomaly	-0.0966	-0.6097
Temperature (°C)		
January Average	2.7	9.3
July Average	22.8	27.2
Land Use Types (km^2)		
Urban	1.86%	6.29%

Agricultural	61.559%	57.13%
Forests/semi-natural/wildlands	36.26%	36.25%
Wetlands	0.0062%	0.0062%
Water bodies	0.28%	0.289%
Human Population	320,601	310,449

Table 22. Campania

15. Campania	**2005**	**2018**
Area (km^2)	13,599.11	13,599.11
Dependent Variables		
Endemic plants	154	177
Endemic plants regionally exclusive	21	21
Total vascular (taxa)	2,844	2,828
Independent Variables		
Precipitation Annual Average (mm)	971.87	958.39
fAPAR	0.1036	0.4111
Soil anomaly	-0.2016	-0.4188
Temperature (°C)		
January Average	7.5	11.2
July Average	25.4	26.8
Land Use Types (km^2)		
Urban	7.15%	18.67%
Agricultural	55.26%	43.748%
Forests/semi-natural/wildlands	37.34%	37.33%

Wetlands	0.028%	0.021%
Water bodies	0.18%	0.20%
Human Population	5,701,931	5,819,344

Table 23. Puglia

16. Puglia	**2005**	**2018**
Area (km^2)	19,354.40	19,354.40
Dependent Variables		
Endemic plants	97	137
Endemic plants regionally exclusive	39	33
Total vascular (taxa)	2,287	2,577
Independent Variables		
Precipitation Annual Average (mm)	669.66	579.36
fAPAR	0.1700	0.5255
Soil anomaly	-0.6858	0.2219
Temperature (°C)		
January Average	7.0	9.6
July Average	25.2	25.8
Land Use Types (km^2)		
Urban	4.928%	17.706%
Agricultural	83.08%	70.31%
Forests/semi-natural/wildlands	10.70%	10.69%
Wetlands	0.436%	0.436%
Water bodies	0.70%	0.709%

Human Population	4,020,707	4,063,888

Table 24. Basilicata

17. Basilicata	**2005**	**2018**
Area (km^2)	9,991.54	9,991.54
Dependent Variables		
Endemic plants	159	190
Endemic plants regionally exclusive	6	6
Total vascular (taxa)	2,636	2,607
Independent Variables		
Precipitation Annual Average (mm)	877.8	715.61
fAPAR	0.1044	0.3894
Soil anomaly	-0.2872	-0.3877
Temperature (°C)		
January Average	5.1	7.5
July Average	24.5	24.7
Land Use Types (km^2)		
Urban	1.477%	6.322%
Agricultural	57.34%	52.505%
Forests/semi-natural/wildlands	40.70%	40.69%
Wetlands	0.0859%	0.0852%
Water bodies	0.399%	0.404%
Human Population	597,768	570,365

Table 25. Calabria

18. Calabria	**2005**	**2018**
Area (km^2)	15,082.78	15,082.78
Dependent Variables		
Endemic plants	205	270
Endemic plants regionally exclusive	49	60
Total vascular (taxa)	2,630	2,799
Independent Variables		
Precipitation Annual Average (mm)	1098.99	1076.15
fAPAR	0.2044	0.4191
Soil anomaly	-0.1955	-0.3825
Temperature (°C)		
January Average	8.5	11.7
July Average	24.2	25.3
Land Use Types (km^2)		
Urban	3.63%	9.378%
Agricultural	48.218%	42.46%
Forests/semi-natural/wildlands	47.88%	47.87%
Wetlands	0.0026%	0.0026%
Water bodies	0.1999%	0.2199%
Human Population	2,011,466	1,955,015

Table 26. Sicilia

19. Sicilia	**2005**	**2018**

Area (km^2)	25,719.30	25,719.30
Dependent Variables		
Endemic plants	321	400
Endemic plants regionally exclusive	344	262
Total vascular (taxa)	3,011	2,787
Independent Variables		
Precipitation Annual Average (mm)	644.57	684.45
fAPAR	0.5755	0.7627
Soil anomaly	-0.3575	-1.0913
Temperature (°C)		
January Average	8.2	12.0
July Average	26.1	26.9
Land Use Types (km^2)		
Urban	4.899%	13.92%
Agricultural	67.746%	58.703%
Forests/semi-natural/wildlands	26.815%	26.807%
Wetlands	0.0805%	0.0805%
Water bodies	0.4007%	0.4007%
Human Population	4,968,991	5,056,641

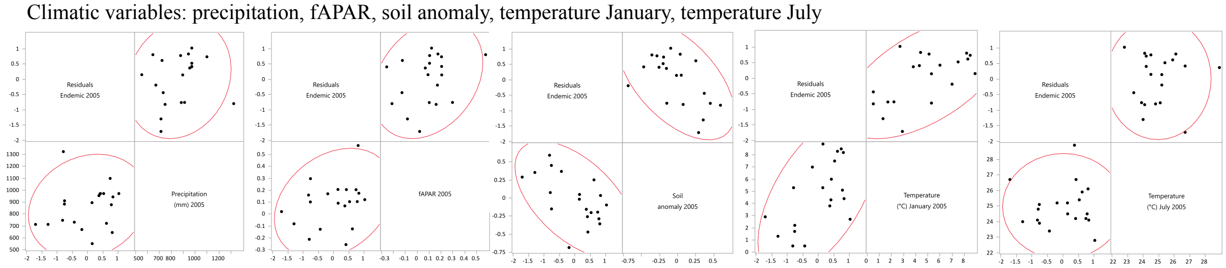
Table 27. Sardegna

20. Sardegna	**2005**	**2018**
Area (km^2)	24,118.30	24,118.30
Dependent Variables		

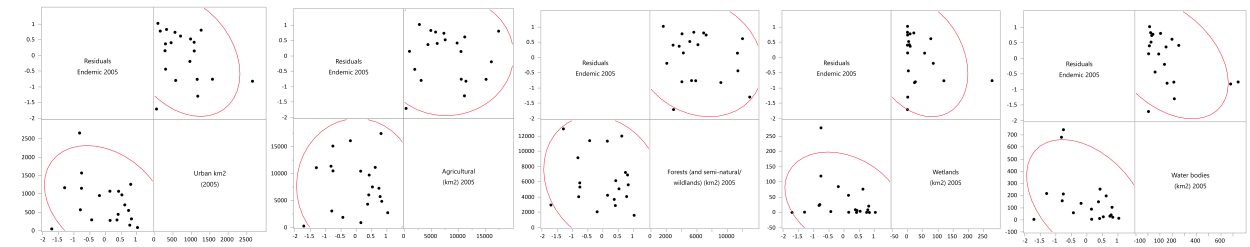
Endemic plants	254	322
Endemic plants regionally exclusive	277	180
Total vascular (taxa)	2,408	2,441
Independent Variables		
Precipitation Annual Average (mm)	721.63	914.39
fAPAR	-0.1250	0.5958
Soil anomaly	0.2513	-0.7577
Temperature (°C)		
January Average	8.3	12.4
July Average	25.9	26.9
Land Use Types (km^2)		
Urban	2.90%	6.948%
Agricultural	46.19%	42.14%
Forests/semi-natural/wildlands	49.68%	49.68%
Wetlands	0.3165%	0.3165%
Water bodies	0.818%	0.821%
Human Population	1,631,880	1,080,556

IX. Appendix II: Variables scatterplots

Climatic variables: precipitation, fAPAR, soil anomaly, temperature January, temperature July



Land use variables: Urban, agriculture, forests (semi-natural and wildlands), wetlands, water bodies



Human population

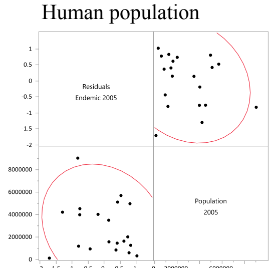
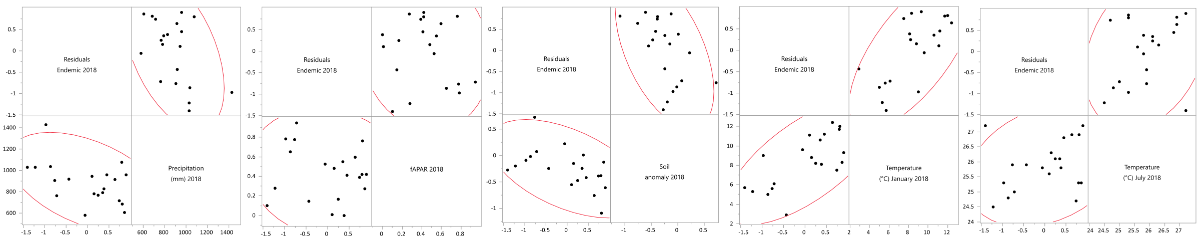
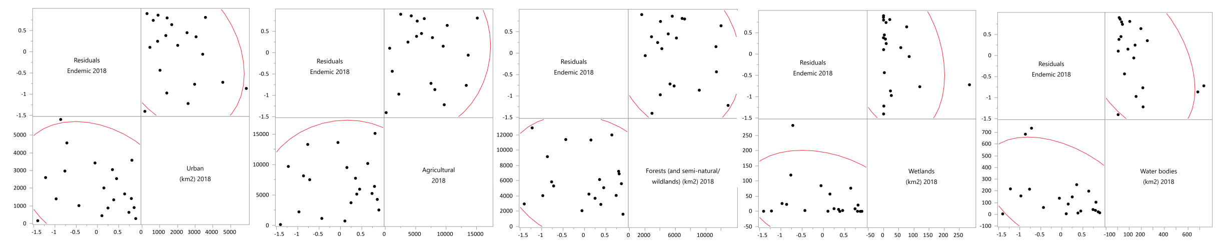


Figure 5. Endemic plants, climatic, land use, and human population variables scatterplots 2005

Climatic variables: precipitation, fAPAR, soil anomaly, temperature January, temperature July



Land use variables: Urban, agriculture, forests (semi-natural and wildlands), wetlands, water bodies



Human population

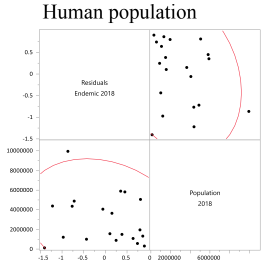
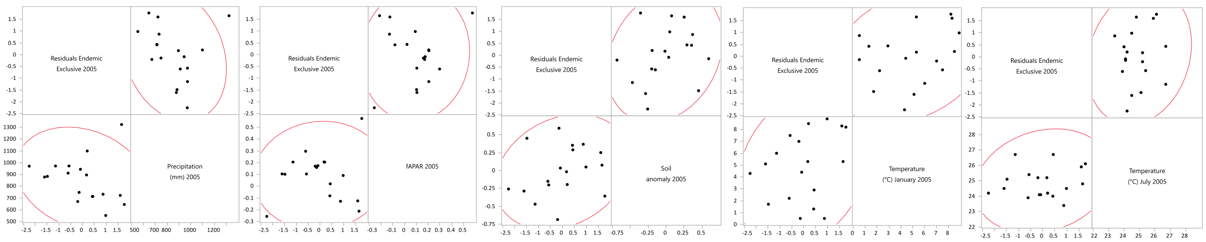
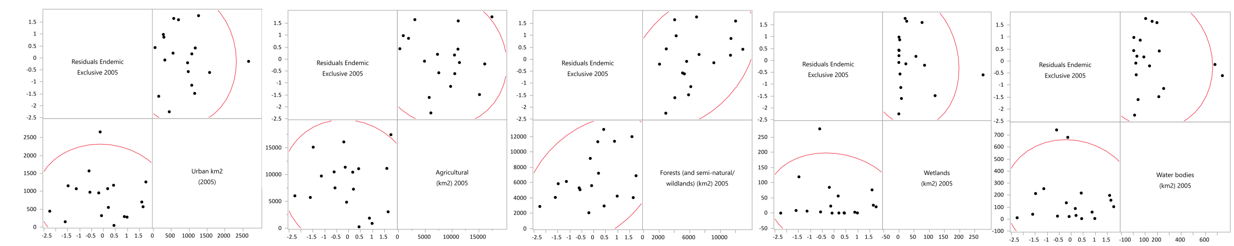


Figure 6. Endemic plants, climatic, land use, and human population variables scatterplots 2018

Climatic variables: precipitation, fAPAR, soil anomaly, temperature January, temperature July



Land use variables: Urban, agriculture, forests (semi-natural and wildlands), wetlands, water bodies



Human population

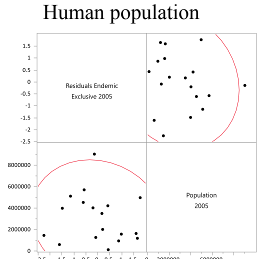
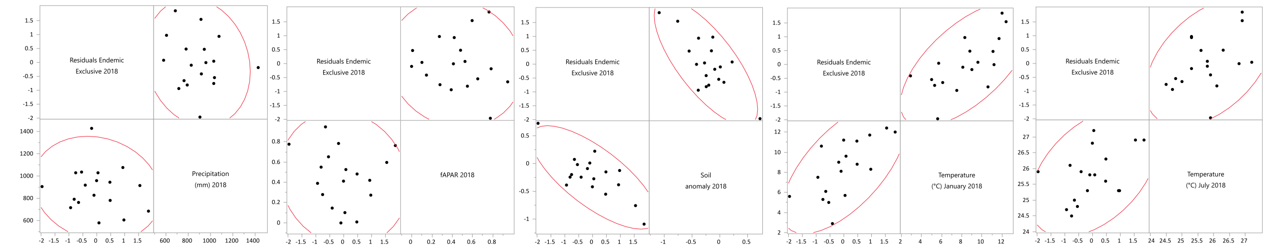
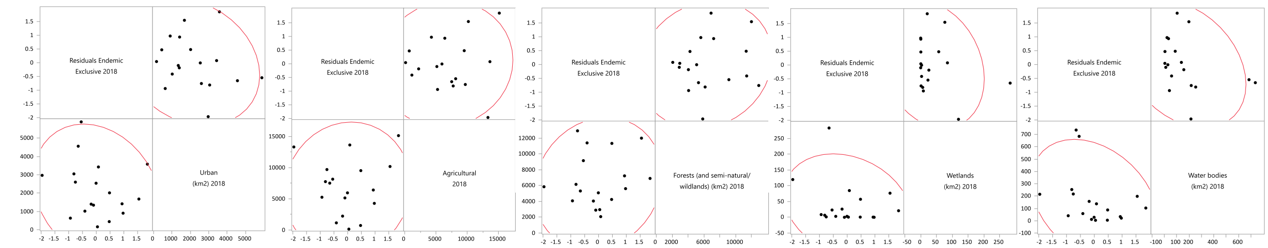


Figure 7. Endemic regionally exclusive plants, climatic, land use, and human population variables scatterplots 2005

Climatic variables: precipitation, fAPAR, soil anomaly, temperature January, temperature July



Land use variables: Urban, agriculture, forests (semi-natural and wildlands), wetlands, water bodies



Human population

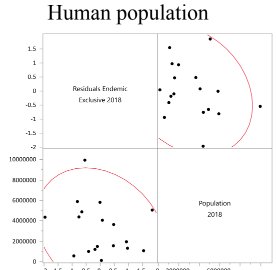
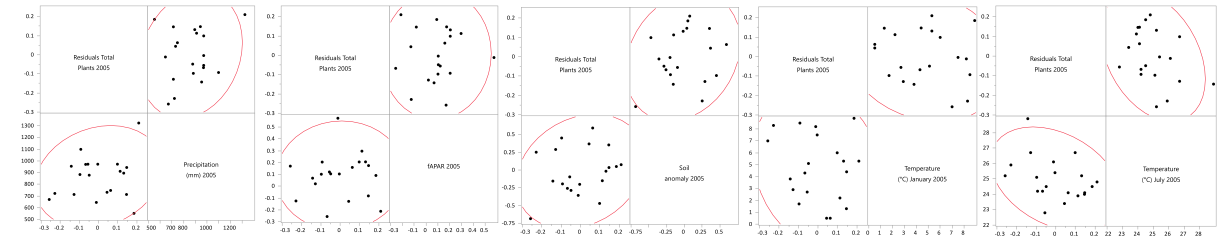
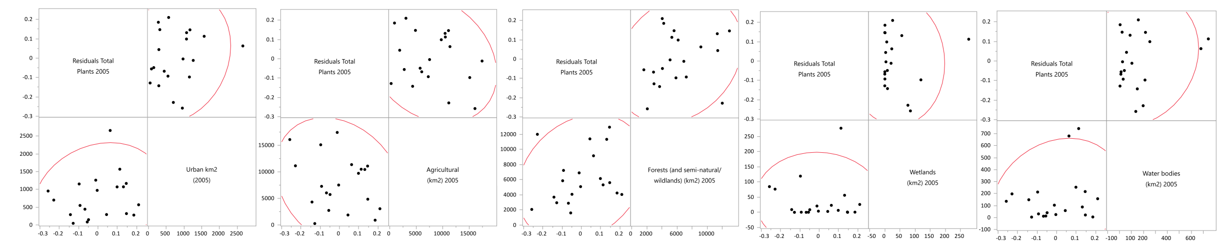


Figure 8. Endemic regionally exclusive plants, climatic, land use, and human population variables scatterplots 2018

Climatic variables: precipitation, fAPAR, soil anomaly, temperature January, temperature July



Land use variables: Urban, agriculture, forests (semi-natural and wildlands), wetlands, water bodies



Human population

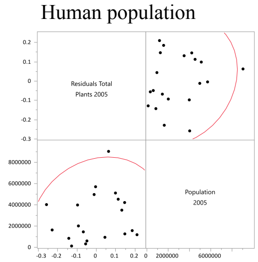
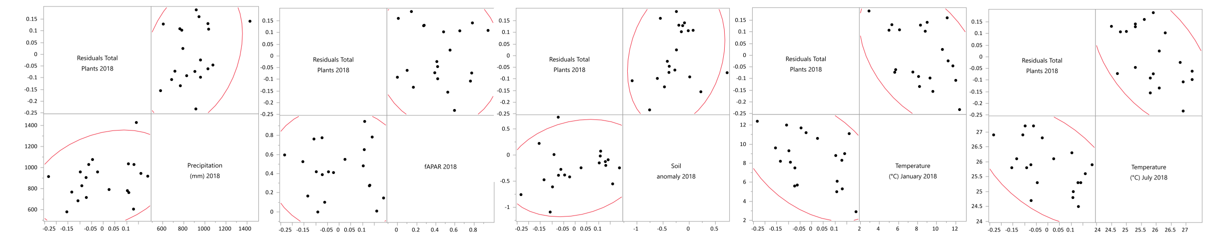
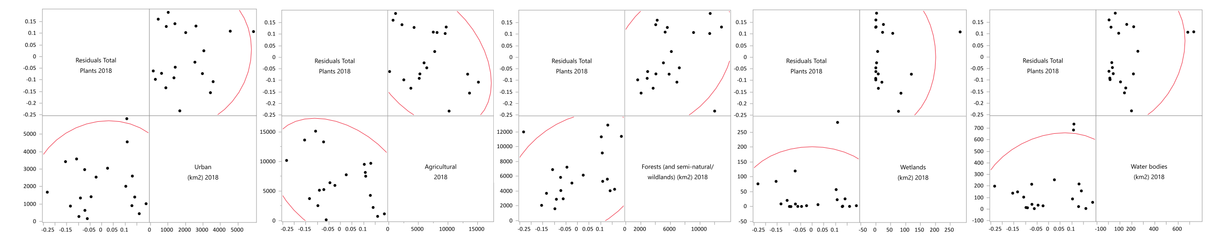


Figure 9. Total vascular plants, climatic, land use, and human population variables scatterplots 2005

Climatic variables: precipitation, fAPAR, soil anomaly, temperature January, temperature July



Land use variables: Urban, agriculture, forests (semi-natural and wildlands), wetlands, water bodies



Human population

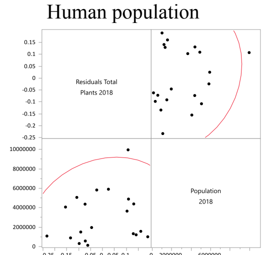


Figure 10. Total vascular plants, climatic, land use, and human population variables scatterplots 2018