

Review

# Extremes Rainfall Events on Riparian Flora and Vegetation in the Mediterranean Basin: A Challenging but Completely Unexplored Theme

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**Abstract:** In a global climate change scenario “Extreme climatic events” are expected to widely affect flora and vegetation in Med-regions, especially “Extremes Rainfall Events” which will have impacts on riparian environments. Aiming to provide an in-depth picture on the effects of these events on the riparian flora and vegetation in the Mediterranean Basin, especially focusing on islands, a bibliographic search was performed in the main international databases, which led to 571 articles published from 2000 to 2021. Most studies have analyzed these phenomena from the climatic point of view identifying three main topics “Rainfall”, “Global/Climate change”, and “Flood”. 81 papers concerned effects of extreme events on Mediterranean woodland formations and cultivated plants. A further analysis focused on European countries and Mediterranean bioregion using “Extreme rainfall events” and “Extreme rainfall and floods” as keywords. A low number of records relating to Mediterranean island regions was found, having Sicily as the study area. Moreover, seven articles had Sardinia as a study area, four of which referred to flora and vegetation. A lack of studies on the effects of extreme rainfall events on riparian flora and vegetation were highlighted. This review constitutes a call for researchers to explore extreme phenomena that have become recurrent in the Mediterranean Basin.

**Keywords:** climate change; extreme climatic phenomena; medicanes; flood; Mediterranean islands; riparian flora; riparian habitat; rainfall; Sardinia



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## 1. Introduction

Climate change can be defined as changes in average climatic conditions on a global or regional scale and it is the result of the synergy between the natural climate variability and all modifications in the composition of the atmosphere mainly attributable to human activities [1]. The Global Climate Observing System (GCOS), established in 1992 with the aim to monitor the climate and facilitate the development and improvement of global climate observations, has identified a series of physical, chemical and biological variables (called Essential Climatic Variables—ECVs) referred to the atmosphere, lands and oceans, which represent the basic data needed for the characterization of the Earth’s climate, understanding its evolution, assessing risks and dictating mitigation and adaptation measures needed [2]. These ECVs are the tools to monitor the most characteristic factors of climate change, the composition of the modified atmosphere and global warming because of the increase in greenhouse gases (GHGs), but also the responses of both terrestrial and marine environments and the effects on the ecosystem services they provide us [2]. However, to date it is unanimously accepted that the change in climate patterns is mainly caused by GHGs derived from sources of natural emissions (linked to forest fires, oceans, permafrost, wetlands, volcanoes and earthquakes) and human activities mainly related to energy production (the use of fossil fuels such as with coal, petroleum derivatives and natural gas), industrial activities, forestry, land use and land use change [3–5]. In fact, in

the so called “Anthropocene” era, GHGs generated by human activities have determined a relevant increase in the concentrations of carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>) and nitrous oxide (N<sub>2</sub>O) in the atmosphere [3] (IPCC, 2014). Linked to this phenomenon the human-induced warming is growing 0.1–0.3 °C per decade as a result of past and current emissions, in fact the global mean surface temperature registered for the decade 2006–2015 was c. 0.75–0.99 °C higher than the average over the 1850–1900 period [1]. The last six years, 2016–2020, were probably the six hottest on record, and in the last five years (2016–2020) and 10 years (2011–2020) the warmest averages were recorded [2]. However, temperature anomalies are not identical across the globe since most terrestrial areas were warmer than average in the 1981–2010 range. Conversely, most of the energy accumulated in the Earth system is absorbed by the oceans with a strong warming trend [6]: in the last 50 years about 93% of the heat excess has been transferred to ocean water masses and the remaining 7% has heated the atmosphere and the continents contributing to the melting of sea and land ice [7]. The same trend of rising Sea Surface Temperature was recorded in the Mediterranean Sea [8]. This phenomenon has led to a rise in sea level derived from the mass loss from glaciers and ice caps with the strongest regional trends in the southern hemisphere. The global increase in temperature together with the rise in anthropogenic gas emissions also contribute to the lowering of the pH of seas, limiting the oceans’ capacity to absorb about a third of global CO<sub>2</sub> emissions [9,10]. The rate at which ocean acidity has intensified over the past few decades (100 times faster than natural events in the last 55 million years) exacerbates the impact of these phenomena on marine ecosystems [10–12].

In this alarming situation, in the IPCC-AR5 (Fifth Assessment Report) [3], the 1.5 °C scenarios above pre-industrial levels and related global greenhouse gas emission pathways have been presented [13]; these scenarios indicate that to limit warming to 1.5 °C above pre-industrial levels it is necessary to achieve net zero CO<sub>2</sub> emissions globally around 2050, and a strong reduction in non-CO<sub>2</sub> forcing emissions as well [2]. These perspectives have brought a widespread awareness of the problem worldwide, as well as the need for urgent coordinated actions. Subsequently in recent years there has been a slowdown in GHGs emission. Although they are different from country to country, emissions are declining in some developed countries while they are still growing in less industrialized countries (non-OECD countries) [14]. A significant decline in GHGs emissions was recorded in European countries with a level, recorded in 2018, 25.2% lower than in 1990. This decline can be attributed to various factors including the effects of policy choices, both in the EU and in each member country, the main agricultural and environmental policies in the 1990s and those on climate and energy over the last two decades [15,16].

Despite this increased awareness worldwide and ongoing efforts, the effects of climate change are occurring with increasing frequency and magnitude. Specifically, some meteorological events occur with greater frequency, intensity, more spatially extended and with a longer duration and timing: the so called “extreme events”; these events are characterized by extreme weather conditions, rare in a certain place and time of year and persistent even for long periods of time [17]. Heat waves, cold spells, droughts, extreme rainfall events, floods, cyclones and fires have been linked to human activities [3] revealing a high degree of vulnerability of ecosystems and human society. The impacts produced by extreme events, in fact, concern not only the alteration of natural ecosystems, but cause damage to infrastructures and settlements, heavily affecting human life [18–26]. Future projections indicate that such phenomena are expected to have a particularly strong effect on Med-regions [27], showing an exacerbation of drought conditions and an increase in the frequency of extreme events greater than the global average [28–32].

In this framework, the Mediterranean Basin is recognized as an area among the most affected by the global warming. This area represents an interesting laboratory for its geological, climatic characteristics and high biodiversity and for the role it plays in the neighboring areas for hydrological exchanges with the Black Sea and the Atlantic Ocean and the European climate [30,33,34]. The climate of the Mediterranean Basin which is characterized by variability both in space and in time of temperatures and precipitations,

is attributed to the geographical position, at the south-eastern limit of the routes of the North Atlantic storms, to the influence caused by the tropical and subtropical systems and last but not least, to the complex morphologies of the territory, the orography and the presence of islands and peninsulas. [35–37]. With an average temperature rise in the Mediterranean Basin, a decrease in precipitation is projected, along with an increase in the frequency and duration of the drought and desertification [24,30,32,38]. Specifically, projections on future precipitation show a decrease of 28% in summer by the end of 21st century, important seasonal differences and a North-South dipole with the wetter northern regions and the already dry southern regions becoming even drier. The Mediterranean Sea will become warmer with consequent variations in the thermohaline circulation and salinity with probable consequences on the exchange of water and heat with the Atlantic Ocean [30,35,36,39]. However, the analyses on different datasets and metrics considered have shown some uncertainties in the projections, highlighting a worsening scenario at local scale, negatively influenced by local forcing such as topography [30,39]. In fact, within the Mediterranean Basin, some differences in projection were detected between the northern and southern areas [40]: an overall global trend towards longer periods of drought and shorter periods of rain [24,32] accompanied by an increase of 7.3–5.0 days for the dry period, by degree of global warming, were measured respectively for the south and north of the Mediterranean. These data highlight critical issues related to the Mediterranean area that will evolve in the future different levels of risk linked to water scarcity, increasing the already critical socio-economic contrasts between North and South [40].

### 1.1. Extreme Rainfall Events (EREs)

All scenarios indicate an increase in extreme rainfall events for the Mediterranean Basin, although not uniformly distributed for the whole area. In fact, the distribution of extreme rainfall events (EREs) shows a seasonal differentiation between the Western and Eastern part of the Mediterranean, the first affecting in autumn and the second in winter. EREs are often linked to thunderstorm or cyclonic formations, which in fact, are predicted to increase in frequency and magnitude due to climate change [41].

The Mediterranean Basin is unanimously considered one of the main cyclogenetic areas in the world, affected by rare types of cyclonic storms known as “Mediterranean tropical-like cyclones” or “Medicanes”, a neologism obtained from the union of the two terms MEDiterranean and HurriCANES [42–44]. Medicanes are caused by synergies of different environmental factors such as low wind shear, high humidity and vorticity [45]. Some features detected by satellite images show similarity to tropical cyclones, albeit smaller in size, equal to a few hundred km, the presence of a spiral-shaped cloud with an “eye” in the center, strong winds and a warm core [44,46–48]. Although characterized by much lower intensity of winds than tropical cyclones, Medicanes still represent a strong threat to islands and coastal regions [49,50].

Medicanes have attracted the attention of researchers and an interesting debate is involving in the scientific community on their reliable definition and classification [45,46,51–59]. In fact, in the last years, several studies have investigated different aspects of these phenomena: characteristics and conditions of formation [60,61], climatological properties [45,51,62], numerical models or simulations [42,63–68].

Medicanes occur with a frequency of about 1.5 events per year throughout the Mediterranean Basin [45,49,69], with an annual distribution with the highest frequency records between September and March, a slight decrease in spring and little activity (tending to zero) in the hottest months of July and August [49,61,69]. As for the (often correlated) extreme rainfall events, not all areas of the Mediterranean Basin are equally affected by the formation of Medicanes as the environmental conditions necessary for their formation have to occur together [45,61]: the most common regions in which they occur are the Western Mediterranean Basin (Balearic Islands, coast of Spain, south of France and the Western coast of Corsica and Sardinia), the widest part of the Ionian Sea (between Sicily and Greece, covering the Ionian Sea until the Lybian coast) and a limited presence is recorded in the

Aegean Sea and in the Eastern Mediterranean [44,48,61,65,69]. However, this distribution is constantly evolving and the projections indicate by the end of the century a decrease of Medicanes up to 40% compared to the present [49,50,70]. Moreover, a different spatial distribution in the localization of Medicanes is expected reaching a more or less uniform distribution at the end of the century over the entire Basin [70]. Although fewer in number, more intense events, more violent winds and more intense precipitations typical of tropical storms are expected to occur [49,55].

In addition to considering the frequency and the future changes in the distribution of such phenomena, one of the main consequences of a Medicane, hitherto little investigated, is linked to the abrupt effects of the correlated extreme and uncommon rainfall events on the riparian ecosystems, directly affected by these events: such consequences can include both mechanical damages, due to the large mass of water in a short space of time, and long-term consequences such as the modification/replacement of riparian ecosystems. Water-based plant communities in Mediterranean regions are in fact particularly sensitive to the expected effects of climate change in the coming decades. Moreno-Rodríguez et al. [71] in a study focusing on the overall effects of climate change in Spain also described such effects at the water-based ecosystem level and riparian plant communities. According to this study, climate change will affect water-based ecosystems in terms of decreasing their surface area until they disappear. In addition, temporary and seasonal variations in river flows are expected, including a decrease in riparian plant biodiversity [71].

### 1.2. Riparian Habitats

Riparian zones are among the most complex ecological systems in the biosphere, often heterogeneous, highly dynamic and highly threatened [72,73]. Therefore, these zones are difficult to classify into predictable systemic entities, as well as to monitor and manage [72–74] and, as a consequence, this natural complexity brought the mismanagement of riparian zones worldwide and often the degradation of their woodland formations [73,75]. Riparian zones represent the interface between aquatic and terrestrial ecosystems: they are areas that include the stream channel between the low and high watermarks and the part of the terrestrial landscape from the high-water mark toward the uplands where vegetation may be influenced by high water tables or flooding and by the capacity of the soils to retain water [72,74,76,77]. Riparian zones have peculiar ecological features that reflect the aquatic-terrestrial interaction; thus, their boundaries can be delineated by changes in soil conditions, vegetation, and other factors [74,77]. These zones are affected by fluvial processes such as flooding and deposition of alluvial soil, and typically support a distinctive flora that differs in structure and function from adjacent terrestrial vegetation [72,74,76–79]. Specifically, riparian vegetation, e.g., floodplain vegetation or vegetation directly adjacent to rivers and streams, influences several ecological functions of aquatic habitats, such as providing food, moderating stream water temperature by evapotranspiration and shading, providing a buffer zone that filters sediments and controls nutrients, and stabilizes stream banks [72,74,80,81]. Moreover, riparian zones represent key systems for regulating aquatic-terrestrial linkages [72,74,82,83] which may provide early indications of environmental change [74,84,85].

In the Mediterranean Basin, distribution patterns of riparian flora showed a strong association with local climate, and the latter was mainly related to the change in the floristic composition between riparian sites [72,86,87]. In such context, the flora and vegetation of Mediterranean riparian ecosystems are not strictly defined as “azonal”, but as “semi-azonal”, in which the truly aquatic and hygrophilous species are few, while those well-suited to marked edaphic dryness are frequent [72,86]. Furthermore, in riparian environments, two variables such as biogeographic location and the longitudinal gradient, are strongly linked and associated with climate change [72,86].

Riparian communities are directly influenced by the climate [72,87,88] due to physiological effects on organisms, limiting their populations and favoring certain life forms and

phytogeographical elements [89–91]. Particularly, riparian flora shows peculiar features within the Mediterranean bioclimatic and biogeographic region [90,92].

In a global change scenario, linked riparian and stream communities are likely to be deeply modified by predicted increases in the synergistic actions of connected extreme events, such as prolonged droughts, increased wildfires, and intense floods accompanying climate change [93]. It is expected that Mediterranean rivers will be affected by changes in community richness and composition, modifications of life-history traits, up to local and regional extinctions [94]. This is mainly due to the avoidance strategies against drought in med-rivers species which are more common than endurance ones, as these are relict species of colder times [95,96]. In fact, riparian vegetation in Med-rivers exhibit many drought avoidance strategies, such as higher root biomass, small leaf sizes, or more frequent branch abscission [97] while no adaptation strategies to brutal events such as an ERE are evident. Moreover, extreme events cause changes in streamflow in Med-rivers: riparian vegetation is adapted to patterns of streamflow disturbances. The attributes of the streamflow regime which govern riparian vegetation dynamics in Mediterranean regions rivers are influenced by the seasonality and variability of precipitation with dry summers and mild winters, and large interannual variability [98]. Med-rivers hydrological regimes being naturally exposed to extreme events, range from no or low flows to flash floods [99,100]. Temporary reduction in water availability is the main driving force behind adaptations to Mediterranean riparian vegetation to such conditions [101]. Therefore, although riparian vegetation may be affected by extreme streamflow disturbances (at plant functional diversity level), the adaptations of local riparian flora in Mediterranean rivers made these effects smaller [98].

In addition to the effects of extreme rainfall events per se, other aspects that contribute to increasing the magnitude of such phenomena must be considered, such as the geographical characteristics due to a varied typology of substrates and soil, altered in many ways and, not least, the ever-increasing coastal urbanization. The combination of all these factors and phenomena will certainly have a strong impact on riparian flora and structure, composition, and succession of riparian vegetation. [27,102].

Although riparian habitats are essential for the maintenance of biodiversity, biogeochemical cycles and ecosystem services which they provide and despite the fact that they are protected by international directives (e.g., Habitat Directive), the attention paid to these environments is still insufficient and there are still knowledge gaps on riparian ecosystems and vegetation that are linked to cumulative impacts to small ephemeral streams and large regulated rivers, as well as understudied ecosystems in the Western Mediterranean Basin [97]. Despite these considerations, there is a lack of an overview of the state of the studies on the specific effects of extreme rainfall events on riparian flora and vegetation at Mediterranean Basin level. For these reasons, our main aim was to provide an in-depth picture of the research carried out in the last 20 years on the effects of extreme rainfall events on the riparian flora and vegetation in the Mediterranean Basin, with a particular focus on the Mediterranean islands and selecting Sardinia as a study case.

## 2. Materials and Methods

To obtain an exhaustive picture on the effects of extreme rainfall events (including Medicanes and floods) on the riparian environments present in the Mediterranean Basin, a two-step in-depth research on the available literature was conducted. Such research was mainly collected from international peer-reviewed papers found via online scientific databases, namely Scopus, Web of Science, and Google Scholar by first crossing different primary keywords “Climate global change”, “Extreme events”, “Medicanes”, “Floods impacts”, “Thunderstorms”, in combination with second keywords including “Mediterranean riparian vegetation” and “Mediterranean riparian flora”. Subsequently, a second step of bibliographic research was carried out on Scopus using keywords like “Extreme rainfall and floods” and “Extreme rainfall events” in combination with “Mediterranean Basin”. The time interval was set at 20 years from 2000 to 2021 in both cases and the results obtained were analyzed separately.



### 3. Results and Discussion

The research on the effects of extreme rainfall events in the Mediterranean Basin produced two different matrices by using the keywords “Extreme rainfall events” (461 articles; Supplementary S1) and “Extreme rainfall and floods” (156 articles; Supplementary S2); as expected, in the two matrices we found several overlapping papers (47 articles) and thus the total of the references relating to the effects of extreme rainfall events in the Mediterranean Basin is of 571 articles (Table 1). The number and distribution of articles per year in the period considered were reported in Figure 1.

**Table 1.** Total articles relating to the effects of extreme rainfall events in the Mediterranean Basin. The articles were classified into category and sub-category, and the number of articles in each category was indicated.

Category	Sub-Category	No. Articles
Rainfall events	Modelling	36
	Estimates by radar	8
	Rainfall pattern	54
	Rainfall distribution	8
	Torrential precipitation events	71
	Precipitation effect on animals	1
	Vegetation	14
	<b>Total: 192</b>	
Floods	Vegetation	4
	Flood forecasting systems	18
	Flood models	19
	Flood frequency	5
	Flood events: study cases	30
	Flooding hazard/risk	16
	Flood distribution	2
	Socio-economic effects floods	4
Ecological response of floods	3	
	<b>Total: 101</b>	
Storm	Vegetation	2
	Storm/cyclone	2
	Storm model/estimate/forecasting	9
	Storm events	7
	Storm impact	2
	Thunderstorm	1
	Rainstorm	1
	<b>Total: 24</b>	
Medicane		2
Extreme weather events	Vegetation	4
	Extreme events model/assessment	25
	Extreme events	3
	<b>Total: 32</b>	

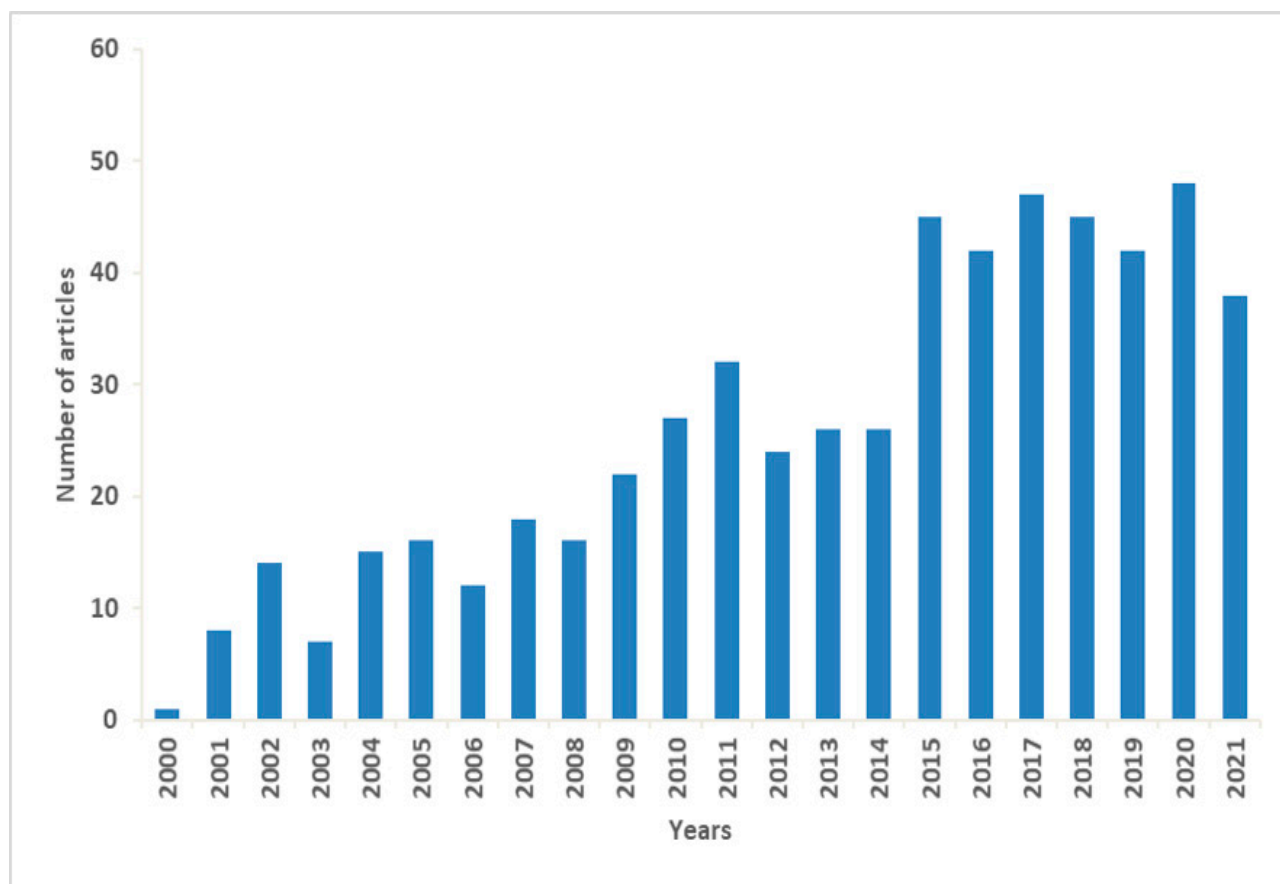
Table 1. Cont.

Category	Sub-Category	No. Articles
Drought	Vegetation	18
	Drought pattern	4
	Drought events	6
	Animal resilience to drought	1
	Drought assessment	1
	<b>Total: 30</b>	
Global/Climate change	Vegetation	34
	Global/climate change	35
	Climate change on crops	12
	Climate change simulation	22
	Climate change on precipitation, flood, water ecosystems	27
	Climate change on animal	3
	Climate change forecasting/risk/assessment	41
<b>Total: 174</b>		
Fires	Vegetation	6
	Fire effects	5
	Fire models	1
	<b>Total: 12</b>	
Lightning		3
Temperature		2

As expected, it is noteworthy to highlight a continuous growth in the number of articles in the last twenty years with a significant increase, from 2015 to 2021. This indicates a great and constantly increasing interest of the scientific community in extreme rainfall events occurring in the Mediterranean Basin, in particular from the second half of the last decade. The pioneers published articles mainly regarding the rainfall modelling and pattern [103–112], analysis and reconstruction of flood events [113–117], and climate change numerical simulations and scenarios' assessment [118–120]. This suggests that researchers initially focused their studies on understanding and describing the causes of these phenomena, in order to gain a detailed knowledge of them and improve assessment and forecasting.

The main topics of the selected articles were particularly heterogeneous, so much so that they had to be classified into categories and each category into subcategories in order to be able to schematize them (Table 1). Among the ten main categories identified, only three are particularly rich in references, "Rainfall events", "Global/Climate change" and "Flood" with 192, 173 and 101 articles respectively.

In the "Rainfall events" category, part of the total references focuses on extreme precipitation events of torrential nature (71 articles), but the greater part is addressed to the analysis of the distribution of rainy events, their estimation with radar, specific studies on rainfall pattern and modelling (106 items).



**Figure 1.** Number of articles on the effects of extreme rainfall events in the Mediterranean Basin published from 2000 to 2021 ( $n = 571$ ).

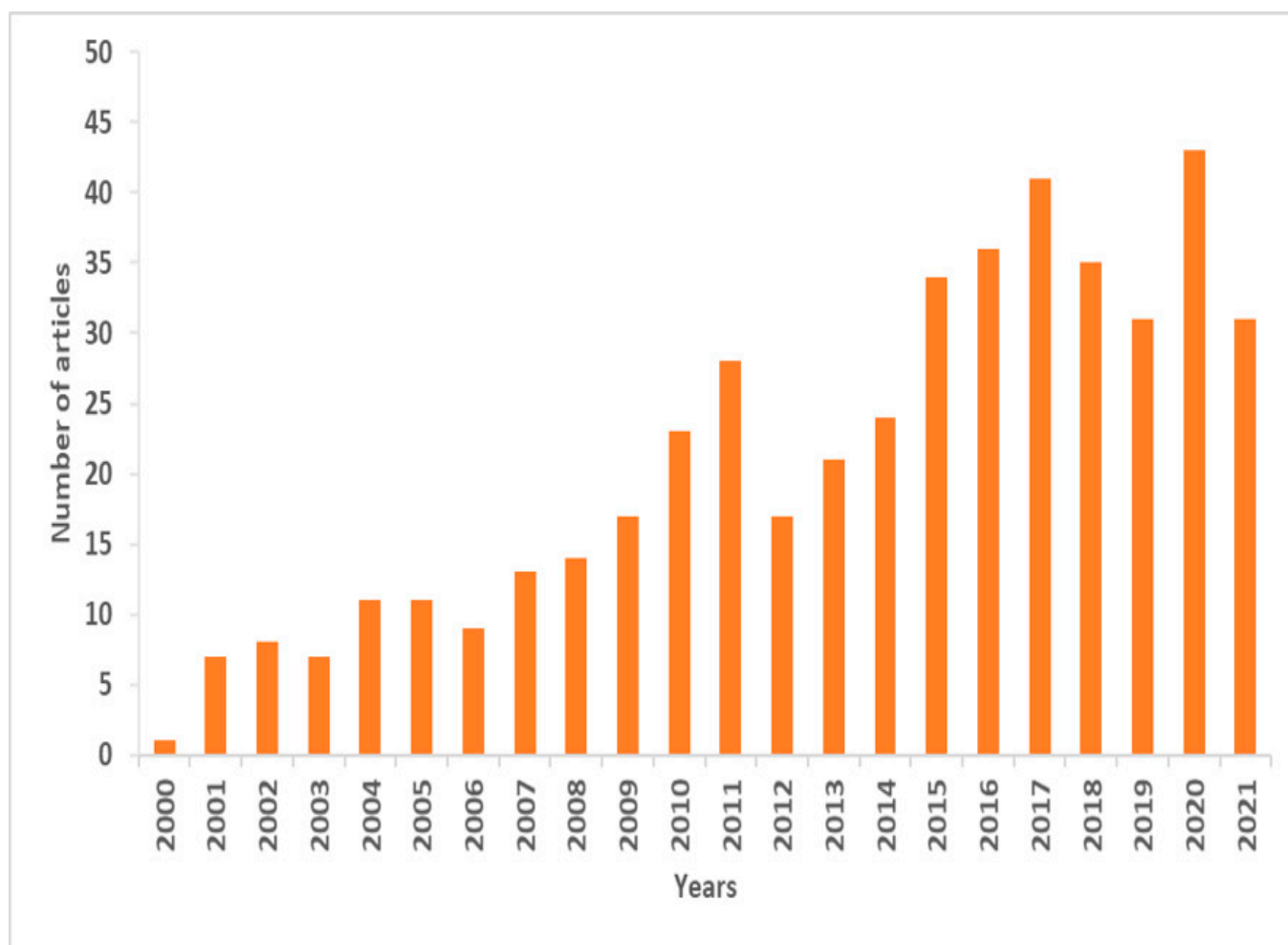
The more general aspects of climate change but above all the effects of climate change as a cause of extreme rainfall, floods, effects on aquatic ecosystems, vegetation and agricultural ecosystems are the issues that characterize the “Global/Climate change” category (72 articles in total). At the same time, researchers place good emphasis on assessments of climate change in terms of risks and to provide reliable forecasts (41 articles) and models for the assessment of extreme events.

The “Flood” category includes research on the distribution and frequency of events, case studies in urban areas (37 articles), but above all flood models, forecasting systems, analyses of flooding hazard and risk especially in urban areas (53 articles). Furthermore, it is important to underline that in this type of study the economic, ecological and vegetational aspects linked to alluvial phenomena are investigated (12 articles). Few articles concern the Storm/Medicanes (9 articles) and Fires (12 articles in total) categories. The first ones mainly focused on storm models, event estimation and forecasting; the second ones, concerned the effects of fires (5) in general, and on vegetation (6), in particular.

### 3.1. Step Two: “Extreme Rainfall Events” and “Extreme Rainfall and Floods”

The second step of bibliographic research, as for the articles on “Extreme rainfall events”, highlighted a growing trend of published papers throughout the period considered (Figure 2).



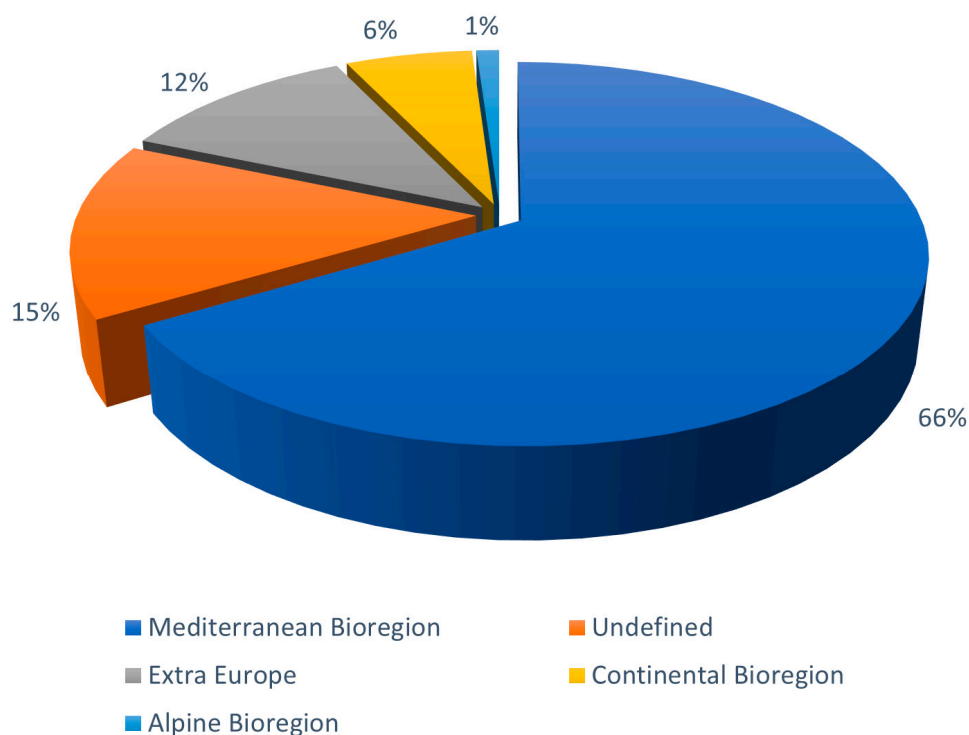


**Figure 2.** Number of articles on “Extreme rainfall events” published from 2000 to 2021 ( $n = 462$ ).

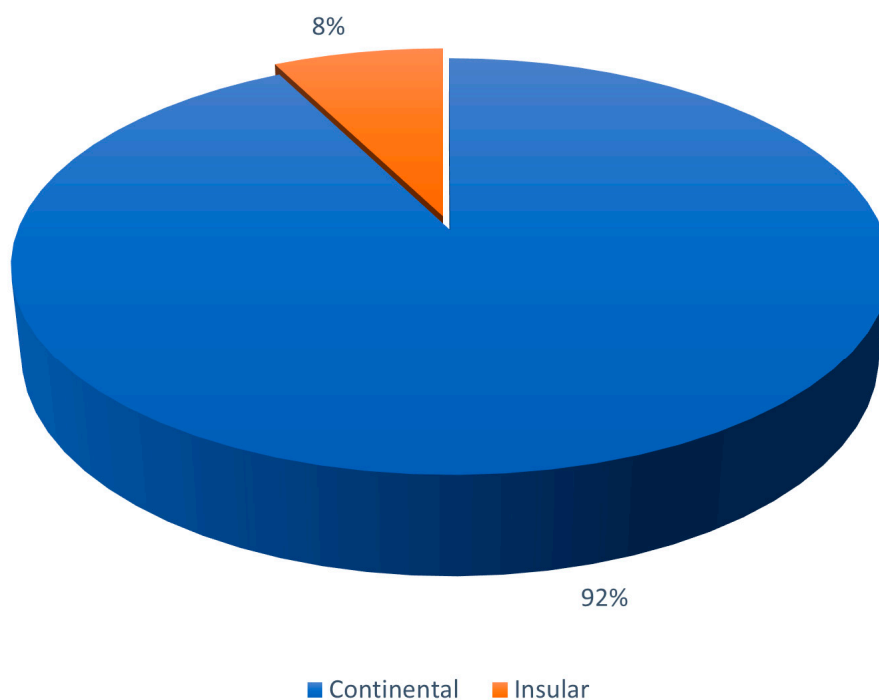
In particular, these articles have recorded a significant increase almost continuously from 2015 to 2021 (Figure 2). Again, this indicated a great interest of scientific community in extreme rainfall events, especially in the second half of the last decade.

In order to understand if there was a geographic context for “Extreme rainfall events”, all articles on this topic have been grouped based on geographical distribution (Figure 3). Specifically, the study area of most of the articles included European countries; despite this, there was a part of articles we categorized as “undefined” study area, which included both those with the wider specific investigated area encompassing in other groups and those without a defined area (15%; 69 articles) and articles relating to Extra European countries (12%; 53 articles). Among European countries, the articles grouped at level of bioregions (*sensu* Habitat Directive 92/43/EEC; [https://ec.europa.eu/environment/nature/natura2000/biogeog\\_regions/](https://ec.europa.eu/environment/nature/natura2000/biogeog_regions/), accessed on 15 December 2021), indicated that most of them concern the Mediterranean bioregion (66%; 307 articles), followed by the Continental (6%; 28 articles) and Alpine (1%; 5 articles) bioregions.

A focus was made on the articles with Mediterranean bioregion and the articles of such area were divided into two categories, continental and insular. We found that most of the articles on “Extreme rainfall events” (92%; 283 articles) concerned the continental territories, while only 8% (23 articles) the insular territories (Figure 4).



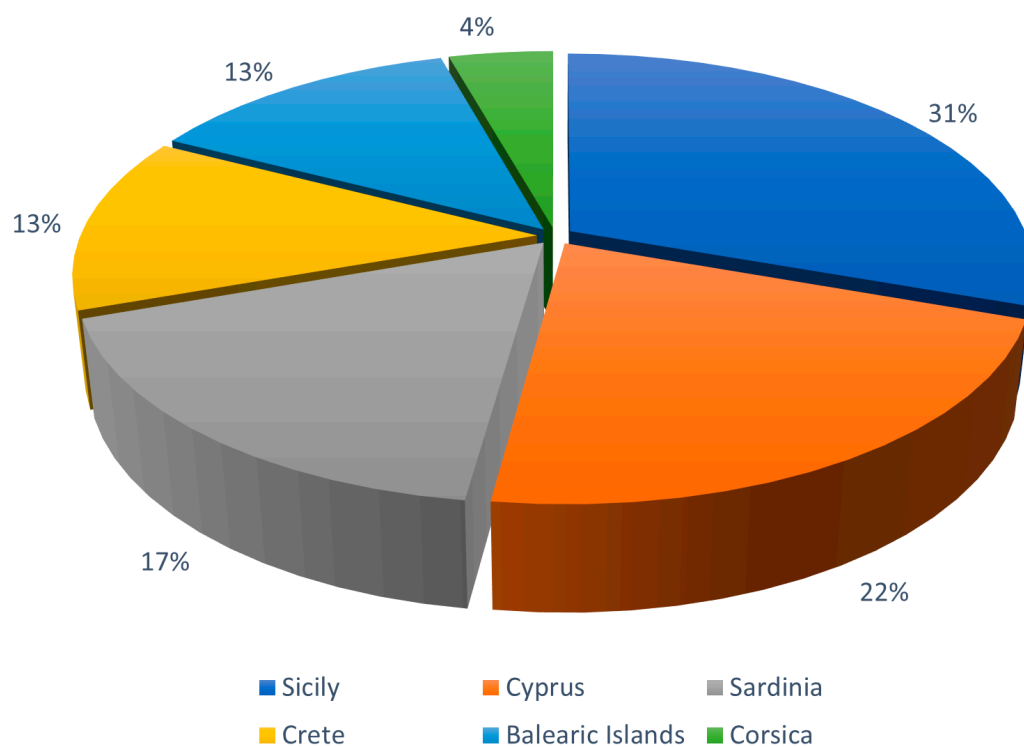
**Figure 3.** Percentage of all “Extreme rainfall events” articles grouped by their geographical distribution.



**Figure 4.** Percentage of all “Extreme rainfall events” articles of Mediterranean bioregion.

Finally, considering only the articles focused on the Mediterranean islands (Figure 5), our results showed that most of these articles had Sicily as study area (31%; 7 articles), followed by Cyprus (22%; 5 articles), Sardinia (17%; 4 articles), Crete and the Balearic Islands (13%; 3 articles), and Corsica (4%; 1 articles). Analyzing in depth these articles, we found that the most part dealt with the issue relating to rainfall (10 articles), following global change (5) and floods (4), accordingly the general trend already seen. Among these, only two papers focused on the impacts of these phenomena on vegetation [121,122]. In

summary, the results relating to the articles on “Extreme rainfall events”, at least in the analyzed literature, are largely specific to the geographic areas to which they are addressed, i.e., European countries and specifically those included in the Mediterranean bioregion. However, the low number of articles concerning Mediterranean islands appears to be in contrast with the fact that these territories, in addition to being hotspots of global biodiversity, lie in one of the areas most susceptible to climate change in the world [34], being highly exposed to Medicanes [49].



**Figure 5.** Percentage of all “Extreme rainfall events” articles of Mediterranean bioregion grouped into islands.

Finally, among “Extreme rainfall events”, there were only 79 articles referring to the impacts of these phenomena on flora and vegetation, however these represent almost all of the articles (81) concerning the effects of extreme events and global change on vegetation in this review. The number and the temporal trend of articles on “Extreme rainfall and floods” is reported in Figure 6. These articles have increased significantly from 2014 to 2021. Such result confirmed a great interest of scientific community especially during the last decade.

The articles on “Extreme rainfall and floods” analyzed by geographical distribution are shown in Figure 7. In particular, in accordance with “Extreme rainfall events” articles, the study area of most of the articles lay in the Mediterranean bioregion (66%; 102 articles), followed by the continental (19%; 30 articles) and Alpine (9%; 14 articles). In addition, there was a percentage of articles with undefined (5%; 8 articles), and extra Europe distribution (1%; 2 articles).

The focus on the articles with the Mediterranean bioregion area of study (Figure 8) confirmed the results achieved for articles “Extreme rainfall events”, with most of them (79%; 81 articles) relating to the continental region compared to 21% (21 articles) of the insular region.

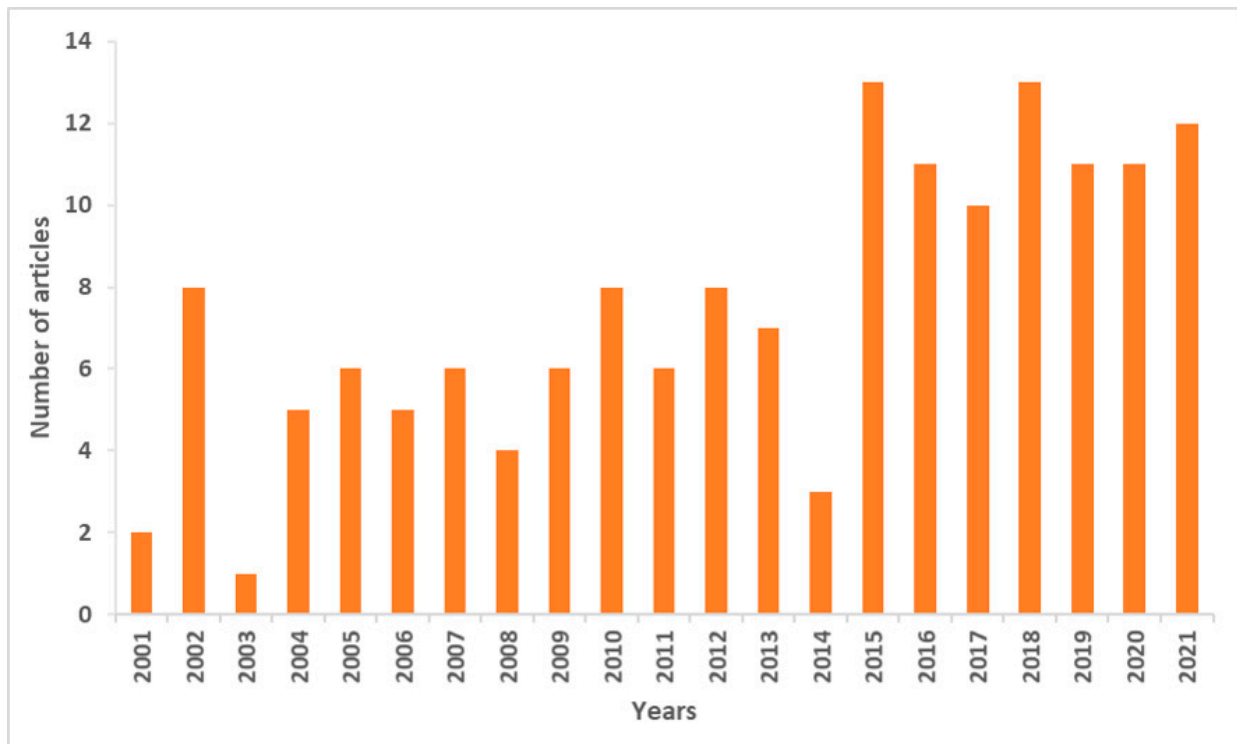


Figure 6. Number of articles on “Extreme rainfall and floods” published from 2001 to 2021 ( $n = 156$ ).

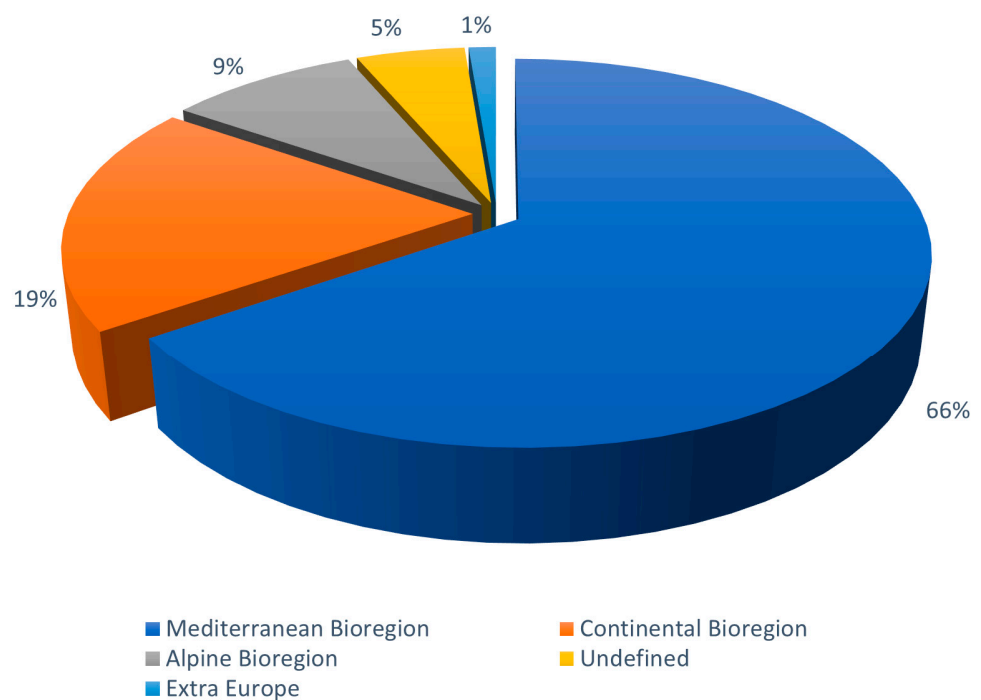
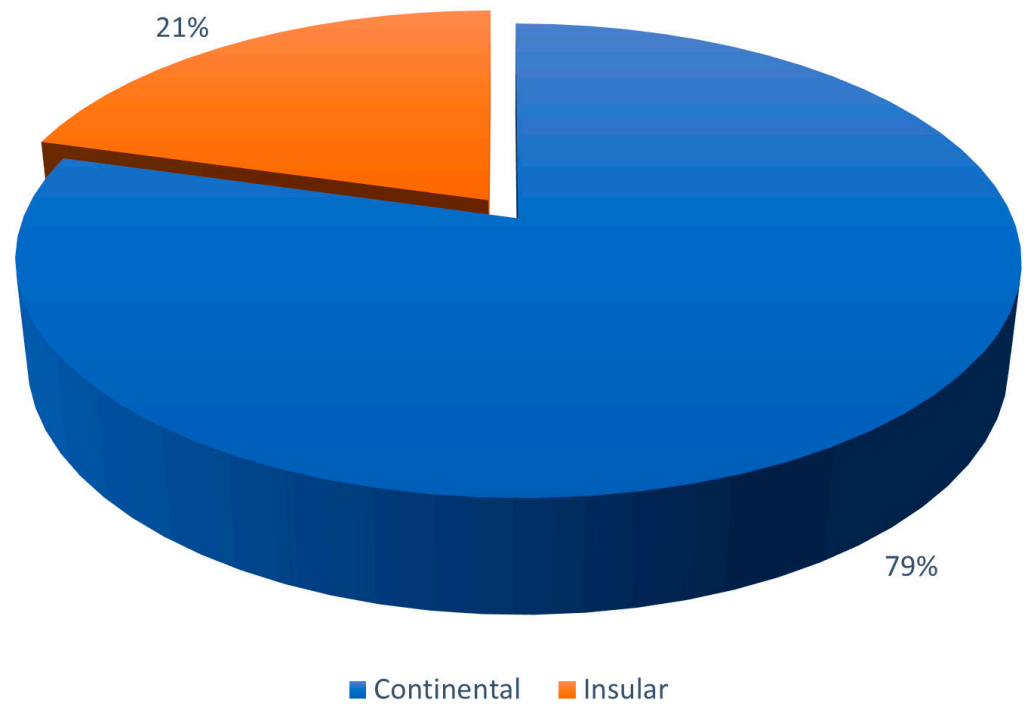
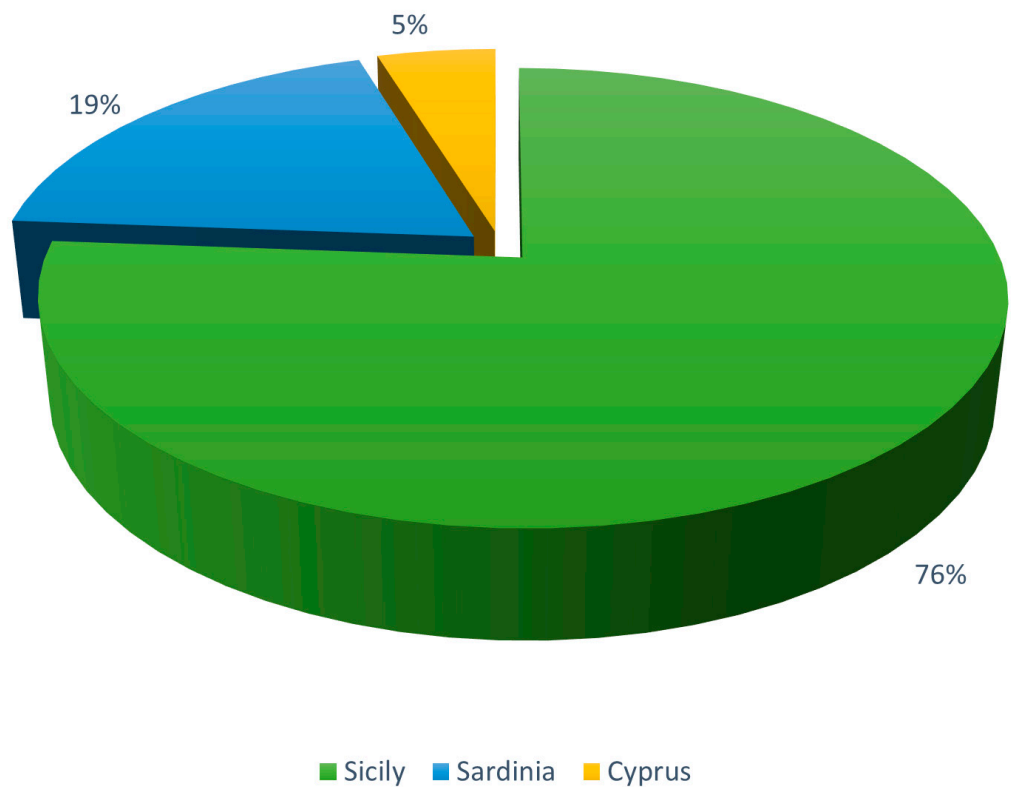


Figure 7. Percentage of all “Extreme rainfall and floods” articles grouped by their geographical distribution.



**Figure 8.** Percentage of all “Extreme rainfall and floods” articles of Mediterranean bioregion.

The analysis of the geographical distribution of the articles on “Extreme rainfall and floods”, focused on the Mediterranean insular bioregion (Figure 9), showed that most of the articles had Sicily (76%; 16 articles) as study area, followed by Sardinia (19%; 4 articles) and Cyprus (5%; 1 articles).



**Figure 9.** Percentage of “Extreme rainfall and floods” articles of Mediterranean bioregion grouped into islands.

Likewise, to what was recorded for “Extreme rainfall events” articles, the most part of papers dealt with the issue relating to precipitation (10 articles), following flood (6) and global change (3).

The results achieved for the articles on “Extreme rainfall and flood” confirmed what has already been recorded for “Extreme rainfall events” articles regarding the geographic distribution, both at the level of bioregions and at the level of islands. As far as articles on “Extreme rainfall and floods” are concerned, unexpectedly, only one was recorded referring to the impacts of these phenomena on flora and vegetation. Specifically, in the study published by Cristiano et al. [123] the performance of CAM (Crassulacean Acid Metabolism) and C3 vegetation (C3 metabolism, in which the CO<sub>2</sub> is fixed into a compound containing three carbon atoms before entering the Calvin cycle of photosynthesis) as green rooftop layers in mitigating extreme rainfall in an urban context was investigated.

These results indicate that, despite the growing interest in this issue, most studies have analyzed these phenomena from the climatic point of view. However, we highlight a lack of specific studies on the effects of climate change from a biological point of view, including flora and vegetation.

### 3.2. Extreme Rainfall Events in Mediterranean Basin: Impacts on Vegetation

Eighty-one articles concerning the effects of extreme events and global change on flora and vegetation have been found. Specifically, the studies concerning the effects of extreme rainfall events in the Mediterranean Basin on vegetation were mainly linked to three types of weather events: “Climate change” (34), “Drought” (18), and “Rainfall” (14). In the articles related to climate change, the effects of global change in general on the growth of Mediterranean forest formations were mainly analyzed and estimated; in particular, for the formations characterized by *Quercus*, *Pinus* and *Fagus* species [124–129]. The articles dealing with the impact of increasing drought on vegetation, on the one hand, concern the assessment of drought, on the other hand, the drought pattern on the Mediterranean formations. The first ones evaluated the impact of drought on the development, composition and productivity of most dominant Mediterranean woodland and shrubland [130–136]; the second ones principally individuated and analyzed the drought patterns and their effects on Mediterranean woodland communities [137–140].

Articles about rainfall effects, for the most part, focused on individuating and describing the impacts of changes in rainfall trends and patterns on productivity, diversity and biological response of Mediterranean woodlands and semiarid plant communities [141–145].

Despite the increase in magnitude and frequency of phenomena such as fires and floods as a result of global change, only a few articles (six and four respectively) have analyzed the impact of these phenomena on vegetation. In the articles related to the fire topic, the main environmental factors that determine severity affecting forest formations located in Mediterranean Basin have been identified and evaluated [146–150]. The studies relating to flood effects on vegetation dealt with flooding risk analysis, assessed on different vegetation types by simulations and models [121,151], by reconstructions of flash floods tree-ring based [152] and by sustainable tools to mitigate urban flood risk [123].

Contrary to our expectations, we found only one article regarding the effects of extreme rainfall events on riparian vegetation. Specifically, Marques et al. [153] evaluated growth trends in riparian tree species, *Alnus glutinosa* (L.) Gaertn. and *Fraxinus angustifolia* Vahl, to assess both their resistance and resilience responses to climate changes. In fact, because of their direct dependence on water, riparian ecosystems display a relatively high level of exposure and sensitivity to changes in climatic conditions. In addition, even though flood inundations hit severely and immediately before all the riparian flora and vegetation, no articles have been found in this regard.

Despite this, the lack of studies on these ecosystems seems to be due to the fact that more attention has been paid to the other types of vegetation, in particular, Mediterranean woodland formations (29 articles), shrubland (12 articles) and grasses (11 articles). Among the Mediterranean woodland formations, plant communities characterized by *Quercus*



sp. were those mainly studied [125,129,133,136,140,143,145,154–158]. The other types of vegetation considered were those including cultivated plants, in particular vine and olive groves [159–166]. These are considered ecosystems with economic and social importance, including their biodiversity and sustainable forest production in these areas; therefore, extremely negative impacts are estimated because of their degradation or loss.

Finally, only three articles concerning alien species resulted among the references found [167–169].

Few articles have been found referring to previous studies regarding the performance of the extreme rainfall events (EREs) on flora and vegetation in the Mediterranean Basin. Among these, articles that analyzed the effects on Mediterranean vegetation in terms of the diversity and resilience to the disturbance due to climate change [170] and the consequences of temperature rising on Mediterranean vegetation, crops and land-use [171]; simulation models were tested to predict changes in Mediterranean plant functional types due to changes in fire recurrence [172] and to predict the response of Mediterranean vegetation characterized by *Quercus suber* L. to global climate changes, especially fires [173]; the effects of water deficits on the physiology and ecology of plants in Mediterranean-type environments [174]; the impacts of global climate change on Mediterranean agriculture [175].

### 3.3. Sardinia as a Study Case

Mediterranean islands are extremely sensitive and exposed to Medicanes [49] including Sardinia. Therefore, we carried out an in-depth analysis on articles concerning rainfall, Medicanes and floods events that have Sardinia as the study site. In Sardinia, there have been records of rainfall and flood events since 1795. However, there is not a complete literature on these events that occurred in Sardinia, even the extreme ones. In recent decades, especially since 1999, Sardinia has been hit by extreme events with a greater frequency, almost annual/biennial. These data, therefore, seem to confirm that there is a strong link between extreme phenomena and global change. Four major catastrophic events in terms of rainfall, flooding and landslides that affected one or more Sardinian areas in this period of time were recorded:

- October 2008: flood in Capoterra (South Sardinia), which affected the Gutturu Mannu River basin, Rio S. Girolamo and Rio Masone Ollastu, as well as Poggio dei Pini village (Capoterra municipality) and the city of Cagliari.
- November 2013: flood in Olbia (North-Western Sardinia) associated with an extratropical cyclone in the western Mediterranean Basin, called “Cyclone Cleopatra”.
- October 2018: flood in Capoterra (South Sardinia), the cities of Cagliari and Capoterra were hit by torrential rains that caused a flood of Santa Lucia River; the same Mediterranean perturbation also affected some localities in the Sarrabus region.
- October 2020: flood in Bitti (North-Eastern Sardinia) caused by a large cyclone that brought heavy rainfall along the Eastern part of the Sardinia region.

Despite all these extreme events, it is noteworthy that the data available on these events come mainly from websites (such as Sardegna Clima Onlus, <https://sardegna-clima.it/>; accessed on 15 December 2021), newspaper articles, and degree theses, while only a few research papers relating to specific extreme weather events have been published. Specifically, such articles concerned the flood of Villagrande Strisaili (Ogliastra) which occurred in 2004 [176,177], the Capoterra flood in 2008 [178,179] and cyclone Cleopatra in 2013 [179–183].

Our bibliographic overview has shown that the number of published papers related to these phenomena is very low. From analysis of articles regarding extreme rainfall events in the Mediterranean Basin with Sardinia as a study area, a total of seven articles were found. Specifically, three of them were climate studies: the first focused on the analysis of the spatial and temporal variability precipitation in Sardinia [184], the second analyzed heavy rainfall events occurred in the Province of Ogliastra in order to improve land use planning and the application of suitable prevention systems [185], and the third assessed the impacts of an extreme flood on the natural and geomorphological heritage in the coastal area [176].

The other four studies concerned the effects of extreme rainfall events on different types of environments and plant organisms: phytoplankton in Cabras Lagoon [122]; Mediterranean holm oak (*Quercus ilex* L.) in the public forest of Marganai [157]; CAM and C3 vegetation in the previously mentioned study published by Cristiano et al. [123]; and assessment of responses of soil in agricultural land-use types in a river basin [121].

#### 4. Conclusions

This review summarizes what has been provided so far in the literature on the effects of extreme rainfall events on the flora and vegetation in the Mediterranean Basin, supplying an in-depth picture of the literature published on this challenging theme.

Taking into account our results, we found that most of the articles published on the effects of extreme rainfall events in the Mediterranean Basin in the last twenty years have focused on the impacts of these phenomena from the climate point of view, in particular, those concerning “Rain/Precipitation”, “Global/Climate change” and “Flood”. Conversely, a limited number of studies have been detected on the effects of extreme events and global change on vegetation. Among the latter, the main types of vegetation investigated were Mediterranean woodland, shrubland, and grasses formations, followed by cultivated plants, in particular vine and olive groves. However, contrary to expectations, we found only one article regarding the effects on riparian vegetation.

In fact, although water and riparian ecosystems show a high level of exposure and sensitivity to changes in climatic conditions, the greatest interest of the scientific community has been directed to the other type of vegetation more common in the Mediterranean Basin and with economic and social importance.

From the point of their geographical distribution, most of the articles related to “Extreme rainfall events” and “Extreme rainfall and floods” referred to the Mediterranean bioregion, of which only a small part focused on the insular Mediterranean bioregion and regarding the same issues already faced for the articles in general. The same topics were recorded for the articles with Sardinian case study, which indicated an increase in extreme events with a greater frequency, almost annual/biennial, in the last two decades.

It is worth highlighting the lack of studies regarding Mediterranean islands, despite the islands’ great value as hotspots of global biodiversity and being in one of the territories most susceptible to climate change in the world. Therefore, these results suggest that further specific studies are needed on the effects of climate change in the Mediterranean Basin, including those concerning the impacts on flora and vegetation and specifically at the islands level. Our analysis highlighted the dramatic lack of studies on the effects of extreme rainfall events on riparian flora and vegetation, which are the first to be abruptly affected by these phenomena. This review constitutes a call for researchers to explore this challenging theme now that extreme phenomena have become extremely recurrent, especially in the Mediterranean Basin.

**Supplementary Materials:** The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/w14050817/s1>, Supplementary S1: Extreme rainfall events; Supplementary S2: Extreme rainfall and floods.

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