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The Impact of Climate Change on Biodiversity: The Ecological Consequences of Invasive Species in Greece

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1 Introduction

1.1 Climate and Biodiversity in Greece

Greece is located between parallels 340 and 420 of the Northern Hemisphere. It is a country in southeastern Europe, situated on the southern tip of the Balkan Peninsula, bordering the eastern Mediterranean. The country covers an area of about 131,000 km^2, the coastline of which extends to 13,676 km and it corresponds to half of the total Mediterranean coastline. The Greek islands are estimated at 2500 from which only 200 are inhabited. The coastal zone includes 85% of the population, 80% of the industry, 90% of the tourism, much of the agriculture and almost all fisheries and aquaculture. A comparison between Greece and Euro-area, follows in Table 1.

The climate of Greece is Mediterranean with mild, rainy winters, relatively warm and dry summers and plenty of sunshine throughout most of the year. Various regions of Greece are characterized by a great variety of climate subtypes, always within the Mediterranean climate. This is mainly due to the topography of the country which has great elevation differences as there are high mountains along the central country. This fact causes significant climatic differences. For example, Eastern Greece has dry climate conditions whereas Northern and Western part of the country is quite humid. It is a fact that big climatic differences still occur in places that are a short distance apart. This creates a special and unique area of interest appearing rarely even in a global scale.

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Table 1 Greece versus Euro-area development indicators (http://data.worldbank.org/)

Factor	Europe	Greece
Cereal yield (kg per hectare)	5898	4404
Foreign direct investment net inflows (percent of GDP)	2.912	1.528
Energy use per units of GDP (kg oil eq./$1000 of 2005 PPP $)	121.681	100.636
Energy use per capita (kilograms of oil equivalent)	3740	2707
CO_2 emissions total (kt CO_2)	2,633,269	97,813
CO_2 emissions per capita (metric tons)	7.991	8.704
CO_2 emissions per units of GDP (kg/$1000 of 2005 PPP $)	259.975	323.591
Population in urban agglomerations >1 million (percent)	17.81	28.89
Nationally terrestrial protected areas (percent of total land area)	15.451	13.833
GDP (Euros)	16.2 trillion	187 billion
GNI per capita (Atlas $)	38,508	27,810
Population growth (annual percent)	0.522439	0.395286
Population	329,523,510	11,237,094
Urban population growth (annual percent)	0.780	0.723
Urban population	241,234,651	6,854,627

Table 2 Climate types of Greece based on Köppen classifications (http://climate-data.org/)

Köppen	Climate classification	Count	Examples
Csa	Hot-summer Mediterranean	5783	Athens, Patras, Larissa
Csb	Warm-summer Mediterranean	808	Karpenisi, Metsovo
Cfa	Humid subtropical	621	Serres, Veria, Naoussa
Cfb	Oceanic	385	Kozani, Florina, Kastoria
BSk	Coldsemi-arid	145	Thessaloniki, Katerini

According to the Köppen climate classification system which considers the average annual and monthly temperatures, the rainfall and the seasonal distribution of precipitation, in Greece the overall climate is Mediterranean (Csa and Csb) which is distinguished in Mediterranean coastal and in inland Mediterranean. Some typical examples illustrating the great climatic differences between Greek regions are presented in Table 2.

The climate in Athens is mild, and generally warm and temperate. The winters are rainier than the summers in Athens. According to Köppen, this climate is classified as Csa. The average annual temperature is 18.1 °C in Athens. About 397 mm of precipitation falls annually. Diagrams with annual temperature and precipitation of Athens, presents in Figs. 1, 2 and 3.

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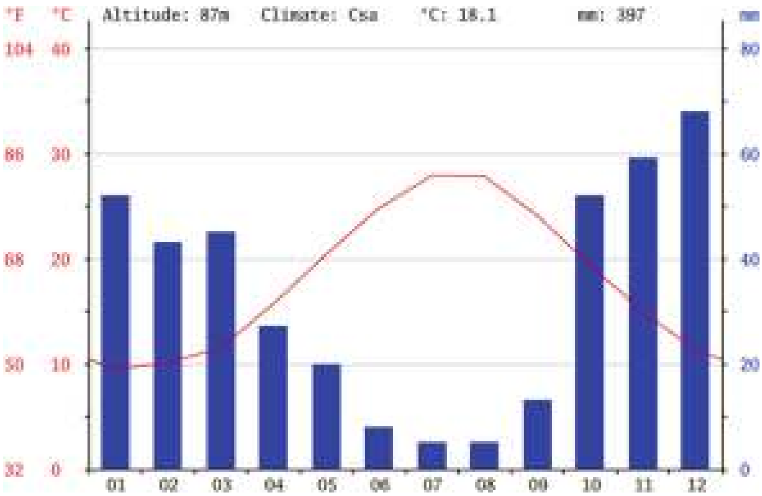

Fig. 1 Precipitation is the lowest in July, with an average of 5 mm. The greatest amount of precipitation occurs in December, with an average of 68 mm (http://climate-data.org/)

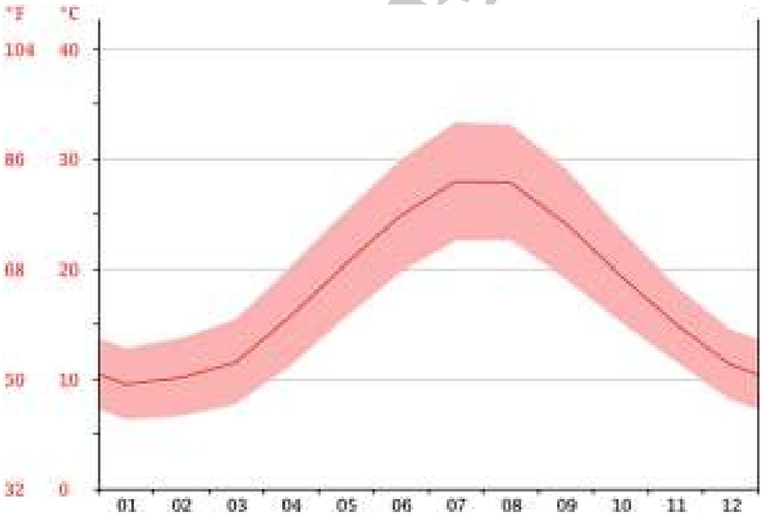

Fig. 2 At an average temperature of 27.9 °C, July is the hottest month of the year. The lowest average temperatures in the year occur in January, when it is around 9.5 °C (http://climate-data.org/)

The climate in Karpenisi (mountainous area) is warm and temperate. The winters are rainier than the summers. The Köppen climate classification is Csb. The temperature here averages 12.0 °C. In a year, the average rainfall is 882 mm. Diagrams with annual temperature and precipitation of Karpenisi, presents in Figs. 4, 5 and 6.

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month	1	2	3	4	5	6	7	8	9	10	11	12
mm	52	43	45	27	20	8	5	5	13	52	59	68
°C	9.5	10.1	11.5	15.7	20.4	24.8	27.9	27.8	24.1	19.4	15.0	11.3
°C (min)	6.3	6.6	7.7	11.2	15.6	19.7	22.5	22.6	19.1	15.2	11.6	8.1
°C (max)	12.8	13.7	15.4	20.2	25.2	29.9	33.3	33.1	29.1	23.6	18.5	14.5
°F	49.1	50.2	52.7	60.3	68.7	76.6	82.2	82.0	75.4	66.9	59.0	52.3
°F (min)	43.3	43.9	45.9	52.2	60.1	67.5	72.5	72.7	66.4	59.4	52.9	46.6
°F (max)	55.0	56.7	59.7	68.4	77.4	85.8	91.9	91.6	84.4	74.5	65.3	58.1

Fig. 3 Between the driest and wettest months, the difference in precipitation is 63 mm. The variation in temperatures throughout the year is 18.4 °C (http://climate-data.org/)

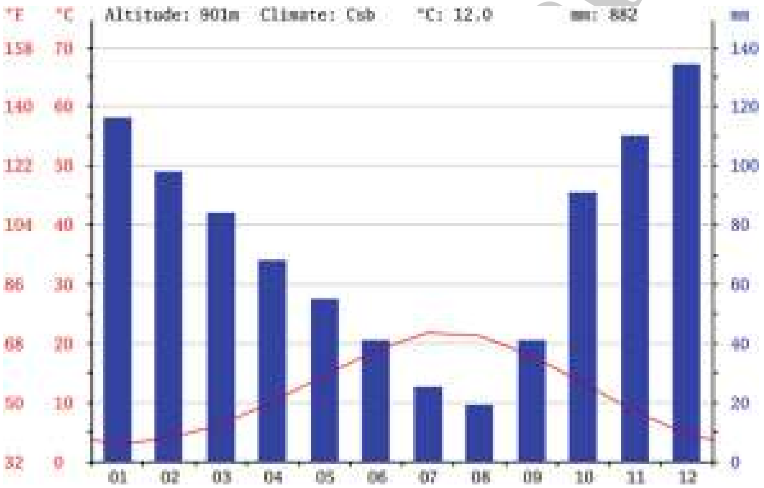

Fig. 4 The driest month is August, with 19 mm of rain. The greatest amount of precipitation occurs in December, with an average of 134 mm (http://climate-data.org/)

In Serres (inland area) the climate is warm and temperate. The is a great deal of rainfall in Serres, even in the driest month. According to Köppen, this climate is classified as Cfa. The average temperature in Serres is 15.1 °C. Precipitation here averages 473 mm. Diagrams with annual temperature and precipitation of Serres, presents in Figs. 7, 8 and 9.

In Florina (highland area) the climate is warm and temperate. There is significant rainfall throughout the year in Florina. Even the driest month still has a lot of rainfall. The Köppen climate classification is Cfb. The average annual temperature in Florina is 11.1 °C. The average annual rainfall is 623 mm. Diagrams with annual temperature and precipitation of Florina, presents in Figs. 10, 11 and 12.

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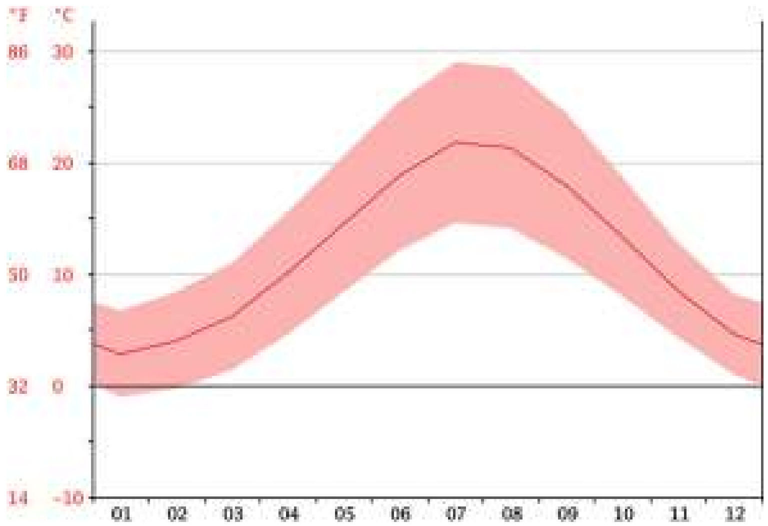

Fig. 5 July is the warmest month of the year. The temperature in July averages 21.8 °C. The lowest average temperatures occur in January, when it is around 2.8 °C (http://climate-data.org/)

month	1	2	3	4	5	6	7	8	9	10	11	12
mm	116	98	84	68	55	41	25	19	41	91	110	134
°C	2.8	4.0	6.2	10.1	14.5	18.8	21.8	21.3	17.9	13.3	8.5	4.6
°C (min)	-1.0	-0.3	1.4	4.6	8.4	12.1	14.6	14.1	11.4	8.0	4.3	1.0
°C (max)	6.7	8.4	11.0	15.6	20.6	25.5	29.0	28.5	24.4	18.7	12.8	8.2
°F	37.0	39.2	43.2	50.2	58.1	65.8	71.2	70.3	64.2	55.9	47.3	40.3
°F (min)	30.2	31.5	34.5	40.3	47.1	53.8	58.3	57.4	52.5	46.4	39.7	33.8
°F (max)	44.1	47.1	51.8	60.1	69.1	77.9	84.2	83.3	75.9	65.7	55.0	46.8

Fig. 6 There is a difference of 115 mm of precipitation between the driest and wettest months. The variation in temperatures throughout the year is 19.0 °C (http://climate-data.org/)

The climate here is considered to be a local steppe climate. In Thessaloniki, there is little rainfall throughout the year. This climate is considered to be BSk according to the Köppen climate classification. In Thessaloniki, the average annual temperature is 15.9 °C. Precipitation here averages 445 mm. Diagrams with annual temperature and precipitation of Thessaloniki, presents in Figs. 13, 14 and 15.

In general, the year can be divided in the cold and rainy season that lasts from mid-October until the end of March and the warm and dry season lasting from April to October. During the first period the coldest months are January and February, where on average the mean temperature ranges at 6.1 °C, whereas the warmest period is the last ten days of July and the first of August, when the average temperature ranges around 24.2 °C. The average monthly temperature for Greece from 1900 to 2015, presents in Fig. 16.

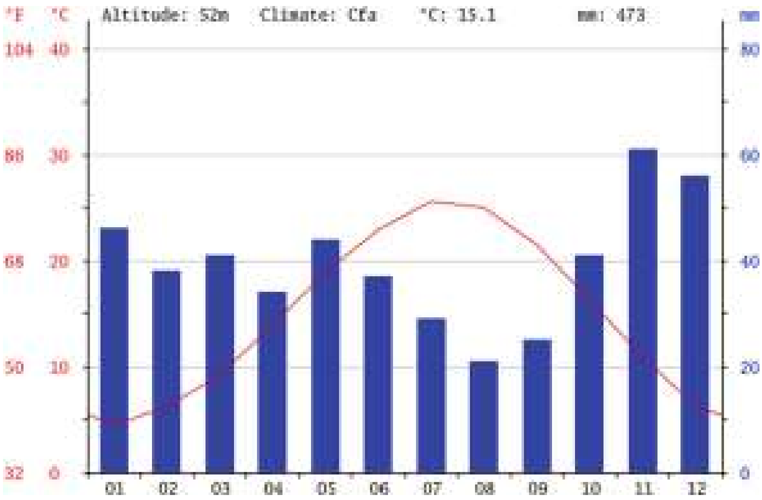

Fig. 7 The driest month is August. There is 21 mm of precipitation in August. The greatest amount of precipitation occurs in November, with an average of 61 mm (http://climate-data.org/)

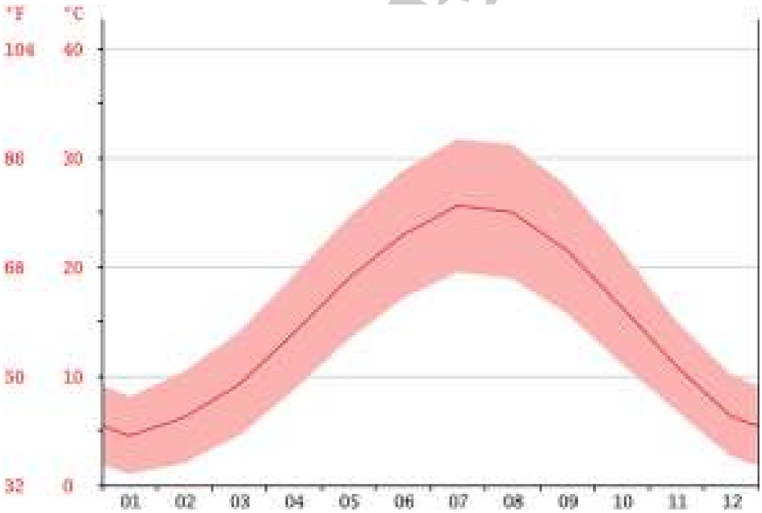

Fig. 8 With an average of 25.6 °C, July is the warmest month. The lowest average temperatures in the year occur in January, when it is around 4.5 °C (http://climate-data.org/)

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month	1	2	3	4	5	6	7	8	9	10	11	12
mm	46	38	41	34	44	37	29	21	25	41	61	56
°C	4.5	6.2	9.2	13.9	18.9	22.9	25.6	25.0	21.5	16.3	10.9	6.3
°C (min)	1.0	2.0	4.5	8.7	13.3	17.1	19.5	18.9	15.7	11.1	6.8	2.6
°C (max)	8.1	10.4	14.0	19.2	24.5	28.8	31.7	31.2	27.4	21.5	15.0	10.1
°F	40.1	43.2	48.6	57.0	66.0	73.2	78.1	77.0	70.7	61.3	51.6	43.3
°F (min)	33.8	35.6	40.1	47.7	55.9	62.8	67.1	66.0	60.3	52.0	44.2	36.7
°F (max)	46.6	50.7	57.2	66.6	76.1	83.8	89.1	88.2	81.3	70.7	59.0	50.2

Fig. 9 The precipitation varies 40 mm between the driest month and the wettest month. The variation in temperatures throughout the year is 21.1 °C (http://climate-data.org/)

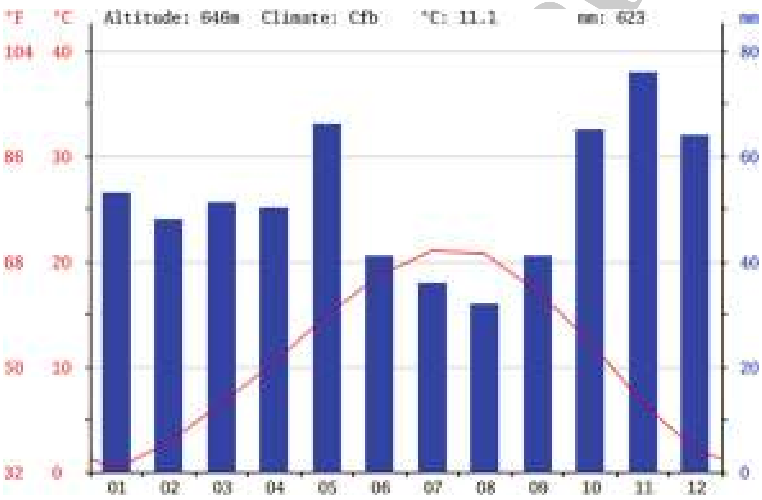

Fig. 10 The driest month is August. There is 32 mm of precipitation in August. Most precipitation falls in November, with an average of 76 mm (http://climate-data.org/)

The rains in the country even in the winter do not last for many days and the sky does not remain cloudy for several consecutive days, as in other regions of the world. Winter storms are often interrupted during January and the first fortnight of February, with sunny days. During the warm and dry season, the weather is stable, the sky is clear, the sun is shining and rapid but short duration storms occur.

During the cold season (in December) the mean average precipitation ranges to 112.6 mm, whereas during the warmer season, namely in August the rainfall level is just 10.4 mm (http://www.worldbank.org/). The average monthly rainfall for Greece from 1900 to 2015, presents in Fig. 17.

Greece is one of the richest European and Mediterranean biodiverse countries, with many endemic species of plants and animals and important habitats. This is due to its geographical position, to its climatic and topographic characteristics, and to its diverse terrain. Another important parameter is the fact that in generally the

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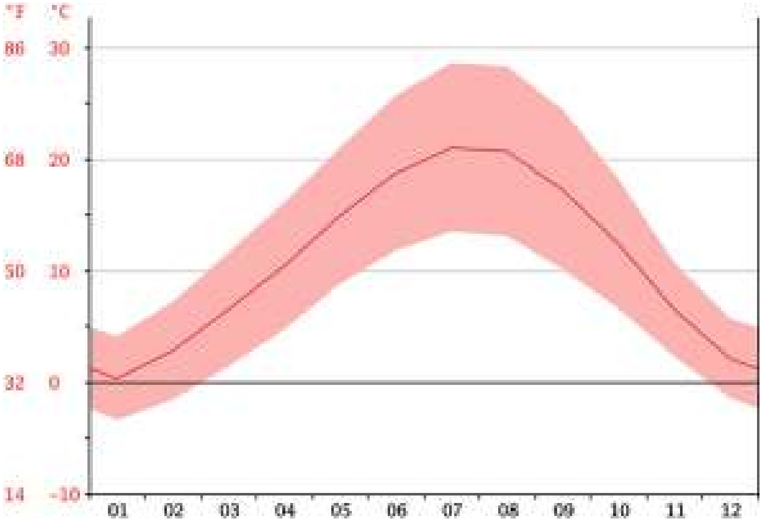

Fig. 11 With an average of 21.0 °C, July is the warmest month. In January, the average temperature is 0.3 °C. It is the lowest average temperature of the whole year (http://climate-data.org/)

month	1	2	3	4	5	6	7	8	9	10	11	12
mm	53	48	51	50	66	41	36	32	41	65	76	64
°C	0.3	2.8	6.5	10.4	14.9	18.7	21.0	20.7	17.2	12.4	6.5	2.1
°C (min)	-3.4	-1.6	1.4	4.7	8.8	11.8	13.5	13.1	10.1	6.6	2.3	-1.4
°C (max)	4.1	7.2	11.6	16.1	21.0	25.7	28.6	28.3	24.4	18.2	10.7	5.7
°F	32.5	37.0	43.7	50.7	58.8	65.7	69.8	69.3	63.0	54.3	43.7	35.8
°F (min)	25.9	29.1	34.5	40.5	47.8	53.2	56.3	55.6	50.2	43.9	36.1	29.5
°F (max)	39.4	45.0	52.9	61.0	69.8	78.3	83.5	82.9	75.9	64.8	51.3	42.3

Fig. 12 The precipitation varies 44 mm between the driest month and the wettest month. The average temperatures vary during the year by 20.7 °C. (http://climate-data.org/)

traditional farming activities cause limited disturbance. More specifically, the total number of species in Greece is estimated approximately to 50,000 whereas the majority of the species are insects.

About 1500 endemic species included among the best known animal groups (Vertebrates, Echinoderms, Molluscs and Orthoptera) have been recorded in a total of 5500 (Endemism 25%) (http://biodiversity.europa.eu/). The major areas of endemism are: Crete, Cyclades, Mountains of mainland Greece and to a lesser extent the Ionian Islands and Peloponnese.

The caves are extremely important for endemism of which only a small percentage has been investigated. Moreover, Greece is home to about 6000 plant species, the largest population of endemic fish fauna species in the Mediterranean

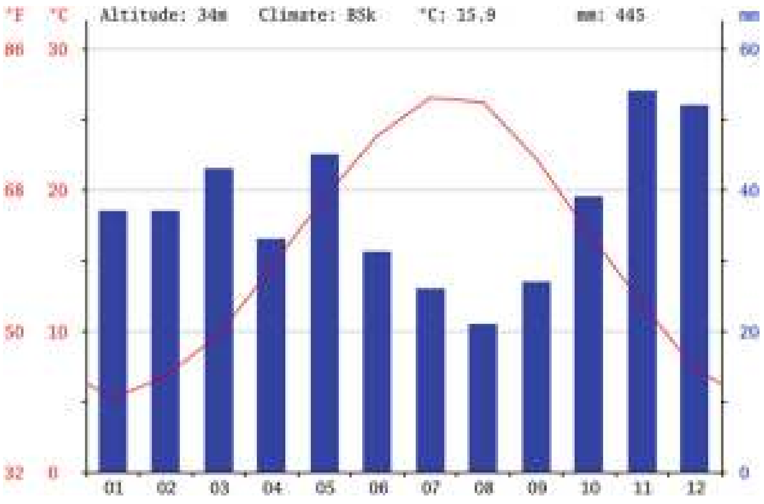

Fig. 13 The driest month is August, with 21 mm of rain. With an average of 54 mm, the most precipitation falls in November (http://climate-data.org/)

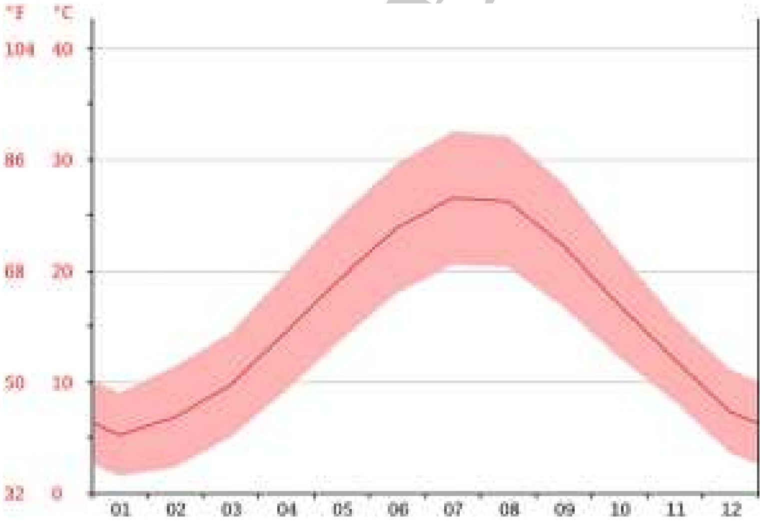

Fig. 14 July is the warmest month of the year. The temperature in July averages 26.5 °C. January has the lowest average temperature of the year. It is 5.2 °C (http://climate-data.org/)

month	1	2	3	4	5	6	7	8	9	10	11	12
mm	37	37	43	33	45	31	26	21	27	39	54	52
°C	5.2	6.8	9.7	14.5	19.4	23.8	26.5	26.2	22.2	16.9	12.0	7.3
°C (min)	1.5	2.3	5.0	9.2	13.8	18.0	20.5	20.3	16.7	12.2	8.2	3.6
°C (max)	9.0	11.4	14.4	19.8	25.0	29.6	32.5	32.1	27.8	21.7	15.8	11.1
°F	41.4	44.2	49.5	58.1	66.9	74.8	79.7	79.2	72.0	62.4	53.6	45.1
°F (min)	34.7	36.1	41.0	48.6	56.8	64.4	68.9	68.5	62.1	54.0	46.8	38.5
°F (max)	48.2	52.5	57.9	67.6	77.0	85.3	90.5	89.8	82.0	71.1	60.4	52.0

Fig. 15 There is a difference of 33 mm of precipitation between the driest and wettest months. During the year, the average temperatures vary by 21.3 °C (http://climate-data.org/)

Fig. 16 Average monthly temperature for Greece from 1900 to 2015 (http://www.worldbank.org/)

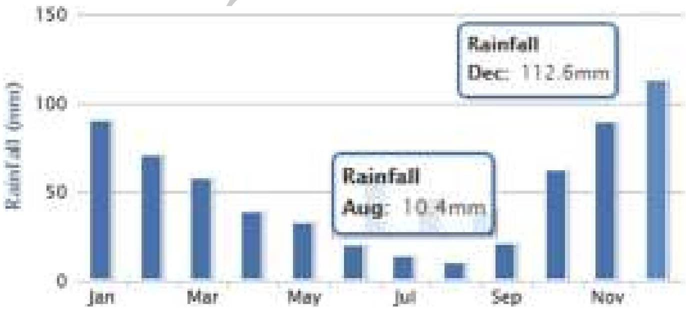

Fig. 17 Average monthly rainfall for Greece from 1900 to 2015 (http://www.worldbank.org/)

ανδ more than 400 species of birds. Though for other organisms (microorganisms, fungi) there are no reliable data, no there are indications that there is a huge variety in the country (http://biodiversity.europa.eu/). The biodiversity of Greece, presents in the Table 3.

Table 3 Biodiversity of Greece (http://biodiversity.europa.eu/)

Species	TAXA	Endemicspecies	Endemic subspecies	Protected	Not protected
Mamals	111	4	35	83	8
Birds	431	0	4	396	1
Reptiles	85	6	71	58	1
Amphibia	21	2	3	18	0
Fish (fresh water)	109	35	16	50	29
Fish (marine)	447	–	–	14	–
Echinoderms	107	–	–	1	–
Orthoptera	365	113	15	11	–
Lepidoptera	3197	142	–	57	39
Hymenoptera	2800	13	–	0	15
Coleoptera	6863	649	–	11	2
Mollusks (land)	763	174	–	24	5

Also as a result of the intense territorial dismemberment and the relatively benign human activities, Greece has a large variety of ecosystems. The most important are those of bush vegetation, the evergreen broadleaved, the phryganic, the coastal and the marine. It should be emphasized that the forest ecosystems of Greece, as in most parts of the Mediterranean region, have been exposed to human activities. This has caused degradation to the coastal forests and forests at low altitude due to urbanization and the conversion to agricultural land.

2 Climate Change and Its Impacts in Greece

By the term "climate change" we refer to serious global average climate alterations that include statistically significant meteorological fluctuations through a large time scale.

Greece due to its geographical position is the point where the climatic conditions favor a variety of activities and is one of the 18 most vulnerable areas of the planet due to climate change. According to climate simulations for the period up to 2100, the results suggest a continuous, gradual and relatively strong temperature increase with a steady decrease in intensity of rainfall.

In the near future (2015–2039) models forecast for Greece an increase in temperature of 1–3 °C and a decrease of in rainfall of the magnitude 5-10%. For the period (2040–2069) it is estimated that the temperature will increase from 3 to 6 °C and the rainfall will be reduced up to 20%. Finally, for the end of the century (2070–2100) the temperature will rise from 6 to 9 °C with a simultaneous reduction of precipitation up to 30%. More specifically, the Intergovernmental Panel on Climate Change (IPCC 2007) A2 scenario, estimates an increase of the greenhouse

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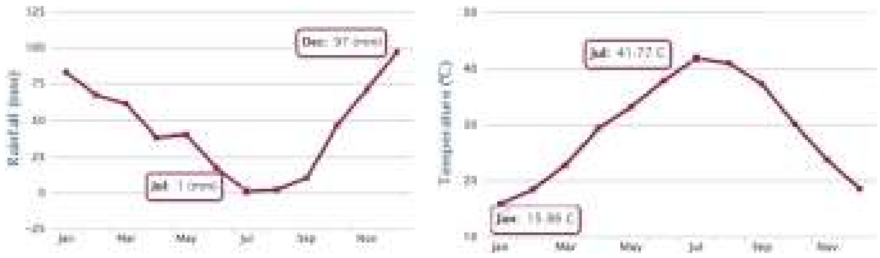

Fig. 18 Minimum monthly rainfall and maximum temperature for Greece from 2015 to 2100 in order to Climate Change Scenario IPCC A2 (http://www.worldbank.org/)

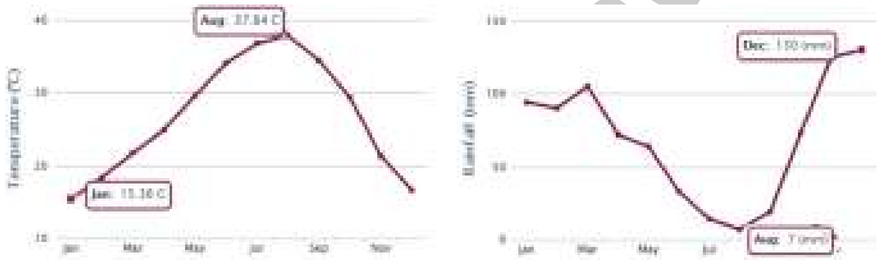

Fig. 19 Minimum monthly rainfall and maximum temperature for Greece from 2015 to 2100 in order to Climate Change Scenario IPCC B2 (http://www.worldbank.org/)

emissions by 250% (compared to the period 1961–1990). This will cause a temperature increase of the magnitude 8–9 °C and rainfall decrease as high as 30%. (http://www.worldbank.org/). Minimum monthly rainfall and maximum temperature for Greece from 2015 to 2100 in order to Climate Change Scenario IPCC A2, presents in Fig. 18.

According to the IPCC B2 scenario, the greenhouse emissions will increase by 62% with a lower temperature of 6–7 °C and rainfall increase higher than 20%. Minimum monthly rainfall and maximum temperature for Greece from 2015 to 2100 in order to Climate Change Scenario IPCC B2, presents in Fig. 19.

Specifically, till mid-century, by warming above 2 °C, the dry areas that are mainly exposed, will particularly suffer from the reduction of water resources, while more hot and dry conditions will result in reduced forest productivity and increased forest fires. There will be changes in algal communities, large dolphin mortality and high insects spreading. The supply of groundwater will be reduced dramatically (by 70%) in southern Greece. The city residents, such as Thessaloniki, Patras, Lamia and Larissa will be subject up to 20 more days of heat per year. Meanwhile, in Lamia, Larissa, Volos, Thessaloniki and Athens, the total annual precipitation will decrease, but extreme rainfall is expected to increase by 10–20%.

The days with heat will increase by 5–15 and there will be a significant increase in the number of nights where the temperature will not fall below 20 °C mainly in islands such as Rhodes or the area of Chania in Crete. Also the ten largest rural prefectures of the country will receive heavy pressure from climate change, thereby increasing the heat days, leading in consecutive days without rain, in reduction of winter rainfall and thus causing a great increase in forest fire risk.

For example, in Evia we will expect more than 25 extra dry days compared to the period 1960 to 2000, Serres and Larissa will live 20 more days of heat, while in the areas of Heraklion and Pella rainfall in winter will decrease by 15% (http://www.worldbank.org/).

Additionally, we expect an overall decrease in the canopy of forests. Also the models forecast a spatial redistribution of species with necrosis of important Scots pine land (*Pinus sylvestris*) and fir (*Abies cephalonica*) and a corresponding invasion of Fir species of conifers (*Abies borissiregis*) and black pine (*Pinus nigra*) in broadleaf forests. It should be noted that the number of forest fires during the summer period and the total burnt area is expected to increase by 10–20% according to the same scenario. This will be due to the rise in temperature and to the corresponding reduction in rainfall, causing additional problems as quantities of timber necessarily remain in the forest after a fire, exacerbate the existing problem of bark eating insect's outbreak, that further degrade the soil quality (http://biodiversity.europa.eu/). Still, the effects of climate change will be significant at different levels of biological organizations and particularly in the variations that occur in habitats and endemic species that appear to be most vulnerable, as they are perfectly correlated with the local climate of their region.

For example, under the assumption of non-immigration the only two endemic species in the country are threatened, namely: The akanthopontikos (*Acomys minous*) and the Cretan shrew (*Crocidura zimmermanni*), as well as the Persian Squirrel (*Sciurus anomalus*) which is the only chipmunk who lives on an island and only appears in Lesvos (http://www.europe-aliens.org/).

According to the climate scenario IPCC A2 the population of the following species will be reduced significantly in Greece. More specifically, the *Quercus ithaburensis* sub macrolepis will be reduced by 56%, the *Matricaria chamomilla* by 88% and the *Sciurus anomalus* by 98%.

On the other hand, according to the scenario IPCC A2 a significant expansion of the brushwood habitat is expected (*Genista acanthoclada* by 386%) and (*Sarcopoterium spinosum* by 198%). This will be done due to the extensive soil degradation caused by climate change combined with the extreme weather phenomena and due to the forest ecosystems destruction caused by forest fires.

The areas mostly at soil degradation and desertification risk are mainly the eastern Central Greece, part of Thessaly, Evia, the Aegean islands, the eastern Peloponnese and part of Macedonia (http://www.cabi.org/cpc/).

Nevertheless, the most important consequences of climate change concerning Greece focus on the rise of sea levels and on the temperature change of surface waters afterthought the occurrence of extreme weather events in the coastal areas. The above may cause permanent flooding of coastal areas, the movement of foreshore areas and beach, coastal erosion from increased wave storms and salinization of coastal groundwater aquifers.

Specifically, according to the scenario IPCCA2, 15% of the coastal wetlands of Greece (about 1000 km^2) is projected to be flooded if finally, the rise level will be as high as 0.5 m by 2100. The coastal wetlands expected to be most affected are the following: The Delta of Evros, Nestos, Axios, Loudias and Aliakmonas rivers, the lagoons of Messolongi and Kyllini and the Bays of Amvrakikos and Pagasitikos.

The availability and water quality of lakes, may be affected significantly. More specifically, a reduction of water surface is forecasted for the lakes of Chimaditis 20–37%, Kerkini 5–14%, Trichonis 10%. Also the concentration of nitrogen will increase by 25%.

Regarding the Aegean Sea, it is expected a warming of the surface waters up to 3 °C, reducing runoff and changes in biochemical and physical properties of sea water, with a significant impact on marine biodiversity, productivity and food webs. This will increase the risk of spreading diseases, toxic bloom of seaweed and dissemination of thermophilic species. Specifically, coastal meadows of the endemic Mediterranean "*Posidonia oceanica*" which are place of nesting and breeding for numerous marine species and play an important ecological role, are particularly vulnerable to extreme weather events such as storms and floods but also to secondary factors such as water pollution. The climate changes of the period up to 2100 and the large amounts of solid and liquid contaminants are expected to pollute the sea, threatening with extinction the certain species.

The potential effects of the phenomena of climate change will lead to the degradation of services provided by ecosystems. As ecosystem services are defined processes and functions provided by the natural environment and benefit the people as the production of food, fuel, fiber and pharmaceuticals, water regulation, air and bioclimate, maintenance of soil fertility, cycle of nutrients (Gallardo and Aldridge 2013). Finally regarding biodiversity, the effects of climate change are multidimensional as they are related to a combination of direct effects on organisms. AQ1

The temperature affects the survival rates, the reproductive success and the dispersion and behavior patterns of the species. Also the effects are related to a combination of biotic interactions, such as the granting of competitive advantage, or they are related to abiotic factors such as bedtime with water or changes in ocean currents, changes in the level of biocoenosis, the extinction of organisms and the appearance of invasive species (Douglas and Gareth 2007).

3 Invasive Species in Greece

The invasive species are non-native, they have no natural predators, they are rapidly spreading and invading the endemic flora and fauna of a place, damaging the natural environment. Their social and economic impacts are considered extremely important on human health, agriculture, fisheries and food production.

Their relocation is mainly because different kinds of species such as birds, reptiles and fish, mollusks, move in search of colder climate conditions, or because their physical environment does not meet the temperature range in which they can survive. Thus they follow different kinds plants or organisms that migrate to colder climates. Excluding the human factor that may cause accidental or deliberate movement of alien species in locations that are hundreds of kilometers from their natural habitat, these non-native species adapt poorly to their new environment and most often they quickly vanish. The largest spreading factor for invasive species is the climate change, which drops the physical barriers due to which the peripheral distinct flora and fauna was developed (http://www.cabi.org/cpc/).

It is noteworthy that this migration of non-indigenous species represents one of the most serious threats to global biodiversity because they deprive from indigenous species, resources and living space. In Europe there are 10,822 non-native species under the Delivering Alien Invasive Species Inventories for Europe (DAISIE) of which 427 are invasive and pose a very serious threat to natural biodiversity as they compete aggressively with native organisms for food and habitat, they are changing the ecosystems structure by hybridization with native species, by direct toxicity and by disruption of pollination, either because they are a source of pests or pathogens and disease carrier (Keller et al. 2009). Cumulative number and groups of alien invasive species, presents in Figs. 20 and 21.

In Greece there are respectively 140 invasive species recorded, of which 48 are Alien, whereas for 9 of them the Biostatus is not specified and 91 are characterized as Native ones. A detailed presentation of the individual items by category, is given in the following diagrams (Figs. 22, 23 and 24) (http://www.cabi.org/cpc/).

The analysis of these invasive species under the habitats in which they live but also based on their taxonomic species, are presented in the following Tables 4 and 5 (http://www.cabi.org/cpc/).

Fig. 20 Cumulative number of alien species established in terrestrial environment in Europe (http://www.europe-aliens.org/)

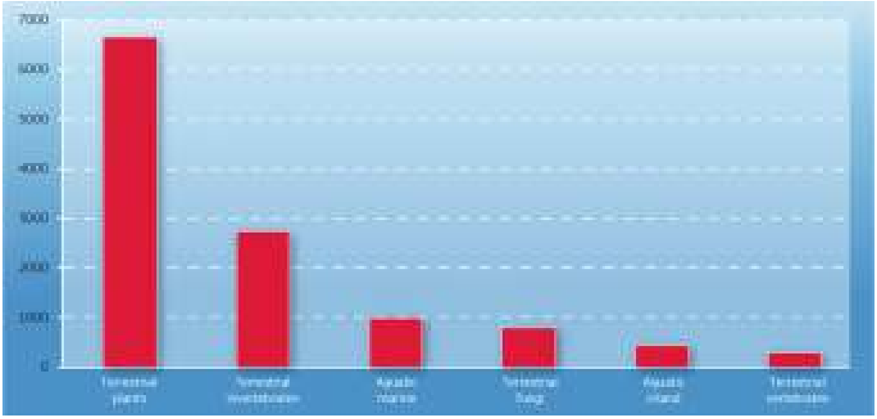

Fig. 21 Groups of invasive alien species in Europe (http://www.europe-aliens.org/)

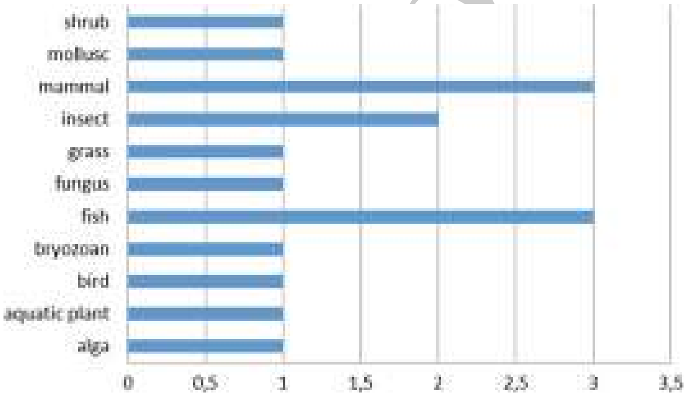

Fig. 22 Distribution of various invasive alien species types (http://www.cabi.org/cpc/)

The invasive species interactions with their new ecosystems are quite complex. Also their global identification and classification based on the determination of their level of threat for a local environment is a very difficult task. For these reasons the Invasive Species Specialist Group (ISSG) of the Species Survival Commission (SSC) of the International Union for Conservation of Nature (IUCN), has constructed a list of the 100 worst invasive species on the planet (Luque et al. 2014), as you can see in Fig. 25. In this list there are species that are already globally widespread, others that can cause cumulative visible damages and others that are currently limited to a few parts of the world but they can have very high potential expansion and biological adaptation possibilities in new environments (Lowe et al. 2000).

It is extremely interesting the fact that 32% of the Invasive Species recorded in Greece are included in the list of the 100 worst invasive species on the planet. Of

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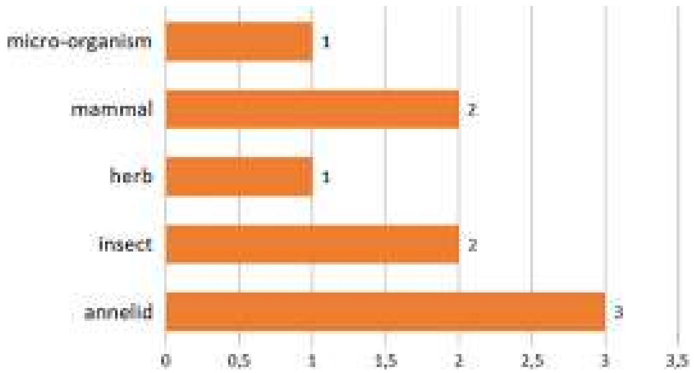

Fig. 23 Distribution of various biostatus not specified invasive species (http://www.cabi.org/cpc/)

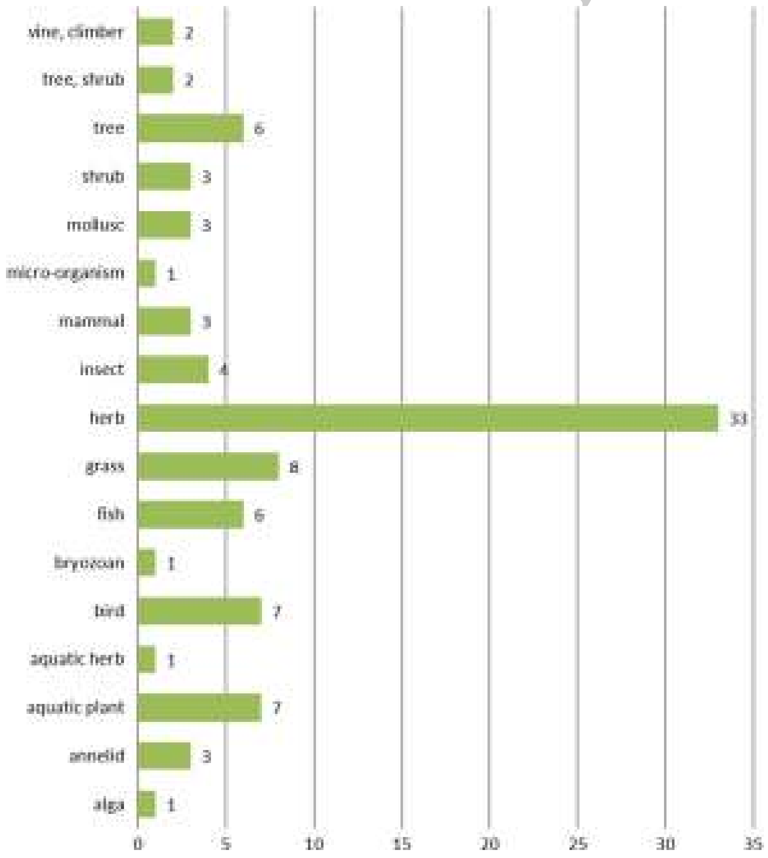

Fig. 24 Distribution of various native invasive species (http://www.cabi.org/cpc/)

Table 4 Invasive species in Greece by habitats (http://www.cabi.org/isc/)

Species	Invasive alien species	Not specified	Native species
MarineHabitats	1	–	1
EstuarineHabitats	12	1	12
Lakes	14	–	18
WaterResources	15	–	21
Wetlands	10	–	20
RiparianZones	12	1	24
Coastland	18	1	15
UrbanAreas	13	1	26
Agricultural Areas	15	3	40
Ruderal/Disturbed	17	2	45
PlantedForests	13	1	14
NaturalForests	13	–	23
Scrub/Shrublands	13	1	18
Range/Grasslands	13	1	34
Tundra	–	1	–
Desert	3	–	4
Ice	–	1	1
Host	3	–	1
Vector	–	1	1

Table 5 Invasive species in Greece by Taxon (http://www.cabi.org/isc/)

Species	Invasive alien species	Not specified	Native species
Micro-Organism	–	1	1
Fungus	3	–	–
Insect	7	1	4
Mollusc	3	–	3
Alga	2	–	1
Bryozoan	2	–	1
Annelid	–	1	3
CombJelly	1	–	–
Fish	16	–	6
Amphibian	1	–	–
Bird	1	–	7
Mammal	5	1	3
AquaticPlant	1	–	3
Tree	2	–	8
Shrub	3	–	5
Grass	2	–	8

(continued)

Table 5 (continued)

Species	Invasive alien species	Not specified	Native species
Sedge	1	–	–
Herb	4	1	34
Vine, Climber	1	–	2
Succulent	1	–	–
Oomycete	1	–	–

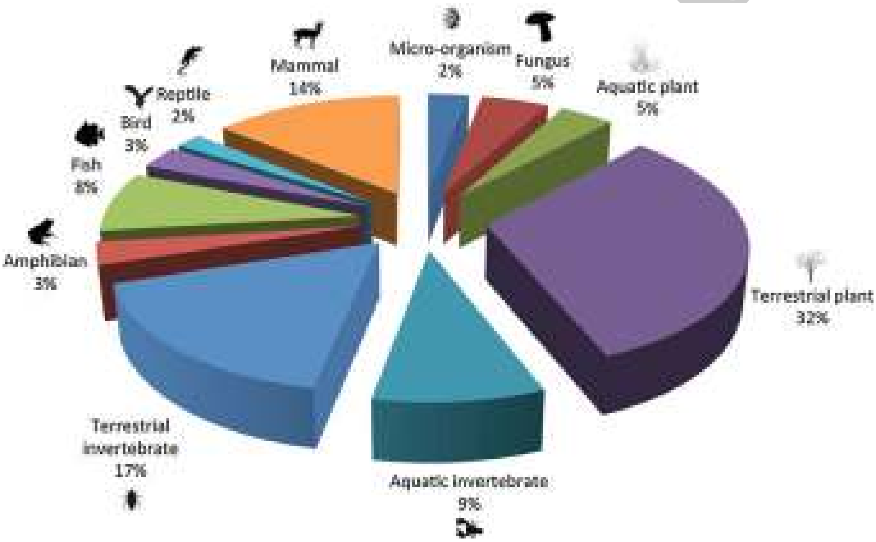

Fig. 25 Taxonomy of 100 of the world's worst invasive alien species (http://www.cabi.org/cpc/)

these, only 5% are Native Species whereas the remaining 27% are Invasive Alien Species (http://www.cabi.org/cpc/).

4 Invasion of Alien Species in Greece and Climate Change Scenarios

Climate change in Greece and in particular the increase in the average temperature, the variability of rainfall (in terms of frequency and intensity) the increase of the greenhouse gases concentrations, the increased frequency and intensity of storms and the rising of sea levels, have a catalytic effect on the potential of invasive species and they create suitable conditions for this problem.

The decreasing rainfall and the increasing temperatures in southern Greece, significantly contribute to higher forest fires frequencies by 20–34% (Moriondo et al. 2006). The large number of forest fires converts the high forests in the undergrowth, which radically changes the local ecosystems, with significant consequences for biodiversity management strategies (Masters and Norgrove 2010).

The changes provided by the IPCC climate change scenario A2, will create a chain reaction in the Greek local ecosystems and especially in the environmental micro-diversity, resulting in mosaic distributions of invasive species.

It should be emphasized that it is extremely difficult to predict the size of the invasion and spread of these species, the location of the boundaries and the changing patterns of abundance in them, as well as the direct effect of micro-environmental conditions that will prevail, regarding the survival factors, the reproduction and further dispersion. What may albeit confidently predicted is that there will be variation in the abundance and distribution in relation to time, which reflects the temporal variation of parameters of the environmental niche. It is certain that in short periods of time the populations and the newly-arrived species will exhibit variations in their abundance whereas for longer periods they may appear stable or they may have a periodic growth cycle (Silva et al. 2013).

Attempting a thorough approach of possible spatial patterns related to the invasive species in Greece, the most prevalent versions are the following three:

- Invasion serially correlated with the space, i.e. when the invasions are most similar in areas nearby. This happens when an invasion reflects the suitability of the local environment and if the parameters of the environmental niche, exhibit spatial autocorrelation. Exemplifies invasive species that may use this type of invasion in the near future is the ostarkodermo *Cerco pagispengoi*. It is included in the list of the 100 worst invasive species on the planet (Zenetos et al. 2006). Is a competitor to other plankton fed invertebrates and smaller fish. It breeds in large numbers against the zooplankton it blocks fishing nets and trawls and is generally associated with serious economic consequences. It is spot in Turley, under a BS—Steppe climate. The favorable annual precipitation is between 430 and 860 mm. Corresponding climate in the immediate area if found in east Macedonia and Thrace, which creates spatial invasion conditions in these Greek regions.
- Invasion ranging systematically, near the borders of a species expansion geographical area. In other words, limited invasion appears to the boundaries of the invasion area, reflecting the fact that in this place there are usually unfavorable parameters. Example of such a case is the species *Trogoderma granarium*, which is considered one of the most serious pests of grain, which also can affect oilseeds and oilcake. It is currently located on the northern border of Greece and in particular in Albania and Fyrom, while the basis of climate change is likely to invade the regions of western Macedonia and Epirus in Greece.
- Invasion above the limits of the geographical range of a species (if the spread limits are determined by a single parameter of the environmental niche that suddenly becomes unfavorable). An example of such an invasion is the mollusk *Musculista senhousia*. It will happen if the surface water temperature in the

Aegean rises by 2 °C, which is certain based on forecasting for the period 2040–2050 (Weber 2003).

In summary, it should be noted that taking into account only environmental and climatic factors for the period up to 2100, over 25 invasive species are expected to invade Greek territory, creating serious problems to the native ecosystem with incalculable socio-economic consequences.

5 Discussion

Climate change is recognized as an additional threat to biodiversity, both in terms of the habitats and the ability of species to survive. It is obvious that due to the special landscape of Greece and because of its geographical location, ecosystems of the country would be substantially affected by the constant increase in the average temperature, the more frequent occurrence of extreme weather events, by the changes in precipitation and by the potential reduction of the quantities of available water.

Preventive measures should be initiated in order to investigate and identify those that exist already in the country (Demertzis and Iliadis 2015). This might help towards spread avoidance (bio-security). Therefore, citizens and authorities' awareness in matters related to alien and invasive species is absolutely necessary. Additionally, addressing impacts in biodiversity requires monitoring, early detection, long-term control, consequences containment measures and effective application of the international conventions.

In situations where biodiversity has been affected by invasive species, measures and actions should be imposed. The aim will be the preservation and restoration of healthy ecosystems in order to enhance their capability to withstand the pressure of climate change and thus to halt the loss of biodiversity due to this cause.

Generally, as a basic precaution, measures should be promoted, capable of addressing climate change. The healthy ecosystems can perform functions related to the regulation of climate. For example, forests, seas and wetlands can contribute to carbon sequestration and they can help towards the reduction of carbon dioxide concentrations and other greenhouse gases in the atmosphere.

6 Conclusions

Climate change will have significant negative impacts on several sectors in Greece, with agriculture, forestry, fisheries, tourism, transport, coastal activities and the urban built environmental expected to be affected by the rise in temperature, drought, extreme weather events and sea level rise. These impacts will lead to reduced productivity, loss of capital and additional expenditure for damage repair. Negative impacts will also affect biodiversity, ecosystems and health.

Also, climate change will disrupt ecosystems due to the invasion of new species. This problem has already been detected especially in marine and terrestrial ecosystems. This paper deals with the climate change impacts on the biodiversity of ecosystems and it presents a spatio-temporal analysis and recording of the invasion of alien invasive species in the flora and fauna of the Greek territory. It also discusses future invasions based on likely climate change scenarios. The study produced projections for Greece, in a detailed geographic breakdown up to the year 2100.

Species abundance is expected to decrease in Southern Europe, in parts of the Iberian Peninsula, Italy and Greece, and species distribution will depend on habitat suitability. It has been recorded that 60 of the 127 native freshwater fish (about 47%) found in Greece are threatened by climate change. With regard to Greece's forest ecosystems, climate change is expected to lead to a contraction in distribution of cold temperate conifers (spruce, forest pine, etc.) and to warm temperate conifers invading into deciduous oak forests. Turning to wetlands, several ephemeral ecosystems are expected to disappear, while other permanent ones will shrink (http://www.bankofgreece.gr/).

The success for biodiversity conservation and adaptation to climate change will require good cooperation between the government and various stakeholders at local and national level, as well as providing guidelines for those who make the decisions.

It is important, in further examining the impact of anthropogenic climate change, to take the sectoral studies deeper, by disaggregating their analysis by geographical area and focusing on the more vulnerable areas and the more vulnerable social groups. Pursuing this research in greater depth, enlarging its scope and disseminating its findings could all contribute decisively to creating a "critical mass" in society, which would, whenever necessary, push for proper policy decisions on climate change on the basis of long-term planning, and not in a myopic manner dictated by short-term political cost-benefit considerations, which would only multiply the burden on future generations.

The present study does not examine issues related to the distributional effects of climate change and of the mitigation and adaptation policies. The impact of climate change has social dimensions which deserve to be explored, especially as regards possible increases in poverty and migration, given that the effects of climate change and of policy responses to it will be most strongly felt by the lower-income population groups, which lack the necessary resources to address the problems caused by climate change and to finance measures for emission abatement and adaptation. Specific policies will be needed to avert the exclusion of any social groups from access to clean energy and technologies and to ensure adequate protection against damage from climate change.

Future studies will have to look deeper into the fundamental strategic question of how dealing with climate change and reducing invasions of alien species can help boost growth in all sectors of the economy. This opportunity, if properly seized, could help reduce the costs of the mitigation and adaptation policies. New technologies, new activities, new standards, need to become the focus of the new growth effort aiming at a high-biosecurity economy and protection against possible climate change-induced damage.

Finally, the continuation of this project will provide both a challenge and an opportunity to improve the mathematical or fuzzy models of integrated assessment and to incorporate re-distributional effects, uncertainty and non-linear modes of the ecosystems' response to climate change.

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