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Estimating soil erosion in Natura 2000 areas located on three semi-arid Mediterranean islands

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Abstract

A major initiative in Europe is the protection of its biodiversity. To accomplish this, specific areas from all countries of the European Union are protected by the establishment of the "Natura 2000" network. One of the major threats to these areas and in general to ecosystems is soil erosion. The objective of this study was to quantitatively estimate surface soil losses for three of these protected areas that are located on semi-arid islands of the Mediterranean. One Natura 2000 area was selected from each of the following islands: Sicily in Italy, Cyprus and Rhodes in Greece. To estimate soil losses, Gerlach troughs were used. These troughs were established on slopes that ranged from 35-40% in four different vegetation types: i) *Quercus ilex* and *Quercus rotundifolia* forests, ii) *Pinus brutia* forests, iii) "Phrygana" shrublands and iv) vineyards. The shrublands had the highest soil losses (270 kg ha^{-1} yr^{-1}) that were 5-13 times more than the other three vegetation types. Soil losses in these shrublands should be considered a major concern. However, the other vegetation types also had high soil losses (21-50 kg ha^{-1} yr^{-1}). Conclusively, in order to enhance and conserve the biodiversity of these Natura 2000 areas protective management measures should be taken into consideration to decrease soil losses.

Key words

Conservation, Mediterranean islands, Natura 2000 areas, Soil erosion

Introduction

Successful protection of biodiversity prerequisites the minimization of major risks such as soil loss. Ecosystems with high biodiversity typically have vigorous vegetative cover that prevents soil erosion (Perry, 1994). However, accelerated surface soil erosion can reduce soil quality and threaten the stability of ecosystems by diminishing the diversity of plants, animals and microbes (Pimentel *et al.*, 1995; Altieri, 1999). This interrelationship indicates that it is essential to evaluate if soil loss is a major risk with regard to the effective conservation of the Natura 2000 areas.

The Natura 2000 network has been established by the European Union (EU) with the goal to conserve and protect its biodiversity, while also ensuring the sustainability of Europe's agriculture as well as its energy and transport policies (European Commission, 2007). This however, is quite difficult to be accomplished because the goals of conserving biodiversity and the goals of production (*e.g.* agriculture) can be conflicting (Henle *et al.*, 2008). Currently, the network has nearly 26,000 protected areas with a total area of more than 850,000 km^2 that protect 200 habitat types and over 1,000 rare and threatened animal and plant species (European Commission, 2009).

While erosion is a natural phenomenon, human activities have accelerated soil erosion worldwide, especially since the beginning of the 19th century (Bakker *et al.*, 2008; Dotterweich, 2008). The driving force of these activities is mainly the world's rapid population growth that has led to the conversion of thousands of hectares of natural ecosystems to agricultural land-uses. In addition, urbanization and human infrastructures (eg. roads, bridges) have also been detrimental to the environment. These activities have resulted in substantial changes of the natural vegetation cover that lead to soil erosion levels that exceed soil formation (soil forms slowly) worldwide, indicating that these land-uses are unsustainable.

Kosmas *et al.* (2002) stated that the Mediterranean region has been impacted by humans more than any other region in the world. These impacts are evident in the few remaining patches of natural forests and other ecosystems in the region, as well as in the agricultural lands of the region that cannot sustain cultivation anymore. In addition, the semi-arid and arid environments of the Mediterranean region, due to limited water availability, especially during the xerothermic periods, limit vegetation growth and cover. Consequently, this results in large unprotected areas vulnerable to intense precipitation events that lead to accelerated soil erosion. Keeping these facts in mind, the objective of this study was to evaluate the risk of surface soil erosion in Natura 2000 areas on semi-arid islands of the Mediterranean region by means of quantitative measurements.

Materials and Methods

Study areas: The research was conducted on three Mediterranean islands: Sicily, Cyprus and Rhodes (Fig. 1). Sicily is an island of Italy, located approximately at the center of the Mediterranean Sea, while Cyprus is located at the Eastern Mediterranean Sea close to the Middle East region. Finally, Rhodes is a Greek island located in the Southeastern Aegean sea. All three islands are characterized by semi-arid environments and have several Natura 2000 areas. For this project, the Bosco di Sant' Andriano (Code ITA020025) in Sicily (Fig. 1a), the Ethniko Dasiko Parko Troodos (Code CY5000004) in Cyprus (Fig. 1b) and the Akramytis, Armenistis, Attavyros Remata and Thalassia Zoni (Karavola-Ormos Glyfada) (Code GR4210005) in Rhodes (Fig. 1c) were selected.

The *Bosco di Sant' Andriano* in Sicily has an average height of 700 m and covers an area of 6,824 ha (Brullo and Spampinato, 1990). The annual temperature ranges from 12 to 18 °C and the annual precipitation ranges from 600 to 1,000 mm. The main forest types are *Quercus ilex* and *Quercus rotundifolia* (Habitat type 9340) with small pockets of *Olea* spp. and *Ceratonia* spp. (Habitat type 9320) and galleries of *Salix alba* and *Populus alba* (Habitat type 92A0).

The *Ethniko Dasiko Parko Troodos* in Cyprus occupies 9,033 ha that extends from 700 to 1,952 m (Kazana *et al.*, 2008). The climatic conditions vary due to the elevation difference. Annual

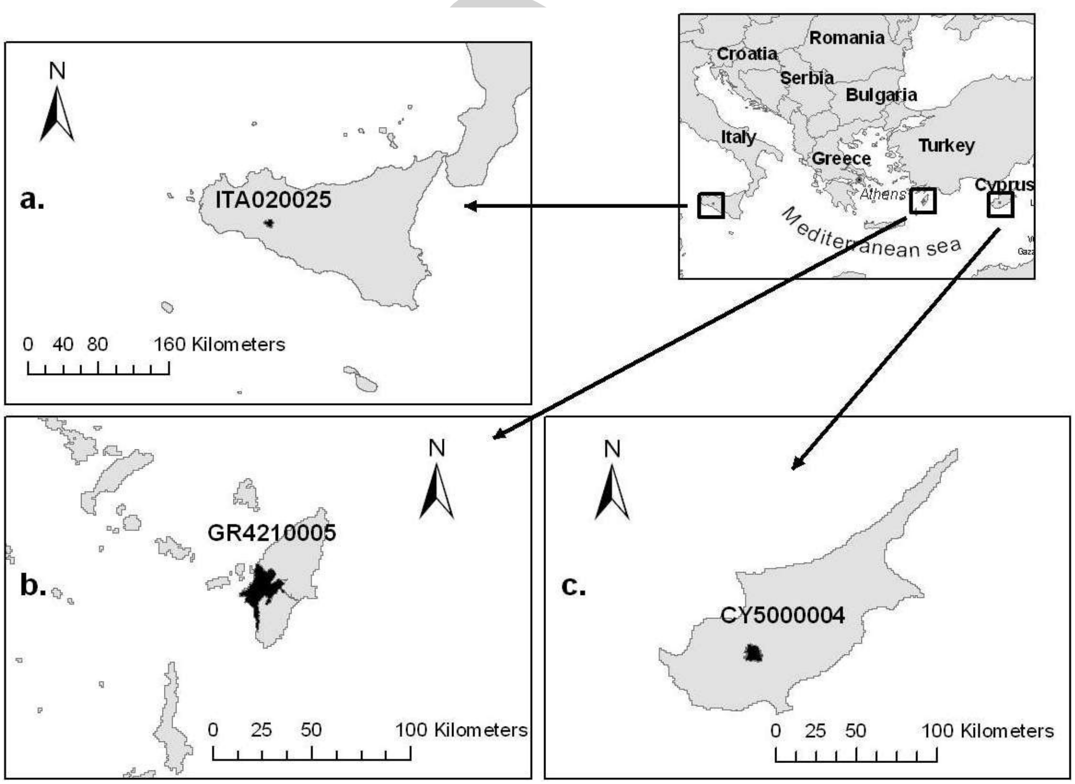

Fig. 1: The three Natura 2000 study areas (in black): (a) Bosco di Sant' Andriano (ITA020025) in Sicily, Italy, (b) Ethniko Dasiko Parko Troodos (CY5000004) in Cyprus, (c) Akramytis, Armenistis, Attavyros Remata kai Thalassia Zoni (Karavola-Ormos Glyfada) (GR4210005) in Rhodes, Greece (graph by George Mallini)

temperature ranges from -3 to 25°C and annual precipitation ranges from 750 to 1,064 mm. Snowfall is common during winters. The dominant forest types are *Pinus brutia* (Habitat type 9540), *Pinus nigra* var. *pallasiana* (Habitat type 9536) and *Juniperus foetidissima* (Habitat type 9563) that occur in pure or mixed stands. There are also a number of different shrub and herbaceous habitat types.

The *Akramytis, Armenistis, Attavyros Remata kai Thalassia Zoni (Karavola-Ormos Glyfada)* in Rhodes, Greece has an area of 27,696 ha. It covers the Attavyros mountain, all the way down to the shoreline (Kazana *et al.*, 2008). The annual temperature ranges from 12 to 27°C and the annual mean precipitation is 690 mm. The main forest type is *Pinus brutia* (Habitat type 9540). There are also degraded *Quercus coccifera* forests (Habitat type 6310), pockets of *Cupressus sempervirens* (Habitat type 9290) and woody shrubs, the "*Phrygana*" (Habitat type 5420). The dominant herbaceous vegetation is *Sedum* spp. (Habitat type 8230).

Soil erosion measurements: For soils that are not ploughed (Lopez-Bermudez, 1990) Gerlach troughs (Gerlach, 1967) are commonly used to determine erosion worldwide (James and Alexander, 1998; Tropeano, 1983; Vigiak *et al.*, 2006). The trough is an aluminum gutter 0.5 m long and 0.1 m broad that is connected with a hose to a 20 l bucket (Fig. 2). The gutter has a movable lid to protect it from direct precipitation and to easily remove the sediment that is collected in it. The hose prevents overflow of the trough during intense precipitation events and moves the runoff into the bucket. Soil loss was estimated by the amount of eroded soil that is collected in the trough, while surface runoff by the water collected in the bucket. The precipitation amounts and intensities were collected from the closest meteorological stations to the troughs. These were the meteorological stations: i) near Burgio, Siciliy, Italy, ii) near Attaviros, Rhodes, Greece and iii) on Troodos mountain, Cyprus.

Each trough was placed in an experimental plot (dimensions 10 x 5 m). Three variables were considered to determine the location of the plots. The first variable was the vegetation type. In the Bosco di Sant' Andriano, the plots were placed only in the *Quercus ilex* and *Quercus rotundifolia* forests that covered approximately 37% of the area. In the Ethniko Dasiko Parko Troodos, the plots were placed only in the *Pinus brutia* forests that covered approximately 45% of the area. The other land-uses in both of these Natura 2000 areas covered less than 13% of the total area. The plots were placed in the dominant vegetation type, to evaluate if surface soil erosion was a risk for the dominant vegetation type of these areas. In the Akramytis, Armenistis, Attavyros Remata kai Thalassia Zoni (Karavola-Ormos Glyfada) the experimental plots were placed in three different vegetative types: i) *Pinus brutia* forests, ii) "Phrygana" (low woody Mediterranean shrubs) and iii) vineyards. In this case, surface soil erosion was evaluated as a risk for the dominant forest type (occupying 34% of the area), shrub type (occupying 5% of the area) and the most common human land-use of the protected area. The second variable was slope because it highly influences surface runoff and soil erosion. All experimental plots had slopes ranging between 35-40%. This slope is considered severe but is very common in all of these Natura 2000 areas. Finally, all the experimental plots were placed between 650-800 m in order to have similar climatic conditions and similar levels of human activities.

In each Natura 2000 area, three Gerlach troughs were placed, for a total of nine troughs. The Bosco di Sant' Andriano and the Ethniko Dasiko Parko Troodos had all three troughs placed in plots in the dominant vegetation type. In the Akramytis, Armenistis, Attavyros Remata kai Thalassia Zoni (Karavola-Ormos Glyfada) only one trough was placed in each of the three selected vegetation types. All Gerlach troughs were left in the field for 1 yr. After every precipitation event, the sediment in the trough and the water in the bucket were collected. In this study, to estimate yearly surface runoff and soil losses, only the 20 most intense precipitation events that produced the greatest surface runoff and soil losses were used. The same number of events was used in all areas in order to compare the surface runoff and soil losses among the three Natura 2000 areas.

Results and Discussion

All Natura 2000 areas had similar yearly precipitation amounts, particularly the Bosco di Sant' Adriano and the Ethniko Dasiko Parko Troodos (Table 1). The Akramytis, Armenistis, Attavyros Remata kai Thalassia Zoni (Karavola-Ormos Glyfada) had less precipitation by approximately 70-90 mm than the other two areas. The Ethniko Dasiko Parko Troodos had the highest precipitation intensity event (Table 1). Its maximum precipitation intensity event was more than double of the other two areas. The Bosco di Sant' Adriano and the Akramytis, Armenistis, Attavyros Remata kai Thalassia Zoni (Karavola-Ormos Glyfada) had similar maximum precipitation intensity events.

The surface runoff of the plots in the natural vegetation types were positively correlated with the yearly precipitation amounts (Table 1). The Ethniko Dasiko Parko Troodos had the most runoff followed by the Bosco di Sant' Adriano. The two plots in natural vegetation types of the Akramytis, Armenistis, Attavyros Remata kai Thalassia Zoni (Karavola-Ormos Glyfada) had the least. Surprisingly, the plot in the "Phrygana" shrublands had less runoff than the plot in the *Pinus brutia* forests, even though the forests had a denser canopy cover and litter layer. The plot in the vineyards had the second highest runoff. The vineyards surface runoff was almost as high as that of the plots in the Ethniko Dasiko Parko Troodos. This was probably because of the minimal litter layer and soil vegetation cover in the vineyards compared to the natural vegetation types.

The plot in the "Phrygana" shrublands in the Akramytis, Armenistis, Attavyros Remata kai Thalassia Zoni (Karavola-Ormos Glyfada) had the highest soil losses despite the fact that it had the least runoff (Table 1). The soil losses were 5-13 times higher than the other three vegetation types. The soil in this area was highly erodible. Biological and physical soil weathering was visually evident. Soil creep (Kirkby, 1967) was observed frequently even

Table - 1: Annual surface runoff and soil losses for the three Natura 2000 areas. The three areas were on the Mediterranean islands of Sicily in Italy (Bosco di Sant' Adriano), Cyprus (Ethiko Dasiko Parko Troodos) and Rhodes in Greece [Akramytis, Armenistis, Attavyros Remata kai Thalassia Zoni (Karavola-Ormos Glyfada)]. The table also includes the vegetation type and precipitation characteristics for the year the data were collected

Natura 2000 area	Vegetation types	Precipitation events (#)	Trough (#)	Precipitation amount[1] (mm yr^{-1})	Precipitation intensity[1] (mm hr^{-1})	Runoff[2] (kg ha^{-1} yr^{-1})	Soil losses[2] (kg ha^{-1} yr^{-1})
Bosco di Sant' Adriano	*Quercus ilex* and *rotundifolia* forests	20	3	1048	3.1-10.0	36 (4)	50 63
Ethniko Dasiko Parko Troodos	*Pinus brutia* forests	20	3	1073	49.-22.1	42 (34)	21 32
Akramytis, Armenistis,	"Phrygana" shrublands[3]	20	1	980	2.9-9.1	22 (25)	270 (420)
Attavyros Remata kai	*Pinus brutia* forests	20	1	980	2.9-9.1	27 (41)	21 (12)
Thalassia Zoni (Karavola-	Vineyards	20	1	98	2.9-9.1	40 (25)	30 (16)

[1] = The precipitation data were collected from the nearest meteorological station, [2] = The standard deviations are included in the parenthesis, [3] = Low woody shrubs of Mediterranean species

Table - 2: Annual soil losses for different land-uses in the European Mediterranean region, reported by other researchers.

Vegetation type / land-use	Soil loss (kg ha^{-1} yr^{-1})	Reference
Shrublands (Maquis)	204	Arhonditsis *et al*., 2000
Cultivated olive groves	65	
Grazed olive groves	55	
Abandoned olive grove for 5 years	30	
Abandoned cultivation fields for 1 year	24	Francis, 1990
Abandoned cultivation fields for 2 years	32	
Abandoned cultivation fields for 5 years	41	
Abandoned cultivation fields for 20 years	19	
Cultivated olive groves with slope 25%	12	Koulouri and Giourga, 2007
Cultivated olive groves with slope 40%	54	
Abandoned olive groves for 5 years with slope 25%	19	
Abandoned olive groves for 5 years with slope 40%	69	
Abandoned olive groves for 20 years with slope 25%	44	
Abandoned olive groves for 20 years with slope 25%	49	
Cereals	176	Kosmas *et al*., 1997
Vineyards	1428	
Eucalyptus spp plantations	238	
Shrublands (Maquis)	67	
Abandoned olive groves for 5 years	8	
Eucalyptus spp plantations	735-3035	Vacca *et al*., 2000
Abandoned grazing lands	124-1376	
Shrublands (Maquis)	264-514	

when no precipitation events occurred. Under such soil conditions, even small amounts of runoff can cause the movement of large amounts of sediment. The highly erodible soils also enhance infiltration rates and were probably responsible for having the least runoff of all plots.

The plots in the *Pinus brutia* forests had the least soil losses (Table 1). These forests had a good overstory canopy and a very dense litter layer with needles that protected the soil surface from precipitation and erosion. Their effectiveness was very evident in the Ethniko Dasiko Parko Troodos, where the plots had the lowest soil losses despite the fact that they had the highest precipitation intensity event and yearly surface runoff.

The plots in the *Quercus ilex* and *Quercus rotundifolia* forests had 40% more soil losses than the plot in the vineyards. This was unexpected since the vineyards had slightly more runoff than the *Quercus* forests. Typically forested areas have less soil losses than land in agricultural production. The *Quercus* forests did not have as dense of an overstory canopy or litter layer as the

Pinus brutia forests. However, it is assumed that the main factor increasing soil losses were the extensive human activities in this protected area compared to the other two protected areas. Disturbances caused by humans and animals can accelerate erosion regardless of the vegetation type (Koulouri and Giourga, 2007).

Overall, yearly soil losses had high standard deviations indicating high variability among individual soil loss events (Table 1). This was particularly evident in the "Phrygana" shrublands and to a lesser degree in the *Quercus ilex* and *Quercus rotundifolia* forests. For the *Pinus brutia* forests it was only evident in the Ethniko Dasiko Parko Troodos. This is something expected in semi-arid regions of the Mediterranean, where extreme soil losses are generated primarily during the few intense precipitation events that occur (Koulouri and Giourga, 2007; Ollesch and Vacca, 2002).

Surface runoff and soil losses did not follow a similar trend for the same vegetation types. A similar trend for surface runoff and soil losses should be expected since more water running on the surface has greater potential to erode and carry more sediment. The slopes of all plots were similar indicating that other factors, such as litter layer density and soil conditions, might have been responsible for not finding similar trends at the studied areas. Dense litter layers protect the soil from erosion and result in large volumes of surface runoff that are low in sediment. In contrast, bare soil that is highly erodible with signs of creep erosion can contribute large amounts of soil losses with relatively small volumes of runoff. Weak relationships between surface runoff and soil losses for cultivated and abandoned fields have also been found by others in the European-Mediterranean region (Blavet *et al.*, 2009; Koulouri and Giourga, 2007).

The annual soil losses from the two forested vegetation types of this study ranged from 21 to 50 kg $ha^{-1} yr^{-1}$ that were within the typical range of soil losses reported by others for shrublands, abandoned olive groves and abandoned cultivated fields in the European-Mediterranean region (Table 2). These past studies reported soil losses (Table 2) that had a wide range from 8 to 514 kg $ha^{-1} yr^{-1}$, although most soil losses ranged from 19 to 69 kg $ha^{-1} yr^{-1}$. For the "Maquis" shrublands a wide range of losses were reported (67 to 514 kg $ha^{-1} yr^{-1}$). Soil losses could differ depending on the condition of the Maquis shrubland. Degraded Maquis shrubland had significantly less soil depth, indicating more soil loss than the non-degraded Maquis shrubland (Zucca *et al.*, 2010). Geologic formation can also play an important role in the soil erosion of Maquis shrubland (Kosmas *et al.*, 2000). In this study, the Phrygana shrublands also had high soil losses (Table 1). The high soil losses of this study's shrublands could be attributed to the fact that most Phrygana shrublands in Greece have been heavily impacted by humans and are considered degraded (Diamantopoulos *et al.*, 1994). When Mediterranean shrublands are degraded they are susceptible to erosion by low and extreme precipitation events (Kosmas *et al.*, 2000).

Vineyards in comparison to other crops in the Mediterranean have been reported to have the highest soil losses (Martinez-Casasnovas and Sanchez-Bosch, 2000; Cerdan *et al.*, 2006). Tropeano (1983) using Gerlach trough measured soil losses of more than 18000 kg ha^{-1} per event in vineyards in northern Italy. The reason why vineyards have very high surface runoff and soil losses is the exposed bare soil and lack of canopy cover during the winter months that coincides with the period that most precipitation events occur in the Mediterranean region (Kosmas *et al.,* 2002). The soil losses in the vineyards of this study were substantially less compared to losses reported by other studies (Table 2). A potential reason could have been different management practices or soil types that can highly influence soil losses and runoff volumes. Vineyards in Southern France with superficial tillage (~ 550 kg ha^{-1} on average) had significantly reduced (by 4.5 times) soil losses compared to vineyards with no tillage that were associated with herbicide application, leading to bare soil (about 2500 kg ha^{-1} on average) (Raclot *et al.*, 2009). Soil losses increased in chemically weeded vineyards while decreased in vineyards that retained the grasses, pruning debris, or placed mulched straw on the ground (Blavet *et al.*, 2009).

The high soil losses in the Phrygana shrublands are a major concern for the ecosystem's sustainability and biodiversity. Conservation measures should be taken immediately to significantly reduce and prevent soil losses. The soil losses in the other vegetation types of these Natura 2000 areas, are also a concern since they were typical of cultivated or abandoned fields and not natural areas. Continuous moderate soil losses for many years can degrade soil condition and alter the quantity, quality and type of the vegetation that can reduce biodiversity levels. Protective measures to reduce the risk of soil losses in all three Natura 2000 areas are required in order to enhance and protect their biodiversity.

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