Environmental Engineering and Management Journal September 2019, Vol. 18, No. 9, 1977-1986
http://www.eemj.icpm.tuiasi.ro/; http://www.eemj.eu

"Gheorghe Asachi" Technical University of Iasi, Romania

GROUND DWELLING INSECTS AS ENVIRONMENTAL INDICATORS OF RIPARIAN HABITATS IN AGRICULTURAL MEDITERRANEAN LANDSCAPES

George Nick Zaimes[1]*, Pantelis Loisios[1], Pavlos Fytopoulos[1], Chrysovalantou Mersina[2], Nikolaos Fyllas[3], Valasia Iakovoglou[1], Dimitrios Avtzis[4]

[1]Laboratory of Mountainous Water Management and Control, Department of Forestry and Natural Environment Management, Eastern Macedonia and Thrace Institute of Technology (EMaTTech), Drama, 66100, Greece
[2]Department of Agricultural Development, Democritus University of Thrace, Orestiada, 68200, Greece
[3]Biodiversity Conservation Laboratory, Department of Environment, University of the Aegean, 81100 Mytilene, Lesbos, Greece
[4]Forest Research Institute, Hellenic Agricultural Organization Demeter, Vassilika, Thessaloniki, 57006, Greece

Abstract

Human activities have intensively relied on and utilized riparian areas that have led to their substantial degradation. This is the reason why easy-to-use, reliable, inexpensive monitoring tools that describe the ecosystem integrity of riparian areas need to be developed. Bio-indicators are such tools, with many recommending the use of ground-dwelling insects. This study evaluates the use of diversity indices on ground-dwelling insects for three representative riparian habitat types of Greece. The studied areas were along torrents with intermittent flow and natural woody riparian vegetation within a flat or hilly landscape and along a stream with perennial flow with woody monoculture riparian plantation vegetation. Based on the number of different species identified and the diversity indices, the riparian habitats along the torrents presented the greatest diversity due to the natural vegetation with the more complex canopy structure. Overall the significant differences found, indicate the usefulness of insects and particularly *Silpha obscura* (Coleoptera: Silphidae) for evaluating riparian habitats in agricultural dominated landscapes of Greece and the Mediterranean.

Key words: bio-indicators, diversity indices, riparian vegetation structure, stream flow

Received: September, 2017; Revised final: July, 2018; Accepted: August, 2018; Published in final edited form: September, 2019

1. Introduction

Riparian areas are key ecosystems, especially in semi-arid and arid regions, because of the many services and social benefits they offer and critical hydrological and biogeochemical functions they perform (Lohman, 2004; Naiman and Décamps, 1997; Zaimes et al., 2010). These services, benefits and functions arise from the higher productivity and biological diversity of riparian areas compared to their upland counterparts, despite the proportionally small area they occupy in the watershed (Naiman et al., 2005; Patten, 1998; Sabo et al., 2005). The greater presence of water in the soil that is more readily available for the riparian vegetation along with the frequent flooding, influences riparian areas and leads to characteristics that differentiate them from their surroundings.

The ecosystem services, benefits and functions of riparian areas have been identified and utilized by humans for thousands of years (National Research Council, 2002). Consequently, human-activity pressures such as river regulation, agricultural development, forestry, gravel mining and urban sprawl, particularly in the last centuries, have progressively altered and led to the degradation of

* Author to whom all correspondence should be addressed: e-mail: zaimesg@teiemt.gr; Phone: +30 2521060416; Fax: +30 2521060411

their ecological structure and function (Bartha et al., 2014; Hughes, 2003; Magdaleno and Fernández, 2011; Vlad and Toma, 2017). Today, riparian areas are considered heavily degraded worldwide because of their intensive use, especially near populated areas (National Research Council, 2002).

Riparian areas are extremely important in environmental management, especially in human-modified environments, since they are able to retain or restore their natural characteristics, even when the adjacent areas have been altered from human activities (Balan et al., 2017; Garcia-Martinez et al., 2017; Schultz et al., 2004). In the European Union (EU), many riparian areas have been designated as Natura 2000 sites, indicating the need to conserve and protect them (European Commission, 2007). In addition, in the Water Framework Directive (2000/60/EC), a key feature to assess freshwater bodies hydromorphologically is the structure of riparian areas (Magdaleno and Fernández, 2011). Finally, the EU Common Agricultural Policy recommends as a conservation practice, the establishment of field margins (e.g. re-establishing natural riparian areas) within agricultural systems because of the extensive agricultural intensification and alteration of the European landscape (Marshall and Moonen, 2002; Vickery et al., 2009). This practice can increase species diversity and density in agroecosystems, provide habitats for rare or endangered species and enhance ecosystem services (Smith at al., 2008).

In Southern Europe maintaining and re-establishing riparian areas is important and at the same time quite difficult, since most have a long history of intensive land-use changes and other human disturbances (Corbacho et al., 2003; Decamps et al., 1998). In addition, many remnant forested areas in Europe are narrow strips along water bodies (e.g. riparian areas) (Rodewald and Bakermans, 2006). Thus, maintaining or re-establishing riparian areas (Ferreira and Moreira, 1999; Salinas et al., 2000) is essential to maintain biodiversity, particularly in water-scarce regions (Costa et al., 2010; Rottenborn, 1999).

In Mediterranean-type environments, riparian corridors, particularly within landscapes dominated by agricultural activities, can be highly valuable and diverse habitats (Corbacho et al., 2003). Large areas of natural environments have and are being altered into agricultural fields and urbanized areas in the Mediterranean region (Luther et al., 2008). This intensification due to land-use changes in/and adjacent to riparian areas has reduced their flora and fauna diversity (Corbacho et al., 2003; Magdaleno and Fernández-Yuste 2013; Robinson et al., 2002). This is also the case especially of lowland riparian areas in Greece, where agriculture is the dominant land-use practice. In the Nestos River in Greece, forests/shrubs (natural vegetation) is the main vegetation of riparian areas in its mountainous regions (Zaimes et al., 2011a). In the lowland areas only the main reach of Nestos River has forested vegetation. In its tributaries, in these lowland areas, the agricultural fields extend to the edge of the stream banks and the natural riparian vegetation in most areas, has been completely eradicated. This is an example of substantially degraded and fragmented riparian areas, typical in lowland landscapes with extensive agricultural use in Greece.

Specialized monitoring for Mediterranean riparian ecosystems needs to be developed and also to be a key component in environmental management plans in order for these plans to be sustainable (Magdaleno and Martinez, 2014). This specialized monitoring will help assess more effectively the impacts of human activities and management changes on the ecological functioning of riparian areas (Garcia-Martinez et al., 2017; National Research Council, 2002). Easy-to-use and efficient assessment and monitoring methods, such as reliable and inexpensive indicators (Parr et al., 2016), are recommended to determine these anthropogenic impacts on habitats (Campos et al., 2014).

Some researchers believe that bio-indicators are more efficient in assessing riparian and river conditions than physicochemical indicators (Sharifinia et al., 2016). Entomofauna have been used as bio-indicators of riparian ecosystems quality at both the habitat and landscape scale (Costa et al., 2010; Garcia-Martinez et al., 2017; Herrera and Dudley, 2003; McCluney and Sabo, 2014; Viegas et al., 2014). The high biodiversity of ground-dwelling insects, along with their interactions with plants and vertebrates and their sensitivity to environmental changes render them as good entomofauna indicators of ecosystem health (Godfray et al., 1999; Higgins et al., 2014; Rouabah et al., 2015; Wall and Moore, 1999; Watts and Didham, 2006). This is especially true for healthy riparian areas that have unique and a greater abundance of insects because they support more productive, different and denser vegetation assemblages than their adjacent uplands (Naiman et al., 2005; National Research Council, 2002). The terrestrial insects of riparian areas utilize their unique vegetation for feeding, resting, refuge and reproduction. These unique insect assemblages of the riparian areas are key factors in the ecosystem food chain. Many wildlife species, such as birds, fish and other vertebrates that visit or live in the riparian areas depend on these insect assemblages (Doyle, 1990; Gray, 1993; Naiman et al., 2005). A common practice aiming to further simplify and enhance the monitoring of conservation and natural area management is identifying key indicator species (Dufrêne and Legendre, 1997). Hassall (2015) suggests utilizing only one model taxon as an indicator.

In Northern America, most European countries, Australia and New Zealand the reduction and alteration of riparian forests has led the scientific community to focus on understanding, protecting and recovering these ecosystems for decades (Ghinea and Gavrilescu, 2013; Hughes, 2003; Naiman et al., 1993). Unfortunately, in the Mediterranean and especially in Greece the study of riparian areas has been a focal point only in the last decade (Zaimes et al., 2011b).

This study investigated if ground-dwelling insects could be used as easily reproducible measurements to evaluate different riparian habitat types. Specifically, diversity indices based on ground-dwelling insects' abundance were compared among three different riparian habitats and an indicator species was identified. The null hypothesis was that differences in ground dwelling insects would not be found among the three representative riparian areas of the Mediterranean region.

2. Material and methods

2.1. Study area

The area studied is located in Eastern Macedonia, Greece (41º10΄ - 40º57΄N, 24º24΄ - 24º11΄E), and specifically included the lowland areas of Kavala and Drama Prefectures (Fig. 1). The riparian areas selected had an elevation range between 50-250 m, and the main land-use adjacent to them was agriculture crops, primarily corn (*Zea mays*). The climate of the study area is Mediterranean. The mean temperature is 15.9ºC and the annual precipitation 496 mm. Overall the hydrologic network of the study area is dense with ephemeral and intermittent torrents, perennial streams, and irrigation and drainage canals.

2.2. Riparian Habitat Types

The criteria for the three selected sites with representative Mediterranean riparian habitat types in agricultural dominated lowlands were: a) lotic type, torrent or stream b) riparian vegetation structure based on anthropogenic interventions and lotic type and c) landscape topography (flat or hilly). In the Mediterranean, torrents that can have intermittent or ephemeral flow, are the most common running water bodies (Emmanouloudis et al., 2011). Torrents have highly irregular water flow with large flash floods after intense precipitation events and no flow during the summer, greater channel slopes and higher sediment transport capacity compared to perennial streams. To minimize the impact of other climatic and environmental factors on the insect communities two additional criteria to select our riparian habitats were considered: a) the proximity of the sites to each other, and b) the homogeneity of the adjacent land uses. Based on all the above criteria, the riparian habitat types selected were: a) a natural riparian woody vegetation within a flat landscape and adjacent to a torrent with intermittent flow (NTF), b) a natural riparian woody vegetation within a hilly landscape and adjacent to a torrent with intermittent flow (NTH), and c) a woody monoculture plantation within a flat landscape and adjacent to a stream with perennial flow (PSF). The NTF habitat was along the Kallifyto torrent, with the main riparian species being Oriental Plane (Sycamore) (*Platanus orientalis*), Rubus (*Rubus* spp.) and Jerusalem or Christ's Thorn (*Paliurus spina-christi*). The topography of the landscape is flat and the neighboring land-uses after the riparian area include prairies, agricultural fields with wheat fields and olive groves. The NTH was along the Palaia Kavala torrent with the same woody vegetation as the previous riparian habitat (NTF). The topography of the landscape was hilly and the main land-uses beyond the riparian areas were shrubs, primarily junipers (*Juniper* spp.) and prairies, but also agricultural fields with primarily wheat and vegetables cultivated as well as Olive (*Olea europaea*) groves. Finally the PSF habitat, was along the Zigakti stream with the riparian overstory vegetation primarily consisting of very tall Black Poplar (*Populus nigra*) trees of similar age, and an understory of regenerating South European Flowering Ash (*Fraxinus ornus*). The land-uses beyond the riparian areas were mainly corn (*Zea mays*), cultivated in agricultural fields with the landscape topography being flat. So, the three selected riparian habitat types were located within an agricultural crop (cereals) landscape, with the average distance ranging from 5-10 km among them. It is important to note that the dominant woody species was native for each selected riparian habitat type.

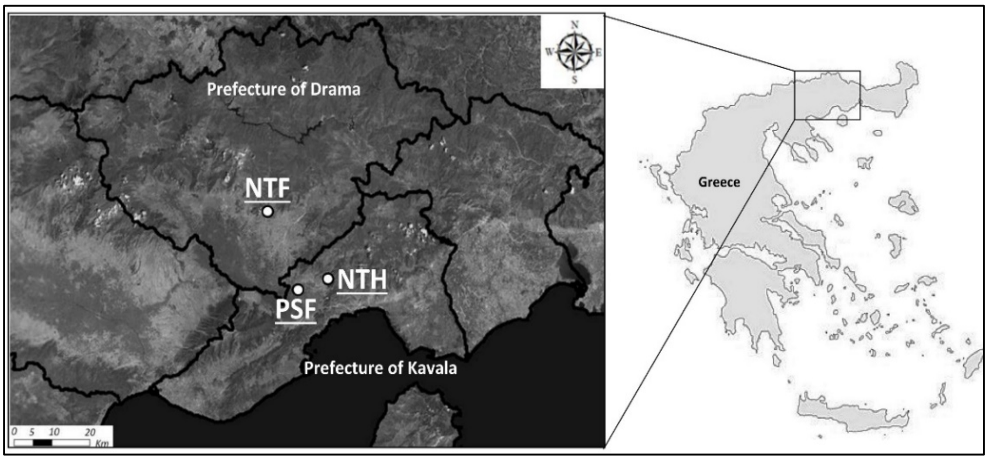

Fig. 1. The locations of the three riparian studied habitat types in Kavala and Drama Prefectures that belong to the Eastern Macedonia Region, Greece. The riparian habitat types were: NTH: natural riparian vegetation along a torrent within a hilly landscape, NTF: natural riparian vegetation along a torrent within a flat landscape and PSF: riparian plantation vegetation along a stream within a flat landscape

2.3. Ground-dwelling Insect Sampling

In each of the riparian habitat types three pitfall traps were installed. Pitfall traps are the most commonly used traps to obtain satisfactory abundance estimates for ground-dwelling arthropods (Baker et al., 2009; Higgins et al., 2014; McCluney and Sabo, 2014; Rouabah et al., 2015). The traps were plastic containers with a diameter of 14.5 cm and depth of 10.5 cm, buried in the ground with the opening of the trap level at the ground surface (Fig. 2). The traps were covered to be protected from rain, dilution, other weather effects, disturbances and potential debris from passing animals. In the traps, 5-10 ml of ethylene glycol (50% diluted with water) were placed as a killing-preserving solution, along with an odorless detergent to break the surface tension of the liquid and allow the insects sink to the bottom of the trap. The distance between the locations of each trap in each of the three riparian habitats was at least 200 m. Traps were placed in representative areas of each riparian habitat type, covered by trees and within 3 m of the stream bank.

Fig. 2. An installed pitfall trap in one of the riparian habitats

All the pitfall traps were installed in March of 2013. The traps were surveyed approximately every month and half until November 2014, except during the winter months (December to February) since there are no ground dwelling insect activity during this period. Fresh ethanol solution was added in the traps when needed. Overall, specimens from the pitfall traps were collected 6 times in 2013 (year 1- from April 2013 till November 2013) and 5 times in 2014 (year 2- from April 2014 till November 2014). All specimens collected were separated by hand and placed in separate vials with ethanol to be preserved. Afterwards they were transferred and identified to family and order level in the Laboratory of Forest Entomology (Forest Research Institute, HAO – Thessaloniki, Greece) using the relevant literature and the proper insect keys (Harde and Severa, 2006; Baehr, 2012).

If it was not possible to identify them to species level due to the damages caused on the specimens, they were identified to the genus or family level.

2.4. Diversity indices

To assess changes and look for patterns in the local diversity of insects taking into account from the presence/absence of species to the dominance, rarity, and community evenness of the three different riparian habitats, three Diversity Indices were used; specifically the: a) *Shannon-Wiener Diversity Index (H)*, b) *Shannon-Wiener Equitability Index* (E_H) and c) *Simpson's Index* ***(D)***.

The *Shannon-Wiener Diversity Index* (H) is commonly used to characterize species diversity in a community (Peet, 1974; Shannon and Weaver, 1949). It measures the abundance and the evenness of a species. The proportion of species (i) analogous to the entire number of species (p_i) is calculated, and then multiplied by the natural logarithm of this proportion (lnp_i). The resulting product is summed across species and multiplied by -1. The higher the number, the higher the species diversity is. The value of H is usually found to fall between 1.5 and 3.5 and only rarely surpasses 4.5. This index is calculated by (Eq. 1):

$$H = -\sum(p_i) x \ln(p_i) \quad (1)$$

where: ∑ is the summation and p_i is the proportion of individuals of each species belonging to the ith species of the total number of individuals.

The *Shannon-Wiener Equitability Index* (E_H) is calculated by (Eq. 2) (Peet, 1974; Shannon and Weaver, 1949):

$$E_H = \frac{H}{H_{\max}} \quad (2)$$

where H_{max} is the maximum possible H (maximum possible diversity) assuming the equal representation of all species. It is calculated from (Eq. 3):

$$H_{\max} = \ln(S) \quad (3)$$

where S is the number of the species of the sample. It has a range from 0 to 1, with 1 indicating complete evenness.

The *Simpson's Index* (D) provides a measurement on the probability that two randomly selected individuals from a sample will be from the same species (or some classification other than species) (Gering et al., 2003; Simpson, 1949; Washington, 1984). The following (Eq. 4) was used to estimate D:

$$D = \sum\left(\frac{n}{N}\right)^2 \quad (4)$$

where n is the entire number of organisms of a specific species and *N* is the entire number of organisms of all species.

The *D* can have values that range from 0 to 1, where 0 means infinite diversity and 1, no diversity. This means that the larger the *D* value, the lower the diversity. The numbers of ground-dwelling insect species collected in year 1 were used to construct a rank-abundance species curve for the three representative riparian habitats using a lognormal model with the "vegan" package. All three diversity indices were estimated with the "vegan" package and the R statistical environment (R Core Team, 2017). In order to test for potential differences in the diversity indices we calculated the bootstrap confidence intervals using 1000 re-samples (Gardener, 2014). However, as species richness is sensitive to the sample size (Gotelli and Colwell, 2001), we also used the rarefication and prediction algorithm described in Chao et al. (2014) to compare species richness between the different habitats, with the iNEXT package (Hsieh et al., 2016). In particular we used the coverage-based curve that plots the species richness with confidence intervals as a function of sample coverage up to a maximum size.

3. Results and discussion

In all three riparian habitat types (NTF, NTH and PSF) the most abundant species in year 1 was *Silpha obscura* (Table 1). *S. obscura* specimens were greater than 75% of the total specimens collected in all riparian habitats indicating the dominance of this species. In the traps located in the NTF, 146 insects were collected that were categorized into 11 species. *S. obscura* was the dominant species, and had a greater percentage compared to the other two habitat types (87.7%). *Myas chalybeus* followed in abundance (3.4%) while every other species contributed less than 1.5% to the total number of specimens collected. The largest number of individuals (153) was collected in the NTH traps that were categorized into nine different species (Table 1). The dominant species was again, *S. obscura* (78.4%), followed by *Harpalus* sp. (8.5%) and *Pterostichus melas* (3.9%). Finally, the PSF was the habitat with the least diverse vegetation structure (e.g. plantation), and only two species were collected. Specifically, *S. obscura* again was the dominant species (85.7%) while the other species was *P. melas* (14.3%), that was also present in NTH. Overall in the PSF traps, a very small number of specimens (21) were collected compared to the other two riparian habitats. The above information is also summarized in the rank abundance species curve (Fig. 3). From this graph the strong dominance patterns identified in the NTF and NTH sites can be seen along with the least diverse pattern in the PSF.

The three diversity indices along with the bootstrap estimates of their 95% confidence intervals are presented in Table 2. The value of the H was higher in NTH, followed by NTF and PSF. The only significant difference in H was identified between NTH and PSF. Overall H was below 1.5 indicating in general, low biodiversity. With regards to the E_H index, the PSF site had the highest value, which however was not statistically different from the E_H in NTF and NTH. Higher E_H values indicate less variation among species in communities, suggesting that PSF had the lowest species richness. In terms of the *D* index, with larger values indicating less diverse sites, NTF and PSF had similar values that were higher than the NTH value although not significantly different.

The estimates of the Hill numbers and in particular q = 0 (species richness), q = 1 (the exponential of the *H*), and q = 2 (the inverse of the *D*) are presented in Table 3, and the coverage-based curve is illustrated in Fig. 4. These estimates suggest that when differences in the sample size are taken into account, PSF is the least diverse plot, only in terms of species richness. These results were as expected, since Minaya et al. (2013) found that macroinvertebrates are more sensitive to the reach-scale characteristics than to the watershed-scale.

Table 2. The Shannon-Wiener Diversity (*H*), Equitability (E_H) and Simpson (*D*) Indices in the three riparian habitats based on the ground-dwelling insects surveyed from March 2013 till November 2013. The confidence intervals were calculated with bootstrap from the 2.5% and 97.5% quantiles

Indices	*NTF[1]*	*NTH[2]*	*PSF[3]*
H	0.64 (0.39 – 0.81)	0.90 (0.66 – 1.08)	0.41 (0.00 – 0.64)
E_H	0.27 (0.20 – 0.36)	0.41 (0.33 – 0.51)	0.59 (0.28 – 0.86)
D	0.77 (0.69 – 0.86)	0.62 (0.53 – 0.72)	0.76 (0.56 – 1.00)

[1]*natural woody vegetation within a flat landscape and adjacent to torrents with intermittent flow.*
[2]*natural woody vegetation within a hilly landscape and adjacent to torrents with intermittent flow.*
[3]*woody monoculture plantation within a flat landscape and adjacent to a stream with perennial flow.*

Table 3. Estimated Hill's numbers for the three riparian habitats based on the ground-dwelling insects surveyed from March 2013 till November 2013

Indices	*NTF[1]*	*NTH[2]*	*PSF[3]*	*Sample Completeness (%)*
q = 0	11.0	9.00	2.00	96.6
q = 1	1.89	2.46	1.51	98.7
q = 2	1.30	1.60	1.32	100.0

[1]*natural woody vegetation within a flat landscape and adjacent to torrents with intermittent flow.*
[2]*natural woody vegetation within a hilly landscape and adjacent to torrents with intermittent flow within a hilly landscape.*
[3]*woody monoculture plantation within a flat landscape adjacent to a stream with perennial flow within a flat landscape.*

This suggests a stronger influence of the local habitat conditions, such as riparian vegetation. Both NTF and NTH have natural riparian vegetation with multiple canopy layers, different woody species that should lead to greater diversity. In contrast, in the PSF one woody species was dominant with all trees having the same age and the approximate same height. The forest structure and habitat conditions such as vegetation composition, leaf litter, solar radiation and microclimate can heavily influence ground-dwelling insects (Baker et al., 2007; Humphrey et al., 1999; Niemela and Spence, 1994). Insects are typically associated with characteristic vegetation types (Thomas, 1995), have distinctive communities in different microhabitats (Liu et al., 2013) and this might be even more true for riparian areas that have more productive vegetation assemblages and can support a greater number of invertebrates than the neighboring uplands (Herrera and Dudley, 2003). Insect community composition, diversity, and abundance of particular taxa can be affected by the availability of water in riparian areas that is related to stream flow, especially in the summer months with the drying of the rivers and streams (McCluney and Sabo, 2014). However, it has been suggested that certain species in riparian areas may show tolerance to river and stream drying in the short-term.

Table 1. The number and percentage of the species of ground-dwelling insects collected from March 2013 till November 2013 in the three riparian habitats. All insects collected belong to the *Coleoptera* Order

Family	***Species***	***NTF***[1]		***NTH***[2]		***PSF***[3]	
		#	**%**	**#**	**%**	**#**	**%**
Carabidae	*Amara* sp. (Bonelli, 1810)	-	-	3	2.0	-	-
	Calosoma inquisitor (Linnaeus, 1758)	2	1.4	-	-	-	-
	Calosoma sycophanta (Linnaeus, 1758)	1	0.7	-	-	-	-
	Chlaenius nitidulus (Schrank, 1781)	-	-	1	0.7	-	-
	Carabus graecus (Dejean, 1826)	1	0.7	3	2.0	-	-
	Carabus granulates (Linnaeus, 1758)	-	-	4	2.6	-	-
	Harpalus sp. (Latreille, 1802)	2	1.4	13	8.5	-	-
	Myas chalybeus (Palliardi, 1825)	5	3.4	-	-	-	-
	Pterostichus melas (Creutzer, 1799)	-	-	6	3.9	3	14.3
Geotrupidae	*Geotrupes spiniger* (Marsham, 1802)	1	0.7	-	-	-	-
Histeridae	*Hister quadrimaculatus* (Linnaeus, 1758)	-	-	1	0.7	-	-
Lucanidae	*Dorcus parallelipipedus* (Linnaeus, 1758)	2	1.4	-	-	-	-
Scarabaeidae	*Cetonia aurata* (Linnaeus, 1758)	1	0.7	-	-	-	-
	Sisyphus schaefferi (Linnaeus, 1758)	2	1.4	-	-	-	-
Silphidae	*Silpha obscura* (Linnaeus, 1758)	128	87.7	120	78.4	18	85.7
Staphylinidae	Staphylinidae (Lameere, 1900)	1	0.7	2	1.3	-	-
TOTAL		**146**	**100.0**	**153**	**100.0**	**21**	**100.0**

[1]*natural woody vegetation within a flat landscape and adjacent to torrents with intermittent flow.*
[2]*natural woody vegetation within a hilly landscape and adjacent to torrents with intermittent flow.*
[3]*woody monoculture plantation within a flat landscape and adjacent to a stream with perennial flow.*

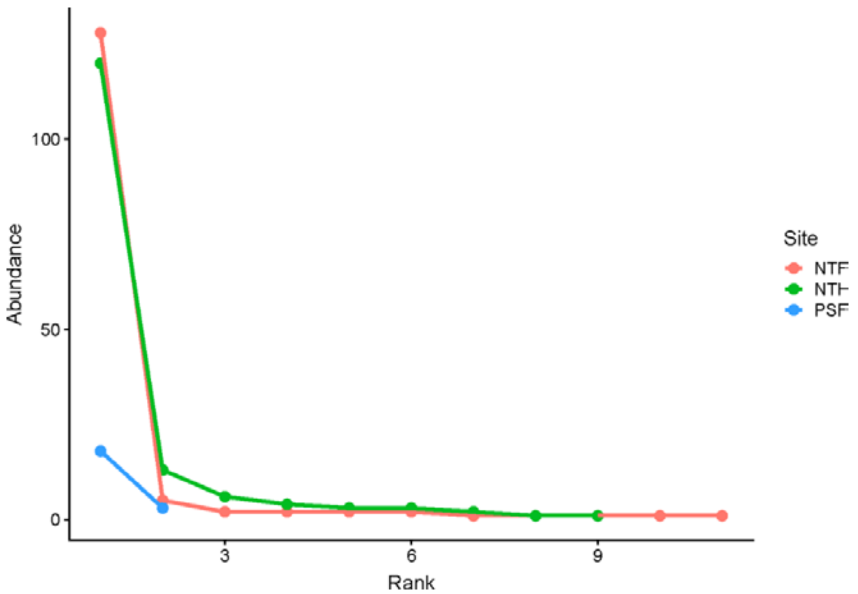

Fig. 3. Rank abundance species curves for the three habitats in year one (NTF: natural woody vegetation within a flat landscape and adjacent to torrents with intermittent flow; NTH: natural woody vegetation within a hilly landscape and adjacent to torrents with intermittent flow; PSF: woody monoculture plantation within a flat landscape and adjacent to a stream with perennial flow)

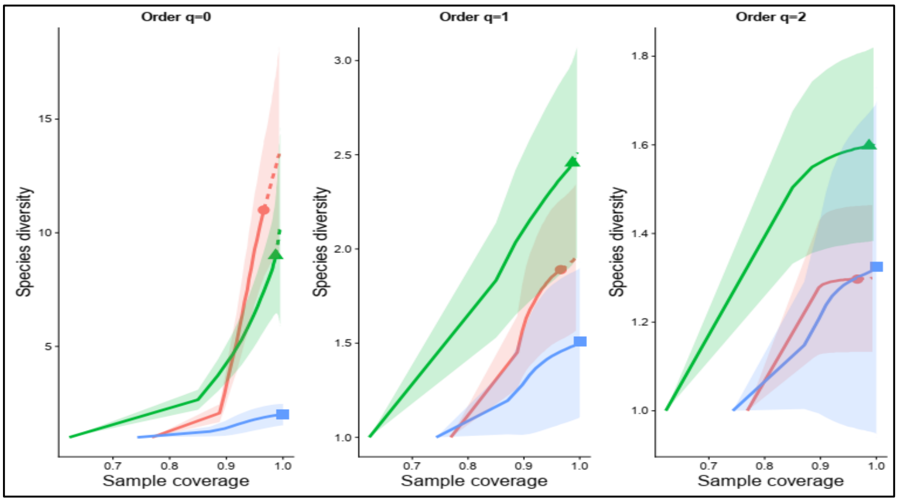

Fig. 4. The coverage-based curve representing the species richness as a function of the sample coverage. Specifically, q = 0 is the species richness, q = 1 is the exponential of Shannon-Wiener Diversity Index (*H*), and q = 2 is the inverse of Simpson's Index (*D*). Different colors indicate the three habitats (red=NTF, green=NTH and blue=PSF). The estimates (including interpolated and extrapolated values) and figures were made with the iNEXT package (Hsieh et al., 2016)

The previous reasoning along with the fact that most running water bodies in the Mediterranean are torrents with intermittent or ephemeral flow (Emmanouloudis et al., 2011), suggests that riparian insects in this region have adapted to these prevailing conditions. The insects' adaptability along with the more complex vegetation structure justifies their greater diversity along the riparian areas of the torrents.

Overall the use of ground-dwelling insects, as an indicator of changes in land use practices is well-documented (Costa et al., 2010; Garcia-Martinez et al., 2015 and 2017; Niemela, 2001). Riparian forests had the highest number of inventoried ground-dwelling insects and the most diverse habitats based on the Shannon and Simpson diversity indices compared to their surrounding habitats (Baz et al., 2014). In other studies of restored riparian areas, ground beetles had significant changes in richness and abundance metrics (Lorenz et al., 2018) or their species richness doubled (Januschke et al., 2011). The results of this study along with other studies conducted in Balkan countries (e.g. Aydin and Kazak, 2010; Brigić et al., 2017) indicate their potential as a useful bio-indicator in the region. Ground-dwelling insects might be more ideal for the Balkan and Mediterranean region since terrestrial insect are better indicators than the aquatic in intermittent and ephemeral streams (Steward et al., 2018) that are very common in these regions (Emmanouloudis et al., 2011). Finally, some researchers recommend that insects should be preferred because they are better indicators of biodiversity than vertebrates (e.g. birds and rodents) (Golet et al., 2011).

To further enhance monitoring efficiency and cost-effectiveness, identifying indicator species are important, especially in regard to the conservation of protected areas and natural ecosystems (Dufrêne and Legendre, 1997; Larrieu et al., 2018). In many cases, some recommend the usage of a single model taxon as an indicator (Hassall, 2015). The indicators selected in the different regions and ecosystems need to have certain characteristics in order to be effective (Aydin and Kazak, 2010). Specifically, the indicators need to: a) be easily measured and identified, b) have measurements easily repeated by others, c) be widely accepted by the scientific community and d) have the capacity to be understood and communicated to decision makers and practitioners. In the three riparian habitat types that were studied, carrion beetles (*S. obscura)* had the desired features of an indicator species. In particular, carrion beetles provide valuable ecosystem services, especially in regard to nutrient cycling, as they enhance the decomposition and recycling of organic matter into terrestrial ecosystems (Peck, 1990; Ratcliffe, 1996). Furthermore, the phenology and habitat selection of carrion beetles has been intensively studied (Kočárek, 2001; Mullins et al., 2013). Finally, carrion beetles have been employed in the selection of important nature conservation sites (Jakubec and Růžička, 2015). The above reasons along with the fact that this was the most frequently found species in the first year of our sampling, led us to focus on this specific species in the second year. Specifically, in the second year, only *S. obscura* specimens were identified and counted. Based on the data of both years, the PSF had the lowest species population in relation to others riparian habitats (first year 18 and second year 14) (Table 4). In the riparian areas along the torrents, *S. obsura* had the greatest number of individuals in NTF during the first year (128) and in NTH (114) during the second. A greater number of specimens indicates excessive organic matter, in other words more food for this species and overall a richer and healthier ecosystem (Koivula, 2011). This agrees with the vegetation characteristics of the three riparian areas monitored since the torrents had natural vegetation with multiple canopies while the plantation was a monoculture with one main canopy layer.

Table 4. The individuals of *Silpha obscura* collected in the three riparian habitats based on the ground-dwelling insects surveyed from March 2013 till November 2013 (first year) and from March 2014 till November 2014 (second year) and the entire sampling period (total)

Year	*NTF*[1]	*NTH*[2]	*PSF*[3]
1st	128	120	18
2nd	82	114	14
TOTAL	200	242	32

[1]*natural woody vegetation within a flat landscape and adjacent to torrents with intermittent flow;*
[2]*natural woody vegetation within a hilly landscape and adjacent to torrents with intermittent flow;*
[3]*woody monoculture plantation within a flat landscape and adjacent to a stream with perennial flow*

4. Conclusions

To manage more effectively and efficiently natural ecosystems, easy-to-use, reliable, and inexpensive monitoring tools are needed. In this study, utilizing the abundance of different ground-dwelling species with different diversity indices from three representative riparian habitat types, illustrated their potential usefulness as bio-indicators in evaluating such habitats in landscapes dominated by agricultural practices in Greece.

Still statistically significant differences were found only based on species richness and the diversity index (*H*) among the riparian habitats. In addition, for these riparian ecosystems it appears that *S. obscura*, could be used as a single model taxon. Vegetation and not stream flow was the main characteristic influencing insect biodiversity in the region. The riparian areas along the torrents with intermittent flow had the greatest diversity due to the natural vegetation and multiple canopy layers. Similar age monoculture plantation riparian areas had the least diversity despite being along a perennial stream. This indicates that ground-dwelling insects might have adjusted to the dominant stream flow conditions of the region, since intermittent or ephemeral torrents are the most common running water body type in the Mediterranean.

Overall, the use of soil coleopteran assemblages or specific coleopteran species for riparian areas is something new and appears to be promising. These insects are overall easily identified, and the pitfall traps used to collect them are easy to use, low cost and not very labor intensive. Out of all the soil coleopteran assemblages collected in this study, the great abundance of carrion beetles (*S. obscura)* suggests that it has the greatest potential to be used as an indicator species in these riparian areas. Still additional studies in similar or other Greek representative riparian habitats with more replications are needed to verify the potential usefulness of ground-dwelling insects. These results represent a first effort for exploring the use of soil coleopterans as an indicator tool that could eventually be expanded for the entire Balkans with similar studies in representative riparian areas of the region. Finally, other insect orders that might be more sensitive to human impacts on riparian areas, could be investigated (e.g. arboreal or subterranean ants, dragonflies or damselflies) and cross-taxon surrogacy studies could also be conducted.

References

Aydin G., Kazak C., (2010), Selecting indicator species habitat description and sustainable land utilization: a case study in a Mediterranean delta, *International Journal of Agriculture and Biology*, **12**, 931-934.

Baehr M., (2012), *Which Beetle is this?*, (in German), Franckh Kosmos Verlag, Stuttgart, Germany.

Baker S.C., Barmuta L.A., McQuillan P.B, Alastair M.M., Richardson A.M.M., (2007), Estimating edge effects on ground-dwelling beetles at clearfelled non-riparian stand edges in Tasmanian wet eucalypt forest, *Forest Ecology and Management*, **239**, 92-101.

Baker S., Barmuta L., Grove S., Richardson A., (2009), Are streamside buffers edge-affected habitat for ground-dwelling forest beetle assemblages?, *Biodiversity and Conservation*, **18**, 3467-3482.

Balan A., Obolewski K., Luca M., Cretescu I., (2017), Use of macroinvertebrates for assessment of restoration works influence on the habitat in floodplain lakes, *Environmental Engineering and Management Journal*, **16**, 969-978.

Bartha J., Vlad L.M., Toma D., Toacă D., Cotiușcă-Zaucă D., (2014), Rehabilitation and extension of wetlands within floodplains of embanked rivers, *Environmental Engineering and Management Journal*, **13**, 3143-3152.

Baz A., Cifrián B., Daniel Martín-Vega D., (2014), Patterns of diversity and abundance of carrion insect assemblages in the natural park “Hoces del Río Riaza” (Central Spain), *Journal of Insect Science*, **14**, 1-10.

Brigić A., Bujan J., Alegro A., Šegota V., Ternjej I., (2017), Spatial distribution of insect indicator taxa as a basis for peat bog conservation planning, *Ecological Indicators*, **80**, 344-353.

Campos F., Velasco T., Sanz G., Casanueva P., Albuquerque M.T.D., Antunes I.M.H.R., (2014), *Ischnura graellsii* (Insecta: Odonata) a water pollution biovulnerability indicator - probability mapping using spatial uncertainty, *River Research and Applications*, **32**, 483-489.

Chao A., Gotelli N.J., Hsieh T.C., Sander E.L., Ma K.H., Colwell R.K., Ellison A.M., (2014), Rarefaction and extrapolation with Hill numbers: A framework for sampling and estimation in species diversity studies, *Ecological Monographs*, **84**, 45-67.

Corbacho C., Sanchez J.M., Costillo E., (2003), Patterns of structural complexity and human disturbance of riparian vegetation in agricultural landscapes of a Mediterranean area, *Agriculture, Ecosystems and Environment*, **95**, 495-507.

Costa C.B., Ribeiro S.P., Castro P.T., (2010), Ants as bioindicators of natural succession in savanna and riparian vegetation impacted by dredging in the Jequitinhonha river basin, Brazil, *Restoration Ecology*, **18**, 148-157.

Decamps H., Fortune M., Gazelle F., Patou G., (1988), Historical influence of man on the riparian dynamics of a fluvial landscape, *Landscape Ecology*, **1**, 163-173.
Doyle A.T., (1990), Use of riparian and upland habitats by small mammals, *Journal of Mammalogy*, **71**, 14-23.
Dufrêne M., Legendre P., (1997), Species assemblages and indicator species: The need for a flexible assymetrical approach, *Ecological Monographs*, **67**, 345-366.
Emmanouloudis D., García Rodríguez J.L., Zaimes G.N., Giménez Suárez M.C., Filippidis E., (2011), *Euro-Mediterranean Torrents: Case Studies on Tools that Can Improve their Management*, In: *Mountain Ecosystems: Dynamics, Management and Conservation*, Richards K.E. (Ed.), Nova Science Publishers, Inc, Hauppauge New York, USA, 1-44.
European Commission, (2007), Nature & Diversity, On line at: http://ec.europa.eu/environment/nature/index_en.htm.
Ferreira M.T., Moreira I.S., (1999), River plants from an Iberian basin and environmental factors influencing their distribution, *Hydrobiologia*, **415**, 101-107.
Gardener M., (2014), *Community Ecology: Analytical Methods Using R and Excel*, Pelagic Publishing Ltd. Devo, UK.
Garcia-Martinez, M.A., Escobar-Sarria F., López-Barrera F., Castaño-Meneses G., Valenzuela-González J.E., (2015), Value of the riparian vegetation remnants for leaf-litter ants (Hymenoptera: Formicidae) in a human-dominated landscape in central Veracruz, Mexico, *Environmental Entomology*, **44**, 1488-1497.
Garcia-Martinez M.A., Valenzuela-Gonzalez J.E., Escobar-Sarria F., Lopez-Barrera F., Castaño-Meneses G., (2017), The surrounding landscape influences the diversity of leaf-litter ants in riparian cloud forest remnants, *PLoS ONE*, **12**, Article ID:e0172464.
Gering J.C., Crist T.O., Veech J.A., (2003), Additive partitioning of species diversity across multiple spatial scales: Implications for regional conservation of biodiversity, *Conservation Biology*, **17**, 488-499.
Ghinea C., Gavrilescu M., (2013), Inter-Reggio: Concept of restoration projects of local streams, *Environmental Engineering and Management Journal*, **12**, 1735-1746.
Godfray H.C.J., Lewis O.T., Memmott J., (1999), Studying insect diversity in the tropics, *Philosophical Transactions of the Royal Society of London, B: Biological Sciences*, **354**, 1811-1824.
Golet G.H., Gardali T., Hunt J.W., Koenig D.A., Williams N.M., (2011), Temporal and taxonomic variability in response of fauna to riparian restoration, *Restoration Ecology*, **19**, 126-135.
Gotelli N.J., Colwell R.K., (2001), Quantifying biodiversity: procedures and pitfalls in the measurement and comparison of species richness, *Ecology Letters*, **4**, 379-391.
Gray L.J., (1993), Response of insectivorous birds to emerging aquatic insects in riparian habitats of a tallgrass prairie stream, *American Midland Naturalist*, **129**, 288-300.
Harde K.W., Severa F., (2006), *The Cosmos Beetle Leader. The Central European Beetles*, (in German), Franckh Kosmos Verlag, Stuttgart, Germany.
Hassall C., (2015), Odonata as candidate macroecological barometers for global climate change, *Freshwater Science*, **34**, 1040-1049.
Herrera A.H., Dudley T.L., (2003), Reduction of riparian arthropod abundance and diversity as a consequence of giant reed (Arundodonax) invasion, *Biological Invasions*, **5**, 167-177.
Hsieh T.C., Ma K.H., Chao A., (2016), iNEXT: An R package for rarefaction and extrapolation of species diversity (Hill numbers), *Methods in Ecology and Evolution*, **7**, 1451-1456.
Hughes F.M.R., (2003), *The Flooded Forest: Guidance for Policy Makers and River Managers in Europe on the Restoration of Floodplain Forests*, University of Cambridge, Cambridge, UK.
Humphrey J.W., Hawes C., Peace A.J., Ferris Kaan R., Jukes M.R., (1999), Relationships between insect diversity and habitat characteristics in plantation forests, *Forest Ecology and Management*, **113**, 11-21.
Jakubec P., Růžička J., (2015), Is the type of soil an important factor determining the local abundance of carrion beetles (Coleoptera: Silphidae)?, *European Journal of Entomology*, **112**, 747-754.
Januschke K., Brunzel S., Haase P., Hering D., (2011), Effects of stream restorations on riparian mesohabitats, vegetation and carabid beetles, *Biodiversity and Conservation*, **20**, 3147-3164.
Kočárek P., (2001), Diurnal activity rhythms and niche differentiation in a carrion beetle assemblage (Coleoptera: Silphidae) in Opava, the Czech Republic, *Biological Rhythm Research*, **32**, 431-438.
Koivula M.J., (2011), Useful model organisms, indicators, or both? Ground beetles (Coleoptera, Carabidae) reflecting environmental conditions, *ZooKeys*, **100**, 287-317.
Liu R., Zhu F., Song N., Yang X., Chai Y., (2013), Seasonal distribution and diversity of ground arthropods in microhabitats following a shrub plantation age sequence in desertified steppe, *Plos One*, **8**, Article ID: e77962.
Lohman K., (2004), *Wildlife Use of Riverine Wetland Habitats*, In: *Wetland and Riparian Areas of the Intermountain West: Ecology and Management*, McKinstry M.C., Hubert W.A., Anderson S.H., (Eds.) University of Texas Press, Austin, Texas, USA, 74-86.
Lorenz A.W., Haase P., Januschke K., Sundermann A., Hering D., (2018), Revisiting restored river reaches – Assessing change of aquatic and riparian communities after five years, *Science of the Total Environment*, **613-614**, 1185-1195.
Larrieu L., Gosselin F., Archaux F., Chevalier R., Corriol G., Dauffy-Richard E., Deconchat M., Gosselin M., Ladet S., Savoie J-M., Tillon L., Bouget C., (2018), Cost-efficiency of cross-taxon surrogates in temperate forests, *Ecological Indicators*, **87**, 56-65.
Luther D., Hilty J., Weiss J., Cornwall C., Wipf M., Ballard G., (2008), Assessing the impact of local habitat variables and landscape context on riparian birds in agricultural, urbanized, and native landscapes, *Biodiversity and Conservation*, **17**, 1923-1935.
Magdaleno F., Fernández J.A., (2011), Hydromorphological alteration of a large Mediterranean river: Relative role of high and low flows on the evolution of riparian forests and channel morphology, *River Research and Applications*, **27**, 374-387.
Magdaleno F., Fernández-Yuste J.A., (2013), Evolution of the riparian forest corridor in a large Mediterranean river system, *Riparian Ecology and Conservation*, **1**, 36-45.
Magdaleno F., Martinez R., (2014), Evaluating the quality of riparian forest vegetation: The Riparian Forest Evaluation (RFV) index, *Forest Systems*, **23**, 259-272.
Marshall E.J.P., Moonen A.C., (2002), Field margins in northern Europe: Their functions and interactions with agriculture, *Agriculture, Ecosystems and Environment*, **89**, 5-21.

McCluney K.E., Sabo J.L., (2014), Sensitivity and tolerance of riparian arthropod communities to altered water resources along a drying river, *Plos One*, **9**, Article ID:e109276.

Minaya V., McClain M.E., Moog O., Omengo F., Singer G.A., (2013), Scale-dependent effects of rural activities on benthic macroinvertebrates and physico-chemical characteristics in headwater streams of the Mara River, Kenya, *Ecological Indicators*, **32**, 116-122.

Mullins P.L., Riley E.G., Oswald J.D., (2013), Identification, distribution, and adult phenology of the carrion beetles (Coleoptera:Silphidae) of Texas, *Zootaxa*, **3666**, 221-251.

Naiman R.J., Décamps H., Pollock M., (1993), The role of riparian corridors in maintaining regional biodiversity, *Ecological Applications*, **3**, 209-212.

Naiman R.J., Décamps H., (1997), The ecology of interfaces: Riparian zones, *Annual Review of Ecology and Systematics*, **28**, 621-658.

Naiman R.J., Décamps H., McClain M.E., (2005), *Riparia-Ecology, Conservation and Management of Streamside Communities*, Elsevier Academic Press, London, UK, 448.

National Research Council, (2002), *Riparian Areas: Functions and Strategies for Management*, National Academy Press, Washington, DC, USA.

Niemela J.K., Spence J.R., (1994), Distribution of forest dwelling carabids (Coleoptera): spatial scale and the concept of communities, *Ecography*, **17**, 166-175.

Niemela J., (2001), Carabid beetles (Coleoptera: Carabidae) and habitat fragmentation: A review, *European Journal of Entomology*, **98**, 127-132.

Parr T.B., Cronan C.S., Danielson T.J., Tsomides L., Simon K.S., (2016), Aligning indicators of community composition and biogeochemical function in stream monitoring and ecological assessments, *Ecological Indicators*, **60**, 970-979.

Patten D.T., (1998), Riparian ecosystems of semi-arid North America: Diversity and human impacts, *Wetlands*, **18**, 498–512.

Peck S.B., (1990), *Insecta: Coleoptera Silphidae and the associated families Agyrtidae and Leiodidae*, In: *Soil Biology Guide*, Dindal D.L. (Ed.), John Wiley & Sons, New York, USA, 1113-1136.

Peet P.K., (1974), The measurement of species diversity, *Annual Review of Ecology and Systematics*, **5**, 285-307.

Ratcliffe B.C., (1996), *The Carrion Beetles (Coleoptera: Silphidae) of Nebraska*, Bulletin 13, University of Nebraska State Museum, Lincoln, Nebraska, USA.

Robinson C.T., Tockner K., Ward J.V., (2002), The fauna of dynamic riverine landscape, *Freshwater Biology*, **47**, 661-677.

Rodewald A.D., Bakermans M.H., (2006), What is the appropriate paradigm for riparian forest conservation?, *Biological Conservation*, **128**, 193-200.

Rottenborn S.C., (1999), Predicting the impacts of urbanization on riparian bird communities, *Biological Conservation*, **88**, 289-299.

Rouabah A., Villerd J., Amiaud B., Plantureux S., Lasserre-Joulin F., (2015), Response of carabid beetles diversity and size distribution to the vegetation structure within differently managed field margins, *Agriculture, Ecosystems and Environment*, **200**, 21-32.

Sabo J.L., Sponseller R., Dixon M., Gade K., Harms K., Heffernan J., Jani A., Katz G., Soykan C., Watts J., Welter J., (2005), Riparian zones increase regional species richness by harbouring different, not more, species, *Ecology*, **86**, 56-62.

Salinas M.J., Banca G., Romero T., (2000), Evaluating riparian vegetation in semi-arid Mediterranean watercourses in the southeastern Iberian Peninsula, *Environmental Conservation*, **27**, 24-35.

Shannon C.E., Weaver W., (1949), *The Mathematical Theory of Communication*, Illinois University Press, Urbana, Illinois, USA.

Sharifinia M., Mahmoudifard A., Imanpour Namin J., Ramezanpour Z., Kong Yap C., (2016), Pollution evaluation in the Shahrood River: Do physico-chemical and macroinvertebrate-based indices indicate same responses to anthropogenic activities?, *Chemosphere*, **159**, 584-594.

Schultz R.C., Isenhart T.M., Simpkins W.W., Colletti J.P., (2004), Riparian forest buffers in agroecosystems – Lessons learned from the Bear Creek Watershed, central Iowa, USA, *Agroforestry Systems*, **61**, 35-50.

Simpson E.H., (1949), Measurement of diversity, *Nature*, **163**, 688, https://doi.org/10.1038/163688a0.

Smith J., Potts S.G., Woodcock B.A., Eggleton P., (2008), Can arable field margins be managed to enhance their biodiversity, conservation and functional value for soil macrofauna? *Journal of Applied Ecology*, **45**, 269-278.

Steward A.L., Negus P., Marshall J.C., Clifford S.E., Dent C., (2018), Assessing the ecological health of rivers when they are dry, *Ecological Indicators*, **85**, 537-547.

Thomas J.A., (1995), Why small cold-blooded insects pose different conservation problems to birds in modern landscapes, *Ibis*, **137**, S112-S119.

Vickery J.A., Feber R.E., Fuller R.J., (2009), Arable field margins managed for biodiversity conservation: A review of food resource provision for farmland birds, *Agriculture, Ecosystems and Environment*, **133**, 1-13.

Viegas G., Stenert C., Schulz U.W, Maltchik L., (2014), Dung beetle communities as biological indicators of riparian forest widths in southern Brazil, *Ecological Indicators*, **36**, 703-710.

Vlad L., Toma D., (2017), Restoring wetlands and natural floodplain along the lower Baseu River in Romania, *Environmental Engineering and Management Journal*, **16**, 2337-2346.

Wall D.H., Moore J.C., (1999), Interactions underground: Soil biodiversity, mutualism, and ecosystem processes, *Bioscience*, **49**, 109-117.

Washington H.G., (1984), Diversity, biotic and similarity indices: A review with special relevance to aquatic ecosystems, *Water Research*, **18**, 653-694.

Watts C.H., Didham R.K., (2006), Influences of habitat isolation on invertebrate colonization of *Sporadanthus ferrugineus* in a mined peat bog, *Restoration Ecology*, **14**, 412-419.

Zaimes G.N., Iakovoglou V., Emmanouloudis D., Gounaridis D., (2010), Riparian areas of Greece: Their definition and characteristics, *Journal of Engineering Science and Technology Review*, **3**, 176-183.

Zaimes, G.N., Gounaridis. D., Fotakis, D., (2011a), Assessing riparian land-uses/vegetation cover along the Nestos River in Greece, *Fresenius Environmental Bulletin*, **20**, 3217-3225

Zaimes G.N., Gounaridis, D., Iakovoglou, V., Emmanouloudis, D., (2011b), Riparian area studies in Greece: A literature review, *Fresenius Environmental Bulletin*, **20**, 1470-1477.

Zaimes G.N., Manikas, N., Spanos, T., Chrisopoulos, V., Avtzis, D.N., (2017), Odonata as indicators of riverine habitats in Central Greece, *Fresenius Environmental Bulletin*, **26**, 4244-4253.