Ecology for the city: analysing the role of green infrastructure in creating liveable cities

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Abstract

Ecosystem services are the direct and indirect contributions that ecosystems make to human well-being. In urban areas, these include improved local climate regulation, flood control, access to food, availability of recreational spaces, and reduced health problems associated with urban living such as through exposure to excess noise and air pollution. This work presents a case-study that spatially assesses the *capacity* of ecosystems to provide ecosystem services in Malta, and the actual use *(flow)* of these services by the Maltese population, for four key ecosystem services. The ecosystem services investigated include food production and beekeeping, biodiversity conservation and aesthetic value of landscapes, and air quality improvement. The study utilises different available datasets, statistical models and indicators based on direct measurements. Results obtained here indicate an important contribution of rural landscapes and green urban areas to human well-being, supporting the notion that planning that develops and maintains green infrastructure can solve urban challenges and contributes significantly to the creation of future liveable cities that support biodiversity and human well-being.

Introduction

Urban areas were home to 54.5% of the world's population in 2016, and by 2030 this number is expected to increase to 60% of people globally, in a trend of urbanisation that is recorded across all regions (United Nations, 2016). Urbanisation poses one of the greatest threats to global biodiversity, and if current trends in population density continue and all areas with high probabilities of urban expansion undergo change, then by 2030, urban land cover will increase by 1.2 million km^2. However, surprisingly, cities can be critical for the conservation of native biodiversity (Hicks et al., 2016; Ives et al., 2016), as green urban areas in the form of natural, semi-natural and artificial ecosystems within and around the city play a vital role in supporting biodiversity (Aronson et al., 2017). But the importance of these spaces for biodiversity will depend on the size, structure and connectivity of the urban green spaces (Beninde, Veith, & Hochkirch, 2015).

Urban biodiversity provides various ecosystem services (ES), defined by The Economics of Ecosystems & Biodiversity (TEEB)[1] initiative as the direct and indirect contributions of ecosystems to human wellbeing, to city inhabitants (Elmqvist, Gomez-Baggethun, & Langemeyer, 2016). For this reason, green urban areas have been integrated in urban planning and design to ensure human well-being. However, the role of green urban areas in supporting biodiversity, ecosystem functions and human well-being have so far received insufficient attention (Aronson et al., 2017). The term Green Infrastructure has been increasingly used, to refer to biodiversity that through the delivery of ES contributes to human well-being, and is defined by the EU Strategy on Green Infrastructure as a strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ES for human society (EC, 2013).

By studying the role of urban ecosystem in the delivery of ES, how these vary across spatio-temporal scales, and the social context in which they exist we can better understand the dynamics of urban ES delivery, thus offering an opportunity to improve practice and ultimately policy. The '*ecology for the city*' paradigm, builds on traditional approaches to the studying of urban biodiversity and urban socio-ecological systems and, involves researchers in shared stewardship relationships. In this paradigm, researchers move into a 'knowledge-to-action' dimension, as they become involved in dialogue with citizens, groups, and decision-makers in order to co-produce useful and relevant knowledge to shape a more sustainable urban future (Pickett, Cadenasso, Childers, McDonnell, & Zhou, 2016).

The aim of this study is to assess how ES capacity and flow vary spatially within the Maltese Islands, and it builds on the recent work of Balzan, Caruana, & Zammit (in press) which has mapped and assessed key ES in Malta. In this work, a distinction is made between the capacity of ecosystems to deliver ES, and the flow of ES, which refers to the actual ES use. This work can provide an understanding of potential mismatches between ES capacity and flow, and hence may be used by landscape and urban planners and decision-makers to redirect ES flows to areas with a higher ES capacity or to plan and develop green infrastructure to improve the capacity of ecosystems to deliver key ES in areas with ES capacity and flow imbalances (Lovell & Taylor, 2013).

[1] http://www.teebweb.org/

Methodology

Conceptual Framework

The creation of a conceptual framework has been a key initial step in many ecosystem service initiatives. These include the iconic frameworks of the Millennium Ecosystem Assessment (MA)[2] and the TEEB initiative, which link ecosystems and ES to human well-being (Millennium Ecosystem Assessment, 2005; TEEB, 2010). Several other conceptual frameworks have been proposed and these include those used for regional and national ecosystem service assessments and other theoretical frameworks. Whilst these frameworks often differ in structure, most attempt to illustrate in some way the transdisciplinary nature of the ecosystem services paradigm by linking representations of biophysical structures and processes to human values and ultimately the benefits to peoples' well-being (Potschin & Haines-Young, 2013).

The distinction between ES capacity and flow builds on the definition of ecosystem services, which considers these as the contributions that ecosystems make to human well-being, and on existing frameworks that links ecosystems to the human society through a chain of components. Based the recent work of Balzan, Caruana, & Zammit (in press), this work distinguishes between different types of indicators to assess and map different components of this chain. Indicators for ES capacity measure the potential of ecosystems to provide services, while ES flow indicators assess the actual use of the ES. This work analyses how ES capacity and ES flows vary spatially (Figure 1), allowing for the identification of different spatial patterns of these two components.

Study area

The Maltese Islands are a group of low-lying small islands situated in the Central Mediterranean Sea at 96 km south of Sicily, almost 300 km east of Tunisia and some 350 km north of the Libyan coast. The Islands have a long cultural history, and human activity has for been a strong factor acting on the Islands' landscapes over millennia. Today agricultural land cover occupies around 51% of the territory, whilst built-up, industrial and urban areas occupy more than 30% of the Maltese Islands (MEPA, 2010). Malta has today has the highest population density in Europe along with a booming tourism industry.

Mapping of ecosystems and their services

A land use land cover (LULC) map was created through the use of Sentinel 2 satellite images provided by Copernicus (Drusch et al., 2012). These were processed and mapped by applying a supervised multispectral classification with the maximum likelihood method. Sentinel 2 is a multispectral satellite developed by ESA, as part of the Copernicus land monitoring system, and has a spatial resolution of up to 10 m (Drusch et al., 2012). The final classification consisted of a LULC map with a total of 13 classes, as described in Balzan, Caruana, & Zammit (in press).

The assessment and mapping of ES was performed through the use of the developed LULC map for the study area in combination with other data sources (Table 1). The calculation of the selected indicators is described in detail in Balzan, Caruana, & Zammit (in press). In addition, data provided by national authorities is also used in this work. The area of green infrastructure in each local council was calculated from the generated LULC map. Given that green infrastructure is considered as being

[2] https://www.millenniumassessment.org/en/index.html

multifunctional, providing a wide range of ES (EC, 2013), the cover of ecosystems contributing to the delivery of multiple ES was summed up for each local council. Population size data in 2014 was obtained from the Demographic Review (NSO, 2016).

Data Analysis

An assessment of the spatial variation of ES, and their capacities and flows, was carried out through a statistical analysis of the generated ES maps (Balzan, Caruana, & Zammit, in press). Total ES capacity and flow were calculated for each local council. The data was then centred and scaled, producing standard Z-scores for each ecosystem service, and checked for multivariate normality. In order to analyse the spatial variation of the ES a Principal Component Analysis (PCA) was carried out. To provide an indication of the association between the spatial overlap of ES and the different LULC classes, cover data for each of these was fitted on the PCA ordination plot (Oksanen et al., 2016).

In order to assess the contribution of green infrastructure to the ES capacity and flow within the study area, average z-scores for each local council were calculated. A regression analysis and generalised linear models were used to estimate the relationship between the ES score and ecosystems contributing to the green infrastructure within each grid.

We used QGIS 2.18 Las Palmas Geographical Information Systems to produce ES capacity and flow maps, and all data analyses were conducted in R (R Core Team, 2016).

Results and Discussion

Spatial patterns in green infrastructure availability and ES delivery

In general, the PCA results demonstrate how the multifunctional landscapes of the study area, characterised with semi-natural and agricultural habitats, are associated with the delivery of multiple ES (Figure 2). Principal component 1 (PC1) corresponded to an axis that varied from urban to agricultural and semi-natural land cover, and explained a total of 35.8% of the total variance of ES data. Agricultural area and honey production were negatively related to PC1. Principal Component 2 (PC2) explained 27.3% of the ES variance, and corresponded to a gradient from agricultural and semi-natural habitats to urban land uses. All ES were positively related to PC2, whilst urban cover was negatively associated with PC2. Each of the remaining PC explained 12% or less of the additional variance in ES. These results demonstrate spatial variation in the delivery of the ES in the Maltese Islands and that this is determined by the presence and type of green infrastructure. Generally, low ES capacity and flow were recorded in the Southern and Northern Harbour districts, whilst the Western and Northern Districts and the Gozo and Comino district were associated with higher ES capacity and flow (Figure 3).

The presence of green infrastructure appears to be an important factor affecting ES delivery. A linear regression was performed on green infrastructure cover and ES capacity and flow data. ES capacity was positively associated with green infrastructure (ES capacity = 0.014 x GI – 0.69; $R^2 = 0.37$; $F(1, 66) = 40.09$; $p<0.001$; Figure 4a), whilst no significant association was recorded between green infrastructure cover and ES flow ($F(1, 66) = 0.07$; $p = 0.79$). A generalised linear model with a log model link function was used to assess the relationship between population density, expected to be higher in urban areas, and the availability of green infrastructure. Urban areas associated with higher population densities had the lowest green infrastructure cover (Figure 4b; $p=0.04$), confirming the PCA

results and suggesting a limited availability of green infrastructure in local councils with high urban development and population density. This appears to translate into lower ES delivery in dense urban areas, as the ES capacity was also negatively associated with population density (ES capacity = 70.92 - 0.007 x Density; $R^2 = 0.71$; $F(1, 66) = 164$;$p < 0.001$, Figure 5a) and population size (ES capacity = 58.6 – 0.001 x Population; $R^2 = 0.04$, $F(1, 66) = 4.41$, $p=0.04$; Figure 5b). The ES flow was not significantly associated with population density ($F(1, 66) = 0.47$; $p=0.49$) but it was negatively associated with population size (ES flow = 0.39 – 0.0001 x Population; $R^2 = 0.25$; $F(1, 66) = 23.86$; $p <0.001$; Figure 5c).

Studies that investigate the spatial patterns of green infrastructure and the variation of ES are important for policy-making and urban planning, and in order to ensure that spatial policies create a balance between ES capacity and flow (Schröter, Barton, Remme, & Hein, 2014), and to optimise the availability of green infrastructure for improved human well-being (Roces-Díaz, Díaz-Varela, & Álvarez-Álvarez, 2014). Urban areas do not necessarily provide fewer ES compared to other regions, as urban green infrastructure, such as tree cover or peri-urban agriculture, can significantly contribute to support biodiversity and ES delivery (Dennis & James, 2016; Larondelle & Haase, 2013). This is also confirmed by results obtained in this study and by Balzan, Caruana, & Zammit (in press), which demonstrate that ES delivery is driven by the availability of green infrastructure and that there is a generally low availability of green infrastructure in cities with high urban land cover.

Results presented here demonstrate a strong dependence of cities on the capacity of rural landscapes, characterised by a matrix of agricultural land covers and semi-natural habitats (Balzan, Caruana, & Zammit, in press), to deliver key ES. Similarly, Tratalos et al. (2007) found a reduction in green space coverage and potential ES delivery in highly dense urban areas in the UK, whilst Łowicki and Walz (2015) found a general decrease in ES capacity in the Dresden (Germany) and Poznan (Poland). In this study, the actual use of ES (flow) was not significantly associated with green infrastructure cover in each local council. This is similar to results obtained by Balzan, Caruana, & Zammit (in press) and Baró et al., (2016), who demonstrate that air quality ES flow, measured as pollutant removal flux, is higher in urban green areas in proximity to areas with high traffic pollution whilst Baró et al., (2016) found a highest flow of recreational ES in forest areas surrounding urban settlements in Barcelona. Hence, whilst non-urban ecosystems are generally more effective at increasing ES capacity (e.g. due to the dominance of agricultural LULC), the flow per unit area is higher in cities where these ecosystems are more strongly used by inhabitants.

Green infrastructure to create liveable cities

The lack of green infrastructure in cities is associated with a limited access to green urban areas and a reduced capacity to deliver key ES. Other studies have shown that the use of green urban areas may lead to significant benefits to human well-being, amongst others through, improved food security and increased biodiversity (Dennis & James, 2016), removal of air pollution (Balzan, Caruana, & Zammit, in press; Baró et al., 2016), increased water infiltration and local climate regulation (Pataki et al., 2011), improved mental health (Alcock, White, Wheeler, Fleming, & Depledge, 2014), reduced stress and lower likelihood of obesity (Nielsen & Hansen, 2007), and increased opportunities for recreation (Casado-Arzuaga, Onaindia, Madariaga, & Verburg, 2013).

Several cities have set threshold values for a per capita availability of urban green infrastructure, which are used to improve the management of green infrastructure in cities and to steer this towards human well-being and sustainability. For instance Berlin's Department of Urban Development and the Environment recommends that every resident should have access to urban green infrastructure with a minimum of 0.5 ha within a 500 m distance from home whilst Natural England, non-departmental public body advising the UK government, recommends that city residents should have access to a

natural green space of a minimum of 2 ha within a distance of 300m from their home, and finally the European Environment Agency recommends that people should have access to green space within a 15-min walking distance (900-1000m) (Kabisch, Strohbach, Haase, & Kronenberg, 2016). Results presented in this work indicate that there may be a generally low availability of green infrastructure in urban areas that are more densely populated. These results are also supported by those obtained by Kabisch, Strohbach, Haase, & Kronenberg (2016), who measured accessibility of green urban areas in European cities and demonstrate that several Southern European cities, including those in Malta, show below-average availability and accessibility of green urban areas to the city inhabitants, whilst in general Northern European cities, and particularly Scandinavian cities, show the opposite.

The negative associations between green infrastructure and urban development and between ecosystem service provision and population parameters (population size and density) demonstrate the need to (1) develop our understanding of biodiversity patterns in the city and (2) to soften the landscape to increase urban green infrastructure and biodiversity, and ES delivery. The development of an understanding of urban ecosystems, the responses of the biodiversity to urbanisation, and the type of biodiversity and design elements (ecosystem structure) that contribute to an improved use by local communities and which lead to enhanced human well-being is a key priority. This knowledge is critical to the development of measures in landscape and urban planning that provide the right green infrastructure, for example in the form of urban tree cover, gardens and urban green spaces, sustainable urban drainage systems, green roofs and walls and others, necessary to facilitate the conservation of urban biodiversity in otherwise highly fragmented urban ecosystems and for a sustained ES delivery to the urban population and human well-being. Within an 'ecology for the city' *transdisciplinary* paradigm, urban scientists and planners along with local communities, and normally through the use of participatory approaches, co-produce knowledge about urban ecosystems and their services, and identify solutions for improved adaptation and urban resilience (Pickett et al., 2016).

Limitations of this study

A key limitation of this work is that it is based on proxies to estimate ES capacity and flow. Whilst the used proxies have often been implemented in other similar studies conducted at local and European scale (example in Maes et al. (2016) and Baró et al. (2016)), there is potential for error if the used proxies are not good spatial predictors within the area of study. However, there is also general limitation associated with the data availability for the measurement of ES that may be used to validate models adopted by this work. This observation is congruent with others made elsewhere that ES information at smaller scales is less likely to be available at local scales rather than for example at regional scales (Hauck et al., 2013; Rodríguez-Loinaz, Alday, & Onaindia, 2014). The role of small and discrete ecosystems, which are often of significant ecological importance, may be underestimated in this study. Similarly, coastal and marine ecosystems provide several key ES within the study area. Through its focus on the landscapes of the Maltese Islands and the provision of key ES that are predominantly provided by terrestrial ecosystems, this work does not capture the important role of coastal and marine ecosystems in the delivery of ES that lead to human well-being in an insular environment. The limitations of the ES mapping and assessment methodology have been discussed in more detail by Balzan, Caruana, & Zammit (in press).

Conclusion

This paper has presented an analysis of the spatial variation of green infrastructure and ES capacity and flow in the Maltese Islands. It provides evidence that green infrastructure, in the form of semi-natural and agricultural and urban ecosystems, provides a range of ecosystem services (ES capacity) and partly determines where the use of the ES occurs (flow). A negative association has been recorded between green infrastructure with population size and density parameters, indicating that highly urbanised environments are characterised with lower ES provisioning, affecting human well-being. This work demonstrate the need for the co-production of knowledge on urban biodiversity and ES in a transdisciplinary approach and the importance of developing the urban green infrastructure in cities for improved human well-being.

Tables

Table 1- Mapping ecosystem services capacity and flow. Indicators for ES capacity and flow and the relevant data source are shown.

Ecosystem Service	*Indicator*	*Capacity/Flow*	*Source*
Food Production	Agricultural Area	Capacity/Flow	Mapped agricultural area in LULC map in Balzan, Caruana, & Zammit (in press)
	Livestock/Km2	Capacity/Flow	National Statistics Office (NSO)
Honey Production	Beekeepers' Habitat Preference	Capacity	Balzan, Caruana, & Zammit (in press)
	Number of bee hives	Flow	Veterinary and Phytosanitary Regulation Department
Air Quality Regulation	NO_2 deposition velocity (mm/s)	Capacity	Balzan, Caruana, & Zammit (in press)
	NO_2 removal flux (ton/ha/year)	Flow	Balzan, Caruana, & Zammit (in press)
Aesthetic	Number of habitats of community importance	Capacity	Balzan, Caruana, & Zammit (in press)
	Preference Assessment with locals (Frequency of responses)	Flow	Balzan, Caruana, & Zammit (in press)

Figures

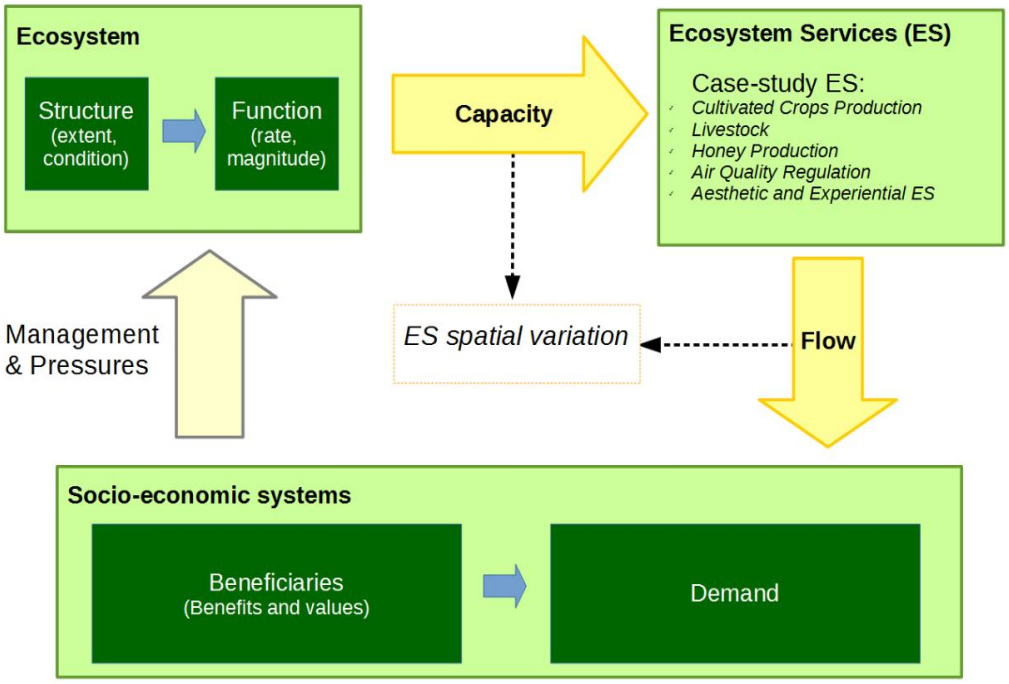

Figure 1 – General conceptual diagram linking ecosystems' capacity and the flow of ES to human well-being. Block arrows indicate the relationship between the ecosystem, ecosystem services and socio-economic systems, while dashed arrows indicate the level of analysis in this study through the identification of spatial overlap and patterns in ES delivery (Adapted from Balzan, Caruana & Zammit, in press).

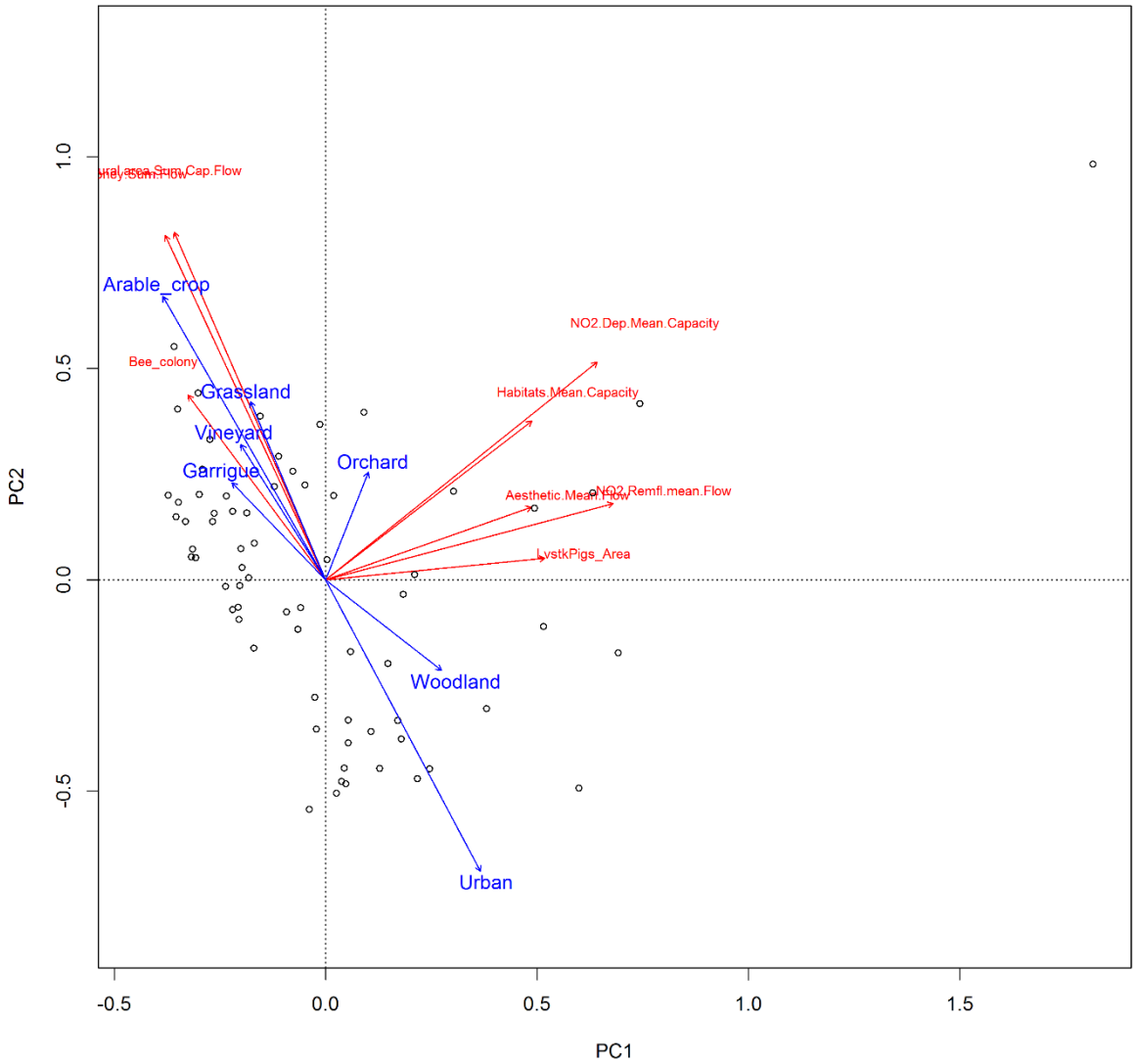

Figure 2 - Principal Component Analysis of multivariate data for the total ES capacity and flow for each local council, with area of LULC category fitted on the PCA ordination plot for significant variables (p<0.05 when using 1000 random permutations of the category levels).

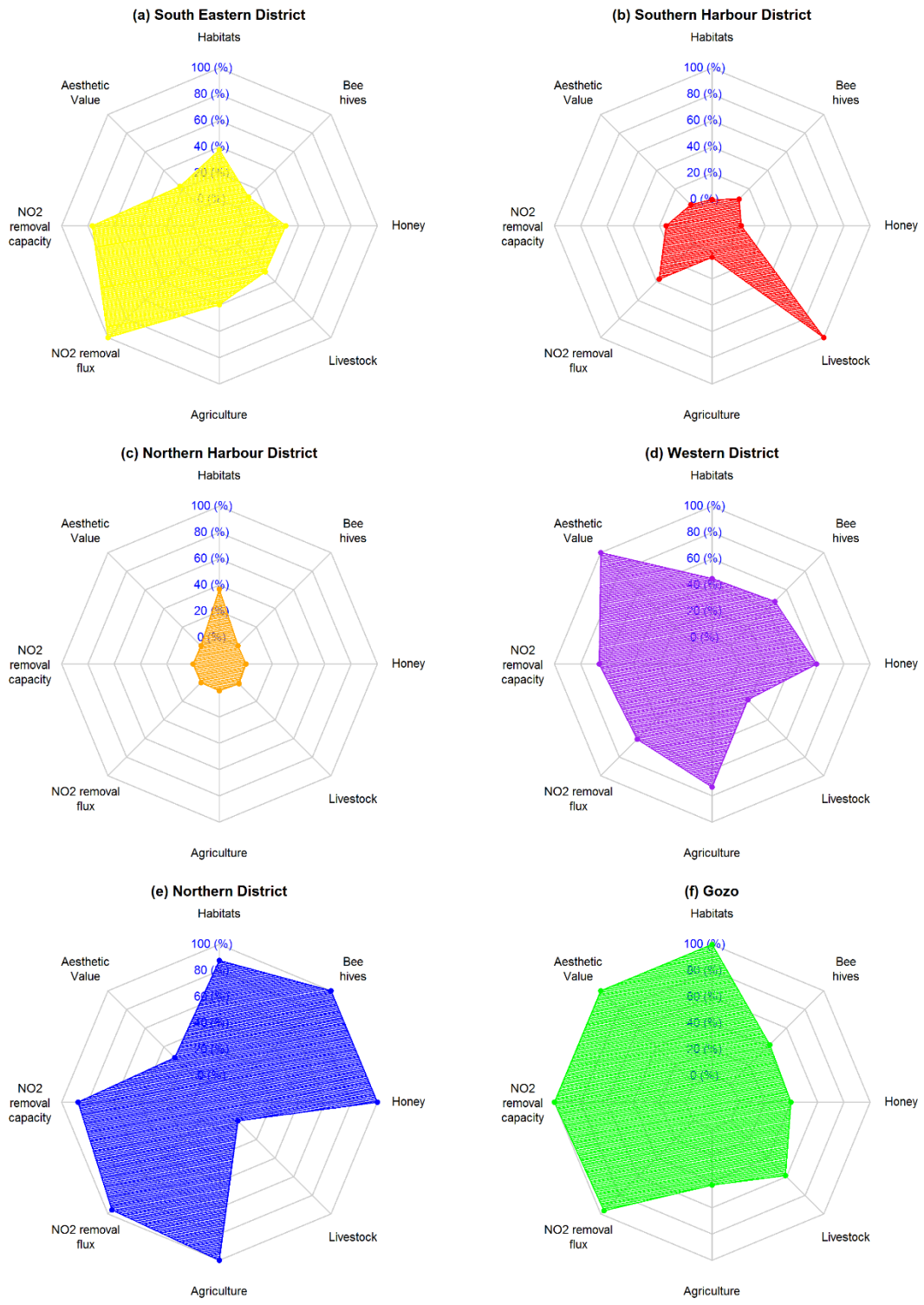

Figure 3 – Assessing the capacity and flow of ecosystem services in different districts of the Maltese Islands.

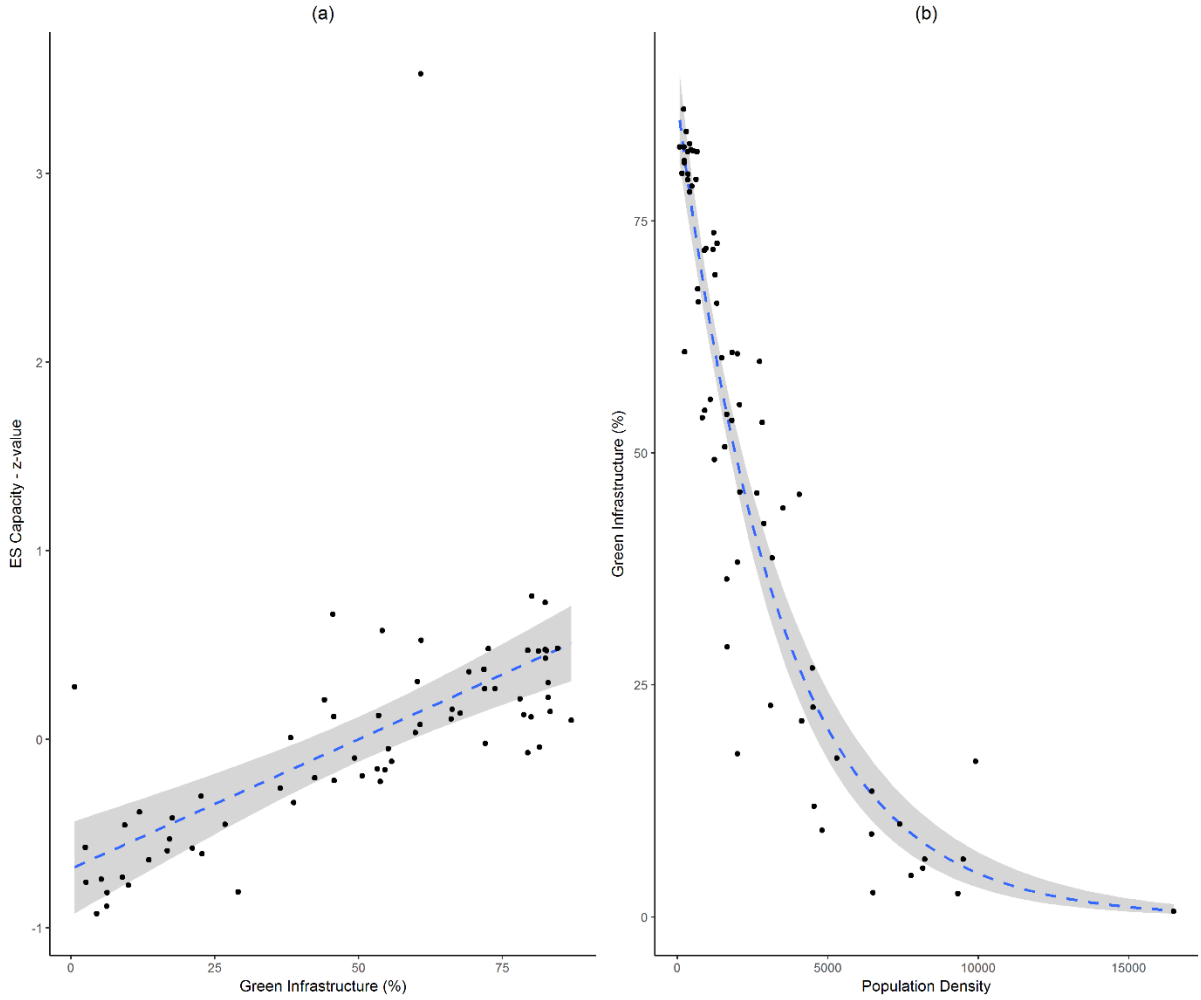

Figure 4 (a) Assessing the relationship between green infrastructure cover (GI) in each local council and average ES capacity. (b)

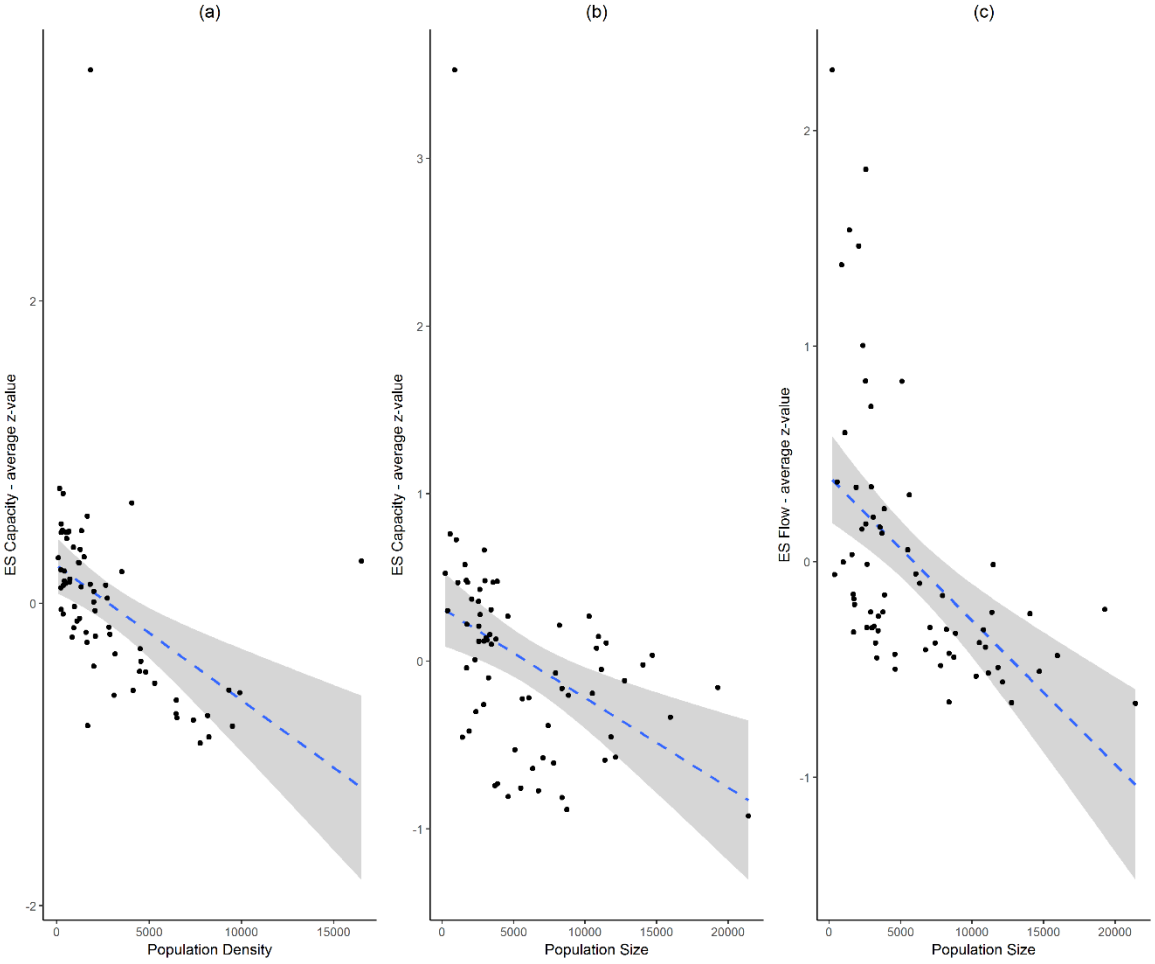

Figure 5 – Scatterplots presenting the association between (a) ES capacity and population density, (b) ES capacity and population size and (c) ES flow and population size for local councils in Malta. Lines represent the linear regression function and 95% confidence intervals plotted on the scatterplot.

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