Landscape modeling and metrics for improved integration of urban land change processes and biodiversity indicators in urban management in Mediterranean coastal zones

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Zusammenfassung

Die Zielsetzung des Beitrags ist (1) die Ableitung raum-zeitlicher Biodiversitätsmaße und Landschaftsveränderungen, (2) die Modellierung des Landbedeckungswandels und der Habitatgefährdung, und (3) die entscheidungsunterstützende, praxisrelevante Visualisierung und Präsentation der Ergebnisse für eine nachhaltige Gestaltung urbaner Transformationsprozesse in Küstenregionen des Mittelmeerraumes. Die Landschaftsanalyse integriert Daten über das Verbreitungsgebiet einer Zielart mit multitemporalen Landbedeckungs- und Biotopkarten unterschiedlicher Maßstabsebenen. Die Auswertungen erfolgen mit Geoinformationssystemen und der integrierten Softwareumgebung „Land Change Modeler for Ecological Sustainability", die Funktionalitäten zur Analyse und Vorhersage von Landbedeckungsveränderungen bietet und sich am sehr spezifischen Analysebedarf zum Biodiversitätsschutz orientiert. Der landschaftsanalytische Ansatz, hier am Beispiel Mallorcas dargestellt, dient der Vertiefung des Systemverständnisses und ist übertragbar auf vergleichbare urbane Kontexte und Regionen.

Abstract

This paper pursues three objectives: (1) derivation of spatially explicit information on past and present biodiversity measures and land change processes; (2) modeling vulnerability to land change, and (3) presentation of results in a suitable format to inform decision-making in urban conservation and planning. Data and maps on species range, land cover and biotopes over a range of temporal and spatial scales are analyzed. The GIS software extension Land Change Modeler for Ecological Sustainability is employed for land change analysis, prediction, and the examination of impacts on habitat and biodiversity. Results may be used for ecological sustainability studies and land planning scenarios. Illustrated for a case study in Mallorca, the workflow could serve as an analysis framework in similar contexts.

1. Background and Motivation

The characteristic process of spatial transformation in an increasing number of Mediterranean coastal municipalities is the expansion of urban and tourist areas. Land cover change detected from comparison of CORINE Land Cover data for 1990 and 2000 showed that already highly populated coastal strips were hot spots of urban sprawl and fragmentation (EEA 2006). Often linked to the development of second homes and an increasing preference for suburban environments, more disperse land use and land cover patterns evolve that can have significant impacts on land resources and ecosystem services. Urbanization typically results in a reduction in biodiversity of native species and landscape diversity, and these effects may be manifest for several decades following urban development and sprawl (HANSEN et al. 2005). In the framework of ecosystem services, biodiversity is one of the most abstract concepts. Biodiversity is rather part of complex mechanisms and processes that generate supporting and provisioning services than an ecosystem service per se (HAINES-YOUNG & POTSCHIN 2010). Current scientific evidence is indicative rather than conclusive as to which causal links exist between biodiversity and human well-being. In the face of the ongoing semantic and analytical challenge and debate, the present paper follows "the contention that for various measures of biodiversity there is a positive association with a number of different measures of ecosystem functioning." (HAINES-YOUNG & POTSCHIN 2010, 122). Hence, monitoring of biodiversity responses in relation to land cover change is an important contribution to the assessment of the effects of environmental change drivers on ecosystem services (HAINES-YOUNG 2009).

The objective of this paper is to demonstrate and discuss landscape ecological methods and workflows to support the knowledge to action transfer into urban management. Landscape ecological knowledge that is condensed via appropriate methods, means of visualization, and mapping is relevant for urban and conservation planning. Moreover, it may inform decision-making that aims at urban development patterns which avoid land conversion where the richness of spatial patterns exhibited by habitat mosaics and landscapes is high and thus potentially supportive to biodiversity and ecosystem functioning. The usefulness of scientific information for urban practice and the likelihood of its integration in decision-making are probably related to the question whether or not biodiversity or conservation issues are already on the agenda of urban planning, policy, and decision-making.

These key aspects are outlined for a case study in Mallorca. The island illustrates the transformation of the economy, society and environment of Mediterranean coastal zones. Links between landcape

[1] The term 'land cover' refers to physical surface characteristics of land as opposed to its economic and social functions that are usually referred to as 'land use' (HAINES-YOUNG 2009). For ease of reading and convenience, no distinction is made and the term 'land cover' is used throughout the remainder of the text.

pattern, land change processes, and biodiversity indicators are explored for the spur-thighed tortoise (*Testudo graeca*), a long-lived endangered terrestrial tortoise inhabiting the Mediterranean region. The species is in serious decline throughout its range due to habitat loss and fragmentation (COX & TEMPLE 2009). The analysis draws on data and maps on species range, land cover, and biotopes over a range of temporal and spatial scales. Land Change Modeler for Ecological Sustainability is used for landscape modeling and metrics calculation. Land Change Modeler (LCM) is an integrated modeling environment of IDRISI Taiga and also available as ArcGIS extension (EASTMAN 2009; PAEGELOW & CAMACHO OLMEDO 2008). The focus is on the conceptual issues of integrating field and sample-based approaches with broader scale information on habitat distribution (e.g. from remote sensing). Another aspect is the integration of biodiversity indicators with empirical information on land change, in particular when intending a use of these tools and their output to inform decision-making and planning.

2. Materials and Methods

2.1 Study area, maps and geodata sources

Mallorca is the northernmost distribution of *T. graeca* whose range is restricted to Calvià municipality in the southwest of the island. Conservation efforts in Mallorca have been in practice since the 1980s, with conservation legislation for the species in effect since 2005. Species range maps of 2007 show an 80% decrease since 1979 (Figure 1), with most of the habitat loss (-63%) occurring between 1990 and 2007 (AGUILAR 1990; LÓPEZ JURADO et al.1979; PINYA & CUADRADO 2008). Habitat loss and species decline in the municipality of Calvià is a facet of the impacts of coastal urbanization on biodiversity in one of the major Mediterranean tourist resorts with an internationally acclaimed Local Agenda 21 and sustainable development as its overarching policy objective (compare HOF & SCHMITT 2008).

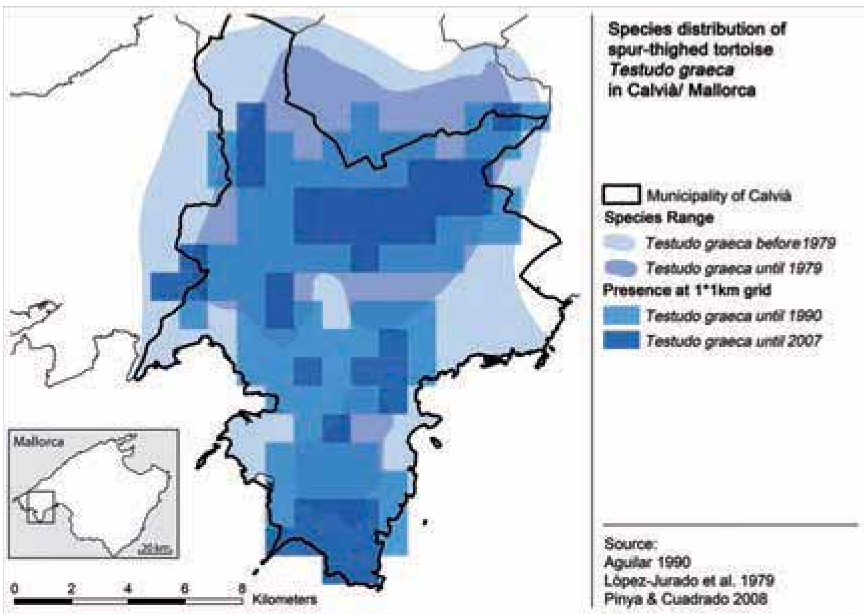

Fig. 1: Distribution range and multitemporal species range grids for *Testudo graeca* in Mallorca. The Balearic Islands are the northernmost distribution range of *T. graeca*, which is found in Mallorca only in Calvià municipality.

Like other reptiles, *T. graeca* has low movement capabilities with home ranges of around 3 hectares for male and 1.5 ha for female individuals. The species is bound to natural and semi-natural Garigue and Maquis vegetation and is very sensitive to anthropogenic disturbance and fragmentation of its habitats (ANÁDON et al. 2006). The lack of information identified in a conservation plan of the Balearic Environment Agency (CONSELLERIA DE MEDI AMBIENT 2009) is taken as a starting point. In this conservation plan, the need to assess the current habitat status and species range of the spur-thighed tortoise (*T. graeca*) is outlined with explicit reference to landscape analysis (e.g. fragmentation and connectivity), but tangible tools or methods are not specified.

Implementation of the conservation plan for the species would ideally consider priority areas for urban nature conservation in the next municipal land use plan revision. However, improved urban management requires a more integrated valuation of biodiversity. In the present analysis framework, the concern is for the vulnerability of tortoise habitat because its protection has wider implications as it stands for semi-arid Mediterranean shrublands that are protected under European directives and agro-environment schemes (ANÁDON et al. 2006). Therefore, either an optimization approach for reserve selection is taken or the focus is on multifunctionality of the landscape that is represented as species range of *T. graeca*. The latter approach is presented here and LCM is employed for the spatially explicit prediction of vulnerability to land cover change to map out the potential consequences of a business-as-usual scenario. Biodiversity, landscape pattern and change process analysis are carried out to convey the process of landscape transformation and its impacts on tortoise habitats in the past.

For landscape ecological analysis the approach integrates data and maps from broader to larger spatial scales. Long-term species range data for 1 km x 1 km grids is available in geodata portals and published literature (AGUILAR 1990; GOVERN DE LES ILLES BALEARS 2009; LÓPEZ JURADO et al. 1979; PINYA & CUADRADO 2008). Land cover maps at scale 1:50,000 for the whole island of Mallorca in 1956, 1973, 1995, 2000, and 2006 were provided by Geographers at the Earth Science Department of the University of the Balearic Islands in Palma de Mallorca (GIST 2010; PONS 2003). Semantically, the maps follow the CORINE land cover classification scheme with 11 classes in 5 categories. The present analysis was carried out for 8 land cover classes and three aggregated land cover 'regions' (artificial surfaces, agricultural areas, and forest and semi-natural areas).

Biotope maps at 1:2,000 scale based on field research in 1992 (SCHMITT 1999) in 2008 (MÖRTL 2008), and 2010 (scale 1:5,000) were used. The biotope maps adhere to the classification methodology described in SCHMITT (1999). All analyses were carried out with the Geographic Information System (GIS) software ArcGIS 9 and the extension Land Change Modeler for ArcGIS.

2.2 Biodiversity, Landscape Pattern and Change Process Analysis with Land Change Modeler for Ecological Sustainability (LCM)

The change process option in LCM was used to compare the 1973 and 2006 land cover maps (GIST 2010). The output map is in the form of a map that depicts the nature of the change underway within each land cover class. Edge density, as a spatially explicit measure of fragmentation, was calculated in LCM for the earlier and later land cover maps and the results were combined with map algebra to map out areas where fragmentation changed (increase or decrease) between 1973 and 2006 or not.

Biodiversity analysis with LCM links species presence and land cover data to produce spatially explicit mapping of regional richness for the land cover maps of 1973 and 2006 and species turnover for the land cover maps of 2006 and the biotope map of 2010. LCM first calculates species richness (total number of species at each location, alpha diversity) for a user-defined focal zone around each pixel. Computationally, regional richness (gamma diversity) is calculated as the total number of species over a region (e.g. land cover class). Species turnover (beta diversity) is calculated as gamma diversity divided by the average alpha diversity within each region (EASTMAN 2009). With a single species used to exemplify the concept here, maximum species richness is 1. All raster cells within a region are assigned the regional species richness as an index value. Regional richness maps can be understood as abstractions of a region's capacity to deliver supporting services such as biodiversity-enhancing landscape structures. LCM yields a mapping of species turnover that is conceptually a measure of the change in species diversity between different locations or regions. With a single species mapped, species turnover is a measure of dissimilarity of species presence between land cover and biotope classes.

2.3 Statistical test

While the identification of important landscape properties that are supportive for *T. graeca* and hence biodiversity is based on spatially explicit analyses, non-spatial approaches deliver supplementary insights into the patterns of change. For an assessment of the impact of tourist and urban land cover change on the habitat status of the species, it is first tested whether differences in landscape composition or long-term rate of land cover change are apparent between species grids where the tortoise persisted in 2007 versus those grids where its occurrence was observed only until 1990. The species range grids and population densities where adapted from the online geodata Bioatlas and the literature (CONSELLERIA DE MEDI AMBIENT 2009). The proportion of biotope types in each grid was summarized by category from the biotope map (2010) at 1:5,000 scale and the long-term rate of land cover change (1973, 1995, 2000, and 2006) was assessed for each grid from the land cover maps at 1:50,000 scale. The differences between the species' presence and absence grids are tested with the Mann-Whitney U-test, the non-parametric alternative to Student's t-test that is most commonly used when there is one nominal variable with only two values (here species absence or presence) and one measurement variable (proportion of biotope types or long-term rate of land change), and the measurement variable does not meet the normality assumption. After ensuring that the observations in the absence and presence grids have the same shape of distribution, the following null-hypotheses were tested:

- Based on the biotope map of 2010 at 1:5,000 scale, the proportion of biotope types in the species range grids (1 x 1 km) where *T. graeca* was absent (n=20) is equal to the proportion of biotope types in the species range grids where the species was present in 2007 (n=15).
- Based on the multitemporal land cover maps at scale 1:50,000, the mean long-term rate of land cover change per species range grids (1 x 1 km) where *T. graeca* was present in 2007 (n=40) is equal to the mean long-term rate of land cover change for those grids where *T. graeca* was present from 1979 until 1990 but absent in 2007 (n=64).

2.4 Land cover change prediction with Land Change Modeler

The land change analysis and modeling process uses 1:2,000 scale biotope maps for a 1,045 ha subset of the *T. graeca* distribution range in Calvià in 1992 (SCHMITT 1999) and 2008 (MÖRTL 2008). It is important to note that the modeling logic for the spatial allocation of change and the temporal rate of change implemented in LCM assumes that the *nature* of change stays the same. Planning interventions (e.g. new reserves) and infrastructure maps (e.g. roads) can be considered in the change prediction. Static (e.g. elevation) and dynamic (e.g. distance to already built-up land) driver variables can be included that are recalculated during modeling steps. The biotope maps of 1992 and 2008 were used to model the future transition of natural and semi-natural biotopes to artificial surfaces in a business-as-usual scenario until 2015. Transitions from eight natural and semi-natural biotope types to artificial surfaces were grouped in the sub-model "soil sealing". Proximity to the coast and empirical transition potentials were set as static driver variables, and proximity to existing artificial surfaces as dynamic driver variable. The modeling approach was described in detail in an earlier article where the focus was on habitat suitability mapping and observed as well as potential habitat loss (compare MICHEL & HOF 2011). In this paper, the multi-criteria workflow is similar and the resulting continuous mapping of vulnerability to the modeled change, i.e. urbanization, is used for a what-if scenario to identify and map biotope structures at scale 1:2,000 that have functional importance for *T. graeca* and are vulnerable to change (Figure 2).

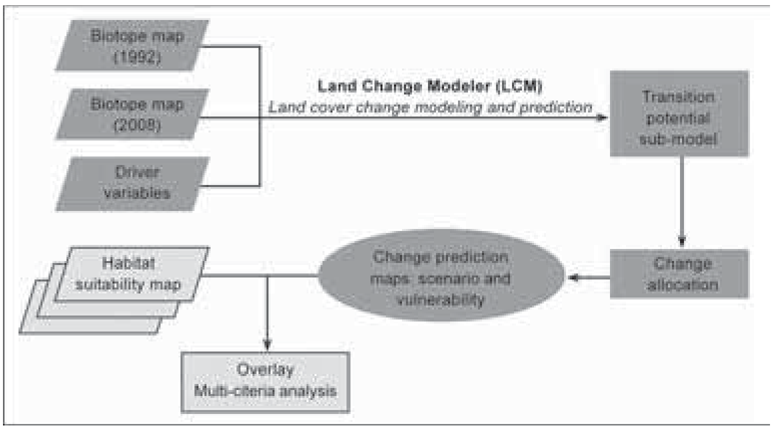

Fig. 2: Schematic workflow for integrating land cover change modeling and prediction to solve multi-criteria problems such as priority site selection for urban nature conservation or habitat management.

3. Results and discussion

3.1 Land change process

In terms of absolute gain, urbanization dominated the land cover change process from 1973 to 2006 in the distribution range of *T. graeca* (Figure 3). Two thirds of the urban fabric in 2006 had transitioned since 1973 from other land cover classes, with urbanization targeting mainly for forest, permanent crops, and arable land. Relative to the initial area of each land cover class in 1973, agricultural areas experienced the highest losses by 2006, followed by forests and semi-natural areas (scrub and/or herbaceous vegetation associations and open spaces).

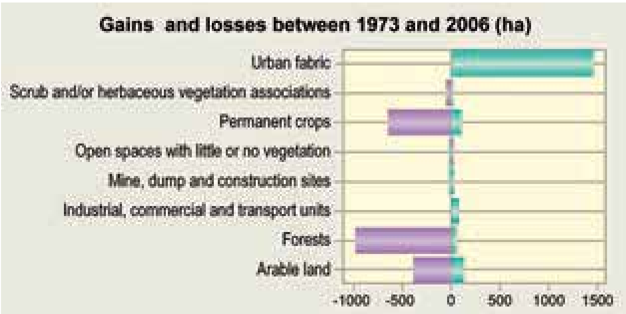

Fig. 3: Quantitative assessment of past land cover change in the distribution range of *Testudo graeca* in Calvia municipality, Mallorca. Own analyses of 1:50,000 land cover maps (GIST 2010).

Long-term change resulted in an artificialisation of the landscape, in particular along the coast (Figure 4, left). This change process map is the result of a decision tree procedure that compares the number of land cover patches present within each class between the two time periods to changes in their areas and perimeters. Three change processes occurred:

- **Attrition** of forests and agricultural areas with a decrease in number and area of patches
- **Aggregation** of urban fabric and open spaces, i.e. the number of patches is decreasing but the area is constant or increasing
- **Creation** of urban fabric: increase in number and area of patches

The analysis of long-term changes in landscape fragmentation (edge density) shows that *T. graeca* tended to persist where edge density hardly changed or decreased (Figure 4, right). In 90% of the *T. graeca* range grids in 2007 (n=40), the majority of raster cells experienced a decrease in fragmentation since 1973, in 53% of the range grids, edge density purely decreased. The biodiversity analysis discussed in the next section focused on the southern part of *T. graeca's* species range (Figure 4, right) because long-term urbanization and recent urban sprawl (1990-2006) were concentrated in this area (compare HOF & SCHMITT 2008).

3.2 Biodiversity analysis: Species turnover and regional richness

The focus for discussing the results is on the regional richness of *T. graeca* mapped to land cover classes in 1973 and 2006. The spatial extent of the analysis is that of the biotope map of 2010 which covers 32.2% of the species range in 2007 (Figure 4 and 5). In this area, continued urban sprawl, pressure on nature conservation areas and highest species densities coincide. In addition, sizable parts of the area may be designated as land for future urban development in the next planning revision and therefore, the analysis concentrates on this part of the species range. Regional richness decline between 1973 and 2006 follows the intuitive pattern of decrease in species range (Figure 5). The shift in regional richness conveys the impact of change processes (Figure 4) on biodiversity (Figure 5), and for planning purposes an additional juxtaposition of regional richness of land cover classes in 1973 and 2006 is instructive (Table 1). Clearly, presence of *T. graeca* is high in forests and semi-natural areas.

Relative to 1973, agricultural areas have recorded higher presence in 2006 which may be related to qualitative alterations of land cover, mainly due to abandonment of agricultural land and consequent proliferation of habitat patches at different successional stages. Species turnover is mapped to land cover classes and biotopes to show the effect of map scale and thematic depth (Figure 6). Owing to smaller scale, the mapping of species turnover to land cover classes (2006) suggests a steeper wild-urban gradient when compared to biotope dissimilarity (2010). Landscape heterogeneity is better represented when species turnover is mapped to the biotopes, in particular in the forest and semi-natural areas (Figure 6). The Natura 2000 site (Cap de Cala Figuera) covers 13 km² and clearly stands out in the biotope map as an area where species turnover is medium to low and landscape heterogeneity is high. The proximity of the Natura 2000 site to urban areas and the major tourist resorts is a reason for concern and the land change modeling concentrates on this area. The maps of change process, edge density change, regional richness, and species turnover complement each other and convey spatially explicit information on biodiversity-enhancing landscape structures (Figure 5, Figure 6).

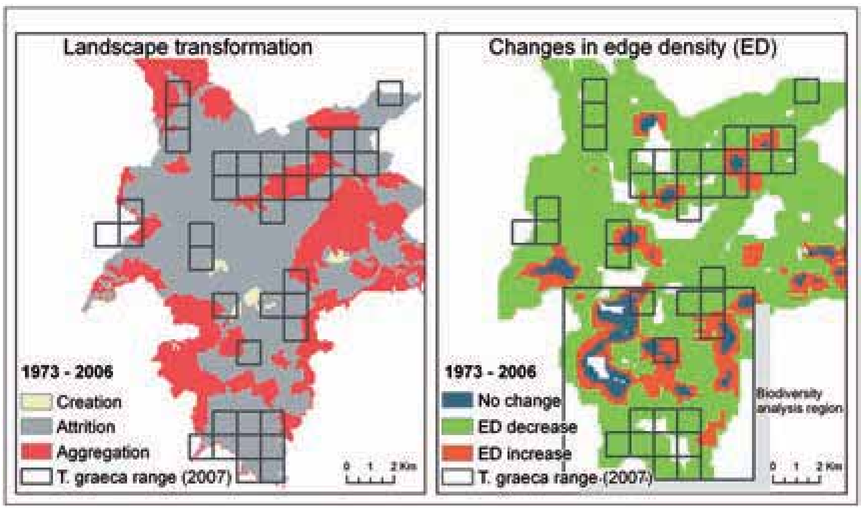

Fig. 4: Change process and landscape fragmentation in the distribution range of *Testudo graeca* in Calvià municipality, Mallorca. Own analyses of land cover maps at 1:50,000 scale from GIST 2010.

Rank	Land cover class (1973)	Rank	Land cover class (2006)
1	Forests	1	Forests
2	Scrub and/or herbaceous vegetation associations	2	Permanent crops
3	Permanent crops	3	Arable land
4	Open spaces with little vegetation	4	Scrub and/or herbaceous vegetation associations
5	Urban fabric	5	Urban fabric
6	Arable land	6	Open spaces with little vegetation
7	Industrial, commercial and transport units	7	Industrial, commercial and transport units
8	Mine, dump and construction sites	8	Mine, dump and construction sites

Tab. 1: Regional richness of *Testudo graeca* mapped to land cover classes. The values were converted to standard scores and ranked for better comparison. Data source: Own calculations with land cover maps at 1:50,000 scale (GIST 2010).

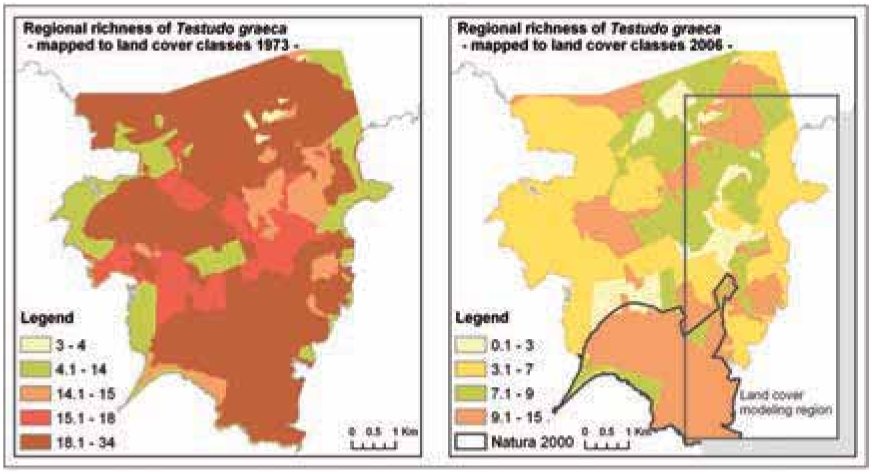

Fig. 5: The richness of *T. graeca* over land cover classes at 1:50,000 scale (GIST 2010) as regions. The value recorded at any raster cell represents the richness within the region to which it belongs and not the richness at that particular location.

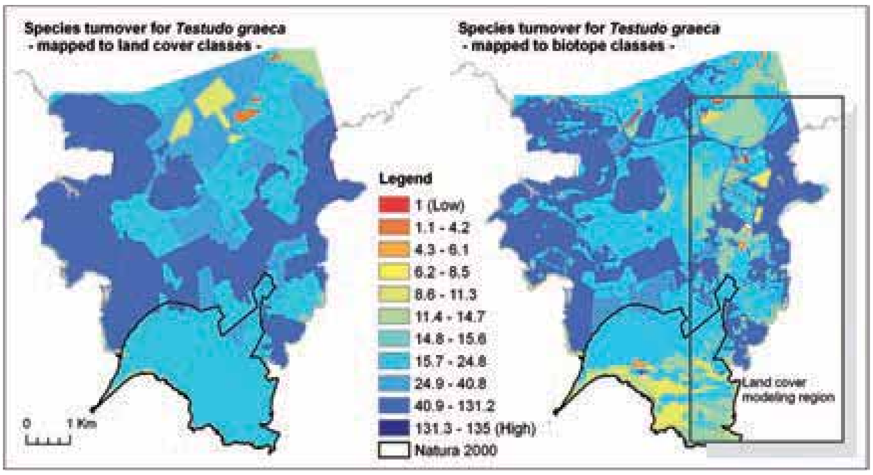

Fig. 6: Species turnover measured as dissimilarity of species presence between 1:50,000 scale land cover (GIST 2010) and 1:5,000 scale biotope classes.

The mean ranks of the long-term growth rate of artificial surfaces (1973 to 2006) are significantly different among the presence and absence grids of *T. graeca* (.02 level for a non-directional test). The null hypothesis cannot be rejected for the long-term rate of change in agricultural areas, forests and semi-natural areas (Table 3).

It can be concluded that the urbanization rate has played an important role in influencing the decrease in population and species range of *T. graeca.* These results are consistent with the observation that the species prefers intermediate successional vegetation stages and that the maintenance of a fine-grained landscape mosaic with patches of different complexity and land covers has a positive effect on habitat availability for the species (ANÁDON et al. 2006). Regional richness mapped to biotopes (2010) was highest for Maquis, Garigue-Pine forests transitional complex and Maquis-Pine forests transitional complex. The proportion of these biotopes to land cover is highly positively correlated to species density of *T. graeca*, while the proportion of artificial surfaces is highly negatively correlated with species density (r=0.82 and -0.91, respectively; Pearson's correlation coefficient). The Natura 2000 site is testimony to the biodiversity value of this part of the island. At the same time, urban sprawl, the proximity to urban areas and the major tourist resorts is a reason for concern. Future revisions of the municipal land use plan may target areas that are transformation and harmonization land which is potentially at stake to be designated as land for future urban development (Figure 7). Therefore, the discussion of the land change prediction focuses on that part of the species range. The combination of maps on vulnerability to land change and habitat suitability informs decision-makers who ask: what areas are optimal for future urban development with the least impact on biodiversity while maintaining landscape

3.3 Species presence or absence and land cover change modeling

Significant differences exist for the proportion of artificial surfaces and semi-natural biotopes at different successional stages between presence and absence grids of *T. graeca* in 2007. The results are significant at and beyond the .05 level for a non-directional test (Table 2).

Biotope type	z-value	p-value	Level of significance (non-directional (two-tailed) test)
Fallow land	-2.18	0.0293 (p<0.05)	0.05 (significant)
Artificial surfaces	-4.22	p<0.001	0.01 (highly significant)
Coastal biotopes	1.4	0.1615 (p>0.05)	Not significant
Ruderal sites (Very low vegetation cover)	0.45	0.6527 (p>0.05)	Not significant
Garigue	0.82	0.4122(p>0.05)	Not significant
Garigue-Maquis transitional complex	1.1	0.2713	Not significant
Garigue-Pine forests transitional complex	2.95	0.0032 (p<0.01)	0.02 (highly significant)
Maquis	0.68	0.4965	Not significant
Maquis-Pine forests transitional complex	2.65	0.008 (p<0.01)	0.02 (highly significant)
Pine forests	1.47	0.1416 (p>0.05)	Not significant
Permanent crops	-0.78	0.4354 (p>0.05)	Not significant
Arable land	-1.05	0.2937 (p>0.05)	Not significant
Grassland	0.02	0.984 (p>0.05)	Not significant

Tab. 2: Results of the Mann-Whitney U-test for difference in biotope type proportions (2010) between 1 km x 1 km presence (n=15) and absence grids (n=20) of *Testudo graeca* in 2007. Data source: Own calculations with biotope map at 1:5,000 scale.

	z-value	p-value	Level of significance (non-directional (two-tailed) test)
Artificial surfaces	2.85	0.0044	0.02 (highly significant)
Agricultural areas	1.31	0.1902	Not significant
Forest and semi natural areas	1.19	0.2340	Not significant

Tab. 3: Results of the Mann-Whitney U-test for the difference in the long-term land cover change rate (1973, 1995, 2000, and 2006) between 1 km x 1 km presence (n=40) and absence grids (n=64) of *Testudo graeca* in 2007.

aesthetical values? How will these ecosystem services be impacted by a continuation of the historic trend in land cover change? A crosstabulation or overlay of the vulnerability map with the habitat suitability map derived from the biotope map (compare MICHEL & HOF 2011) shows that the areas that are highly vulnerable to change to artificial surfaces are exclusively Maquis and Maquis-Pine forest transitional complexes (Figure 7). These biotopes were impacted by land cover change between 1992 and 2008 and covered only 10.2% of the modeled area in 2008. The bigger part of this area is in the urban land zone (42%) or within the transformation and harmonization zone (18%) that successively may be designated as land for future urban development. However, a sizable proportion (40%) is found in the Natura 2000 site which underscores the importance of this site for biodiversity conservation but also its vulnerability if land cover change follows the business-as-usual scenario.

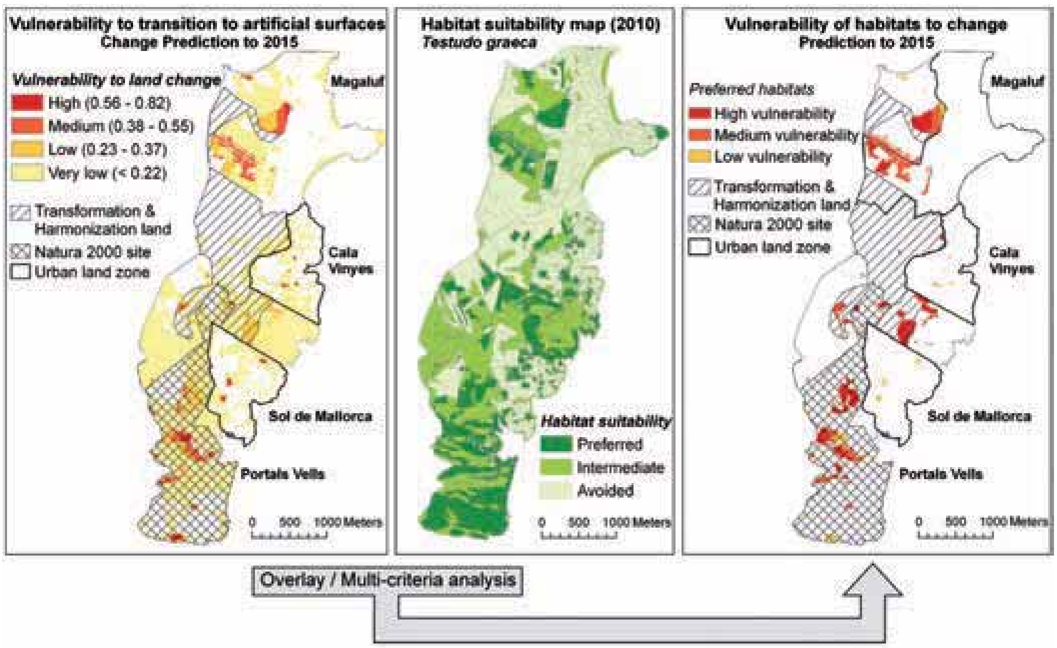

Fig. 7: Continuous mapping of vulnerability of eight natural and semi-natural biotope types to transition to artificial surfaces by 2015 in a business-as-usual scenario. The combination of vulnerability and habitat suitability maps indicates how preferred habitats might be impacted by a continuation of the historic trend in land cover change. Own analyses of biotope maps (1:5,000) from MÖRTL (2008) and SCHMITT (1999).

This is just one example for an overlay analysis to solve multi-criteria problems such as site selection and suitability models (Figure 2). The weights and importance assigned to the input layers are ultimately the outcome of a definition of goals and objectives. If biodiversity were an objective, the change process and biodiversity measures maps and the prediction of vulnerability to change could be used by decision-makers to reflect past land change processes for improved integration of landscape ecological knowledge into future urban conservation, management, and planning.

4. Conclusions and outlook

With an emphasis on applicability and usefulness of landscape ecological knowledge for decision-making in conservation and planning as integral parts of urban management, this paper demonstrates a workflow of mapping land change processes and biodiversity measures that could be further used in multi-criteria analyses. Accessible data were used in conjunction with Geographical Information Systems functionality; in particular Land Change Modeler for Ecological Sustainability, an application that is oriented to the problem of accelerated land change and the specific analytical needs of biodiversity conservation. The workflow to generate information on the long-term pathway of landscape functions is exemplified for land cover change and a single key species. Available data allow including all endangered species' range grids on the island of Mallorca (GOVERN DE LES ILLES BALEARS 2009) for comprehensive mapping of biodiversity measures to land cover regions at the island scale (GIST 2010). The visualization of land change processes and biodiversity measures is one of the main benefits of the approach. Maps communicate the effects past land cover changes have had on landscape structure and fragmentation, species richness, and dissimilarity of land cover classes. This is a novel perspective on the biodiversity impacts of coastal urbanization in the Mediterranean and a basis for discussing future land planning scenarios.

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