



THE LAND USE - LAND DEGRADATION NEXUS IN MEDITERRANEAN LANDSCAPES –
DRIVERS OF CHANGES AND KEY PROCESSES AT SELECTED
NATURA 2000 SITES OF CRETE, GREECE

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Abstract

The land use–land degradation nexus in Cretan landscapes in regions with Natura 2000 sites was analyzed by an explorative expert driven study based on literature, field work and photo documentation methods with the aim of determining status, drivers and key processes of change. Drivers of current land use changes have been worked out by (1) general tourism developments and tourism related land uses; (2) irrigated olive yard developments; (3) fenced large-scale goat pastures and (4) large scale greenhouses. Key processes of change have been identified and qualitatively assessed for 5 regions with NATURA 2000 areas based on a non-ranked set of 11 descriptive indicators. The analysis includes the status-description and the importance assessment of land degradation processes in selected NATURA 2000 sites. Threats and pressures taken from the NATURA 2000 documentation and the land use – land degradation nexus and the analysis are a suitable basis for future land management in order to reach land degradation neutrality. The result of our analysis opens a new research field for a better integration of the normally thematically isolated analysis in geography, biology/nature conservation and agricultural policy analysis about the drivers and processes in landscape systems towards a better understanding the trends in land cover change (e.g. vegetation/soil degradation), the trends in productivity or functioning changes caused by land uses and as well for the trends in carbon stock change.

Keywords: integrative land use analysis, landscape change, agriculture, nature conservation, processes of land use change

INTRODUCTION

The Cretan economy and its landscapes as well as most regions in the Mediterranean have been centered on agricultural activities since prehistoric times. Subsistence consisted of cereal cropping in lower regions with fertile soils, whereas in mountainous areas animal husbandry, mostly sheep and goat, was the dominating activity and land use. In some areas, a transhumance system was well developed. The land use history of Crete has caused widespread and still ongoing soil degradation linked with a transformation of the natural vegetation, processes also dating back to ancient times. Locally, the dense Mediterranean evergreen and semi-deciduous forests have already been transformed into Maquis shrublands and Phrygana vegetation in prehistoric times, with an expansion of such areas and further degradation throughout different phases of intense land use (Rother 1992). As a result, nearly the entire island of Crete can be considered and labeled a cultural landscape.

Several sites of this old cultural landscape are protected today as Natura 2000 sites with high qualities for nature protection (EC 1992). Nature conservation, agriculture and tourism are today in a problematic competition for land and water. In order to reach the protection goals of the Natura 2000 guideline, a balanced land management is missing to reduce the negative threats and pressures (Barredo et al., 2016; Dimopoulos et al., 2006; Cuttelod et al., 2008; Underwood et al., 2009).

While agriculture was the dominating activity of the Cretan economy until the middle of the 20th century, the touristic sector has become increasingly important in the last fifty years. In the first decades after World War 2, tourists started to visit Crete and created some extra income for local farmers, mostly in the dry summer months (Donatos and Zairis, 1991). However, there was a strong emigration movement, depleting the rural areas of the young generation and workforce. This led to an abandonment of fields and sometimes entire villages, especially in mountainous areas and a reduction in stocking rates and herd numbers (Papanastatis et al. 2004; Watrous, 1982). Besides tourism, agricultural production continues to be an important land use activity. On fertile soils cash crops like olives, citrus and regionally also potatoes have replaced the traditional cereals. Although the touristic infrastructure developments are centered on the northern coast, there is a growing competition for land and water between tourism and agriculture on the entire island. As the demand for irrigation for cultivation as well as tourist arrivals concentrate in the dry summer season, the pressure on water resources is especially pronounced.

With Greece joining the European Union (EU) in 1981, the agricultural and the tourism sector developments started to accelerate. EU Common Agricultural Policy (CAP) subsidies stimulated and incentivized an increase in numbers and stocking rates of grazing animals (Lorent et al. 2009). For example, the number of grazing sheep and goats has increased from 1.56 to 2.51 million in the period

from 1980 to 2010 with stocking rates increasing from around 1 to 2.0–2.3 animal units (AU) per ha (Kosmas et al., 2015). As stocking rates around 1 to 1.5 AU/ha are considered appropriate for sustainable grazing, recent stocking rates result in severe overgrazing and an increasing degradation of soils and vegetation (Ispikoudis et al., 1993; Kairis et al., 2015).

Subsidies from the European Union have also encouraged the intensification of olive cultivation in Crete and across the Mediterranean, leading to rapid landscape changes from a diverse system to monocropping olive yard structures (Allen et al., 2006). In 2017, there were a total number of 27 220 000 olive trees, mostly in compact plantations and under irrigation, on an area of 136 400 ha (Hellenic Statistical Authority 2019). Of these, 41 200 ha with 7 850 000 trees have been in use for more than 50 years, while about 10 000 ha containing 2 000 000 trees are only 10 years old or younger. Most of these are used for oil production. A new form of agricultural land use is increasingly applied by the construction of greenhouses, where mostly legumes and bananas are grown year-around (Karamesouti et al., 2015).

Due to the long history of intense land use, the Mediterranean can be best described as cultural landscapes. It holds valuable assets of culture and nature vital for the cultural land perception and recreation (Farina, 2000). With Natura 2000 (EC, 1992, further referred to as NATURA 2000) the EU developed a coherent network of nature protection areas in its member states facing the goal to halt ongoing biodiversity loss by the protection of habitats and species of flora and fauna on terrestrial and marine ecosystems. So far, only few studies have developed management ideas and practices for a future integration of culture and land use in NATURA 2000 sites by management planning (NK2-Group, no year), or for biosphere reserve developments (Kusova et al., 2008). Even though the Cretan NATURA 2000 Special Areas of Conservation (SAC) network seems to be insufficient to ensure at least a satisfactory representation of the regional plant biodiversity (Dimitrakopoulos et al., 2005), these areas cover about 17 % of the islands terrestrial area. European management guidelines are available for farming (e.g. on the grazing on high value grasslands) in NATURA 2000 (EC, 2014) as well as for the forest's management (EC, 2015). Guidelines for land use practices in NATURA 2000 sites dominated by tourism or recreation - important especially on Mediterranean islands like Crete - have not been developed so far.

The land degradation neutrality goal (defined by the Sustainability Development Goals) has not yet been specified for landscapes comprising NATURA 2000 sites in Crete, since complex explorative studies are missing. Land degradation problems caused by land use, its management and changes, land degradation processes, their determining societal and land drivers and their interlinkages on habitat qualities are generally rarely in the focus of applied research due to their complexity. The aim of the presented explorative study is therefore to work out by literature, photo and expert field analysis important ongoing drivers and processes in landscape systems to determine the status, important to clarify the land use – land degradation nexus in Mediterranean landscapes of Crete.

STUDY AREAS AND METHODS

A number of characteristic Cretan landscapes comprising NATURA 2000 sites were visited during a field campaign in spring 2018 aiming at the clarification and description of critical developments in land use systems including land degradation and depletion of biodiversity (Fig. 1, Fig. 2). The analysis of respective drivers is based on the authors' field observation and is as well based and supported by literature and data interpretations of the NATURA 2000 public database (EC without year). The selection of study areas is based on a general analysis of different landscape types in Crete, focusing on landscape ecology, geomorphology, soil, vegetation and land use. The study area selection includes varying land uses in high mountains, lower mountain ranges, forests, abandoned and active arable lands, intensively irrigated arable lands, vineyards, irrigated and non-irrigated olive yards, important cultural sites, villages, tourism facilities, beaches, dunes and multiple mixed landscape configurations as Maquis shrublands and Phrygana vegetation as well as abandoned terraced landscapes.

Regions and sites have been selected with the objective to get a major overview of typical current developments within the land use – land degradation nexus, facilitating a better understanding of the status, drivers and active processes potentially causing changes to land and landscape degradation.

Drivers of land use change potentially affecting study areas are analyzed by varying methods focusing on (1) General tourism developments and tourism related land uses; (2) Irrigated olive yard developments; (3) fenced large-scale goat pastures and on (4) Large scale greenhouses. These driver's selection is based on authors expert judgments, on landscape observations, map interpretation and literature.

The main methodological approach was structured observations of recent processes and their activity level influencing land degradation based on photo-documentation and field research. For the traditional Cretan cultural landscapes, the observations are focused on the processes of depopulation, road infrastructure development, forest fires, overgrazing, water resources in quality/quantity, soil erosion, slope modification, disturbances, habitat fragmentation, land cover change and the abandonment of important cultural landscape elements.

Due to the complex geology, relief, related climatological conditions and more or less intense anthropogenic modifications, the island of Crete is characterized by a large variety of natural and man-made habitats at a comparably small surface area of 8265km², mainly given to the intense elevational gradients of the three main mountain ranges (see Fig. 1) and the long history of human presence and activity. The vascular plant flora of Crete comprises 2240 species with a level of endemism of 17% and 6,7% alien or non-native species (Médail, 2017; Turland et al., 1993). With its high level of endemism and high percentage of habitat loss the island is part of the Mediterranean biodiversity hotspot (Médail and Myers, 2005), endangered by continuing habitat destruction and land degradation due to land use

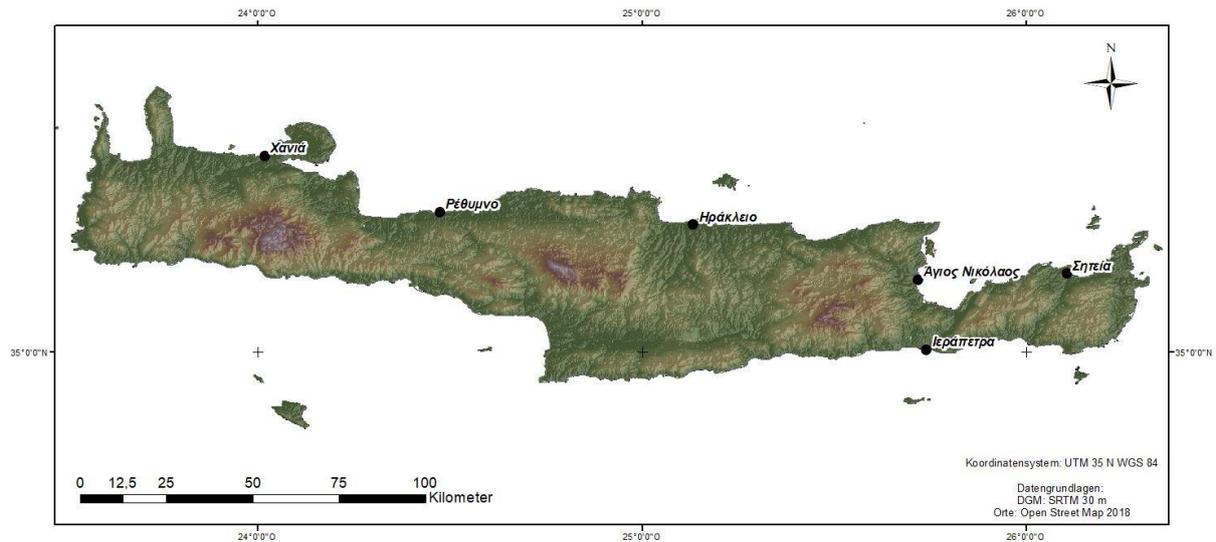


Fig. 1 Topography of Crete (Data Source: SRTM, OpenStreetMap). The map shows the rough and diverse topography of Crete holding high mountains (white, dark brown), multiple hilly areas (brown) and lowland plains and valleys (green)

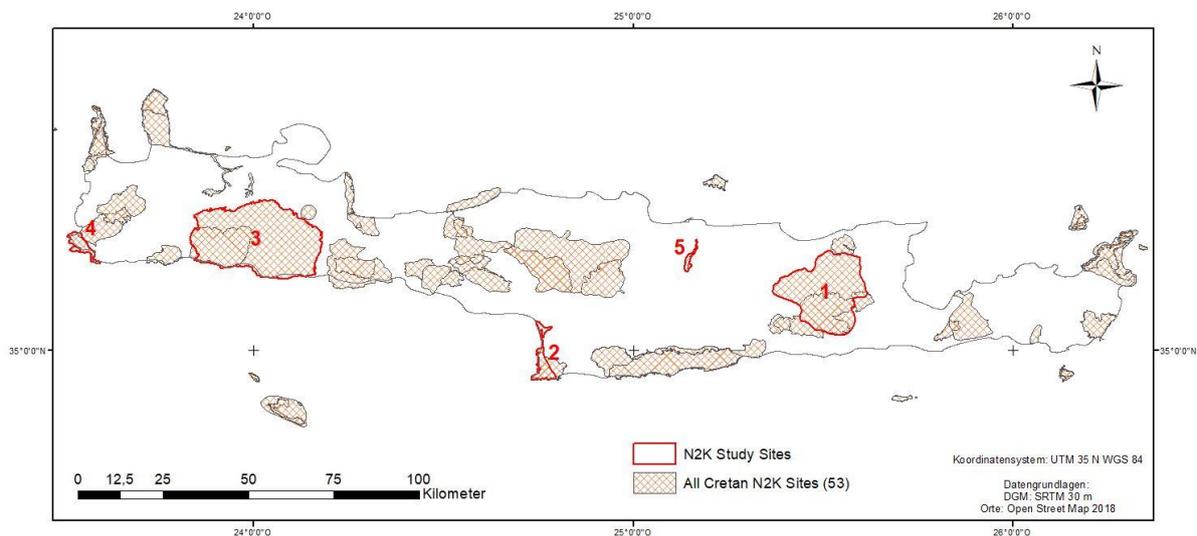


Fig.2 NATURA 2000 (N2K sites) of Crete and analysed N2K study sites (red edging) (1) Lasithi plateau, (2) Ekvoli Geropotamou Mesara, (3) Lefka Ori Kai Parakti, (4) Nisos Elafonisos and Paralia Apo Chrysoskalitissa Mechri Akrotirio Krios and (5) Giouchtas Farangi Agias Eirinis

intensification (olive groves, goat and sheep overgrazing, tourism), forest fires and biological invasions, e.g. *Ailanthus altissima*, *Nicotiana glauca* and *Oxalis pes-caprae* (D'Agata et al., 2009) but as well by abandonment of terraces and land use (e.g. followed by forestation and forest succession).

Crete's habitat diversity has been partially taken into account in our NATURA 2000 area selection process, including areas from the shore up to mountainous regions at 2400 m a.s.l. (Vogiatziakis et al., 2003). For a first overview survey we selected areas comprising NATURA 2000 sites in Mid- and Western Crete ranging from the southwestern coast to the central mountain formations, based on the assumption that all sites are actually affected by more or less strong anthropogenic impacts such as tourism and agricultural land use. Other impacts such as water resources exploitation, land levelling for greenhouse cultures, expansion of livestock breeding (e.g. goats, sheep, bees) and infrastructural development measures have also been taken

into account. Basic information about the NATURA 2000 features of these areas can be found in Table 1a,b, that also include threats and pressures recorded at the moment of the designation of the NATURA 2000 sites. The selected areas differ considerably with respect to their geological and geomorphological setting, their traditional land use system and settlement pattern as well as their current significance for agricultural production and tourism.

The site selection therefore addresses combinations of landscapes, habitats and drivers of degradation being typical and representative for Crete. According to Dimitriou (2008) and our own observations, the most significant threats for (natural) habitats in Crete are i) Hydrological alteration due to water overexploitation, artificial drainage and recharge, ii) Overgrazing due to the intense stockbreeding practices, iii) Water pollution and especially eutrophication originating from unsustainable agricultural practices, iv) Solid waste disposal, v) growing and intensified tourism and a lack of legally enforced protection.

Table 1a Threats and pressures of the selected NATURA 2000 study sites in Crete

Name (Code)	DIKTI: OROPEDIO LASITHIOU (GR4320002)	DYTIKA ASTEROUSIA (GR4310004)	LEFKA ORI KAI PARAKTIA (GR4340008)			
Total area (ha)	34007	2651	53364			
Marine area (%)	0,00	0,00	3,35			
N2K Type	B (Habitat directive site)	B (Habitat directive site)	B (Habitat directive site)			
Precipitation (mm/y)	900-2200	450-550	500-2800			
Altitude (m a.s.l.)	800-2148	0-400	0-2443			
Threats and Pressures: inside (i), outside (o), both (b) and Rank (High,Medium,Low)	wind energy production	iH	Taking and removal of animals (terrestrial)	bH	grazing	bH
	genetic pollution (animals)	bH	Outdoor sports, leisure and recreational activities	bH	Improved access to site	iH
	grazing	bH/M	Sand and gravel extraction	iM	Hunting and collection of wild animals	oH
	fire (natural)	bH/M	marine constructions	bM	trapping, poisoning, poaching of terrestrial animals	iH
	Cultivation	iM	dispersed habitation	bM	other hunting, fishing or collecting activities	iH
	use of biocides, hormones and chemicals	iM	Professional passive fishing, netting, spear-fishing	bM	attraction park	iH
	Fertilisation	iM	Illegal taking/ removal of marine fauna	bM	roads, motorways, all paved/ tarred roads	iM
	dispersed habitation	iM	camping and caravans, wildlife watching	iM	genetic pollution (plants)	iM
	Hunting and collection of wild animals	oM	human trampling, overuse, vandalism	iM	Erosion	iM
	Taking and removal of animals (terrestrial)	iM	intensive maintenance of public parcs /cleaning of beaches	iM	Sand and gravel extraction	iL
	Taking / Removal of terrestrial plants, general	iM	marine animals death or injury by collision	oM	disposal of household / recreational facility waste	iL
	Erosion	iM	oil spills in the sea	bM	Outdoor sports and leisure activities, recreational activities	iL
	competition	bM	marine macro-pollution	oM		
	Irrigation	iL	Light pollution	iM		
	artificial planting on open ground (non-native trees)	iL	Erosion	iM		
	forestry clearance, clear-cutting, removal of all trees	iL	collapse of terrain, landslide	bM		
	removal of forest undergrowth	iL	use of biocides, hormones and chemicals	bL		
	discontinuous urbanisation	iL	Irrigation	bL		
	disposal of household / recreational facility waste	iL	artificial planting on open ground (non-native trees)	iL		
	walking, horseriding and non-motorised vehicles	iL	car parcs and parking areas	iL		
	motorised vehicles	iL	diffuse pollution to surface waters due to agricultural and forestry activities	bL		
	mountaineering, rock climbing, speleology	iL	inundation (natural processes)	iL		
	fire and fire suppression	bL				
	human induced changes in hydraulic conditions	iL				
	inundation (natural processes)	iL				

Table 1b Threats and pressures of the selected NATURA 2000 study sites in Crete

Name (Code)	NISOS ELAFONISOS (GR4340002)		PARALIA APO CHRYSOSKALITISSA MECHRI AKROTIRIO KRIOS (GR4340015)		GIOUCHTAS (GR4310002)	
Total area (ha)	271		2253		718	
Marine area (%)	83,73		31,18		0,00	
N2K Type	B (Habitat directive site)		B (Habitat directive site)		B (Habitat directive site)	
Precipitation (mm/y)	450		450		600-800 mm	
Altitude (m a.s.l.)	0-39		0-160		100-808	
Threats and Pressures: inside (i), outside (o), both (b) and Rank (High,Medium,Low)	Taking / Removal of terrestrial plants	iH	disposal of household / recreational facility waste	iH	Urbanised areas, human habitation	iH
	camping and caravans	iH	Taking / Removal of terrestrial plants	iH	disposal of household / recreational facility waste	iH
	marine constructions	bM	leisure activities with motorized vehicles	iH	grazing	iM
	dispersed habitation	bM	camping and caravans	iH	Animal breeding, stock feeding	oM
	Professional passive net fishing	bM	genetic pollution (animals)	bH	Restructuring agricultural land holding	oM
	leisure spear-fishing	bM	Sand and gravel extraction	iM	artificial planting on open ground (non-native trees)	iM
	Hunting and collection of wild animals	iM	open cast mining	iM	roads, motorways, all paved/ tarred roads	iM
	Accidental capture of terrestrial animals	bM	marine constructions	bM	mountaineering, rock climbing, recreational cave visits	iM
	Illegal taking/ removal of marine fauna	bM	Professional passive net fishing	bM	attraction park	iM
	motorized nautical sports	bM	leisure spear fishing	bM	Vandalism	iM
	recreational visits of terrestrial/marine caves	bM	Hunting and collection of wild animals	iM	missing or wrongly directed conservation measures	iM
	Pollution to surface waters (limnic, terrestrial, marine)	bM	Illegal taking/ removal of marine fauna	bM	fire and fire suppression	iM
	Marine water pollution, oil spills in the sea	bM	motorized nautical sports	bM	cultivation incl. increase of agricultural area	iL
	collapse of terrain, landslide	bM	recreational visits of terrestrial/marine caves	bM	use of biocides, hormones and chemicals	IL
	sea-level changes	bM	Pollution to surface waters (limnic, terrestrial, marine)	bM	open cast mining	oL
			Marine water pollution, oil spills in the sea	bM	paths, tracks, cycling tracks	iL
			collapse of terrain, landslide	bM	discontinuous urbanisation	oL
			sea-level changes	bM	dispersed habitation	iL
			continuous and dispersed urbanisation	bM/L	disposal of inert materials	oL
			grazing	iL	Agricultural structures, buildings in the landscape	oL
				Hunting and collection of wild animals	iL	
Taking / Removal of terrestrial plants	iH	disposal of household / recreational facility waste	iH	Urbanised areas, human habitation	iH	
camping and caravans	iH	Taking / Removal of terrestrial plants	iH	disposal of household / recreational facility waste	iH	
marine constructions	bM	leisure activities with motorized vehicles	iH	grazing	iM	
dispersed habitation	bM	camping and caravans	iH	Animal breeding, stock feeding	oM	

Five areas containing NATURA 2000 sites were selected and analyzed to get an overview of important geo-ecological features, land use and main NATURA 2000 area qualities (Fig. 2).

Threats and pressures of the selected NATURA 2000 study sites in Crete as described in Table 1a and Table 1b are taken from the official site descriptions (available by the Natura 2000 Public Database). The same data have been firstly used for the designation of the NATURA 2000 sites. The database as well includes information about the threats and pressures affecting the sites by differentiating them by their activity inside the site (i), outside the site (o), or in both inside and outside (b) and as well by an importance ranking (high, medium, low) to clarify the importance of the treats and pressures in the respective site context.

RESULTS: DRIVERS AND PROCESSES OF LAND USE CHANGE AND LAND DEGRADATION IN REGIONS WITH NATURA 2000 SITES

Drivers of landscapes and NATURA 2000 site change

Four major drivers, all strongly influenced by European policies after the integration of Greece into the European Union in 1981, have been identified as of major importance on land use change and land degradation in NATURA 2000 sites and surrounding areas in Crete. These are interpreted as general determinants of land use intensification. Since the NATURA 2000 site designation (between the years of 1995 and 2004 and today) the main drivers have been found in (a) tourism developments and tourism related land uses, (b) irrigated olive yard developments, (c) fenced large scale goat pasture systems and (d) large scale greenhouse farming strongly modified the land use systems. All four drivers are influenced by regional development policies and measures including water management measures, agricultural measures in production systems development of the European Union as well as by protective settings for NATURA 2000 development. A rural population decrease of 47 % was measured between 1991-1995 at the southern coast of Crete in an investigation area around Omalos and Samaria Gorge (Papanastasis et al. 2004). The same process is as well verified for the Asterousia Mountains by a depopulation of 30 % between 1961 and 2011 (Kizos et al.2014).

The potential general nexus linking the main drivers via key processes to land degradation is shown in Fig.3. The four main drivers of tourism and agricultural developments, irrigated olive yard developments, large scale fenced goat pasturing and greenhouse developments for vegetable production were identified to be the main forces driving the degradation of soil, water, vegetation and landscape components in NATURA 2000 sites and its surroundings.

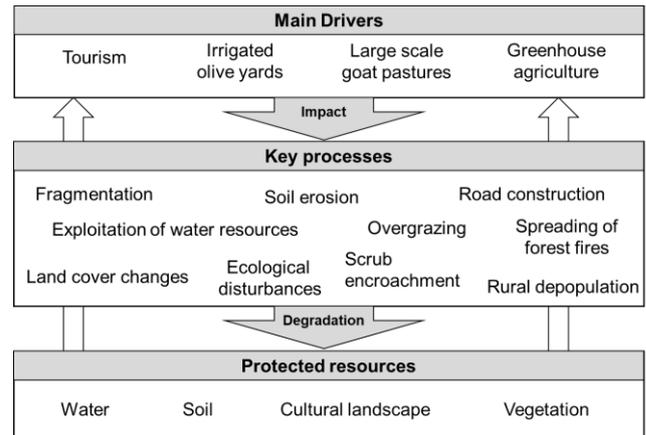


Fig.3 Drivers of change influencing selected processes of change and causing land degradation and degradation of cultural landscape qualities in NATURA 2000 sites and its surroundings of Crete

The four key drivers influencing the NATURA 2000 sites can be described as follows:

(a) *General tourism developments and tourism related land uses:* Since the 1980s Crete has faced an increased tourism development in number and intensity of beach tourism with large scale touristic estate developments especially on the northern coast. Organized and individual day tourism increased, mainly in the form of ecotourism e.g. by hiking activities. In peripheral communities this driver leads to the abandonment of settlements, depopulation, habitat fragmentation, water scarcity, direct vegetation and ecosystem modifications and ecosystem destruction as well as increased disturbances in NATURA 2000 sites (Kourgialas et al. 2018, Andriotis 2006). See Fig. 4a.

(b) *Developments in irrigated olive yards:* Large scale irrigated olive yard developments in many Cretan landscapes have been established on arable land formerly used for rain fed agriculture, on former pasture lands as well as on old terrace systems (Karydas et al. 2009, Allen et al. 2006; Price and Nixon 2005, Frederic and Krahtopdlou 2000). Non-irrigated olive cultures have been replaced on a large scale by irrigated olive cultivation. This driver leads to increased water consumption, changes in cultural landscapes and to a strong decrease of the agricultural land use diversity. See Fig. 4b.

(c) *Intensive fenced large-scale goat pasture systems:* Severe vegetation degradation is caused by management changes from extensive shepherds herding of sheep and goats to large scale fenced areas and the concentration on intensive goat husbandry (with external fodder supply throughout the dry months of the year, when winter and early spring vegetation has run out). See Fig. 4d. The key degradation driver seems to be overstocking and overgrazing of the open landscapes and a problematic grazing management with sheds, feeding facilities and watering places for the animals (Kosmas et al. 2015, Kairis et al. 2015, Lorent et al. 2009). Dispersed extensive grazing of browsing animals is also found in areas of less intensive goat and sheep grazing.

(d) Large scale greenhouse farming developments:

The production of vegetables in greenhouses is an important feature of agricultural intensification stimulated by road developments. See Fig. 4c. A strong relief modification by large scale terracing is applied as a baseline for construction; in some places soils and sediments have been excavated from dolines (formerly used for grazing or cereal production) and serve as basic soil substrates in greenhouses (Fig. 4e). Greenhouse farming has a high water consumption and the applied pesticides, herbicides and nutrients bear the risk of negatively influencing public health (Daliakopoulos et al. 2016, Tsatsakis et al. 2008, Anton et al. 2014) and the NATURA 2000 area biodiversity qualities. Furthermore, pollution with macro- and micro-plastics originating from abandoned and degrading greenhouses is affecting both marine and terrestrial ecosystems (Gundogdu and Cevik 2017).



Fig.4 Major drivers affecting Natura 2000 sites – a) Tourism development near Loutro, Western Crete; b) Irrigated olive yards with terracing, Central Crete; c) large scale greenhouse agriculture near Arvi, Southern Crete; d) degraded slopes with intensive fenced large-scale goat pastures near Elos, Western Crete; e) soil excavation for greenhouse substrates near Elafonisi, Western Crete

Important processes observed and identified in the land use change – landscape degradation nexus and described for the selected NATURA 2000 sites are (see Figures 5-7):

(1) depopulation of remote villages and single farmsteads leading to abandoned cultural landscapes and conversion into summer houses (Fig. 6a),

(2) road construction for agricultural, forestry or energy production purposes (Fig. 5d),

(3) frequent large-scale forest fires causing habitat destruction (Fig. 5a),

(4) vegetation degradation on pastures and forest vegetation by overgrazing (Fig. 5b, 5c and 5e),

(5) water resources management measures by intensive water abstraction and modification of water household parameters for irrigation including the desiccation of rivers and water pollution (Fig. 6b and 6c),

(6) soil erosion caused by overgrazing in fenced goat pastures (fig 6d), in olive yards (Fig. 6e) as well as geomorphological surface change by greenhouse construction (Fig. 4c),

(7) slope modification for the construction of greenhouses (Fig. 4e) or irrigated olive yards (Fig. 4b),

(8) disturbances caused by the increasing individual day tourism (Fig. 7b and 7c),

(9) habitat fragmentation of landscapes by agricultural, forest and road infrastructure developments (Fig. 7a),

(10) land cover changes e.g. from extensive pastures to olive yards, pastures to greenhouses and fenced animal husbandry on areas of formerly shepherds herding of goat and sheep (fig 4 in all photos), as well the replacement of grasslands/cereal fields by forests on terraces (Fig. 7d),

(11) abandonment of characteristic cultural landscape elements including terraces, pathways, stone walls and former agricultural infrastructure as storage buildings and threshing sites (Fig. 7a).



Fig.5 Examples of processes with an impact on land degradation – a) Slopes affected by forest fires near Kapetaniana, Southern Crete; b) Tree damaged by goat grazing near Anopolis, Western Crete; c) Destruction of vegetation in fenced goat and sheep browsing area, Central Crete; d) Country road construction for goat pasture management near Anopolis, Western Crete; e) Construction of sheds, watering and fodder places for animals, near Anopolis, Western Crete



Fig.6 Examples of processes with an impact on land degradation – a) Depopulated village (Kalami, Southern Crete); b) Drowned village (Sfendili) in a large-scale water storage facility in Northern Crete; c) Water pond near Anogia, Central Crete; d) Soil erosion as a result of goat trampling and overgrazing in Ida mountains, Central Crete; e) Olive plantation affected by soil erosion in marly substrates near Agia Varvara, Central Crete



Fig.7 Examples of processes with an impact on land degradation – a) Habitat fragmentation by construction of infrastructure near Livadia, Western Crete; b) Disturbed Juniper thicket at Kedrodassos beach, Western Crete; c) Parking lots in dune formations for day tourism at Elafonisi beach, Western Crete; d) Forest plantations on abandoned traditional terraces near Agios Ioannis, Western Crete; e) Abandoned traditional threshing site (Aloni) near Elafonisi, Western Crete

These processes influence the status in the regions analysed in a complex way and are contradictory to the NATURA 2000 objectives named in the documents submitted to the European Commission during the NATURA 2000 designation process in many cases. The management of these processes should be further detailed as a subject for research based on mapping, process identification and process analysis, process modelling and assessments usable for the regional local and flora/fauna development planning in NATURA 2000 management, which is still lacking at all sites investigated in this study.

Status and intensity of land degradation processes in selected NATURA 2000 sites

The analysis of processes influencing land degradation in the five investigated areas is based on literature analysis and field observations during the field work campaign. Two summarizing tables are study results by substantiating (i) the drivers affecting the NATURA 2000 sites studied (Table 2) and (ii) the intensity of the observed processes with influence on land degradation and the transformation of the traditional cultural landscapes of Crete (Table 3).

The analysis of factors driving the change and the degradation in the selected NATURA 2000 sites (Table 2) highlights the complexity of landscape intensification processes. Direct and indirect forces and processes are often obscure and hard to distinguish. Hence, such drivers are rarely considered and in the focus of NATURA 2000 management activities. Table 2 therefore gives the drivers investigated as most important in the studied areas.

The activity of key processes with influence on land degradation and the degradation of traditional cultural landscapes (see Table 3) is assessed by the authors' expert judgments and based on field observations. The analysis reveals a complex mosaic of drivers and related processes in the NATURA 2000 sites. It is based on a wide range of overlaying and interrelated processes (Fig.3). All NATURA 2000 sites and their surroundings face more or less intensive forms of land degradation. Nevertheless, processes with impact on the Table 1 habitat types are also in interdependences with the processes in the categories of "land degradation" (soil, water and vegetation) and "landscape degradation" (cultural landscape). Such complex landscape nexus is not yet clarified and should be subject of further research.

NATURA 2000 area threats and pressures and the land use – land degradation nexus

The land use – land degradation nexus analysis based on the threats and pressures taken from the official NATURA 2000 site characteristic descriptions in Table 1a,b (last published update 12/2016) and the drivers and processes of land degradation in Crete analysis of our research results in contradictory outcomes. In the following these threats and pressures are shortly interpreted regarding the drivers and processes. While the NATURA 2000 documentation denotes a set of single threats and pressures per site, our approach tries to address the interlinkages (nexus) of such factors in the context of land degradation.

Table 2 Drivers affecting the selected NATURA 2000 sites and its surroundings on Crete: (1) Lasithi plateau, (2) Ekvoli Geropotamou Mesara, (3) Lefka Ori Kai Parakti, (4) Nisos Elafonisos and Paralia Apo Chrysoskalitissa Mechri Akrotirio Krios, (5) Giouchtas Farangi Agias Eirinis

Drivers	NATURA 2000 areas and surroundings				
	1	2	3	4	5
General tourism developments and tourism related land uses	intense day tourism	medium tourism pressure by summer and day tourism	Intense concentration of day tourism activities along Samaria Gorge, some ecotourism	high pressure by day tourism	low tourism pressures by sports
Irrigated olive yard agricultural developments,	no direct influence; indirect influence via water uptake	strong influence in the wider surroundings	no influence	multiple new developments	strong influence in the surroundings
Intensive fenced large-scale goat pasture agricultural systems	high influence in the surrounding mountains	no influence; some extensive grazing of sheep and goat	high influence in most areas	high influence in the surrounding mountains and on abandoned cultural land	few influence, some extensive grazing of sheep and goat
Large scale greenhouse farming developments	no direct influence; indirect via water uptake	strong influence in the wider surroundings	some developments on coastal sites	multiple new developments	few developments in the surroundings

Table 3 Activity of processes with influence on land degradation and the degradation of traditional cultural landscapes at the selected NATURA 2000 sites and its surroundings: (1) Lasithi plateau, (2) Ekvoli Geropotamou Mesara, (3) Lefka Ori Kai Parakti, (4) Nisos Elafonisos and Paralia Apo Chrysoskalitissa Mechri Akrotirio Krios, (5) Giouchtas Farangi Agias Eirinis

Actual processes with impact on land degradation	NATURA 2000 areas and surroundings				
	1	2	3	4	5
Depopulation	ongoing	not visible	strong	not visible	not visible
Road infrastructure development	few	strong	few	strong	not visible
Forest fires	in the surrounding	not visible	strong	strong	some
Overgrazing	strong in the surroundings	not clearly visible	very strong	very strong	strong
Water resources in quality /quantity	extraction of water from the plain	strong use of water for irrigation	not clearly visible	intensive	intensive in the surroundings
Soil erosion	water erosion strong in the surroundings	wind erosion active	active	active wind and water erosion	some activities, intensive in the surroundings
Slope modification	ponds developments, overall minor	multiple modification for divers uses	minor modification	large scale slope modification and excavation of dolines for olive and greenhouses	large scale slope modification for wine and olive
Disturbances	minor by local tourism	medium by day and beach tourism	high along Samaria gorge; low in most of the area	very high by day beach tourism	few by sport and recreation
Habitat fragmentation	minor	high caused by new infrastructure activities	medium by activation of old road infrastructure	high by road and agricultural activities	minor; strong in the surroundings
Land cover change	conversion of grasslands to degraded forest; forest succession	diverse local changes, multiple abandoned sites partly military sites	enlargement of forest areas;	change to irrigated olive yards and greenhouses; multiple abandoned sites, some tourism infrastructure, abandoned water infrastructure	forest succession on former terraces
Abandonment of important cultural landscape elements	windmills, divers water pump infrastructure, flooded pastures	old olive orchards, extensive arable land (cereal production) pasture of dunes	terraces, historical paths network, stone-walls around arable former arable fields, old olive orchards, threshing sites	threshing sites, extensive doline land grazing, extensive arable land (cereal production)	pastures, orchards, terraces on lower slopes

The threats and pressures information in the documentation mentioned above is qualitatively described and ranked and attributed with importance levels (high/medium/low) in Table 1a,b. The currentness of the information is not clarified as the threats and pressures may relate to the moment of first reporting for the foundation of the Cretan NATURA 2000 sites. The documentation states important and significant information on highly ranked (important) pressures and threats such as grazing, erosion, fire, fertilization and taking and removal of terrestrial plants. This information is usable as general information about impacts on the habitat types. The land use intensity changes related to agriculture, tourism and infrastructure have been identified as important drivers of degradation of various habitat types in Crete, comparable to and observed in other Mediterranean landscapes (Dimopoulos et al. 2006; Cuttelod et al. 2008; Underwood et al. 2009). Nevertheless, a comparison of status and intensity of land degradation in selected NATURA 2000 sites and of the respective effects of different land uses as described above is difficult as long as detailed model analysis and more statistical data are lacking.

The comparison of major threats stated in the NATURA 2000 documentation and the authors' field observations explained in sections above by the drivers effecting NATURA 2000 sites and its surroundings on Crete reveals some open fields of problem analysis for a better understanding of the land use – land degradation nexus compared with the NATURA 2000 documentation:

- (1) The general touristic developments and tourism related land use activities are often named as threats and pressures in the NATURA 2000 documentation without a management goal formulation or related protective measures as subject of the still missing management planning;
- (2) The irrigated olive yard agricultural developments are not named as a threat or pressure;
- (3) The large-scale fenced goat pastures are named as a threat and pressure by overgrazing and animal breeding, agricultural structures, new agricultural buildings (e.g. sheds in the landscape) in most of the Natura 2000 sites;
- (4) Large-scale greenhouse farming as well as the road infrastructure developments as a problem of habitat fragmentation are not a subject of threats and pressures documentation for NATURA 2000 sites.

Landscape degradation processes in the Mediterranean landscapes

The list of current processes determined by land uses with impact on land degradation with importance on landscape, vegetation, soil and water systems is interpreted by the authors as a missing link or knowledge gap for a better understanding of the regeneration potential of Mediterranean landscapes. Land degradation is defined by the United Nations Convention to Combat Desertification (UNCCD 1994) convention as “a reduction or loss, in arid, semi-arid and dry sub-humid areas, of the biological or economic productivity and complexity of rain fed cropland, irrigated cropland, or range, pasture, forest and woodlands resulting from land

uses or from a process or combination of processes, including processes arising from human activities and habitation patterns, such as: soil erosion caused by wind and/or water; deterioration of the physical, chemical and biological or economic properties of soil; and long-term loss of natural vegetation”. When focussing on the degradation of cultural landscapes and by widening the definition from land degradation analysis towards the analysis of the landscape degradation “as an irreversible or non-resilient system change to a landscape that affects the landscape system components (i.e., their geo-factors, land use and inter-linkages) and the natural and cultural capacities of the landscape (productive, ecological and social structure, processes and landscape functions” (Meyer et al. 2017), the focus of such an analysis in the Mediterranean should be widened into the landscape context - e.g. on the economically very important tourism and agricultural intensification developments in the Cretan context – into a new land use and landscape pattern and landscape configuration perspective.

For both land degradation and landscape degradation analysis of the soil, water and vegetation degradation is required since the authors observations on revegetation, e.g. after fire events in degraded limestone landscapes, shows a fast renewal of the former, mostly already modified status of the Phrygana vegetation. A new view on the degradation problem in the Mediterranean is needed since the changes in the intensity of land uses are not known in a landscape systems context. The land use / landscape changes influencing the NATURA 2000 sites are determined by general and external factors as changes in agricultural or regional policies, management techniques, land use measures and practices interpreted in our study as land use intensity changes. A degradation of vegetation types listed in Habitat directive (Council Directive 92/43/EEC) was found during the field analysis. A system degradation of water management facilities is observed by abandoned irrigation systems and strongly modified surface waters of the karst water systems and multiple other water related infrastructure measures. Soil degradation is obviously found in areas of land and slope surface change by terrace abandonment, active and former erosion gullies, and geomorphologic levelling for greenhouses and by soil abstraction. Landscape degradation is interpreted by the conversion of abandoned or extensive cultural landscape features to a more industrial and less diverse land use pattern, especially by olive yard plantation. Problematic intensification practices of bee keeping and honey production were observed in the analysed NATURA 2000 sites by the introduction of scale insects on pine trees providing a continuous nectar source throughout the entire year. This practice results in local dieback of entire pine tree populations and potentially increases forest fire risk.

CONCLUSION

The land use – land degradation nexus in Mediterranean landscapes was analysed by status, drivers and key pressures using the example of selected areas comprising NATURA 2000 sites. The changing land use intensity e.g. in the fenced large-scale goat pasture systems may

promote further and strong vegetation degradation and is of importance regarding the degradation of soil and water resources. The large-scale greenhouse developments and the irrigated olive yard developments are primarily driving degradation pressures in the landscape context but also lead to degradation of water, soil and vegetation resources. The tourism developments and tourism related land uses including road developments have a significant impact on landscape degradation and may have influence the depletion of vegetation, water and soil resources.

Further analysis is needed for a more complex identification of land degradation within the land use intensity context. The critical limits/levels or thresholds of the observed land degradation are not yet fully known and the respective interpretation of landscape degradation needs to be revised as well. Detailed research is needed for a better understanding of the land use – land degradation nexus in Mediterranean landscapes especially for karst landscapes since degradation processes are less known for soils developed on calcareous rocks, as well as their potential of natural and managed revegetation is not yet scientifically clarified. The Land Degradation Neutrality goal of the UN has to be investigated, measured and analysed by 3 key indicators: (i) by the trends in land cover, (ii) by the trends in land productivity or functioning of the land and (iii) by trends in above and below ground carbon stocks (IUCN 2015). Based on the results of the presented study we suggest that future research on land degradation should lay a stronger emphasis on trends in land use and land cover developments as drivers of change and as a basis for the analysis of the temporal changes in the vegetation, water, soil and cultural landscape systems. At the same time, it is important to understand how the multiple related processes/pressures and threats identified in this study influence land productivity and carbon stocks in the context of climate change.

The aim of the presented explorative study has been to work out by literature, photo and expert field analysis important drivers and ongoing processes in landscape systems to clarify the land use – land degradation nexus in Mediterranean landscapes of Crete. Next steps should be developed towards a better and integrative analysis and description of the sensitivity of the landscapes and its patches and by the determination of thresholds to clarifying the processes changes. Methods used in the expert approach in our study by the example of Crete should be further specified by diverse data sets for a better process description and by model developments applicable for policy and planning advice.

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