Riparian Landscape Dynamics & Ecosystem Services in a Mediterranean River of W. Greece

ΠΑΝΕΠΙΣΤΗΜΙΟ ΠΑΤΡΩΝ
UNIVERSITY OF PATRAS

Eva Papastergiadou [a],

K. Kostara [a], A. Retalis [b], Th. Georgiadis

[a] University of Patras, Dept. of Biology, Patras, Greece

[b] National Observatory of Athens, Greece

Cost 2019
CONVERGES meeting

**Belgrade,
04-06/09/2019**





Rivers & Riparian Landscapes

are among the most *fragmented, degraded & threatened ecosystems* in the world (Millennium Ecosystem Assessment, 2005).

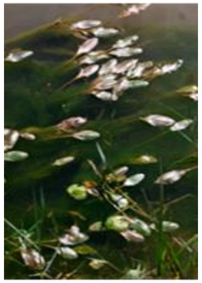
- **Rivers** provide direct benefits to human wellbeing by supporting a number of *regulating, provisioning & cultural* ***Ecosystem Services (ES).***

- The *functioning* of rivers & riparian ecosystems depends primarily on the maintenance of a *natural Hydrologic Regime & Biodiversity* (Brauman et al. 2007), that ensure the delivery of ***ES*** (Mace et al. 2012).

- However, *human activities* have altered ***river ecological integrity***, mainly through the effects of land cover/use (**LCLU**) changes, global climate change & biodiversity.

- ***Mediterranean Landscapes*** [*Riparian corridors*] have been experiencing more <u>*rapid changes*</u> in **LCLU** that affect *ecological functions & processes*.





Rivers & Riparian Landscapes

•**LCLU** changes impact the capacity of ecosystems to provide goods & services to the human society (Burkhard et al. 2012).

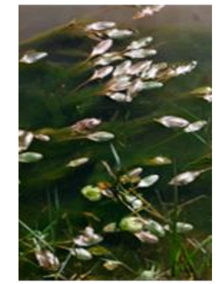
The individual **Ecosystem capacities** to supply **Services** are strongly linked *to natural conditions & human impacts*

Conceptual framework linking ecosystem integrity, ecosystem services & human well-being as supply and demand sides in human–environmental systems (Burkhard *et al.* 2012)

- Thus, **understanding & predicting** response of rivers to **LCLU** changes is **critical** for managing aquatic resources & **ES** & consists an emerging area of research.

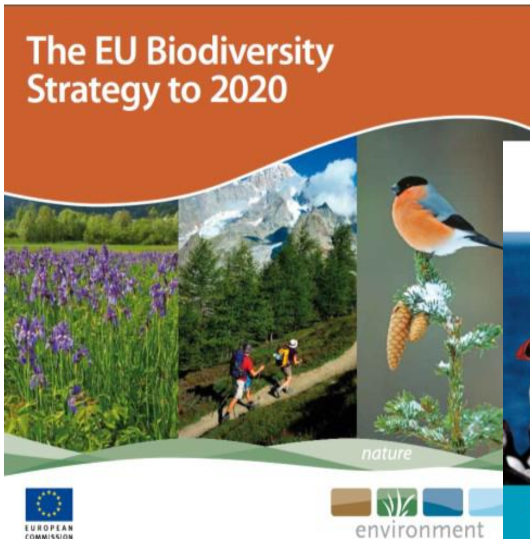
- Up today, there are few documented approaches & guidelines on how to undertake such an exercise.

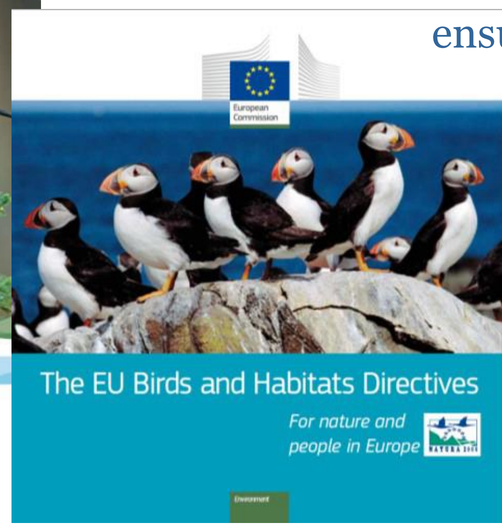




EU-Policy context of **E**cosystem-based **M**anagement for **A**quatic **E**cosystems

The **WFD 2000/60** introduced a legal framework to protect and restore the **W**ater environment across Europe and ensure its long-term, **S**ustainable **U**se.



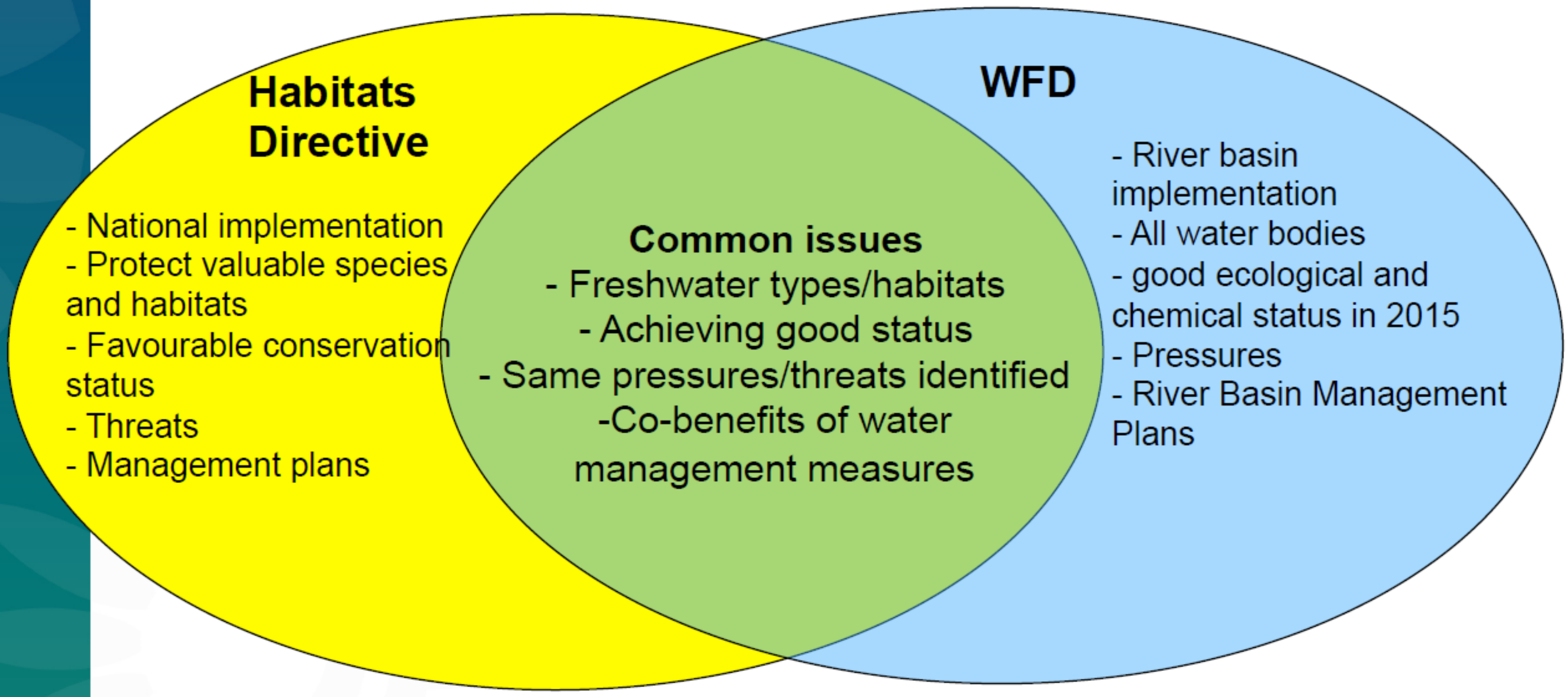


The **EU Biodiversity Strategy** recognizes the need to incorporate **E**cosystem **S**ervices into land-use management, conservation, and restoration actions.

Birds & Habitats Directives

EU POLICIES ON FRESHWATER ENVIRONMENT, NATURE & BIODIVERSITY

Cross-walk between Habitats Directive 92/43 & WFD 2000/60

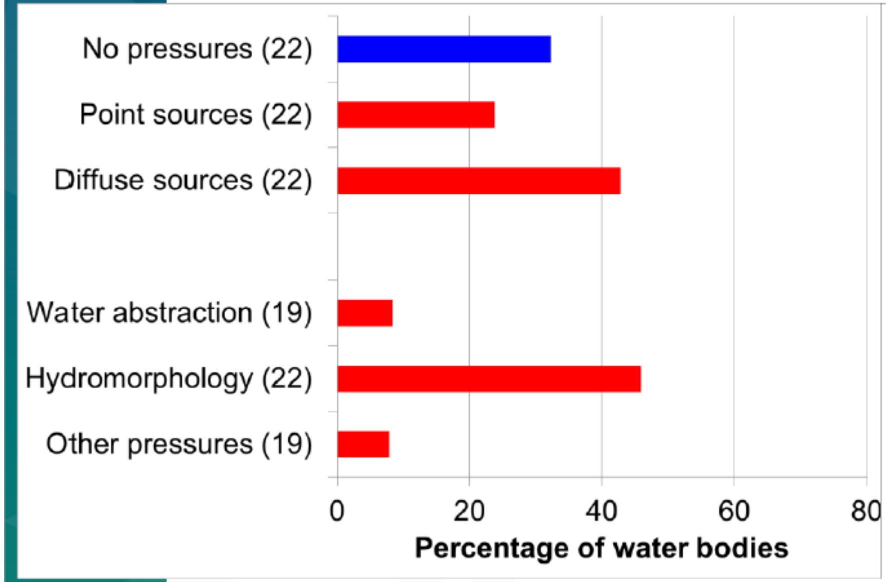


Coordinated activities under the Habitats directive and WFD may help to ensure better protection of freshwater ecosystems and water management

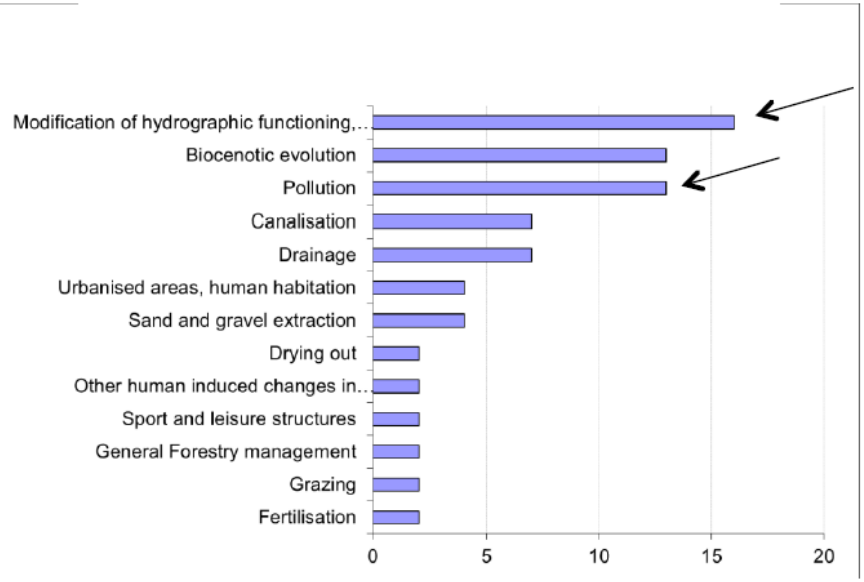
Source: *European Freshwater Assessment* , ETC/ICM 2015

WFD pressures and HD threats: EU-level

WFD: Rivers affected by specific pressures



Freshwater Habitat types affected by specific pressures

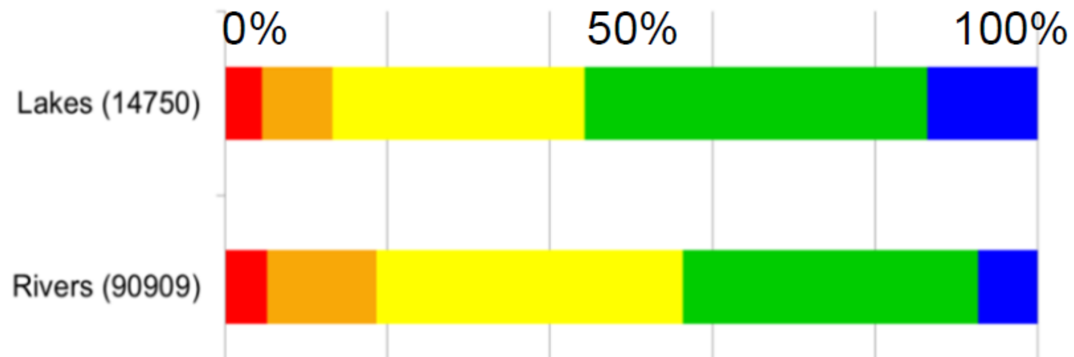


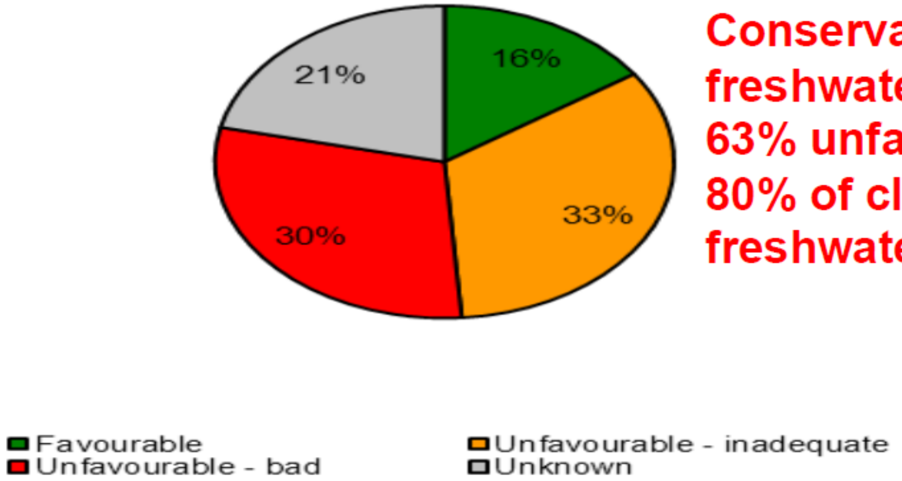
Pollution (mainly nutrients) and hydromorphological modifications most important in both directives

Source: *European Freshwater Assessment* , ETC/ICM 2015

WFD and HD status – EU level

WFD – ecological status in classified rivers: 55% < good, 40% of lakes < good





Habitats Directive – Conservation Status of freshwater habitats: 63% unfavourable or 80% of classified freshwater habitats

Source: *European Freshwater Assessment* , ETC/ICM 2015

WFD Implementation & **E**cosystem **S**ervices

The link between environmental characteristics of surface waters & Ecosystem Services in the **WFD**

Linking WFD implementation with ecosystem services

WFD

Environmental Characteristics
Biological elements, hydromorphology, Physico-Chem, specific pollutants and priority substances

Water Quality Criteria

Environmental Quality

Ecological & Chemical Status - Structure

Ecosystem Services

Ecosystem Functions

The capacity of ecosystems to *provide* ***Ecosystem Services*** that satisfy **human well-being** depends on its ***Ecosystem Functions*** (De Groot et al. 2002)

Source: Vlachopoulou et al. / Science of the Total Environment 470–471: 2014

Rivers & Riparian Landscapes in W. Greece

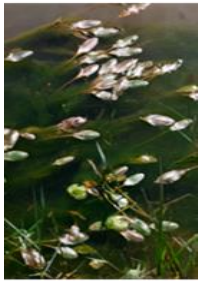
- an **integrated approach** for assessing *the impact of human intervention* to riparian landscape in the ''ancient'' Greek river ***Acheron*** was conducted,

by incorporating the information collected at **landscape** & **local scale** levels in order to gain a holistic understanding of the river & riparian ecosystems dynamics.

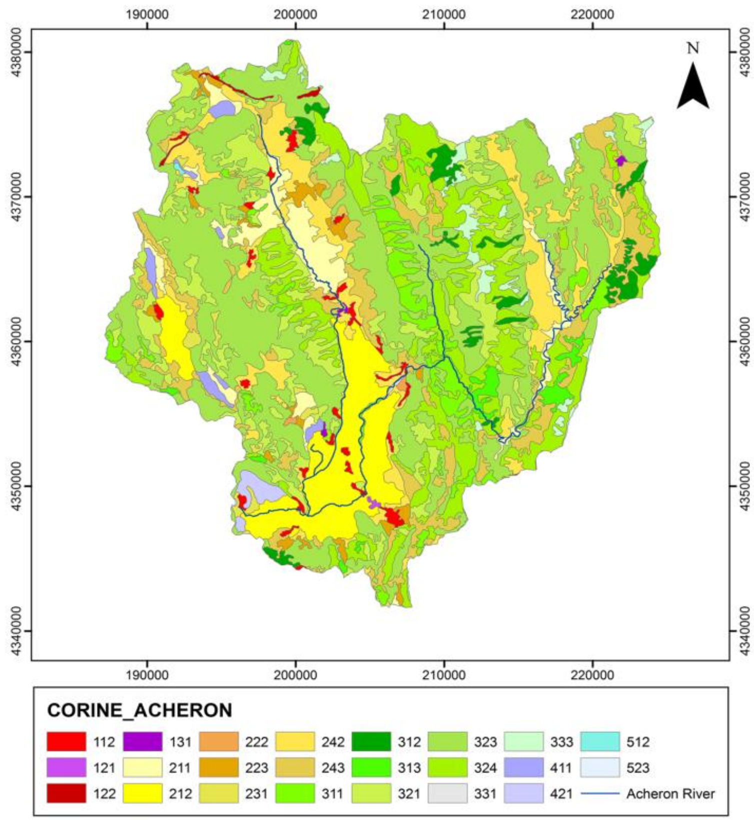
- Landsat-TM imagery, air photos, GIS & Remote Sensing techniques for detecting the spatiotemporal dynamic patterns of **LCLU changes** were applied.

- The utmost goal of the study was the examination of the **degree** in which **LCLU changes** affect the ability of the riparian ecosystems to *deliver* ***ES.***





STUDY RIVER: Acheron catchment area



Location of the studied Acheron River in W. Greece. LCLU types based on *CORINE 2000* Land Cover classification system.

Source: Papastergiadou et al. 2012, 2014, 2016

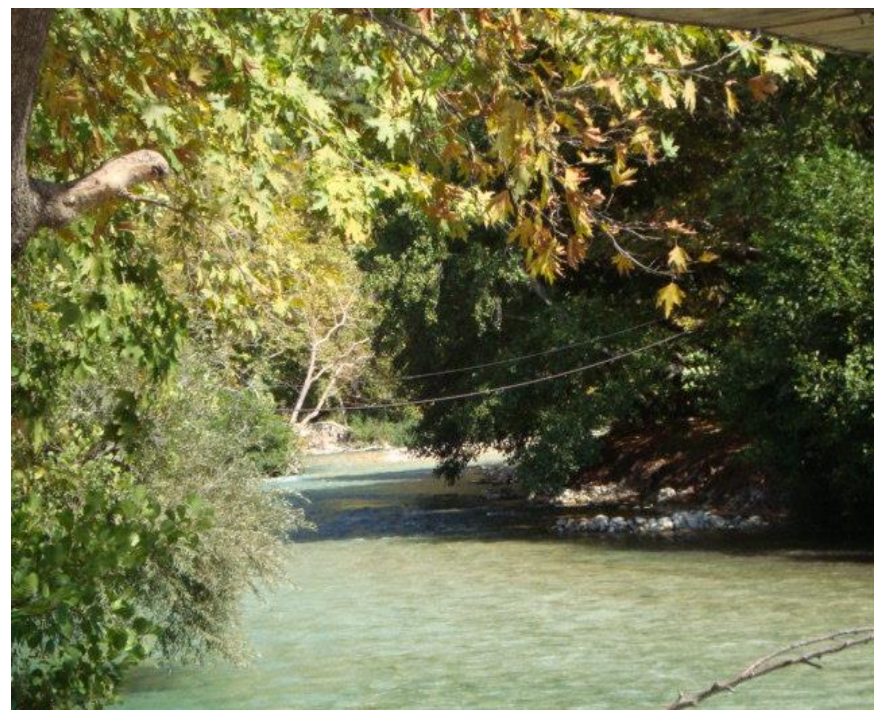
GIS spatial geo-database- CORINE land cover Classification System

Level 1	Level 2	Level 3	Abbrev.	
1. Artificial surfaces	1.1 Urban	1.1.1 Urban Fabric	AUU	Artificial surfaces
	1.2 Industrial, commercial and transport units	1.2.2 Road and rail networks & associated land	AIR	
2. Agricultural areas	2.1 Arable land	2.1.1 Non irrigated arable land	AAN	Cultivations
		2.1.2 Permanently irrigated land	AAP	
	2.2 Permanent crops	2.2.2 Fruit trees	APF	
		2.2.3 Olive groves	APO	
	2.4 Heterogeneous agricultural areas	2.4.1 Agro forestry areas	AHF	
3. Forests & semi natural areas	3.1 Forests	3.1.1 Broad-leaved forest	FFB	Natural Land
		3.1.2 Coniferous forest	FFC	
	3.2 Shrub / herbaceous vegetation associations	3.2.1 Natural grassland	FSN	
		3.2.3 Sclerophylous vegetation	FSS	
	3.3 Open spaces with little or no vegetation	3.3.1 Beaches, dunes & sand plains	FOB	Bare Land
		3.3.3 Sparsely vegetated areas	FOS	
4. Wetlands	4.1 Inland wetlands	4.1.1 Inland marshes	WIM	Wetlands
	4.2 Coastal wetlands	4.2.1 Salt marshes	WCM	
5. Water bodies	5.1 Inland waters	5.1.1 Water courses	WIC	Water
		5.1.2 Water bodies	WIB	
	5.2 Marine waters	5.2.1 Coastal lagoons	WME	

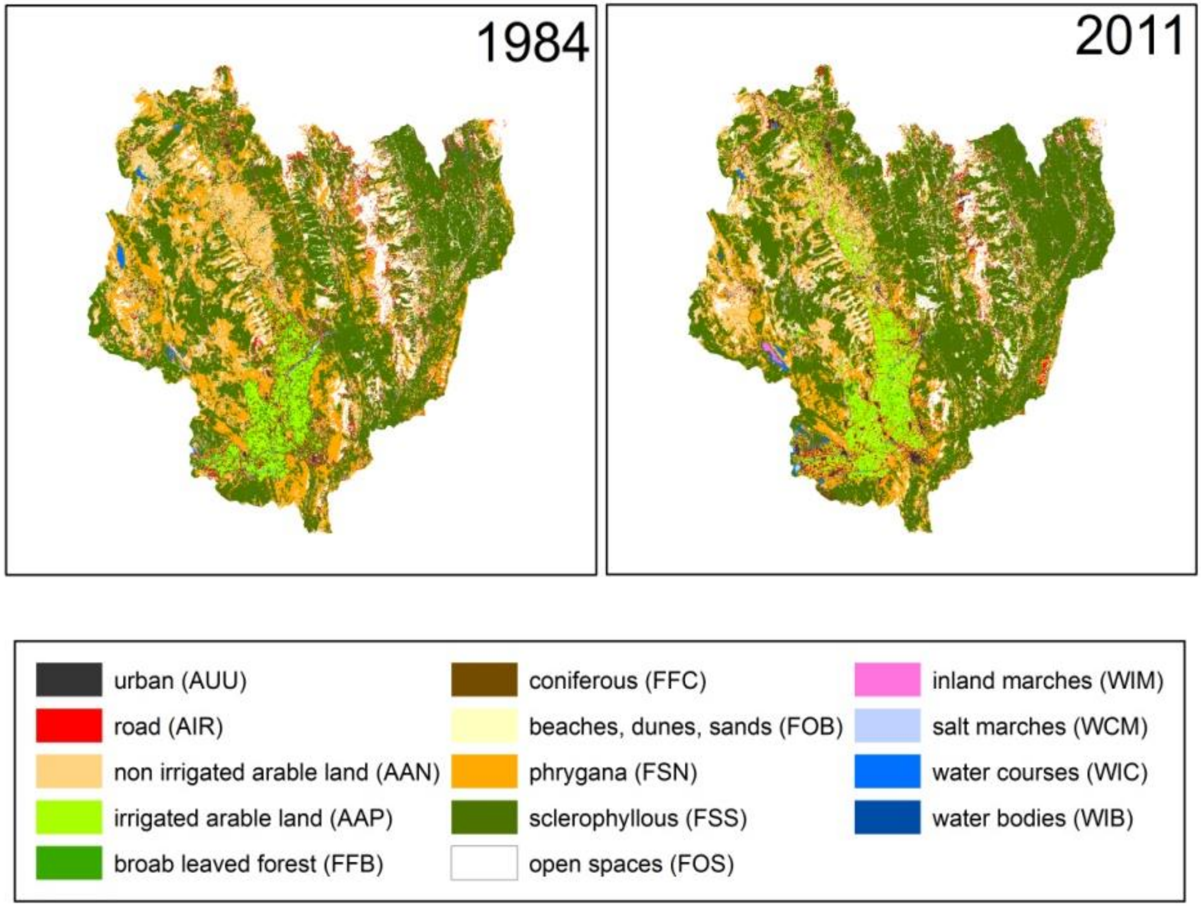




Code	Habitat types of Acheron riparian forest	3.1.1	Broad-leaved forest
91E0*	Residual alluvial forests *Alnus glutinosa* & *Fraxinus excelsior*		
91F0	Mixed oak-elm-ash (*Quercus robur, Ulmus laevis, U. minor, Fraxinus excelsior, F. angustifolia)* forests of great rivers		
92A0	*Salix alba & Populus alba galleries*		
92C0	*Platanus orientalis* & *Liquidambar orientalis* woods		
92D0	Thermo-Mediterranean riparian galleries (Nerio-Tamaricetea & Securinegion tinctoriae)		



Spatiotemporal Land cover/use changes at the Catchment level of Acheron river (Satellite Landsat TM Images 1984–2011)



Source: Kostara et al. 2013, 2015

Natural vegetated areas, which are dominated by ***sclerophyllus vegetation & phrygana***, cover a significant part of the catchment.

On the lowland areas ***urban areas*** expanded enormously the last years.

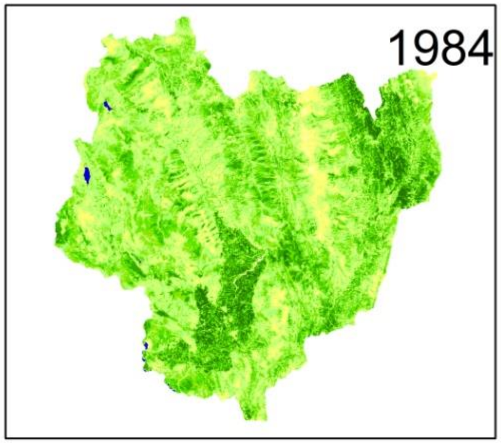
Irrigated & non irrigated arable land continuously *increased* mainly due to the land consolidation, to proliferation of drainage channels, the drying & shrinkage of wetlands.

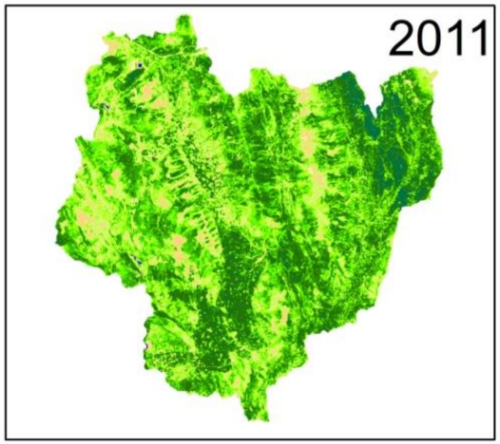
Salt marches restrictive drastically due to the expansion of *urban & agricultural land*.

The negative effect of these interventions has a significant influence *on **degradation** of **wetland habitats** & **loss** of valuable ecosystems*.

The Normalized Difference Vegetation Index - (NDVI) at the Catchment level of Acheron river

NDVI represents one of the most sensitive landscape components to environmental degradation





$$\mathrm{NDVI} = \frac{\mathrm{NIR} - \mathrm{RED}}{\mathrm{NIR} + \mathrm{RED}}$$

- ✓ High values of **NDVI** were obtained in the _upper part_ of the catchment at *middle & high altitude* areas, dominated by *sclerophyllous vegetation* (restricted human activities exists)
- ✓ *Regeneration* of the natural vegetation seems to happen in *middle (low hills) & higher altitudes areas*, due to _abandonment of shipping_.
- ✓ _*Sclerophyllous vegetation*_ replaced areas without or with sparse vegetation, like open spaces & *phrygana* .
- ✓ *Agricultural land* replace _*broad leaved forest*_ in riverine area.

This index ranges from **-1 to 1**,
(values 0.5 =dense vegetation and values < 0 = no vegetation) represents the combination of its normalized difference formulation & use of the highest absorption & reflectance regions of chlorophyll

Source: Kostara et al. 2013, 2015

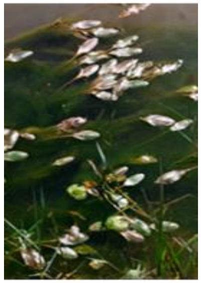
Rivers & Riparian Landscapes in W. Greece

- We define the *riparian area as buffer widths*, including the whole land in a distance of 200m of a river (Castelle et al. 1994, Ferreira et al. 2005, 2011)
- We examined the main characteristics & spatial distribution of **LCLU** change & we assessed the impact of **LCLU** intensification on the spatial patterns of the riparian zone.
- In order to achieve a more targeted mapping & quantifying of ***land transformations*** & **ES** we conduct the analysis at ***Grid cell level*** using ArcGIS 10.5 software.
- For local or regional differences, we used the **model** of ***weighed Land Use Dynamic Degree*** **(S,** Liu et al. 2003) in a spatial grid of **5** km×**5** km, which is mainly applied for **LCLU** change measurement of each type of land cover & can reflect the structural differences of **LCLU** types in different regions & different periods.

$$S = \{\Sigma (\Delta S_{i\text{-}j} / S_i)\} \times (1/t) \times 100\%$$

Si is the area of land type ***i*** in the beginning of the period,
ΔSi–j is the total area of land type ***i*** converted into other types,
t is the study period;
S is the land use dynamic degree in the period of ***t***





Model & method

Change detection analysis was applied to the **LCLU** vector format of **1945 & 2006**, in order to derive changes on spatial basis.

Spatio-temporal **LCLU** were measured by using *transition matrices* obtained by cross-tabulating the maps of **1945 & 2006**:

-the **row** totals show the size of each LCLU category at the start date (**loss- L**),

-the **column** totals show the corresponding sizes at the finish date (**gain- G**),

-the "**net change**" is the sum of the gross gain (column total minus persistence) of each category in one location & the gross loss (row total minus persistence) in another location

The **dynamic Gain** (G^t_{e+}) & **Loss** (L^t_{e+}) during period **t** is calculated as follows:

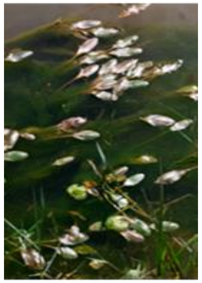
$$\mathbf{G^t_{e+} = \Sigma A^t_{i\rightarrow e} \quad \& \quad L^t_{e+} = \Sigma A^t_{i\rightarrow e}}$$

where $A^t_{i\rightarrow}e$ & $A^t_{i\rightarrow}e$ refer to the area converted from & to type **I** during period **t, m** is the total number of **LCLU** types.

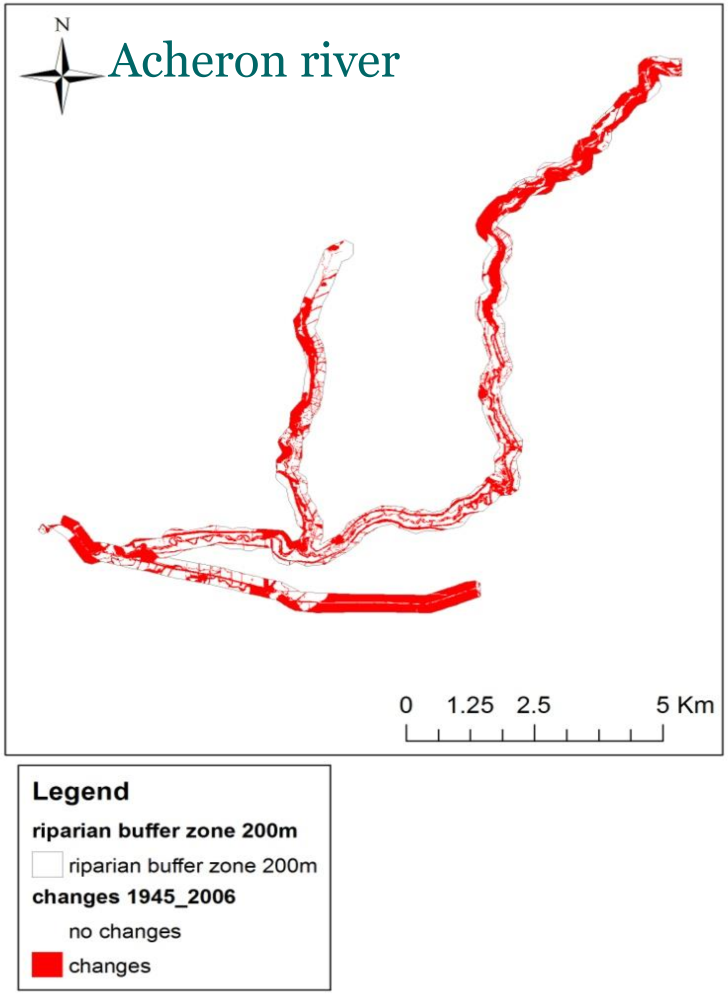
The **Net Change** is also calculated: $\mathbf{NC^t_e = G^t_{e+} - L^t_{e+}}$

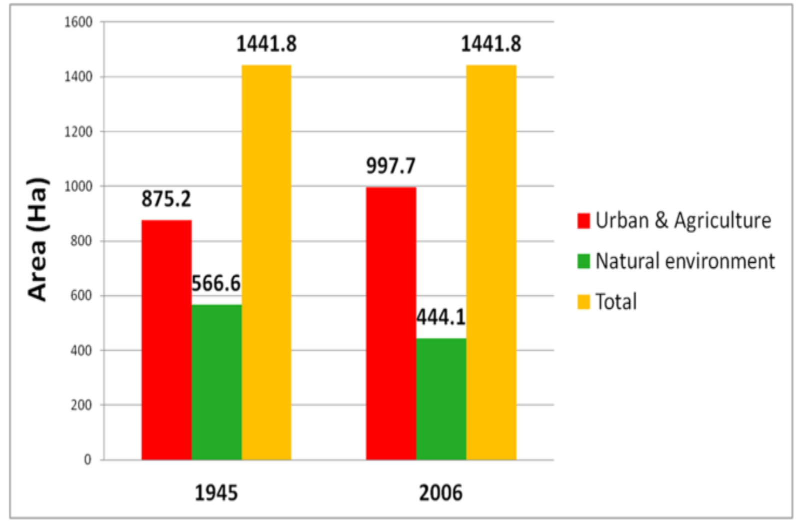
Finally, we examined the influence of the resulting changes on the provision of the **ES** & to support ecological integrity. The **ES 'matrix' approach** was used to assess the riparian areas' capacity to supply **ES** (Burkhard et al. 2009, 2012)





Spatiotemporal Land cover/use changes in the Riparian Buffer zone level (aerial photo's 1945–2006)





-significant increase of ***artificial surfaces***

[urban fabric & road networks]

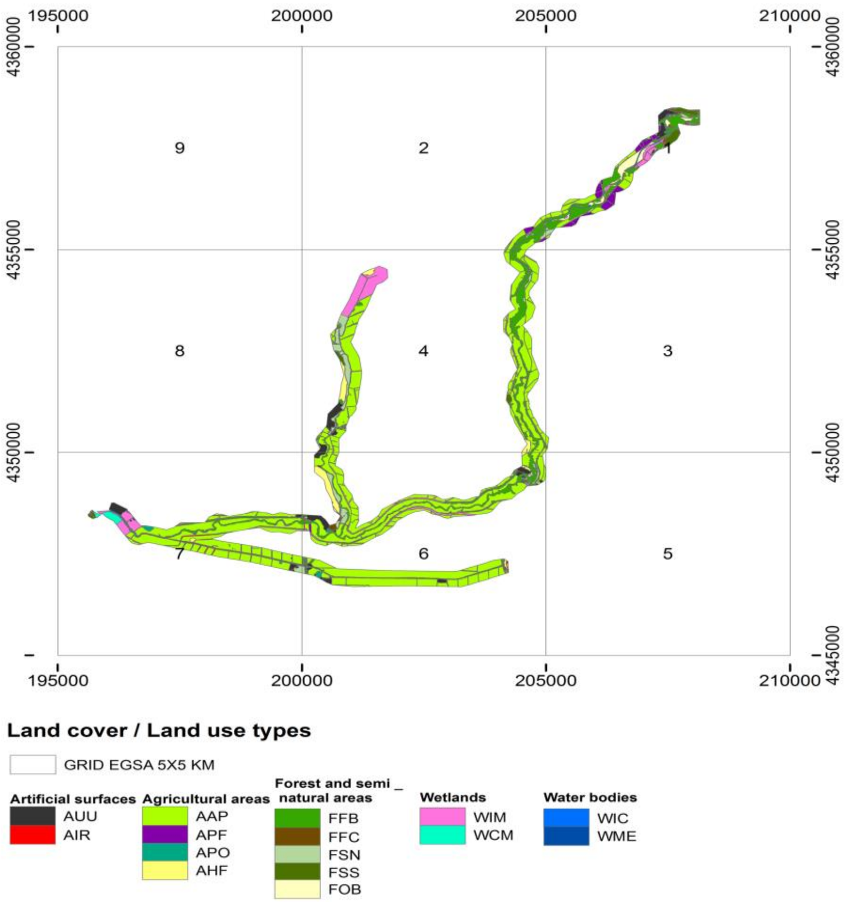
-increase of the total area of ***agricultural land***

[cropland, fruit trees, olive groves]

Extent of **LCLU classes** & **Land Cover Net Change (%)**

	Area (ha)		Area %		Net Change %	GROUPING (aggregated LCLU)
LCLU	**1945**	**2006**	**1945**	**2006**	**1945-2006**	
1.1.2 Discontinuous urban fabric	9.76	53.5	0.68	3.71	448.16	**1.** Artificial surfaces
1.2.2 Road and rail networks and associated land	3.36	54.64	0.23	3.79	1.054.13	
2.1.2 Permanently irrigated land	771.45	824.86	53.51	57.21	6.92	**2.** Cultivations
2.2.2 Fruit trees and berry plantations	-	27.68	-	1.92	-	
2.2.3 Olive groves	1.31	4.95	0.09	0.34	277.86	
2.4.1 Annual crops associated with permanent crops	89.33	32.06	6.2	2.22	-64.12	
3.1.1 Broad-leaved forest	128.49	210.33	8.91	14.59	63.7	**3.** Forest and Semi natural areas
3.1.2 Coniferous forest	-	2.46	-	0.17	-	
3.2.1 Natural grasslands	28.08	51.1	1.95	3.54	81.94	
3.2.3 Sclerophyllous vegetation	26.99	18.76	1.87	1.3	-30.49	
3.3.1 Beaches, dunes, river islands and sand plains	128.61	24.9	8.92	1.73	-80.64	
4.1.1 Inland marshes	191.33	97.72	13.27	6.78	-48.93	**4.** Wetlands
4.2.1 Salt marshes	25.99	16.02	1.8	1.11	-38.4	
5.1.1 Water courses	37.08	22.76	2.57	1.58	-34.8	**5.** Water Bodies
5.1.2. Estuaries	2.31	0.1	0.16	0.01	-95.67	

General characteristics & spatial pattern of land use change



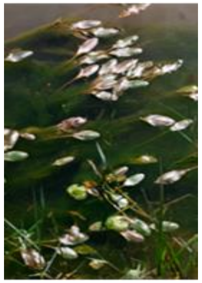
LCLU interpretation map of the studied Acheron riparian buffer zone (200m) in 2006.

•Land use disturbances in the catchment's are more **intense in the riparian buffer zone**, with maximum ***habitat integrity*** recorded in the *upper river reaches.*

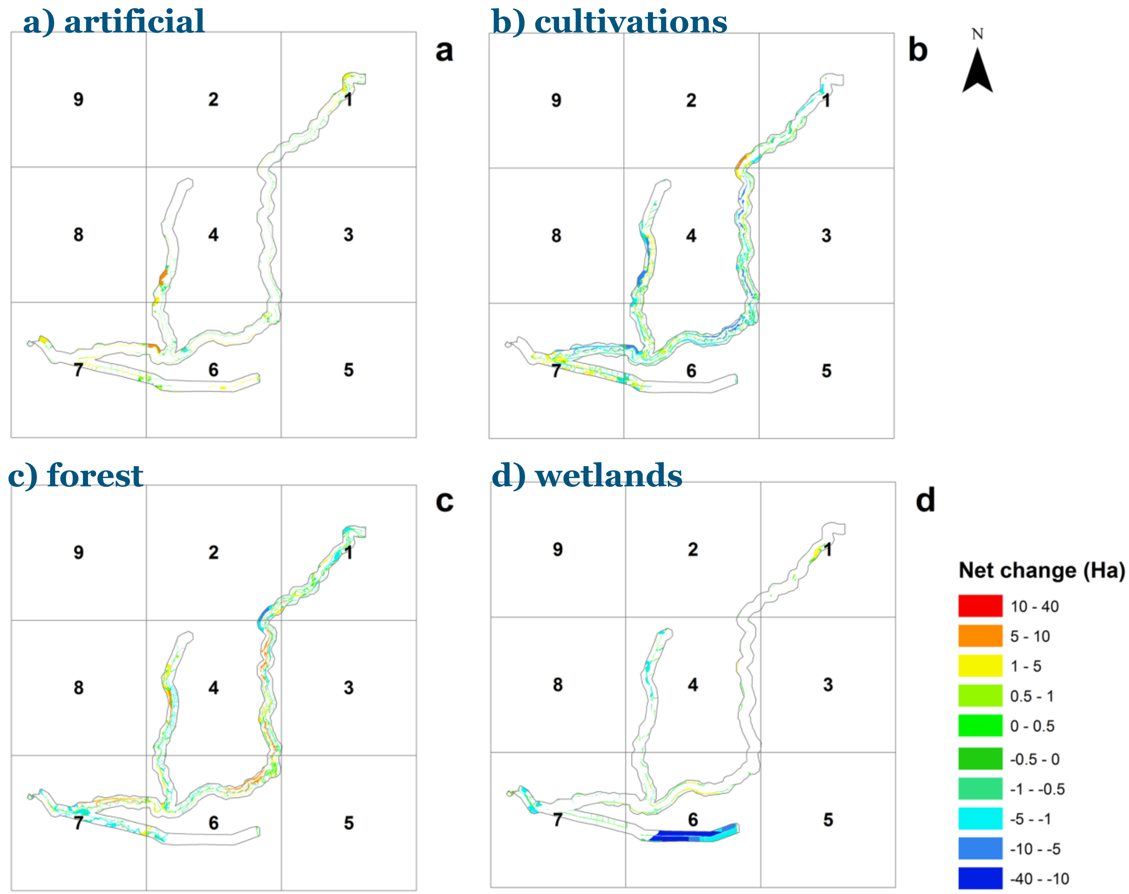
•the changes since **1945** extended mainly throughout the ***middle & lower river*** *courses*

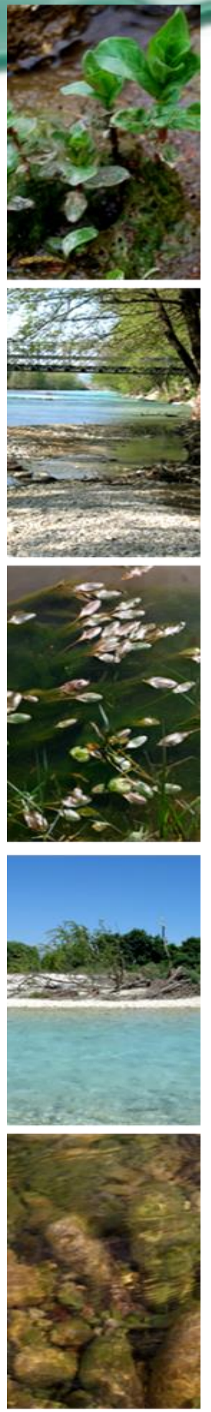
• the *disturbance* from ***agriculture*** due to the low altitude & the proximity of locals to the water courses

•leading to the subsequent *drastic* ***decreases*** *of* ***natural land covers*** [forests, grasslands, sclerophyllous vegetation, water courses & marshes]



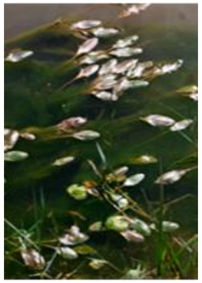
Regional characteristics & spatial pattern of Land Use Net Change





LCLU changes of aggregated types in the second half of 20th century. The legend represents the ***Net Change*** area (ha) in each **5km x 5km Grid cell** & the difference between **G**ain & **L**oss area of the land types.

Regional characteristics & spatial pattern of Land Use Net Change



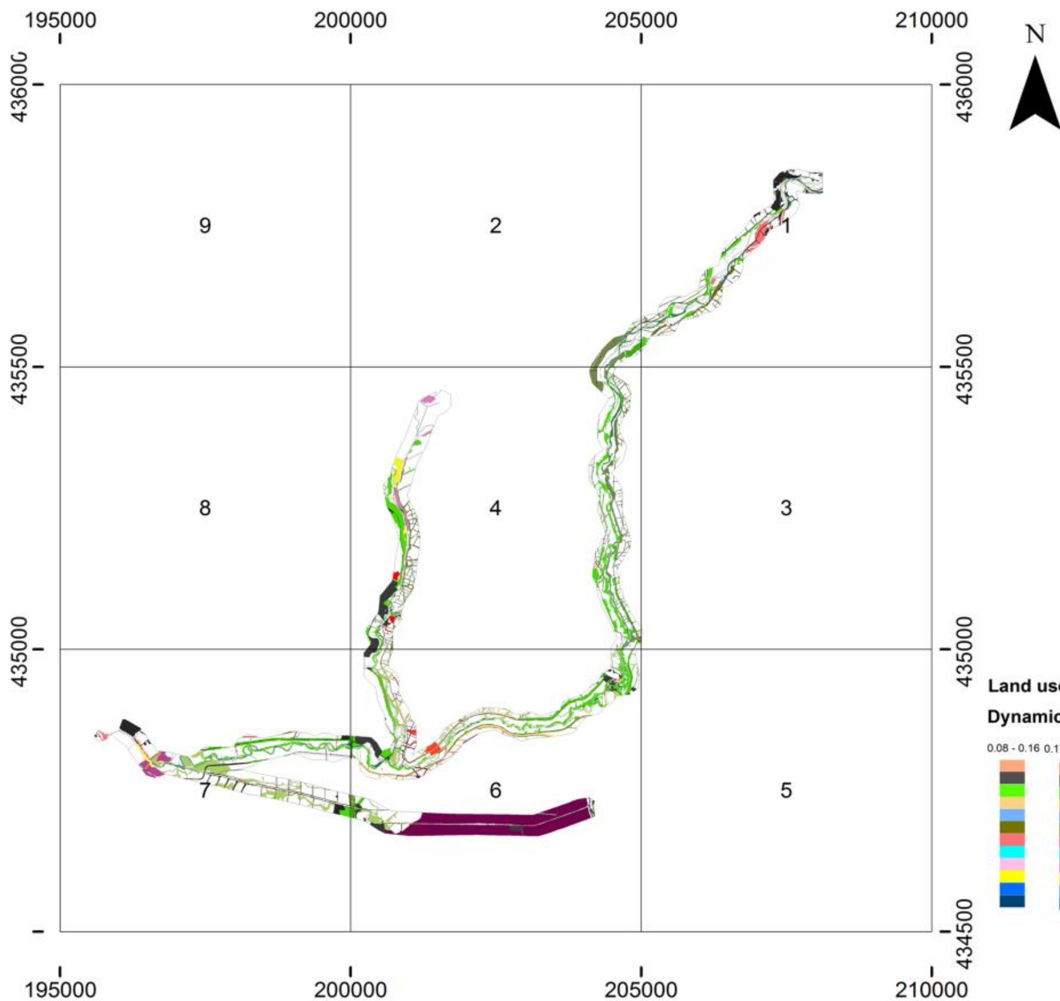
- ***Artificial surfaces:*** increased at whole Grid cells, with the largest increase in Grids 6 (31.40ha) & 7 (22.49 Ha).

- ***Cultivations:*** increased in the lower part of the river [Grids 6 (54.10ha) & 7 (8.26ha)], while gain areas from the drainage of the ancient lake "Acherousia", were turned into fertile arable soils, through land consolidation projects. In the upper part of the river *traditional cultivated land decreased & abandoned* [Grids 1 (-13.09 ha) & 4 (-29.52ha)].

- ***Forests & semi-natural areas:*** increased in the middle part of the river [Grids 4 (19.11ha) & 6 (17.23ha), while they decreased in the others. Land owners in the lower parts of the Acheron (Grid 7) cut riparian trees, e.g. *Alnus glutinosa* in order to expand their cultivations.

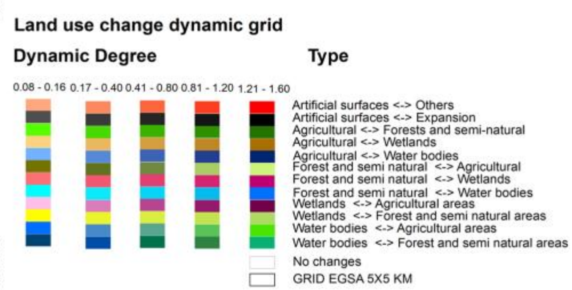
- ***Wetlands & water bodies;*** reed beds increased only in the upper part of the river [Grids 1, 2] & decreased in others, especially in Grid 6, while a significant decline in ***water bodies*** has been recorded in the whole area.

Land Use Dynamic Classification map



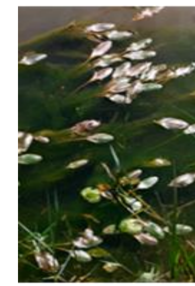
The **Land Use Dynamic Degree model** was used for the **LCLU** change measurement of a single type of land & thus a '**Land use Dynamic classification map**' was generated .

[**LCLU** type conversions among *Artificial surfaces, Agricultural areas, Forest & semi natural areas, Wetlands & Water Bodies*].



LCLU Dynamic Classification map for the Acheron riparian buffer zone





Regional transformations & Land Use Dynamic classification

- The most important changes resulting from the transformation of ***wetlands*** into cultivated areas in the lower part of the river [Grid 6 (112.38 Ha) & to a lesser extent to 7].

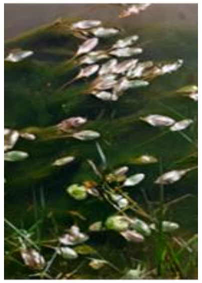
- Significant parts of ***forests & semi-natural areas*** mainly in the lower part of the river [Grids 6, 7] transformed into cultivated areas.

- In **1945,** the middle & lower part of the Acheron plain was covered by Acherousia Lake which was later drained & turned into fertile arable soils.

- The land reclamation & drainage projects of the former lake in the **1960s,** led to the embankments & stabilisation of the river banks & resulted in the delivery of significant areas to agriculture.

- This trend continued in the ***lowest reaches*** of the Acheron River [Grid 7], where a significant reduction in **wetlands** (e.g. salt marches) was also recorded, with their simultaneous transformation into *Artificial surfaces & Cultivations*.





Ecosystem Services (ES) ‘Matrix’ Approach

CORINE land cover type:	Ecological Integrity Σ	Abiotic heterogeneity	Biodiversity	Biotic waterflows	Metabolic efficiency	Exergy Capture (Radiation)	Reduction of Nutrient loss	Storage capacity (SOM)	Regulating services Σ	Local climate regulation	Global climate regulation	Flood protection	Groundwater recharge	Air Quality Regulation	Erosion Regulation	Nutrient regulation	Water purification	Pollination	Provisioning services Σ	Crops	Livestock	Fodder	Capture Fisheries	Aquaculture	Wild Foods	Timber	Wood Fuel	Energy	Biochemicals and Medicine	Freshwater	Cultural services Σ	Recreation& Aesthetic Values	Intrinsic Value of Biodiversity
Continuous urban fabric	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Discontinuous urban fabric	7	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	3	1	0	1	0	0	1	0	0	1	0	0	0	0	0
Industrial or commercial units	2	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Road and rail networks	4	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Port areas	2	1	1	0	0	0	0	0	3	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0
Airports	7	1	1	1	1	1	2	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Mineral extraction sites	4	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0
Dump sites	8	2	1	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Construction sites	3	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Green urban areas	18	3	3	2	1	4	3	2	11	2	1	0	2	1	2	1	1	1	2	0	0	0	0	0	1	0	1	0	0	0	3	3	0
Sport and leasure facilities	16	2	2	2	1	4	3	2	9	1	1	0	2	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	5	5	0
Non-irrigated arable land	22	3	2	3	4	5	1	4	5	2	1	1	1	0	0	0	0	0	21	5	5	5	0	0	0	0	0	2	1	0	1	1	0
Permanently irrigated land	21	3	2	5	2	5	1	3	5	3	1	1	0	0	0	0	0	0	18	5	5	2	0	0	0	0	0	1	1	0	1	1	0
Ricefields	20	3	2	5	1	5	1	3	4	2	0	0	2	0	0	0	0	0	7	5	0	2	0	0	0	0	0	0	0	0	1	1	0
Vineyards	14	3	2	3	1	3	0	2	3	1	1	0	1	0	0	0	0	0	5	4	0	0	0	0	0	0	1	1	0	0	5	5	0
Fruit trees and berries	21	4	3	4	2	3	2	3	19	2	2	2	2	2	2	1	1	5	13	5	0	0	0	0	0	4	4	1	0	0	5	5	0
Olive groves	17	3	2	3	2	3	1	3	7	1	1	0	1	1	1	1	1	0	12	4	0	0	0	0	0	4	4	1	0	0	5	5	0
Pastures	24	2	2	4	5	5	2	4	8	1	1	1	1	0	4	0	0	0	10	0	5	5	0	0	0	0	0	1	0	0	3	3	0
Annual and permanent crops	18	2	2	3	2	4	2	3	7	2	1	1	1	1	1	0	0	0	20	5	5	5	0	0	0	0	0	1	1	0	1	1	0
Complex cultivation patterns	20	4	3	3	2	4	1	3	5	2	1	1	1	0	0	0	0	0	9	4	0	3	0	0	0	0	0	1	2	0	2	2	0
Agriculture& natural vegetation	19	3	3	3	2	3	2	3	13	3	2	1	2	1	3	0	1	0	21	3	3	2	0	0	3	3	3	2	1	0	5	2	3
Agro-forestry areas	27	4	4	4	3	4	4	4	13	2	1	1	1	1	2	1	1	3	14	3	3	2	0	0	0	3	3	2	0	0	3	3	0
Broad-leaved forest	31	3	4	5	4	5	5	5	39	5	4	3	2	5	5	5	5	5	21	0	0	1	0	0	5	5	5	1	5	0	10	5	5
Coniferous forest	30	3	4	4	4	5	5	5	39	5	4	3	2	5	5	5	5	5	21	0	0	1	0	0	5	5	5	1	5	0	10	5	5
Mixed forest	32	3	5	5	4	5	5	5	39	5	4	3	2	5	5	5	5	5	21	0	0	1	0	0	5	5	5	1	5	0	10	5	5
Natural grassland	30	3	5	4	4	4	5	5	22	2	3	1	1	0	5	5	5	0	5	0	3	0	0	0	2	0	0	0	0	0	6	3	3
Moors and heathland	30	3	4	4	5	4	5	5	20	4	3	2	2	0	0	3	4	2	10	0	2	0	0	0	1	0	2	2	0	0	10	5	5
Sclerophyllous vegetation	21	3	4	2	3	3	4	2	7	2	1	1	1	0	0	0	0	2	8	0	2	0	0	0	1	0	2	0	3	0	6	2	4
Transitional woodland shrub	21	3	4	2	3	3	4	2	3	1	0	0	0	0	0	0	0	2	5	0	2	0	0	0	1	0	2	1	0	0	4	2	2
Beaches, dunes and sand plains	10	3	3	1	1	1	0	1	6	0	0	5	1	0	0	0	0	0	2	0	0	0	0	0	0	0	0	1	0	0	7	5	2
Bare rock	6	3	3	0	0	0	0	0	3	0	0	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	4	4	0
Sparsely vegetated areas	9	2	3	1	0	1	1	1	3	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Burnt areas	6	2	1	0	0	0	0	3	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Glaciers and perpetual snow	3	2	1	0	0	0	0	0	10	3	3	0	4	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	5	5	5	0
Inland marshes	25	3	2	4	4	4	3	5	14	2	2	4	2	0	0	4	0	0	7	0	2	5	0	0	0	0	0	0	0	0	0	0	0
Peatbogs	29	3	4	4	4	4	5	5	24	4	5	3	3	0	0	3	4	2	5	0	0	0	0	0	0	0	0	2	0	0	8	4	4
Salt marshes	23	2	3	4	3	3	3	5	8	1	0	5	0	0	0	2	0	0	2	0	2	0	0	0	0	0	0	0	0	0	3	3	0
Salines	2	1	1	0	0	0	0	0	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	0
Intertidal flats	13	2	3	0	2	1	4	1	7	1	0	5	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	4	4	0
Water courses	18	4	4	0	3	3	3	1	10	1	0	2	1	0	0	3	3	0	12	0	0	0	3	0	4	0	0	3	0	5	10	5	5
Water bodies	23	4	4	0	4	4	3	4	7	2	1	1	2	0	0	1	0	0	12	0	0	0	3	0	4	0	0	0	0	5	9	5	4
Coastal lagoons	25	4	4	0	5	5	3	4	5	1	0	4	0	0	0	0	0	0	16	0	0	0	4	5	4	0	0	1	0	0	9	5	4
Estuaries	21	3	3	0	5	5	3	2	9	0	0	3	0	0	0	3	3	0	17	0	0	0	5	5	4	0	0	2	0	0	7	4	3
Sea and ocean	15	2	2	0	3	3	4	1	13	3	5	0	0	0	0	5	0	0	11	0	0	1	5	5	0	0	0	3	0	0	6	4	2

Table. Assessment matrix illustrating the capacities of different **LCLU** classes to support **ecological integrity** & to supply **Ecosystem Services** (Burkhard *et al.*, 2009).

The *Ecosystem features & Services* were plotted on the y-axis & the **LCLU** types on the x-axis respectively.

The **ES** matrix approach is based on a normalisation of *ES indicator values* to a relative scale ranging from **0 to 5** for their supply, flow &/or demand ranking.

scale for assessing capacities:

- 0 = no relevant capacity
- 1 = low relevant capacity
- 2 = relevant capacity
- 3 = medium relevant capacity
- 4 = high relevant capacity
- 5 = very high relevant capacity

Ecosystem Services (ES) Assessment in Acheron river

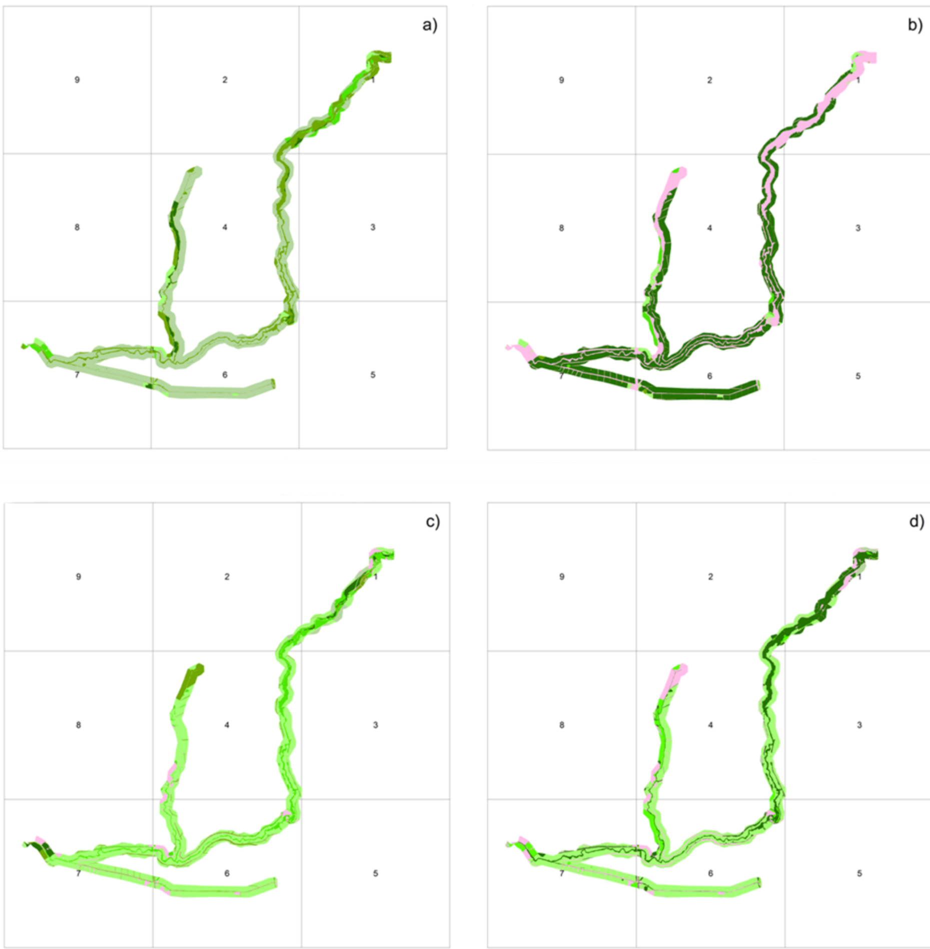
In this context, we linked different **LCLU** types to the **E**cological **I**ntegrity & **ES** supply in the studied river.

- The **first group** of indicators describes *ecosystem structure*, like habitat components or biological diversity & the processes through energy and matter budgets relevant for long term ecosystem functionality.
- The **second** & **third groups** consider *regulating & provisioning services*
- The **fourth group** consider indicators of *cultural, recreational & aesthetic values* (*scenery, scenic beauty*).

Overall, less-disturbed more natural **LCLU** types (*natural forests & semi natural areas, grasslands, wetlands, salt marshes*), have higher capacity to supply regulating **ES.**

	ART	CLT	NTR	WTL	WTR	BRL
Ecological integrity						
Abiotic heterogeneity	1	2	4	4	4	3
Biodiversity	1	2	5	4	4	2
Biotic water flows	0	3	5	4	1	0
Metabolic efficiency	0	3	4	4	4	0
Exergy capture	1	4	5	4	4	0
Reduction of nutrient loss	0	2	5	4	3	0
Storage capacity	1	3	5	5	3	1
ESSc (EI)	4	19	33	29	23	6
Regulating ecosystem Services						
Local climate regulation	0	1	5	3	2	1
Global climate regulation	0	1	4	3	1	1
Flood protection	0	1	4	4	3	4
Groundwater recharge	1	2	3	3	3	2
Air quality regulation	0	1	5	3	1	0
Erosion regulation	0	1	5	1	0	0
Nutrient regulation	0	1	5	5	2	0
Water purification	0	1	4	5	3	0
Pollination	0	1	4	3	0	0
ESSc (Res)	1	10	39	30	15	8
Provisioning ecosystem services						
Crops	0	5	4	0	0	0
Livestock	0	4	3	1	0	0
Fodder	0	4	3	2	0	0
Capture fisheries	0	0	0	0	4	0
Aquaculture	0	0	0	0	4	3
Wild foods	0	0	2	0	1	0
Timber	0	1	3	0	0	0
Wood fuel	0	1	4	0	0	0
Biochemicals and medicine	0	1	1	0	0	0
Freshwater	0	0	4	4	5	4
ESSc (Pes)	0	16	20	4	11	6
Cultural ecosystem services						
Recreation & aesthetic values	0	0	3	4	5	3
ESSc	0	0	3	4	5	3

Ecosystem Services (ES) Assessment- Acheron riparian area



a) ecological integrity (*biodiversity*),
b) provisional services (*crops*),

c) regulating services (*flood protection*),
d) cultural services (*recreation*)

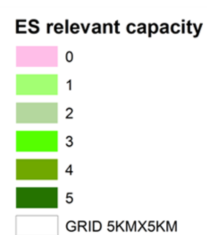
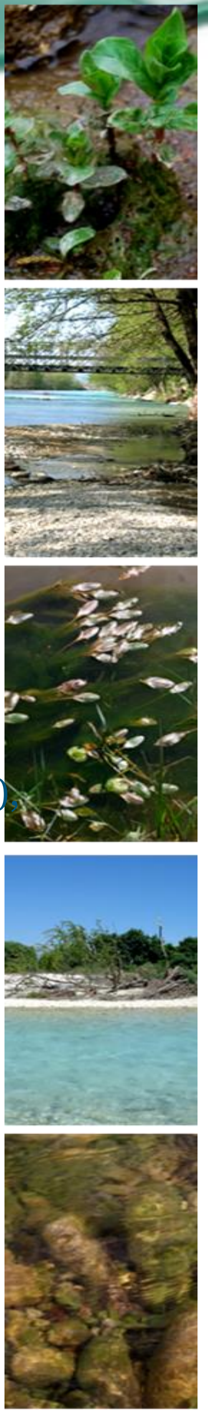


Fig. 6. Spatial distribution of selected **Ecosystem Services** (ES) in the studied area;

-***dark green*** patches show *high capacity* of **ES** support or supply

-***pink & lighter green*** patches show areas of *lower capacity*



Ecosystem Services Capacity index (ESC)

- Additionally an **index ESSc** (Clerici et al. 2014) was then calculated for each **LCLU** category **c** as the sum of the matrix **ESSj,c** values for all the **j** indicators used:

$$\mathrm{ESSc} = \sum_{j=1}^{I} \mathrm{ESSj,c}$$

- **ESSc** represents a measure of the overall capacity for the **LCLU** group **c** to provide specific ES & support Ecological integrity, as measured using the set of **j** indicators considered.

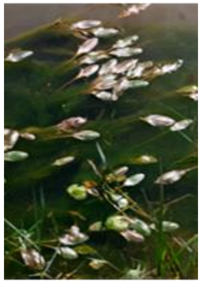
- <u>In order to derive the **total ESS capacity** </u>of the riparian zones which experienced a **LCLU** change, the **Ecosystem Service Capacity index (ESC)** was calculated for the years 1945 & 2006:

$$\mathrm{ESSc} = \sum_{c=1}^{M} \mathrm{ESCc} = \sum_{c=1}^{M} A_C\,\mathrm{ESSc}$$

- <u>ESC is equal to the summation </u>of the products between the ESSc **LCLU** values & their correspondent extension Ac, for all the M land-cover categories considered. A ratio index between the ESC indices for the years 2006 (t_1) & 1945 (t_0) will finally provide a measure of the relative **loss** or **gain** of the overall **ES** capacity following the **LCLU** change process:

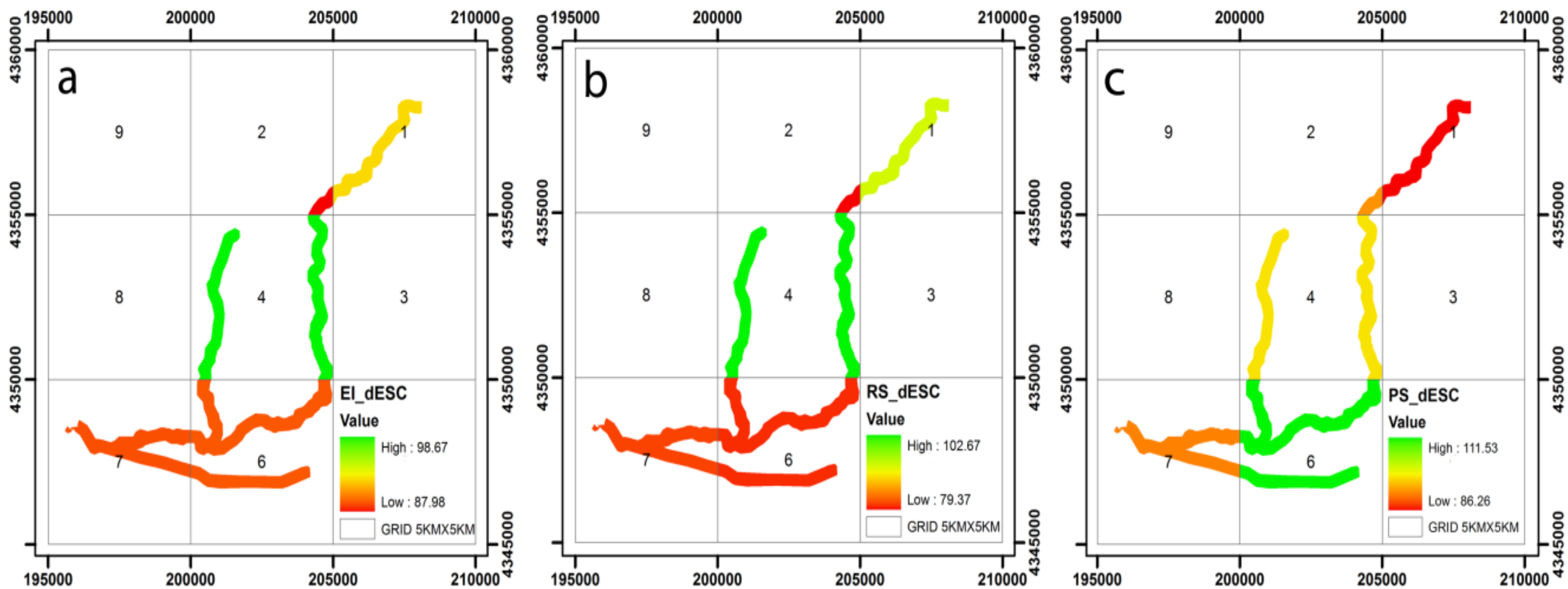
$$dESC = \frac{\mathrm{ESC}_{t1}}{\mathrm{ESC}_{t0}} \times 100$$





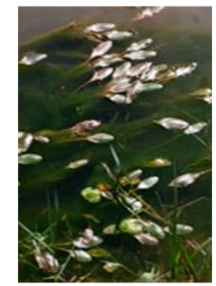
Ecosystem Services Capacity index (ESC) assessment for the Acheron riparian area following the **LCLU** conversion in 1945–2006

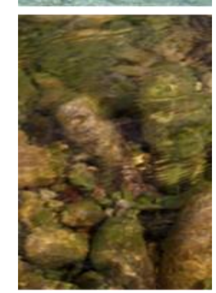
a) **E**cological **I**ntegrity (*biodiversity*) **b**) Regulating services (*floods*) **c**) Provisional services (*crops*)



-along the examined riparian zone & in all reference Grids, there is a reduction in the **ESC** index for the **EI** [variation ranging -7.41 to -12.02 between Grids].

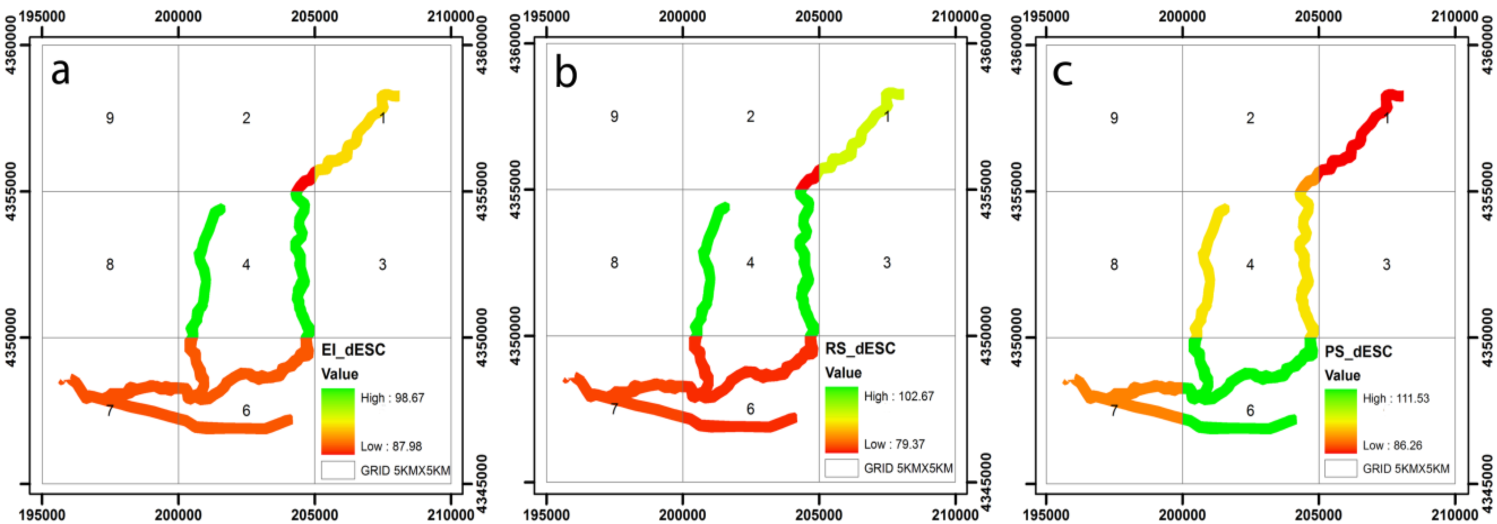
-the *high proportion of change events* represented by **LCLU *transitions*** between forests, semi-natural areas & agricultural areas (appr. 21.62 %) led to the *decreased* of the **ESC** value for **EI** & *loss of naturalness* [increase of urban & agricultural land].





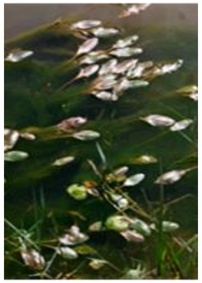
Ecosystem Services Capacity index (ESC) assessment for the Acheron riparian area following the LCLU conversion in 1945–2006

a) **E**cological **I**ntegrity (*biodiversity*) **b**) Regulating services (*floods*) **c**) Provisional services (*crops*)



- The ***Regulating service*** indicators group most affected Grids 2, 6, 7 [Grids 2 (-20.63%), 6 (-19.56%) & 7 (-18.78%)]. In Grid 4, an increase had occurred (2.67%) over the period considered.
- Similarly, the ***Provisioning services*** in Grid 1 were most negatively affected (-13.74%). The most notable increases in the values were in Grid 6 (11.53%).





Concluding Remarks

Riparian zones in Mediterranean rivers are highly dependent on the ***life-history features of land use*** & on its *long-term effects*.

These conflicts of *natural conditions* & *human activities* over time also reveal **the capacity of** different **LCLU** to supply **ES**, considering current states & temporal changes in **LCLU**.

The results demonstrated that the ***pattern & intensity*** *of land use* **changed** greatly due to *intense human activities*, especially at the *lowlands* & where *natural land* cover type's ***decreased*** & *arable land & artificial surfaces* ***increased***.

Human interventions have changed *the river beds*, increased *landscape fragmentation* & led to the *degradation & loss of wetland* habitats.

Concluding Remarks

Our findings highlight the importance of *understanding* ***land cover change dynamics*** & the *capacity* of different LCLU to supply **ES** in a typical Mediterranean middle-sized river.

In addition, this study underlines the importance of ***local-specific characteristics***, such as the *socio-economic development* of the country, *agriculture & urbanisation* as **drivers** of *land use change*.

In conclusion, monitoring & evaluating the **ES** functions & its changes could lead to a better understanding of the human-environment interaction, as well as support decision-making for riparian landscape management, & thereby ecological protection in the area.

The results can be used to form the base for **ES** based ***landscape management*** & to contribute significantly in future conservation priorities in the *Mediterranean rivers*.






Thank you for your attention


Thank you for your attention