Modelling Ecosystem Services in Europe

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VOLANTE

LECA Laboratoire d'Ecologie Alpine

VOLANTE Summer School

Lesvos, 18 June 2013

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Lecture outline

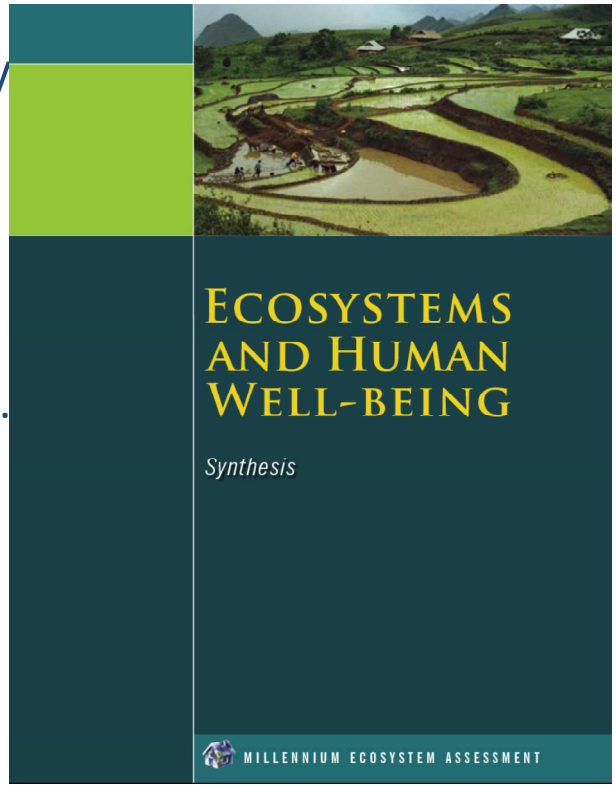
- The Ecosystem Service (ES) concept and definitions
- Challenges for spatially explicit modelling ES
- Ecosystem Service models at European scale
- Ecosystem Service bundles and trade-offs at European scale
- Downscaling Ecosystem Service assessments
- Towards Ecosystem Service scenarios

What good is biodiversity for humans?

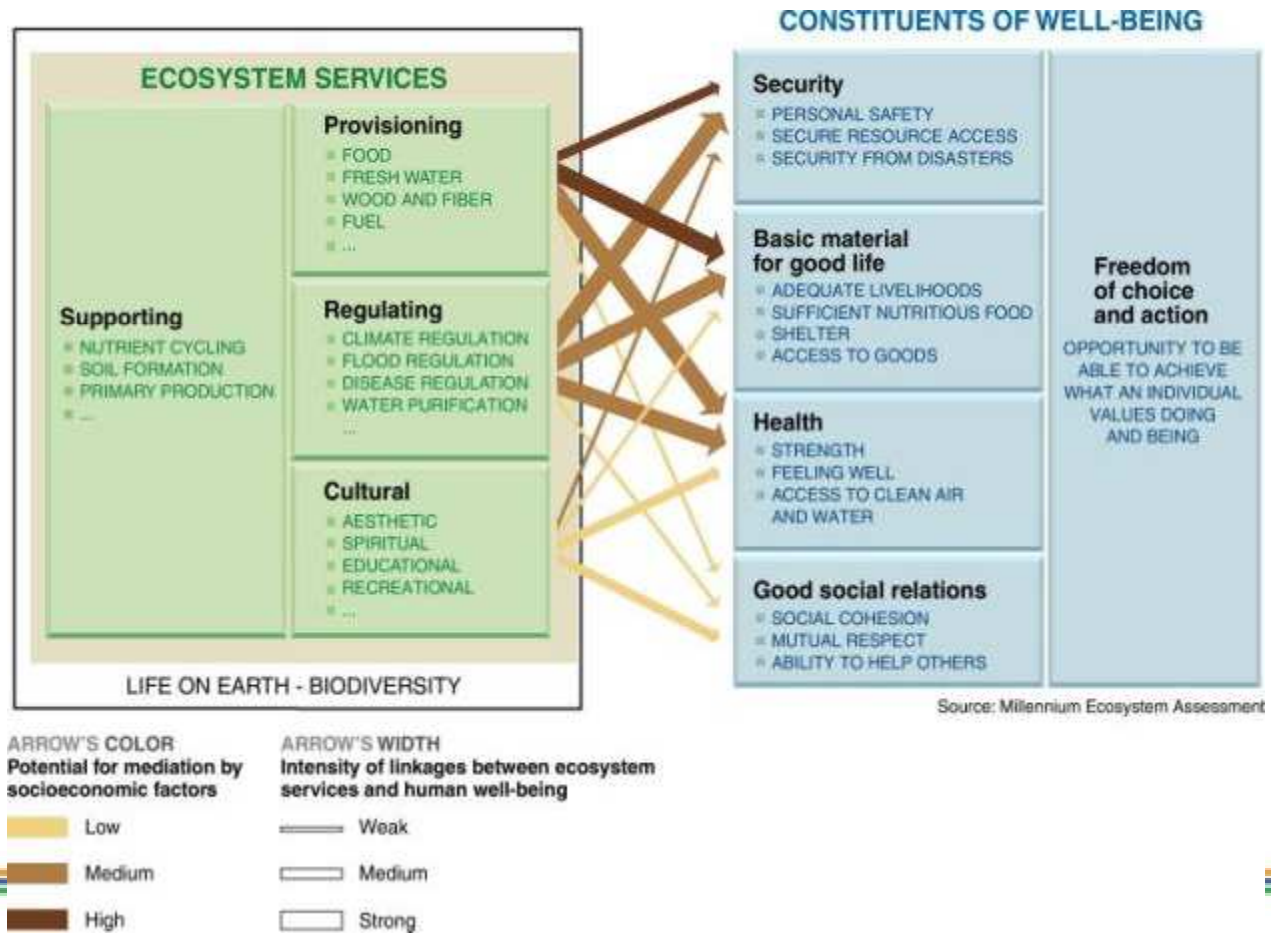
- Nothing !
  - → Intrinsic value of nature
- Essential for life on Earth
  - → Role of biodiversity for ecosystem functioning and the biosphere
- Services to society
  - → Nature's contributions to individual et collective well-being
- New objectives :
  - → Accounting for nature's services in private and public decisions

Ecosystem services and the ecosystem approach

- Ecosystem Services :
  - The benefits that society receives from biodiversity and ecosystem functioning
    - Ehrlich, P. R., and H. A. Mooney. 1983. Extinction, substitution, and ecosystem services. BioScience 33:248–254
    - Daily, G.C. ed. (1997) Nature's Services: Societal Dependence on Natural Ecosystems. Island Press.
- Millennium Ecosystem Assessment (2003):
  - Putting biodiversity and ecosystem services on the political agenda
  - Directs and indirects benefits of biodiversity
  - Conceptual and methodological framework
  - First consensus on the role of biodiversity in ecosystem service provision



MA: Consequences of Ecosystem Change for Human Well-being via changes in Ecosystem Services



Main conclusions from the MA (2005): Gains and losses of services at historical scale

- Ecosystem changes by land use => substantial net gains in human well-being and economic development
  - Since 1960: 2 x population, 6 x economic activity, 2 ½ x food production, ↘ food prices
  - BUT: 2 x water use, 3 x wood harvest, 2 x hydropower

➢ **These gains have been achieved at growing costs that, unless addressed, will substantially diminish the benefits that future generations obtain from ecosystems**

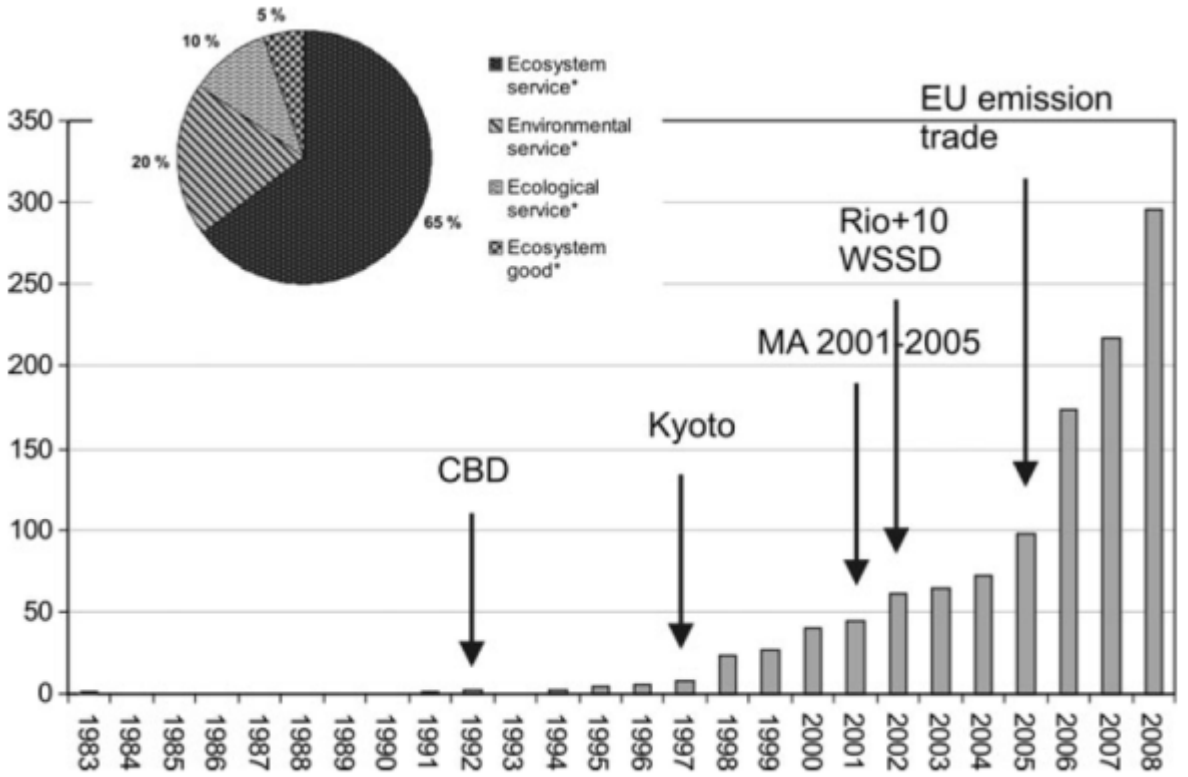
- Degradation and unsustainable use of ecosystem services
  - Approximately 60% (15 out of 24) of the ecosystem services evaluated are being degraded or used unsustainably
  - The degradation of ecosystem services often causes significant harm to human well-being, and represents a loss of a natural asset or wealth of a country

Status of Regulating and Cultural Services

	Status
Regulating Services	
Air quality regulation	↓
Climate regulation – global	↑
Climate regulation – regional and local	↓
Water regulation	+/–
Erosion regulation	↓
Water purification and waste treatment	↓
Disease regulation	+/–
Pest regulation	↓
Pollination	↓
Natural hazard regulation	↓
Cultural Services	
Spiritual and religious values	↓
Aesthetic values	↓
Recreation and ecotourism	+/–

Future threats to ecosystem services from abrupt climate change effects

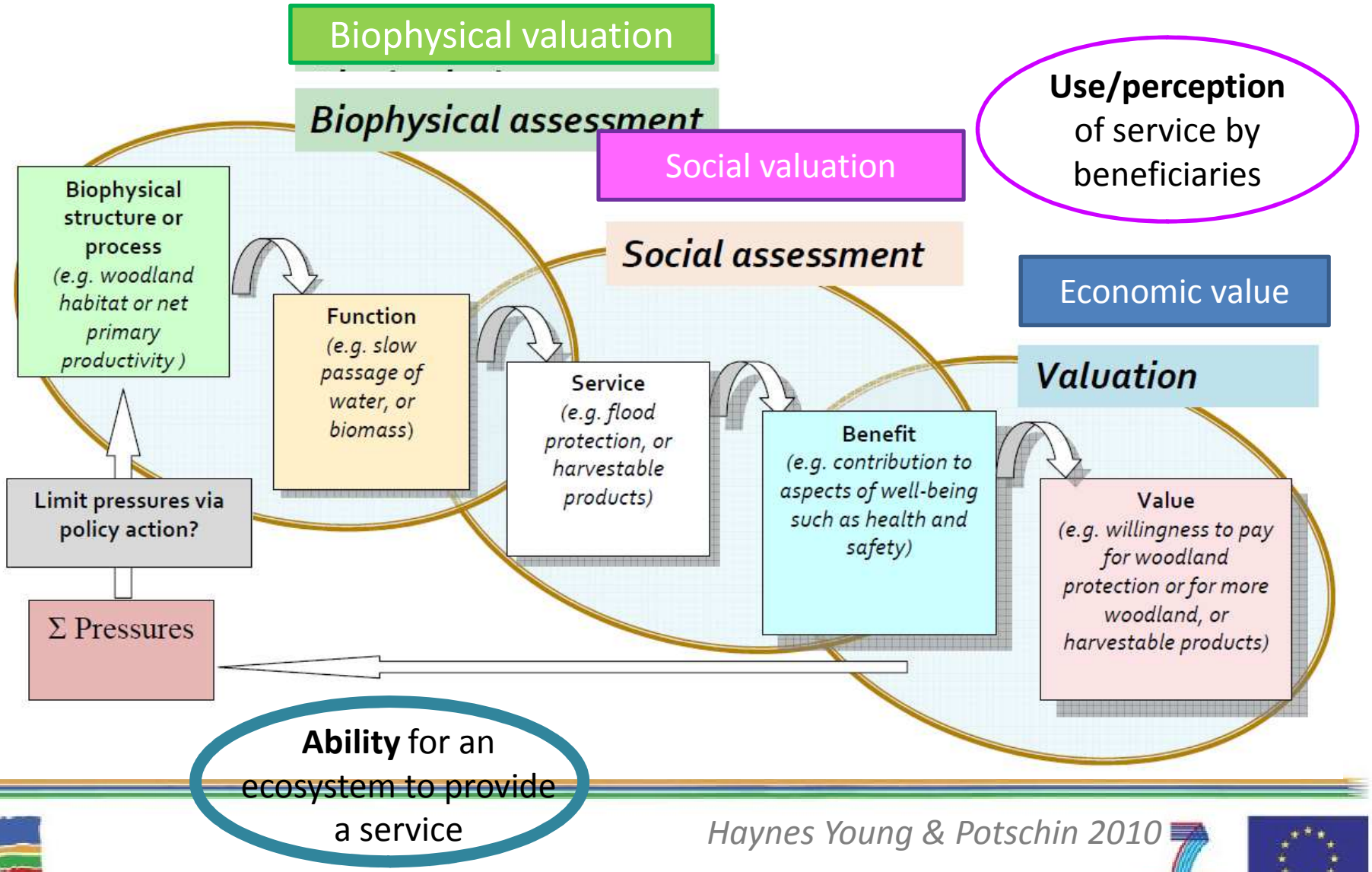
From the political arena to the scientific arena



Vihervaara et al. 2010 Ambio

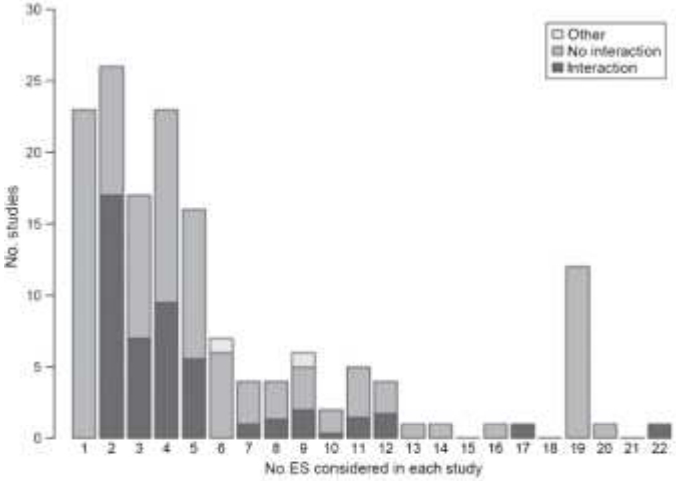
- An emerging research theme
- Direct or indirect motivation by policy processes
- Stimulation of research on biodiversity – ecosystem functioning linkages

How to quantify ecosystem services ?



Haynes Young & Potschin 2010

The challenge of modelling Europe's Ecosystem Services in VOLANTE

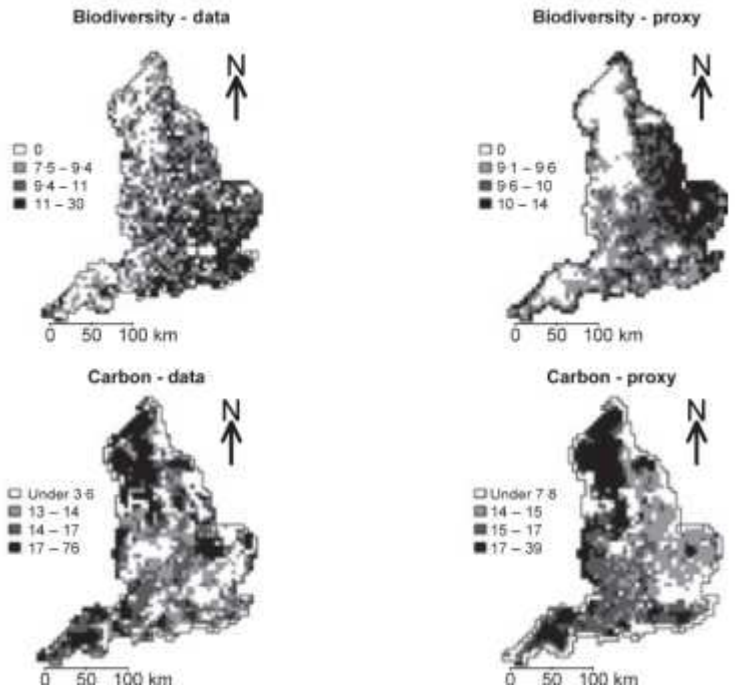


- Most ES studies consider only few services, and don't quantify their interactions (trade-offs or synergies)

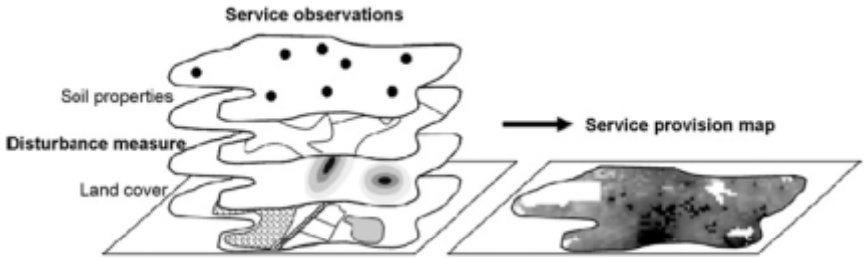
Seppelt et al. J. Appl. Ecol. 2011

- Objectives for modelling ES in VOLANTE
  - Use state-of-the art spatially explicit models applicable to the European scale for MULTIPLE ES supplied
  - Develop a tool box for the analysis of trade-offs and synergies among ES
  - Analyse ES trade-offs and synergies and identify their drivers

Improving methods for ecosystem services quantification



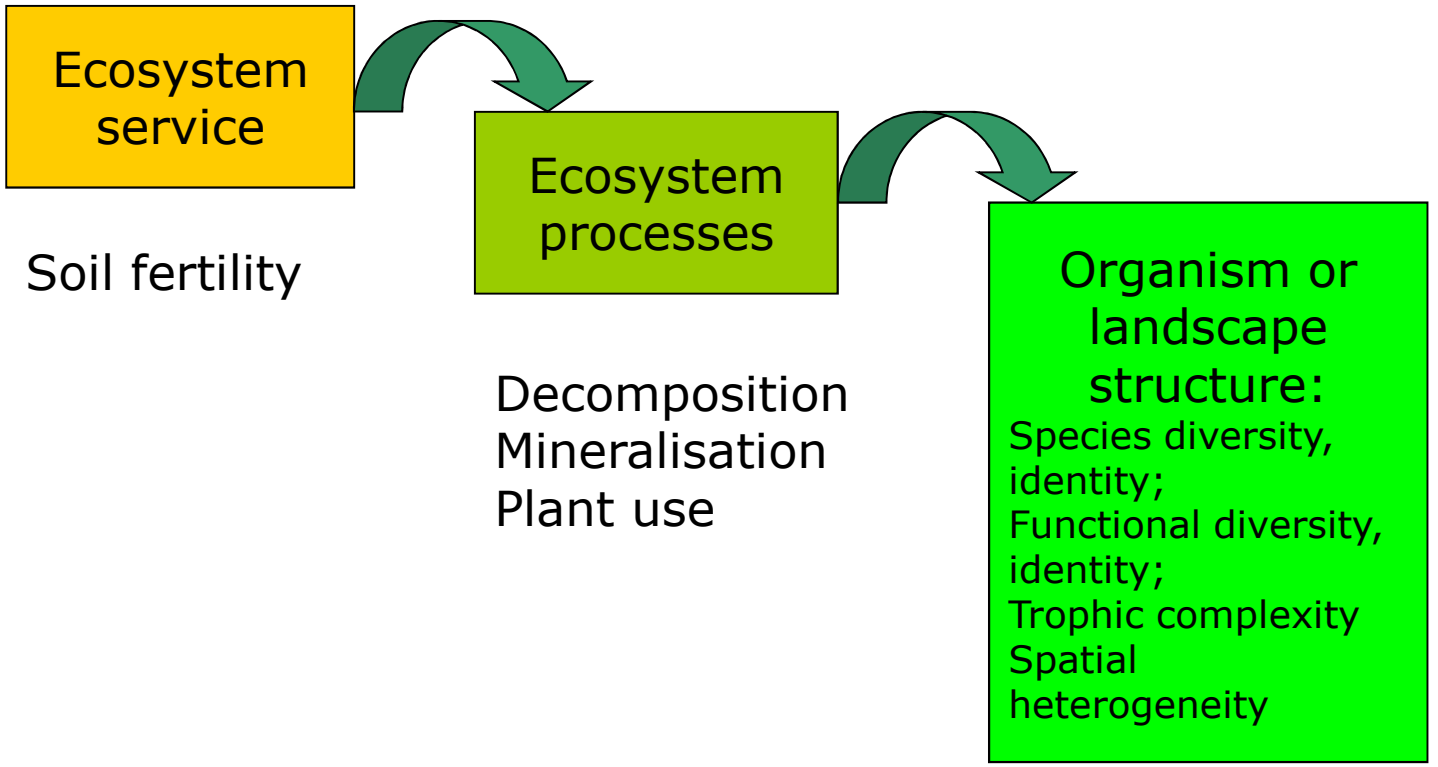
Eigenbrod et al. J. Appl. Ecol. 2010



De Groot et al. Ecol. Complex. 2010

- Mapping ecosystem services based on land use / land cover maps
- ➢ Ignoring biotic patterns: Major source of uncertainty
- ➢ Empirical relationships with environmental variables

Quantifying the effects of biodiversity on ecosystem services: Methodology



The role of different components of biodiversity

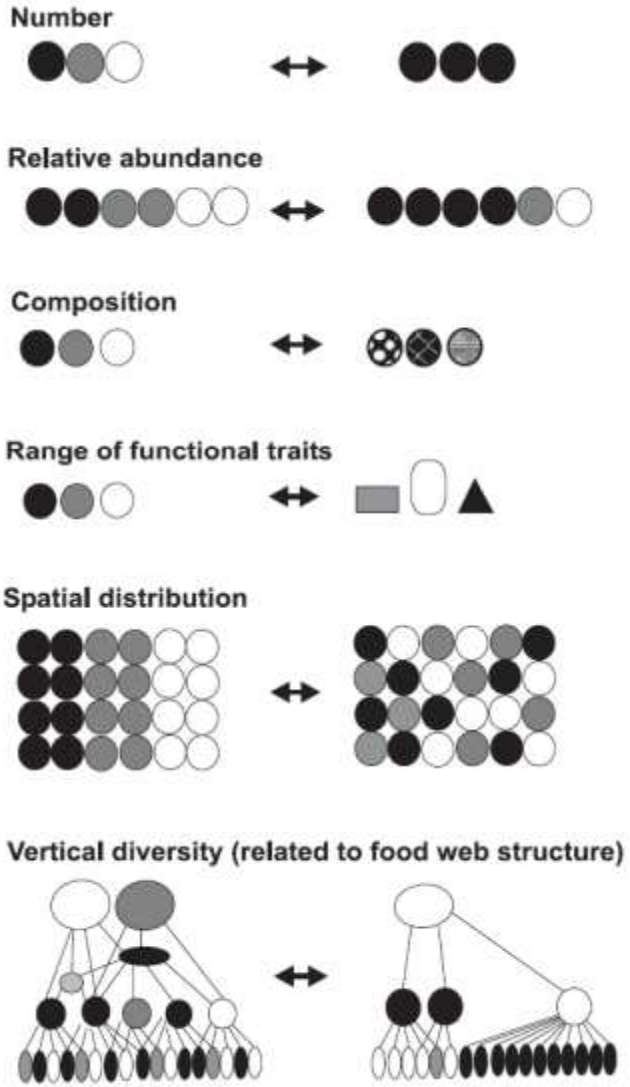


Figure 2. The Different Components of Biodiversity

All of these components can be affected by human intervention (arrows), and in turn have repercussions for ecosystem properties and services. Symbols represent individuals or biomass units. Symbols of different shades represent different genotypes, phenotypes, or species.

Diaz et al. PLoS 2006

Modelling ES in VOLANTE

1. Mapping ES at EU scale
2. Identifying ES bundles (trade-offs or synergies)
3. Identifying drivers of ES bundles
4. Application of ES models to future scenarios

Modelling ES in VOLANTE

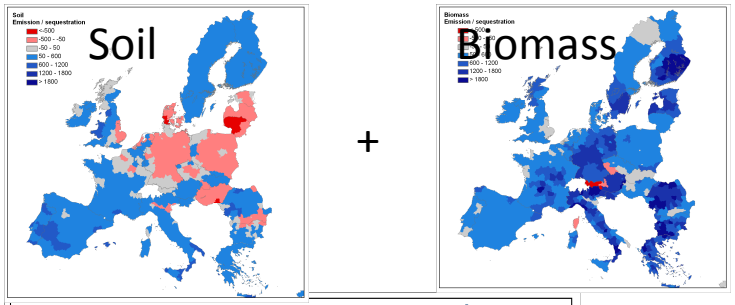
1. **Mapping ES at EU scale**
   - **Consolidated list of ES quantified in WP8**
   - **ID cards detailing models and data used to produce ES maps**
   - ➢ ***VOLANTE Deliverable D8.1***
2. Identifying ES bundles (trade-offs or synergies)
   - Developing a toolbox of methods
   - Applying toolbox to ES analysis in the EU
3. Identifying drivers of ES bundles
   - Which biophysical or socio-economic variables determine the distribution of ES bundles
4. Application of ES models to future scenarios

D 8.1: List of modelled ES and driving variables

Service category	Ecosystem service	Indicator name	Inputs	Partner
CULTURAL	Recreation	Territorial capital of rural tourism	PDO, Protected regions, CLU/CLC, travel time to urban location, leader sites, camping sites, ski resorts, DEM, precipitation, temperature, UNESCO and UN sites	IVM VU
		Recreation potential index - Availability of the ES to citizen	CLC, water quality, N input (CAPRI), livestock density (CAPRI), forest, protected areas (NATURA2000, Protected areas), road network, population density	JRC
		Recreation value of EU forests	Age structure by tree sp, Recreation scores (expert-based)	EFI
PROVISIONING	Food-feed-fibre	To be defined	CAPRI outputs	JRC/IVM VU
	Raw material	Wood (roundwood and harvest residues)	Round wood from thinning, Round wood from final felling, Harvest residues from thinning, Harvest residues from final felling	EFI
REGULATING	Climate regulation	Carbon sequestration in biomass and soil of European forests	Carbon stocks in forest biomass - Carbon stocks in forest soil	
		Carbon sink and cumulative carbon sink	LU18, Soil organic carbon, Age of land use, Emission factors, Forest biomass content	IVM VU
	Moderation of extreme events	Forest fire risk	Sensibility scores, EFISCEN outputs	EFI
		Fire risk level	EFI's vulnerability index, FWI, topography, CLC, climate	LECA
		Flood regulation	Land use, DEM, Temperature, Precipitation, Soil types	IVM VU
	Pollination	Relative pollinators abundance	CLC, crops (CAPRI), forest, farmland presence, road network, rivers, floral availability and nesting suitability by crops/CLC class	JRC (IVM VU?)
DIS-SERVICE	Invasive species	Alien threat score	DAISIE outputs	LECA
PRIMARY PRODUCTION	HANPP	Human appropriation of NPP	Based on outputs from LPJ, CORINE, CAPRI, EFISCEN, FAO stat and FRA	UNIKLU
	NPPact	NPP of the actual veg		
	NPPh	NPP harvested		
	NPP0	NPP of the potential veg		
HABITAT SERVICE	Maintenance of genetic diversity	Dead wood	Standing deadwood - Downed deadwood - Residues remaining in forest - Forest area	EFI

Carbon sequestration

- Based on EFISCEN A1 + EURALIS A1 land use change scenario
- Amount of carbon that is sequestered or emitted from land use, land use change and forestry



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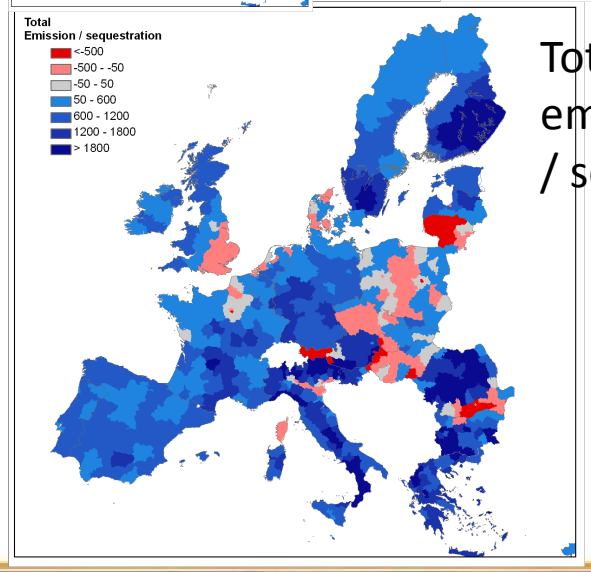
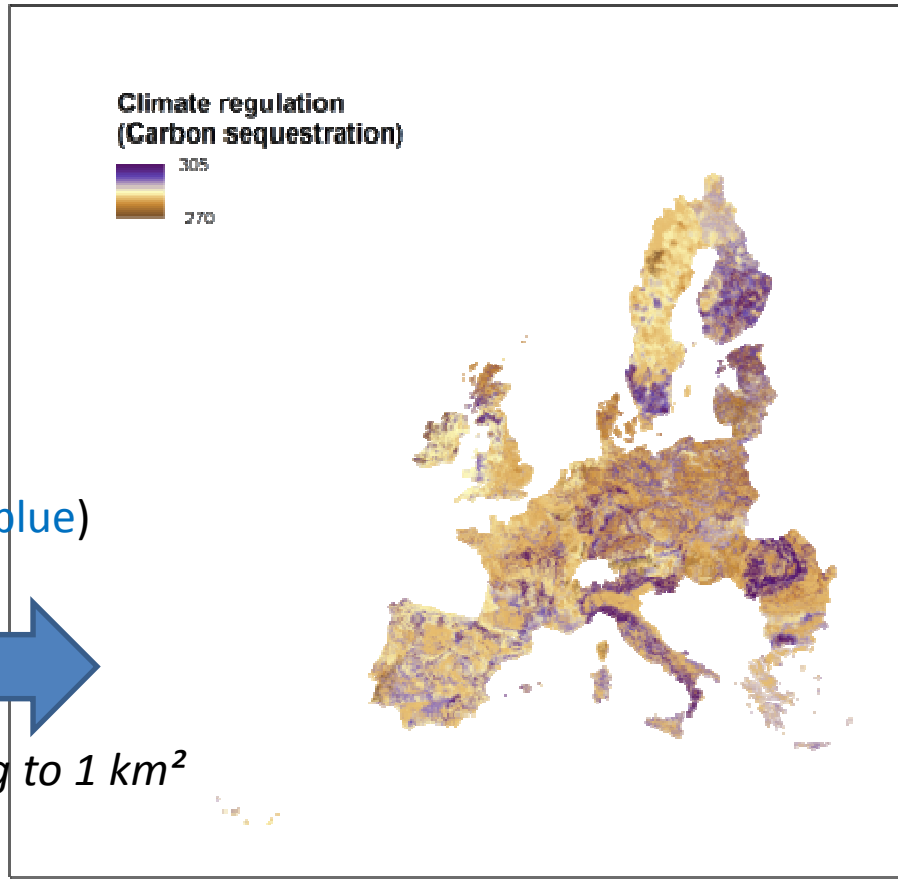
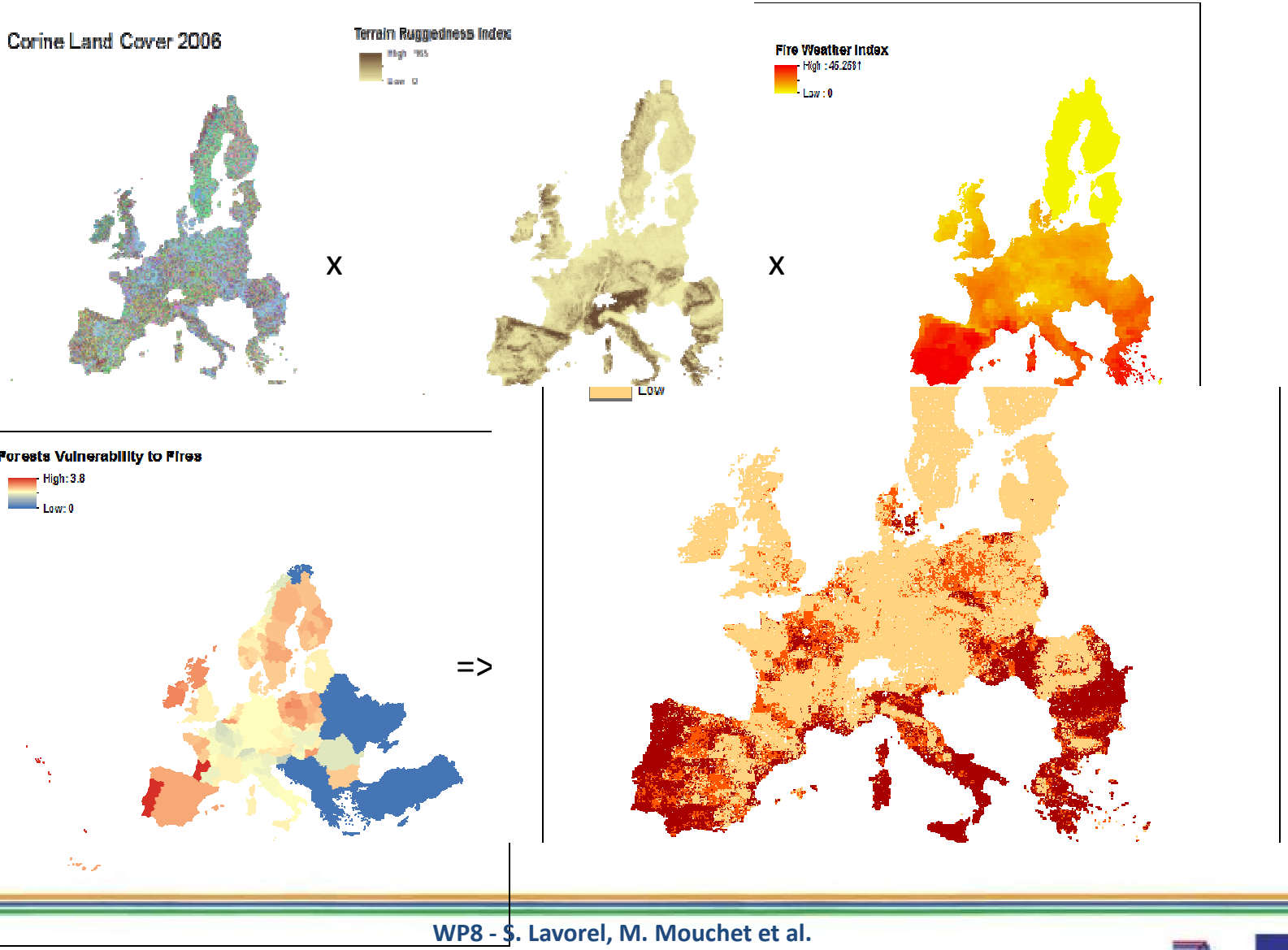


Total
emission (red)
/ sequestration (blue)

Downscaling to 1 km²

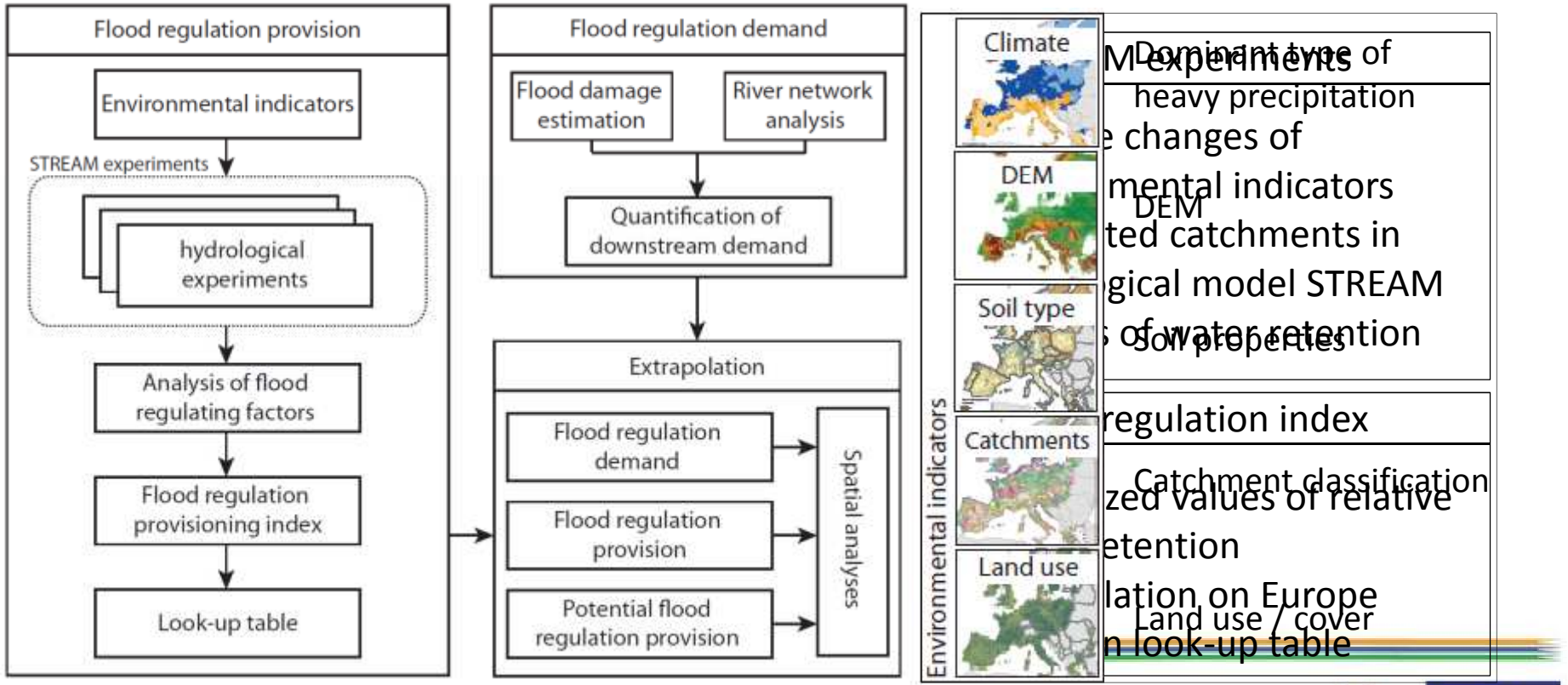


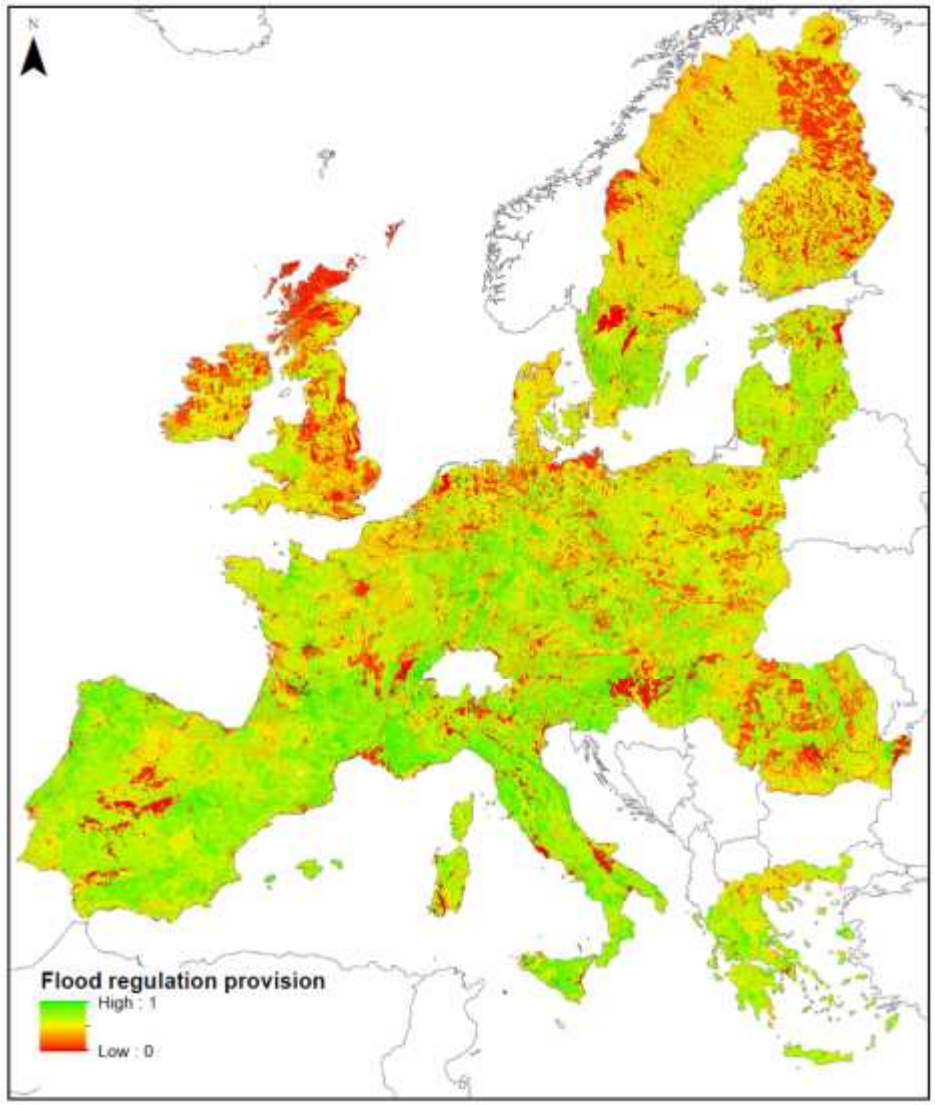
Fire risk


Corine Land Cover 2006
Terrain Ruggedness Index
Low
Fire Weather Index
High : 46.2581
Low : 0
X
X
X
=>
Forests Vulnerability to Fires
High: 3.8
Low: 0

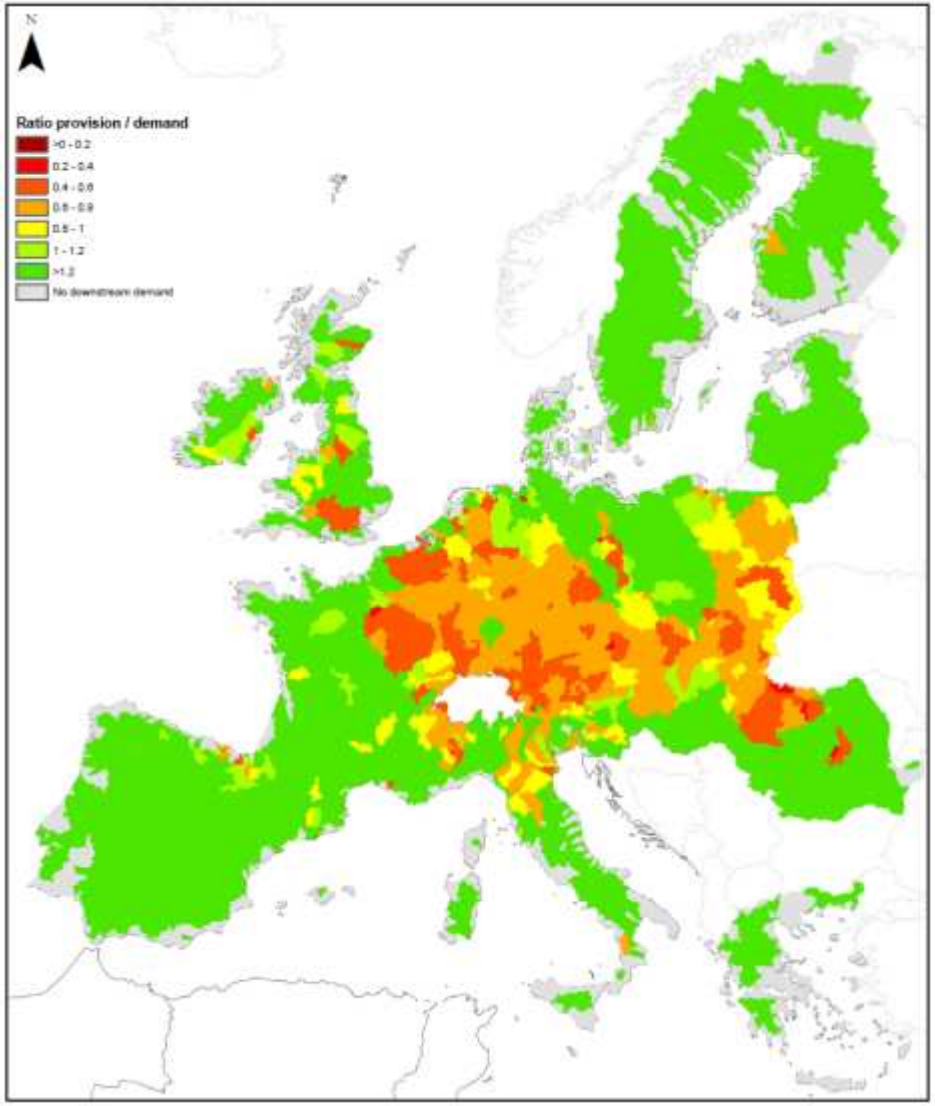
Flood regulation

- The landscapes' capacity to mitigate and lower downstream flood damages
- Aims of this study: Spatial comparison between areas of flood regulation demand and provision



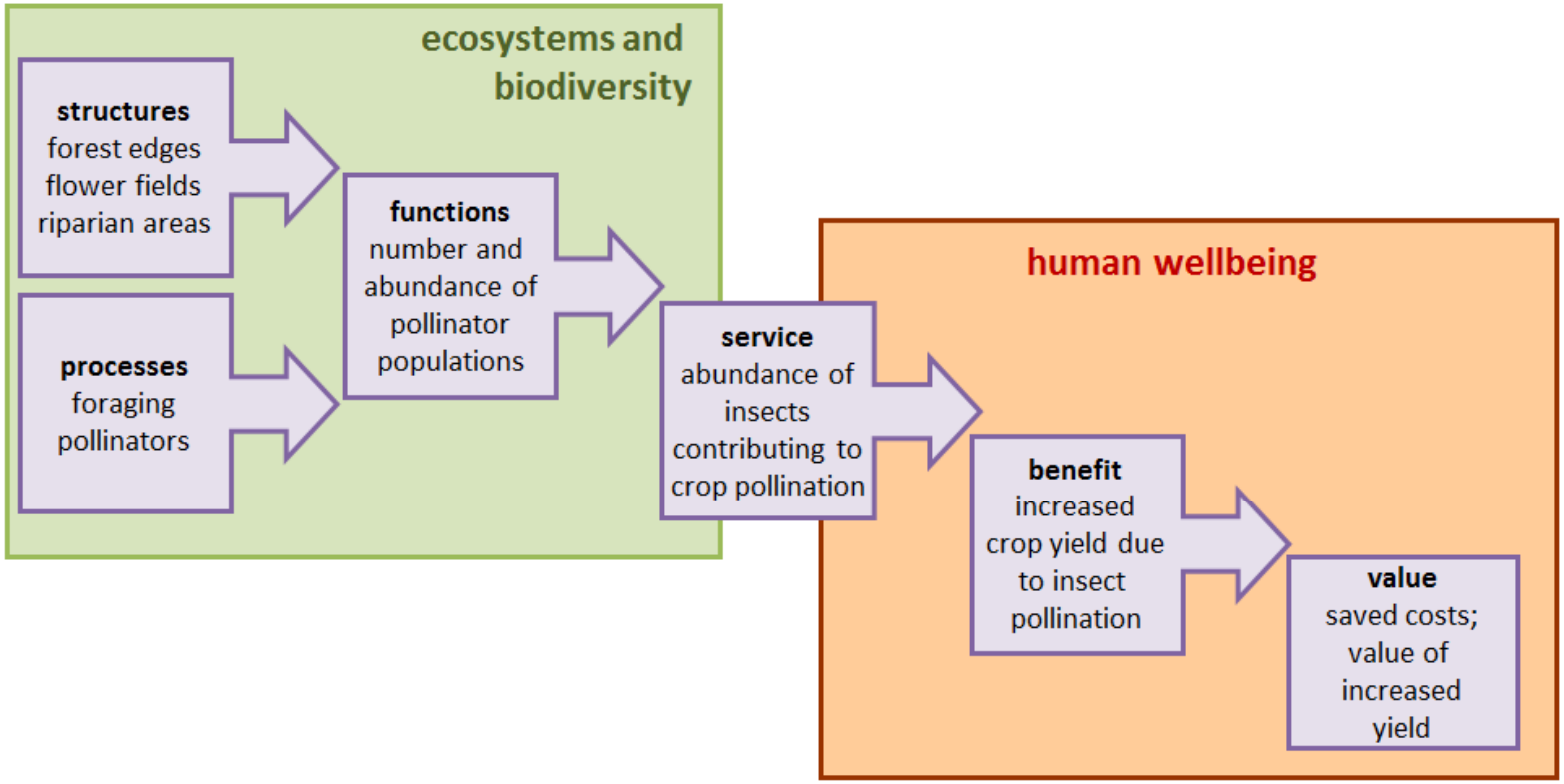


Flood regulation provision.

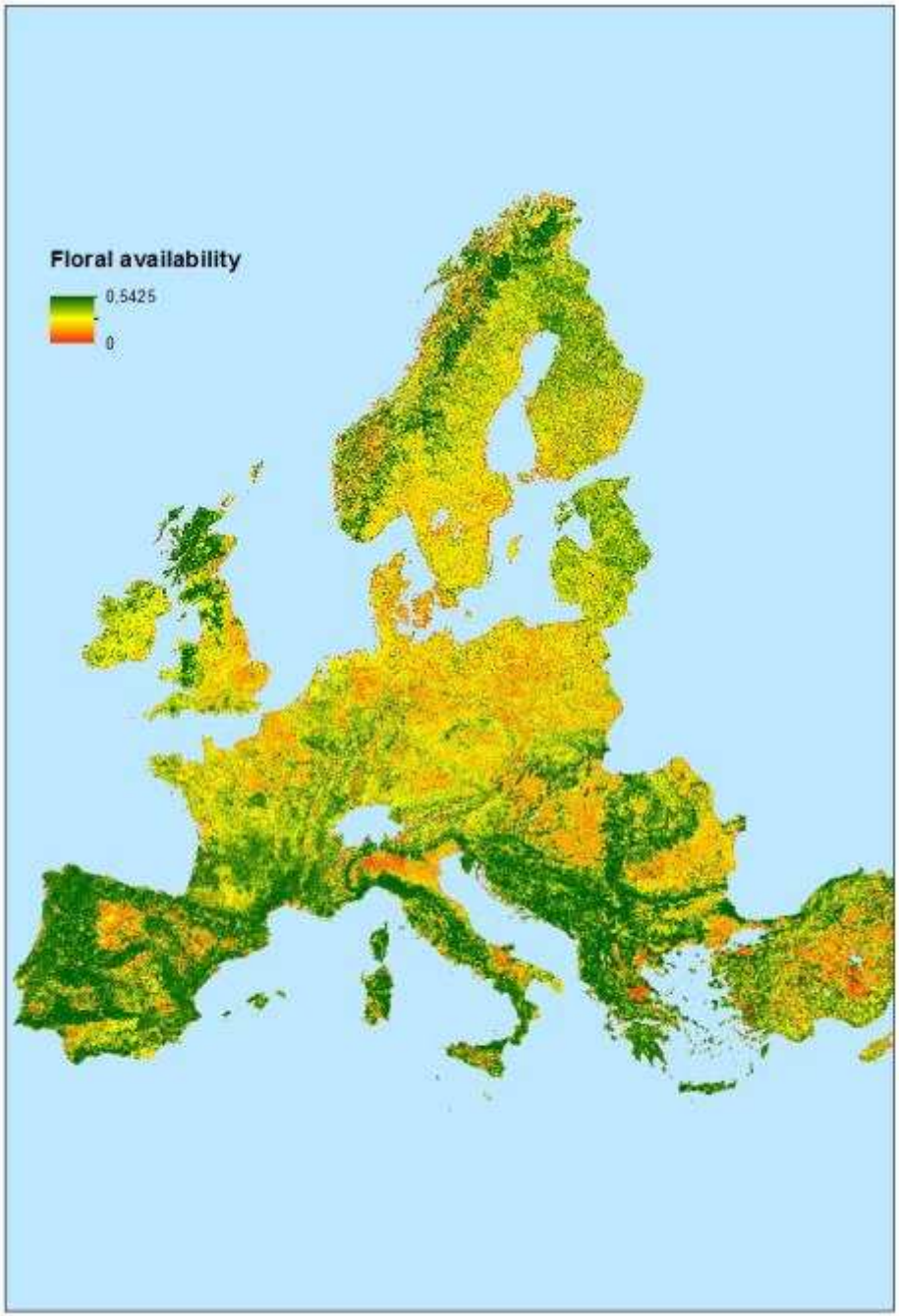


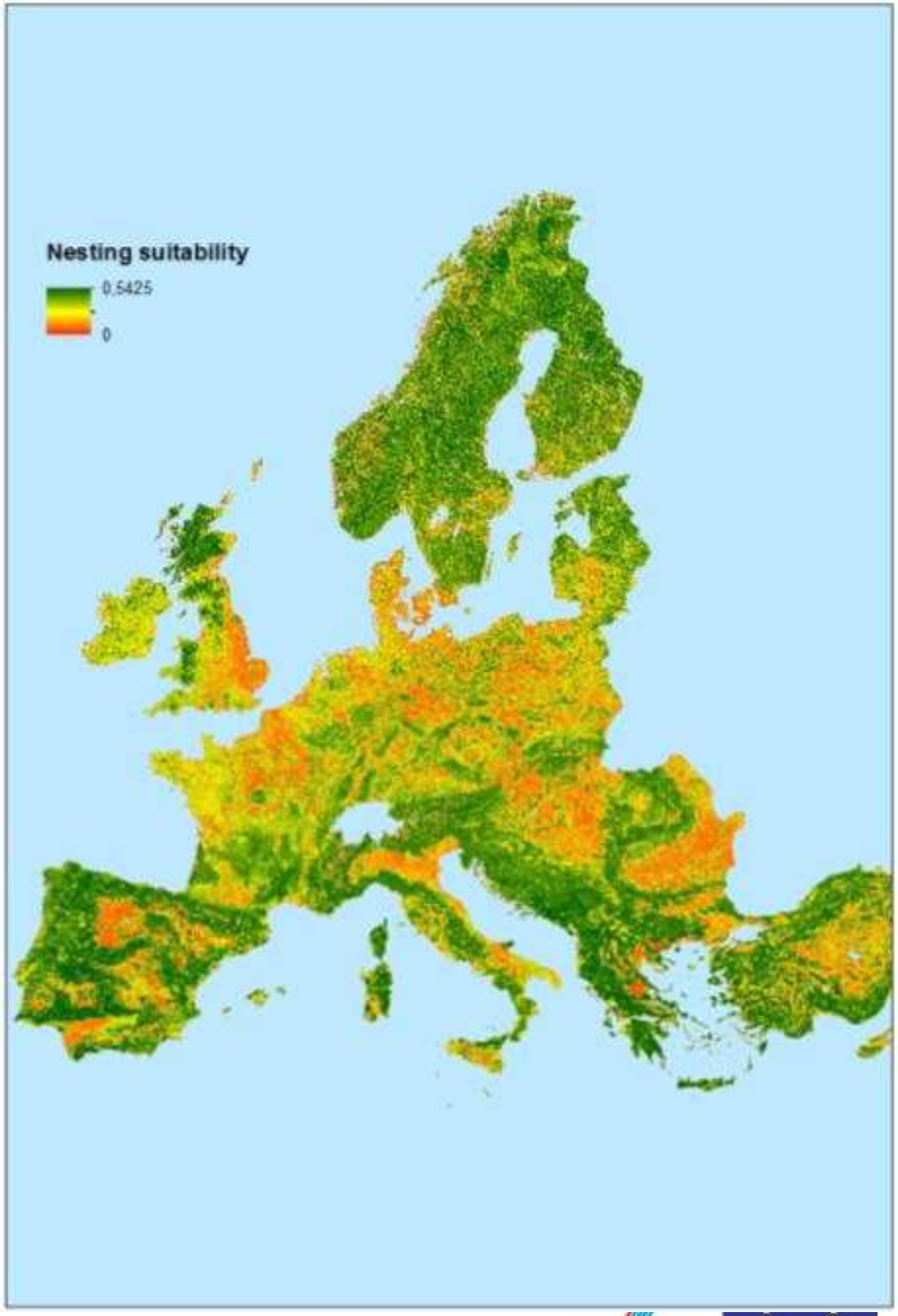
Ratio flood regulation provision / demand.
(aggregated to catchment scale)

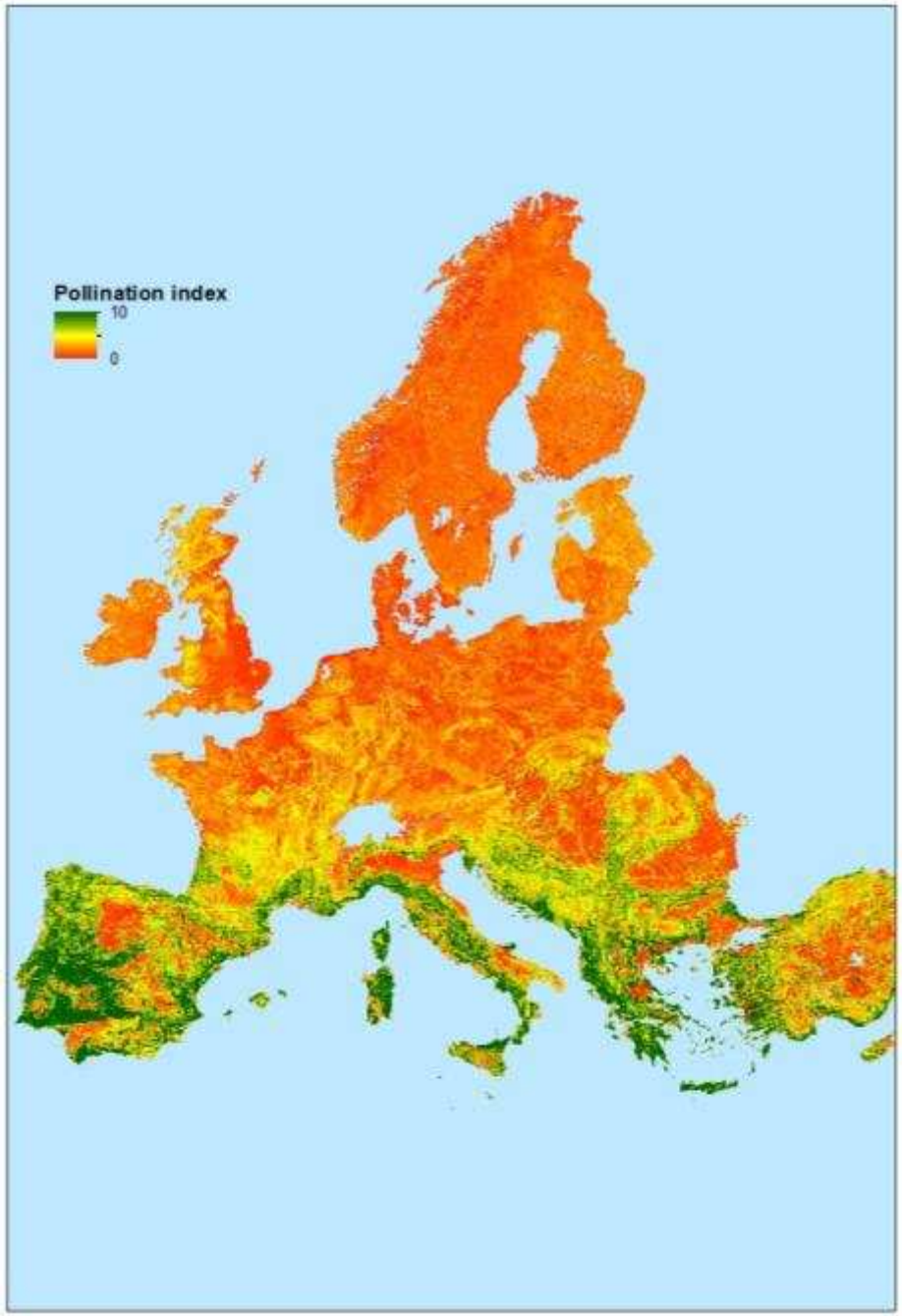
Pollination



➢ **The model uses estimates of the availability of floral resources, bee flight ranges and the availability of nesting sites to derive an index of bee abundance on each cell on a landscape.**


Floral availability
0,5425
0

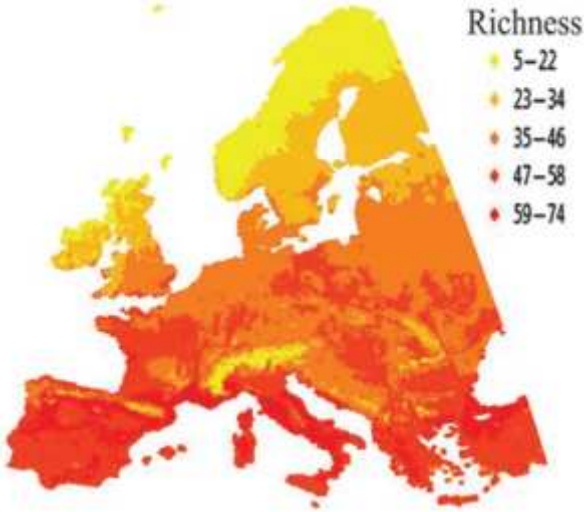

Nesting suitability
0,5425
0


Pollination index
10
0

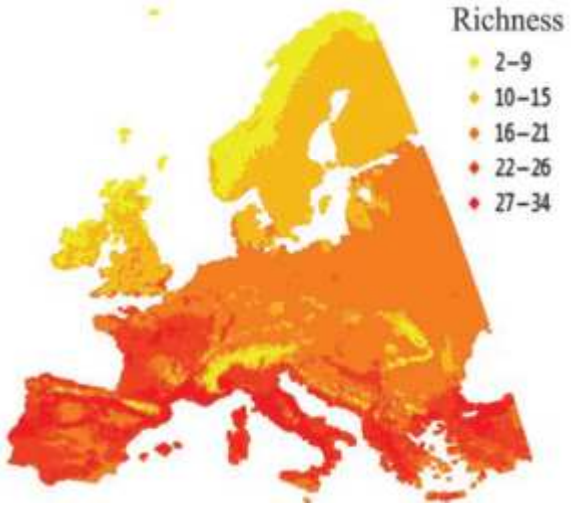
Biocontrol by vertebrates

- Species distribution modelling for all vertebrate species known to be predators of (a) invertebrates, (b) rodents depending on climate and land cover classes

Biocontrol of invertebrates

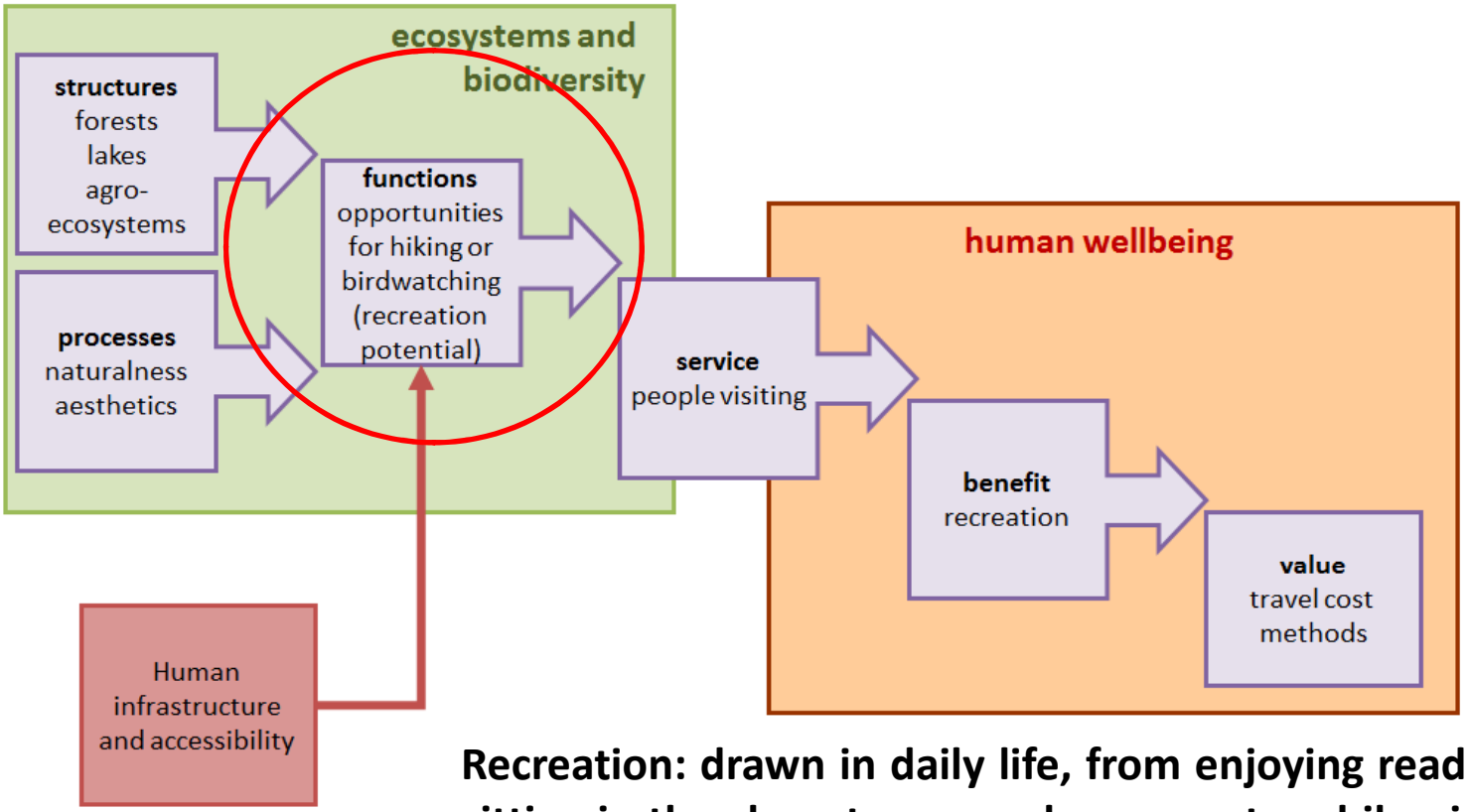


Biocontrol of rodents



Civantos et al. Bioscience 2012

Recreation



Recreation: drawn in daily life, from enjoying reading the newspaper sitting in the closest green urban area, to a bike ride after work, to a daily trip to nature. All ecosystems are considered to be potential providers of the service, irrespective from their conservation status, though the range of provision changes accordingly to it. Tourism and long distance (>100 km) travelling not included.

Input data

Water:

Bathing water quality → NO
Distance from coast → YES
Marine protected areas → YES (unchanged)

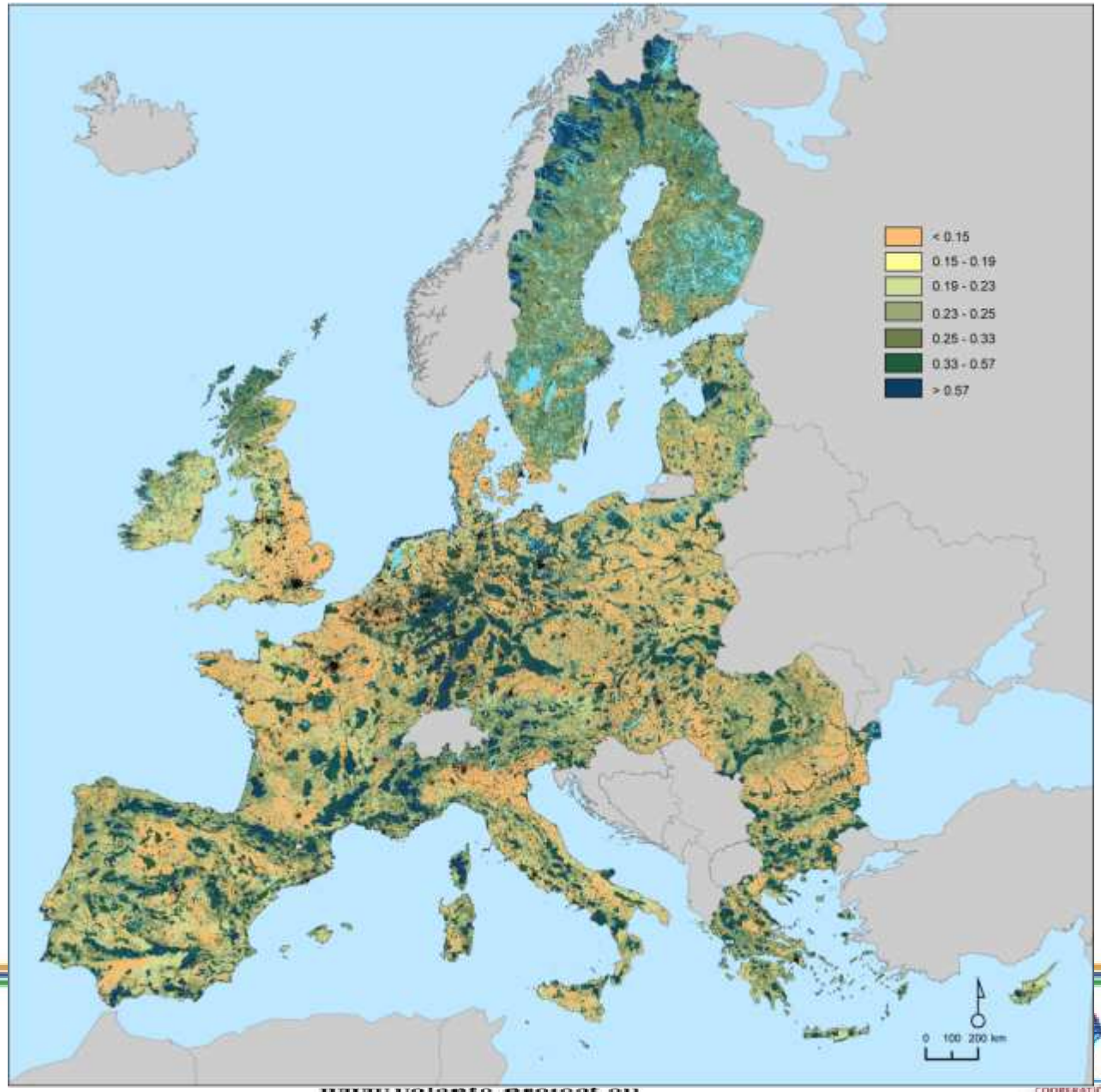
Natural Areas:

Protected areas → YES (unchanged)
Green Urban Areas → not in Dyna-CLUE

Degree of naturalness:

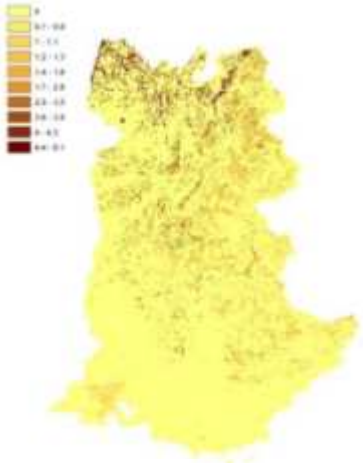
Dyne-CLUE classes are assigned to classes of different degree of naturalness. CAPRI data needed for agricultural areas

Recreation potential

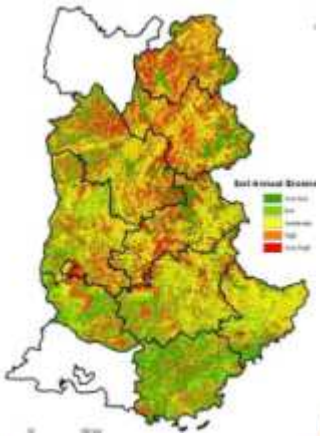


Modelling ES at regional scale: French Alps

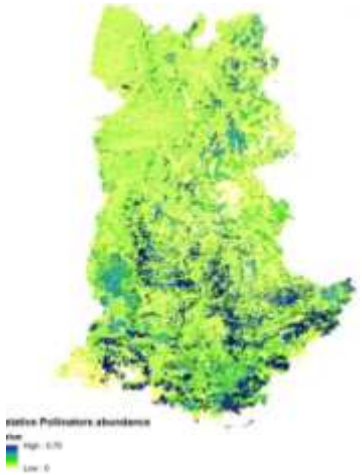
Fodder production



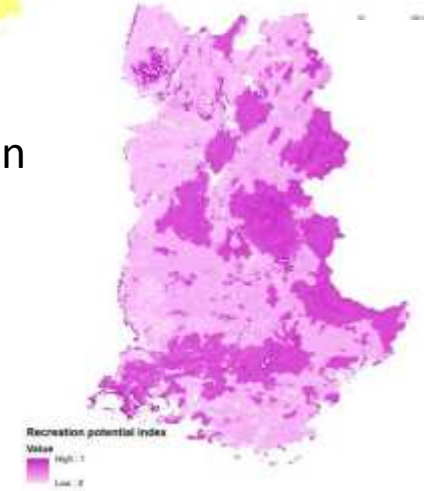
Soil erosion (ClimChalp ©)



Pollination (JRC)



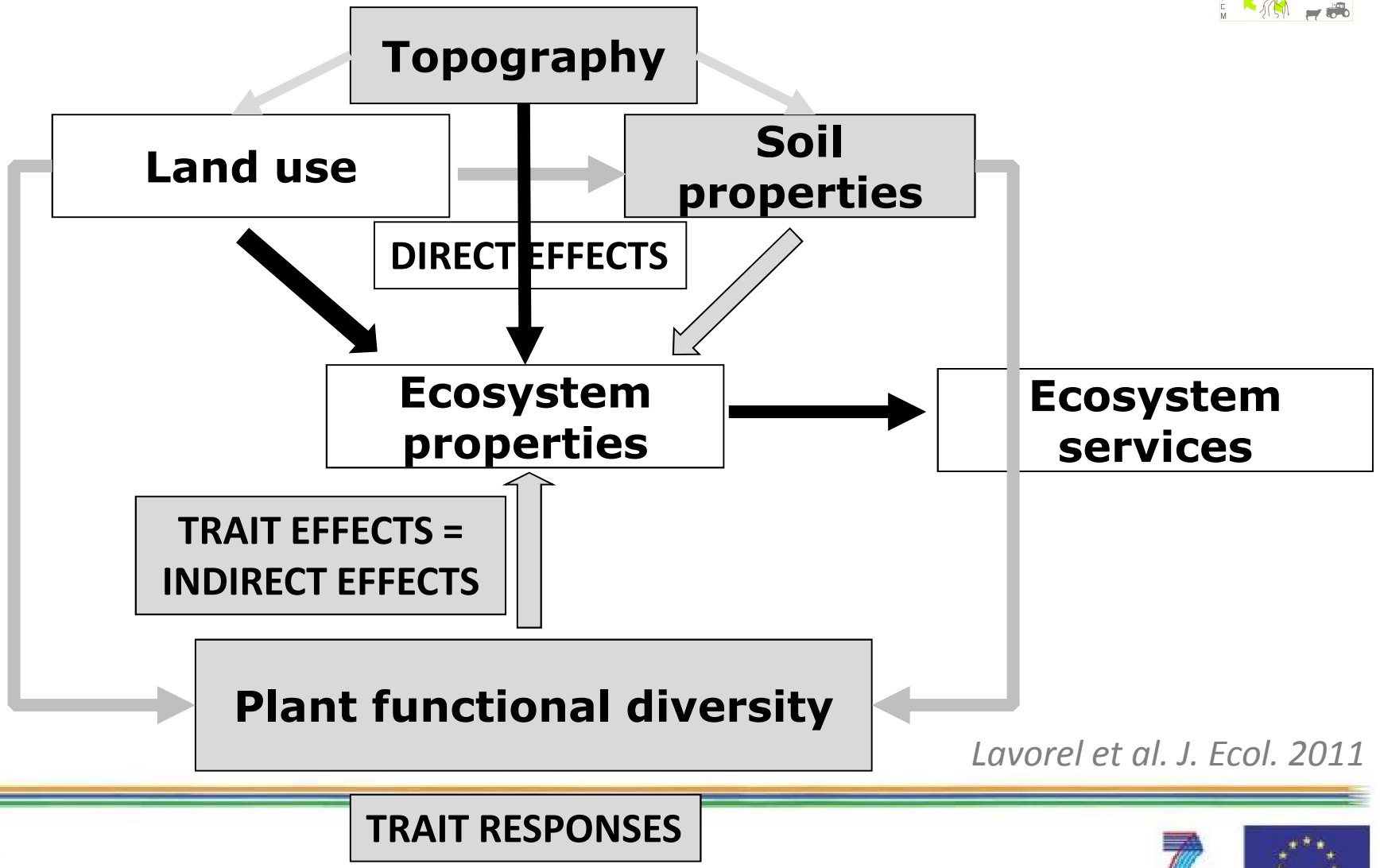
Recreation Potential (JRC)



Vertebrate species richness

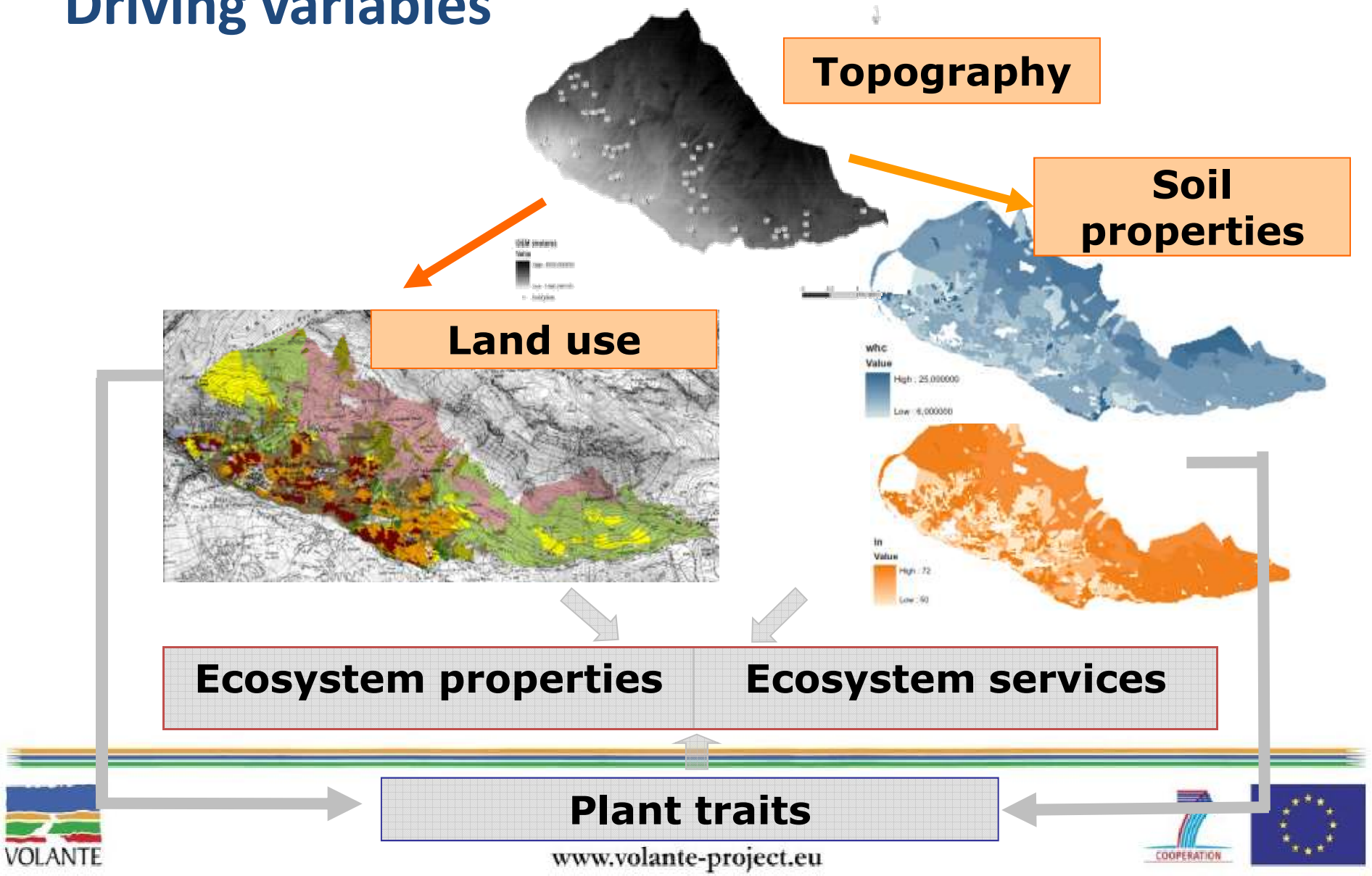
Crouzat et al. in prep.

Method for quantification of ecosystem services at landscape – regional scale



Lavorel et al. J. Ecol. 2011

Driving variables



From field data to ecosystem services maps

Generalized linear models to extrapolate 60 plots measurements to whole landscape

Step 1	Step 2	Step 3	Step 4
Environmental drivers	Response and effects traits	Ecosystem properties	Ecosystem services

Plant

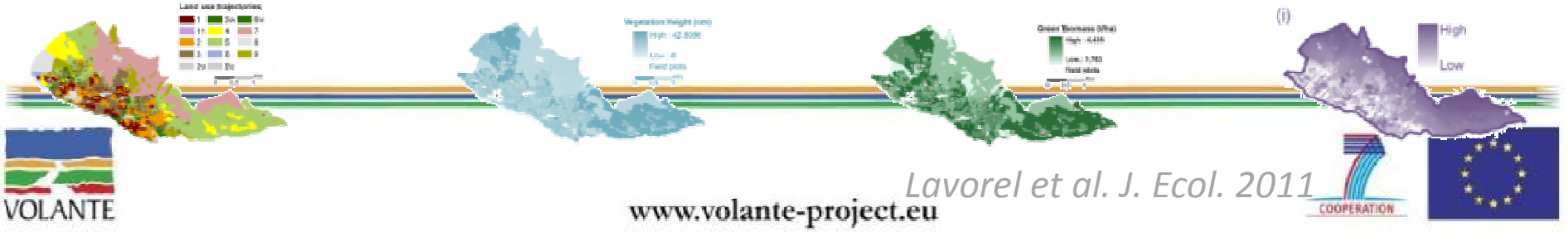
Microbial

*NNI= LUT+ β_1*Altitude*

*VegHt = LUT+ β_1*N*

*Green biomass = $\beta_0 + \beta_1$ *NNI + β_2 *VgHt – β_3 *LDMC*

Stakeholders' perceptions



Lavorel et al. J. Ecol. 2011

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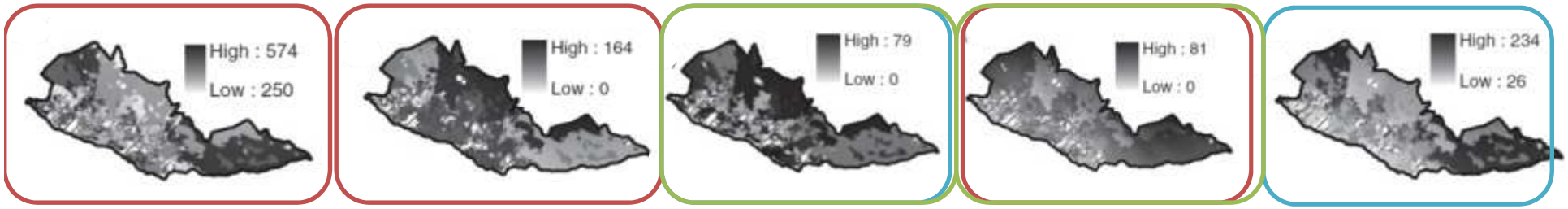
COOPERATION

Landscape-scale ecosystem services supply

Ecosystem properties

Green biomass | Fodder crude protein content | Plant diversity | Mean flowering onset date | Litter Mass



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Ecosystem services

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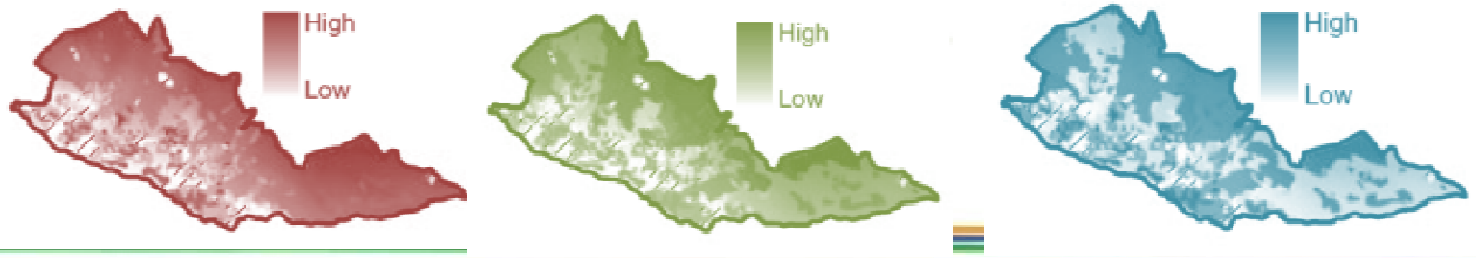
Agronomic value | Pollination | Cultural value



Lavorel et al. J. Ecol. 2011

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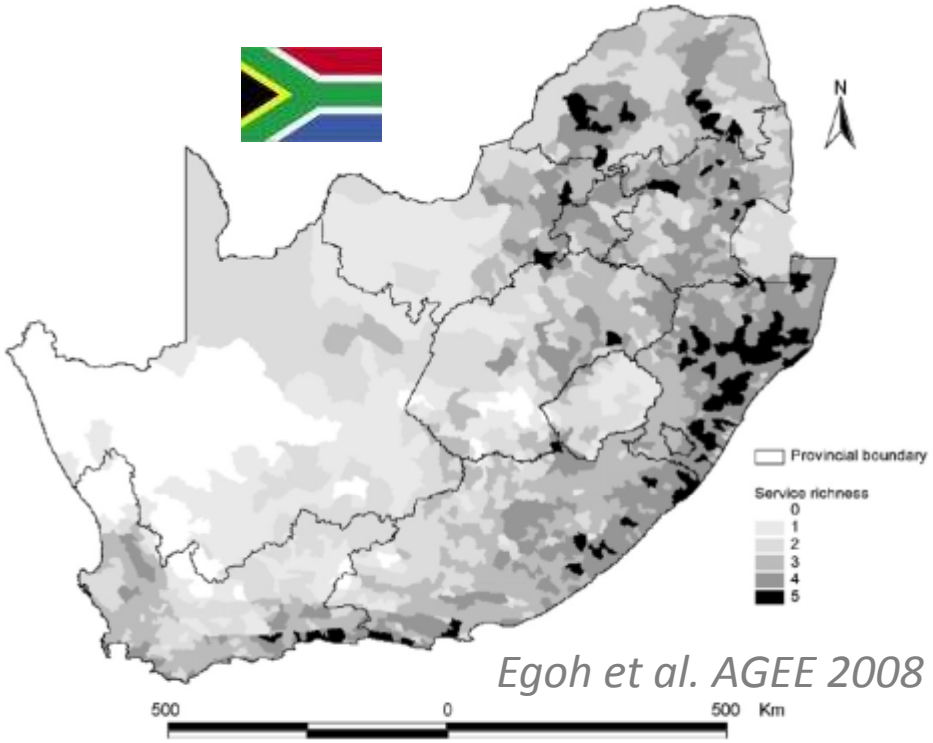
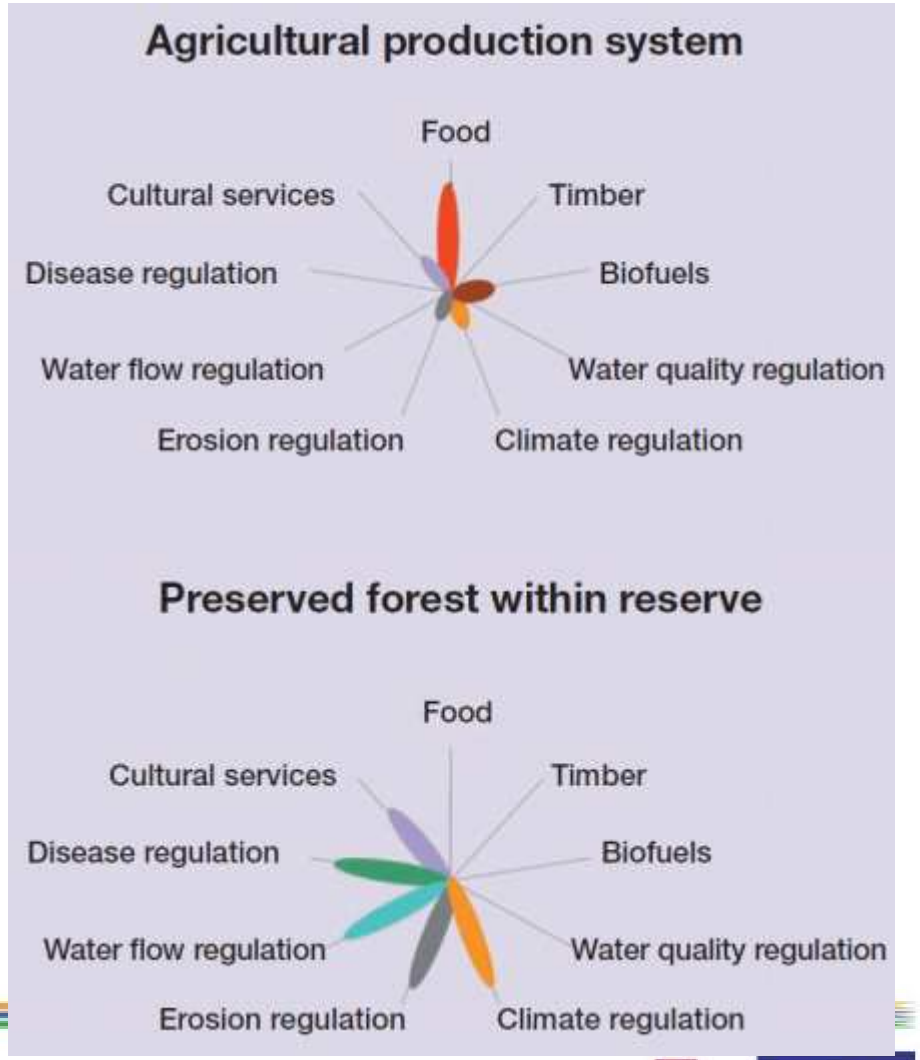
Analysing bundles and trade-offs of Ecosystem Services across Europe

A key question for management and policy: trade-offs and synergies among ecosystem services



Egoh et al. AGEE 2008



- **The responses of biodiversity to management and the fundamental functioning of ecosystems do not allow for all services to be provided at the same place or time…**

Bennett & Balvanera Frontiers Ecol. Evol. 200

Challenge for management and policy: Trade-offs and synergies in ES provision in space and time

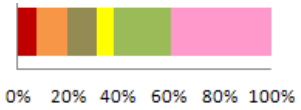
- Ecosystem services trade-offs in space and time
  - In space:
    - Analysis of ‘hot spots’ and spatial comparison between provision and demand
    - Larger scales:
      - Import of ES from outside the modelling geographic domain (EU)
  - In time:
    - As a result of climate and/or land use change
    - Different time scales for different ES => not compromising future ecosystem services by current use; restoration ecology

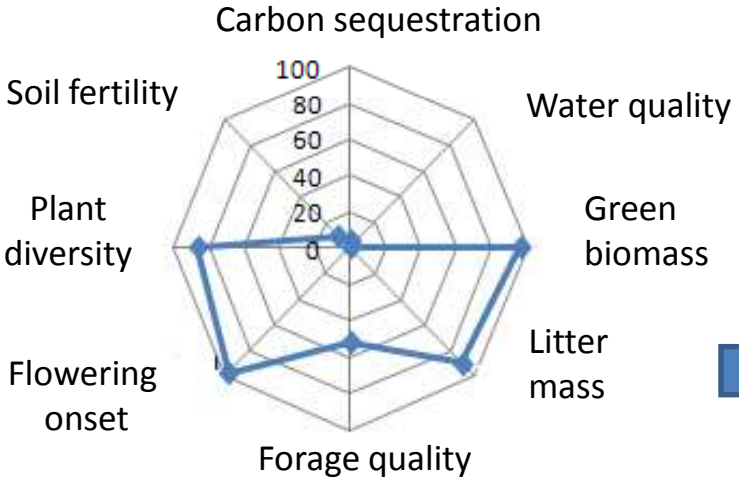
Identifying spatial bundles and spatial or temporal trade-offs

ES bundles

➢ **Spatial trade-offs**

Current Land use





➢ **Temporal trade-offs**

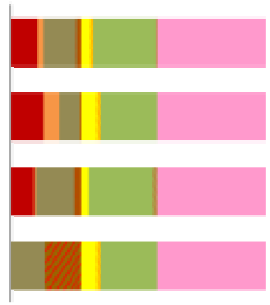
Scenarios

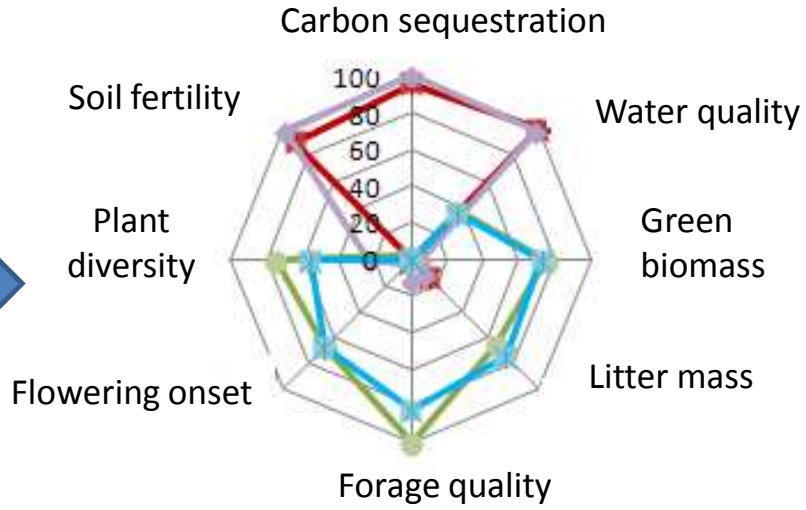
Intermittent international

Intermittent local

Drastic international

Drastic local





Lamarque et al., PNAS in revision

Modelling ES in VOLANTE

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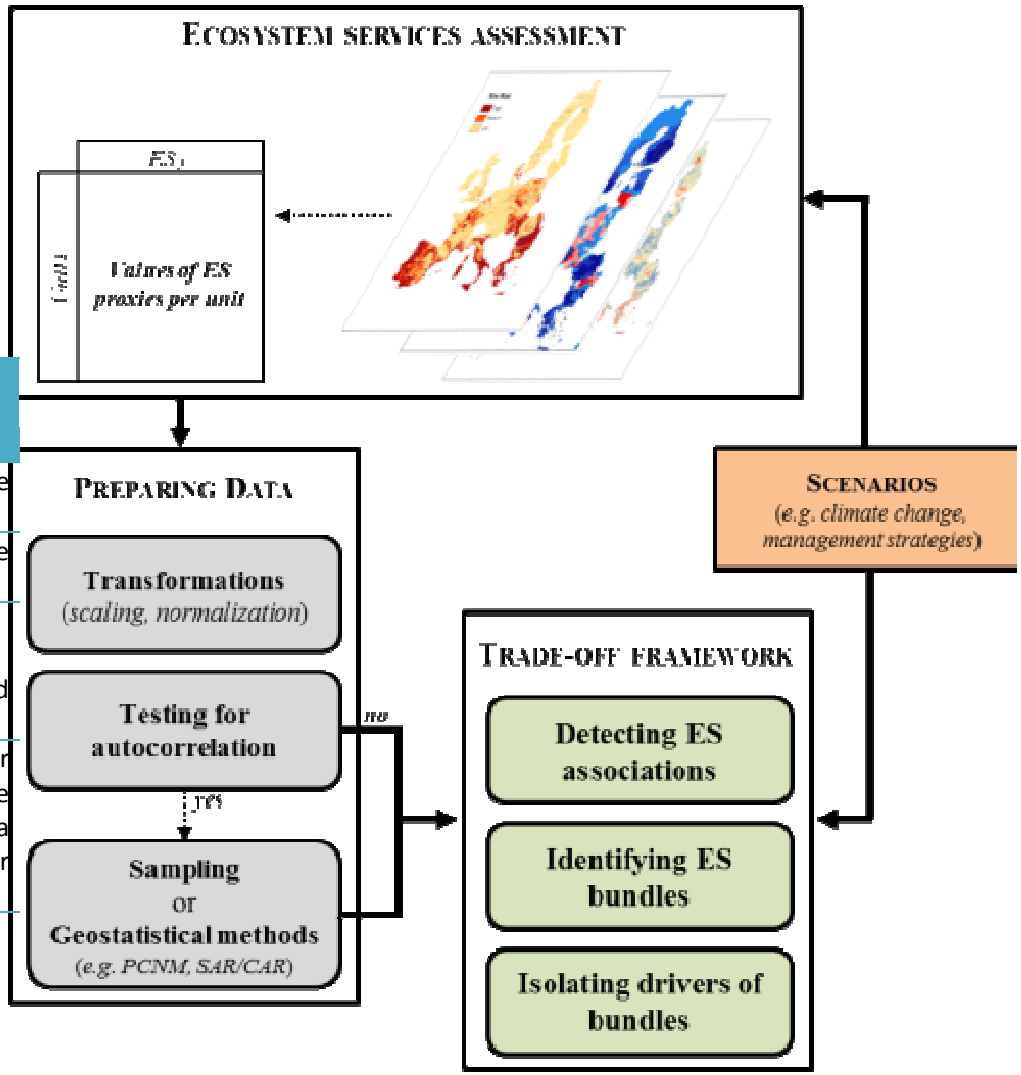
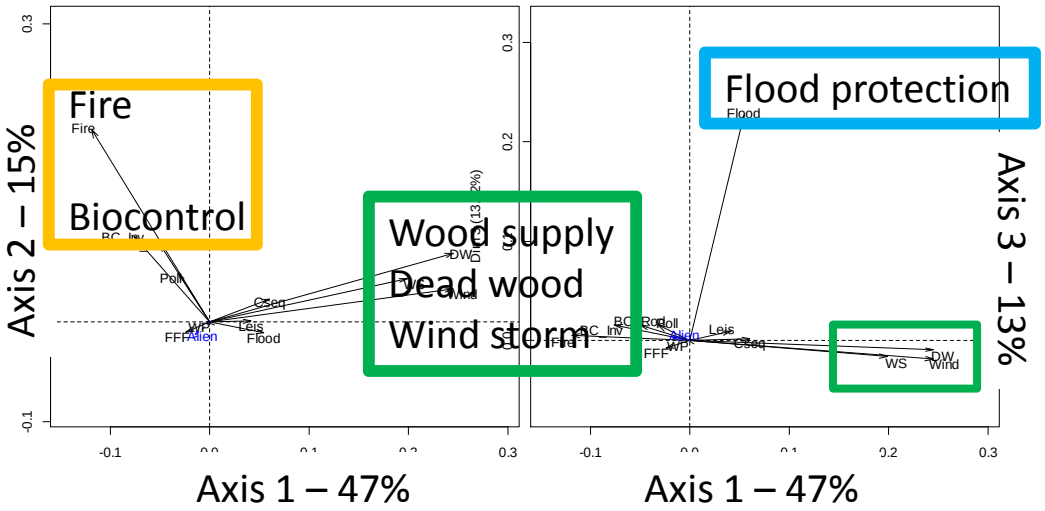
A toolbox for the analysis of bundles and trade-offs among ES

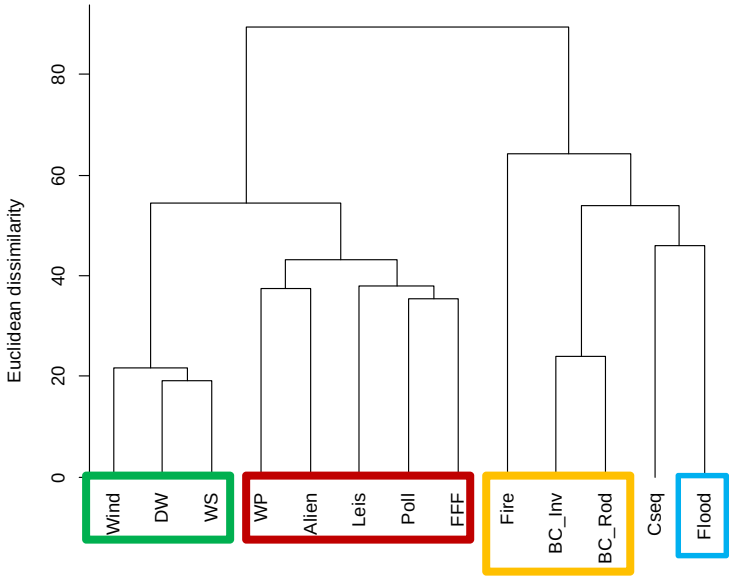
Step of the framework	Method	Number of ESs to compare	Dimension and types of the variables to be related
Detecting	Correlation coefficients	2	Compares quantitative univariate variables
Detecting	Chi-squared test	2	Compares categorical univariate variables
Detecting	Multivariate statistics	2 and more	PCA : quantitative variables MCA: binary variables FAMD : both quantitative and qualitative variables
Detecting	Overlap analysis	2	Univariate quantitative or qualitative variables. Qualitative variables can be either binary (a supply threshold is required) or categorical



Maud Mouchet et al. in prep.

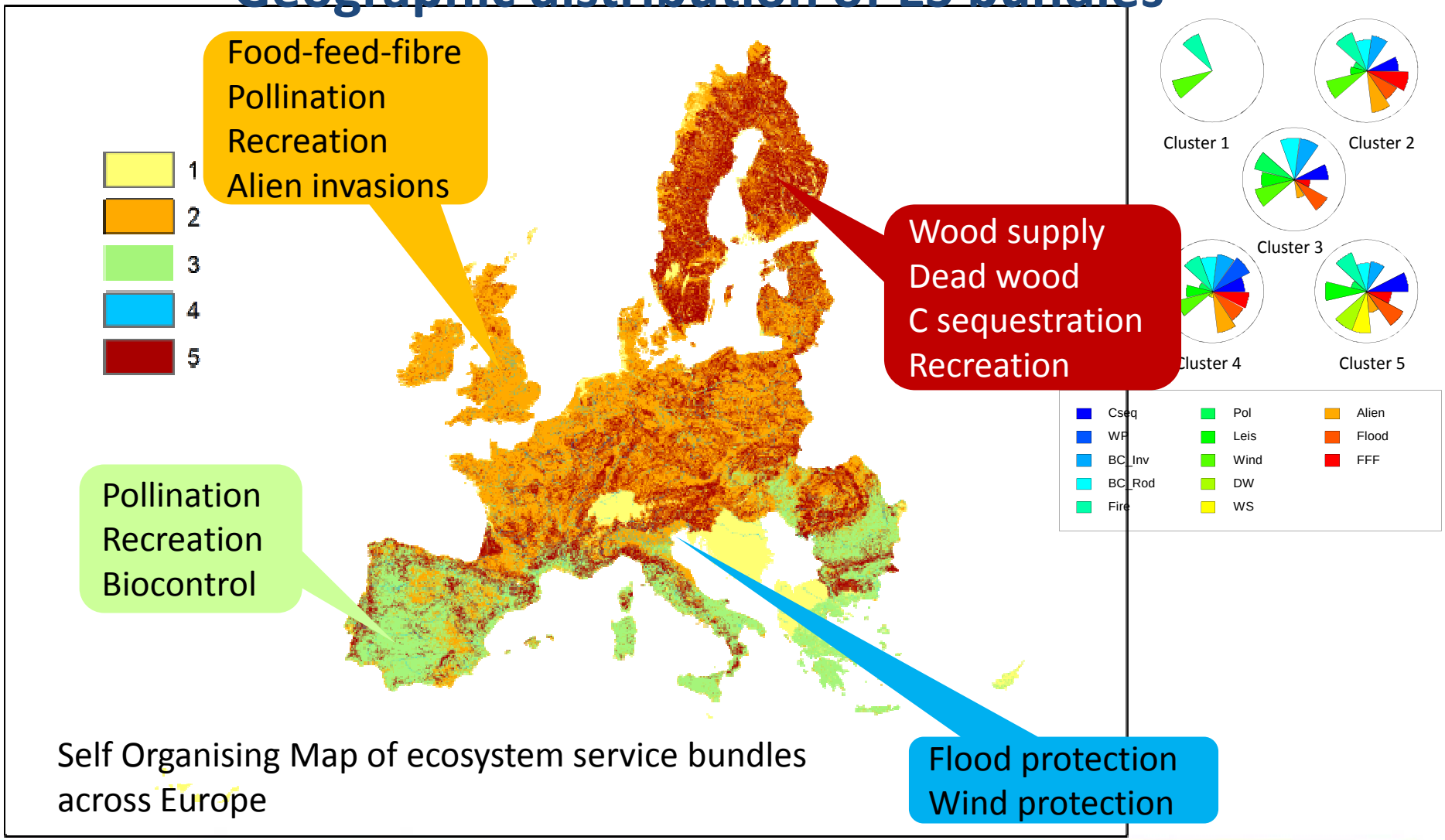
Trade-off analysis framework
Step 1: Detecting ES bundles





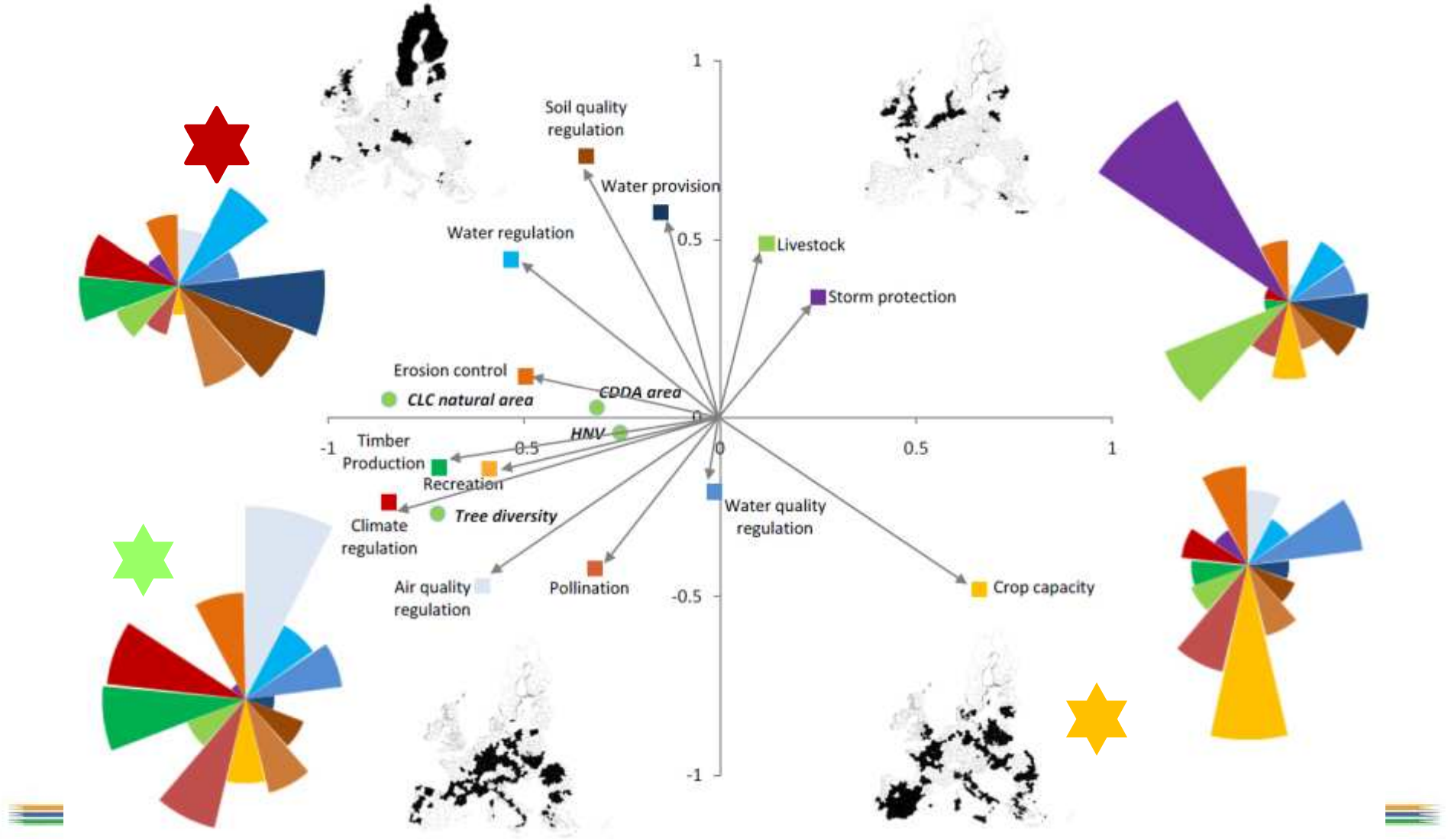
- Three broad bundles of ES
  - Forested areas: dead wood, wood supply, and wind disturbance risk
  - Natural areas: biocontrol by vertebrates, fire risk, flood moderation and carbon sequestration
  - Productive areas: agricultural areas (food-feed-fibre, recreation, pollination) or wetland areas (water purification, alien)

Detecting bundles
Geographic distribution of ES bundles



Self Organising Map of ecosystem service bundles across Europe

Comparison with JRC analysis of trade-offs in ecosystem services across Europe



Joachim Maes, Maria Luisa Paracchini, Grazia Zulian, 2011. A European assessment of the provision of ecosystem services - Towards an atlas of ecosystem services

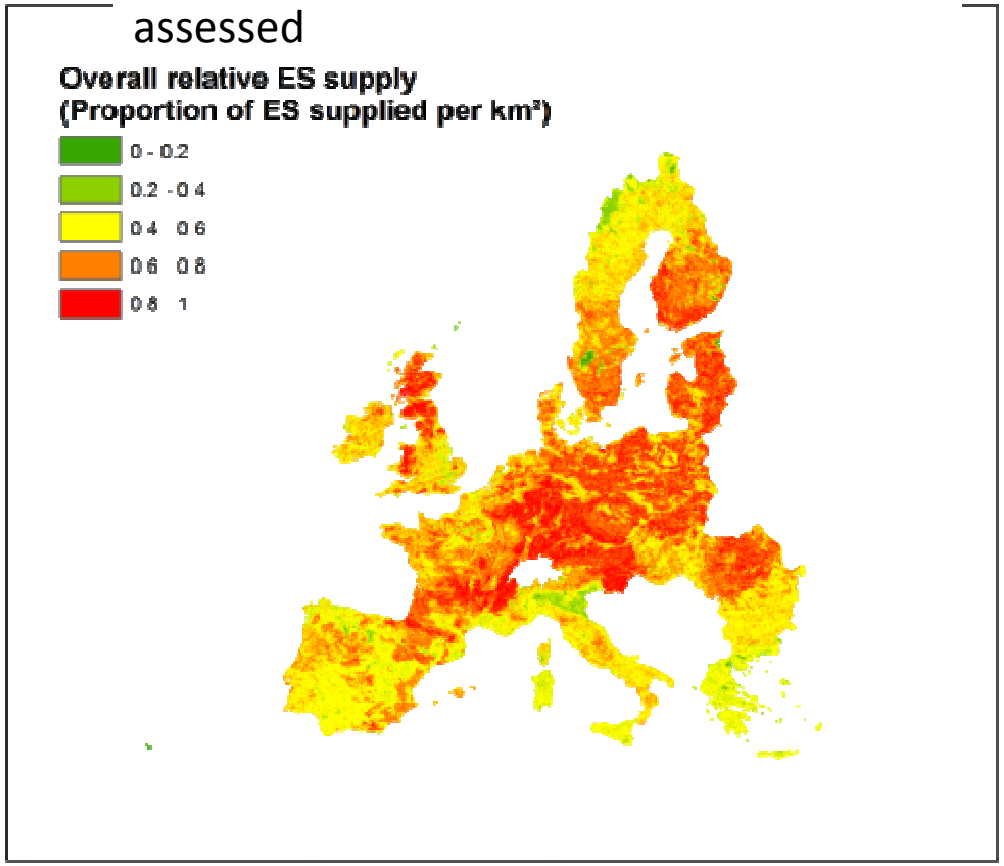
Step 2: Identifying ES bundles
Quantitative analyses

- Overlap 2 by 2 (or more)
  - Nb or % of overlapping cells (binary indicator) *(Eigenbrod et al 2010)*
  - Nb of overlapping cells/smallest area *(Egoh et al 2009, Gos et al 2012)*
  - Overlap of categories (high/high, low/high, high/low, low/low ES supply) *(Swallow et al 2009)*
- Pb => defining a supply **threshold**

	Cseq	WP	BC_Inv	BC_Rod	Fire	Flood	Poll	Leis	Wind	DW	WS	Alien	FFF
Cseq	1	0.998	0.99	1.02	1.12	1.08	1.08	1.21	1.42	1.39	1.38	0.98	0.93
WP		1	1.15	1.12	1.03	0.94	0.95	0.93	0.64	0.71	0.68	0.92	1.10
BC_Inv			1	1.32	0.76	1.08	1.13	0.94	0.7	0.88	0.8	0.94	1.13
BC_Rod				1	0.78	1.08	1.14	1.0	0.79	1.02	0.9	0.96	1.11
Fire					1	0.94	0.8	1.13	1.43	1.19	1.31	0.98	0.88
Flood						1	1.1	1.11	1.16	1.17	1.15	0.97	1.04
Poll							1	1.15	1.03	1.16	1.11	0.98	1.08
Leis								1	1.7	1.67	1.67	1.03	0.89
Wind									1	1.10	1.22	1.18	1.05
DW										1	4.0	1.07	1.13
WS											1	1.08	1.14
Alien												1	0.94
FFF													1

Quantiative analyses
Overall ES supply across Europe

Proportion of ES supplied over the 12 ES assessed



- Most of Europe is quite rich in ES
- Overall ES supply greater in mid-latitude Europe
  - densely forested areas and wetlands
  - fine-grained landscapes (including some croplands and grasslands as well as forests and wetlands) that are characteristic of much of mid-latitude Europe

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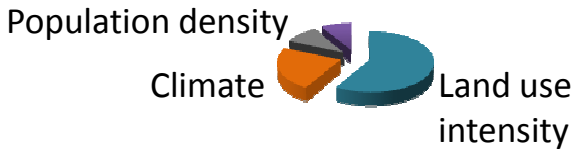
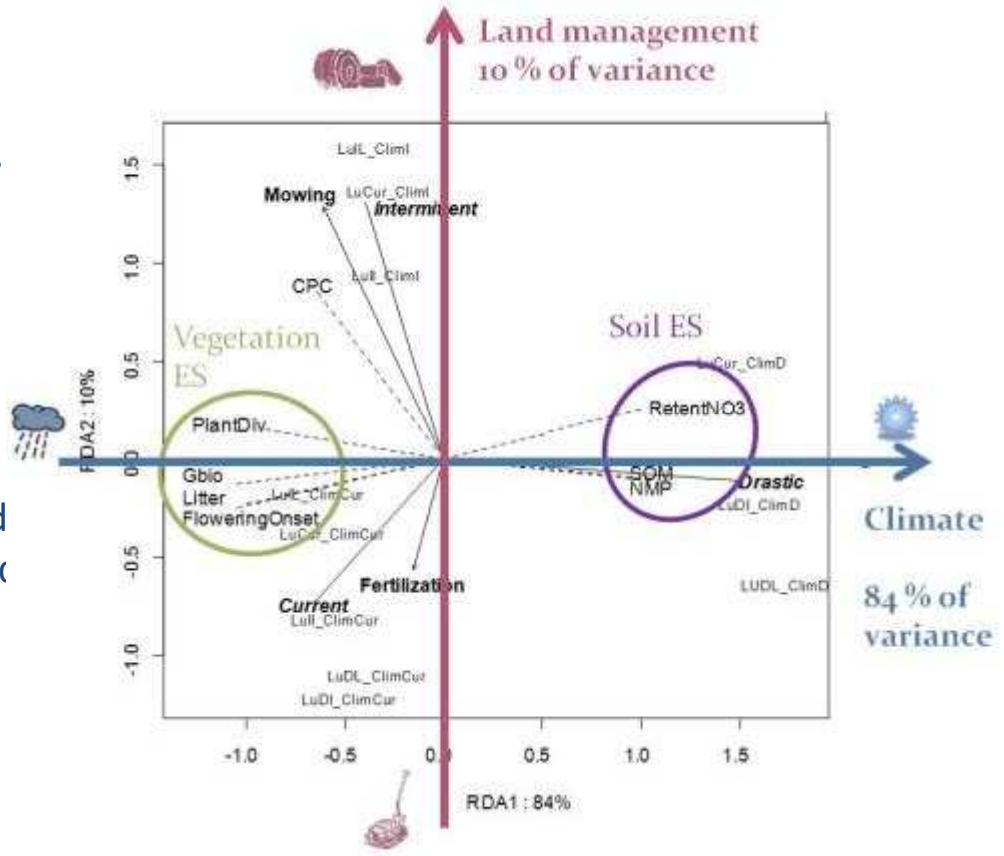
ES & Trade-off analyses framework
Step 3: Drivers of bundles and trade-offs

- RDA & regressions:
  - Explanatory variables: LU classes, HANPP, climate …
  - Response variables: ES values or bundle values
- Partial tests:
  - Determinants of bundles
  - Discounting land cover/types and area of the spatial unit considered conditional variables
- + Variance partitioning





Lamarque et al. PNAS in revision

Drivers of ES bundles and trade-offs in Europe

F stat	ALL CLUE classes	Forest & Semi Nat	Agricult areas	Wetlands	Artificial areas
bio1	**2969**	**17**	**1071**	89	**1250**
bio7	**1129**	**33**	**838**	8	143
bio12	196	2.9	89	8.9	**752**
bio15	224	8.91	214	3.2	263
aridity	**1901**	**43**	**1926**	**40**	393
Terrain	155	6.9	143	**22**	394
NPPorig	218	2.8	247	5.4	180
econoDens	124	5.4	77	5.0	28
popDens	36	3.7	23	1.55 (NS)	8.1
HANPP	498	7.3	147	**72**	443
Biodiv	**1711**	**16**	**1155**	**75**	**682**

Selection of driving variables by Redundancy Analysis (RDA)

Annual mean T and T range

Annual total precip and seasonality

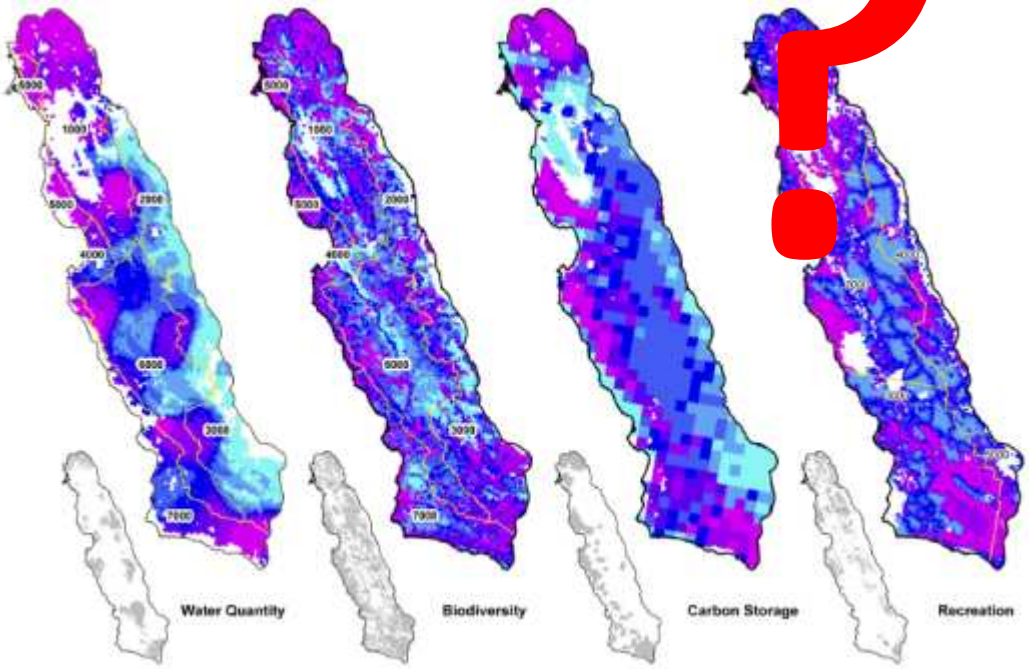
- **Prevalent role of climatic contrasts – North-South & aridity gradient**
- No significant role of socio-eonomic variables tested and limited role of land use intensity (HANPP)
- Correlation with biodiversity (species richness) of vertebrates

Challenge for management and policy: Biodiversity and Ecosystem Services How do they overlap?

Table 4 – Spearman rank correlation between species richness and ecosystem service hotspots. Only significant r values are reported. Correlations are significant at $p < 0.05$.

	Water flow regulation	Surface water supply	Soil retention	Soil accumulation	Carbon storage
Birds	0.22	0.1	0.1	0.14	
Frogs	0.1	0.23	0.19	0.23	
Butterfly	0.19	0.15	0.16	0.15	0.1
Mammals	0.17	0.18	0.19	0.27	
Animals combined	0.18	0.16	0.18	0.24	
Threatened and endemic plants	0.18	[illegible]	0.11		0.11
Threatened plants	0.1			−0.08	0.06
Endemic plants	0.14				0.23
Vegetation diversity	0.18				0.26

Egoh et al. Biol. Cons. 2009



'Targeting ecosystem services directly can meet the multiple ecosystem services and biodiversity goals more efficiently but cannot substitute for targeted biodiversity protection (biodiversity losses of 44% relative to targeting biodiversity alone).'

Chan et al. PLoS Biol. 2006

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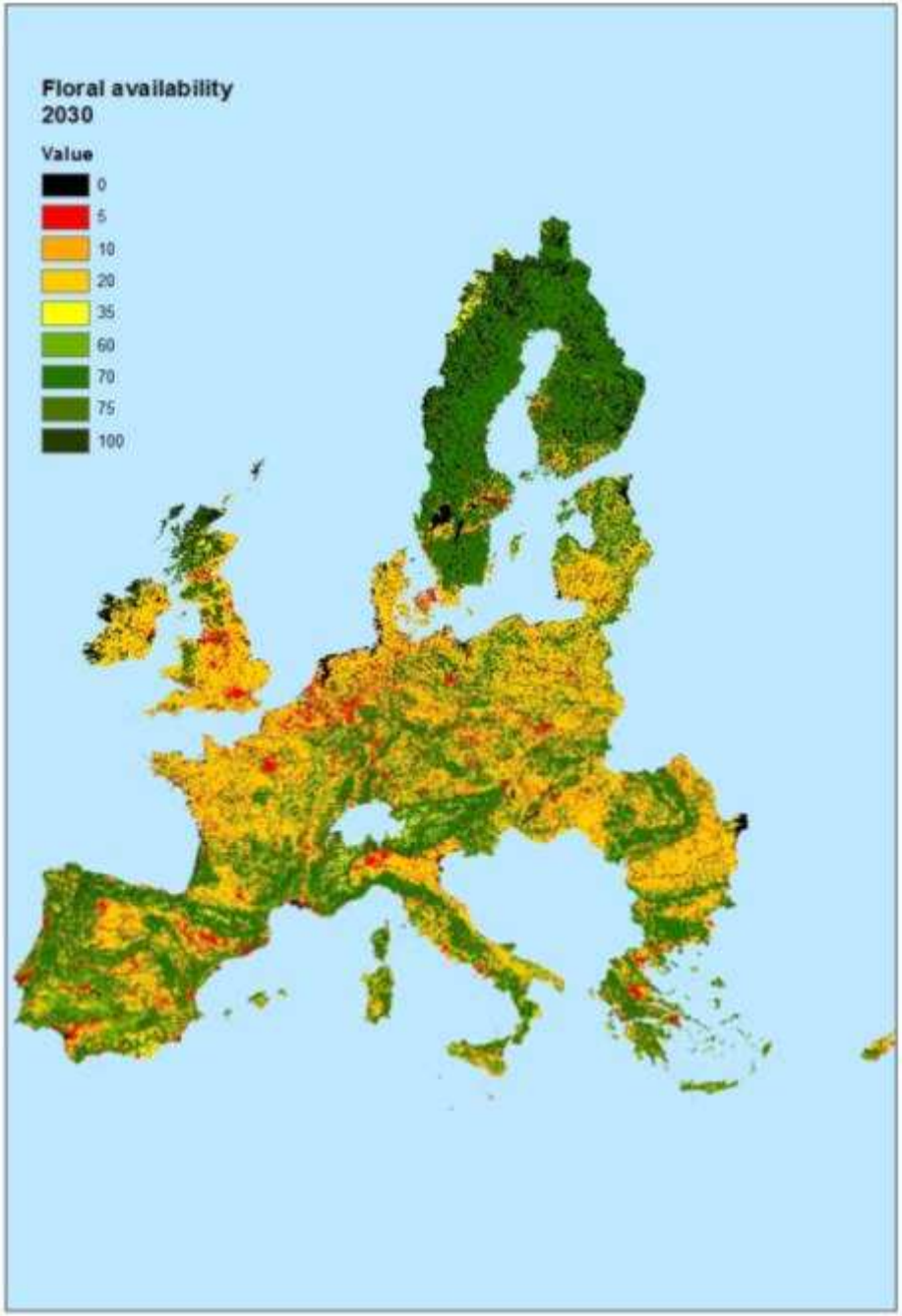
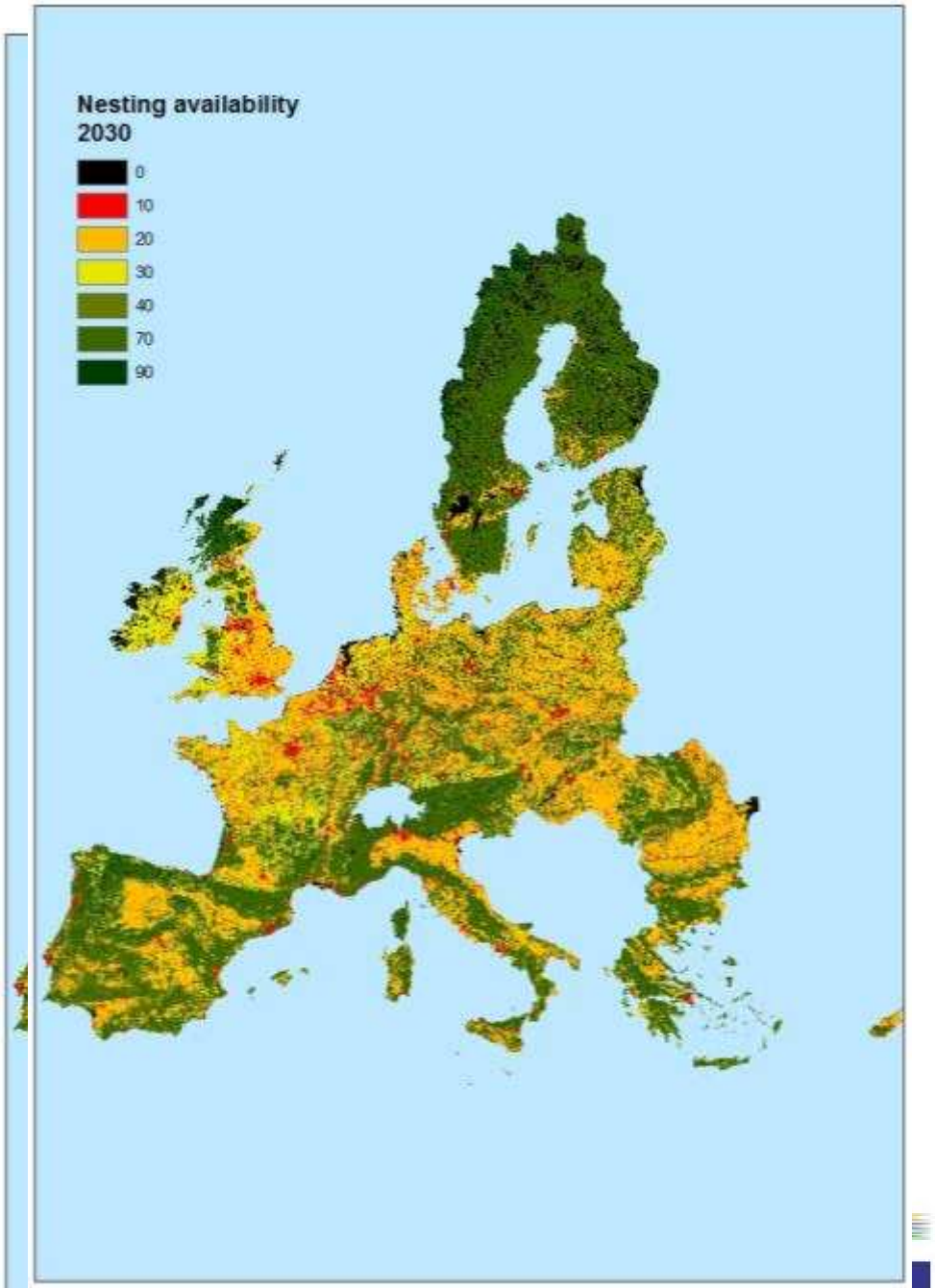
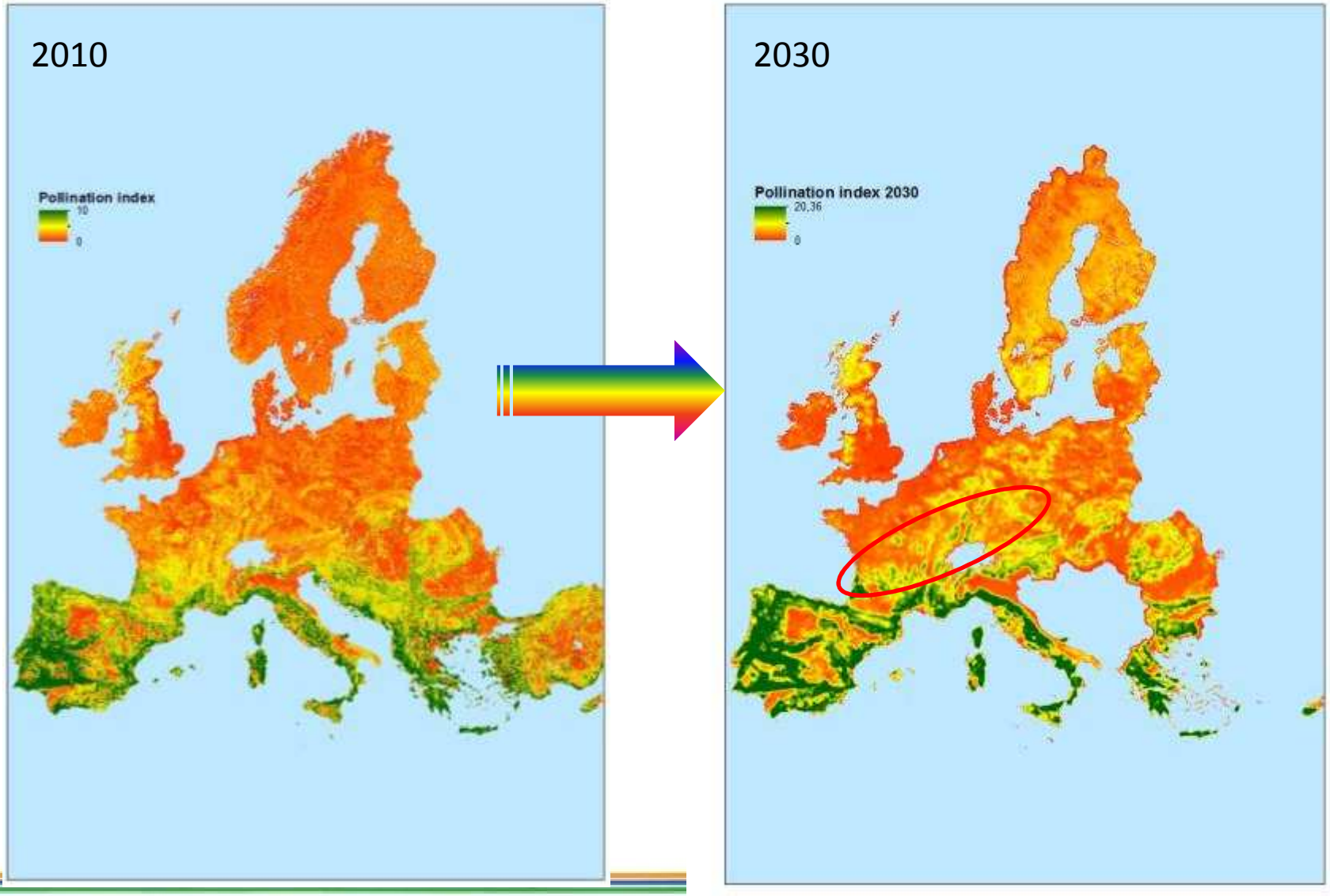


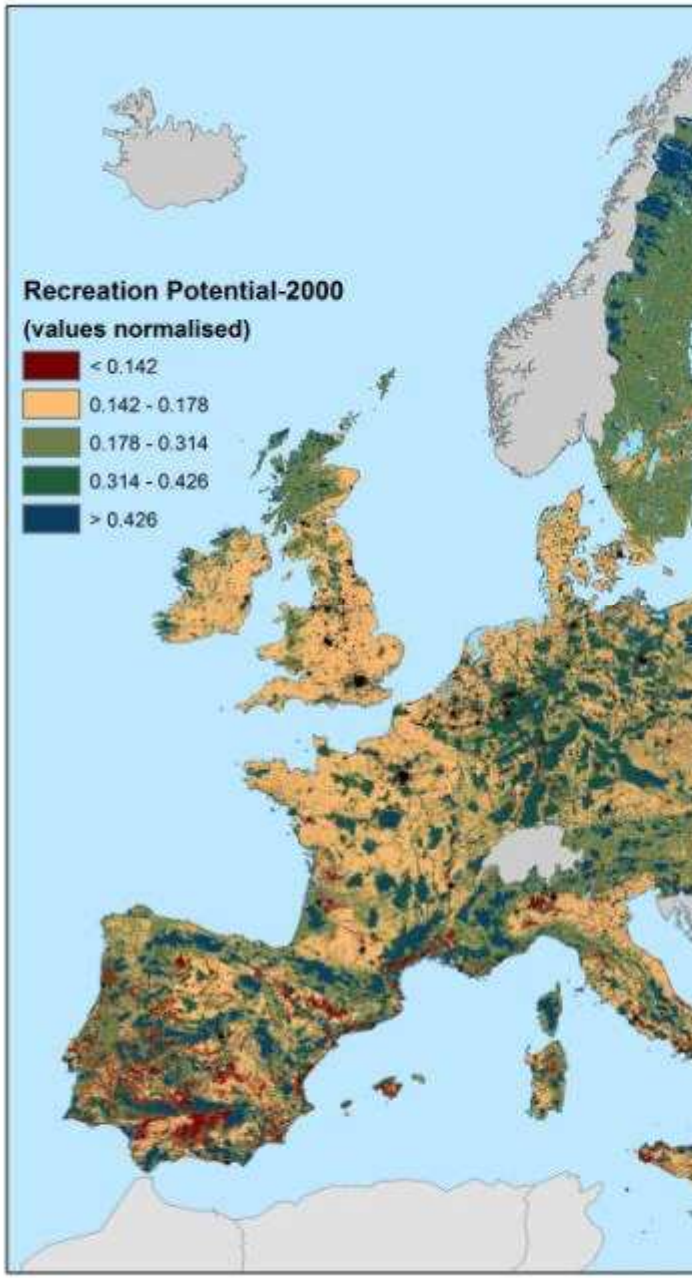


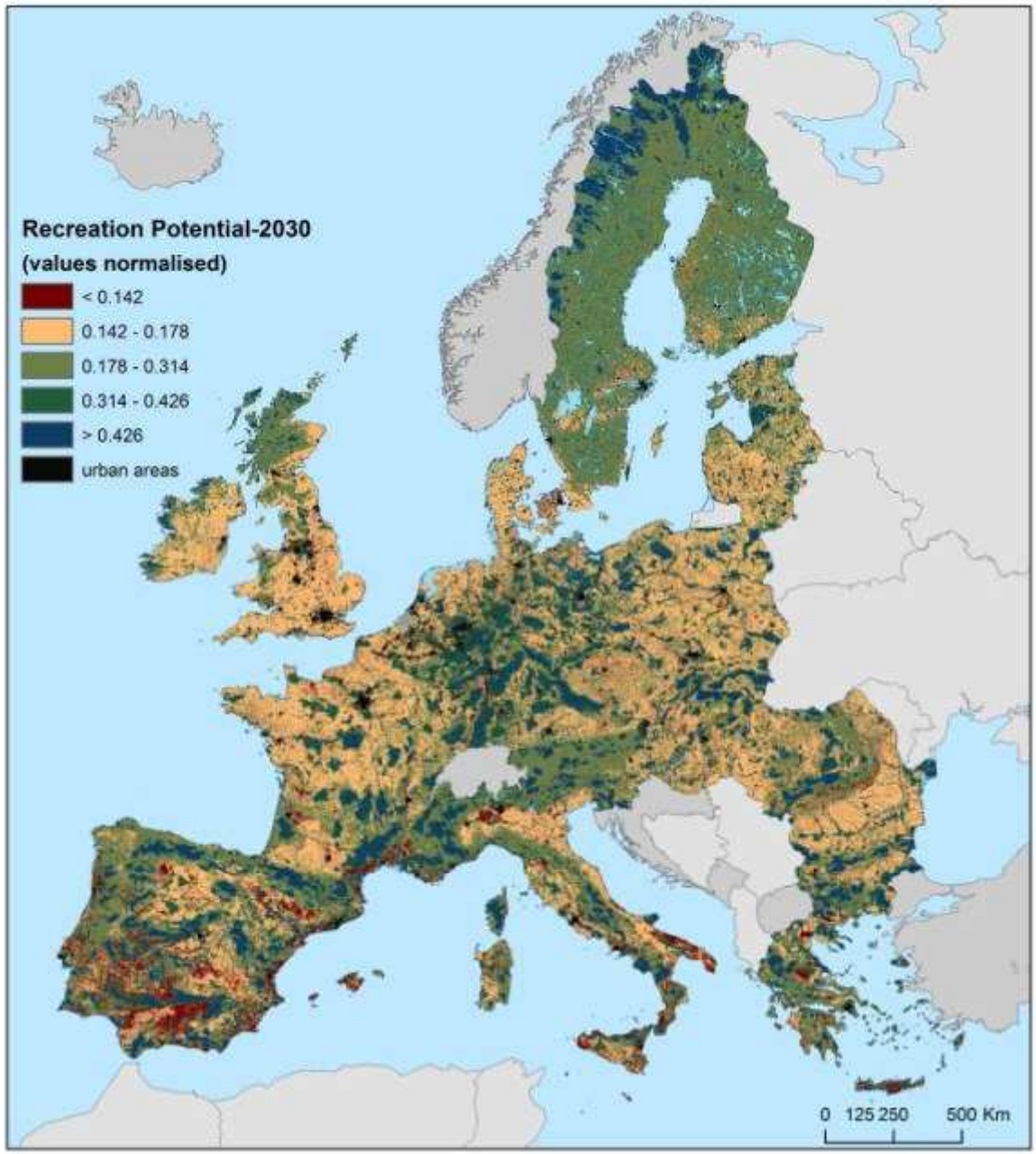
ng, place, date

Pollination

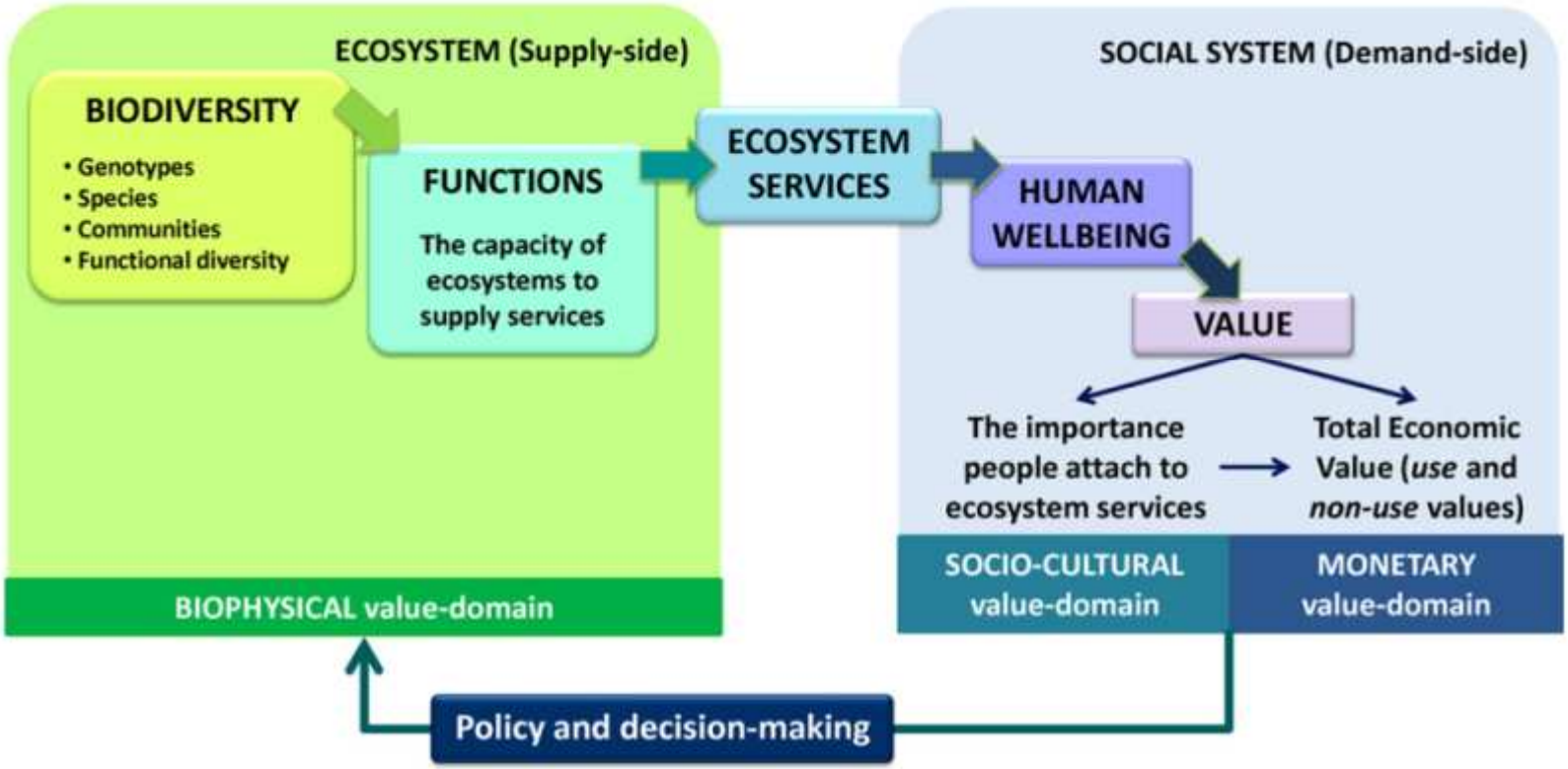


Recreation potential





Assessment of ES scenarios => WP12



Martin Lopez et al. Ecol. Ind. 2013

Conclusions

- Ecosystems and their biodiversity have an intrinsic value, but also plays an essential role for the provision of ecosystem services (ES) that benefit to society
- Strong determinism of ES by land use via its effects on land cover and biodiversity
- Trade-offs between best available knowledge and data availability to map ecosystem services
- Research challenges:
  - Trade-offs and synergies in ES provision in space and time
  - Quantitative approaches to quantify ES and understand synergies and trade-offs across services
  - Biodiversity and Ecosystem Services - How do they overlap?

➢ Implications for land management and policy

Any questions?