Spatial Ecosystem Service Models

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What are models (in an ES context)?

Computer models are **simplified representations of the environment** that allow biophysical, ecological, and/or socio-economic characteristics to be quantified and explored.

Modelling approaches differ from mapping approaches as:

(i) they are **not forcibly spatial** (though many are)

(ii) they focus **understanding/quantifying the *interactions*** between different components of social and/or environmental systems

(iii) They **are exploratory**: by changing parameters within models, they are capable of exploring both alternative scenarios and internal model dynamics

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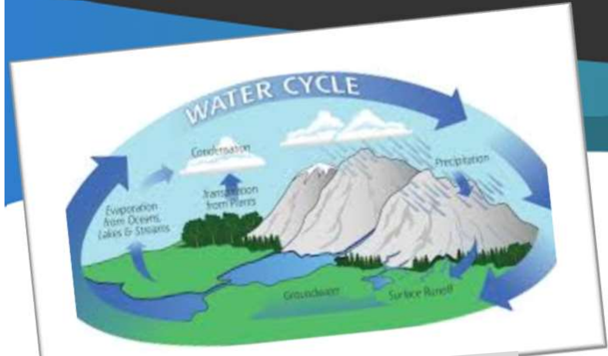
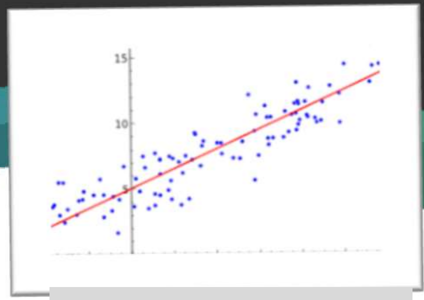


Conceptual model



Statistical model

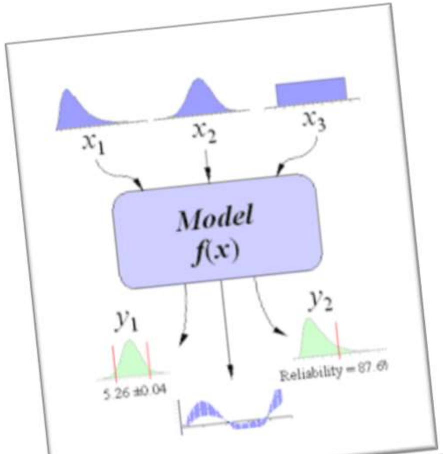
Deterministic model

$$A = R \cdot K \cdot LS \cdot C \cdot P \quad (8.1)$$

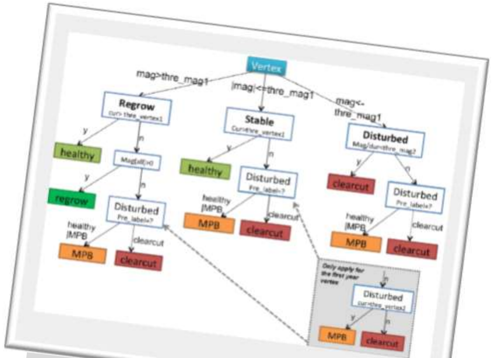
where A is the annual soil loss due to erosion [t/ha year]; R the rainfall erosivity factor; K the soil erodibility factor; LS the topographic factor derived from slope length and slope gradient; C the cover and

Types of model

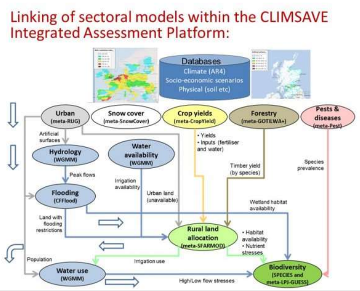
- Conceptual models
- Statistical models
- Deterministic models
- Probabilistic models
- Rule-based models
- Integrated modelling systems



Probabilistic model



Rule-based model



Integrated modelling systems

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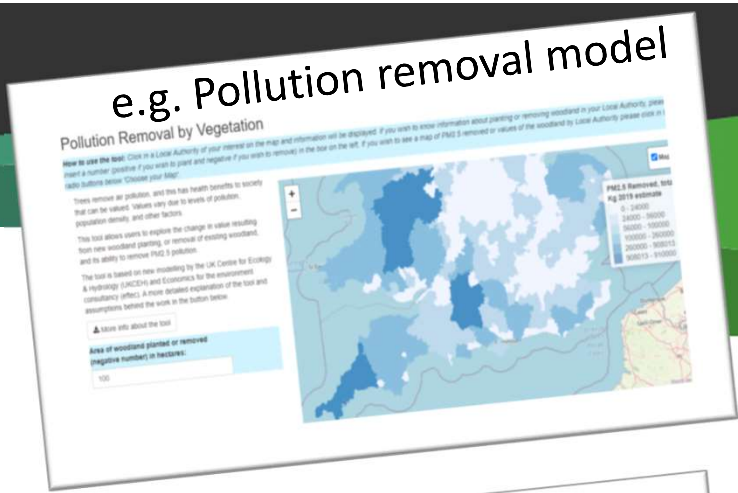
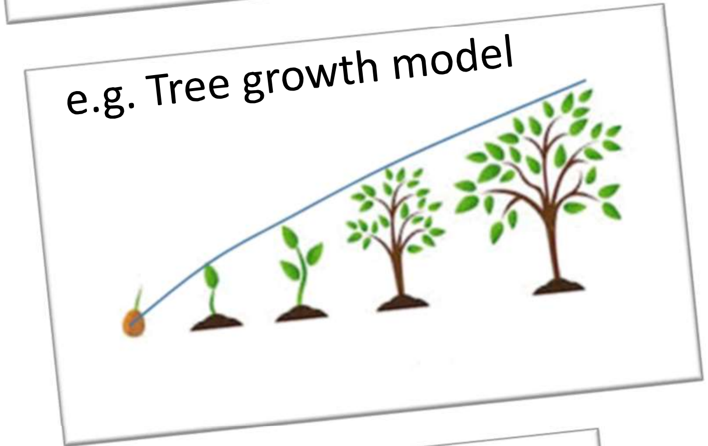
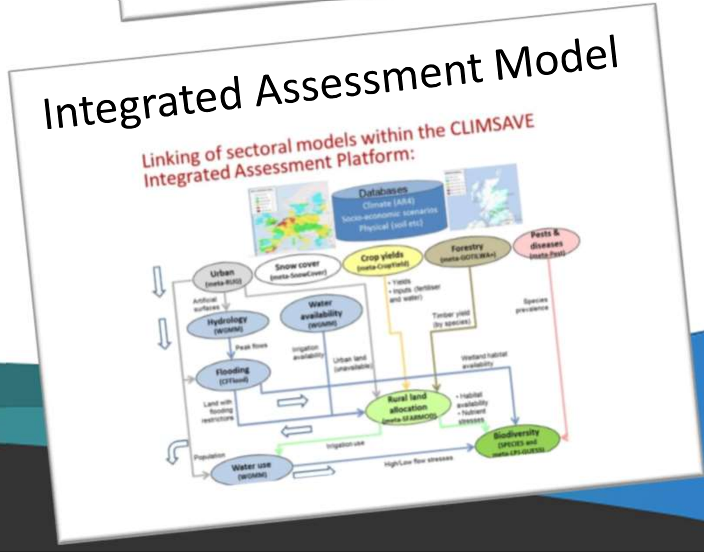
How can models help us better understand ES?

- Modelling ecosystem services directly *(Ecosystem Service Models)*
- Modelling natural environment parameters needed to understand ES *(Natural environment models)*
- Modelling interactions between different environmental sectors *(Integrated assessment models)*

In this presentation I'll give some examples – but they are just examples there are many options out there!







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Matrix-based approaches

- Between mapping and modelling
- Can be very simple → more complex by including additional datasets
- At most simple combine land cover data with scores for ES provision across a wide range of ES provision types
- Advantages: Quick, transparent, easy to understand and communicate, can be done with stakeholders
- Disadvantages: Open to the critique of over-simplification and subjectivity…
- … but make point that modelling needn't be complex

Type		Ecological integrity								Regulating services											Provisioning services														Cultural services					
	Name	Exergy capture	Entropy production	Storage capacity	… & Nutrient loss reduction	Biotic water flows	Metabolic efficiency	Heterogeneity	Biodiversity	…lobal climate regulation	…ocal climate regulation	Air quality regulation	Water flow regulation	Water purification	Nutrient regulation	Erosion regulation	…atural hazard regulation	Pollination*	…st and disease control*	Regulation of waste*	Crops	Biomass for energy	Fodder**	Livestock (domestic)	Fibre	Timber	Wood Fuel	…, seafood & edible algae	Aquaculture	Wild foods & resources	…ochemicals & Medicine	Freshwater	Mineral resources***	…iotic energy sources***	Recreation & Tourism	…pe aesthetics & inspiration	Knowledge systems	…ous & Spiritual experience	…heritage & Cultural diversity	…heritage & Natural diversity
CLC111	Continuous urban fabric	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	0	0	0	0	0	0	1	3	3	1	5	1	0
CLC112	Discontinuous urban fabric	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	1	0	0	0	1	3	2	1	5	1	0
CLC121	Industrial or commercial units	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	1	0
CLC122	Road and rail networks	0	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	0	0	0	0	0	0	0	0	0	1	0
CLC123	Port areas	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	0	0	1	0
CLC124	Airports	1	1	0	2	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
CLC131	Mineral extraction sites	0	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	0	0	0	5	5	0	0	1	0	0	0
CLC132	Dump sites	0	0	5	0	0	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CLC133	Construction sites	0	0	0	0	0	0	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	1	0	0	0	0	0	0	0
CLC141	Green urban areas	4	3	2	3	2	1	3	3	1	2	1	2	1	1	2	0	1	1	1	0	0	0	0	0	0	1	0	0	1	0	0	0	0	3	3	1	0	2	0
CLC142	Sport and leisure facilities	4	3	2	3	2	1	2	2	1	1	1	2	1	1	1	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	1	0	0	1	0
CLC211	Non-irrigated arable land	5	4	4	1	3	4	3	2	1	2	0	1	0	0	0	1	0	2	2	5	2	3	0	5	0	0	0	0	0	1	0	0	0	1	1	2	0	3	0
CLC212	Permanently irrigated land	5	4	3	1	5	2	3	2	1	3	0	0	0	0	0	1	0	1	2	5	1	2	0	2	0	0	0	0	0	1	0	0	0	1	1	2	0	3	0
CLC213	Rice fields	5	4	3	1	5	1	3	2	0	2	0	2	0	0	0	0	0	1	1	5	0	2	0	0	0	0	0	0	0	0	0	0	0	1	1	2	0	4	0
CLC221	Vineyards	3	2	2	0	3	1	3	2	1	1	0	1	0	0	0	0	0	1	1	4	1	0	0	0	0	1	0	0	0	0	0	0	0	5	2	2	0	5	0
CLC222	Fruit trees and berries	3	2	3	2	4	2	4	3	2	2	2	2	1	1	2	2	5	3	2	5	1	0	0	0	4	4	0	0	0	0	0	0	0	5	2	2	0	4	0
CLC223	Olive groves	3	2	3	1	3	2	3	2	1	1	1	1	1	1	1	0	0	3	2	4	1	0	0	0	4	4	0	0	0	0	0	0	0	5	2	2	0	4	0
CLC231	Pastures	5	5	4	2	4	5	2	2	1	1	0	1	0	0	4	1	0	2	4	0	1	5	5	0	0	0	0	0	0	0	0	0	0	3	2	2	0	3	0
CLC241	Annual and permanent crops	4	3	3	2	3	2	2	2	1	2	1	1	0	0	1	1	0	2	2	5	1	5	5	5	0	0	0	0	0	1	0	0	0	1	1	2	0	2	0
CLC242	Complex cultivation patterns	4	3	3	1	3	2	4	3	1	2	0	1	0	0	0	1	0	3	2	4	1	3	0	4	0	0	0	0	0	2	0	0	0	2	2	2	0	3	0
CLC243	Agriculture & Natural vegetation	3	2	3	2	3	2	3	3	2	3	1	2	1	0	3	1	0	3	2	3	2	2	3	4	3	3	0	0	3	1	0	0	1	2	2	3	0	2	3
CLC244	Agro-forestry areas	4	3	4	4	4	3	4	4	1	2	1	1	1	1	2	1	3	3	3	3	2	2	3	2	3	3	0	0	0	0	0	0	0	3	2	2	0	3	0
CLC311	Broad-leaved forest	5	4	5	5	5	4	3	4	4	5	5	2	5	5	5	3	5	4	4	0	1	1	0	0	5	5	0	0	5	5	0	0	0	5	5	5	3	3	5
CLC312	Coniferous forest	5	4	5	5	4	4	3	4	4	5	5	2	5	5	5	3	5	4	4	0	1	1	0	0	5	5	0	0	5	5	0	0	0	5	5	5	3	4	5
CLC313	Mixed forest	5	4	5	5	5	4	3	5	4	5	5	2	5	5	5	3	5	5	5	0	1	1	0	0	5	5	0	0	5	5	0	0	0	5	5	5	3	4	5
CLC321	Natural grassland	4	3	5	5	4	4	3	5	3	2	0	1	5	5	5	1	0	1	2	0	0	1	3	0	0	0	0	0	5	0	0	0	0	3	4	5	1	4	3
CLC322	Moors and heathland	4	3	5	5	4	5	3	4	3	4	0	2	4	3	0	2	2	2	3	0	2	0	2	0	0	2	0	0	1	0	0	0	0	5	4	5	1	2	5
CLC323	Sclerophyllous vegetation	3	2	2	4	2	3	3	4	1	2	0	1	0	0	0	1	2	2	3	0	0	0	2	0	0	2	0	0	1	3	0	0	0	2	3	4	1	2	4
CLC324	Transitional woodland shrub	3	2	2	4	2	3	3	4	0	1	0	0	0	0	0	0	2	2	3	0	1	0	2	1	0	2	0	0	1	0	0	0	0	2	3	4	1	2	2
CLC331	Beaches, dunes and sand plains	1	0	1	0	1	1	3	3	0	0	0	1	0	0	0	5	0	1	1	0	1	0	0	0	0	0	0	0	0	0	0	1	0	5	4	4	0	2	2
CLC332	Bare rock	0	0	0	0	0	0	3	3	0	0	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	4	3	4	0	2	0
CLC333	Sparsely vegetated areas	1	1	1	1	1	0	2	3	0	1	0	1	0	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	4	0	2	0
CLC334	Burnt areas	0	0	3	0	0	0	2	1	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0
CLC335	Glaciers and perpetual snow	0	0	0	0	0	0	2	1	3	3	0	4	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	5	0	0	5	5	3	2	0	0
CLC411	Inland marshes	4	3	5	3	4	4	3	2	2	2	0	2	0	4	0	4	0	2	3	0	0	5	2	0	0	0	0	0	0	0	0	0	0	0	2	4	0	2	0
CLC412	Peatbogs	4	3	5	5	4	4	3	4	5	4	0	3	4	3	0	3	2	3	4	0	2	0	0	0	0	0	0	0	0	0	0	0	0	4	2	3	0	2	4
CLC421	Salt marshes	3	2	5	3	4	3	2	3	0	1	0	0	0	2	0	5	0	2	2	0	0	0	2	0	0	0	0	0	0	0	0	0	0	3	2	3	0	2	0
CLC422	Salines	0	0	0	0	0	0	1	1	0	2	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	3	0	2	0
CLC423	Intertidal flats	1	1	1	4	0	2	2	3	0	1	0	0	0	1	0	5	0	2	3	0	1	0	0	0	0	0	0	0	0	0	0	0	0	4	2	3	0	2	0
CLC511	Water courses	3	1	1	3	0	3	4	4	0	1	0	1	3	3	0	2	0	3	5	0	3	0	0	0	0	0	3	0	4	0	5	0	5	4	4	4	0	3	5
CLC512	Water bodies	4	2	4	3	0	4	4	4	1	2	0	2	0	1	0	1	0	3	5	0	0	0	0	0	0	0	3	5	4	0	5	0	5	5	4	4	0	3	4
CLC521	Coastal lagoons	5	4	4	3	0	5	4	4	0	1	0	0	0	0	0	4	0	3	5	0	1	0	0	0	0	0	4	5	4	0	0	0	0	4	4	4	0	2	4
CLC522	Estuaries	5	4	2	3	0	5	3	3	0	0	0	0	3	3	0	3	0	4	5	0	2	0	0	0	0	0	5	5	4	0	0	0	0	4	5	4	0	2	3
	Sea and ocean	3	2	1	4	0	3	2	2	5	3	0	0	0	5	0	0	0	3	5	0	3	1	0	0	0	0	5	5	0	0	0	1	3	4	5	4	0	4	2

Transferable ES modelling frameworks

- **Designed to address a suite of services and to be immediately portable between contexts.**

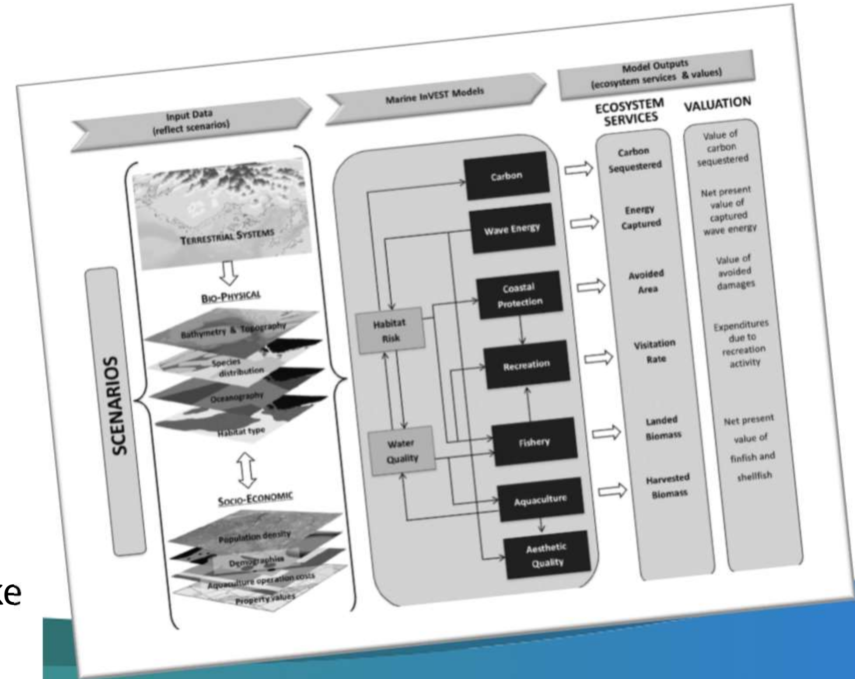
InVEST

integrated valuation of ecosystem services and tradeoffs

InVEST

- Suite of modelling tools for 18 marine, coastal, freshwater and terrestrial ES supply and demand

- Advantages:
    - Freely available, Open-source
    - Recognised, standardised approach
    - Applied in a wide range of contexts
- Considerations:
    - GIS skills needed to map outputs
    - Collecting and curating the required inputs can take time and effort
    - Interactions between ES not explicitly considered
    - Weaker on cultural ES

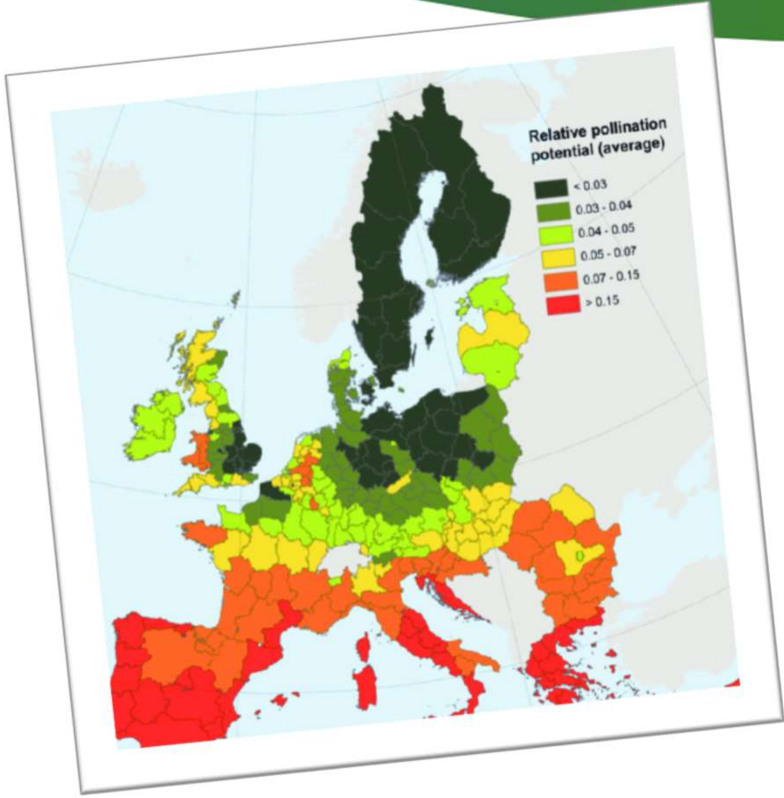


Transferable ES modelling frameworks

- **Designed to address a suite of services and to be immediately portable between contexts.**

ESTIMAP

- Developed to run within a GIS – uses python
- Designed by JRC to be a standardised replicable system for the EU
- **Different services & approaches to InVEST**
- Focus primarily on regulating ES (air quality, soil protection, water retention, pollination), but also bird habitat and recreation
- Customisable to local scale (but needs modeller)



https://publications.jrc.ec.europa.eu/repository/handle/JRC116334
https://publications.jrc.ec.europa.eu/repository/handle/JRC120383

Other tools and frameworks also available,

- e.g. ARIES, LUCI, MIMES
- There are papers that compare strengths and weaknesses (e.g. Bagstad et al., 2013)

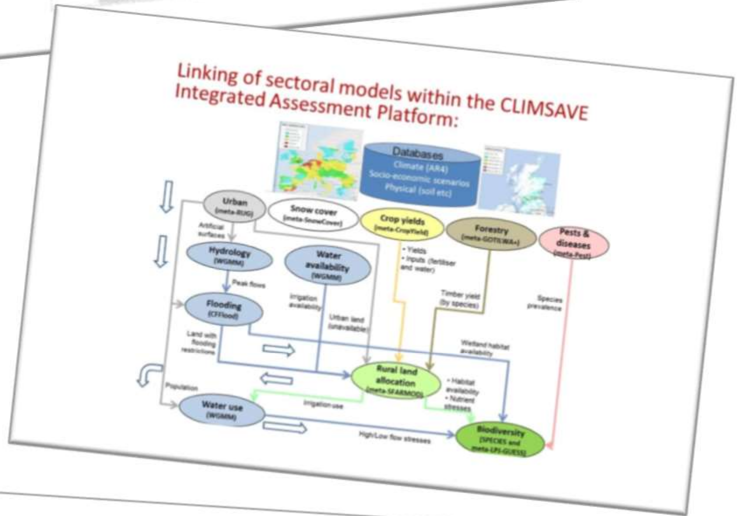
ARIES ARtificial Intelligence for Ecosystem Services
InVEST integrated valuation of ecosystem services and tradeoffs
LUCI

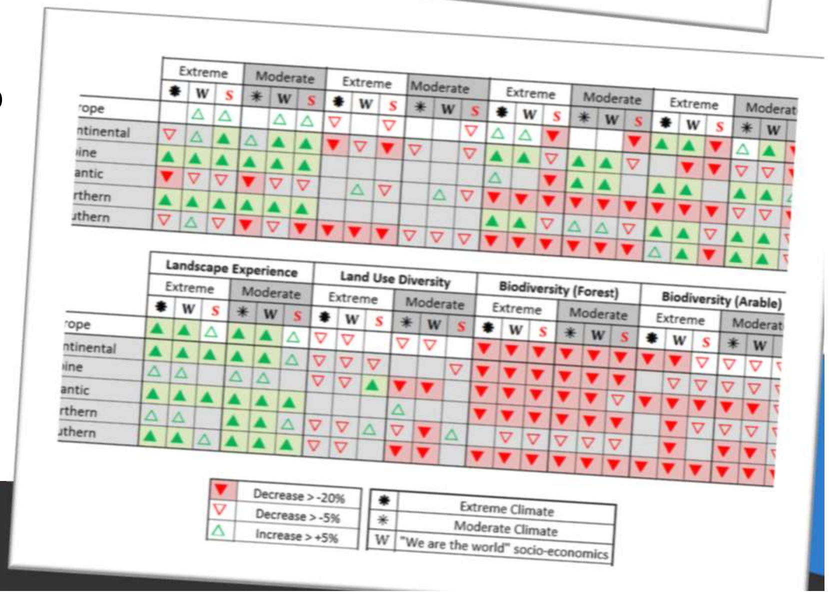
Integrated Assessment Models

- Advantages:
  - Single sectoral models can misrepresent direction, magnitude and spatial patterns (Harrison et al., 2016)
  - IAMs allow for an assessment of a range of ES in ways that deliberately consider interactions between sectors
  - Consider linked climate and socio-economic scenarios
  - Often also produce land use data

- Considerations
  - Technically challenging and time consuming to create
  - Complexity of interactions means can be perceived to be “black-box”
  - Often limited number of ES

- Examples:
  - **CLIMSAVE IAP/IAP2 (EU Scale)**
  - **IMAGE-GLOBIO (Global Scale)**

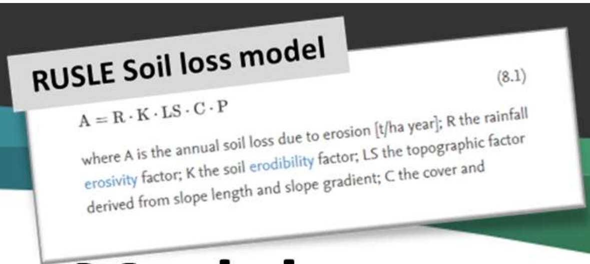




Natural Environment Models

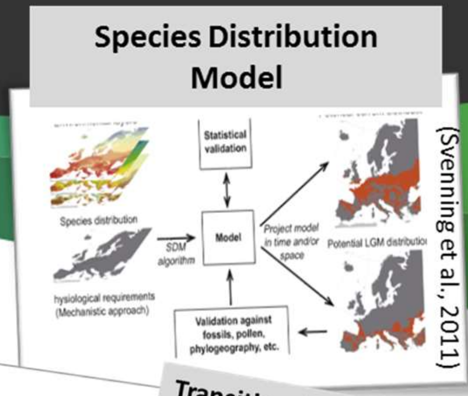
Not ES directly can to contribute to ES analyses (examples):

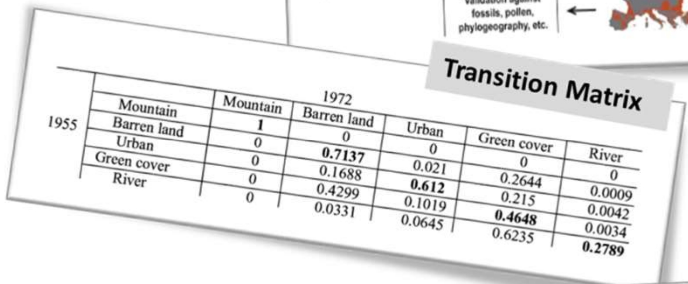
- **Biophysical models**
  - Often sectoral / focussed on a single aspect of the environment
  - E.g. RUSLE (soil erosion), SWAT (soil & water)
  - Often long history → trusted
- **Species Distribution Models (SDMs)**
  - Insight into environmental suitability of species
  - Often driven by bioclimatic information
  - Can include connectivity and dispersal
- **Land use models**
  - Land use can be a key input to ES analyses
  - Lots of approaches (examples):
    - Transition matrices
    - State & Transition models (STMs)
    - Agent Based Models (ABMs)
    - Integrated Assessment models (IAMs)


RUSLE Soil loss model

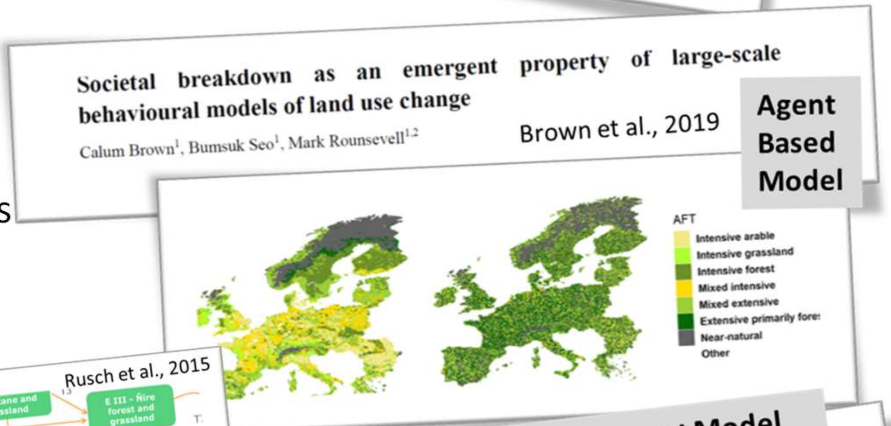
$$A = R \cdot K \cdot LS \cdot C \cdot P \quad (8.1)$$

where A is the annual soil loss due to erosion [t/ha year]; R the rainfall erosivity factor; K the soil erodibility factor; LS the topographic factor derived from slope length and slope gradient; C the cover and

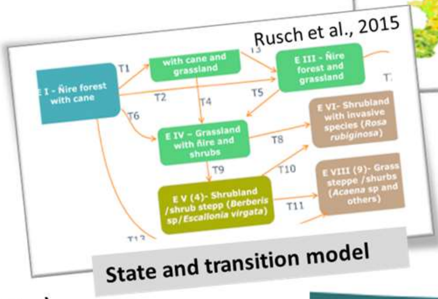


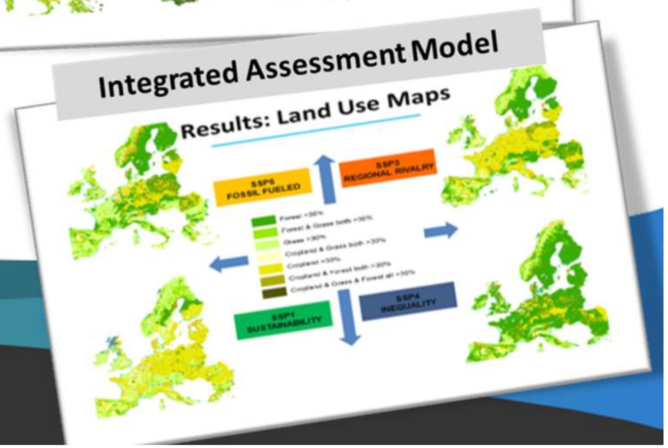

Transition Matrix

1955 \ 1972	Mountain	Barren land	Urban	Green cover	River
Mountain	1	0	0	0	0
Barren land	0	**0.7137**	0.021	0.2644	0.0009
Urban	0	0.1688	**0.612**	0.215	0.0042
Green cover	0	0.4299	0.1019	**0.4648**	0.0034
River	0	0.0331	0.0645	0.6235	**0.2789**


Societal breakdown as an emergent property of large-scale behavioural models of land use change

Calum Brown[1], Bumsuk Seo[1], Mark Rounsevell[1,2]





Considerations when modelling ES (1: Which ES?)

- Primary advantage of ES approach is its attempt to address the environment in a holistic manner

- But not all ES are as easy to model

- **Cultural services particularly challenging** and often limited to physical aspects (e.g. recreation, tourism and to some extent aesthetic beauty):
  - Need to **consider value-added of combining modelling with other methods** or using a participatory approach within the modelling process to facilitate the inclusion of these ES

Considerations when modelling ES (2: Values)

Values

- "Why do ES matter and how much?"
  - There are different ways to assess value - What type of value (biophysical/ monetary/ socio-cultural)?
  - Values are plural – values for who?
  - Values are time-bound – values from when?

- This is a challenge for ES models:
  - Particularly if deterministic and/or with a single output **(not plural!)**
  - **Particularly for cultural services** , though regulating and provisioning services also change value in response to **changing environment, politics and/or socio-economic context**

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Considerations when modelling ES (3: Uncertainty)

Uncertainty

- Many different sources of uncertainty
  - **Data uncertainty:** Accuracy/choice of input data (and validation data!)
  - **Scenario uncertainty**: Is/are the scenario(s) selected an accurate representation of the future?
  - **Model uncertainty:**
    - Different models produce different answers – have you picked the right one?
    - Decisions / assumptions are made within models – how much do they affect the results you'd get?
  - **Holistic uncertainty**: To what extent does the results of this model reflect the real world it is intended to? – very difficult to ascertain!
  - **<u>All models are imperfect</u>** – sensitivity testing can help

Validation

- Validation is good practice
  - Inter-model comparison can help with model uncertainty
  - Is validation data available?
    - especially for ES expert- or stakeholder-derived data
    - Or cultural values where there are no 'objective' values to test against

Final words on ES Models

Models – things to remember:

- Models are man-made abstractions of reality
- They are just one way of accessing information about the environment.
- They need to be considered in context … with transparently documented assumptions … and used with a clear understanding of their strengths and limitations
- **BUT Lots of options out there, lots of expertise out there.**
- Focus on the needs of the study and be creative, brave and transparent about the impacts of your decisions on what can be known