System of Environmental Economic Accounting

Biophysical modeling for ecosystem accounting

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Outline

- Biophysical modelling (what; why?)
- Guidelines on biophysical modeling for SEEA Ecosystem Accounting
- Key elements
  - > Modelling techniques
  - > Main modelling platforms
- Modelling ecosystem services
  - > Example from South Africa
- Conclusions

What is biophysical modelling?

- Biophysical modelling: the quantitative estimation of biophysical phenomena or processes that are difficult to fully observe directly.
- Distinguish between models and modelling platforms.
  - Models are highly diverse in purpose and approach, many are set-up to analyse a specific problem (e.g. a model to estimate carbon sequestration).
  - Modelling platforms: tools consisting of multiple models
- Biophysical models can be useful for compiling many of the extent, condition, as well as supply and use tables and maps produced in SEEA EA.
- Biophysical modelling may be instrumental, it can never replace data collection processes:
  - Earth observation data sets need ground-truthing
  - Models rely on in situ data (adjust model setup to local circumstances / calibration)

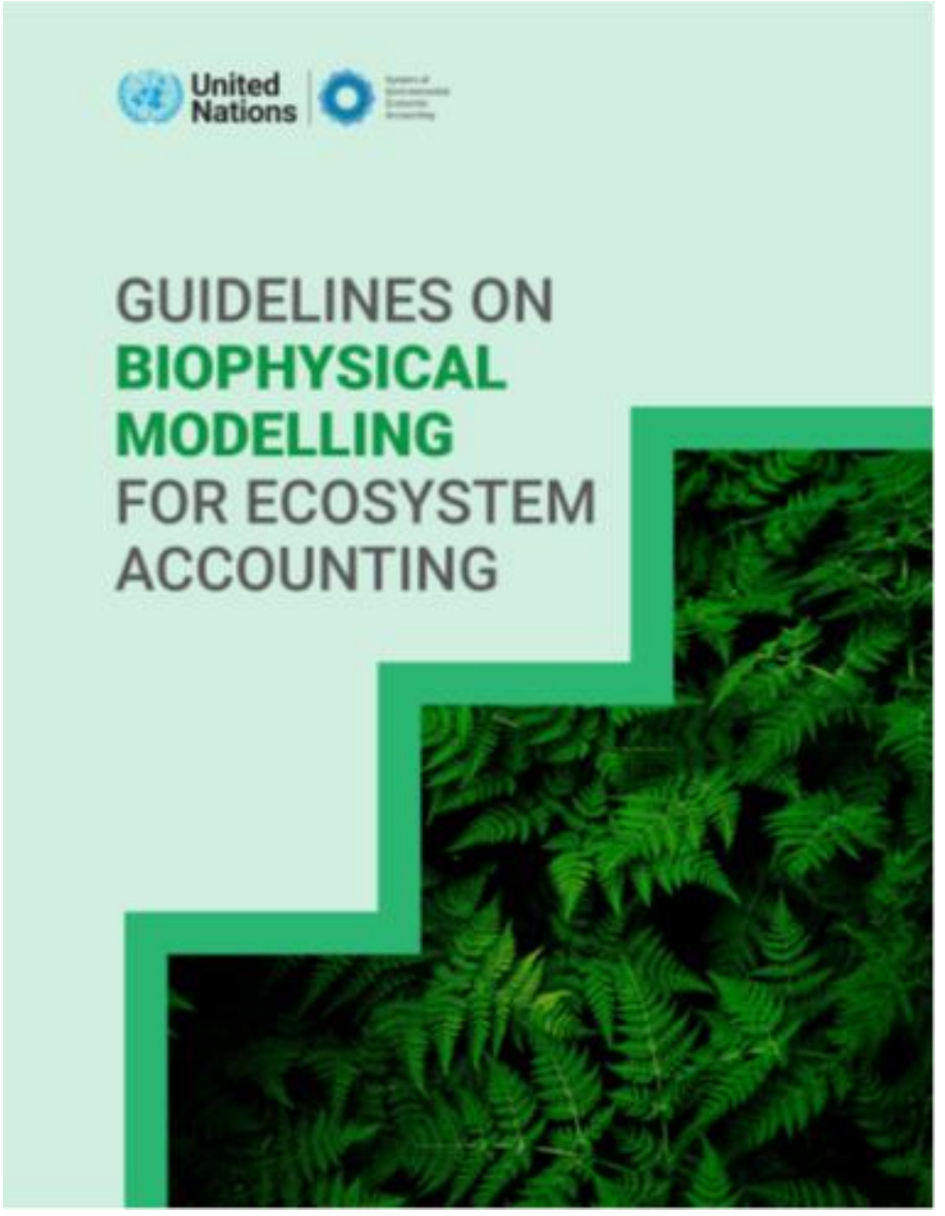
Why do we need modelling?

- Ecosystem accounting - as spatially explicit - requires maps with full spatial cover of ecosystem types, condition variables, and ecosystem services flows

- Data needed for ecosystem accounts not usually captured in regular data sources
  - Measuring ecosystem services directly is often difficult or costly to measure *in situ*.
- For some services or condition indicators, data are only available for specific locations
  - Spatialize tabular data (e.g. visitors, or water quality
- Usually, data from various sources and scales need to combined (e.g., point field data and satellite data)

Biophysical guidelines (1/3)

- Why developed?
  - > Diverse models and tools have proliferated over the past decade and are constantly evolving.
  - > Most models not developed specifically for accounting purposes, many models produce results can be used directly in SEEA EA or produce results that can be modified for use in SEEA EA.
- Audience:
  - > Ecosystem accounts compilers + managers
  - > Assumes familiarity with SEEA Ecosystem Accounting but does not assume knowledge of biophysical modelling
- Process:
  - > Under auspices of UNCEEA
  - > Global consultation in 2021
  - > Adopted by UN Statistical Commission



Biophysical guidelines (2/3)

1. Introduction
2. Process guidance for agencies
3. Modeling for ecosystem accounts
4. Modeling for extent accounts
5. Modeling for condition accounts
6. Modeling for ecosystem service accounts
7. Data quality
8. Future of biophysical modeling

Annexes

1. Global data sources + data portals
2. Modelling techniques
3. Cartography essentials
4. Literature list (16 pages)

NB: Living document: see for latest tables:

https://seea.un.org/ecosystem-accounting/biophysical-modelling

Biophysical guidelines (3/3)

- Tiered approach
  - recognizes countries are in different circumstances (data availability + expertise)
  - may differ per ES
  - progress over time
- Decision trees to facilitate choices

TIER 1

Ecosystem services modelled from global datasets with no or little user input data

TIER 2

Ecosystem services modelled from national datasets customized for national contexts, some validation

TIER 3

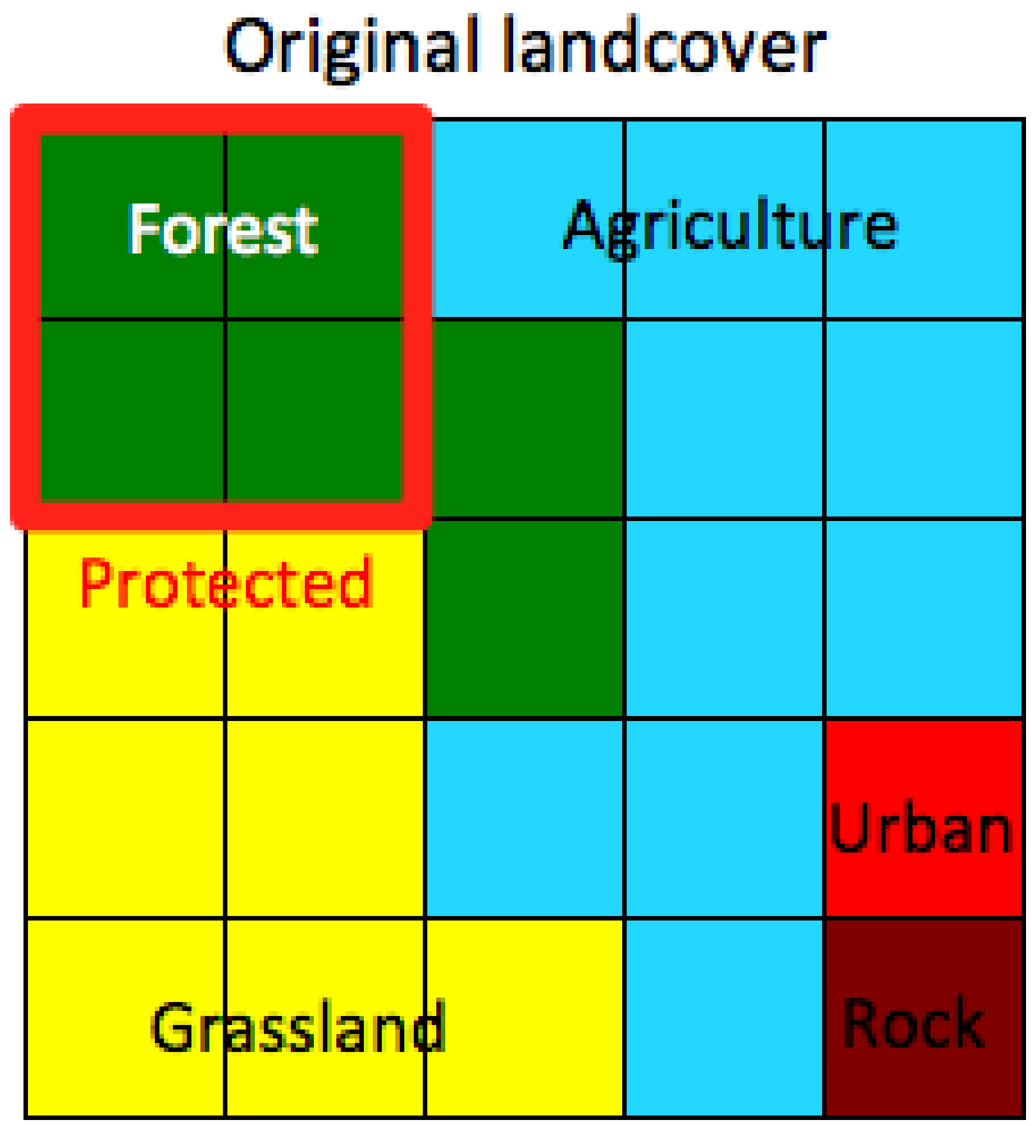
Ecosystem services modelled with local data and direct surveys, better validation, and best available tools

Figure 2: *Tiered approach*

Modelling techniques

Model technique	Definition	Data needs	Efforts
Look-up Table	Specific values for an ecosystem service or condition variable are attributed to every pixel in a certain class, usually a land cover, land use, or ecosystem type class.	Limited	Easy
Spatial interpolation	Creates surfaces from measured points	Moderate	Moderate
Geostatistical models	Statistical algorithms predict the value of un-sampled pixels based on nearby pixel values in combination with other characteristics of the pixel.	Moderate	Moderate
Statistical models	Values of pixels are assigned based on a set of underlying variables. The relation between the value and the independent variables is developed with a regression analysis.	Moderate	Moderate
Dynamic systems (such as process-based models)	Dynamic systems modelling uses sets of differential equations to describe responses of a dynamical system to all possible inputs and initial conditions. The equations include a set of state (level) and flow (rate) variables in order to capture the state of the ecosystem, including relevant inputs, throughputs and outputs, over time. Most process-based models are examples of dynamic systems models that predict ecosystem services supply or other variables based on a mathematical representation of one or several of the processes describing the functioning of the ecosystem.	High	High
Machine learning	A type of artificial intelligence. Machine learning uses training data to build algorithms to make predictions without explicit programming.	High	Moderate

Example modelling techniques (1/2)



Source: Natural Capital Project

- Look-up table:
  - Attribute values for an ecosystem service (or other measure) to every Spatial Unit in the same class (e.g., a land cover class).
  - Example: Carbon storage
    - one ha of forest = X tonnes
      ◎ attribute to each ha of forest

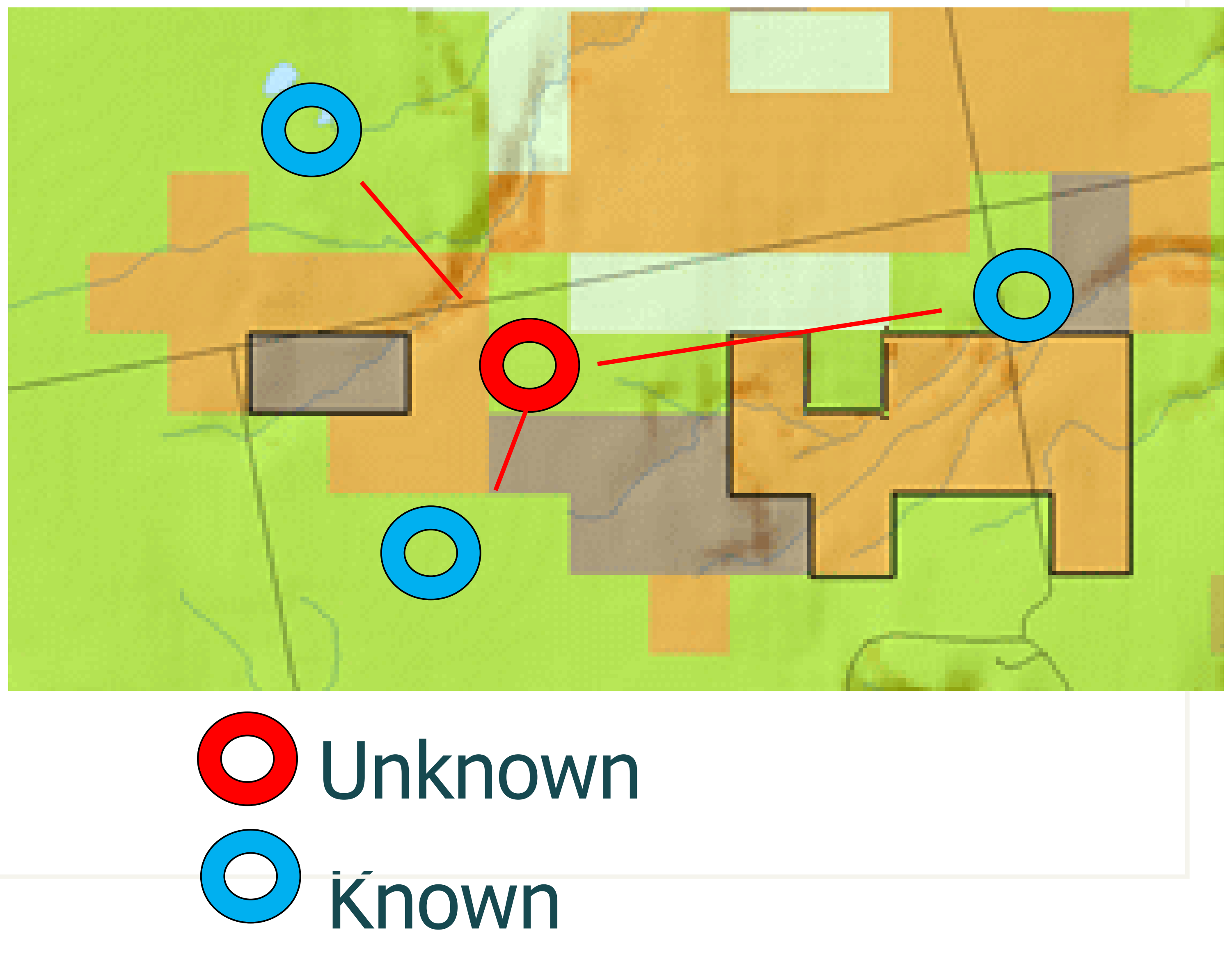
- Statistical model:
  - Estimate ecosystem services, asset or condition based on known explanatory variables such as soils, land cover, climate, distance from a road, etc., using a statistical relation.
  - Example: **Habitat quality**

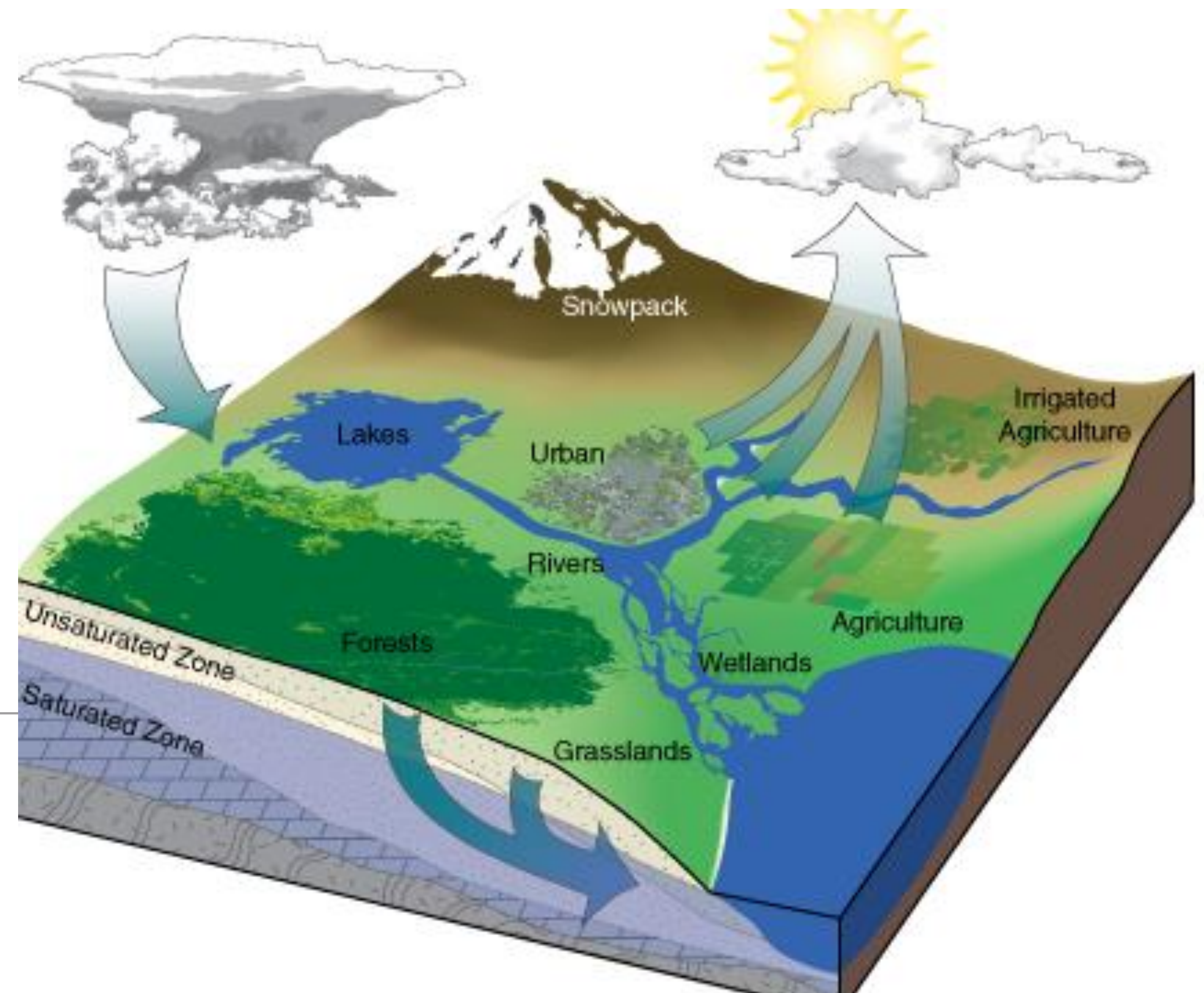
  value = f(land cover, population, distance to roads, climate,..)

Example modelling techniques (2/2)

- Geostatistical model
  - Use algorithms to predict the measure of unknown locations on the basis of measures of nearby known measures:
  - Spatial interpolation

- Dynamic systems (such as process-based models)
  - Predict ecosystem services based on modelling of processes involved in supplying the service:
  - Example:
    - Hydrological model to model water flow regulation
    - SWAT





Software and tooling

- Depending on types of accounts prioritized, available data and expertise in the country, different ecosystem extent, condition and service models may require different software.
- GIS software for displaying spatial data will likely be needed regardless
- Two most widely used GIS systems are:
  - ArcGIS: commercial product
  - QuantumGIS (also called QGIS): freeware
- Which one to select - depends upon context:
  - Which systems are already used in the government agencies supplying / processing data?
  - Budget
- Also other web-based platforms to consider such as Google Earth Engine
- Programming languages like R or phyton have several packages for spatial analysis that can facilitate efficient workflows in the production of results and reports

Overview of platforms with potential use in SEEA EA

Modelling platform	Primary goal of platform	Coverage
ARIES (Villa et al., 2014)	ARIES (Artificial Intelligence for Ecosystem Services). Provides easy access to data and models through a web-based explorer and using Artificial Intelligence to simplify model selection, promoting transparent reuse of data and models in accordance with the FAIR principles.	Extent, Condition, Ecosystem Services
Data4Nature	Data4Nature (formerly known as EnSym - Environmental Systems Modelling Platform) is a decision support tool that is designed to answer questions about where organizations should invest in their natural resources. Data4Nature is specifically designed with SEEA EA in mind.	Extent, Ecosystem Services
ESTIMAP (Zulian et al., 2018)	ESTIMAP (Ecosystem Services Mapping tool) is a collection of models for mapping ecosystem services in a multi scale perspective (it can be applied at different scales) (Zulian et. al 2018).	Ecosystem Services
InVEST (Sharp et al., 2018)	A compilation of open-source models for mapping and valuing ecosystem services. InVEST is the flagship tool of the Natural Capital Project and has been the most widely used ecosystem service modelling tool globally.	Ecosystem Services, Condition
i-Tree	i-Tree is a tool developed by the USDA Forest Service with capabilities of modelling ecosystem services related to trees, particularly in urban settings (i.e. air filtration, carbon storage urban heat island mitigation, and rainfall interception and infiltration).	Ecosystem Services (forest related)
Nature Braid (Jackson et al., 2013)	The Nature Braid (formerly LUCI/Polyscape) provides a suite of high spatial resolution ecosystem services models designed to improve decision-making around restoration and land management. The Nature Braid is particularly well suited for mapping soil, water and chemical transport processes at high resolution.	Extent, Condition, Ecosystem Services (hydrological, soil)

Platforms: additional considerations

- There are large differences between these modelling platforms, in terms of scope/level of detail/accuracy/data needs and flexibility of the modelling approaches
- Advantages:
  - Models often rely on similar input data across services (e.g. land cover) -: efficiency
  - Easy entrance points for novice modelers, suitable for countries with fewer resources
  - Easier to compare outputs across countries.
- Limitations:
  - Some multi-service platforms require collaboration with model developers.
  - In some cases models may be overly simplified to ensure applicability under a wide range of conditions which are not necessarily present in the ecosystem accounting area.
  - Using models created and maintained by outside organizations creates a risk that these models may evolve or no longer be available in the future.
    - Many of these modelling platforms have been around a decade or more suggesting they have some staying power
    - Also. many platforms are open source (e.g. ARIES, InVEST, and the Nature Braid), which may alleviate some of these issues.

ARIES for SEEA Explorer

- ARrtificial Intelligence for Environment and Sustainability
- Application on Aries platform (by Basque Centre for Climate Change):
  - Uses global data and models to generate a basic set of ecosystem accounts
  - Enables compilation anywhere on earth (country; watershed;)
  - AI -> machine reasoning to construct “best available model”
  - Aries has around 150 global data sets, many of them based on EO (e.g. land-cover; elevation; precipitation)
  - Improvement with national data where available
  - Transparent (metadata + download)

https://seea.un.org/content/aries-for-seea

BASQUE CENTRE FOR CLIMATE CHANGE
Klima Aldaketa Ikergai
Sustainability, that's it!
EXCELENCIA MARÍA DE MAEZTU

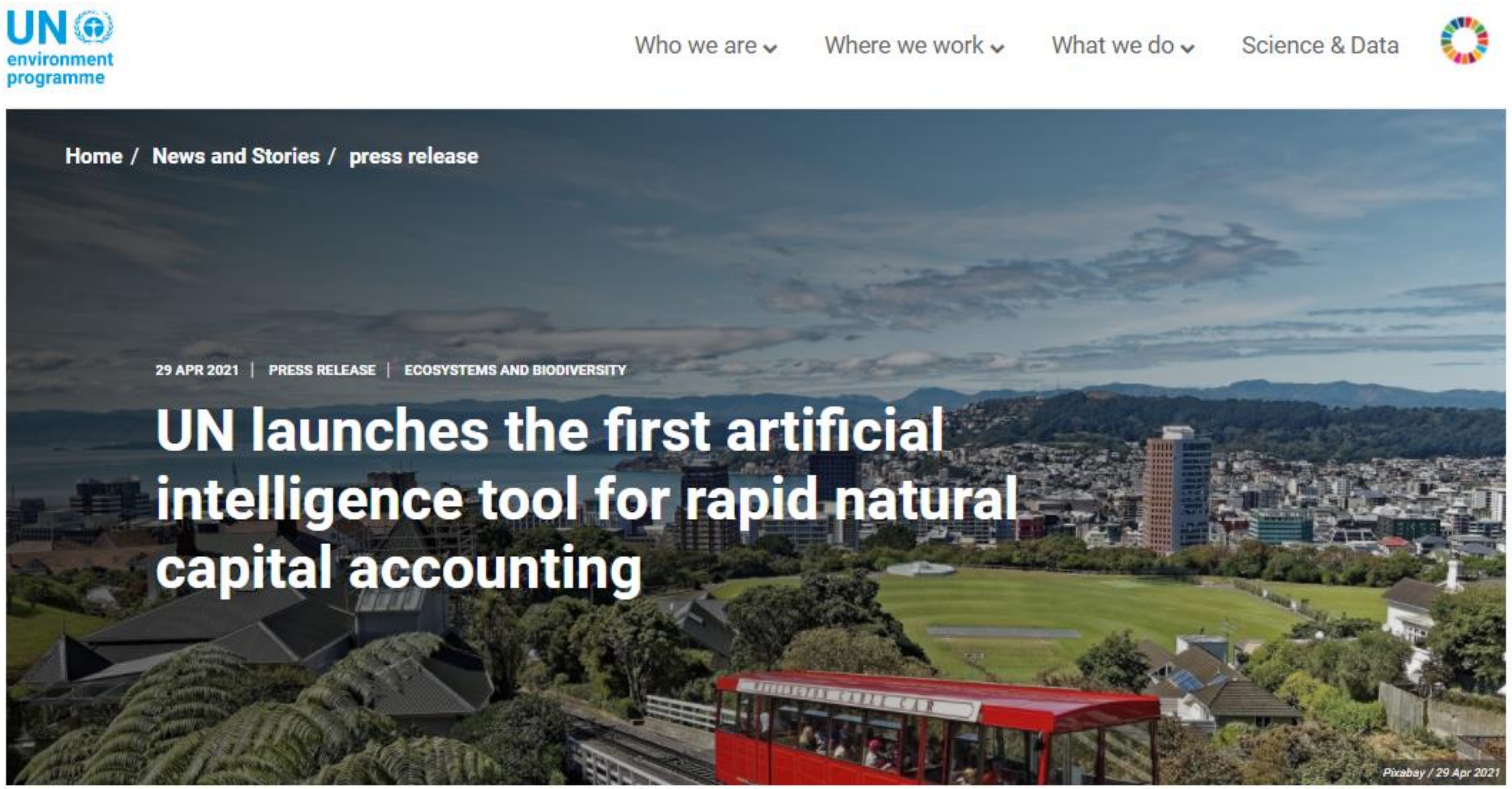


Table 1. Occurring ecosystem types (selected level 3 Ecosystem Functional Groups of the IUCN Global Ecosystem Typology 2.0)

	Intertidal forest shrubland	Coastal saltmarsh reedbed	Cropland	Urban industrial ecosystem	Temperate
Extent at start of 2012 (km²)	158.25	366.39	16017.82	650.13	390.60
Extent at start of 2014 (km²)	158.25	360.81	15978.72	692.57	403.63
Net change	0.00	-5.59	-39.10	42.45	13.03

Table 2. Occurring ecosystem types (selected level 3 Ecosystem Functional Groups of the IUCN Global Ecosystem Typology 2.0)

			Intertidal forest shrubland	Coastal saltmarsh reedbed	Cropland	Urbai
Opening extent (at start of 2012)			158.25	366.39	16017.82	650.1
	Additions to extent					
		Expansions	0.00	0.00	32.39	42.45
	Reductions in extent					
		Regressions	0.00	5.59	71.49	0.00
Net change in extent			0.00	-5.59	-39.10	42.45
Closing extent (at start of 2014)			158.25	360.81	15978.72	692.5

k.LAB Contextualization report

Computed at Mon Jun 22 18:29:14 CEST 2020

1 Introduction

1.1 Ecosystem Extent

The Ecosystem Extent Account is the first SEEA-EEA account. It defines the spatial extent of each ecosystem type, showing how ecosysteSEEAms change over time. Ecosystem types are used in all other accounts, so are fundamental to SEEA-EEA.

Ecosystems are defined as units whose functioning is governed by resources, ambient environmental conditions, disturbance regimes, biotic interactions, and human activity. Ecosystems in this context should not be confused with habitats (provided by ecosystems for particular species).

A complete list of all the diverse ecosystem types remains a work in progress; IUCN's Global Ecosystem Typology is the current standard proposed for ecosystem accounting Reference 1. IUCN's ecosystem typology improves on past ecosystem extent data, which for many past SEEA-EEA applications relied exclusively on land cover data Reference 2.

A full ecosystem extent account includes changes (additions and reductions), as well as net change between opening and closing values among subcomponents of the same ecosystem type and for each accounting period. Each change can be classified into managed expansion/regression, natural expansion/regression, and reappraisals upward or downward. Each ecosystem is influenced by different abiotic and biotic conditions, which interact to produce a supply of ecosystem services in the formulation of the SEEA-EEA.

2 Methods

2.1 Ecosystem Extent

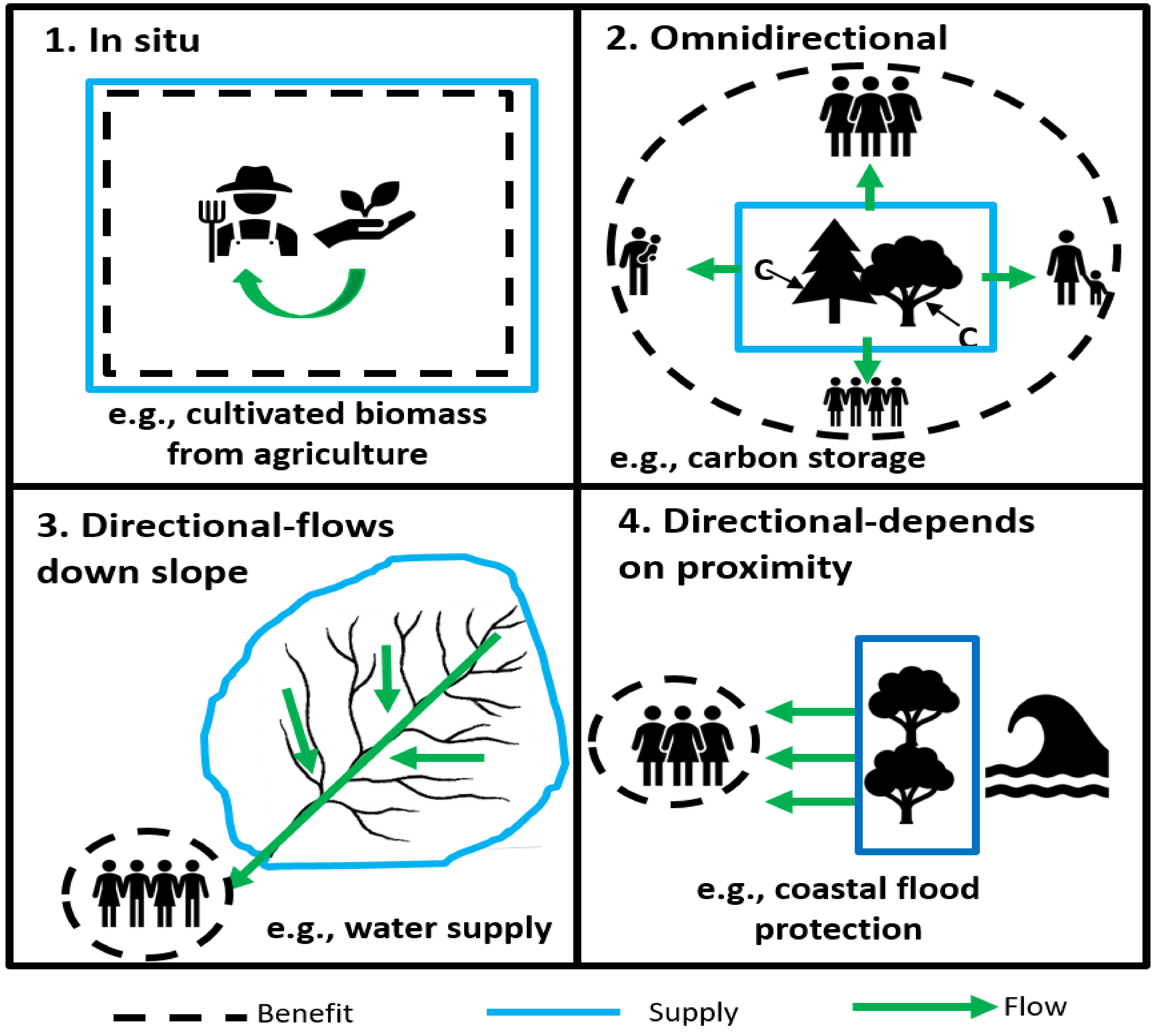
Keith et al. Reference 1 recognize 25 Level 2 ecosystems (termed biomes): four marine, three freshwater, seven terrestrial, four subterranean, and seven in transitional realms. These are further subdivided into 100 Level 3 Ecosystem Functional Groups. However, information is currently lacking on how to map these Level 3 ecosystems using global data. At the biome level, we similarly lack reliable data to distinguish between biome types for all but terrestrial biomes. ARIES thus currently models seven terrestrial biomes as well as open water and wetlands. With additional global data and rules describing how to use spatial data to map the remaining biomes, we will be able to better distinguish additional biomes, as well as ecosystem functional groups.

The methods for mapping Level 2 ecosystems follow's Sayre et al.'s Reference 3 temperature and moisture domains, combined with land cover data in a lookup table. This enables the mapping of ecosystem change over time using the best available data.

landcover	aridity	mean_annual_temperature	mean_july_temperature	ecosystem_type
landcover:Forest	> 0.05	>18	*	ecology.incubation:Tropica
landcover:Forest	> 0.05	0 to 18	*	ecology.incubation:Temper
landcover:Shrubland	> 0.05	>0	*	ecology.incubation:Shrubla
landcover:BareArea	> 0.05	>0	*	ecology.incubation:Shrubla
landcover:LichenMoss	> 0.05	>0	*	ecology.incubation:Shrubla
landcover:SparseVegetation	> 0.05	>0	*	ecology.incubation:Shrubla
landcover:Grassland	> 0.05	>0	*	ecology.incubation:Savann

Modelling Ecosystem Services

- ES: both a supplier and user
  - > The supply may occur in different location (service providing areas) from benefits (service benefiting areas).
- Different ecosystem services may hold certain spatial characteristics and may also follow certain flow paths
  - > In situ
  - > Omnidirectional ecosystem
  - > Directional: downstream / downslope
  - > Directional: spatial proximity.



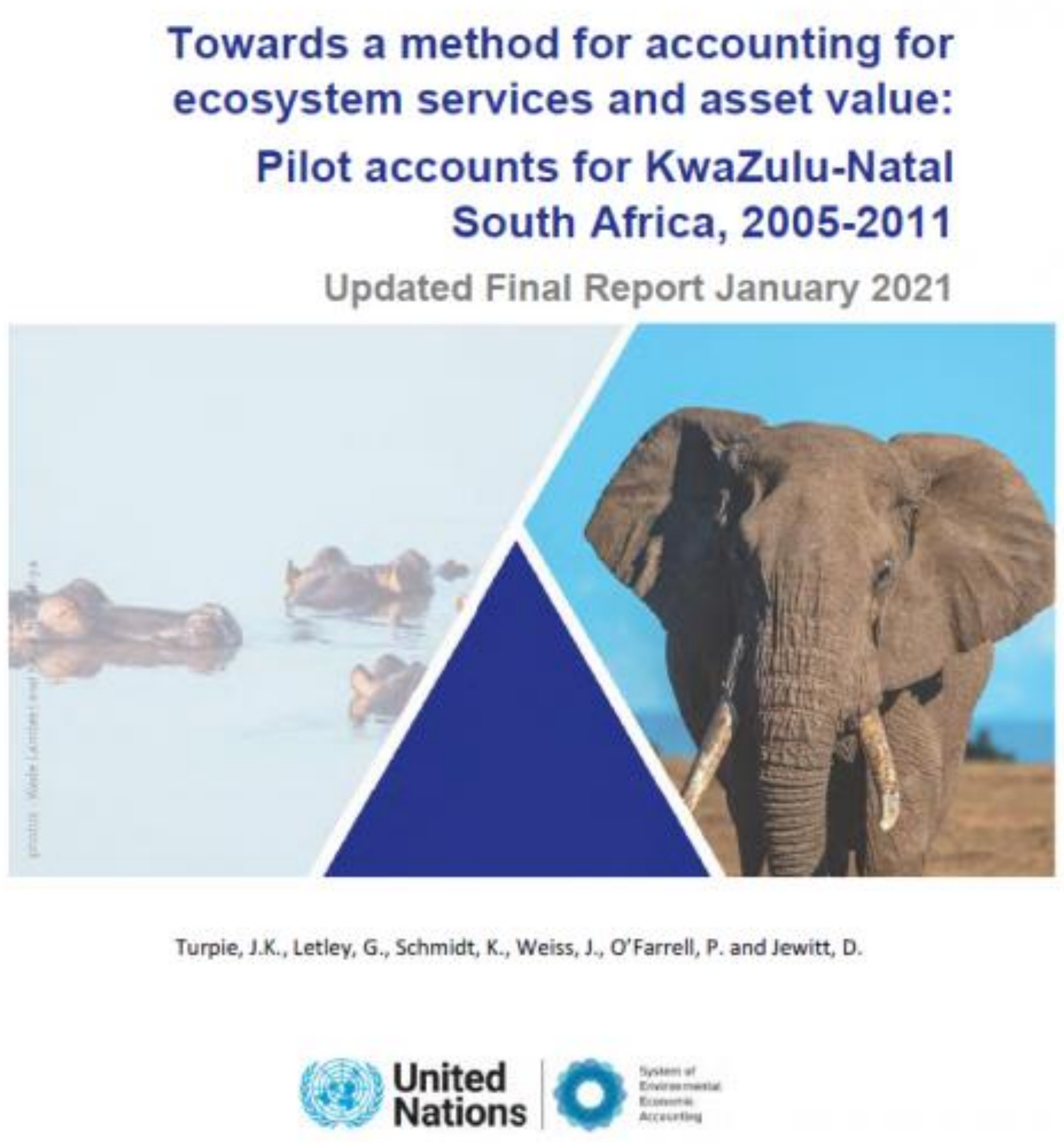
A framework highlighting the spatial characteristics of ecosystem services. Figure adapted from Fisher et al. (2009

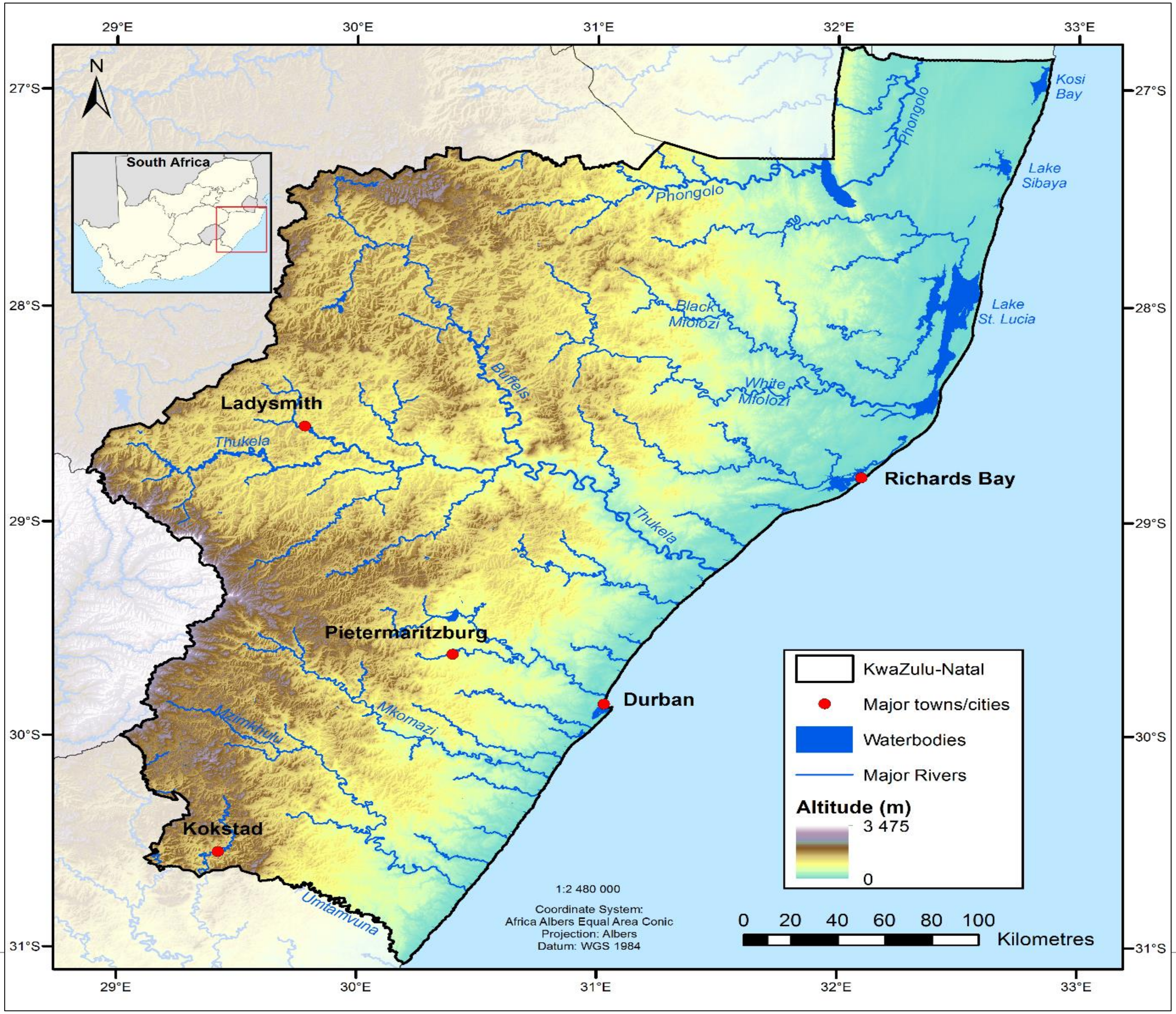
Coverage by selected modeling platforms

			ARIES	InVEST	LUCI	ESTIMAP	Data4Nature	iTree
Provisioning services								
	Biomass pr	Crop provisioning	x	x	i		x	
		Grazed biomass provisioning					x	
		Timber provisioning	x				x	
		Non-timber forest products and other biomass provisioning	m					
		Fish and other aquatic products provisioning		x				
	Water supply		x		x		x	
	Genetic material							
Regulating and maintenance services								
	Global climate regulation services		x	x	x		x	x
	Rainfall pattern regulation services						x	
	Local (micro and meso) climate regulation services			i			x	x
	Air filtration services					x		x
	Soil erosion control services		x	x	x	x	x	
	Water purification services			x	x	x	x	
	Water flow regulation services			x	i	x	x	
	Flood mitigation services (coastal or riverine)		x	i		x	x	
	Storm mitigation services					x		x
	Noise attentuation services							
	Pollination services		x	x		x		
	Pest control services					x		
	Nursery population & habitat maintenance services					x	x	
	Soil waste remediation services							
	Other regulating and maintenance services						x	
Cultural services								
	Recreation-related services		x	x		x		

Example: South Africa (1/10)

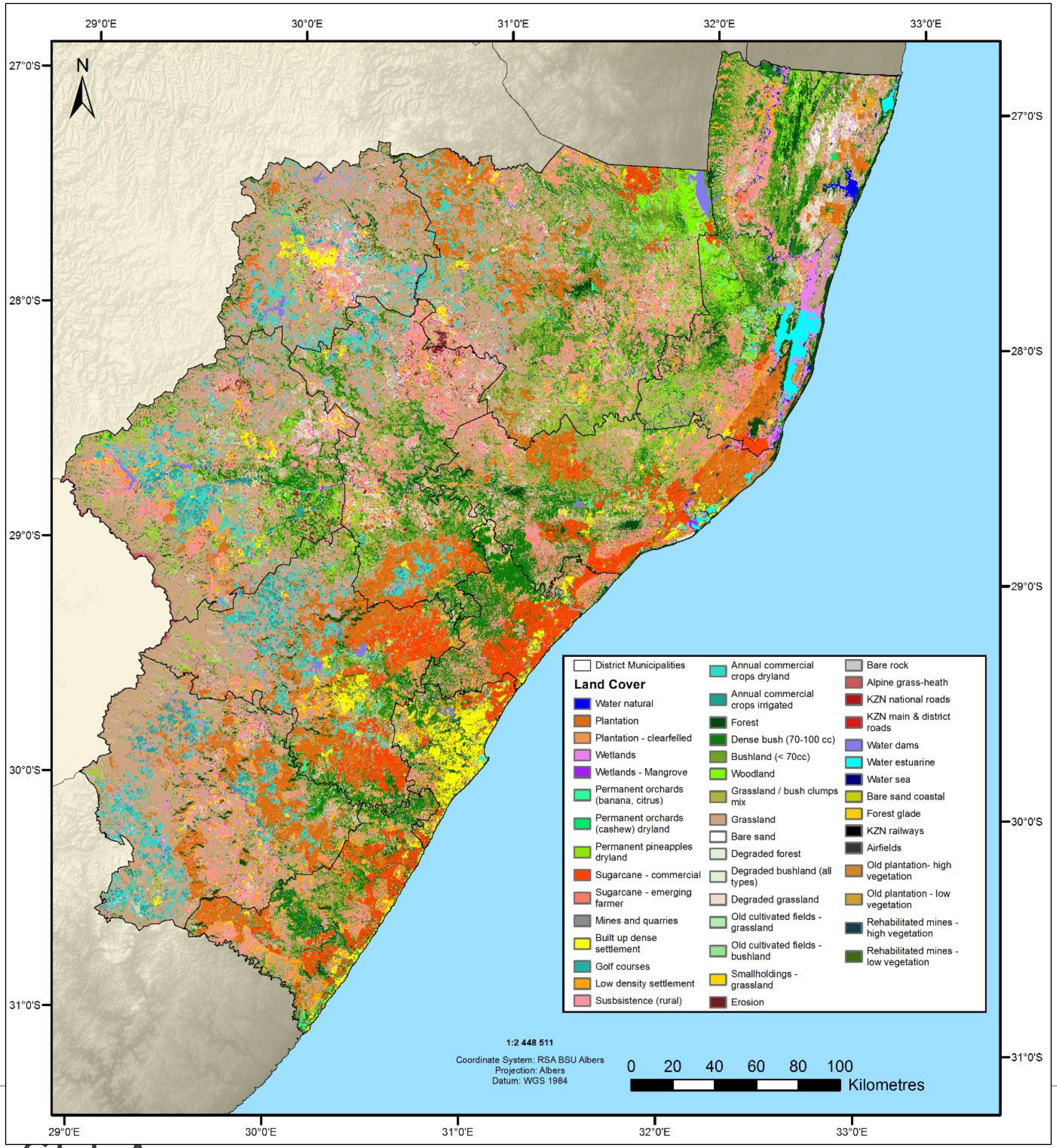
- Output of the NCAVES project
- Modelled 11 different ES for 2005 and 2011
- Kwazulu-Natal (KZN) province
- Physical + monetary

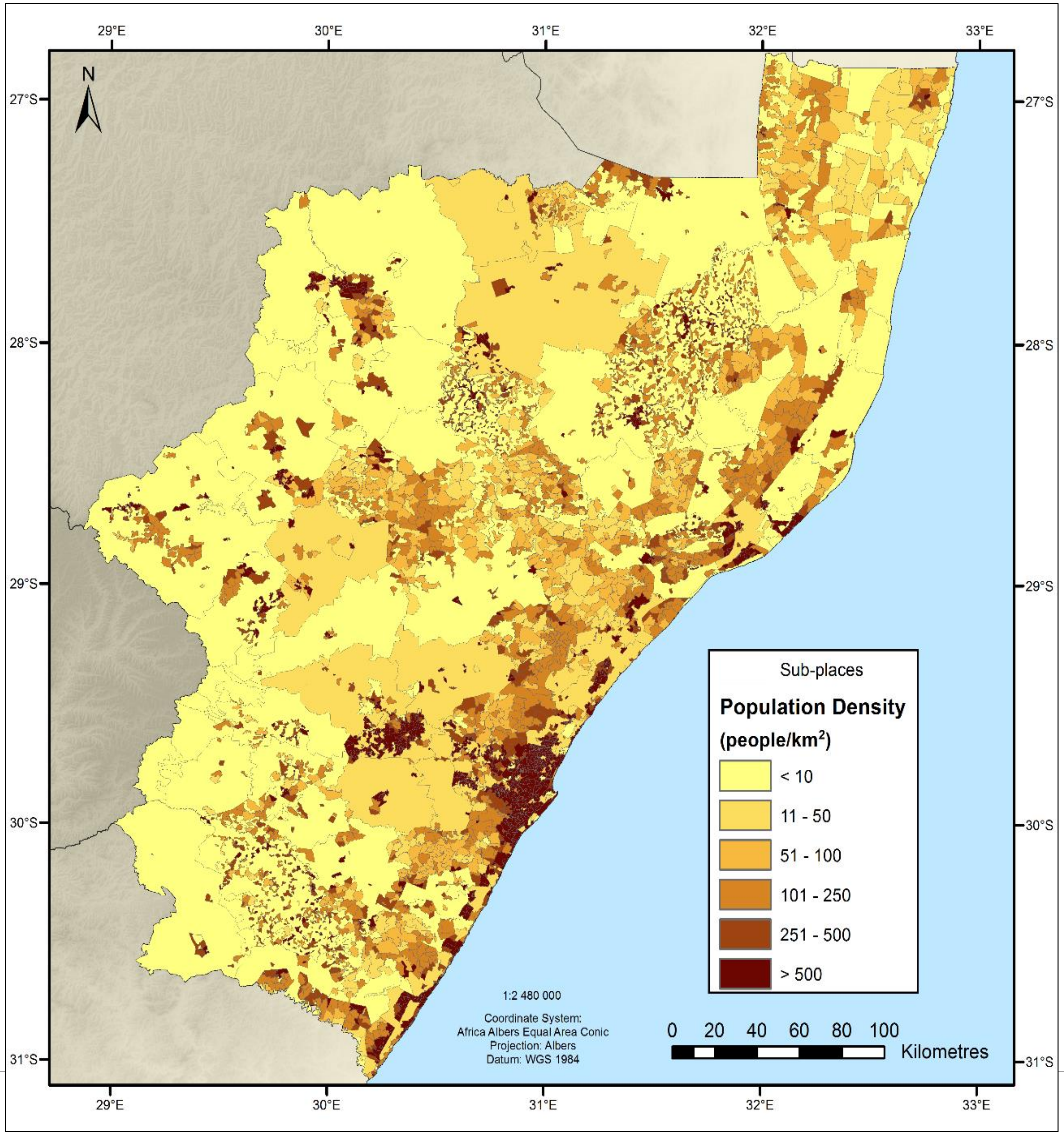




Source: Turpie et al. 2021

Example: South Africa (2/10)





Source: Turpie et al. 2021

SEEA

Example: South Africa (3/10)

ES1: Wild resources

- People in KZN use hundreds of species of plants and animals for food, medicine, energy and raw materials.
- For the purposes of this study and based on the nature of the data, the resources were grouped

	Purpose	Group
Wild plant resources	Nutrition and health	Wild plant foods and medicines
	Energy	Wood fuel
	Raw materials	Grass
		Reeds and sedges
		Palm leaves
		Poles and withies
		Timber
		Wood for carving/curios
Wild animal resources	Nutrition	Terrestrial birds and animals
		Fish and other aquatic organisms

Source: Turpie et al. 2021

- Step 1: Quantities demanded
  - Estimated at the census sub-place (~village) level based on household survey data and census data on numbers of households and types of dwelling.
  - Relevant census data: population, number of households, average household size, number of traditional dwellings, number of informal dwellings, households using wood, number of households collecting water from rivers and streams, and number of households using wood for heating and cooking.

Example South Africa (4/10)

- Step 2: Aggregate potential household demand estimated using additional information but also statistical models
  - To relate average use to household characteristics,
  - in this way, the total demand (e.g. kg/y, m3/y) for each resource was estimated for each sub-place

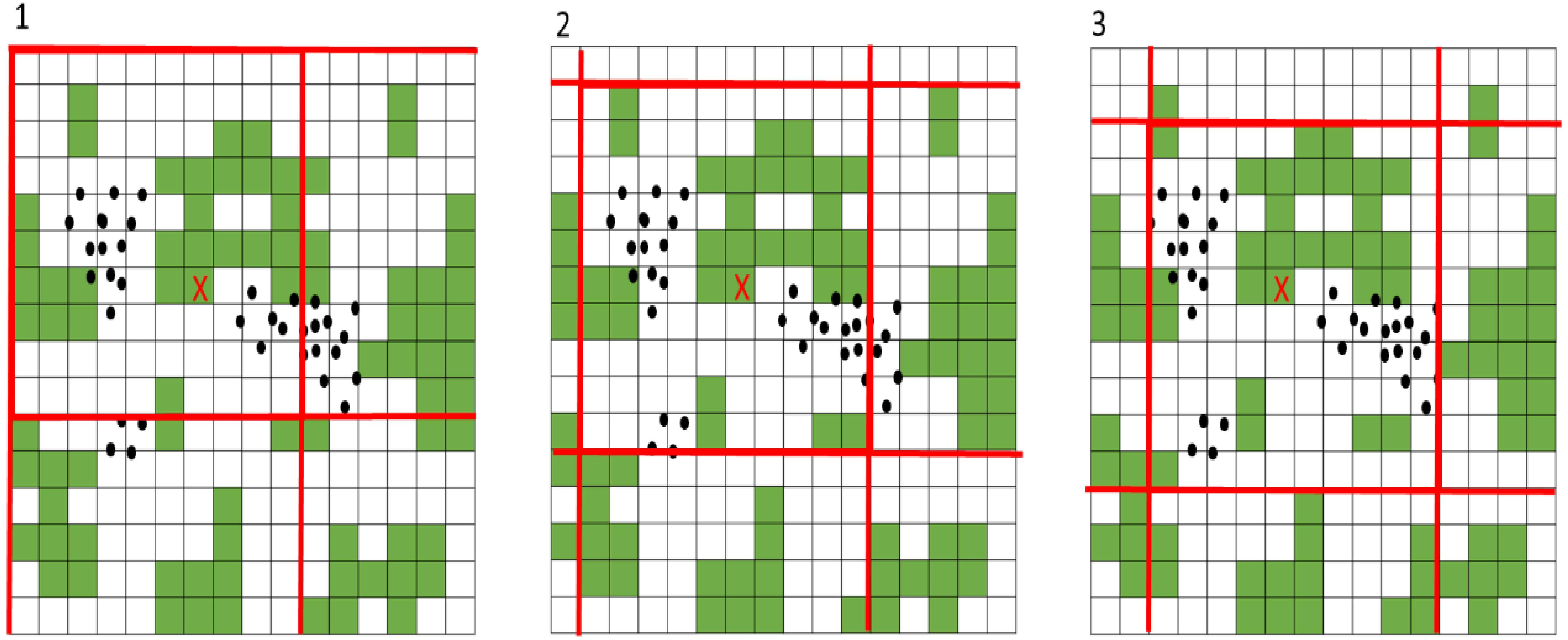
Resource group	Method/assumptions	Number of studies used	Other information
Fuelwood	hh using fuelwood; 3000 kg/hh/year	18	Converted kg/y into m^3/y using avg. wood density of 0.855 g/cm^3 (FAO)
Poles & withies	66% hh, 200 kg/hh/year	12	
Timber & wood	4% hh; 900 kg/hh/year	3	
Grass	33% hh; 76 bundles/hh/year	7	Grass bundle = 4.9 kg
Reeds & sedges	Turpie *et al.* (2010a) model	2	Reed bundle = 7 kg
Palm leaves	1.2% trad. hh; 660 leaves/hh/year	2	Each leaf provides 0.31 kg of weaving material
Wild fruits	Turpie *et al.* (2010a) model	1	
Wild vegetables	75% hh; 20 kg/hh/year	9	
Medicines	26% hh; 32 kg/hh/year	4	
Wild animals	Turpie *et al.* (2010a) model	1	
Wild birds	Turpie *et al.* (2010a) model	1	Avg. bird weight of 0.9kg
Fish	Turpie *et al.* (2010a) model	1	

Source: Turpie et al. 2021

- Step 3: Estimate the supply:
  - Estimated using vegetation maps
  - All harvestable resources were considered fully available and accessible within areas under communal land tenure.
  - Availability reduced to 10% of standing stocks in protected areas and for natural land under private ownership, such as commercial rangelands or wildlife ranches.

Example South Africa (5/10)

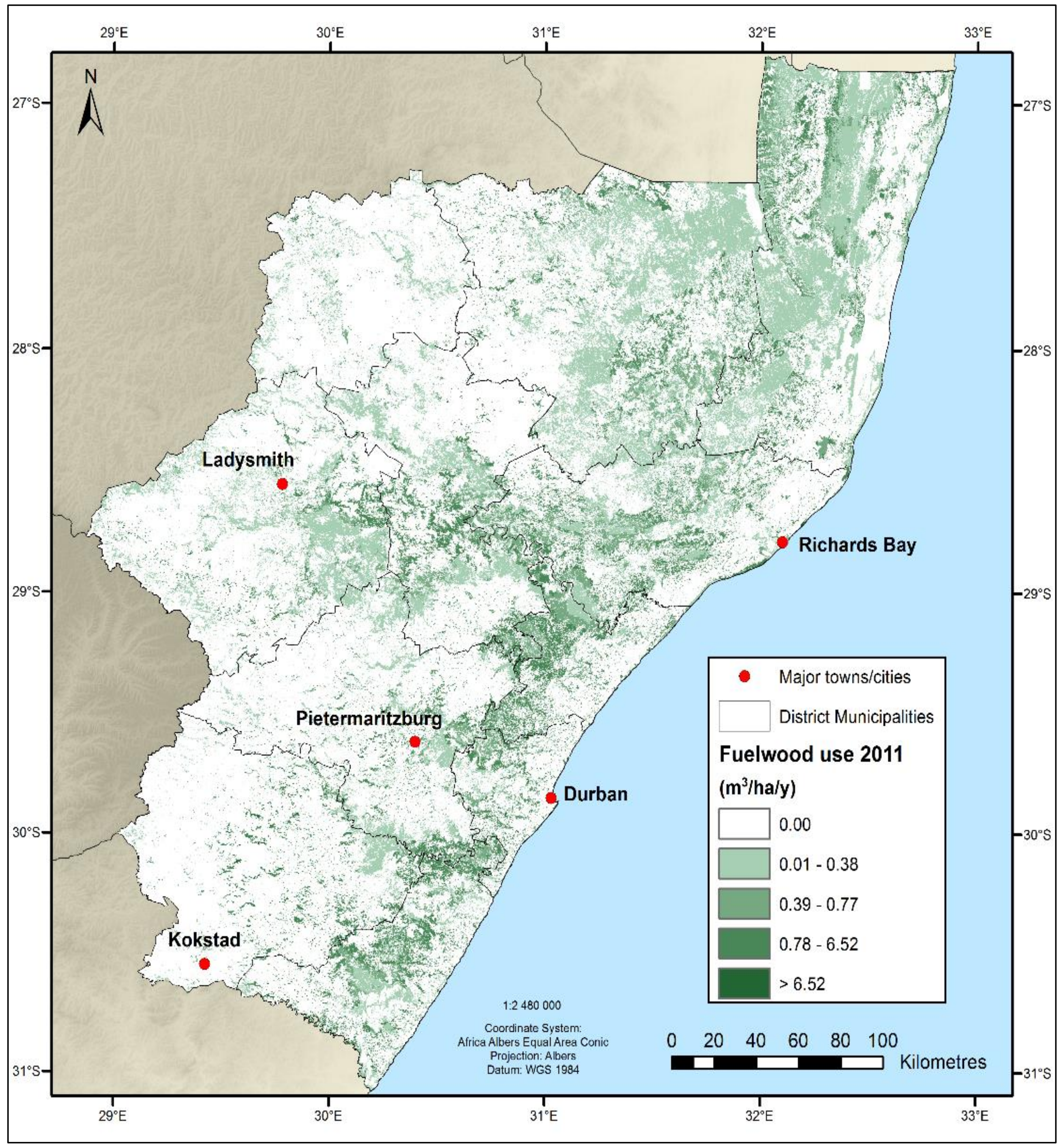
- Step 4: Model actual amount of wild resources harvested for subsistence using a geostatistical model:
  - estimated based on the minimum of the estimated demand and the estimated available stocks of resources within a specified distance of the demand source
  - an estimated average travelling distance to harvest natural resources of about 6 km
  - implemented with a "running mean" model

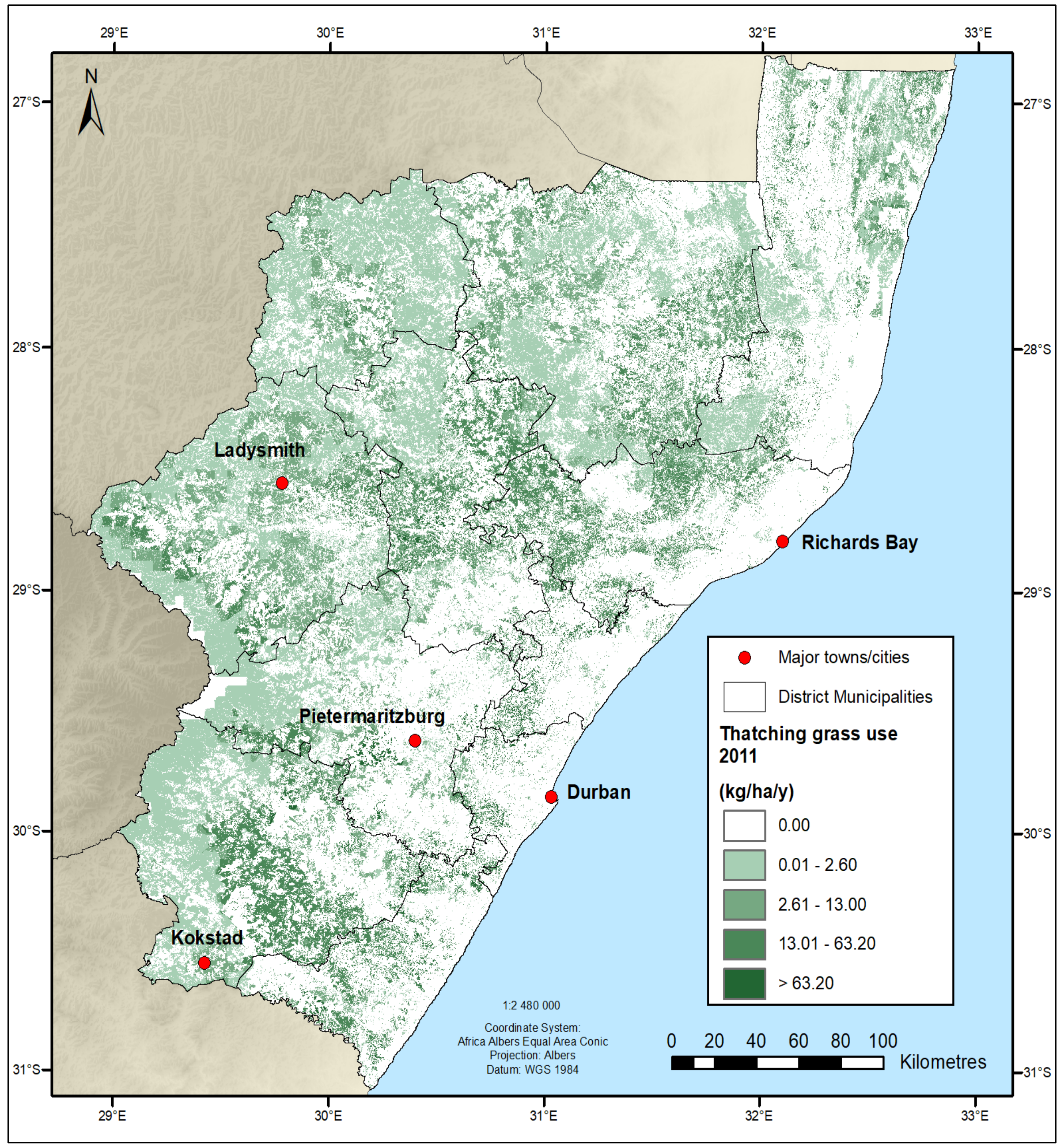


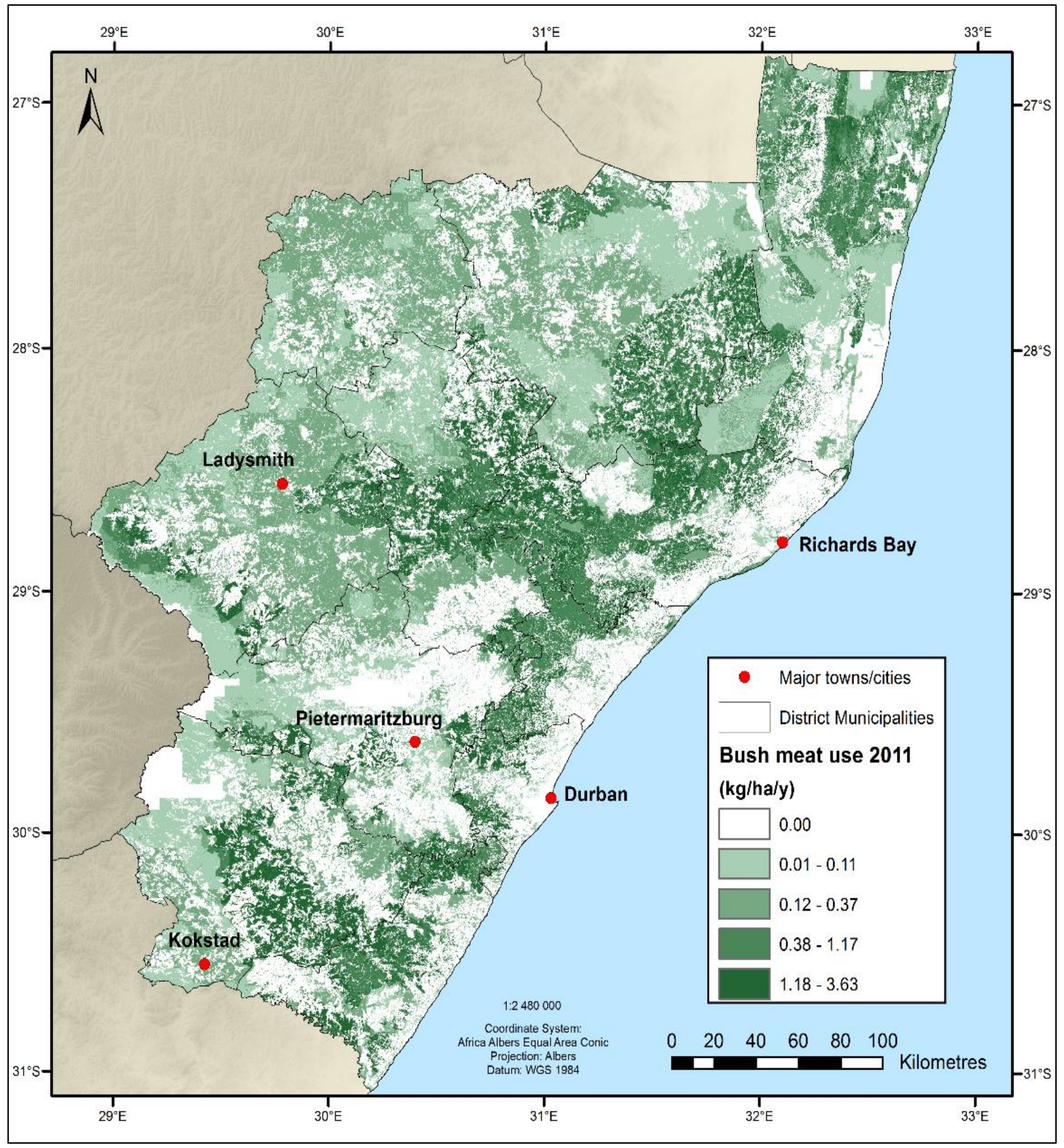
Source: Turpie et al. 2021

Running mean model used: Green areas are areas with stocks of a resource, and the dots are households demanding the resource at a certain rate.

Example South Africa (6/10)







- Results in form of maps

Source: Turpie et al. 2021

Example South Africa (7/10)

- After spatial overlay with ecosystem extent map
- Summarized as physical supply and use tables

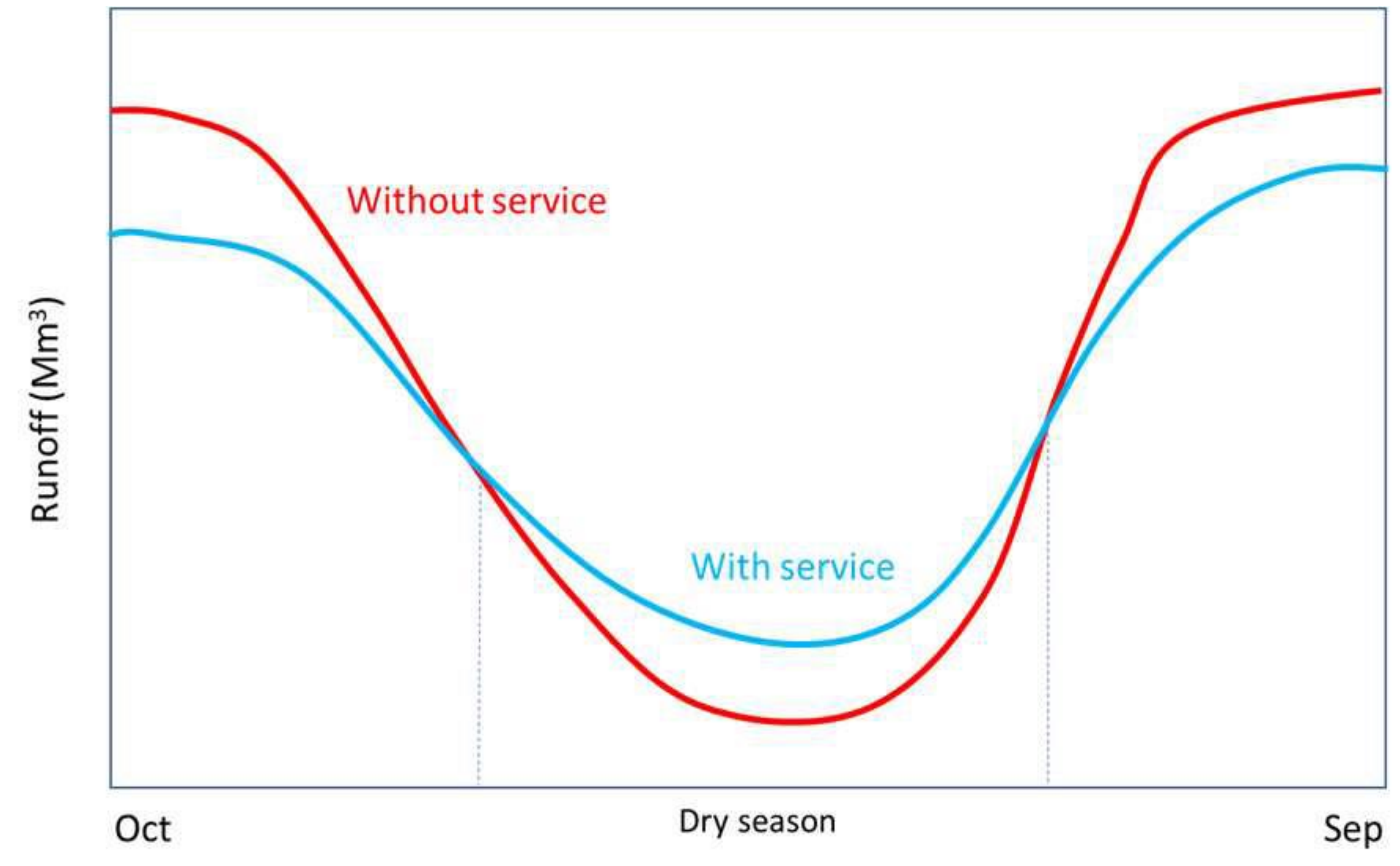
Resource / Biome	Freshwater ecosystems	Grassland	Indian Ocean Coastal Belt	Savanna	Forests	Estuaries	TOTAL
Fuelwood (m³)	3 341	663 349	223 178	755 244	247 315	158	**1 892 584**
Poles (m³)	163	29 645	10 948	28 560	11 165	8	**80 489**
Timber (m³)	20	2 643	999	3 491	8 567	3	**15 723**
Thatching grass (tonnes)	33	25 973	4 935	17 383	59	3	**48 384**
Reeds & sedges (tonnes)	752	3 801	1 508	2 371	324	22	**8 779**
Palm leaves (tonnes)	-	-	292	-	-	-	**292**
Wild foods/med (tonnes)	121	14 483	4 951	13 113	2 327	6	**35 001**
Bushmeat (tonnes)	6	1 542	338	1 934	179	0	**3 998**
Fish (tonnes)*	42	315	75	298	22	8	**759**

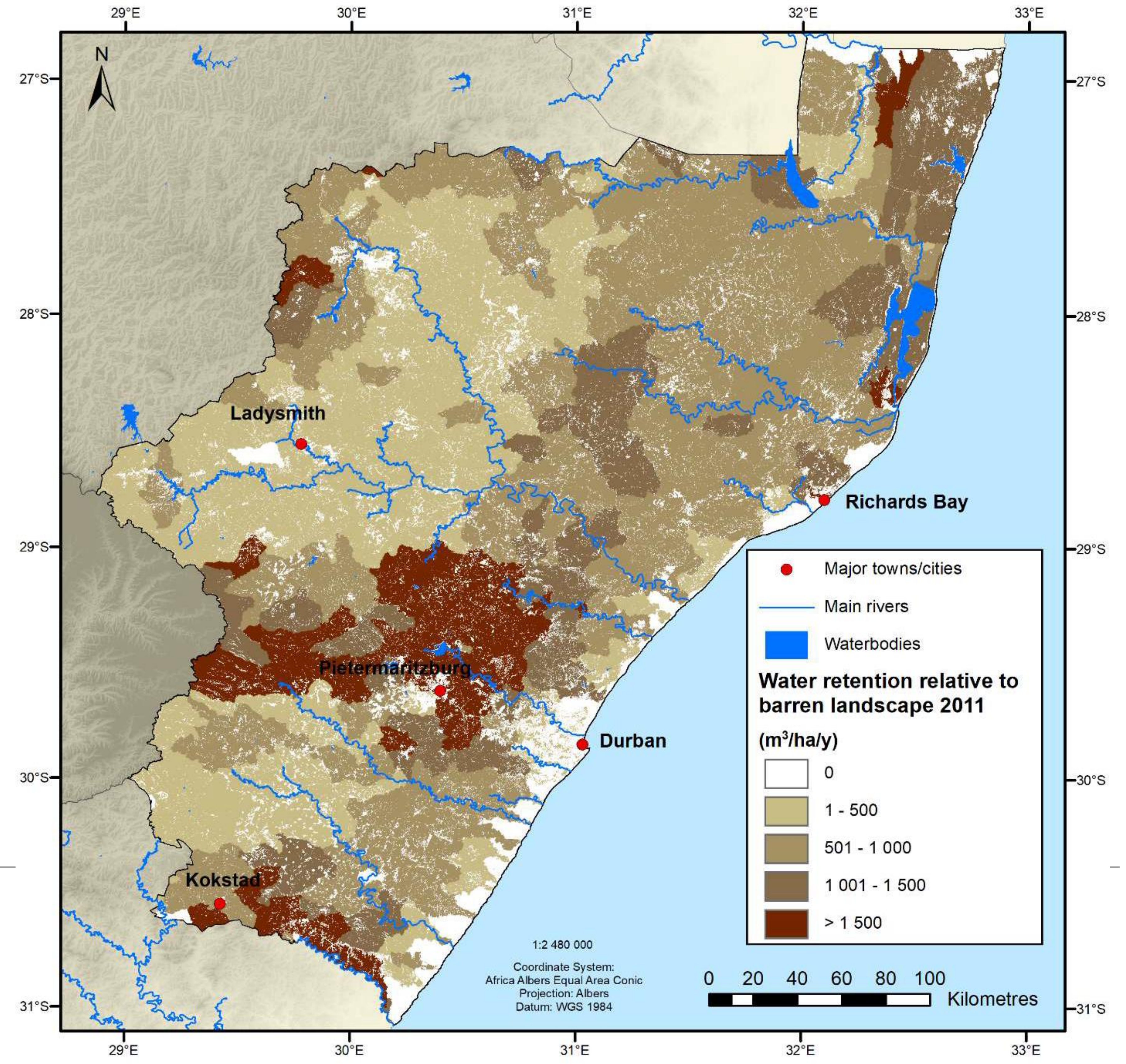
Source: Turpie et al. 2021

Example South Africa (8/10)

ES 2: Water flow regulation

- KZN – water flow regulation modelled with SWAT – process-based model
- ES measured as difference in infiltration relative to a barren scenario, in m3 per ha. This was obtained from the SWAT output "Percolation", given in mm.
- Main intuition: ecosystems function as 'sponges' mitigating peaks and ensuring higher base flows
- Modeled at sub river basin level
- Results:
  - > Maps
  - > Tables





SEEA

Source: Turpie et al. 2021

Example: South Africa (9/10)

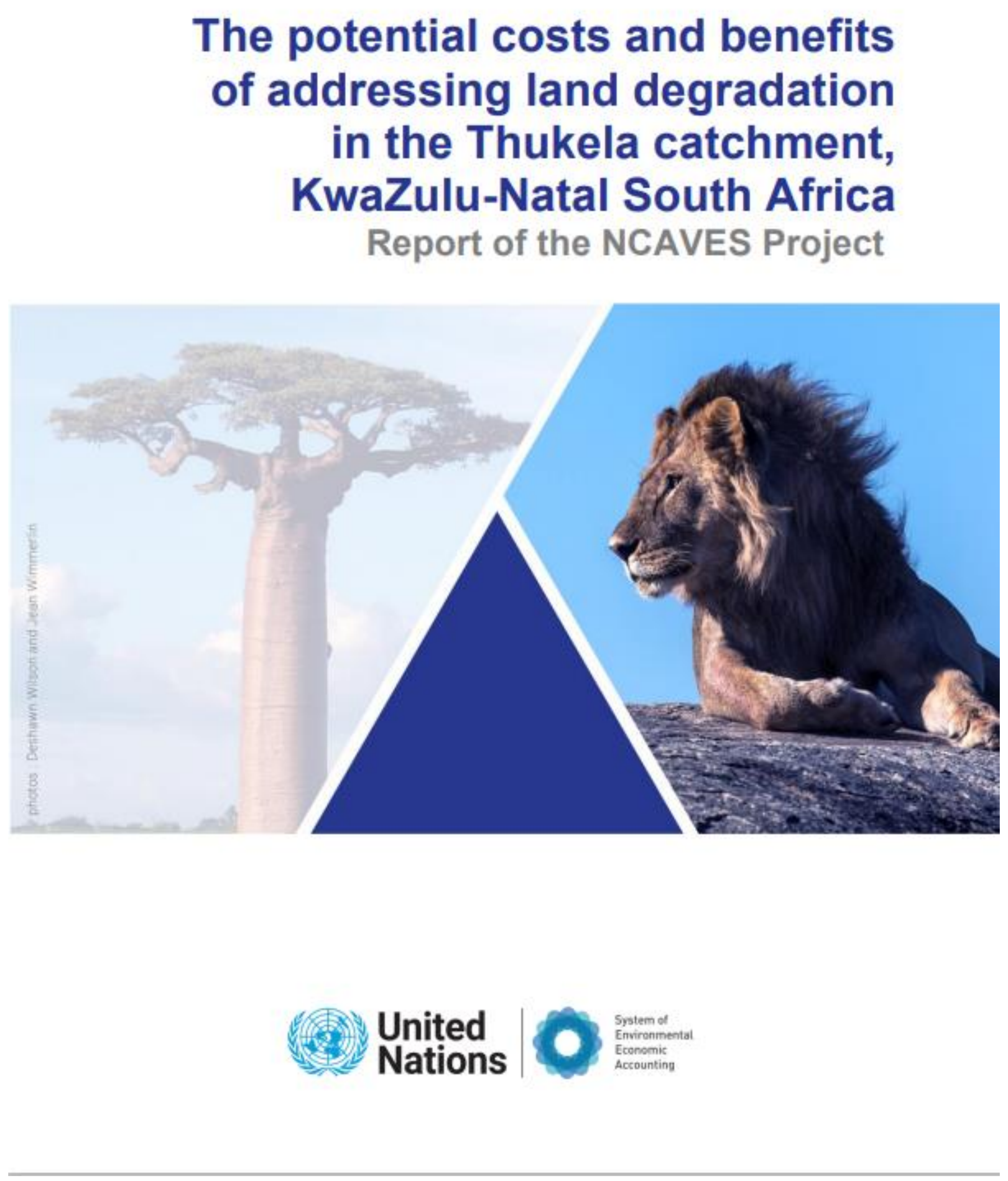
- All 11 ES modeled spatially
- After integration, physical supply and use tables (and monetary SUTs + monetary asset account

Table 5.1. Total biophysical supply per ecosystem type 2005

Resource \ Biome	Freshwater ecosystems	Grassland	Indian Ocean Coastal Belt	Savanna	Forests	Estuaries	Cultivated	Urban green space	Total
Wood products (m^3)	3 523	695 638	235 125	787 294	267 047	169			**1 988 796**
Non-wood products (tonnes)	834	46 494	11 489	34 952	2 911	38			**96 718**
Livestock production (LSU)	1 716	684 698	52 162	289 663	2 010	340			**1 030 589**
Crop production (tonnes)							43 305 781		**43 305 781**
Experiential value (R millions)	14	237	179	218	55	24	85	885	**1 698**
Carbon storage (Tg C)	5	512	61	348	33	0	279		**1 237**
Pollination (R millions)	0	12	6	31	2	0			**51**
Flow regulation (million m^3)	78	3 315	421	2 198	634	36			**6 682**
Flood attenuation (R millions)								31	**31**
Sediment retention (million tonnes)	2	45	6	27	18	2			**99**
Water quality amelioration (tonnes P)	-	3 829	525	5 394	97	6			**9 850**

Source: Turpie et al. 2021

Example South Africa (10/10)



- Policy use:
  - Accounts applied in policy scenario analysis
  - Cost-benefit analysis of addressing land degradation in the Thukela catchment
- Key outcomes:
  - Halting and reversing ecosystem degradation has positive net economic benefits
  - Preventing degradation now is more cost effective than fixing it later.
  - In summary, the benefits of restoring the Thukela basin would outweigh the costs.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It pays to save the Thukela River catchment
Sheree Bega 17 Jul 2021

Benefits: The Wagendrift Dam on the Bushmans River, a tributary of the Thukela River. Rehabilitating the Thukela River catchment in KwaZulu-Natal would reduce soil erosion, improve the grasslands and water supply, all of which

SEEA

Source: Turpie et al. 2021 b

Conclusions

- There is no 'one size fits all'; choice of approach, model, tools, will depend on country specific circumstances
- Oftentimes we need a combination of techniques, models (platforms)
- Tiers allow for a growth model of accounts compilation
- Biophysical modelling may be instrumental, it can never replace data collection processes

THANK YOU

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