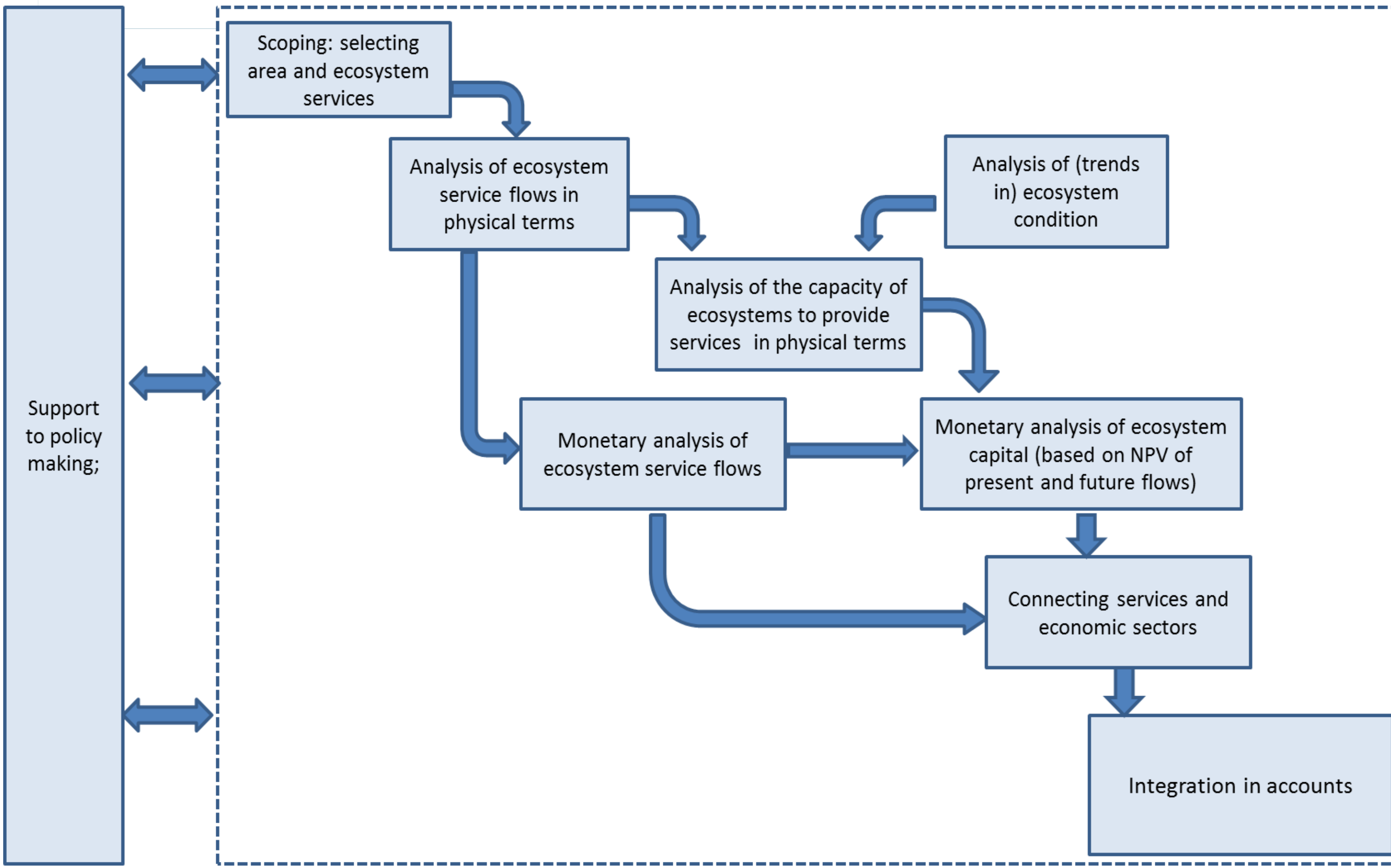
Developing the ecosystem accounts / biophysical modelling of ecosystem services

Lars Hein

Contents

- The analytical framework
- Spatial modelling – recap
- Temporal modelling – recap
- Experiences in Palawan (results thesis Verna Duque)
- From models to accounts

Analytical Framework



Including provisioning, regulating and cultural services

Spatial modelling

Spatial modelling involves combining spatial datasets (maps, remote sensing images), point data and statistical data for administrative units to estimate ecosystem services flow and capacity. It can be used:

- For calculating flow and capacity of specific data points
  - Look-up tables
  - Geostatistical interpolation (e.g. kriging)
  - Statistical approaches
  - Process based modelling (e.g. USLE)
- For modelling spatial aspects of ecosystem services (in particular regulation services except carbon sequestration)
  - E.g. hydrological services, air filtration

Mapping approaches

Mapping Approach	Basic characteristic	Mapping techniques applied
Dedicated ecosystem services mapping tool such as InVEST;	Predefined modules for mapping ecosystem services	Mostly based on Look-up Tables, predefined techniques for specific services.
Modeling framework such as ARIES	Enables designing specific algorithms for individual ecosystem services in a dedicated GIS environment, using predefined modules where appropriate	Flexible, different mapping techniques are supported in ARIES.
Using ArcGIS or a freeware GIS programs.	All services need to be modelled individually	Flexible, all mapping techniques can be used.

Mapping techniques

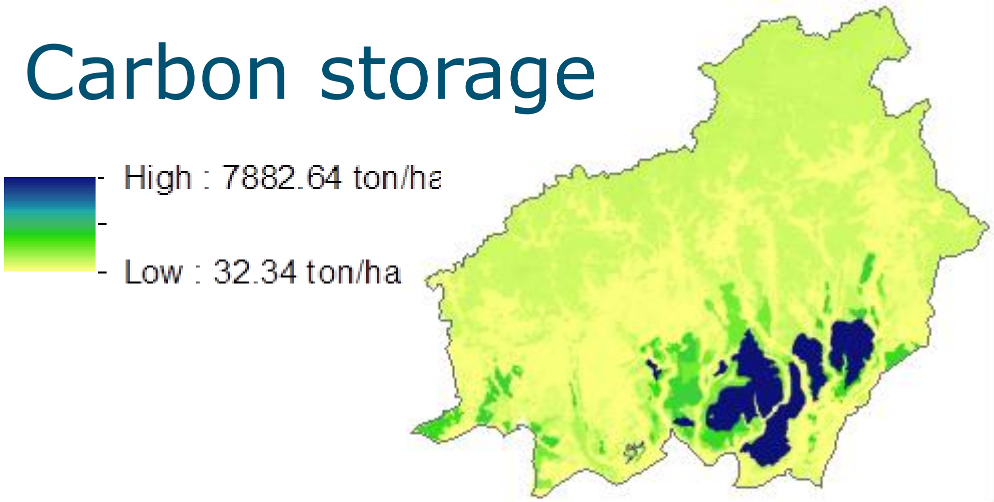
- **Look-up tables**. A specific value for an ecosystem service or other variable is attributed to every pixel in a certain class,
- **Geostatistical interpolation**. Use of statistical algorithms to predict the value of un-sampled pixels on the basis of nearby pixels in combination with other characteristics of the pixel. (e.g. kriging).
- **Statistical approaches**. For instance Maxent analyses the likelihood of occurrence of a species (or other services) as a function of predictor variables, based on an analysis of the occurrence of that species in those data points where the species occurrence has been recorded.
- **Process based modeling**. This method involves predicting ecosystem services flows or other variables based on a set of environmental properties, management variables and/or other spatial data sources.

Ecosystem services

- Spatial models are needed to
  - Map ecosystem condition
  - Map ecosystem services flows (depend on the supply - by the ecosystem, and the demand - from society)
  - Map ecosystem capacity (assets)

Ecosystem services Central Kalimantan

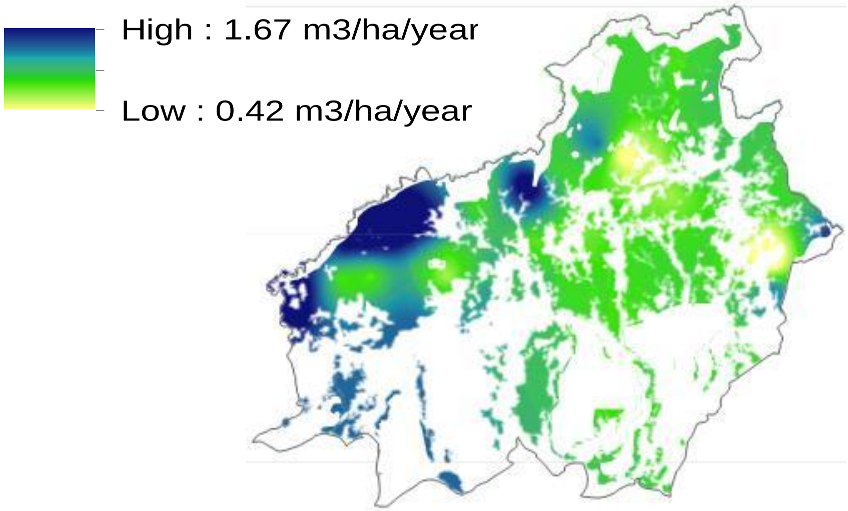
Carbon storage



Modelled using

Look Up Tables

Timber production

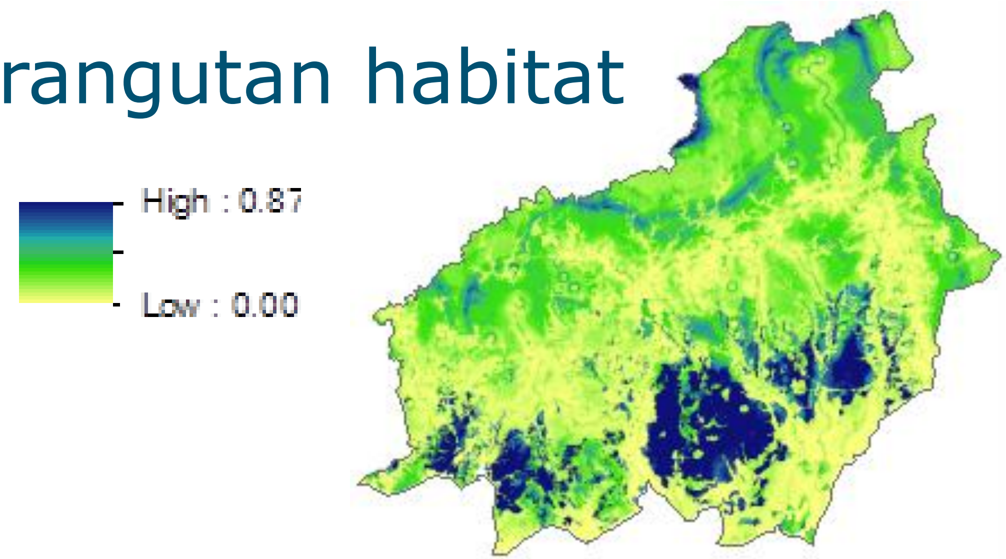


Kriging

Source: Sumarga and Hein, submitted

Ecosystem services in Central Kalimantan

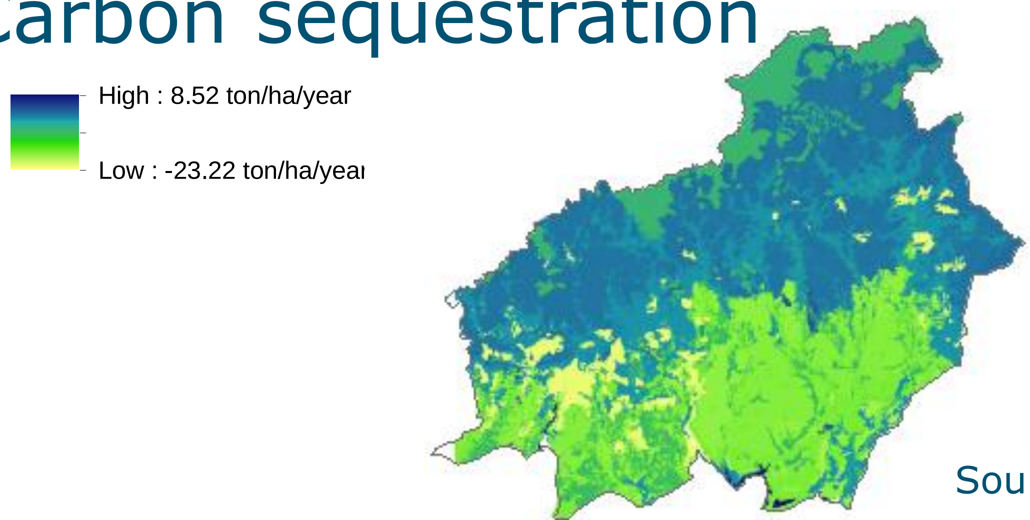
Orangutan habitat



Modelled using

Statistical models (Maxent)

Carbon sequestration



Look up tables (or: NPP minus soil respiration)

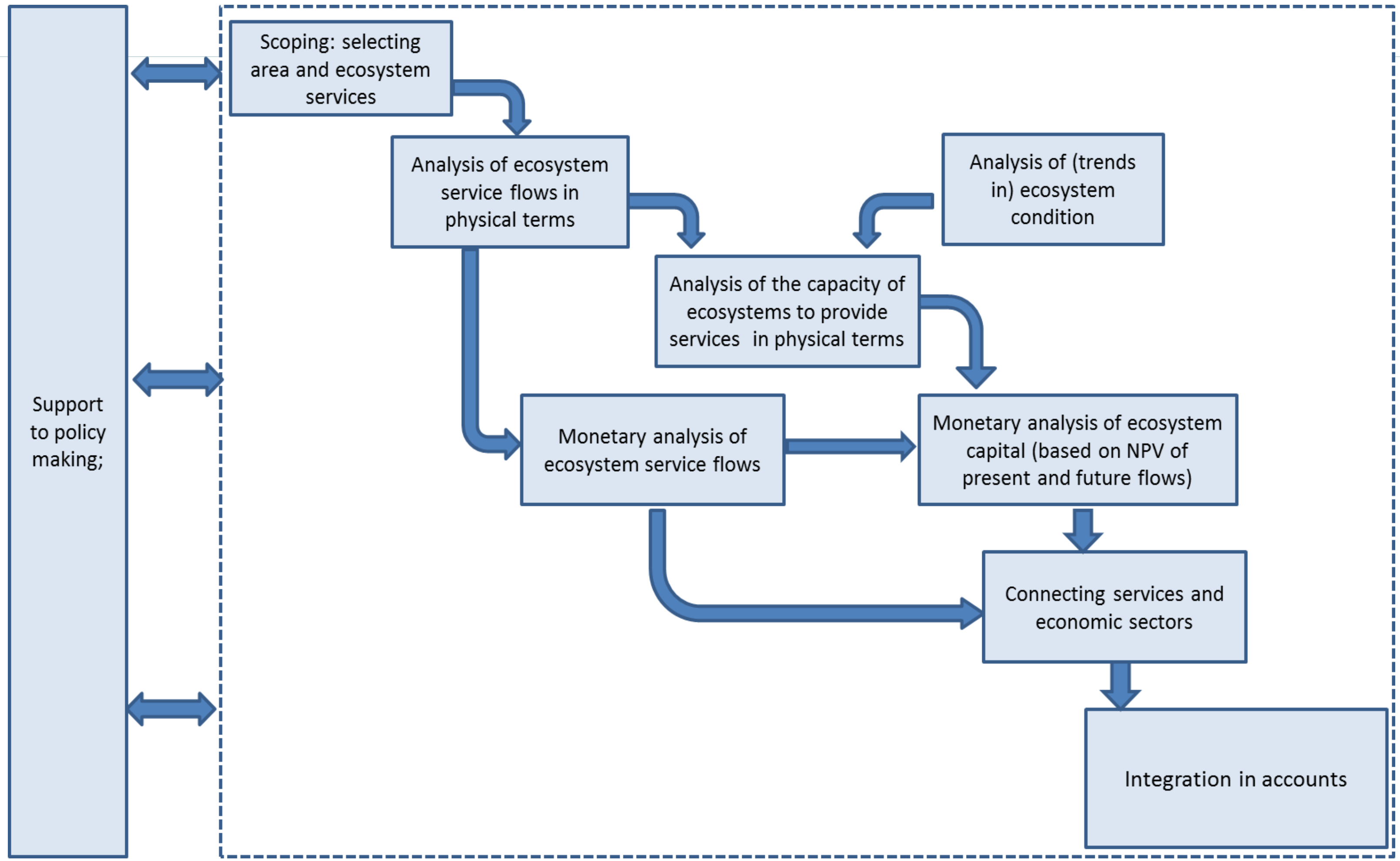
Source: Sumarga and Hein, submitted

Sometimes possible to apply different techniques: e.g. carbon sequestration

Method	total seq in t C (forest)	seq tC/ha
1Forest inventory data and maps	546 578	0.63
2. MODIS NPP minus soil respiration model after Raich et al. (2002)	1 070 123	1.28
3. NEP: MODIS GPP minus TER after Luyssaert et al. (2007)	911 651	1.04

Source: Schröter et al., 2014)

Dynamic (temporal) Modelling is required for analysing changes in ecosystem capacity



Recording ecosystem services and assets in an account

Example of timber production

- Timber:
  - Opening stock (1 January): 1000
  - Natural additions: 100
  - Harvest: 50
  - Closing stock (1 December): 1050

The model underlying the account analyses : natural additions, as a function of capacity and, in turn, condition

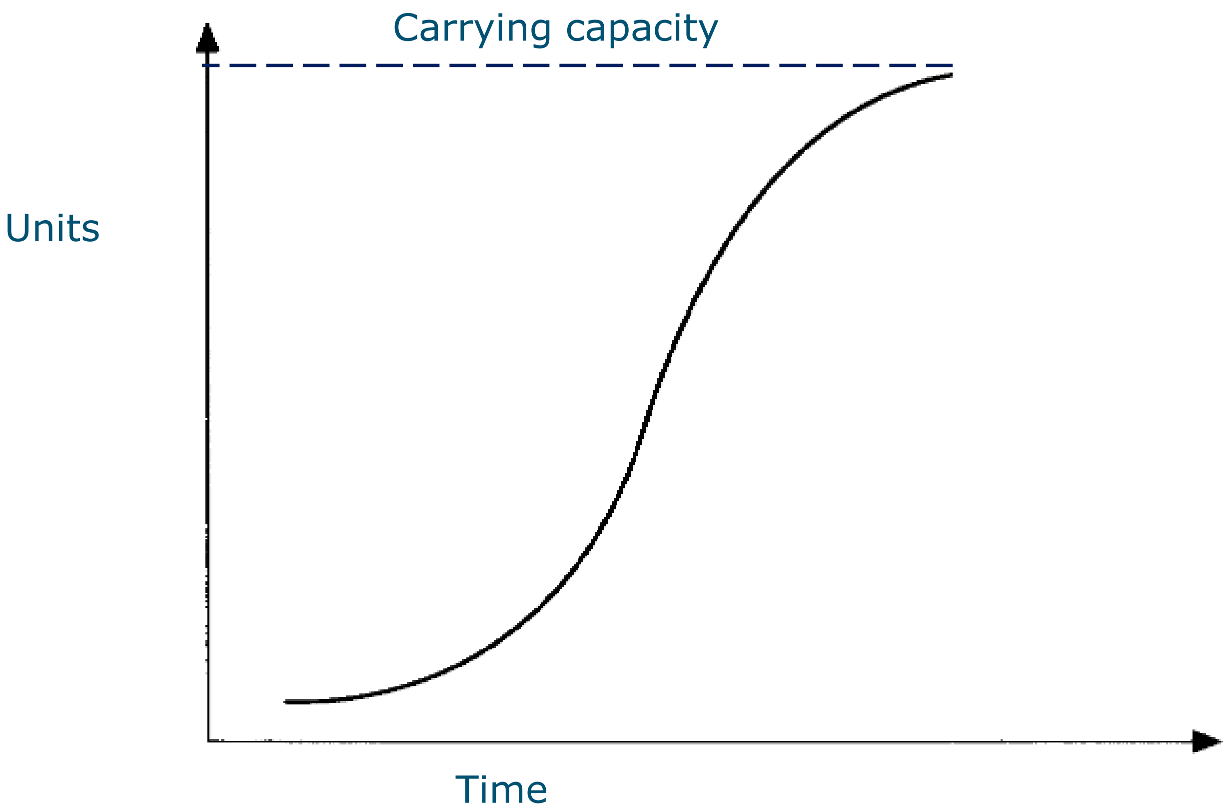
What is the benefit and what is the ecosystem service ?

Basic methodologies - provisioning services

- Flows of provisioning services:
  - Data: Recording outputs of the ecosystem: production statistics, surveys, production models.
  - Mapping: Interpolation (spatial tools), allocation (allocation models)
  - Cross validation

- Analysis of capacity to generate provisioning services
  - Analyse current stock of the service involved (e.g. standing stock of timber)
  - Analyse regrowth (varies as a function of stock, carrying capacity and management; assumption: under current management)

Simplified growth curve biological resource



$$\frac{dP}{dt} = rP\left(1 - \frac{P}{K}\right)$$

Logistic growth curve

- The capacity to generate a provisioning service can be estimated for a given year, and may vary over time as a function of management and ecological processes

Analysing capacity, an example

Moose populations per municipality estimated with a basic population model (Austrheim et al. 2011)

$$N_t = Q_t \left\{ \left(\frac{C_t - M}{1 - C_t} \right) - (\lambda - 1) \right\}^{-1}$$

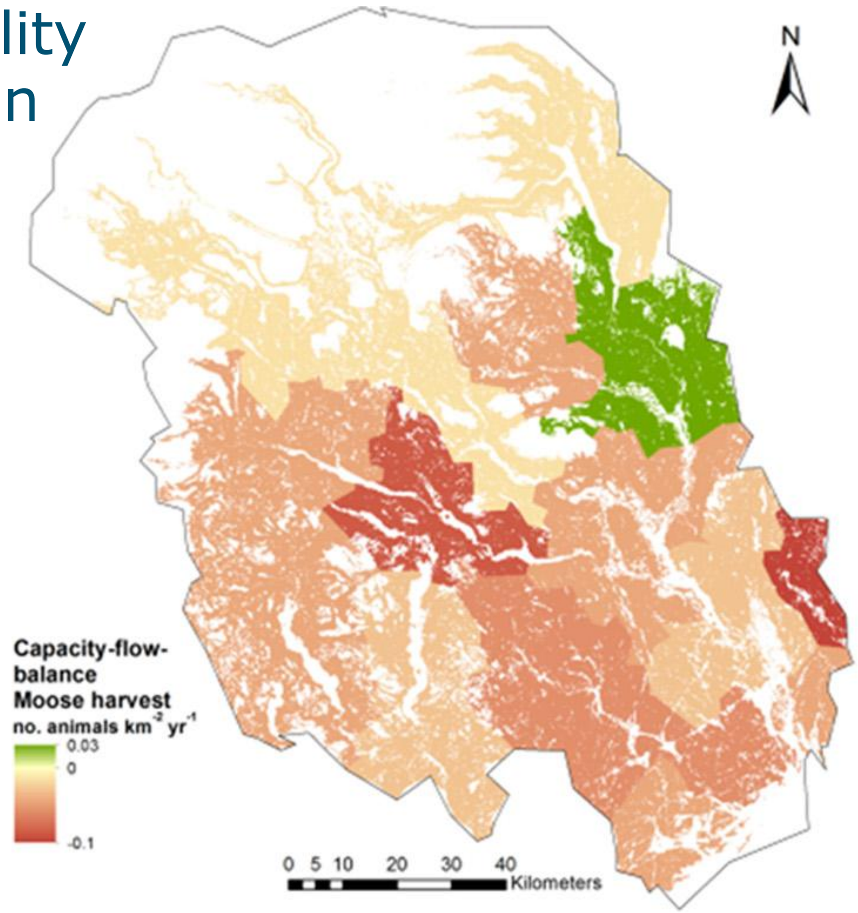
N_t = post-harvest population,

Q_t = annual harvest

C_t = pre-harvest proportion of calves in the population

M = natural mortality rate: 0.05

λ = population growth rate



Capacity–flow-balance for moose hunting in Telemark (Schröter et al., 2014)

Recording regulating services

Example of carbon sequestration

- Carbon sequestration
  - Opening stock (1 January): 10000 ton carbon
  - Natural additions (sequestration): 500 ton C
  - Emissions (e.g. LUC, degradation): 300 ton C
  - Closing stock: 10200 ton C

- What is the service ? The benefit ?
- Note: the service is the sequestration only....

Recording regulating services (2)

- Example of water storage (Laguna Lake)
  - Opening stock: 1,000,000 m3
  - Net additions: -100 m3 (input sediments)
  - Closing stock: 999,900 m3

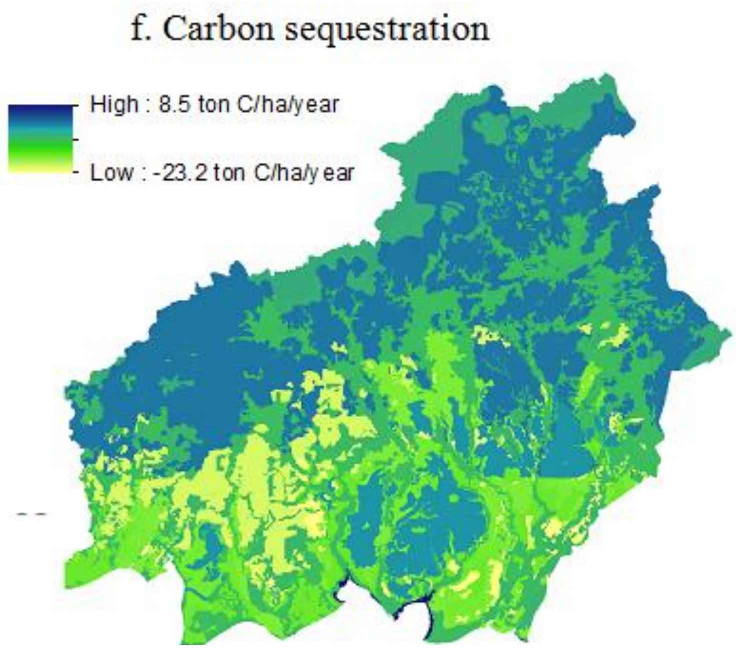
- What is the service ? The benefit ? The capacity ?

Basic methodologies - regulating services

Usually requires maps

- Carbon sequestration
  - Look-up tables / NPP models based on remote sensing / forest statistics
  - Aggregation per Land Cover Ecosystem Unit (LCEU)
  - Validation

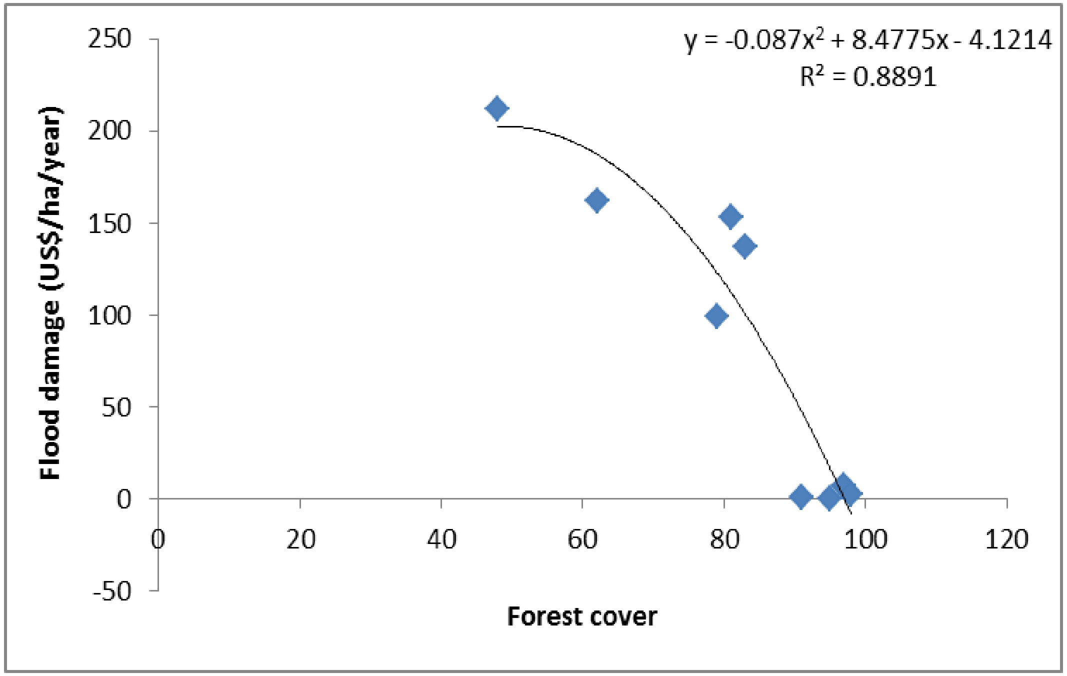
Land cover	Carbon flux; + indicates sequestration, - is emission (ton C/ha/year)	Sources
Mangrove	8.5	Komiyama (2006)
Primary dipterocarps forest (protected forest)	0.8	Hirata et al. (2008)
Primary dipterocarp forest	0.6	Hirata et al. (2008)
Secondary dipterocarp forest	4.0	Luyssaert et al. (2007); Hirata et al. (2008); Saigusa et al. (2008)



Source: Sumarga and Hein, 2014

Basic methodologies - regulating services

- Hydrological services:
  - Define service, identify indicators
  - Spatial modelling of effects of vegetation on water flows / Comparison of watersheds
  - Cross validation

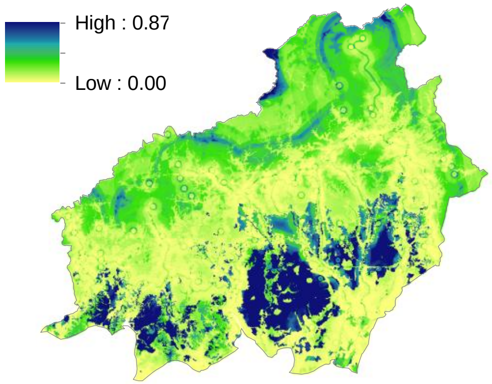


Trinidad: Relation between forest cover in catchments and flood damage costs. The value of the flood control service varies from US$ 60 to US$ 460 per ha forest/year.

Source: Brookhuis and Hein, in preparation

Basic methodologies - cultural services

- Recreation and tourism:
  - Flow: number of tourists per area per year
  - Capacity: maximum number of tourists that can be sustained and can be expected (given access to an area, facilities, etc.)
- Biodiversity (Biodiversity account)
  - Flow: presence of species (# red list, functional species, species in groups, species abundance)
  - Capacity: potential presence (may be higher or lower)

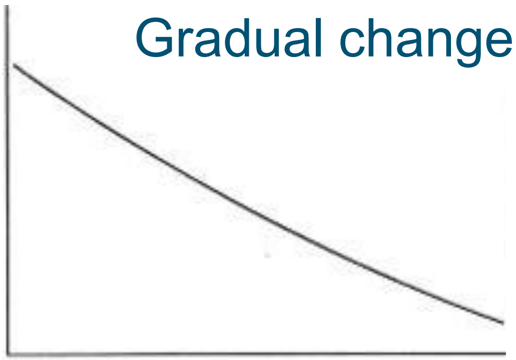


Suitability for orang utan, Central Kalimantan, from Sumarga and Hein 2014

Complex ecosystem dynamics

State

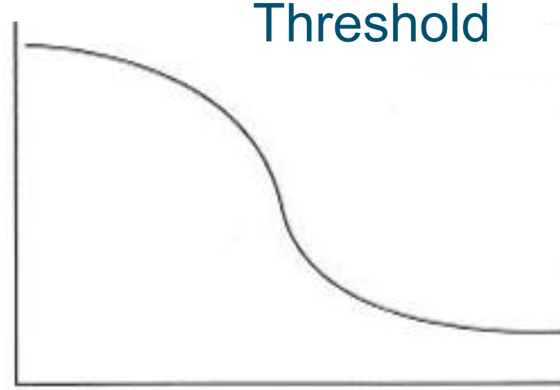
Gradual change



Pressure

State

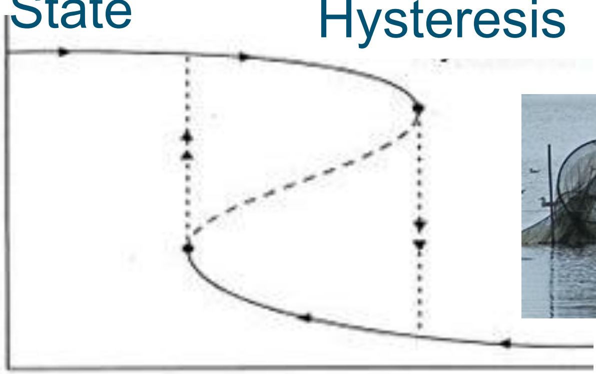
Threshold



Pressure

State

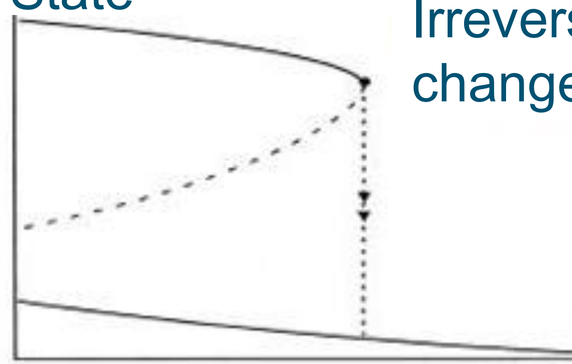
Hysteresis



Pressure

State

Irreversible change



Pressure

How to model complex dynamics ?

- Systems approach, using differential equations, for instance a logistic growth curve:

$$\frac{dP}{dt} = rP\left(1 - \frac{P}{K}\right)$$

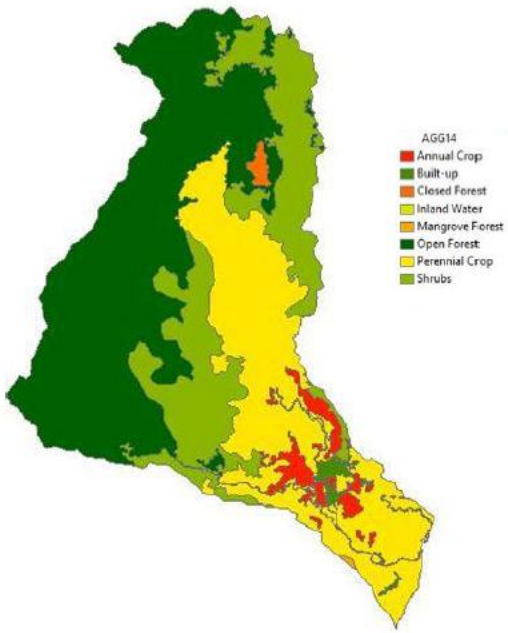
- The carrying capacity (K) may be related to environmental factors (condition indicators), introducing **feedback mechanisms**
- These relations may be found using regression analysis provided that data are available
- Regulating services (except carbon) often depend on spatial relations, spatial-temporal modelling is required

Capacity, flows and pollution

- Increased pollution levels, or clean-up of waterways will be reflected in year-to-year changes of ecosystem accounts.
- Pollution may change the capacity of ecosystems to provide services, the flow of services itself, or the value of these services (e.g. more effort needed to harvest, or lower quality product)
- Trends (but not potential policy measures) can be considered...however often difficult to anticipate effects of changes in pollution loads on ecosystem services

Results thesis Verna Duque Palawan (1)

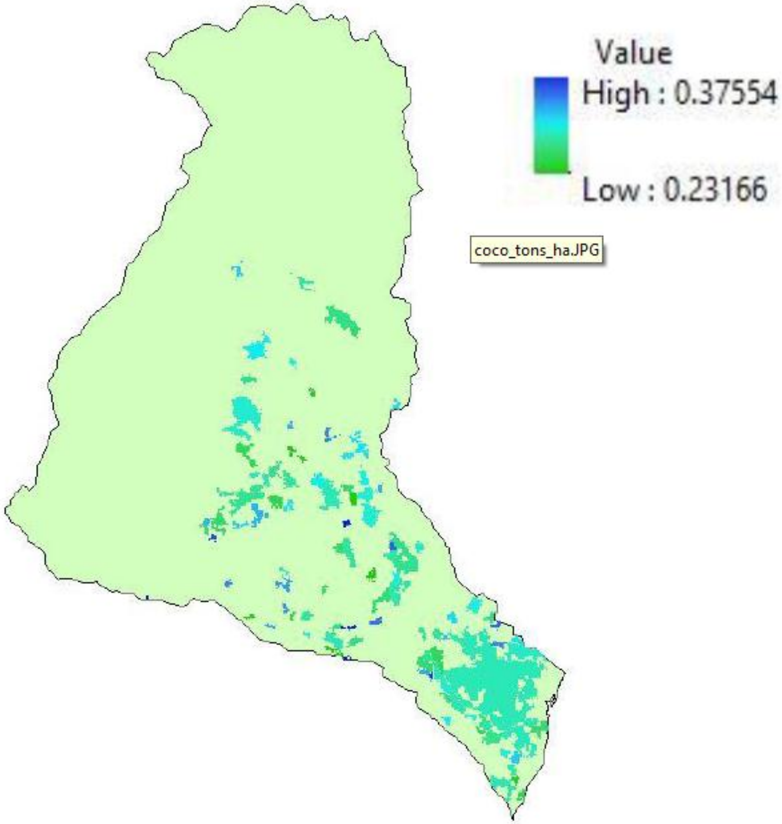
1. Land-use map



Source: pulot_lancover.shp
Palawan Council for Sustainable Development
Year: 2010

Results thesis Verna Duque Palawan (2)

1. **Coconut production (Copra)**



Mapped per pixel not hectare (yet)

Figure 1 Map of Copra yield (tons pixel^{-1}) in Pulot Watershed

Table 2 Detailed statistics of Coconut Map (Copra)

Average yield (tons ha^{-1}yr^{-1})	Mean (tons pixel^{-1})	STDEV	MAX	MIN	Area (ha)	# of Pixels	Area per pixel	Total Yield (tons yr^{-1})
1.32	0.38	0.01	0.38	0.23	903	6350	0.142205	1319

Results thesis Verna Palawan (3)

2. Paddi rice production (Palay)

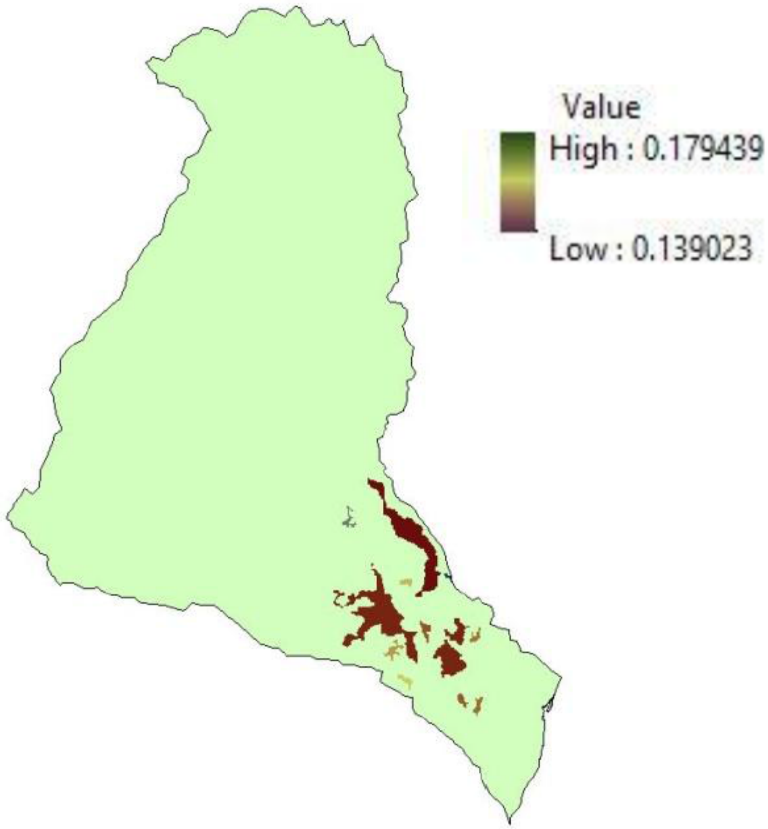


Figure 3 Map of Palay yield (tons pixel^{-1}) in Pulot Watershed

Table 3 Detailed statistics of Paddi Rice Map (Palay)

Average yield (tons ha^{-1}yr^{-1})	Mean (tons pixel^{-1})	STDEV	MAX	MIN	Area (ha)	# of Pixels	Area per pixel	Total Yield (tons yr^{-1})
4.06	0.14	0.01	0.18	0.14	496	15057	0.032941	3689

Results thesis Verna Palawan (4)

3. Palm oil production (Palm fruit bunch)

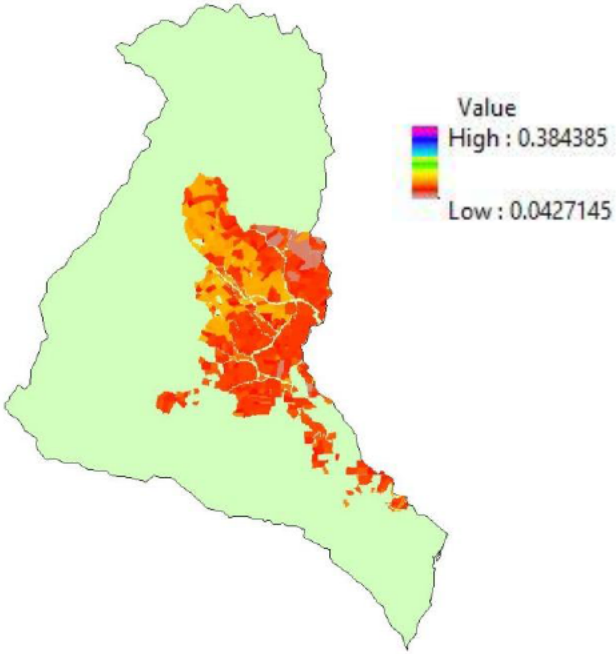


Figure 5 Map of Palm fruit yield (tons pixel^{-1}) in Pulot Watershed

Table 4 Detailed statistics of Palm Oil Map (Palm fruit bunch)

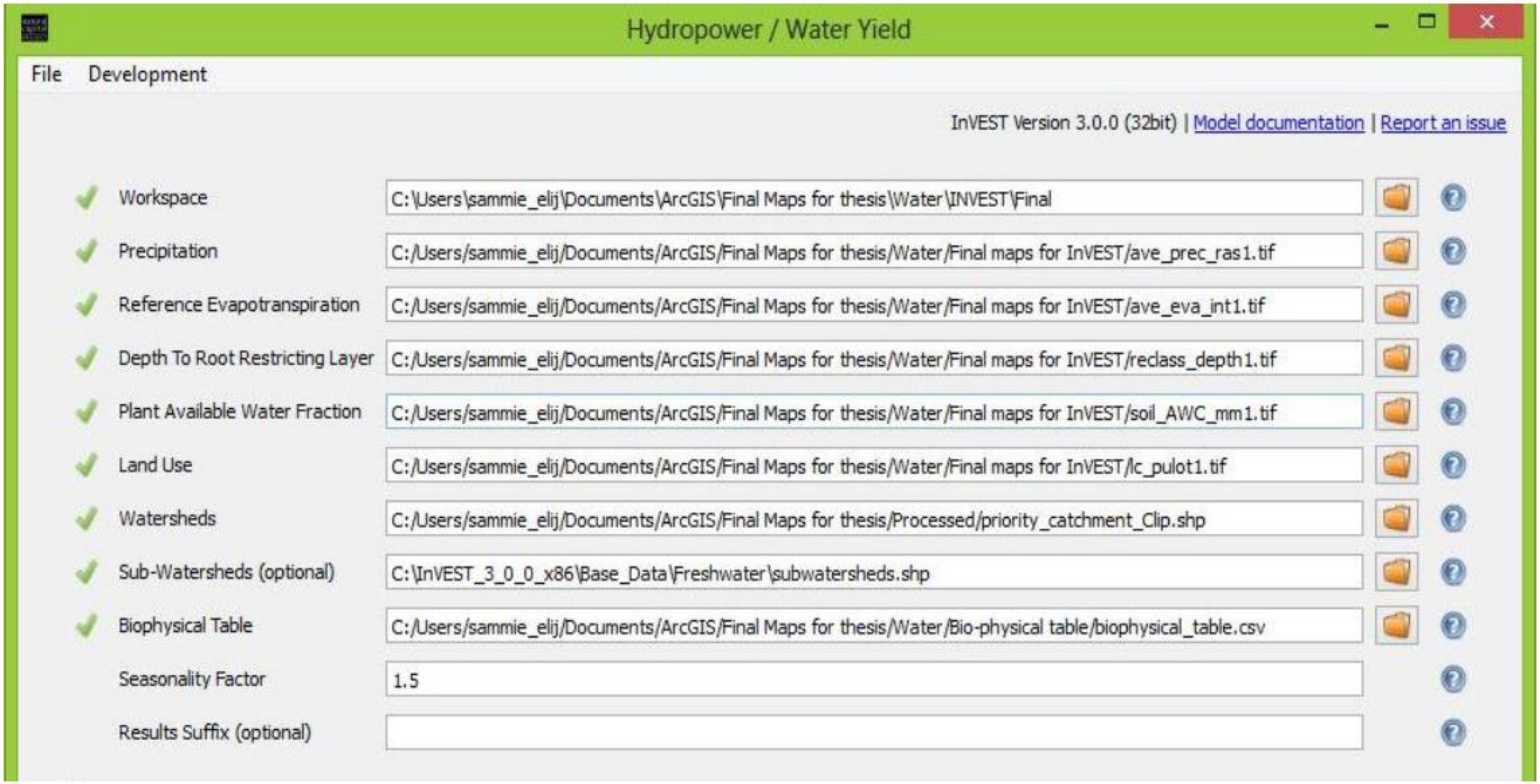
* Average yield (tons ha^{-1}yr^{-1})	Mean (tons pixel^{-1})	STDEV	MAX	MIN	Area (ha)	# of Pixels	Area per pixel	Total Yield (tons yr^{-1})
0.39	0.10	0.04	3.06	0.00	665	22936	0.028994	165,167
**0.61								
0.83								

* Average yield was based on data from Cooperatives.

** Represents the average value of the other two average values which was assigned for lot numbers not belonging to any Cooperatives but is classified as Palm oil plantation using SPOT 2.5 image.

Results thesis Verna Palawan (5)

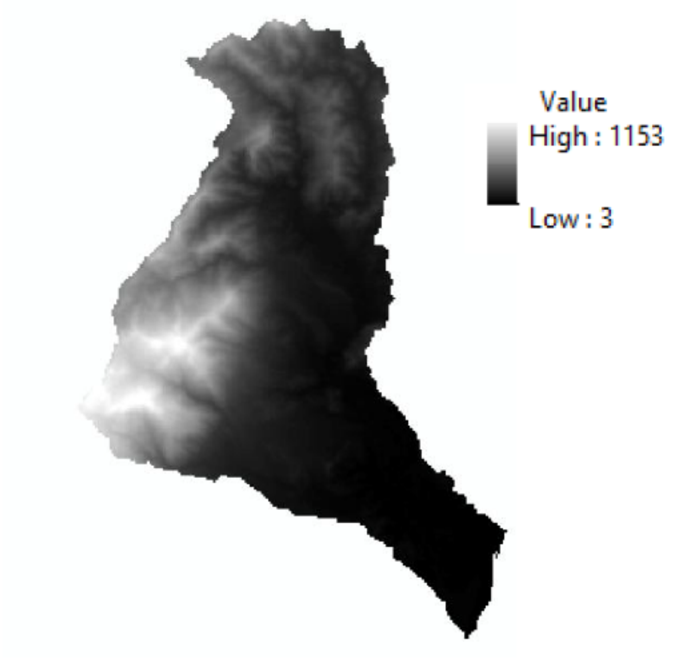
4. Water Yield through InVEST



Results thesis Verna Palawan (6)

Appendix 5. Derived maps for Water yield Model

1. Pulot SRTM DEM

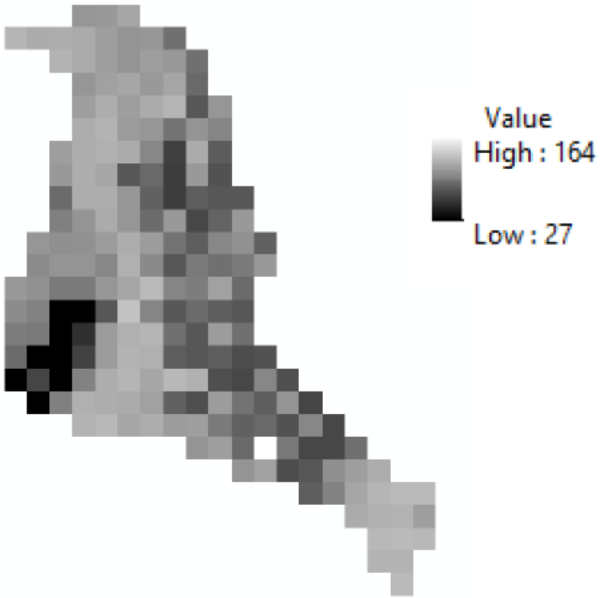


DEM not needed in InVEST but would be needed in more sophisticated model

Source: SRTM DEM (Shuttle Radar Topography Mission - Digital Elevation 90-m spatial resolution mosaic of entire country (Philippines) Model) http://www.philgis.org/freegisdata.htm

Results thesis Verna Palawan (7)

2. Average evapotranspiration

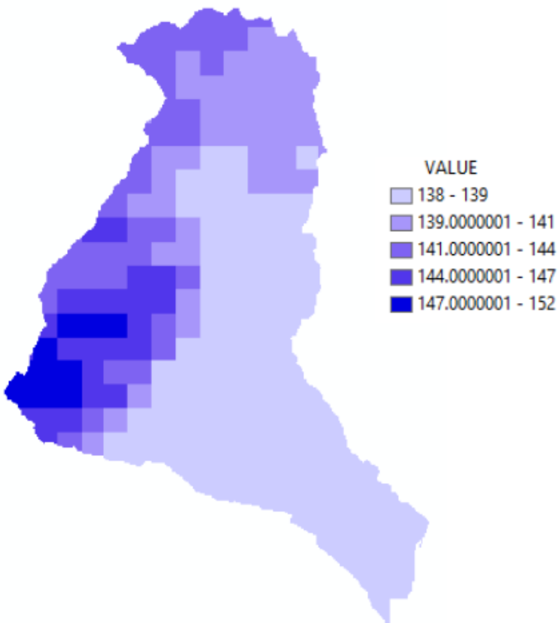


Source:

- MODIS Toolbox
  http://resources.arcgis.com/gallery/file/geoprocessing/details?entryID=9CC382D2-1422-2418-34F8-DC9F97B24052
    - Description: This toolbox contains scripts that download NASA satellite imagery from MODIS and import it into ArcMap.

Results thesis Verna Palawan (8)

3. Average precipitation



Source: PHILGIS
http://www.philgis.org/freegisdata.htm

Main Source: World Climate Data (www.worldclim.org/bioclim)
http://www.worldclim.org/current

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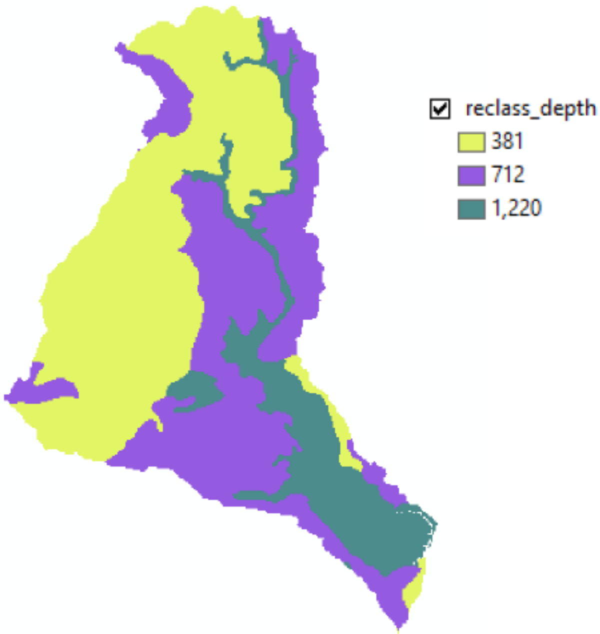
Results thesis Verna Palawan (9)

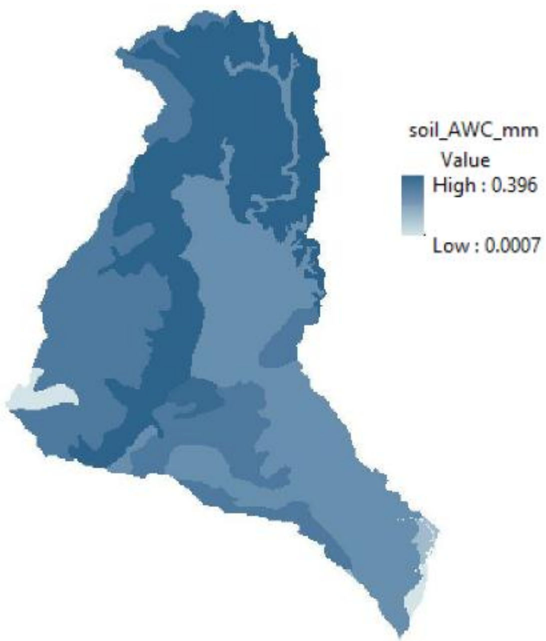
4. Average soil depth as proxy to plant restrictive rooting depth



Source:	pulot_soils.shp Palawan Council for Sustainable Development
Specific data used:	Soil depth qualitatively defined as: Deep, Moderately deep and Shallow

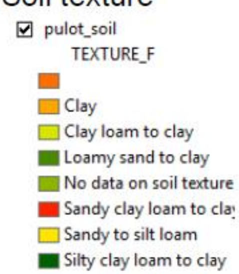
Results thesis Verna Palawan (10)

5. Soil available water content



Source: pulot_soils.shp
Palawan Council for Sustainable Development

Specific data used: Soil texture



Results thesis Verna Palawan (11)

6. Seasonality Factor

Source: InVEST User Guide 3.0.0

Reference: Xu, Xianli, Wen Liu, Bridget R. Scanlon, Lu Zhang, and Ming Pan. "Local and global factors controlling water-energy balances within the Budyko framework."Geophysical Research Letters 40, no. 23 (2013): 6123-6129.

Description: According to InVEST User Guide (Release 3.0.0), Z is an empirical constant that captures the local precipitation pattern and hydrogeological characteristics, with typical values ranging from 1 to 20.

ϖ values = average value of 2.7 – 3.1 is 2.9 (values corresponding to Philippines)

P = average precipitation of 143.5 mm (derived from precipitation map)

AWC = average available water content of 162. 9784 mm (derived from AWC map)

$$Z = \frac{(\omega - 1.25)P}{AWC}$$

=((2.9-1.25)*143.5) /162.9784

= 1.4528

Results thesis Verna Palawan (12)

4. Water yield

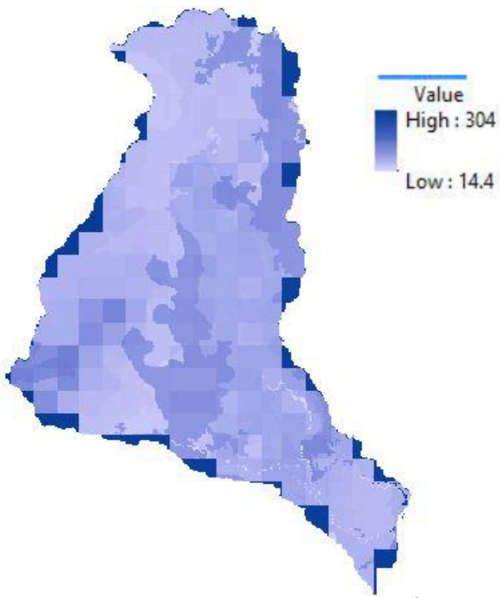


Figure 7 Map of water yield (mm pix^{-1}) in Pulot Watershed

But: the model only results in water yield, not in water storage (and water flows are not taken into account)

Table 5 Detailed statistics of water yield in Pulot Watershed

ws_id	num_pixels	precip_mn (mm)	PET_mn (mm)	AET_mn (mm)	wyield_mn (mm)	wyield_vol (m^3)
1.00	40942.00	137.46	81.66	68.05	78.62	14450093.34

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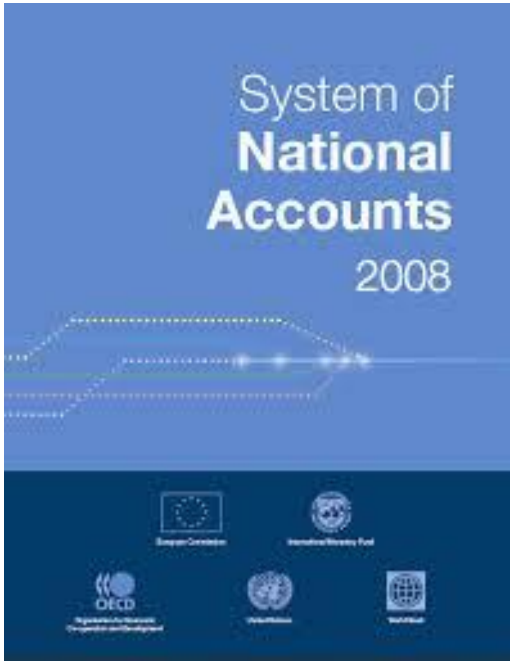
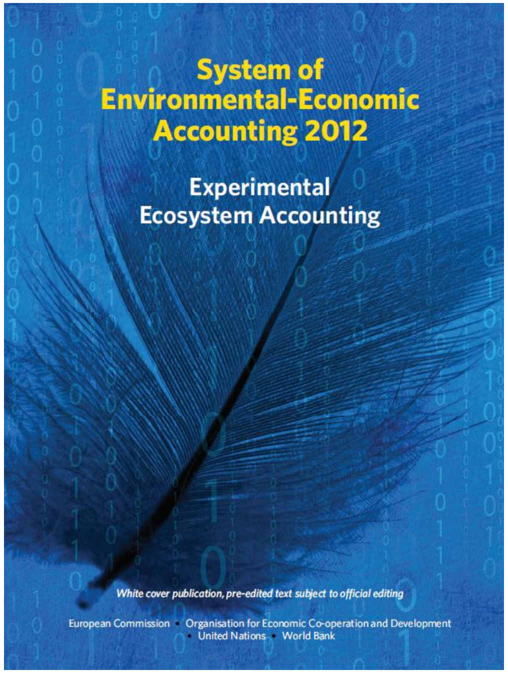
From models to accounts





The System of National Accounts

Describes transactions (e.g. buying a product, or paying a tax) between institutional units such as households, the central government, or enterprises (classified in sectors such as agriculture or mining).

Transactions are described in a sequence of accounts:

- The current accounts (production, distribution and use of income) provide information on production, value added and income : gross and net domestic product (GDP and NDP) and national income (NNI).
- The accumulation accounts (capital, financial, other changes in volume) describe changes in **assets** by ownership. The resulting net worth and changes therein is recorded in the balance sheets.

Source: Edens and Hein, 2013

Production and assets

- SNA: economic production = "an activity carried out under the control and responsibility of an institutional unit that uses inputs of labour, capital and goods and services to produce outputs of goods or services" (6.24)
- Criteria: (i) presence of institutional unit; and (ii) ownership of output/ potential to be compensated/paid
- Excluding natural processes from the production boundary
- The SNA defines assets in terms of two necessary conditions of benefits and ownership
- The SEEA defines environmental assets more broadly as "the naturally occurring living and non-living components of the Earth, together comprising the bio-physical environment, that may provide benefits to humanity" (SEEA Central Framework, 2.17).

Why Ecosystem Accounts ?

- Ecosystem assets not covered in the SNA
- In recognition of the holistic nature of ecosystems: the combination of biotic and abiotic components and processes, and human management leads to the generation of services and benefits to people
- An ecosystem services approach allows for a comprehensive recording of the various services of ecosystems, hence better insight in trade-offs and complexities
- Spatial approach allows more comprehensive assessment PLUS additional applications

The ecosystem account**s** (as currently under development)

- Ecosystem condition account
- Physical ecosystem production account
- Monetary ecosystem production account
- Physical ecosystem asset account
- Monetary ecosystem asset account
- Supply- Use Table
- Biodiversity account

The system is somewhat flexible: allowing countries to select accounts and indicators that are most relevant to their setting.

Spatial approach

- The Ecosystem accounts follow a spatial approach: for each ecosystem account there is a map and a summary table.
- In the digital map, every grid cell has multiple values reflecting the various condition indicators, ecosystem service flow indicators (physical and monetary), asset indicators (physical and monetary) and biodiversity indicators
- Only the input – output table is not spatial (even though a spatial application could in principle be designed, however this involves somewhat more complex GIS modelling, and this aspect requires further thinking)

The ecosystem condition account

- Contains indicators that reflects the condition/state of the ecosystem
- Indicators are specific to countries and ecosystems
- Contains indicators may reflect, e.g.:
  - Physical condition, e.g. soil fertility (for instance soil organic matter concentration), water table, (ground)water quality
  - Biological condition, e.g. crown cover, standing biomass
  - Processes: e.g. Net Primary Production
  - The presence of species that indicate ecological quality, e.g. species sensitive to pollution
  - The presence of conservation flagship species indicating ecological condition and important for ecotourism and biodiversity conservation such as the orangutan
  - The presence of species that reflect ecosystem functioning such as keystone species

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Ecosystem condition account (physical), e.g.

Aspect	Indicator (e.g.)	Paddy fields	Annual cropland	Oil palm plantations	Forests	Rivers / lakes
Soil fertility	% organic matter	x	x	x		
	C/N ratio	x	x			
Vegetation status	Crown cover (%)				X	
	Biomass (ton/ha)			x	X	
Biodiversity	MSA				x	X
	Occurrence of black rhino (n/ha)				x	
Water quality	BOD					X
	Algae content					X

Production account – physical and monetary

- Expresses the supply of ecosystem services in physical and monetary terms, in a map
- Supply of each ecosystem service is calculated for each grid cell (i.e. BSU)
- Information can also be organised in a table, for instance per land cover unit (LCEU) (or per administrative unit if relevant)
- With GIS, the spatial variability can be calculated (mean, standard deviation)
- The map is essential, examples of the summary tables are provided in the next slides

Physical ecosystem production account, example

Land cover/ ecosystem unit	Rice production (ton)/1	Vegetable production (ton)	Oil palm production (ton FFB)	Coconut production (ton)	Timber production (ton)	NTFP production (ton)	Carbon seque-stration (ton C)	(dry season) River water generated (ton)	Erosion avoided (ton sediment)
Paddy field									
Annual cropland									
Oil palm plantation									
Forest									
Etc.									
TOTAL									

Note: in the map: all units in ton per ha; in the table: total ton per LCEU (plus SD)

Monetary ecosystem production account, e.g.

Land cover/ ecosystem unit	Rice production ($)	Vegetable production ($)	Oil palm production ($)	Coconut production ($)	Timber production ($)	NTFP production ($)	Carbon seque-stration ($)	(dry season) River water generated ($)	Erosion avoided ($)
Paddy field									
Annual cropland									
Oil palm plantation									
Forest									
Etc.									
TOTAL									

Valuation of provisioning services follows the same logic as the SNA production account, i.e. the resource rent approach. For regulating services different valuation methods apply as discussed

Ecosystem asset account, principal components:

- Opening, changes in assets and closing stocks
- Challenges remain for including regulating services, perhaps for some services not useful to work with opening and closing stocks, in this case there is a need to reflect on different indicators to express the asset and its value.
- Again, the maps are essential, the summary tables just organise the data at a higher aggregation level to make it easier to communicate (see next ppt slides).
- Opening stock, natural increases and losses, harvest and closing balance are to be defined for every pixel (/BSU)

Physical ecosystem asset account, e.g.

	Paddy fields	Annual cropland	Oil palm plantations	Forests				
Ecosystem service	Rice production	Vegetable production	FFB production	Timber production	NTFP production	Carbon seque-stration	Water regulation	Erosion control
Unit	ton/ha	Ton/ha	ton/ha	ton/ha	Ton/ha	Ton/ha	Water storage capacity in mm	not relevant
Opening stock	x (may be zero)	x (may be 0)	x	x	x	x	x	not relevant
Natural replenishment	x	x	x	x	x	x (sequestration)	? (e.g. soil formation)	not relevant
Natural losses	x	x	x	x	x	x (e.g. fire)	x (e.g. due to erosion or land use change)	x (erosion rate)
Harvest	x	x	x	x	x	x (e.g. wood)	not relevant	not relevant
Closing stock	x	x	x	x	x	x	x	not relevant

Monetary asset account, e.g.

	Paddy fields	Annual cropland	Oil palm plantations	Forests				
Ecosystem service	Rice production	Vegetable production	FFB production	Timber production	NTFP production	Carbon seque-stration	Water regulation	Erosion control
Unit	$/ha	$/ha	$/ha	$/ha	$/ha	$/ha	$/ha (as a consequence of avoided floods or avoided water storage costs downstream)	$/ha (expressed as benefits of avoided erosion due to vegetation ?)
Opening stock	x (may be zero)	x (may be 0)	x	x	x	?	x	not relevant
Natural replenishment	x	x	x	x	x	x (sequestration)	x (?)	not relevant
Natural losses	x	x	x	x	x	x (e.g. fire)	x (?)	x
Harvest	x	x	x	x	x	x (e.g. wood)	not relevant	not relevant
Closing stock	x	x	x	x	x	Not relevant	x	not relevant

Biodiversity account

- Useful in order to capture biodiversity, which is of key interest for environmental management and policy making.
- Note that some biodiversity data may also be captured in the condition account, (the biodiversity account may build upon the condition account, for instance to express habitat quality)
- Relevant indicators depend on the country and ecosystem, but may include aspects such as species diversity, species numbers, red list species, mean species abundance, occurrence of specific flagship species, habitat quality etc.
- Complementary to the other ecosystem accounts, since many aspects of biodiversity are not reflected otherwise in the accounts.
- Also requires a spatial approach, i.e. a map expressing the selected indicators per pixel, complemented with summary tables organised as per the requirements of the user (e.g. per administrative unit, or land cover unit) – in particular to express trends over time (since biodiversity in different ecosystems is difficult to compare)

Supply – Use table

- Reflecting supply and use from non-financial, financial co-operations, central government, households, NPISHs and the ecosystem sector (see bullet point 1 next slide)
- The suppliers of the service are the land owners (in case of private goods) or the 'ecosystem sector' (in the case of intermediate or final regulating services) (– see Edens and Hein paper for details and an example)
- The final users of provisioning services may be industries (e.g. using oil palm fruit to produce palm oil), governments, or households (picking berries)
- The user of the regulating services may be the household sector (e.g. in case of reduced air pollution) or the government sector (perhaps in case of flood control)

Practical

- Identify which accounts you want to develop in the case study site
  - Condition
  - Physical and Monetary Ecosystem Services flow account
  - Physical and Monetary Ecosystem Asset account
  - Biodiversity account ?
  - Supply-Use table ?
- Which rows will be included ?
- Which indicators will you use ?
- Are the data available to map these indicators and populate the tables ?
- How will this be done ?