Estimating the Annualized Costs and Capacity (Supply) of Ecosystem Services in a Resource Assessment

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Rationale and Motivation

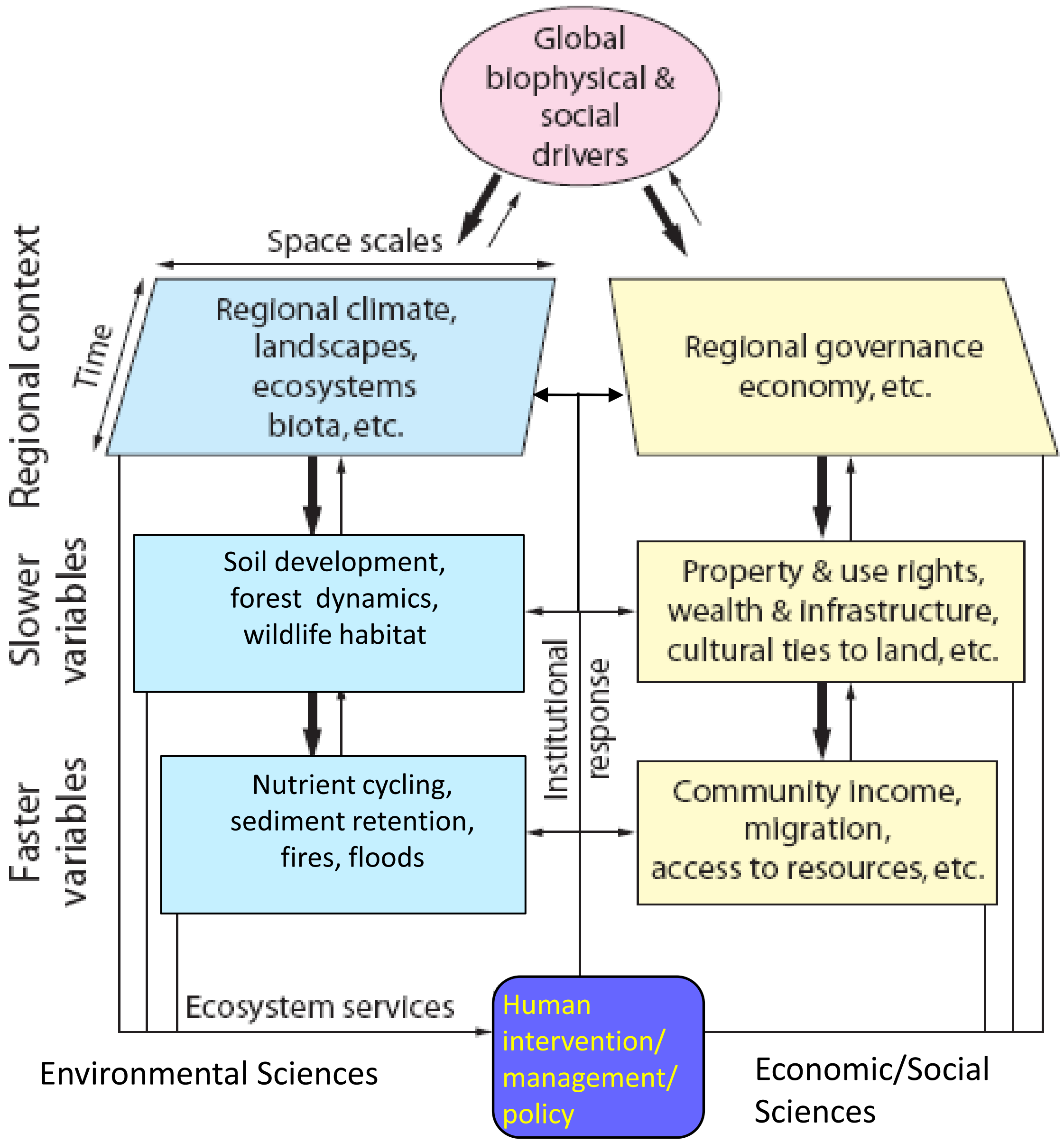
The United States Geological Survey (USGS) was established by an Act of Congress on March 3, 1879, to provide a permanent Federal agency to **conduct up-to-date systematic and scientific ''classification of the public lands, and examination of the geological structure, mineral resources, and products of the National domain.''** … Its activities include conducting detailed assessments of the energy and mineral potential of the Nation's land and State offshore areas… (FY 2012 Interior Full Committee Report. USGS)

The Energy Independence and Security Act of 2007: "… **estimate the annual carbon sequestration capacity of ecosystems under a range of policies in support of management activities to optimize sequestration.**" Section 712: One set of policies involved in such an optimization are **policies that regulate the impacts of the specific land use activities** associated with sequestering carbon and other ecosystem services

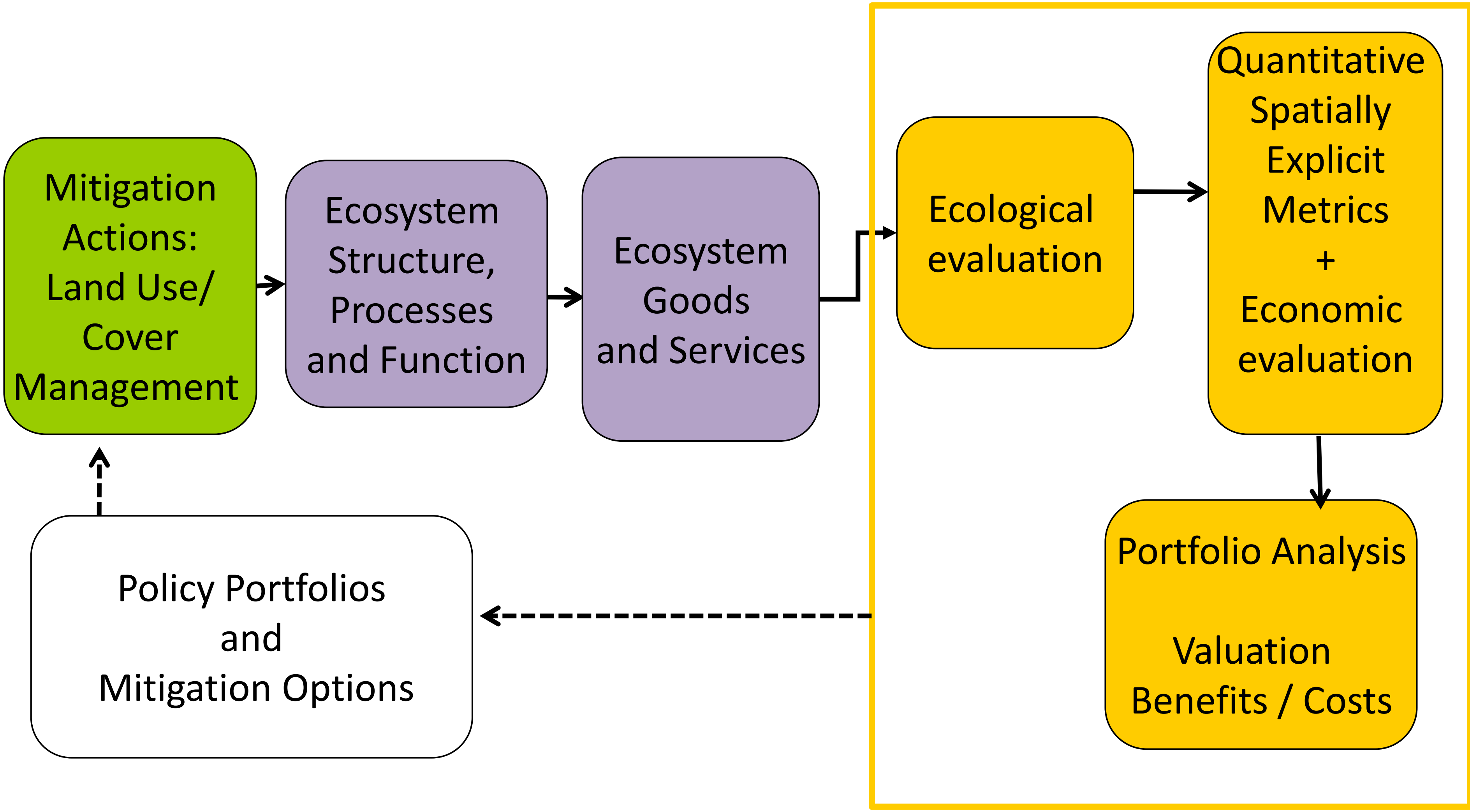
Key Science Questions

What are the ecosystem effects from likely terrestrial carbon sequestration actions?

How do we incorporate social and economic sciences that enhance our ability to quantitatively evaluate the full range of effects of proposed terrestrial carbon sequestration strategies?


Global biophysical & social drivers
Space scales
Time
Regional context
Regional climate, landscapes, ecosystems biota, etc.
Regional governance economy, etc.
Slower variables
Soil development, forest dynamics, wildlife habitat
Property & use rights, wealth & infrastructure, cultural ties to land, etc.
Institutional response
Faster variables
Nutrient cycling, sediment retention, fires, floods
Community income, migration, access to resources, etc.
Ecosystem services
Human intervention/ management/ policy
Environmental Sciences
Economic/Social Sciences

Policy/Management Strategies and Ecosystem Services Approach



Rationale and Motivation

Approach: A land use / land cover (LULC) portfolio analysis based on maximizing the joint production of economic activities and ecosystem services is applied to estimate the expected return and risk of a change in the quantity of ecosystem services and their values in a regional scale resource assessment.

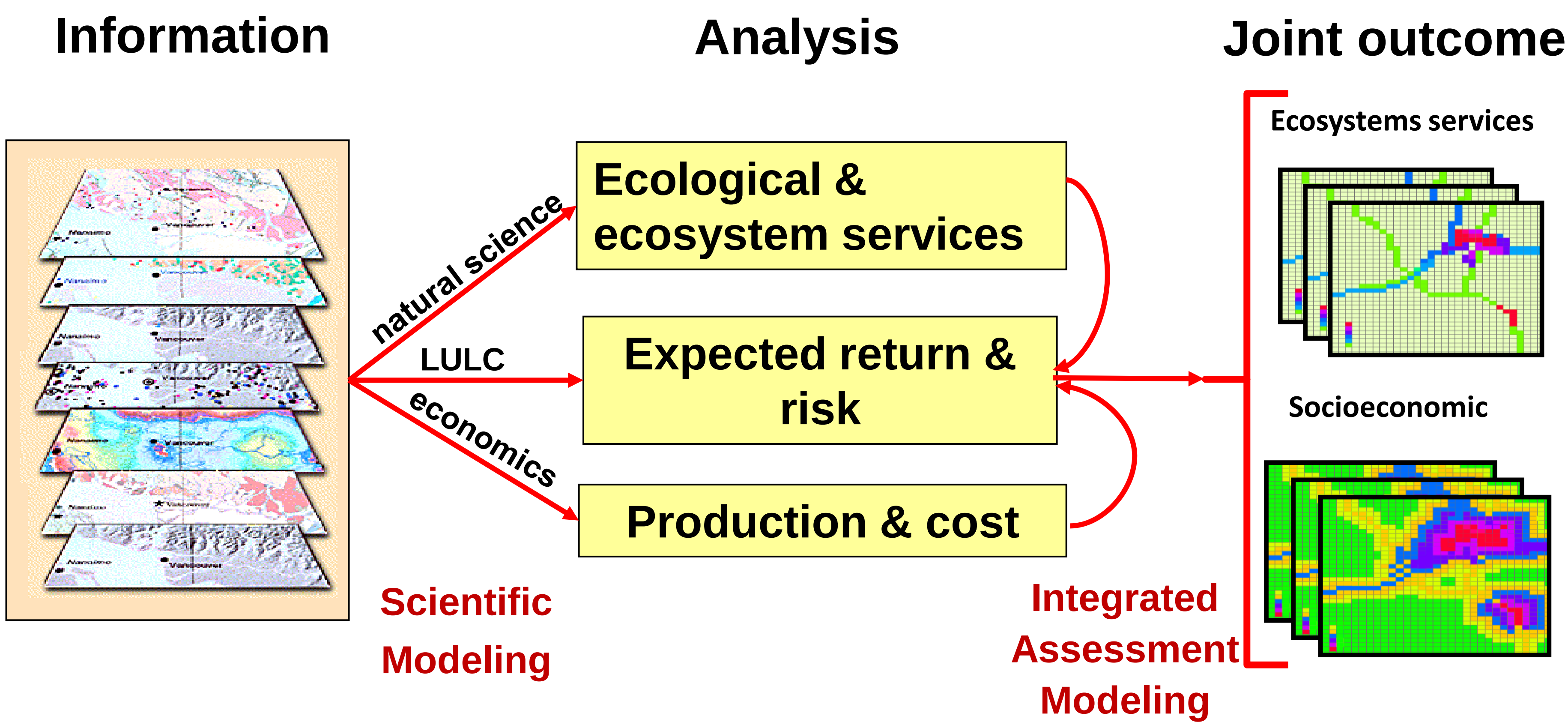
Portfolio Analysis: highest return with lowest risk (uncertainty):

$$\text{Return} = \frac{(\text{end-of-period wealth}) - (\text{beginning-of-period wealth})}{\text{beginning-of-period wealth}}$$

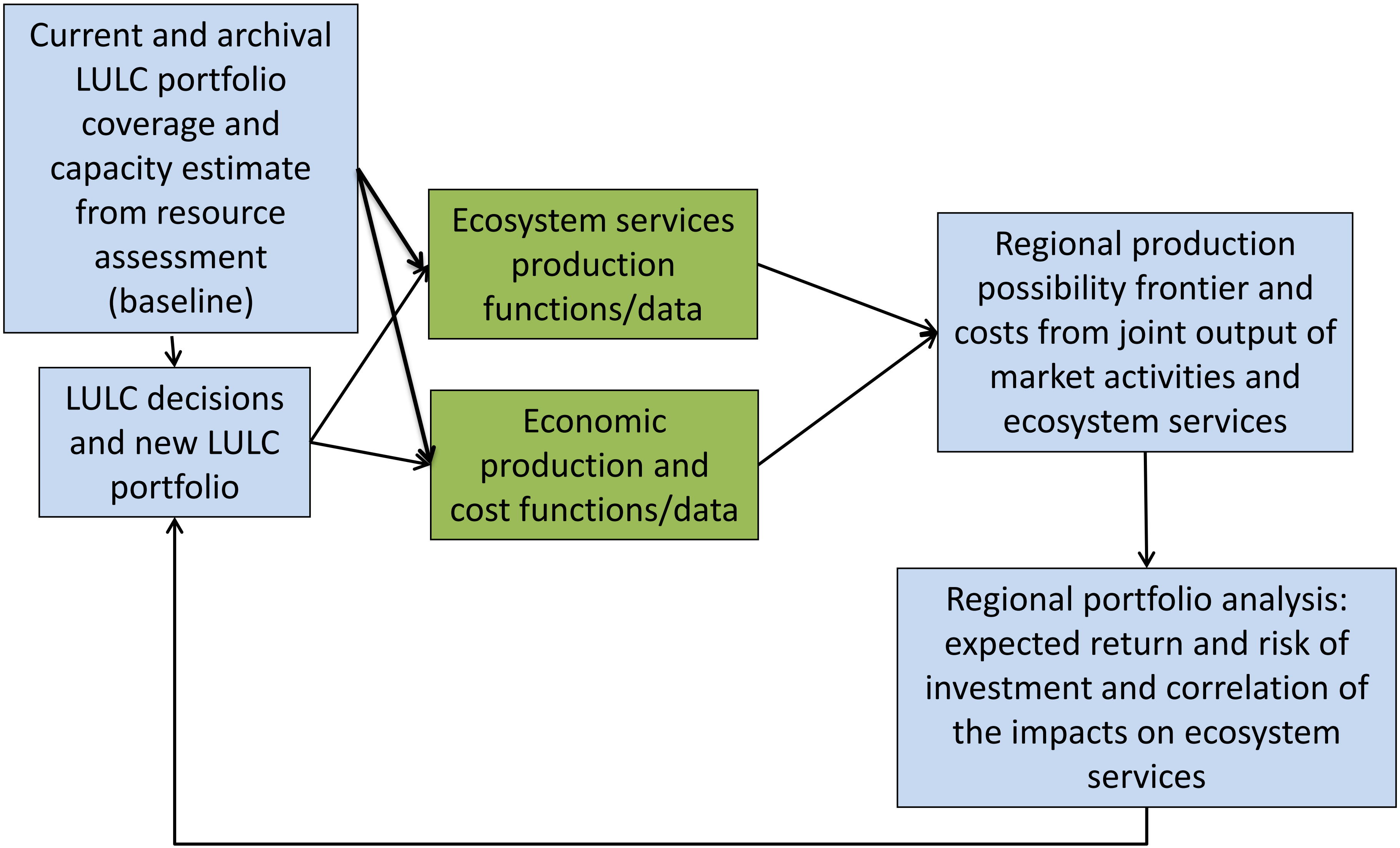
Sharpe, W. Alexander, G. & Bailey, J. 1999. Investments. 6th ed. Prentice Hall, Upper Saddle River, NJ.

A Geospatial Decision Framework

Process models and data that integrate natural science information with social and economic models and factors to describe the implications of policy and management decisions.



Schematic for LULC portfolio analysis of ecosystem services



The components of a carbon resource assessment

- classification of the geographic extent of carbon and other ecosystem services, which is dependent on land use/land cover
- carbon capacity, including baseline measures, are affected by periodic changes and potential ancillary effects on other ecosystems services
- uncertainty estimation such as fire disturbance and economic development, policy, and regulatory influences
- cost of supply

The components of a carbon resource assessment

Resource quantity and uncertainty (1): Components of carbon resource assessment

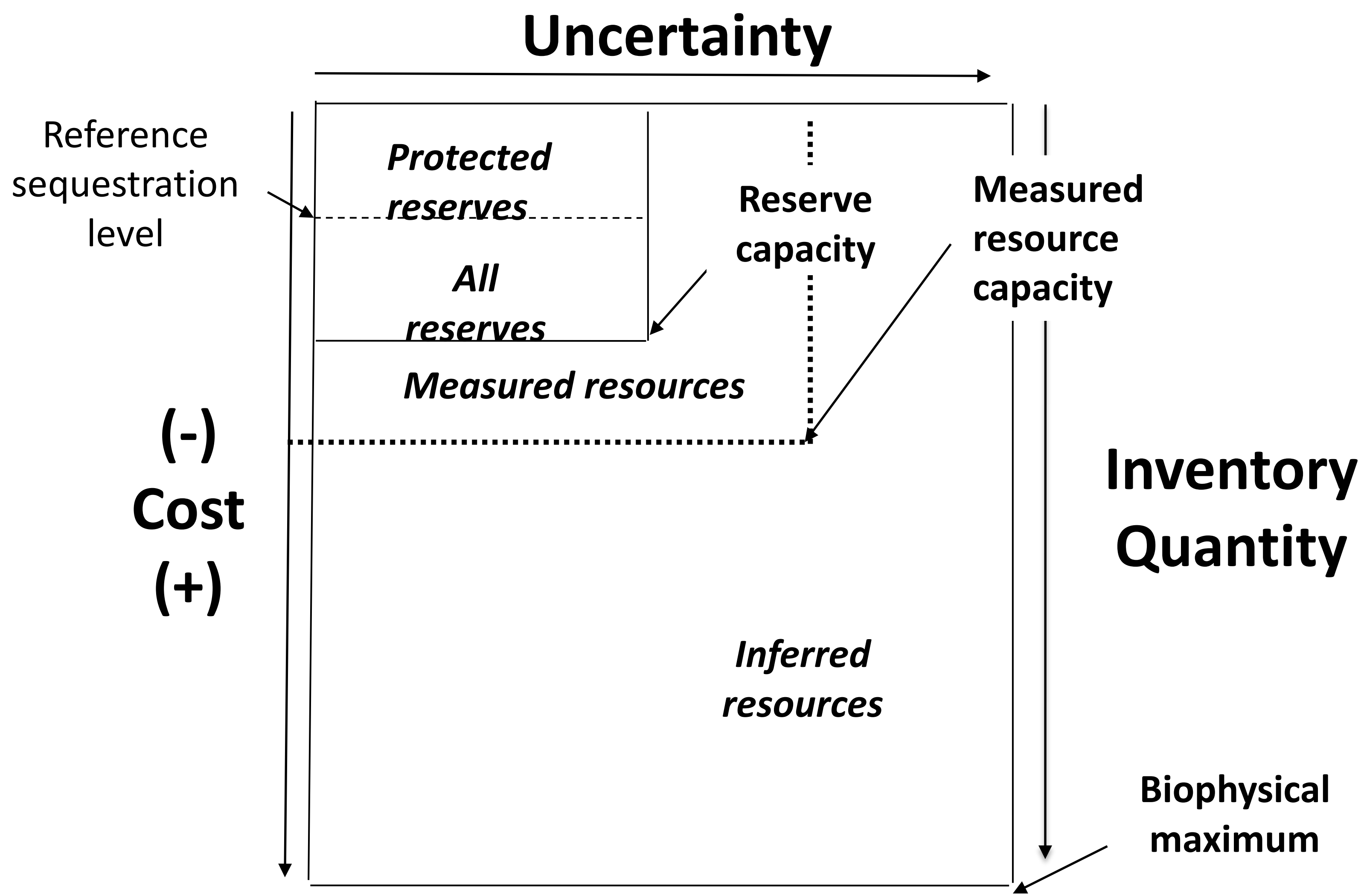
Assessment Dimensions	**Variables**
Estimated capacity	Expected biomass quantity
Uncertainty in physical properties and processes and management processes	Ecological, regulators, land managers
Cost	Land price, management practice costs, market prices for products, market- and non-market-valued services

A conceptual resource model of regional capacity

Resource quantity and uncertainty (2): Carbon capacity categorization

Assessment categories	**Carbon Capacity**	**Uncertainty**
Reserves Protected lands All public lands	Known capacity and quality; current inventory on public lands	Vulnerability to decay, weathering, fire, drought, ecosystem service tradeoffs, regulation on public lands
Measured Resources (MR)	Known location and estimated capacity and quality; current inventory on private and public lands	Reserve + private lands
Inferred Resources (IR)	Scenario based extensions of current land inventory based on economic, regulatory, and climate trends	Reserve + Measured + former land use reinstated, e g., reforestation, and novel land uses and management practices

Regional terrestrial carbon quantity, cost, and uncertainty



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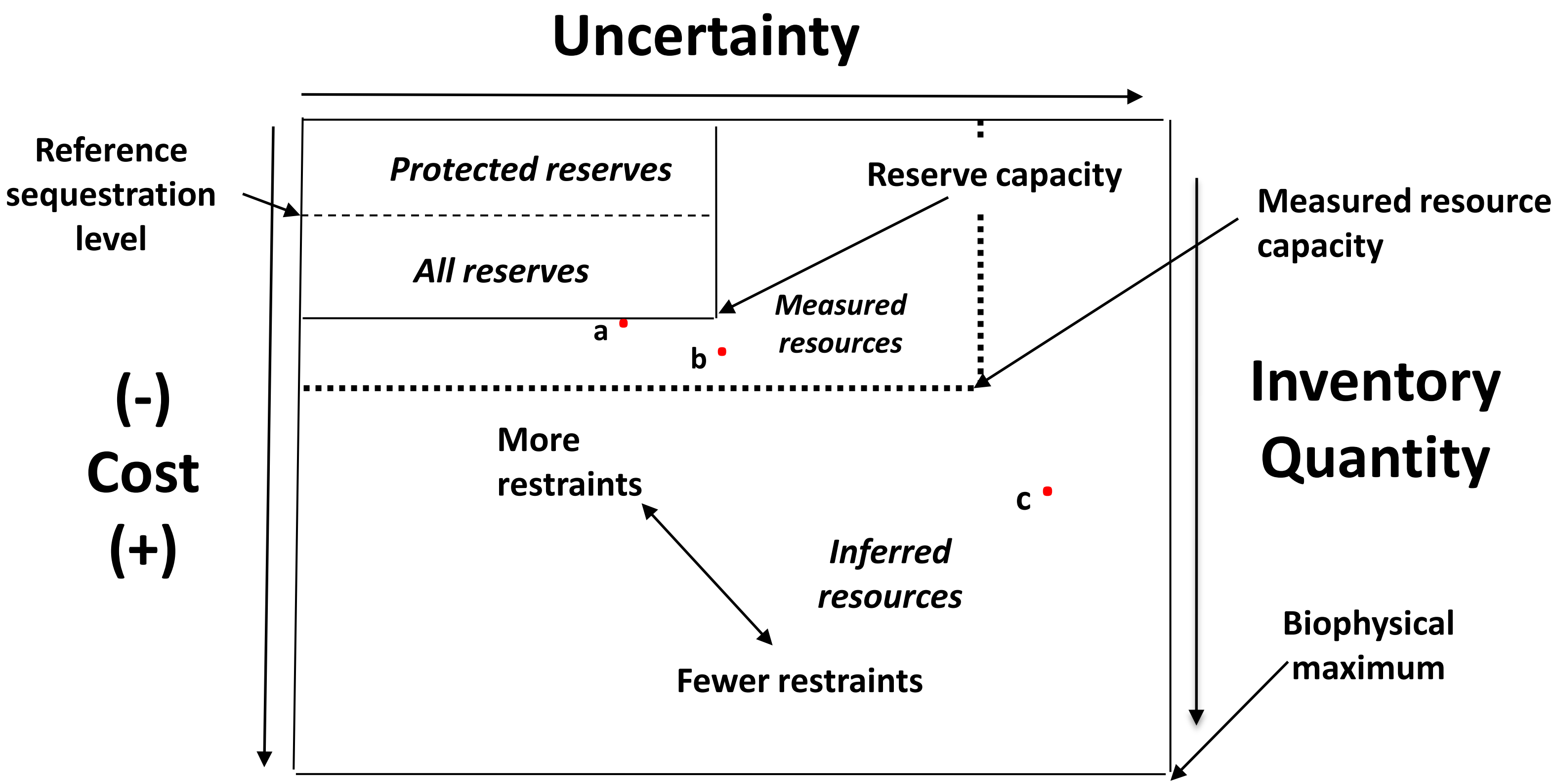
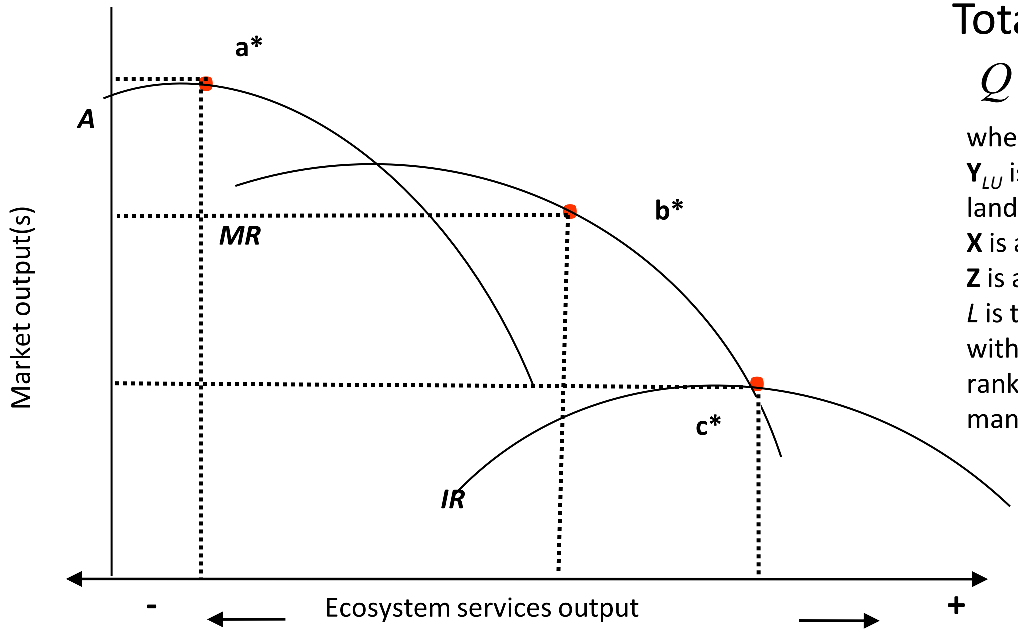


Point a: estimate of a current inventory on private and public lands under assumptions of specific regulatory guidelines, disturbance history, and other environmental hazards

Point b: additional potential capacity in the measured resources category (point b is based on a scenario of policies and risks that yield a higher capacity while it is accompanied with greater uncertainty, possibly due to soil variability)

Point c: scenario of policies to increase the amount of land to be developed with carbon sequestration as its main purpose (point c is a scenario of policies and risks that yield a much higher potential capacity while it is accompanied with much greater uncertainty, possibly due to climate change, economies of scale, and land conversion costs)

Regional production possibility frontiers and value function for maximizing agricultural output, land management changes, and land use changes

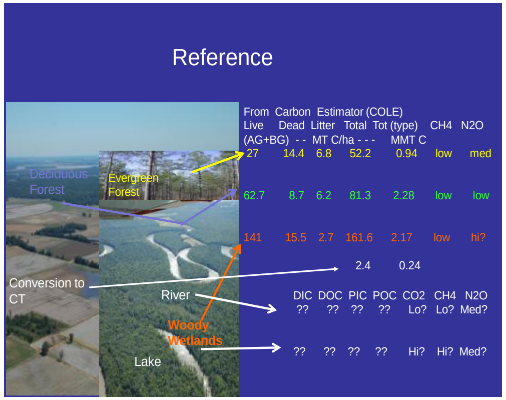


Total regional output

$$Q = F\left(\mathbf{Y}_{LU}, \mathbf{X}, \mathbf{Z}, \mathbf{L}\right)$$

where Q is total regional output
$\mathbf{Y}_{LU}$ is a vector of market outputs of a land use
X is a vector of inputs
Z is a vector of ecosystem services
L is the land available for a land use with a range of physical attributes ranked by its quality for a particular management activity and land use

(a*)



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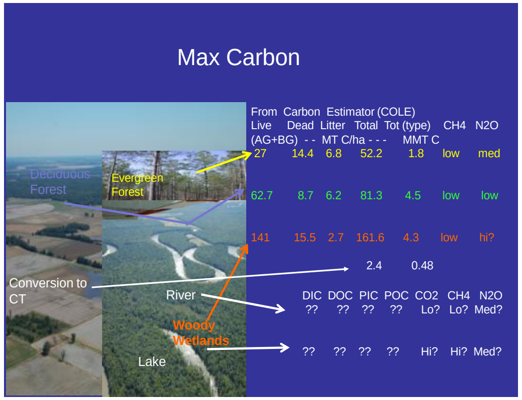
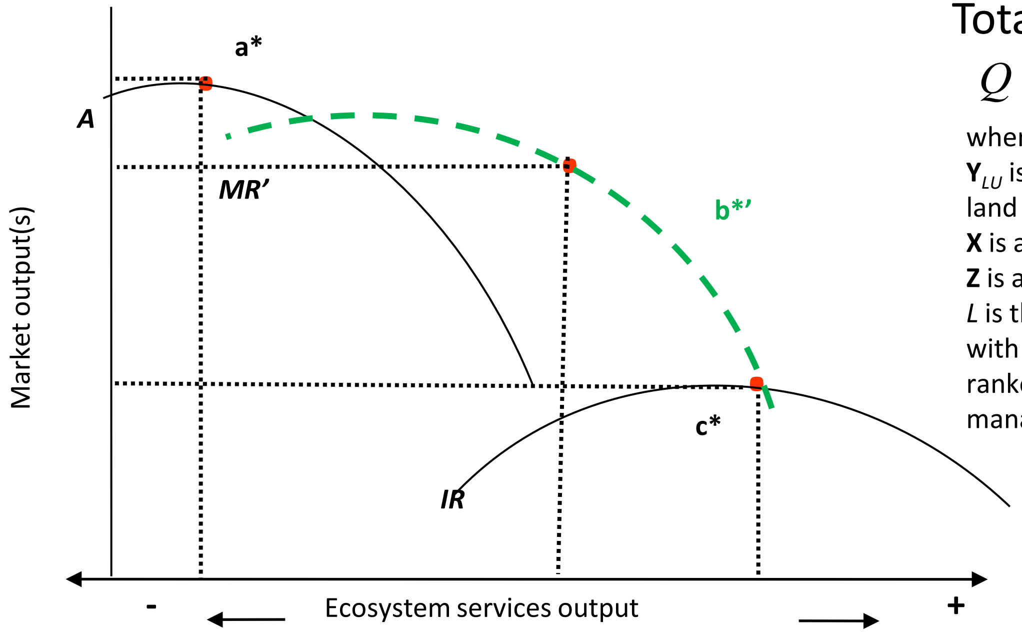


Regional production possibility frontiers and value function for maximizing agricultural output, land management changes, and land use changes



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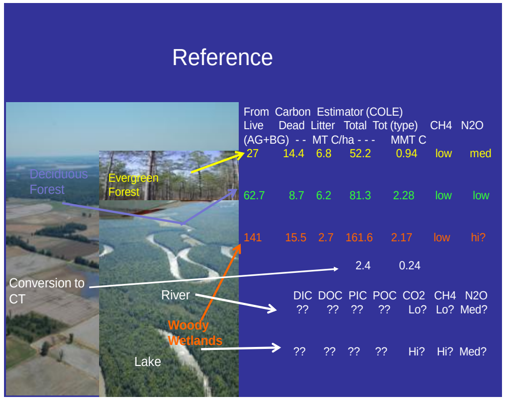

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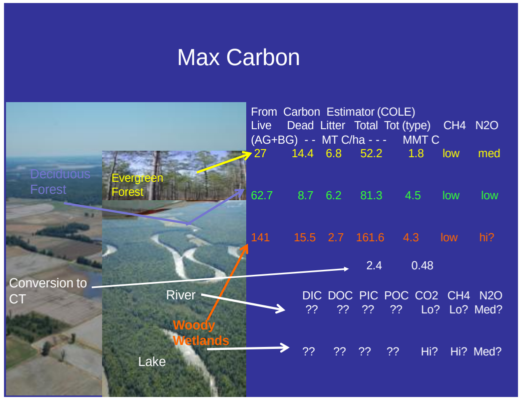
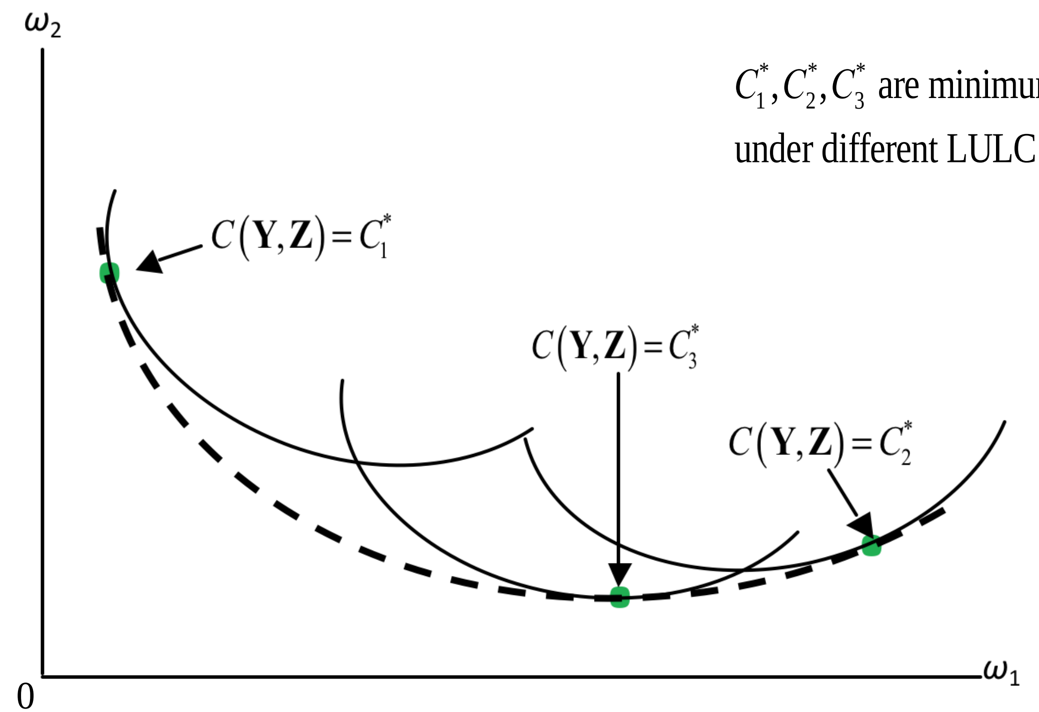


Regional cost minimization



C_1^*, C_2^*, C_3^* are minimum cost solutions under different LULC scenarios and policies

$$\min_x \; C(\mathbf{Y},\mathbf{Z},w) = w\mathbf{X}$$

$$s.t. \quad F_1(\mathbf{X},\mathbf{Z};\mathbf{L}_D) \geq \bar{\mathbf{Y}}_{LU}$$

$$F_2(\mathbf{X};\mathbf{L}_D) \geq \mathbf{Z}_{\min}$$

$$G(x_i) = \bar{\mathbf{X}}(L_D)$$

$$L \geq 0$$

$C = (C_A + C_{LM} + C_{LU})$ is total direct cost

w is input price

L_{RC}^d is the acreage of land cover in the RC resource category with d land characteristics

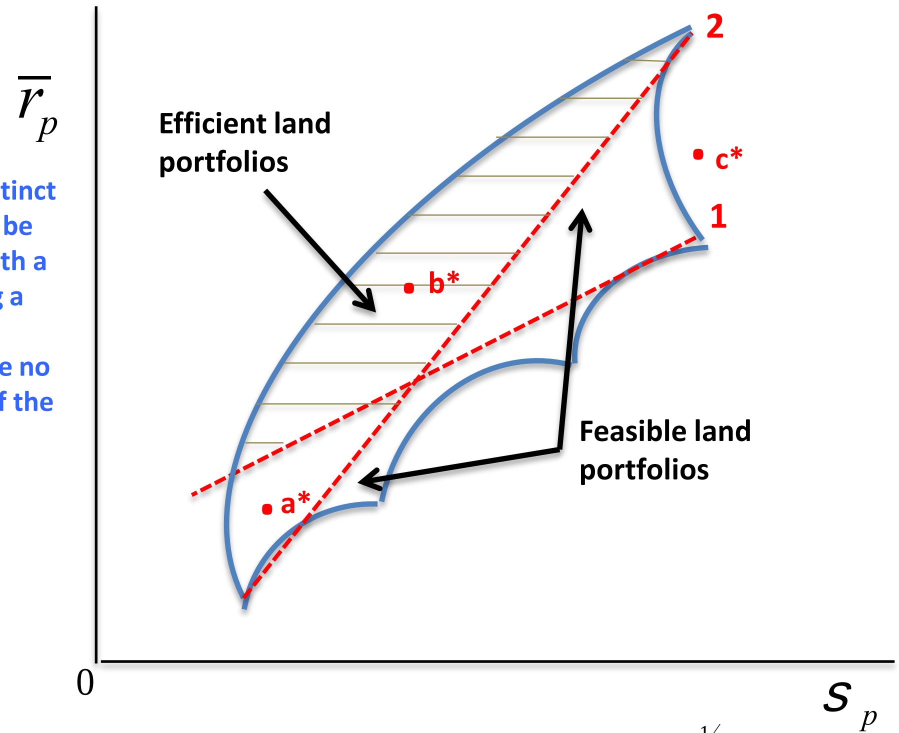
$$\sum_{d=1}^{D} \sum_{RC=1}^{3} LC_{RC}^d = L_D$$

$Z_{\min}$ is the minimum level of ecosystem services provided by policy

Cost for agriculture is annual variable costs C_A.
Cost for land management are the annualized cost of the present value of fixed plus annual variable costs C_{LM}.
Cost of land use change is the annualized cost of the present value of fixed and annual variable costs, C_{LU}.

Expected returns on investment and risks for a set of LULC portfolios

Locations in a region represent distinct investment opportunities and can be thought of as risky securities (*i*) with a unique probability of experiencing a positive payoff. The chance that a mitigation investment will produce no economic benefit, or a total loss of the investment, is one minus that probability.



Efficient land portfolios must meet two conditions

1. **Maximum expected return for varying levels of risk**
2. **Minimum risk for varying levels of expected return**

Point a* is a feasible land portfolio at a minimum cost
Point b* is an efficient land portfolio at a minimum cost
Point c* is not feasible

$$\bar{r}_p = \sum_{i=1}^{N} B_i \bar{r}_i \qquad s_p = \left[\sum_{i=1}^{N}\sum_{j=1}^{N} B_i B_j s_{ij}\right]^{1/2},\ s_{ij} = r_{ij} s_i s_j$$

$\bar{r}_p$ = expected return of the land portfolio

B_i = proportion of the portfolio's initial value invested in security i

$\bar{r}_i$ = expected return on security i

N = number of securities in the portfolio

s_{ij} = covarience of the returns bewtween security i and security j

r_{ij} = correlation coefficient between the return on security i and return on security j

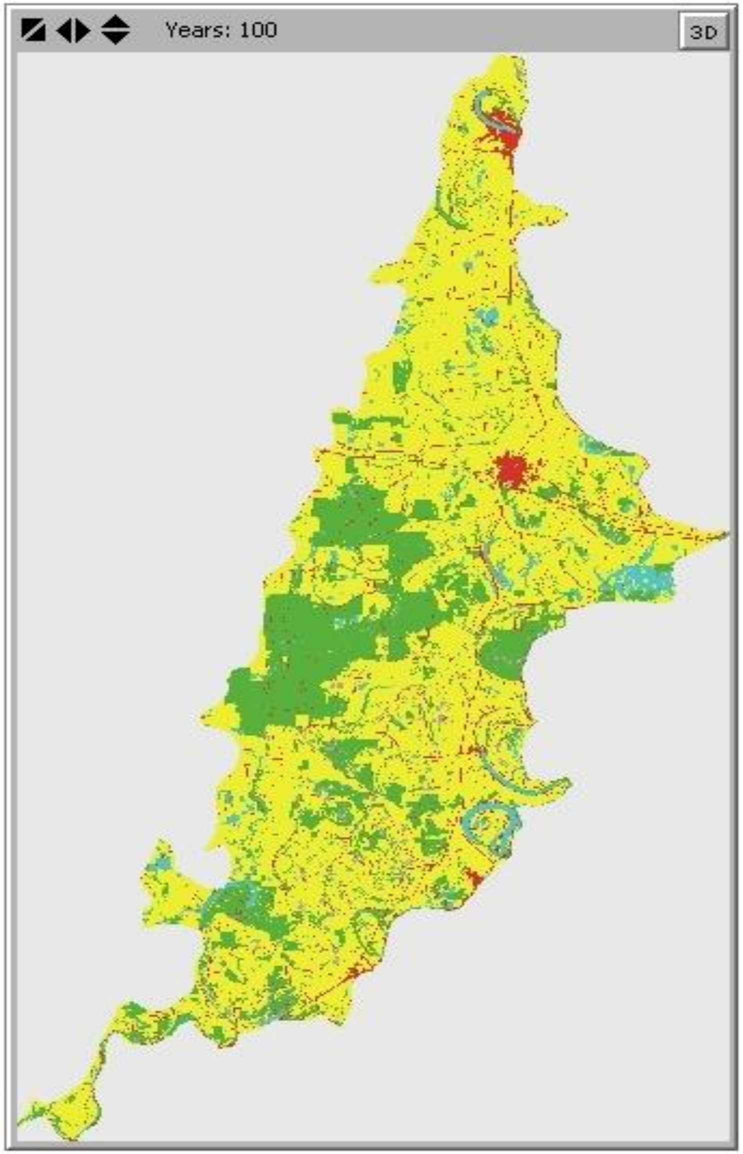
B_j = proportion of the portfolio's initial value invested in security j

s_i = standard deviation of return on security i

s_j = standard deviation of return on security j

Application to the Mississippi Alluvial Valley

Based on data and models we simulate a range of land cover / land use maps that represent various patterns of future use



Simulation of site: Tensas Basin   Scenario: Landscape series   Years: 100
Forest Composition: Nuttall Oak - Willow Oak 60% Overcup Oak - Water Hickory 40%
Active management: Yes   Connectivity level: Max

Bird Species Richness			
Start	End	%Change	Average
10.84	11	1	11
Carbon Stocks [Mg/ha]			
Start	End	%Change	Average
55.1	59	7	54
Duck Energy Days /ha			
Start	End	%Change	Average
254	262	3	260
Nitrate Retention [kg/ha]			
Start	End	Change	Average
5.9	8.8	2.9	7.6
Frog Occupancy Rate			
Start	End	%Change	Average
0.32	0.33	2	0.33
Soil Erosion Potential [Mg/ha/yr]			
Start	End	Change	Average
0.4	0.4	0	0.4

Simulation of site: Tensas Basin   Scenario: Optimized WRP   Years: 100
Forest Composition: Nuttall Oak - Willow Oak 60% Overcup Oak - Water Hickory 40%
Active management: Yes   Connectivity level: Max

Bird Species Richness			
Start	End	%Change	Average
10.98	13.8	25	12
Carbon Stocks [Mg/ha]			
Start	End	%Change	Average
55.4	88	59	69.7
Duck Energy Days /ha			
Start	End	%Change	Average
264	410	55	350
Nitrate Retention [kg/ha]			
Start	End	Change	Average
5.6	12.1	6.5	7.9
Frog Occupancy Rate			
Start	End	%Change	Average
0.34	0.42	23	0.37
Soil Erosion Potential [Mg/ha/yr]			
Start	End	Change	Average
0.4	0.3	-0.1	0.3

Next steps

Simulation in the MAV

- Empirical estimation of the regional production possibility frontiers for regional LULC
- Empirical estimation of the cost optimization model to estimate feasible solutions that ecosystem services minima
- Policy analysis of alternative management strategies

Measuring the impact of a change in access

Estimation of the willingness to accept a change in the quality or supply of ecosystem services due to natural variations in weather and climate trends and the use of the land. A supply-side option value can be estimated in terms of an equivalent option price; the willingness to accept (Shafran 2010).

Shafran, A. Revisiting Cost Benefit Analysis With Supply Uncertainty. 2010. http://dare.colostate.edu/seminars/2010%20links/shafran-cbauncertainty-aug09.pdf.

Thank you

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