Modelling Ecosystem Services Flows from Nature to Humans

Ferdinando Villa, BC3

Ken Bagstad, Gary Johnson, Brian Voigt, Marta Ceroni, Josh Farley

Rosimeiry Portela, Miroslav Honzák, Nalini Rao, Celia Harvey

Dave Batker, Maya Kocian, Jen Harrison-Cox, Jim Pittman

Silvia Silvestri, Kristian Teleki, Mónica Barcellos-Harris
ECOSYSTEM SERVICES in the MILLENNIUM ASSESSMENT
Optimal for communication, raising awareness

<table>
<thead>
<tr>
<th>Supporting services</th>
<th>Regulating services</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Nutrient cycling</td>
<td>- Climate regulation</td>
</tr>
<tr>
<td>- Net primary production</td>
<td>- Disturbance regulation</td>
</tr>
<tr>
<td>- Pollination &amp; seed dispersal</td>
<td>- Water regulation</td>
</tr>
<tr>
<td>- Hydrologic cycle...</td>
<td>- Nutrient regulation...</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Provisioning services</td>
<td>Cultural services</td>
</tr>
<tr>
<td>- Water supply</td>
<td>- Recreation</td>
</tr>
<tr>
<td>- Food</td>
<td>- Aesthetic</td>
</tr>
<tr>
<td>- Raw materials...</td>
<td>- Spiritual &amp; historic...</td>
</tr>
</tbody>
</table>

Ecosystem Services are a multiple-scale problem where provision and use have different modes and scales, and flow across the landscape in different manners. Quantitative, spatially explicit assessment and valuation require more systematic and less general definitions.
A quantitatively based framework for ES

"Supporting services" or ecosystem processes

"Easy" for ecologists to study, impossible to value economically

Hydrologic cycle
Ecosystem water needs
Photosynthesis, net primary productivity
Rainfall interception & infiltration, evapotranspiration
Soil formation
Soil binding by vegetation
Viewsheds, topography

Millennium Assessment ecosystem services, "intermediate services"

Traditionally viewed as ecosystem services, not always easy to conceptualize & value economically

Water supply
Water regulation
Carbon sequestration and storage
Disturbance regulation
Soil retention
Aesthetic value

Benefits for human beneficiaries

"Easy" for economists to value economically

Water for agriculture, electricity generation, households, industry, recreation
Climate stability
Avoided flood damage
Avoided landslide/mudslide/avalanche damage
Avoided erosion
Avoided sedimentation
Sensory enjoyment
ARIES in a nutshell

- A rapid assessment toolkit for ecosystem services and their values; not a single model but an intelligent system that customizes models to user goals.
- Demonstrate a mapping process for ecosystem service provision, use, and flow where most ES assessments only looks at provision.
- “Honest” probabilistic models inform decision-makers of likelihood of all possible outcomes; users can explore effects of policy changes and external events.
- Web based, customizable for specific user groups, geographic areas and policy goals; custom tools implement specific “bottom line”
ARIES in a nutshell

• A rapid assessment toolkit for ecosystem services and their values; not a single model but an intelligent system that customizes models to user goals.

• Demonstrate a mapping process for ecosystem service provision, use, and flow where most ES assessments only looks at provision.

• “Honest” probabilistic models inform decision-makers of likelihood of all possible outcomes; users can explore effects of policy changes and external events.

• Web based, customizable for specific user groups, geographic areas and policy goals; custom tools implement specific “bottom line”
ARIES in a nutshell

- A rapid assessment toolkit for ecosystem services and their values; not a single model but an intelligent system that customizes models to user goals.
- Demonstrate a mapping process for ecosystem service provision, use, and flow where most ES assessments only looks at provision.
- “Honest” probabilistic models inform decision-makers of likelihood of all possible outcomes; users can explore effects of policy changes and external events.
- Web based, customizable for specific user groups, geographic areas and policy goals; custom tools implement specific “bottom line”
ARIES in a nutshell

• A rapid assessment toolkit for ecosystem services and their values; not a single model but an intelligent system that customizes models to user goals.

• Demonstrate a mapping process for ecosystem service provision, use, and flow where most ES assessments only looks at provision.

• “Honest” probabilistic models inform decision-makers of likelihood of all possible outcomes; users can explore effects of policy changes and external events.

• Web based, customizable for specific user groups, geographic areas and policy goals; custom tools implement specific “bottom line”
Project details

- Funded by the US National Science Foundation; follows NSF-funded valuation database project
- NSF grant to UVM, CI, EE from ABI program ($927,000); additional funding from UNEP-WCMC, CI. Project lead moved to BC3, Bilbao in 9/2010
- Meant to construct a new web-accessible modeling platform and a set of innovative, spatially explicit and easy to use ESAV models based on new, strong science, targeted to researchers, governmental decision makers and policy makers, corporate ESR offices.
AREAS of APPLICATION so far

Western Washington:
Carbon, Flood & sediment regulation, Aesthetics

Orange County:
Carbon, Flood regulation

San Pedro River:
Water supply, Carbon, Recreation, Aesthetics

Vermont:
Carbon, Recreation

Dominican Republic:
Sediment regulation

Veracruz:
Water supply

Madagascar:
Carbon, Sediment regulation, Subsistence fisheries, Coastal protection

BC3 FOR CLIMATE CHANGE
Klima Aldaketa Ikergai

www.bc3research.org
Conceptual Ecosystem Service framework
**ECOSYSTEM SERVICES in ARIES**

Benefit-oriented, optimal for quantification, modeling and spatial mapping

---

**Ecosystem Services:**

the effects on human well-being of the flow of benefits from an ecosystem endpoint to a human endpoint at given extents of space and time
EXAMPLE of ARIES ONTOLOGY

Benefits

- Avoided flood damage
  - Flood mitigation
- Climate stability
  - Avoided intense storms
  - Avoided sea level rise
- Snowpack maintenance
- Food source
- Cultural icon
- Recreational amenity
- Nutrient source to ecosystem
- Carbon storage and sequestration

Salmon
EXAMPLE of ARIES ONTOLOGY
EXAMPLE of ARIES ONTOLOGY

Benefits

- Food source
- Cultural icon
- Recreational amenity
- Nutrient source to ecosystem

Beneficiaries
- Subsistence fishermen
- Recreational fishermen
- Commercial fishermen
- Native Americans
- Farmers near stream
- Salmon wildlife watchers

Sea level rise

Snowpack maintenance

Carbon storage and sequestration

Salmon

b3 BASQUE CENTRE FOR CLIMATE CHANGE
Klima Aldaketa Ikergai

www.bc3research.org
EXAMPLE of
ARIES ONTOLOGY

Benefits

Use process
- Existence of salmon
- Observation of salmon
- Catch and release
- Salmon capture

- Food source
- Cultural icon
- Recreational amenity
- Nutrient source to ecosystem

- Intense storms
- Avoided sea level rise
- Snowpack maintenance
- Carbon storage and sequestration
ENABLING TECHNOLOGY: Integrated modeling platform

Multi-scale variability (context)

**SPATIAL**
Vector vs. raster, projections, resolutions

**TEMPORAL**
Continuous vs. discrete, regular vs. irregular

**STRUCTURAL**
Aggregation, choice of variables

Multi-representation

Deterministic
Probabilistic

Classifications
Measurements
Rankings
Currencies
Binary

Explicit semantics

Multi-paradigm

Agent-based
DDE, process-based
Bayesian networks
Static (GIS)

Semantically annotated data & models -> True Modularity, Substitutability
Content mediation and propagation -> Automatic Scaling & Matching

BASQUE CENTRE FOR CLIMATE CHANGE
Klima Aldaketa Ikergai

www.bc3research.org
Session workflow

Databases
- UVM
- Others

Knowledge
- Ontologies
  - Model definitions

Assemble and train custom model

Result observation
- Compute
  - Datasets

User side
- Contextualization
  - Area of interest
  - Ecosystem services
  - Application type
- Web 2.0
  - Command Line
  - Desktop
  - Web service

Visualization and storage

Web 2.0

Basque Centre for Climate Change
Klima Aldaketa Ikergai

www.bc3research.org
The three elements of ES modeling in ARIES

1. provisionsheds

1. Areas of provision of ES and biodiversity

2. Areas of use of ES and biodiversity where beneficiaries are located

3. Flow paths between areas of provision and areas of use

2. benefitsheds
Modeling ES provision

- For entire model or model inputs:
  - Use existing ecological models & their outputs if they exist
  - If no good models exist, build ad hoc models based on expert ecological knowledge
- How much of a given benefit is produced for each landscape district?
“Conventional” ES source mapping

Source mapping estimates the potential value provided by each ES (tonnes of sequestered C in this image).

ARIES builds the source models according to the geological, ecological and climate variables describing the areas.

ARIES is the only approach that also estimates in conditions of data scarcity.

Pink overlay is a visual cue to uncertainty.
Modeling ES sinks

- Depending on the service, sinks could provide a benefit:
  - Absorption of flood water, nutrients
- Or a be a detriment:
  - Visual blight reducing the quality of views
  - Dampening out of values over distance
Example: wave sink model (coastal protection MG)
Modeling ES use

- Similar process to modeling ES provision
  - How do we locate (potential) users of ES on the landscape and quantify their need?
STAKEHOLDER MAPPING
Analysis can be performed for all relevant beneficiary groups

Maps the location and level of need of the potential beneficiaries of each service.

Beneficiary maps can be also made for actual and potential beneficiaries through flow analysis.

Potential beneficiaries can be the object of planning enhanced flows for positive impact assessment.

Blue overlay represents local farming communities and their dependence on soil deposition/erosion.
Service flows will accrue at use locations on the landscape. **Note: Beneficiary regions may be of different scale than provisioning regions**
Identifying carriers & flow paths

Hydrologic services

Aesthetic viewsheds

Carbon sequestration, some cultural values

Recreation, aesthetic proximity, some cultural services

Recreation, flood regulation, many ecosystem goods

www.bc3research.org
Flow mapping
An agent-based approach

- All flow districts start in an empty state
- Edges represent transition probabilities
- Each location contains:
  - Source value
  - Sink and use rates & capacities
  - Sink cache
  - Use cache
  - Carrier cache
4. ES flow propagation

- Carrier used
- Carrier sunk
4. ES flow propagation

Carrier used

Carrier sunk
4. ES flow propagation

Carrier used

Carrier sunk
4. ES flow propagation

Carrier used

Carrier sunk
4. ES flow propagation

Carrier used

Carrier sunk
4. ES flow propagation

Carrier used

Carrier sunk
4. ES flow propagation

Carrier used

Carrier sunk
4. ES flow propagation

Carrier used

Carrier sunk
ES FLOW MAPPING
Flows connect sources and beneficiaries

Critical flow paths show areas most critical to ensure ES flow to the intended beneficiaries.

Regions of high flow density should be protected or enhanced for positive impact.

Regions of lower flow density can be developed without impacting ES provision.

More suited to development

Critical ES flow regions
1. total demand for subsistence fisheries
2. met demand fraction
3. unmet demand fraction.

The model uses poverty, population density, pollution, habitat suitability and harvest data. Problem areas are immediately visible.
VERACRUZ water services: some results

Total demand from:
- Agriculture
- Aquaculture
- Industrial
- Residential

Stream network, elevation, porosity…

Actual flow to beneficiaries

Selected results of flow modeling
- Possible (usable) source
- Actual surface water use
- Inaccessible water source
Novel results from flow analysis

- Analysis of flows wasn’t available before ARIES and computes source, sink, use and flow profiles.
- Flow analysis yields crucial maps to assist decision, such as critical flow contours, **unmet service demand** or **unused service production**.
- Quantification is based on **flow strength, actual use and provision**. **Policy scenarios** can be analyzed by comparing such contextual information, resulting in more accurate, beneficiary-dependent, science-based estimates of values. **Uncertainty** is preserved in flow computation and can be visualized.
Novel results from flow analysis

- Analysis of flows wasn’t available before ARIES and computes source, sink, use and flow profiles.
- Flow analysis yields crucial maps to assist decision, such as critical flow contours, **unmet service demand** or **unused service production**.
- Quantification is based on *flow strength, actual use and provision*. **Policy scenarios** can be analyzed by comparing such contextual information, resulting in more accurate, beneficiary-dependent, science-based estimates of values. **Uncertainty** is preserved flow computation and can be visualized.
Novel results from flow analysis

- Analysis of flows wasn’t available before ARIES and computes source, sink, use and flow profiles.
- Flow analysis yields crucial maps to assist decision, such as critical flow contours, unmet service demand or unused service production.
- Quantification is based on *flow strength, actual need and provision*. **Policy scenarios** can be analyzed by comparing such contextual information, resulting in more accurate, beneficiary-dependent, science-based estimates of values. **Uncertainty** is preserved throughout flow computation and can be visualized.
NEW AGGREGATED INDICATORS

Using information about actual flows, new overall indicators can be computed \((\text{with associated uncertainties})\) for:

- **EFFICIENCY** of provision (actual vs. potential) \(0 - 1\)
- **EFFICIENCY** of use (need met or unmet vs. total) \(0 - 1\)
- **EQUITY** of distribution (winners and losers) \(0 - 1\)
- **TOTALS**: actual use, actual production, unused potential, unmet need

Such indicators can be used as good objective functions in scenario analysis.
TARGETING PRECISE AREAS THROUGH FLOW ANALYSIS
applicable to source, use and sink
TARGETING PRECISE AREAS THROUGH FLOW ANALYSIS
applicable to source, use and sink

User draws source area of interest

Flows trajectories identified

Specific use areas computed

Total value of identified area can be precisely computed;
Analysis can also identify sources that supply given users or sinks in their way.
VALUATION and ARIES: getting real?

ARIES is agnostic about valuation and tries to counteract inaccuracy in the “state of the art” by incorporating:

- explicit uncertainty
- flexible definition of value
- flexibility and innovation in methods
- validation opportunities.

VALUE can be BASED ON:

- ACTUAL or POTENTIAL physical flows or source values
- Concordance value with stakeholder priorities
  - MCA (Electre3, Prometheus, Evamix)
  - AHP
- Economic valuation
  - Bayesian and Econometric modeling can be easily integrated
  - Intelligent benefit transfer methods are in development
Criticality thresholds and valuation

Marginal valuation no longer relevant

Values highly sensitive to supply

Elastic demand: Values change slowly with supply, and change is reversible

Supply determines price, e.g. Cap & auction

Price determines supply (green taxes…)

Natural Capital stocks

Ecological restoration

Marginal value
VALUATION in ARIES can be INFORMED BY CRITICALITY

Users can set thresholds based on scenarios

Beneficiaries are classified based on criticality of actual provision

Provision areas contributing to different beneficiary classes can be computed and valued independently
CONCORDANCE VALUE vs. MONETARY

abstract valuation = concordance between benefit flows and stakeholder priorities

<table>
<thead>
<tr>
<th>Benefit</th>
<th>C</th>
<th>F</th>
<th>W</th>
<th>R</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Climate</td>
<td>1</td>
<td>9</td>
<td>9</td>
<td>9</td>
<td>377</td>
</tr>
<tr>
<td>Flood</td>
<td>1</td>
<td>9</td>
<td>3</td>
<td></td>
<td>455</td>
</tr>
<tr>
<td>Water</td>
<td>1</td>
<td>2</td>
<td></td>
<td></td>
<td>51</td>
</tr>
<tr>
<td>Raw mat</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td>51</td>
</tr>
</tbody>
</table>

Relative importance values for benefits are input by users

Overall value map is recalculated to reflect stated priorities in each scenario of management

Concordance values are the equivalent of value to stakeholders, and vary between 0 (no value) to 1 (complete concordance)
ARIES and economic valuation

- **Primary valuation:**
  - WTP surveys, hedonics, travel cost, consumer expenditures, avoided/replacement cost

- **Secondary valuation:**
  - *Value transfer:* apply primary values from elsewhere to site of interest
  - Function transfer
    - Land use driven
    - Traditional multiple regression
    - Bayesian multiple regression
    - Artificial Intelligence mediated (choice of source studies and transfer function learning)
    - Flow-based

- Ecological-economic modeling
Ex-ante scenario definition
Global change scenarios can be merged with local land use changes

Pre-defined GLOBAL SCENARIOS
  e.g. IPCC climate change

MODEL PARAMETERS
  and THRESHOLDS of
  RELEVANCE (options,
  law or governance
  indications)

Completed scenarios are saved and compared

SPATIAL CHANGE EDITOR
  Hand-draw or upload
  planned intervention,
  e.g. land conversion forest
Routing linear features (roads, pipelines)

Scenario 1: routing that minimizes impact to flows of ES under *business as usual* scenario. A long feature is required to avoid impacting water provision.

Scenario 2: routing that minimizes impact on flows of ES with reforested corridors. Shorter feature offsets reforestation costs.
Identification and ranking of areas for offsetting

ARIES can produce a full ES profile for a set of areas under consideration for offsetting, under baseline or ex-ante intervention scenarios.

Such profiles help selection of areas and documentation of ES offsets.

Multiple Criteria analysis allows customizing the ES profiles to pre-existing priorities or legal constraints.
Scenario based quantitative valuation
Quantify impact of choices on specific stakeholder groups

Two alternative options (different buffer zone widths) evaluated for impact on ecosystem services...

...against the different needs of two different stakeholder groups.
THANK YOU
For more information:

www.ariesonline.org

info@ariesonline.org