Ecosystem Services Research Program

Pollutant-based studies: Nitrogen

July 14-15, 2009  SAB presentation

Our goal: connect the effects of increasing reactive nitrogen to ecosystem services, in order to improve policy and management related to nutrients.
**ESRP Organizational Matrix**

<table>
<thead>
<tr>
<th>Projects and Long term Goals →</th>
<th>LTG 3 Pollutant-Specific Studies: 6%</th>
<th>LTG 4 Ecosystem Specific Studies: 23%</th>
<th>LTG 5: Community Based Demonstration Projects: For National, Regional, State and Local Decisions 28%</th>
<th>Theme Leads</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cross Program Themes and Research Objectives</td>
<td>Nitrogen (6%)</td>
<td>Wetlands (22%)</td>
<td>Coral Reefs (5%)</td>
<td>Willamette (11%)</td>
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<td>Integration, Well-Being, Valuation, Decision Support, Outreach and Education</td>
<td>Ecosystem Services and Human Well-Being (3%)</td>
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<td>LTG 1 9%</td>
<td>Valuation of Ecosystem Services</td>
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<td>Decision Support (6%)</td>
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<td>Outreach &amp; Education to</td>
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<td>Inventory, Map, and Forecast Ecosystem Services at multiple scales</td>
<td>Landscape Characterization and Mapping (12%)</td>
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<tr>
<td>LTG 2 31%</td>
<td>Inventory and Monitoring of Services (14%)</td>
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<td>Modeling (5%)</td>
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<td>Pollutant Specific Studies</td>
<td>Nitrogen (6%)</td>
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<td>LTG 3</td>
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<tr>
<td>Ecosystem Specific Studies</td>
<td>Wetlands (22%)</td>
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<td>LTG 4</td>
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<tr>
<td>Project Area Leads</td>
<td>Rick Linthurst and Iris Goodman</td>
<td>Jana Compton</td>
<td>Janet Keough</td>
<td>Bill Fisher</td>
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<tr>
<td></td>
<td>Hal Walker: Place Based Coordinator</td>
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</table>

ESRP-N began as a row and has expanded to integrate across columns, particularly in LTG2.
Nitrogen Writing & Implementation Team

Jana Compton NHEERL-WED
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Annie Neale NERL RTP
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NRC post-doc NHEERL-WED

Expert hire: John Harrison
Washington State University,
Vancouver, Washington
Outline of presentation

- Background
- Research directions and early results
  - Much new since 2008 SAB review
  - Implementation plan external review May 2009; Final version now in management approvals
  - National, Regional and Place-based work
- Science needs and the end goals
Why Nitrogen and Ecosystem Services?

- Nitrogen is a critical component of energy, food, and fiber production, benefiting humans in many ways.

*from Galloway et al. (2003)*
Why Nitrogen and Ecosystem Services?

- However, N is a major stressor for many ecosystems.

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The Nitrogen Cascade

from Galloway et al. (2003)
Why N and Ecosystem Services for EPA?

- **Air quality regulations**
  - Currently National Ambient Air Quality Standards review process underway for secondary NOxSOx standard (current standards set in 1971)
  - Ecosystem service impacts included in risk assessment

- **Water quality regulations**
  - Nitrogen in top 3 of stressors causing stream impairment
  - Nutrient criteria needed for many streams
  - Seasonal hypoxia, algal blooms, fisheries impact in many areas

- **EPA’s SAB Integrated Nitrogen Committee**
  - Draft report calls for greater intra- and interagency cooperation
  - Ecosystem services viewed as one tool to improve management
Key question for ESRP-Nitrogen:
How do we use nitrogen most efficiently to balance human needs with impacts on water, air and aquatic life?
ESRP-N Conceptual Framework

Human Behavior
- Individual Actions
- Regulations & Incentives
- Markets, Technology
- Policy & Land Management

Human Outcomes
- Quality of Life
- Human Health
- Economic Condition
- Values

Social Context
- Population Growth
  - Globalization
  - Greenhouse Gas
  - Fine Particulates

Disturbance Regimes
- Presses
  - Nutrient Loading
  - Air, Water, & Soil Quality
  - Ozone Exposure
  - Warming & Sea Level Rise
- Pulses
  - Runoff & Discharge
  - Hydrologic Alterations
  - Disease & Pest Outbreaks
  - Drought, Fire, Storm, Flood,

Ecosystem Services
- Provisioning
  - Food, Fiber, & Fuel
  - Clean Water & Air
- Regulating
  - Climate Regulation
- Supporting
  - Denitrification
  - Habitat / Refugia
- Cultural
  - Sense of Place
  - Recreation, Aesthetics

Biophysical Context
- Community Structure
  - Species Composition
  - Biomass & Turnover
  - Trophic Complexity
  - Landscape Pattern

Ecosystem Function
- 1° and 2° Productivity
- Biogeochemical Cycles
- Erosion & Sedimentation
- Eutrophication
- N / P Interactions

Adapted from U.S. Long Term Ecological Research, Decadal Plan (LTER 2007)
ESRP-N “Road Map”

**Identify and bundle Services**

**Develop ESRFs (effects of drivers on ES)**

**Maps of N loads**

**Response of ES bundles to mgmt/policy change**

**Decision Support**

**Available relationships of sensitive ecosystems**
(e.g. Critical Loads, Indicators, TMDLs)

**Develop Ecological Response Functions**

**System-based Studies**
- Terrestrial
- Wetlands
- Freshwater
- Coastal
- Corals

**Place-based Studies**

**Place-based Studies**

**Response of ES bundles to mgmt/policy change**

**Modeling**

**Mapping**

**Place-based Studies**

**Available relationships of sensitive ecosystems**
plus NCEA assessment and OAR and Interagency work on Critical Loads

**Decision Support**

**Create maps of At risk Ecosystems**

Colored boxes identify work with other ESRP themes
ESRP-N Research Themes

- **National Scale Themes**
  - Theme 1: Nutrient Loading (sources, flux and fate)
  - Theme 2: Identification of Services

- **Regional Scale Themes**
  - Theme 3: Nutrient Cycling and Ecosystem Services
  - Theme 4: Tipping Points in Ecosystem Condition and Services

Will include phosphorus where possible. We hope this work will inform management of other nutrients.
Theme 1 – N sources and removal

- **N sources at National Scale**
  - Deposition - CMAQ
  - Confined Animal Feedlots - Mapping
  - Fertilizers – with Mapping
  - Sewage Treatment Plants - Mapping

- **Modeling tools to estimate N removal**
  - SPARROW (workshop fall 2009)
  - Global NEWS (with expert John Harrison)
  - Estuarine fate modeling (AED)
Human activities accelerated transfer of N from the atmosphere to biosphere

Nitrogen fixed from atmosphere
North America early 1990s
25 Tg N yr\(^{-1}\)

Fate of fixed N

Outputs ~40%  
* Rivers, Advection, Commodities
Denitrified to N\(_2\) ~45%  
* By difference
Storage ~15%  
* Plants, Soils, Groundwater

*Greatest Uncertainties

Galloway et al. 2004  Biogeochemistry
Land use and N inputs

• Better land use information and spatial resolution → better N accounting

• Partition fertilizer application by crop type

• National coverage 2011
Modeling and ESRP-N

- National run of NEWS-DIN
- Regional run of NEWS-DIN for Mississippi Basin
- Approaches for estimating N removal by river networks, and lakes/reservoirs
- Comparisons of SPARROW, NEWS, AGNPS (& others) for “weight of evidence” approach to N removal and futures projections - similar to IPCC
NEWS-DIN Model Structure

**N Sources**
- Naturally Fixed N + Non-point-source N (Fertilizer, Manure, Legumes, Atmos. N Dep.)
- Point-source N (Urban Sewage)

**N Sinks**
- Sewage Treatment
- River and Reservoir N Retention + Consumptive Water Use (Primarily Irrigation)

Hydrology

DIN Yield (kg N km$^{-2}$ yr$^{-1}$)

John Harrison, WSU
Scenario DIN yields (kg N/km²/yr)
2030 scenarios vs. mean 2030 rate

→ Different actions = very different outcomes

Global Orchestration

Techno-garden

Order from Strength

Adapting Mosaic

John Harrison, WSU
N removal: Ecosystem service

- uses stream survey data
- scales with stream depth
- estimate for network
- value of stream N removal

Brian Hill and Dave Bolgrien, in review
Theme 2: Identification of Services and Relationship to Nitrogen inputs

Adaptive Management

Δ Human Actions

Δ Drivers & Disturbance

Δ Ecosystem Properties

Δ Ecosystem Services

Δ Human Benefits

Δ Human Actions

Δ Drivers & Disturbance

Δ Ecosystem Properties

Δ Ecosystem Services

Δ Human Benefits

FUNCTION
Nutrient Cycling, Soil Formation, Competition, Reproduction, Mortality

STRUCTURE
Species distribution and abundance, Food Webs, Spatial Organization

ENVIRONMENTAL DRIVERS
- Climate
- Soils
- Nutrient loading
- Acid deposition
- Ozone exposure
- Water use
- Land use

PRESSES AND PULSES OF DISTURBANCE

- Climate
- Soils
- Nutrient loading
- Acid deposition
- Ozone exposure
- Water use
- Land use

FUNCTION
Nutrient Cycling, Soil Formation, Competition, Reproduction, Mortality

STRUCTURE
Species distribution and abundance, Food Webs, Spatial Organization

- Farm & Forest Production
- Air Quality
- Recreation
- Water Quality
- Climate (GHG) Regulation
- Fisheries Production
- Biodiversity
- Biogeochemical cycling
- Aquatic Habitat
- Aesthetics

- Farm, Fish & Forest Harvest
- Drinking Water Provision
- Swimming and Recreation

- Human health
- Farm, Fish & Forest Harvest
- Drinking Water Provision
- Swimming and Recreation

- Individual Decisions
- Markets
- Management
- Regulations
- Technology

Adaptive Management

Δ Human Actions

Δ Drivers & Disturbance

Δ Ecosystem Properties

Δ Ecosystem Services

Δ Human Benefits
State of Science paper 2010 – sources

- ESRP-N literature survey
  - 1900+ references; with Holly Campbell (JD, LLM, MS)

- National Ambient Air Quality Standards process
  - Integrated Science Assessment (ISA) for Oxides of Nitrogen and Sulfur – Ecological Criteria (Final Report 12/08)
  - Risk and Policy Assessments underway
  - These include impacts on Ecosystem Services

- EPA’s Science Advisory Board
  - Integrated Nitrogen Committee (final report Fall 2009)
  - Gulf of Mexico Hypoxia 2007 report

- Multiple recent special issues on denitrification
### Deposition Levels & Ecological Effects

<table>
<thead>
<tr>
<th>Kg N/ha/yr</th>
<th>Ecological effect</th>
<th>Image</th>
</tr>
</thead>
<tbody>
<tr>
<td>~1.5</td>
<td>Altered diatom communities in high elevation freshwater lakes and elevated N in tree leaf tissue high elevation forests in the western U.S.</td>
<td><img src="image1.jpg" alt="Image" /></td>
</tr>
<tr>
<td>3.1</td>
<td>Decline of sensitive lichen species in the western U.S.</td>
<td><img src="image2.jpg" alt="Image" /></td>
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<tr>
<td>4</td>
<td>Altered growth and coverage of alpine plant species in the western U.S.</td>
<td><img src="image3.jpg" alt="Image" /></td>
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<tr>
<td>5</td>
<td>Onset of decline of species richness in grasslands of the U.S. and U.K.</td>
<td><img src="image4.jpg" alt="Image" /></td>
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<tr>
<td>5.5-10</td>
<td>Onset of nitrate leaching in Eastern forests of the U.S.</td>
<td><img src="image5.jpg" alt="Image" /></td>
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<td>5-10</td>
<td>Multiple effects in tundra, bogs and freshwater lakes in Europe</td>
<td><img src="image6.jpg" alt="Image" /></td>
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</tbody>
</table>
EPA-Office of Water National Stream Survey
- Nitrogen is key stressor for stream impairment

Relative Extent of Aquatic Stressors

- Total Nitrogen
- Total Phosphorus
- Riparian Disturbance
- Excess Sediments
- Instream Habitat
- Riparian Vegetation
- Salinity
- Acidification

% of Stream Length in Most Disturbed Condition

Relative Risk to Macroinvertebrate Integrity

Relative Risk Factor

EPA Wadeable Streams Assessment (2006)
## Wetland N service hierarchy

<table>
<thead>
<tr>
<th>Nr</th>
<th>Affected Ecosystem (N-limited)</th>
<th>Ecosystem Effect</th>
<th>Primary Symptom</th>
<th>Secondary Symptom</th>
<th>Ecological Indicators</th>
<th>Impact on Ecological Endpoints</th>
<th>Affected Ecosystem Services</th>
<th>Economic Indicator of Affected Ecosystem Services</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Wetlands</td>
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<td></td>
<td></td>
<td>C &amp; N removal, fishery production, water storage, endangered species loss</td>
</tr>
<tr>
<td>1</td>
<td>Primary production</td>
<td>Fertilization</td>
<td>Above-ground biomass increase</td>
<td>Plant biomass, density, species composition, denitrification, loss of sensitive species</td>
<td>Improved habitat, increased C sequestration, increased N removal, species shifts, changes in water storage¹</td>
<td>Provisioning, regulating, cultural</td>
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<tr>
<td>2</td>
<td>Eutrophication (not N-limited)</td>
<td>Plant succession</td>
<td>Soil and water quality degradation</td>
<td>Species composition, diversity, sulfides, algae blooms</td>
<td>Degraded habitat, HAB risk, decreased N removal, increased N₂O emission</td>
<td>Provisioning, regulating, cultural</td>
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</tbody>
</table>

¹Loss of N-sensitive species in bogs can reduce water retention and storage.

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*Steve Jordan, NHEERL-GED*
Gulf of Mexico Coastal Wetlands
N removal efficiency

- Higher N load – less % N removed
- Values from literature, mostly LA & WWT
- Need values for salt marsh, mangroves, rest of GOM

Virginia Engle EPA-NHEERL-GED et al.
Chlorophyll a – TN relationships for Four Estuarine Embayments

The vertical displacements of these four systems are quantitatively explained by water clarity.

Edward Dettmann et al. (EPA-NHEERL-AED)
Northeastern Lakes Evaluation of Management Alternatives

How will local or regional management choices affect the delivery of ecosystem service benefits to stakeholders?

What tradeoff and conflicts will occur among users?

Who will benefit from management choices and who will pay the cost of unintended consequences and lost opportunities?
Place-based studies are being used to compare methods for a variety of environmental settings, scales, & stakeholder issues, and to look at future scenarios.
<table>
<thead>
<tr>
<th>Research Questions</th>
<th>Theme 1: Nutrient loading</th>
<th>Theme 2: Service Measures</th>
<th>Theme 3: Nutrient cycling</th>
<th>Theme 4: Tipping Points</th>
<th>Place-Based FML</th>
<th>Place-Based Tampa</th>
<th>System-Based Wetlands</th>
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</thead>
<tbody>
<tr>
<td>R1. N delivery and removal</td>
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<td>R2. N impacts on structure and function (ERF development)</td>
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<td>R3. N impacts on multiple services (ESRF development)</td>
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<td>R4. Identification of key services impacted by N</td>
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<td>R5. Human health and well-being impacts</td>
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<td>R6. Human benefits &amp; decisions impacted by N</td>
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<td>R7. Tradeoffs between N and services</td>
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<td>R8. Technology and restoration impacts on N</td>
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<td>R9. Effectiveness of management and policy options to reduce N</td>
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<td>R10. Human decisions and N delivery</td>
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Challenges for ESRP-N

- **Nutrients are a substantial and persistent problem**
  - N removal may decrease with N load
  - Population growth and water treatment (→3°)
  - Climate change interactions

- **Strategic approach.** Nitrogen comes from many sources, has many processes, many fates, many systems impacted. Deciding where to focus our limited energy while not neglecting the whole is key.
  - **Media** - Land, air, water.
  - **Sources** - Power plants, mobile sources, fertilizers, etc.
  - **Scale** - Produce tools and information that can/will be used.
  - **Spatial and temporal variability** - Timing of inputs vs. impacts.
  - **Regulatory and Management options** - sewage treatment, wetland restoration, emission reductions, reducing fertilizer applications, better feedlot management, BMPs, etc.

- **Ecosystem services is new territory.** No reviews or models exist to link N and ecosystem services – we must create these.

- **Models.** How do we best use models to address our questions? Which models?
The end result of this work will be the development of credible, scientifically-based methods to:

- Inventory, measure and map ecosystem services related to reactive nitrogen at multiple scales;

- Connect the effects of reactive nitrogen to ecosystem services;

- Provide regulatory community with sound data and tools that represent the appropriate uncertainties in order to understand N impacts on ecological and human systems, so decisions can be made.
Thank you

Jana Compton, ESRP-N lead
compton.jana@epa.gov
# Timeline for ESRP-N

<table>
<thead>
<tr>
<th>Year</th>
<th>Event Description</th>
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<tbody>
<tr>
<td>FY09</td>
<td>Implementation Plan – April 2009</td>
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<tr>
<td>FY09</td>
<td>Review paper on ES and reactive N – draft fall 2009</td>
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<tr>
<td>FY10</td>
<td>National NEWS model – 2010</td>
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<tr>
<td>FY10</td>
<td>Regional NEWS (MidWest) – 2011</td>
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<tr>
<td>FY11</td>
<td>Ecosystem services and nutrient cycling – site-specific studies</td>
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<tr>
<td>FY11</td>
<td>Sensitive ecosystems and critical loads – 2011</td>
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<tr>
<td>FY12</td>
<td>Report on the value of ecological services provided by and affected by Nr - 2012</td>
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*Theme 1, Theme 2, Theme 3, Theme 4*
Economic N cascade

Economic Nitrogen Cascade: Chesapeake Bay
(Damage cost per tonne reactive nitrogen emitted, by source)

ATMOSPHERE
Climate change
Ozone depletion
Visibility

TERRESTRIAL
Acid deposition damage to materials, agriculture, forestry, and other ecosystem services; ozone damage to human health, agriculture, forestry, and other ecosystem services; particulate matter damage to human health; household soilng.

ESTUARY
Nitrate damage to recreation, fisheries, and other ecosystem services.

TOTAL KNOWN MONETARY DAMAGE
$16,000

Moomaw and Birch 2005 Science in China