NEP-ORD Collaborations on Quantifying the Ecosystem Goods and Services of Estuaries

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August 3, 2017
Tampa Bay Ecosystem Services Research

What is our approach to Ecosystem Goods and Services?

Ecosystem Goods and Services (EGS) are things or related processes in nature that humans benefit from (eg. presence and or quality of fauna or flora, water, air, materials etc.)

Our **Final Ecosystem Goods and Services (FEGS)** approach to decision making separates humans as a specific beneficiary of the rest of nature to determine how our actions ultimately effect our well-being

By focusing on how humans interact with ecosystems we can:
• develop more relatable metrics and indicators and
• constrain the quantification of EGS to things that directly matter to people
Final Ecosystem Goods and Services Approach

Final Ecosystem Goods and Services are the “components of nature, directly enjoyed, consumed, or used to yield human well-being” (Boyd & Banzhaf 2007)

Example FEGS class codes from EPA’s FEGS -Classification System
https://gispub4.epa.gov/FEGS/

Specific numerically coded classes of beneficiaries, their interactions with nature and in what environmental context allows us to classify FEGS metrics and indicators and thereby identify and group beneficial things:

- Across ecosystems for specific types of human uses and/or
- Across different types of uses in a specific ecosystem.
Tampa Bay Ecosystem Services Demonstration Project

ORD project launched in 2007 to develop and demonstrate the application of EGS concepts and approaches within the Tampa Bay community—Key to success was stakeholder engagement through TBEP

Elements of Tampa Bay Demonstration Project

1) Conceptual models, knowledge gap analysis and fieldwork

2) Simple mapping website and interactive tools

3) Restoration and habitat valuation and monetization
Conceptual Modeling

- Conceptual maps defined the pathways from stressors to ecological services.
- Non-landscape change stressors:
  - Nitrogen Loading
  - Phosphorus Loading
  - Mercury Loading
  - Atmospheric CO2
  - Temperature
  - Precipitation
  - Sea Level
- Concept maps linked to ecological response function graphs and reference materials
- Functions ranked by state of knowledge and relative importance in producing eco-services.
Research Prioritization

- Knowledge gap analysis
- Focus on ecological functions associated with maintenance of water of sufficient quantity and quality for designated uses

Relative valuation and fieldwork

Work with Stakeholder Representatives
Relative Ecosystem Services Valuation Index (RESVI)
Several Applications Around GoM including:
• Tampa Bay Regional Planning Council and EPA
• Barataria-Terrebonne National Estuary Program’s Management Council

A 20-year created mangrove chronosequence

Presented at ANEP Meeting November 2010
Marc J. Russell, Michael Osland
Gulf Ecology Division

Osland et al. (2012): Ecosystems 15, 848-866
Public Outreach: Website and Assessment tool

- Lit reviews applied to map ecosystem services for existing community scenarios
- Conceptual model shows decision intervention points lead to changes in well-being

Tampa Bay Reality Check

Challenge: Add 3.2 million people and 1.5 million jobs to the current landscape by 2050

- Produce Alternate Futures for Tampa Bay Region
- Scenario generation: 2050
Among Many Alternatives
Tampa Bay Ecosystem Services Website

Scenario Comparisons with EPA H2O Tool: Publically Available Tool
Example PDF Report

• **Usable Water Value (US$)**: Human activities produce water pollutants. As water moves through a watershed it is filtered by wetlands, forests, and aquatic areas. Replacement costs for removing a pound of nitrogen from various sources range from less than $10 to as high as $855. Costs increase as the nitrogen becomes harder to route towards treatment areas and as simpler, more cost efficient mechanisms for removing nitrogen need to be replaced by more centralized advanced waste water treatment facilities. Value below is summarized for the upstream area of the AOI that user has selected.

  Replacement Value ($US/yr) : 387,254,590

• **Flood Protection Value (US$)**: Description + Replacement Value ($US) : 1,261,566,470

• **Stable Climate Value (US$)**: Description + Social Cost of Carbon Value ($US) : 220,460

• **Usable Air Value ($/ha/yr)**: Description + Annual Value ($/ha/yr ) : 1,610
Restoration of habitat valuation and monetization

Ways to present relevant and relatable results to your stakeholders:

• **Total Dollars**: Infrastructure costs to replace ecosystem function
  – How much would it cost to build a treatment plant to clean water

• **Individual’s Budgets**: Service fee increases if function is lost
  – Increases in customer service fees to maintain system in current state without continued ecosystem function

• **Individual’s financial futures**: Maintenance of current function compared to increasing future demands of a growing population
  – Current natural capability vs infrastructure substituability

• **Other relatable units of value**: How many more WWTP are avoided by maintaining nature
“At just over 1.2 million kilograms N removed per year, bay habitats are equivalent to about two-thirds of the City of Tampa’s, Howard F. Curren advanced wastewater treatment plant’s current annual nitrogen removal rate…the world’s largest denitrification facility”.

We estimate ecosystem function replacement value at $18 per kg N, while current fees are $20-90 per kg N removed.

As fees increase into the future, due to the need for more treatment of a growing populations waste, the value of maintaining ecosystem functions increases as well.

Fig. 2 Annual ecosystem goods production value estimates by habitat type (1982–2010) and extending to when restoration goals are met. 1 As determined by social costs of carbon ($20 per metric ton carbon dioxide). 2 As determined by replacement/abatement costs ($18 per kg N)

https://www.researchgate.net/publication/256486029_Estimating_Benefits_in_a_Recovering_Estuary_Tampa_Bay_Florida
ORD scientists are currently working in cooperation with:

- San Juan Bay Estuary Program (SJBEP),
- Tillamook Bay Estuary program (TBEP), and
- Mobile Bay Estuary Program (MBNEP)

in the development of tools and approaches to investigate the potential impacts of alternative watershed management decisions on benefits to the local communities and potential disparate impacts on vulnerable populations.

This work addresses how watershed land uses, ocean conditions, and weather affect tributary water quality and quantity, estuarine water quality, and the production of ecosystem services such as source water for drinking water, tourism, and fish/shellfish production that coastal communities depend on.
Ways other NEPS can incorporate EGS approaches to meet their missions

1) Conceptual models, knowledge gap analysis and fieldwork

2) Simple mapping website and interactive tools

3) Restoration of habitat valuation and monetization
How TBEP uses ES results

• Maps of existing and future denitrification ‘hot spots’ in the watershed help to identify potential conservation or restoration sites (stream and river corridors) to provide additional N reductions to Tampa Bay.

• Soil accretion rates in estuarine wetlands for carbon sequestration estimates and for SLR scenarios used to help prioritize coastal and estuarine areas for preservation. (Can accretion keep up with SLR?)

• Ecosystem functions and interactions

• Valuation estimates
It’s worth how much?!?
Incorporating valuation metrics into long-term goals in Tampa Bay

Holly Greening, Tampa Bay Estuary Program
Marc Russell, EPA ORD Gulf Breeze Lab
Tampa Bay in the 1970s

Highly eutrophic

Fish kills

Excess N inputs from WWTP and other sources

“The Kitchen” (Hillsborough Bay)

Photo by JOR Johansson
• 45+ public and private partners throughout watershed-collaborative approach to meeting regulatory water quality goals.

• 500 projects and actions

• Consortium developed and agreed to voluntary ‘caps’ on nitrogen loads at 2003-2007 levels for all sources. Caps now incorporated into permits.
Nitrogen load has decreased
Water quality has improved

Annual average chl-a concentration thresholds

Advanced wastewater treatment begins

Stormwater regulations enacted

TBEP formed

NMC formed

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Data source: EPCHC
2016- Seagrass Expansion Continues

Seagrass Coverage Recovery Goal (38,000 acres)

Data: SWFWMD
Clearer water and more seagrass: Good news for fish, wildlife and human users of the Bay.

So what’s the big deal for the other ~50% of people living in our watershed?

Economic valuation metrics
Ecosystem Services: Nitrogen removal (denitrification) value of meeting the seagrass goal

1618 ton N removed per year

$26.4 M per year in replacement value based on WWTP costs

Precluded the need for a new medium-sized wastewater treatment plan

* 9 g N/m²/year  Nitrogen removal of seagrass (Welsh et al. 2001) at $18 per kg N (Birch et al 2011) x 40,295 acres of seagrass

Russell and Greening 2015
CLEAN WATER MEANS MORE THAN YOU THINK

Despite massive growth, water quality in Tampa Bay has improved dramatically in 20 years.

HEALTHY BAY
1 out of every 5 jobs in the TBEP Watershed depend on a healthy bay.

$22B
within all six counties

13%
of economy for all six counties

Dorian Photography Inc.
Tillamook Estuaries Partnership
The Tillamook Estuaries Partnership was officially recognized in 1999 after the completion of the CCMP.

TEP became a non-profit in 2002.

While Tillamook Bay is our “Bay of National Significance”, our study area covers all watersheds and estuaries in Tillamook County.
The TEP Study Area

- Nehalem Watershed
- Tillamook Watershed
- Netarts Watershed
- Sand Lake Watershed
- Nestucca Watershed

With just over 25,000 residents and a strong tradition of forestry, farming, and fishing, clean water and functioning ecosystems are of paramount importance.
CCMP Overview

4 Areas of Concern identified in the 1999 CCMP:

1. Key habitat loss
2. Water quality
3. Erosion and sedimentation
4. Flooding

Each of these focal points directly impacts the social, economic, and resource values of our community.
Land uses and management practices are the major stressors on the systems resulting in:

1) Disconnected floodplains and wetlands
2) Channelization
3) Water quality issues including bacteria, temperature, dissolved oxygen, and sedimentation
4) Coastal acidification
5) Fish passage barriers
6) Lack of large woody debris
7) Explosion of riparian invasive species
8) Many others
The project is still in its early stages but TEP expects the outcomes to inform decisions both in revising its CCMP but also in how we implement its many actions:

- **Water Quantity:** This is an emerging issue in our temperate rain forest and understanding how both human and climate-induced variables affect water quantity will be critical to future planning efforts.

- **Water Quality:** Bacteria is a major driver in our watersheds with multiple 303(d) listings. To date, bacteria has been used as a surrogate for nutrients.
CCMP

- Better understanding of nutrients in our system and an improved understanding of their impacts, if any, to facilitate development of monitoring and management strategies.
- Delineating sources (cow, wildlife, human) of fecal bacteria to more accurately determine the sources of contamination and assist us and partners in developing additional strategies to address those water quality impacts.
- Ocean Acidification is an emerging issue and one which TEP has taken a lead role in bringing partners together to develop a monitoring network along the entire Oregon Coast. This project has facilitated the use of Tillamook Bay as a pilot
CCMP

• **Shellfish:** In the early 1990’s, commercial shellfish harvest closures were (and continue to be) a key issue. As TEP and partners work on the water quality issues, around bacteria specifically, understanding the best habitat needs for harvested shellfish will also support restoration efforts.

• **Ecosystem Services:** Better quantifying human uses to coastal (aquatic/estuarine/near-shore) habitats and the ecosystem services the habitats provide will provide TEP and its partners with the tools we need to communicate and highlight the social and economic values of functioning healthy ecosystems to our community.
Tillamook Case Study: NHEERL/WED Research

Background:

• many water quality (WQ) dependent ecosystem goods & services (EGS)
• history of impairments, but with recent improvements in WQ and provision of EGS
• human & natural sources of change alter biophysical drivers of ecosystem processes

Science/Management Questions:

• How do changes in watersheds, ocean conditions, and weather affect WQ & EGS production in coastal ecosystems?
• What actions will sustain improvements in WQ and EGS production in the face of different types of environmental change?

Consistent with priorities & goals of:

• EPA/ORD National Research Partnership
• Tillamook Estuaries Partnership
## Tillamook Case Study Participants

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<tr>
<th>WED Staff</th>
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Conceptual Model

Human & Natural Drivers of Change

Stressors

Ocean Condition

Ecosystem Goods & Services (EGS)

Coastal Community Well-being
- economic
- health
- social

Watershed Condition

Estuary Condition

Stakeholder Decisions and Actions

Watershed & Rivers

Estuary

Coastal Ocean
Linking Ecosystem Services to Water Quality & Land Uses

Stressors: weather/climate, land uses
- Condition of watershed landscape
  - River/stream water quantity & quality
    - Water source for drinking water
  - Estuarine habitat, DO, temperature
    - Fish (salmon) for recreation & consumption

Stressors: weather/climate, nutrients, SLR, DO, land uses
- Condition of watershed landscape
  - River/stream water quantity, temperature, substrate
  - Estuarine salinity, DO, substrate, depth, Ω
    - Shellfish for consumption

Stressors: weather/climate, FW input, SLR, nutrients, DO, acidification
- Condition of estuarine water & benthos
  - Estuarine habitat, DO, temperature
  - Microbial pathogens

Stressors: weather/climate, FW input, land uses
- Condition of estuarine water & benthos
  - Estuarine salinity, DO, substrate, depth, Ω
  - Microbial pathogens
### Tillamook Case Study – Approach & Endpoints

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**Watershed & Rivers**

**Estuary**

**Coastal Ocean**
Tillamook Bay Basin – Geography

- Kilchis R.
- Tillamook R.
- Trask R.
- Tillamook Bay City
- Garibaldi
- Miami R.
- Wilson R.
- Trask R.
- Tillamook Bay
- Tillamook R.
Tillamook Bay Watersheds Modeling
Water Quantity & Quality

VELMA: Visualizing Ecosystem Land Management Assessments

Interaction of hydrological & biogeochemical processes:
- Hydrological
- Biogeochemical
- Drivers of change

Daily time-step estimates of
- streamflow, dissolved N/C/contaminants export
- soil moisture, temperature

Data sources
USGS – streamflow (1996-present), soil map
USFS – nutrients (2006-2016)
OSU – vegetation cover map, disturbance map
Trask R. Watershed Modeling

- Hydrology model calibrated ($r^2 = 0.86$ for 2007-2016)
- Nutrient calibration in progress
- Next Steps:
  - Simulate environmental change scenarios
  - Apply to four other river watersheds feeding Tillamook Bay
  - Connect to Tillamook Bay hydrodynamics model
  - Salt marsh - tidal module

Model results useful for:
- EGS – drinking water, salmon habitat, timber
- WQ – freshwater, nutrient & carbon loading
Goals of Study

1) Identify sources of nutrients, bacteria, and organic material
   - Stable isotopes
   - Microbial source tracking

2) Role of local drivers on carbonate chemistry and oxygen dynamics

3) Role of nutrients in enhancing acidification thru mesocosm experiments

4) Develop models to predict impacts of climate change on water quality

Collaboration with TEP, ODEQ, ODA, Region 10 (RARE Project), and USGS-Menlo Park

Nutrient sources include:
1) Forest
2) Agriculture
3) Wastewater treatment
4) Nonpoint sources
5) Pacific Ocean
Tributary WQ Studies

Sampling above & below anthropogenic sources since June 2016

• Twice per month for nutrients
• Once a month for stable isotope, microbial source tracking (MST), & carbonate chemistry

Moving downriver there is:

• Elevation of $\delta^{15}$N-NO$_3$ isotope
• Increase in nitrate concentration
  • Potential signature of human/animal waste
  • Denitrification not cause
  • Source(s) unknown, but MST may help

➢ Anthropogenic inputs increase along tributaries between forest and estuary
Fecal Bacteria in Tillamook Bay

Environmental Drivers Affecting Spatial & Temporal Distribution

Analysis of existing data
- fecal coliform bacterial levels (ODA)
- potential drivers: hydrological, tidal, and weather-related variables

Results could be used to develop area-specific models to forecast elevated levels of fecal coliform bacteria
Fecal Bacteria in Tillamook Bay

**Microbial Source Tracking**

- Measurement of a host-associated (animal versus human) molecular marker from environmental waters
- Sampling conducted in coordination with nutrients & nitrate stable isotopes
  - EPA & ODA sampling, since summer 2016

- MST markers detected in high regularity in receiving waters
- Increased detection of human and ruminant MST markers associated with wet weather
  - Similar trends observed in nitrate levels
Hydrodynamic and Biogeochemical Models of PNW Estuaries & Nearshore Ocean

Model domain includes continental shelf and OR & WA estuaries

Includes tidal and river flows

Refining grid for Tillamook Estuary, incorporating LiDAR data

Collaboration with US Navy Research Laboratory

Next steps:
Assess performance of hydrodynamic model & link to CGEM biogeochemical model

Tributary sampling for boundary conditions for nutrients & carbonate chemistry

Link to VELMA watershed model in Tillamook

https://www7320.nrlssc.navy.mil/NLIWI_WWW/ORNFS_WWW/ORNFS.html
Estuary-scale Assessment of Causes and Dynamics of Acidification

Research questions:
• When & where is acidification and hypoxia occurring?
• Role of local drivers versus ocean conditions on occurrence of estuarine acidification and hypoxia

Continuous measurement deployments:
• SAMI pCO₂ & SeaFET pH
• Temperature & salinity
• In situ fluorescence
• Dissolved oxygen

Bi-monthly down-Bay & tributary sampling:
• Water quality [temp, salinity, DO, pH]
• Nutrients & chlorophyll a
• Carbonate chemistry [DIC and pCO₂]
• Natural abundance stable isotopes
  • NO₃ & NH₄, DIC, DOM, POM, sediment
• Respiration rates

Data also used to calibrate & validate hydrodynamic & CGEM models
Laboratory Studies of Nutrient Enhanced Hypoxia & Acidification

Mesocosm experiments with seagrasses, macroalgae, phytoplankton & epiphytes:
• plant responses to nutrient enrichment, temperature, and residence time
• plant influence on acidification

Mesocosm systems:
• 10 independent chambers
• Controlled environmental conditions
• Simulate tidal flushing

Manipulate:
• Temperature
• Flushing rate
• Nutrient levels

Response metrics:
• Plant condition metrics
• pH (discrete samples for carbonate chem)
• Dissolved oxygen
• Nutrient conc.

• Green macroalgae were more dominant at warm temperatures
• Eelgrass more susceptible to disease at 20°C and increased nutrient loads
• At high nutrient loads, plant community may be CO₂-limited
Ecosystem Services

Habitat Suitability Modeling for Harvested Bivalves

Tolerance limits (literature)

<table>
<thead>
<tr>
<th>Sediment (% fines)</th>
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<tbody>
<tr>
<td>Cockle</td>
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<tr>
<td>Softshell</td>
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<td>Gaper</td>
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<td>Butter</td>
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<td>Littleneck</td>
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</tbody>
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Environmental variable maps (interpolated from existing data)

- Sediment
- Bathymetry (m)
- Salinity (PSU)
Habitat Suitability Maps

Validation of HS models

- Simple approach, based on existing natural history information and environmental data
- Robust for multiple species and estuaries
- Useful for:
  - estimating how environmental change may alter the distribution of bivalve habitats
  - prioritizing areas for in-Bay activities
Literature weight of evidence (WOE) linking coastal habitats to EGS beneficiaries

Planned NEP case studies to evaluate application for resiliency planning
Tillamook Case Study

Uses of the Anticipated Results:

• Decrease risks to WQ & EGS production
• Evaluate how changes in land cover could affect riverine and estuarine WQ & EGS production
• Evaluate likely outcomes of restoration activities

Partnership with TEP & R10 (RARE)

• Co-develop decision contexts, priorities, and scenarios
• Outreach & liaison with community, stakeholders, and agencies
• Connection to other relevant research
• Sharing knowledge on history, ecology, and community of Tillamook estuary and watershed
• Participate in research: site selection, field assistance, data sharing, interpretation