Review of the Impacts of Land Use and Land Cover Change Effects in Coastal Zones

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LCLUC Conceptual Scheme

- socio-economic drivers
- land use/cover change
- ecol/biogeochem consequences

Feedback

Focus of talk

Tools
- observations
- modeling
- prediction
Topics:

- **Approaches**
  - Direct experiments (usually deforestation)
    - Primarily hydrologic consequences
  - Space for time swaps
    - Based on spatial variations in land cover
- How does stream flow and chemistry vary with land cover/use?
- What does hydrochemical modeling tell us?
Historical Reconstructions

- Socioeconomic drivers
  - historical data or records
- Land use/cover
  - maps, aerial photos, satellite imagery
- Biogeochemical consequences
  - data rarely available
LULCC in the Choptank River Basin, MD

1990 Landuse
- Agriculture: 1070 km² or 52%
- Developed: 96 km² or 5%
- Feedlots: 11 km² or 1%
- Forest: 542 km² or 26%
- Wetlands: 39 km² or 2%
- Water: 300 km² or 15%

Benitez and Fisher, 2001
Focus of the talk:

- Effects of changes in land use/cover on
  - export of materials from land to water

- Two components:
  - stream discharge (storm response, water yield)
  - “water quality” = conc. of diss. or part. materials
    - Low conc = good water quality

- Effects on soils
Approach:

- Ideal situation:
  - monitoring WQ during land use/cover change
  - rarely observed (no colonial water data)
  - sediment cores reveal erosion and plant changes
    - Good validation data, but not spatially explicit

- Alternative: “space for time swaps”
  - Use variations in space to infer trajectory of a time course
  - Sample WQ in basins with varying amounts of land cover
  - Substituting spatial variations for temporal ones
Approach (con’t):

Problems:
- Assumes common temporal trajectory for all land cover conversions
  - sampling in space = sampling in time
- Ignores real spatial heterogeneity with differing trajectories and histories
1 year of stream sampling (~1990)
Lower forest cover is associated with higher N conc.

Extrapolation of regression line agrees with data for undeveloped basins.

Clark et al. (2000):
TN in undeveloped basins: 0.26 mg N L⁻¹
The two main land covers are inversely correlated.

%ag = 96 - 0.98 * %for

$r^2 = 0.96**$

Increasing agriculture and decreasing forest result in higher total N in streams, primarily as nitrate.
Increasing agriculture may have a more linear relationship with stream N over a narrower range of % ag and exhibit geological effects (Jordan et al 1997).
Agriculture and human populations are the primary cause of increased N in groundwater.
Groundwater nitrate increases with housing density in unsewered areas.

Cape Cod: Valiela et al. 1992
Fertilizer applications and nitrate in groundwater on the Delmarva Peninsula

Groundwater nitrate has also increased exponentially over the same period from 1945-1980.

Fertilizer applications increased exponentially from 1945-1980.
Total P, primarily sampled at base flow, showed no clear relationship with land cover.
Saturating for plant uptake

Source: Sims et al. 1998

Depth, cm

Soil test P (Mehlich 1) (mg/kg)

Fertilized control
Low Swine Effluent Rate
Medium Swine Effluent Rate
High Swine Effluent Rate
Increases in soil P lead to increased leaching of P in overland flow. Source: Carpenter et al. 1998
Hydrology (some direct experiments)

- Forest removal and urbanization
  - Increased rate of response to a storm and loss of baseflow
    - Less capacity to retain water (= lower baseflow)
  - Total volume of water increased
    - Less evapotranspiration (= more stormflow)
Urbanization increases stream velocity and total runoff.

Increased velocity and bank erosion.

The effect of urbanization on storm runoff.

Source: Chow et al. 1988
Impervious surfaces decrease stream baseflow between events.

Source: Klein 1979
Watershed export

- Export = water flow * concentration
  - Increased rates of water flows
  - Increased concentrations in stream water
- Conversion from forest to ag to urban
  - Exports greatly increased
- Often normalized per unit area watershed
  - kg ha$^{-1}$ y$^{-1}$ (area yield coefficients)
Agriculture and human populations are the primary cause of increased mobility of N and P in watersheds and export in streams.

Useful estimates from classified imagery.
Other relationships with land use:

- Potassium and agriculture
- Urban and ag land uses (C, sed)
- EMAP surveys of land cover effects (NO$_3^-$, Cl$^-$)
New England basins

Source: Driscoll and Whitall, unpub.
Hudson River Subbasins

source: Howarth et al. 1991
EPA EMAP strategy:

- Sample a stream once in time
- Sample extensively in space
- Use land cover to understand stream chemistry

\[
\log(\text{conc}) = a_1(LULC_1) + \ldots + a_n(LULC_n) + \text{error}
\]
EPA Region III: Intensive spatial sampling, single stream water sample.
[Cl⁻] was primarily associated with urban areas and road salt applications. Modeled values agreed well with observed.
[NO$_3^-$] was exponentially associated with forested land, much as we observed in the Choptank.
Relationships with soils:

- N transfer coefficient in Choptank subbasins
  - Use land cover to estimate \([\text{NO}_3]\) in groundwater
  - Compare with \([\text{NO}_3]\) in stream base flows
    - Base flows are derived from groundwater flows
  - Base flow \([\text{NO}_3]\) < estimated groundwater \([\text{NO}_3]\)
    - Some \(\text{NO}_3\) is lost as groundwater moves to streams
Choptank Basin, transfer of groundwater NO$_3$ to baseflow

$r^2 = 0.55$ **
What can we learn from hydrochemical modeling?

- Calibrate model to current conditions
- Model experiments
  - Withhold fertilizers
  - Eliminate human wastewaters
  - Compare with all forested condition
<table>
<thead>
<tr>
<th>polygon</th>
<th>% urban</th>
<th>% ag</th>
</tr>
</thead>
<tbody>
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<td>Broad Cr.</td>
<td>2</td>
<td>77</td>
</tr>
<tr>
<td>Tilghman</td>
<td>29</td>
<td>46</td>
</tr>
</tbody>
</table>
1. Large wastewater effect: ~50% increase

2. Current P export 400% of forested scenario

1. Strong fertilizer effect: 200-300% increase

2. Strong wastewater effect: 500-900% increase

3. Current N export ~20 X forested scenario
Summary of land use effects

- Of all land covers, forests have the lowest water yields and export of materials
  - Highly retentive
- Agriculture increases N and K losses via enrichment of groundwater $K^+$ and $NO_3^-$
- Soils moderate ag N losses and accumulate P
  - Release P from surface materials during storm events
- Urban and agricultural areas export 10-100 x sediment and C as forested areas
- Urban areas increase water yields, export NaCl from road salt use, and increase $NO_3^-$ in groundwaters
IT IS HARD WALKIN' ON THIS STUFF.

YEP, SON, WE HAVE MET THE ENEMY AND HE IS US.
TN and NO$_3$ data from the Chester were similar to those in the Choptank, but there is no clear relationship with agriculture.

Why this difference?
Four of the stations were tidal in summer, and in-stream loss of NO₃ reduced annual concentrations. Three other stations had unusually well-drained soils, leading to greater leaching losses of NO₃.
The activities of human populations increase nitrate concentrations in rivers and N export from large river basins.

Source: Peierls et al (1992)
\[ \text{Ca}^{2+} = 16.7 + 0.5X, \quad R^2 = 0.57 \]

Choptank example

- Degraded water quality now observed
  - EPA 303d list of impaired waters
- Short history of observations
- Little undisturbed information available
Choptank River near Greensboro

USGS: 1964-2001

$r^2 = 0.32$, $p < 0.01$

slope = +0.73 $\mu$M y$^{-1}$ (+0.010 mg NO$_3$-N L$^{-1}$ y$^{-1}$)
Choptank River near Greensboro


$r^2 = 0.08$ NS
Application of area yield coefficients to land cover yielded good agreement with observed river export.

Source: Marchetti and Verna (1992)
What about wastewater (sewage) inputs to the Choptank?
There is about 5-7 millions of gallons of sewage entering the Choptank per day from 11 licensed WWTPs.
Concentrations of N and P have decreased over time due to plant management.

Discharge volumes have increased over time due to population growth.
Despite increases in discharge volume, P fluxes are down, and N fluxes have remained stable due to improved WWTP management.
Agriculture is the primary source of N, and wastewater + agriculture are primary sources of P in the Choptank basin.

What has been happening to estuarine water quality in the Choptank?
Algae and turbidity are increasing over time in the Choptank estuary.

Choptank River station ET5.2, 1985-1999

- Chla increasing, $r^2 = 0.28$ *
- TSS increasing, $r^2 = 0.35$ *
- Secchi decreasing, $r^2 = 0.48$ **
Effects of land use on water quality:

- Fertilizer applications have greatly increased nitrate in groundwater since 1950.
- N concentrations in streams are elevated in basins dominated by agriculture.
- Human wastewaters are high in P and are an important source if only secondary treatment is used.
- The increasing size of human populations is a primary driver of eutrophication.
Management Recommendations:

- Tertiary treatment of wastewater
  - P removal will have more impact than N
- Target BMP application to high load subbasins dominated by agriculture
  - Winter cover crops
  - Stream buffers
  - Restored wetlands
- Integrate management of oysters, SAV, TSS, and nutrients
  - Let the benthic biota help improve WQ
How can we reconstruct the land use history of the Choptank basin?

- Satellite imagery after 1972
- Aerial photographs after 1936
- Historical maps after 1845
- Socioeconomic statistics when available
Counties in Choptank Basin:
Queen Anne, MD
Talbot, MD
Dorchester, MD
Caroline, MD
Kent, DE
Socioeconomic Statistics

- # people
- Food requirements
- Exports
- Crop yields
- Calculate land needed
Summary of the land use history in the Choptank basin

- Initial settling and tobacco production resulted in scattered deforestation.
- After 1750, wheat production resulted in rapid expansion of agriculture.
- 1900 represented the agricultural maximum in the Choptank, about 75% of land use.
- Urban areas have been small, but growing exponentially with the human population.
Exponential expansion *(urbanization)* of small towns was a consistent pattern observed in the GIS coverages of the Choptank basin.
Annual Discharge at Greensboro, MD (01491000)

Annual mean cfs

WY mean cfs for 1949-2000, $r^2 = 0.01$ NS

mean discharge

WY mean cfs for 1985-2000, $r^2 = 0.25$ *
1990 Landuse.

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Choptank River near Greensboro

[NO₃ line]

USGS: 1975-2000

$r^2 = 0.20$  NS
Approach (con’t): 

- Assumption: spatially varying intensity can illustrate
  - Trajectory
  - Consequences
    - Stream discharge (some direct observations)
    - Water quality
Trajectories of LCLUC effects

“water quality”

% agriculture

basin A

basin B

basin C

time

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Trajectories of LCLUC effects

“water quality”

% agriculture

basin A

basin B

basin C

time