EXPLORING THE POTENTIAL FOR SPRAWL
ALTERNATIVES TO REDUCE ENVIRONMENTAL DEGRADATION AND ACCOMMODATE ECONOMIC GROWTH

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Urbanization: A Strategic Opportunity

“We do not know the effects of different urban forms, densities, land use mix, and alternative infrastructures. We do not know, for example, how clustered versus dispersed and monocentric versus polycentric urban structures differently affect ecological conditions.”

Marina Alberti, 2010

• In information vacuum we routinely exchange nature’s benefits for economic growth (Polasky et al 2013)

• Needed are studies that analyze the relationship between urban pattern and ecosystem performance
Plausible Patterns of Urban Growth

- **Status Quo**, or business as usual
- "Sprawl", disjunct and leapfrog development
- **Infill**, or growing around existing infrastructure
- Entitle increased density, thereby reducing demand for land consumption
- De-regulate, increase per capita land consumption

*US

12/08/2016
Assessing Landscape Performance

- Realistic Projections
- Change over time

FUTURES (Meentemeyer et al. 2013)

Scenario analyses of urban growth patterns
Caveats:

- Results drawn from a simulated study system
- Correspondence with “real world conditions” untested
- Limit analyses to comparisons of alternative futures

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- Many ecosystem services are not monitored
- Practice should incorporate a wide range of services
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- Results drawn from a simulated study system
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- Many ecosystem services are not monitored
- Practice should incorporate a wide range of services
Study System: Rapidly Growing Charlotte NC

2006
Population: approx. 1.1 million
(+235% since 1976)
Area: 346,000 ha

Long urban gradient ideal for sampling
46% Canopy Cover*, Tops Med-Large US Cities
*American Forests 2010

NSF ULTRA-Ex Site 2009-2012
Published Studies
Meentemeyer et al. 2013
Bendor et al. 2014
Dorning et al. 2015a
Dorning et al. 2015b
Smith et al. In review

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Scenario analyses of urban growth patterns
Which Fragments More?

Fragmentation

Development    22.68%
Forest         53.22%
Agriculture Intensive 6.81%
Agriculture Passive 16.62%
Water          0.50%

Forest/Agricultural Land Covers

Subwatershed Delineation

Start 2006

Fragmentation Analyses

Extant Development
Forest/Agricultural Land Covers
Subwatershed Delineation

Scenario analyses of urban growth patterns
Scenario analyses of urban growth patterns

### Fragmentation Analyses

- **Projected Development**
  - Forest/Agricultural Land Covers:
    - Forest, 30.67%
    - Agriculture Intensive, 4.70%
    - Agriculture Passive, 10.27%
    - Water, 0.50%
  - Development New, 31.32%
  - Development Extant, 22.68%

- **Extant Development**
  - Development Extant, 22.68%

### Status Quo 2030

Which Fragments More?

### Fragmentation Analyses

- Status Quo
- 2030
Scenario analyses of urban growth patterns

**Projected Development**
- Forest/Agricultural Land Covers
- Subwatershed Delineation

**Development**
- Extant Development, 22.68%
- Projected Development, 30.11%
- Development New, 10.98%
- Extant Development, 30.96%

**Agriculture**
- Intensive, 4.80%
- Passive, 10.98%
- Forest, 30.96%
- Water, 0.50%

**Fragmentation Analyses**

**Sprawl 2030**
Scenario analyses of urban growth patterns

**Which Fragments More?**

- **Fragmentation**
- **Habitat**
- **Nitrogen**
- **Phosphorus**
- **Carbon**
- **Revenues**

### Infill 2030

- **Development New, 32.30%**
- **Development Extant, 22.68%**
- **Forest, 29.49%**
- **Agriculture Intensive, 4.90%**
- **Agriculture Passive, 10.18%**
- **Water, 0.50%**
Scenario analyses of urban growth patterns

Projected Development
- Forest/Agricultural Land Covers
- Subwatershed Delineation

Extant Development
- Development Extant 22.68%

Projected Development
- Development New 36.83%

Forest
- Forest 26.55%

Agriculture
- Intensive 4.30%
- Passive 9.20%

Water
- Water, 0.50%

Fragmentation Analyses

Which Fragments More?

+ Land Consumption

2030
Scenario analyses of urban growth patterns

### 12/08/2016

**Projected Development**
- Forest, 34.79%
- Agriculture Intensive, 5.05%
- Agriculture Passive, 11.39%
- Water, 0.50%
- Development New, 25.59%
- Development Extant, 22.68%

**Extant Development**
- Forest, 34.79%

**Fragmentation Analyses**

**Habitat**

**Nitrogen**

**Phosphorus**

**Carbon**

**Revenues**

### Which Fragments More?

**+ Density**

**2030**

**Fragmentation Analyses**

- Extant Development
- Projected Development
- Forest/Agricultural Land Covers
- Subwatershed Delineation

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Scenario analyses of urban growth patterns

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How Does Habitat Change?

- Fragmentation
- Habitat
- Nitrogen
- Phosphorus
- Carbon
- Revenues

Urban Tolerance
Vertebrates
- Intolerant
- Partial Tolerance
- Moderate Tolerance
- High Tolerance
- Water

Start
Sprawl
+ Land Consumption
Status-quo
Infill

Model source: SE GAP

+ Density

12/08/2016

Scenario analyses of urban growth patterns
How Does Habitat Change?

- Fragmentation
- Habitat
- Nitrogen
- Phosphorus
- Carbon
- Revenues

**Start**

**Sprawl**

Significant Change from Status Quo
- Green: Increase
- Red: Decrease

+ Land Consumption

**Urban Tolerance**

- Vertebrates
  - Intolerant
  - Partial Tolerance
  - Moderate Tolerance
  - High Tolerance
  - Water

**Status-quo**

**Infill**

*The mean difference is significant at the 0.05 level*
How Does Habitat Change?

Fragmentation
Habitat
Nitrogen
Phosphorus
Carbon
Revenues

Urban Tolerance
Vertebrates
Intolerant
Partial Tolerance
Moderate Tolerance
High Tolerance

Start

How Does Habitat Change?

Urban Tolerance
Intolerant
Partial
Moderate
High

Water

+ Density

Scenario analyses of urban growth patterns
Which Exports Least N NPS Pollution?

Start

Sprawl

+ Land Consumption

N Exports kg/ha

High: 26.64

Low: 0.1

0

Water

Fragmentation

Habitat

Nitrogen

Phosphorus

Carbon

Revenues

Status-quo

Infill

Model source: InVEST 3.1x

+ Density
Which Exports Least N NPS Pollution?

Start

Sprawl

Significant Change from Status Quo

+ Land Consumption

+ Density

Status-quo

Infill.

N Exports

kg/ha

High : 26.64
Low : 0.1
0
Water

The mean difference is significant at the 0.05 level.
What Are The Costs Over Time?

Start

Fragmentation
Habitat
Nitrogen
Phosphorus
Carbon
Revenues

NC Nitrogen offset Fee = $43.85/kg

Present value of the cost of N offsets=

N kg/yr * $43.85/kg * 24 yrs, discounted 4.0%/yr

N Exports
kg/ha

High : 26.64
Low : 0.1
0
Water

Effluent
High : 12.64
Low : 0.1
0
Water

What Are The Costs Over Time?
Scenario analyses of urban growth patterns

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Which Exports Least P NPS Pollution?

- Fragmentation
- Habitat
- Nitrogen
- Phosphorus
- Carbon
- Revenues

Start
Sprawl
+ Land Consumption
Status-quo
Infill

P Exports Kg/ha

- High: 5.71
- Low: 0.20
- 0
- Water

Model source: InVEST 3.1x
**Which Exports Least P NPS Pollution?**

- Fragmentation
- Habitat
- Nitrogen
- Phosphorus
- Carbon
- Revenues

---

**Start**

**Sprawl**

**Status-quo**

**Infill**

Significant Change from Status Quo
- Decrease
- Increase

- + Land Consumption
- + Density

**P Exports**
- Kg/ha
  - High: 5.71
  - Low: 0.20
  - 0
  - Water

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- The mean difference is significant at the 0.05 level

12/08/2016
What Are The Costs Over Time?

NC
Phosphorus offset Fee = $524.32/kg

Present value of the cost of P offsets =

N kg/yr * $524.32/kg * 24 yrs, discounted 4.0%/yr
Which Sequesters the Most Carbon?

- Fragmentation
- Habitat
- Nitrogen
- Phosphorus
- Carbon
- Revenues

Start

C Storage (Mg per ha)
- High: 271.44
- Low: 13.83
- Water: 0

Sprawl

C Sequestration
- Mg/Pixel
- High: 17.38
- Unchanged: 0
- Low: -18.17

Status-quo

Infill

+ Land Consumption

+ Density

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Scenario analyses of urban growth patterns
Which Sequesters the Most Carbon?

- Fragmentation
- Habitat
- Nitrogen
- Phosphorus
- Carbon
- Revenues

Start

Sprawl

Significant Change from Status Quo

- Increase
- Decrease

Status-quo

Infill

+ Land Consumption

+ Density

C Storage (Mg per ha)
- High : 271.44
- Low : 13.83
- Water : 0

C Sequestration
- High : 17.38
- Unchanged : 0
- Low : -18.17

Which Sequesters the Most Carbon?

- The mean difference is significant at the 0.05 level.
Societal Cost of Carbon = $60/Mg

Present value of C sequestration =

C Mg/yr * $60.00/Mg * 24 yrs, discounted 4.0%/yr
Research Design

**Landowner Revenues**
$$/ha/yr$

- $0$ (Water)
- $65.57$
- $88.83$
- $364.89$
- $12,140.48$

- **Start 2006**

- **Estimate of net returns to landowners from urban development, forests, cropland and pasture, 2015 dollars ($USD/year)**
- **Source:** Lubowski et al 2008, cited in Polasky et al 2010.
- **Character:** Spatially implicit
- **Method:** Relate land covers to empirically derived net return estimates
- **Caveats:** Revenues for + Density and + Land Consumption adjusted to per-pixel population (scaling factor 1.4, 0.6 respectively)

Scenario analyses of urban growth patterns
Which Generates the Most Returns to Landowners Over Time?

Start

Sprawl

+ Land Consumption

Status-quo

Infill

+ Density

Landowner Revenues

$/ha/yr

$0 (Water)

$65.57

$88.83

$364.89

$12,140.48

USD$ 2015

Which Generates the Most Returns to Landowners Over Time?

Present value of returns of land 2007-2030 ($USD 2015, discount rate 4%)
Which Is Least Costly Environmental Services (N, P, C)?

- **Costs, Environmental Services**
- **Trade-offs**
- **Role of Configuration**

### Costs, Environmental Services

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Offset N Exports</th>
<th>Offset P Exports</th>
<th>Avoided Cost</th>
<th>Combined Suite</th>
<th>Environmental Services</th>
</tr>
</thead>
<tbody>
<tr>
<td>Status Quo</td>
<td>$29.5</td>
<td></td>
<td></td>
<td></td>
<td>$30.2</td>
</tr>
<tr>
<td>Sprawl</td>
<td>$28.3</td>
<td></td>
<td></td>
<td></td>
<td>$30.2</td>
</tr>
<tr>
<td>Infill</td>
<td>$30.2</td>
<td></td>
<td></td>
<td></td>
<td>$30.2</td>
</tr>
<tr>
<td>+LC</td>
<td>$29.5</td>
<td></td>
<td></td>
<td></td>
<td>$30.2</td>
</tr>
<tr>
<td>+DEN</td>
<td>$28.3</td>
<td></td>
<td></td>
<td></td>
<td>$28.3</td>
</tr>
</tbody>
</table>

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How Do Environmental Costs Compare with Revenues?

Costs, Environmental Services
Trade-offs
Role of Configuration

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Combined N, P, C Costs</th>
<th>Estimated Returns to Landowners</th>
</tr>
</thead>
<tbody>
<tr>
<td>Status Quo</td>
<td>$30.2</td>
<td>$760.6</td>
</tr>
<tr>
<td>Sprawl</td>
<td>$29.5</td>
<td>$646.9</td>
</tr>
<tr>
<td>Infill</td>
<td>$32.2</td>
<td>$636.4</td>
</tr>
<tr>
<td>+LC</td>
<td>$32.1</td>
<td>$655.3</td>
</tr>
<tr>
<td>+DEN</td>
<td>28.3</td>
<td>$495.1</td>
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</tbody>
</table>
What are Trade-offs with Biodiversity?

Costs, Environmental Services

Role of Configuration

INTOLERANT VERT. HABITAT (ha)

Landscape Net
For a Suite of Values

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Costs</th>
<th>Environmental Services</th>
</tr>
</thead>
<tbody>
<tr>
<td>Status Quo</td>
<td>$616.8</td>
<td>$463.0</td>
</tr>
<tr>
<td>Sprawl</td>
<td>$606.9</td>
<td>$463.0</td>
</tr>
<tr>
<td>Infill</td>
<td>$623.2</td>
<td>$463.0</td>
</tr>
<tr>
<td>+LC</td>
<td>$463.0</td>
<td>$463.0</td>
</tr>
<tr>
<td>+DEN</td>
<td>$732.3</td>
<td>$732.3</td>
</tr>
</tbody>
</table>
Are There “Traps” to Avoid?

Costs, Environmental Services

Trade-offs

Role of Configuration

Urban Tolerance

Sprawl

Infill

Nitrogen Exports

Sprawl

Infill

Phosphorus Exports

Sprawl

Infill

Carbons Sequestration

Sprawl

Infill

Trap 1. Aspatial Thinking >> Place Matters

Trap 2. “One size fits all” thinking

Trap 3. Failure to embrace “density”

Change from SQ:

Green: -1
Red: 1

*The mean difference is significant at the 0.05 level.