Controls on arctic tundra vegetation dynamics on the Yamal Peninsula, Russia – an integrative study using ArcVeg and multi-temporal Landsat imagery

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Objectives:
• Understand ecological controls on tundra vegetation on the Yamal Peninsula, Russia
• Detect land use changes and effects on tundra vegetation

Methodology: Ecosystem model and remote sensing

Outline:
• ArcVeg and modeling
• Change detection based on multi-temporal Landsat imagery
• Summary
Factors affecting arctic tundra vegetation

- Physical Controls
  - Soils
    - Soil organic nitrogen
    - Active layer depth
  - Climate zones
    - Temperature
    - Precipitation
  - Animal Husbandry
    - Grazing
    - Trampling

- Biological Controls

- Anthropogenic Factors
  - Climate Warming
    - Temperature increase
    - GHG, permafrost ...
  - Land Use Change
    - Population increase
    - Road, oil/gas development
Simulating effects of soils, grazing, climate warming on tundra community dynamics along the Yamal P.

Study background:
• Lack of understanding on the interactive effects of soil nutrients, climate, and animal grazing

Research questions:
• (1) How do SON levels affect tundra vegetation in terms of total biomass and net primary productivity (NPP) and responses to warming?
• (2) How does grazing affect tundra vegetation in terms of total biomass and NPP and responses to warming?
• (3) How do SON, grazing and climate interact to affect tundra vegetation?
ArcVeg – a vegetation dynamics model

- Climate (Bioclimatic subzones - spatial)
- Climate warming (temporal)
- Grazing
- Soil nutrients

Epstein et al. 2000
Controls on tundra vegetation dynamics on the Yamal Peninsula, Russia – Model input

- ArcVeg simulations with field collected data (subzones, soils)
  - Bioclimate subzones
  - Soil nutrients – soil organic nitrogen
  - Grazing: 0.1, 25% and 0.5, 25%
  - Warming: 1 subzone warming/ 2°C warming

Walker et al. (2009)
Model Validation in NAAT

Above Ground Biomass Comparison (g m\(^{-2}\))

- After Warming
  - \(y = 1.2106x\)
  - \(R^2 = 0.5712\)

- Before Warming
  - \(y = 0.8038x\)
  - \(R^2 = 0.6326\)
Model Validation in YAT

Above Ground Biomass Comparison (g m\(^{-2}\))

- **After Warming**
  - \(y = 0.5035x\)
  - \(R^2 = 0.4404\)

- **Before Warming**
  - \(y = 0.3251x\)
  - \(R^2 = 0.3375\)
Model Validation in YAT - MOSS

Above Ground Biomass Comparison (g m$^{-2}$)

- **Model Simulated Biomass (g m$^{-2}$)**
- **Observed Biomass (g m$^{-2}$)**

**Equations and Correlation Coefficients:**

- After Warming:
  
  \[ y = 0.8674x \]
  
  \[ R^2 = 0.2261 \]

- Before Warming:
  
  \[ y = 0.5455x \]
  
  \[ R^2 = 0.361 \]
SON determines how much TB/NPP each site can support

The magnitude is modified by climate subzones

Warming causes more absolute increase in TB/NPP for nutrient rich sites; while more relative increase in TB/NPP in nutrient poor sites.
Above ground biomass of each PFT simulated with ArcVeg shows that:

- SON significantly affects PFT richness in each site.
- Response to warming is more significant in high SON site than in low SON site.
- Note the changes in tall shrubs after warming.
Results

Soil and Grazing effects (Total biomass and NPP)

- Increase grazing frequency generally causes **decrease in TB/NPP**

<table>
<thead>
<tr>
<th>Subzone</th>
<th>SON (g m⁻²)</th>
<th>Mean Total Biomass (g m⁻²)</th>
<th>Mean NPP (g m⁻² Year⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LV-1 E</td>
<td>570</td>
<td>87 ± 15</td>
<td>122 ± 18</td>
</tr>
<tr>
<td>LV-2 E</td>
<td>148</td>
<td>135 ± 15</td>
<td>114 ± 18</td>
</tr>
<tr>
<td>VD-1 D</td>
<td>271</td>
<td>135 ± 15</td>
<td>114 ± 18</td>
</tr>
<tr>
<td>VD-2 D</td>
<td>201</td>
<td>191 ± 18</td>
<td>15 ± 15</td>
</tr>
<tr>
<td>VD-3 D</td>
<td>498</td>
<td>191 ± 18</td>
<td>15 ± 15</td>
</tr>
<tr>
<td>KH-1 C</td>
<td>484</td>
<td>191 ± 18</td>
<td>15 ± 15</td>
</tr>
<tr>
<td>KH-2 C</td>
<td>599</td>
<td>191 ± 18</td>
<td>15 ± 15</td>
</tr>
</tbody>
</table>

![Graphs showing mean total biomass and NPP under low and high grazing conditions for different subzones.](image-url)
Part I - Results

Model simulated NPP is controlled by:

- Temperature (subzone and warming)
- Herbivore
- Nutrient supply

SON efficiency = \( \frac{NPP}{SON} \)

Productivity efficiency = \( \frac{NPP(t)}{Biomass(t - 1)} \)

- Nutrient-poor sites generally have higher SON efficiency than nutrient-rich sites

<table>
<thead>
<tr>
<th>Sites (SON)</th>
<th>Before Warming</th>
<th>After Warming</th>
</tr>
</thead>
<tbody>
<tr>
<td>LV-1 (570)</td>
<td>0.26</td>
<td>0.42</td>
</tr>
<tr>
<td>LV-2 (148)</td>
<td>0.4</td>
<td>0.72</td>
</tr>
</tbody>
</table>

SON, Warming, Grazing effect

- SON Efficiency affected by climate warming and Grazing over time

LV‐1 (570)

- Low Grazing: 0.26
- High Grazing: 0.42

LV‐2 (148)

- Low Grazing: 0.4
- High Grazing: 0.72
Higher grazing frequency led to either slower SON accumulation rates or more rapid SON depletion rates.

Warming accentuated these differences caused by grazing, suggesting the interaction between grazing and warming may yield greater differences in SON levels across sites.
Soil nutrients are a limiting factor to plant growth, and also limit the plant responses to climate warming.

Warming and grazing are affecting plant biomass and NPP in opposite directions.

Grazing suppresses plant responses to warming effects.

The interaction between grazing and warming may yield greater differences in SON levels across sites.
Land use change detection and effects on tundra vegetation

Land Cover Land Use Changes along the Yamal Peninsula, Russia (Multi-temporal image analysis)
Zonal vegetation at Kharasavey (subzone C) Vasikiny Dachi (subzone D), and Laborovaya (subzone E). Note the increasing greenness with warmer temperatures toward the south. Photo: D.A. Walker.

Locations of field sites across the Yamal Arctic Transect (YAT) (Walker et al. 2009)
### Background

- Oil and gas industry
- Road and pipeline construction
- Surface hydrology including Thermakarst lakes
- Vegetation
- Permafrost

### LUC related changes
Research Objectives

- Methodology to detect changes
- Identify changes across the Yamal Peninsula
- Analyze the causes of the changes
- Identify the spatial influence of specific land use changes
We classify our imagery based on four-integrative indices for Landsat TM/ETM+:

- NDVI = f (band3, 4) (Rouse et al., 1989)
- Albedo = f (band 1, 3, 4, 5, 7) (Liang, 2001)
- Land surface temperature = f (band6) (Qin et al., 2001)
- NDWI = f (band4, 5) (Gao, 1996)
Multispectral Image 2007

- Red - Band 4
- Green - Band 3
- Blue - Band 2

Image Processing Flow Chart

- Red - NDVI
- Green - Albedo
- Blue - Ts

Integrative indices 2007
<table>
<thead>
<tr>
<th>Study sites</th>
<th>Date</th>
<th>Mission and Sensor</th>
<th>Path/row</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nadym</td>
<td>1988-6-19</td>
<td>Landsat-4, TM</td>
<td>160/14</td>
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<tr>
<td></td>
<td>2007-7-7</td>
<td>Landsat-5, TM</td>
<td>160/14</td>
</tr>
<tr>
<td></td>
<td>2006-7-15*</td>
<td>Landsat-5, TM</td>
<td>160/14</td>
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<td>Laborovaya</td>
<td>1988-8-2</td>
<td>Landsat-4, TM</td>
<td>164/10</td>
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<tr>
<td></td>
<td>2006-6-25</td>
<td>Landsat-5, TM</td>
<td>164/10</td>
</tr>
<tr>
<td>Vaskiny Dachi/Kharasavey</td>
<td>1988-8-7</td>
<td>Landsat-4, TM</td>
<td>167/10</td>
</tr>
<tr>
<td></td>
<td>2000-7-7</td>
<td>Landsat-7, ETM+</td>
<td>167/10</td>
</tr>
<tr>
<td>Belyy Ostrov</td>
<td>1988-8-7</td>
<td>Landsat-4, TM</td>
<td>167/8</td>
</tr>
<tr>
<td></td>
<td>2000-7-16</td>
<td>Landsat-5, ETM+</td>
<td>167/8</td>
</tr>
</tbody>
</table>
Results

- Nadym region as the example which encompasses city, gas and oil development, grazing and climate change
Difference 2007-1988 for four indices
Changes detected near the Nadym field sites

- Increase in Ts and albedo
- Increase in NDVI
- Increase in albedo
Soil

2007 TM Band 7

Nadym1 - Clayey

Nadym2 - Sandy

2007 TM Band 7/4/3
Changes detected associated with Soils

Significant Changes Associated with Soils

Difference Composited Map 2007-1988

2007 Landsat TM (Soil Characteristics)

R: NDVI G: albedo B: NDWI

R: Band 7 G: Band 4 B: Band 3
Based on the integrative indices, it is easier to interpret changes occurred in decades.
We detected changes such as new facilities, road/pipelines, recovery of vegetation on disturbed regions, reduced moisture content on the ground, etc.
Further detailed analysis is needed.
Acknowledgment

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