The potential importance of plant-fungus interactions for sustainable ecosystems

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What is ecological sustainability?

= distribution of resources that is equitable, between all humans living now and among present and future generations, and use of these resources so as not to jeopardize the continued persistence of the planet's biodiversity and ecosystems (Mayer et al. 2004)

= meeting human needs while conserving the earth's life support system (Palmer et al. 2005)

**Ecosystem functioning** is the collective life activities of plants, animals, and microbes and the effects these activities have on the physical and chemical conditions of their environment. (Naeem et al. 1999)

**Ecosystem services** are ecological functions that sustain and improve human life (Kremen and Ostfeld 2005)
Ecosystem Services
What Nature provides us for free

- Supporting
  - Soil Formation
  - Photosynthesis
  - Biodiversity
  - Habitat
  - Stewardship
  - Aesthetic
  - Recreation
  - Education

- Provisioning
  - Food
  - Clean Water
  - Fish
  - Wood
  - Pollination
  - Cool Temperatures
  - Control Flooding
  - Purify Water
  - Store Carbon
  - Clean Air

- Cultural
  - Recreation
  - Education

- Regulating
  - Soil Formation
  - Photosynthesis
  - Biodiversity
  - Habitat
  - Stewardship
  - Aesthetic

www.metrovancouver.org
Different combinations of services are provided to human populations from the various types of ecosystems represented here. Their ability to deliver the services depends on complex biological, chemical, and physical interactions, which are in turn affected by human activities.

### Ecosystems and Some Services They Provide

<table>
<thead>
<tr>
<th>Ecosystem Type</th>
<th>Services</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mountains and Polar</strong></td>
<td>Food, Fiber, Fresh water, Erosion control, Climate regulation, Recreation and ecotourism, Aesthetic values, Spiritual values</td>
</tr>
<tr>
<td><strong>Inland Water</strong></td>
<td>Fresh water, Food, Pollution control, Flood regulation, Sediment retention and transport, Disease regulation, Nutrient cycling, Recreation and ecotourism, Aesthetic values</td>
</tr>
<tr>
<td><strong>Cultivated Lands</strong></td>
<td>Food, Fiber, Fresh water, Dyes, Timber, Pest regulation, Biofuels, Medicines, Nutrient cycling, Aesthetic values, Cultural heritage</td>
</tr>
<tr>
<td><strong>Coastal</strong></td>
<td>Food, Fiber, Timber, Fuel, Climate regulation, Waste processing, Nutrient cycling, Storm and wave protection, Recreation and ecotourism, Aesthetic values</td>
</tr>
<tr>
<td><strong>Forest and Woodlands</strong></td>
<td>Food, Timber, Fresh water, Fuelwood, Flood regulation, Disease regulation, Carbon sequestration, Local climate regulation, Medicines, Recreation, Aesthetic values, Spiritual values</td>
</tr>
<tr>
<td><strong>Drylands</strong></td>
<td>Food, Fiber, Fuelwood, Local climate regulation, Cultural heritage, Recreation and ecotourism, Spiritual values</td>
</tr>
<tr>
<td><strong>Urban</strong></td>
<td>Air quality regulation, Water regulation, Local climate regulation, Cultural heritage, Recreation, Education</td>
</tr>
<tr>
<td><strong>Marine</strong></td>
<td>Food, Climate regulation, Nutrient cycling, Recreation</td>
</tr>
<tr>
<td><strong>Island</strong></td>
<td>Food, Fresh water, Recreation and ecotourism</td>
</tr>
</tbody>
</table>

Source: Millennium Ecosystem Assessment
Different combinations of services are provided to human populations from the various types of ecosystems represented here. Their ability to deliver the services depends on complex biological, chemical, and physical interactions, which are in turn affected by human activities.

**Ecosystems and Some Services They Provide**

- **Mountain and Polar**
  - Food
  - Fiber
  - Fresh water
  - Erosion control
  - Climate regulation
  - Recreation and ecotourism
  - Aesthetic values
  - Spiritual values

- **Inland Water**
  - Rivers and other wetlands
  - Fresh water
  - Food
  - Pollution control
  - Flood regulation
  - Sediment retention and transport
  - Disease regulation
  - Nutrient cycling
  - Recreation and ecotourism
  - Aesthetic values

- **Cultivated**
  - Food
  - Fiber
  - Fresh water
  - Dyes
  - Timber
  - Pest regulation
  - Biofuels
  - Medicines
  - Nutrient cycling
  - Aesthetic values
  - Cultural heritage

- **Coastal**
  - Food
  - Fiber
  - Timber
  - Fuel
  - Climate regulation
  - Waste processing
  - Nutrient cycling
  - Storm and wave protection
  - Recreation and ecotourism
  - Aesthetic values

- **Forest and Woodlands**
  - Food
  - Timber
  - Fresh water
  - Fuelwood
  - Flood regulation
  - Disease regulation
  - Carbon sequestration
  - Local climate regulation
  - Medicines
  - Recreation
  - Aesthetic values
  - Spiritual values

- **Drylands**
  - Food
  - Fiber
  - Fuelwood
  - Local climate regulation
  - Social and cultural values
  - Recreation and ecotourism
  - Aesthetic values
  - Spiritual values

- **Urban**
  - Parks and gardens
  - Air quality regulation
  - Water regulation
  - Local climate regulation
  - Cultural heritage
  - Recreation
  - Education

- **Marine**
  - Food
  - Climate regulation
  - Nutrient cycling
  - Recreation

- **Island**
  - Food
  - Fresh water
  - Recreation

Source: Millennium Ecosystem Assessment
Ecological Sustainability in Agriculture

-over 50% of global land surface in agriculture (cultivation or grazing)

-modern agriculture manages the ecosystem service of productivity (crop yield) via external controls (e.g. fertilizers and pesticides) rather than internal controls (e.g., species interactions) (Robertson and Swinton 2005)

Figure 2. A ladybird beetle (Harmonia axyridis) consuming the exotic soybean aphid Aphis glycines on a Midwestern soybean plant. Plant protection by beneficial insects is an important service provided in all cropping systems.
Ecological Sustainability in Agriculture

Goal: to increase other ecosystem services provided by agricultural systems while maintaining high crop yield

Methods: switch from external to internal controls for ecosystem services

natural ecosystem

intensive cropland

cropland with restored ecosystem services
Ecological Sustainability in Coastal Systems

- Coastal regions are home to half of world’s major cities and half of the US population, while only comprising 17% of land area (MEA)

- Coasts are heavily impacted by human activities

Figure 13. Main Direct Drivers of Change in Biodiversity and Ecosystems (CWG)
## Ecological Sustainability of Beaches and Dunes

<table>
<thead>
<tr>
<th>Ecosystem Services</th>
<th>Controls</th>
<th>Threats</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coastal protection</td>
<td>Sand supply and chemistry</td>
<td>-sand mining</td>
</tr>
<tr>
<td>Erosion control</td>
<td>Dune and beach spatial area</td>
<td>-exotic species</td>
</tr>
<tr>
<td>Tourism</td>
<td>Wave action and sea levels</td>
<td>-recreation</td>
</tr>
<tr>
<td>Raw materials</td>
<td>Dune height</td>
<td>-Off-road vehicles (ORVs)</td>
</tr>
<tr>
<td>Water purification</td>
<td>Vegetation type</td>
<td>-Pedestrian overuse</td>
</tr>
<tr>
<td>Carbon sequestration</td>
<td></td>
<td>-home development</td>
</tr>
<tr>
<td>Wildlife</td>
<td></td>
<td>-blowouts</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-natural: wind, wave action</td>
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<tr>
<td></td>
<td></td>
<td>-climate change</td>
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<tr>
<td></td>
<td></td>
<td>-drought and heat stress</td>
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<tr>
<td></td>
<td></td>
<td>-increased storm activity</td>
</tr>
</tbody>
</table>

Barbier et al. 2011
Long history of dune restoration for erosion control

These New Jersey residents are planting ‘Cape’ American beachgrass to protect their property.
**Physical Processes**
- Sea level
- Sediment supply
- Wave dynamics

**Climate Processes** (temp, ppt, wind)

**Biological Processes**
- Plant species identity
- Species interactions
- Engineering traits
- Plant biomass
- Dispersal rate

**Dune Geomorphology**

**Dune Ecosystem Services**
- Coastal protection
- Habitat for biodiversity
- Carbon sequestration
- Shelter to wetlands
- Water purification
- Tourism and recreation

**Sand Capture & Retention Processes**
So what do corn fields and beaches have in common?

My research: Can species interactions (ecology) improve sustainability of ecosystem services?

Ammophila breviligulata
(American beachgrass)
Plant-Fungus Interactions

Mycorrhizal fungi
• 80% of all flowering plants
• water and nutrient uptake

Endophytic fungi
• 20 to 30% of grasses
• herbivore resistance, nutrient uptake, drought resistance
Mycorrhizal Fungi

http://morganplaysinthedirt.blogspot.com
Endophytes

- Endophyte is found in the embryo of infected seed.
- The endophyte grows into the emerging leaf as the seed germinates.
- The endophyte grows up the stem and into the seed head of the reproductive plant.
- The endophyte is concentrated in the base of the plant, not in the roots.

*Image showing different stages of endophyte growth.*
My Research

1. Can different management techniques enhance mycorrhizal fungi abundance and benefits in agricultural systems?
   A. Current work: Row-Crop Agriculture
   B. Future work: Biofuels

2. Can endophytes enhance vegetation performance and function in sand dunes?

3. Can plant-fungus interactions improve ecosystem sustainability in light of climate change?
1A. Can different management techniques enhance mycorrhizal fungi abundance and benefits in agricultural systems?

-W.K. Kellogg Biological Station, MI

-a Long-Term Ecological Research Experiment running since 1989
Four main agronomic management practices at KBS; all on corn-soybean-wheat rotation:

**Conventional (T1):** annual tilling, full dosages of herbicides and pesticides

**No-Till (T2):** no tilling, full dosages of herbicides and pesticides

**Organic (T4):** annual tilling, no chemical inputs

**Successional (T7):** no crop planting, no chemical inputs
We are examining AMF spore abundance and diversity, extra-radical hyphae growth, carbon storage and crop root colonization.
Preliminary Findings

Fig. 3. Spores isolated from agricultural soils

- AMF spores per g soil
- June 2010
- Oct. 2010

Agronomic treatment

Conv, No-Till, Organic, Oldfield

Gottshall, unpub. data
Undergraduate Student Project:
Carbon Storage and Mycorrhizal Activity
- measured glomalin production, a protein associated with mycorrhizal hyphae

• Successional fields (T7) had significantly higher GRSP than any agricultural treatment in each year (2010-12).

• In 2012, no-till agricultural plots (T2) had higher GRSP than conventional plots (T1).

• In 2012, organically managed plots (T4) had higher GRSP than conventional (T1) or low-input plots (T3).

Key:
T1= Conventional
T2= No till
T3= Low input
T4= Organic
T7= Early successional
1B. Future Research: Biofuels

-mandate by the U.S. Energy Independence and Security Act of 2007 for 16 billion gallons of cellulosic ethanol production by 2022

-Switchgrass (*Panicum virgatum*) is a likely candidate for cellulose feedstock to be grown in the Midwest due to its perenniality (10+ yrs of production), efficient water use, drought tolerance, and nativity

-Switchgrass is strongly mycorrhizal and will most likely be grown in marginal lands with low external inputs

Photo credits: KBS GLBRC
Possible Research Questions:

- Does field quality influence plant-mycorrhizae interactions?

- Do switchgrass varieties differ in their dependence and benefits from mycorrhizae?
2. Can endophytes enhance vegetation performance and function in sand dunes?

-The Great Lakes contain 84% of fresh surface water in North America, and the most extensive freshwater dunes in the world (>1,000 km² in Michigan alone)

-Dune building mostly done by American Beachgrass (Ammophila breviligulata)
Endophytes and *Ammophila*

-Different commercial varieties available for restoration efforts
  - ‘Cape’ variety 100% infected with endophyte
  - ‘Vans’ variety 0% infected with endophyte

-2011 survey showed variable presence of endophytes in native *Ammophila* populations

Emery et al. 2010
Greenhouse and field experiments show that endophytes in *Ammophila* increase survival and growth.
Number of tillers per plot, 2011

Endophyte treatment

- E-
- E+
Endophytes increase ecosystem function

Sand accumulation 2010-12 (cm)

Endophyte treatment

E- E+

http://flora.huji.ac.il
3. Can plant-fungus interactions improve ecosystem sustainability in light of climate change?

**Resilience** = the time required for a system to return to a particular dynamic regime after a perturbation, or to the amount of perturbation that a system can absorb before shifting to an alternate dynamic regime (Mayer et al. 2004)

**Resistance** = the ability of a system to withstand a disturbance
Climate Change in the Great Lakes Region

• Climate change scenarios predict a 2-11°C rise in summer maximum temperatures and up to 30% decrease in soil moisture in the Great Lakes region over the next 50 years (IPCC 2001, 2007)

Projected Changes in Great Lakes Levels under Higher Emissions Scenario

Average Great Lakes levels depend on the balance between precipitation (and corresponding runoff) in the Great Lakes Basin on one hand, and evaporation and outflow on the other. As a result, lower emissions scenarios with less warming show less reduction in lake levels than higher emissions scenarios. Projected changes in lake levels are based on simulations by the NOAA Great Lakes model for projected climate changes under a higher emissions scenario.
Sand Dunes and Climate Change

- A 5°C increase in temperature reduced *Ammophila* survival by 45% and growth by 30-60%.

- Growth increased by 13% in augmented vs. reduced precipitation treatments in field.

- Endophytes provided no protection against changing climate.
Agriculture and Climate Change

Future work: could mycorrhizal fungi provide resistance or resilience to climate change in agricultural systems?
Ecological Sustainability

Climate Change

- Biodiversity (the building blocks)
- Ecosystem functioning (the factory)
- Ecosystem services (the products)
- Human well-being
Potential Funding Opportunities

NSF: Dynamics of Coupled Natural and Human Systems
SYNOPSIS: The Dynamics of Coupled Natural and Human Systems (CNH) Program promotes interdisciplinary analyses of relevant human and natural system processes and complex interactions among human and natural systems at diverse scales.

Deadline(s): 11/19/2013

NOAA Climate Program Office
Climate and Societal Interactions (CSI) Program
COCA—Ecosystem Services for a Resilient Coast
“In FY14, COCA will solicit proposals focused on the development and application of methodologies for integrating ecosystem services into coastal adaptation efforts (e.g. the integration of green infrastructure for coastal protection) to support sustainable coastal communities and ecosystems in a changing climate”

-Sept. letter of intent deadline; up to $200K/yr

USDA NIFA AFRI-- Climate Change: Climate Change Mitigation and Adaptation in Agriculture
For Fiscal Years 2014 and 2015, the Agriculture and Natural Resources Science for Climate Variability and Change Challenge Area anticipates advancing research, education and extension efforts in the topical areas listed below.
1) New and/or improved crop and livestock varieties, lines, populations, and breeds adapted to climate driven abiotic and biotic stresses and/or for enhanced climate mitigation.
2) New and/or improved strategies or technologies that protect food from climate driven environmental changes and contamination to ensure food safety.
3) Impacts of climate variability and change on farm income support programs, such as farm loans and subsidies, and disaster payments and loans.
4) Impacts of climate variability and change on farm risk management financing, such as crop insurance, matching grants and low-interest loans.
5) Impacts of climate variability and change on transboundary movement of plant and animal diseases leading to morbidity and economic loss.
6) Impacts of climate variability and change on ecosystem services and ecological markets.
Thank you!

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References


