Ecological Engineering and Ecosystem Restoration: History, definitions, and principles

William J. Mitsch

Professor of Natural Resources and Environmental Science
Director, Olentangy River Wetland Research Park
The Ohio State University
Columbus, Ohio USA
ECOLOGICAL ENGINEERING and ECOSYSTEM RESTORATION

2004
Everglades Restoration, Florida

Historic Conditions

Current Flow

Restoration Plan
Delta Restoration, Louisiana

Protect Shoreline
- Keep shoreline in place in critical areas.

Maintain Shoreline Integrity
- Let shore roll back, but prevent intertidal marsh erosion.

Maintain Sabine River Inflow

Maintain Atchafalaya Mudstream
- Continue shoreline erosion along Cheramit Plain.

Improve Hydrology/Drainage
- Lower water levels in swamps. Allow more natural flow of water. Provide flood protection if necessary.

Reduce Sedimentation in Calo Blanche Bays and Vermilion Bay and Maintain as Brackish

Lower Water Levels
- Modify flow patterns to tidal marshes to the south.

Move Fresh Water South into Tidal Marshes
- Move Atchafalaya waters into tidal marshes in Chenier Plain. Use water from lakes to freshen southern brackish marshes.

Beneficial Use of Dredged Material or Dedicated Dredging
- Create marsh in various sites along the coast.

Optimize Atchafalaya Flow to West and East
- Use Atchafalaya sediments and nutrients to preserve marshes.

Conveyance Channel from Mississippi River to Build Deltas
- Build marsh and nourish adjacent wetlands in areas of highest land loss.

Solve the Mississippi River Gulf Outlet Problem
- Close MRGO when deep draft container facilities are available on river. In marsh, stabilize north bank, guard face oyster levees, create marsh in southern loes of Lake Borgne.

Delta-building Diversions from Mississippi River (15,000-100,000 cfs)
- Build marsh and nourish adjacent marsh. Address oyster issues.

Multi-purpose Control of Navigation Channels
- Prevent saline water from continuing to damage marshes to north. Return fresh water.

Coast 2050 Ecosystem Strategies

Restore maintain Barrier Islands, Headlands, Shorelands
- Use most cost-effective means to protect these first lines of defense from storms.

Prevent Loss of Sediments into the Deep Gulf
- Separate navigation from riverine processes. Build sediment traps and pump out to create marsh.
Mississippi River Basin Restoration, USA

- created wetland intercepting tile drainage
- restored bottomland forest
River Channel Restoration, Skern River Denmark
River Channel Restoration, Skern River Denmark
Wetland Creation/ Restoration  Columbus, Ohio

6.1 ha mitigation wetland
Olentangy River Wetland Research Park  Columbus, Ohio

12-ha wetland research facility on Ohio State University campus
Floodplain Forest Restoration

Olentangy River Wetland Research Park  Columbus, Ohio
Treatment Wetland, Central Ohio
Salt Marsh Restoration, New Jersey
Salt Marsh Restoration, New Jersey
Biosphere 2, Arizona
Change in population 1805-1999 and an optimistic (but realistic) prognosis 1999-2050
The graph shows the percent change in atmospheric CO₂ and global nitrogen fixation over the years from 1900 to 2000. The y-axis represents the percent change, while the x-axis represents the years. The graph indicates a significant increase in both atmospheric CO₂ and global nitrogen fixation over the century, with a steep rise in the latter towards the end of the century.
History of Ecological Engineering

- H.T. Odum (1960s) mention of ecological engineering in several publications
- Ma Shijun (1960s-70s in China; 1985 in Western literature) “father of ecological engineering in China”
- Ecotechnology of Uhlmann, Straskraba and Gnauek (1983-1985)
History of Ecological Engineering

- *Ecological Engineering* journal started (1992)
- IEES started in Utrecht, The Netherlands (1993)
- SCOPE project in ecological engineering and ecosystem restoration established in Paris (1994-2002)
- Discussions of American ecological engineering society in Columbus (1999); AEES first meeting, Athens, GA (2001)
<table>
<thead>
<tr>
<th>Workshop Title</th>
<th>Location/ Date</th>
<th>Publication in Ecol Eng</th>
</tr>
</thead>
<tbody>
<tr>
<td>Remediation of ecosystems damaged by environmental contamination</td>
<td>Tallinn, Estonia November 1995</td>
<td>Mitsch and Mander, 1997</td>
</tr>
<tr>
<td>Ecological engineering in developing countries</td>
<td>Beijing, China October 1996</td>
<td>Wang et al., 1998</td>
</tr>
<tr>
<td>Ecological engineering applied to river and wetland restoration</td>
<td>Paris, France July 1998</td>
<td>Lefeuvre et al., 2002</td>
</tr>
<tr>
<td>Ecology of post-mining landscapes</td>
<td>Cottbus, Germany March 1999</td>
<td>Hüttl and Bradshaw, 2001</td>
</tr>
</tbody>
</table>
Ecological Engineering

the design of sustainable ecosystems that integrate human society with its natural environment for the benefit of both

Source: Mitsch and Jørgensen, 2004
Goals of Ecological Engineering

1. the restoration of ecosystems that have been substantially disturbed by human activities such as environmental pollution or land disturbance; and

2. the development of new sustainable ecosystems that have both human and ecological value.
Ecological Restoration

the return of an ecosystem to a close approximation of its condition prior to disturbance

Source: NRC, 1992
Terms that are synonyms, subdisciplines, or fields similar to ecological engineering

- synthetic ecology
- restoration ecology
- bioengineering
- sustainable agroecology
- habitat reconstruction
- ecohydrology
- ecosystem rehabilitation
- biospherics
- biomanipulation
- river and lake restoration
- wetland restoration
- reclamation ecology
- nature engineering
- ecotechnology
- engineering ecology
- solar aquatics
Contrasts with Other Fields

- Environmental engineering
- Biotechnology
### Comparison of ecotechnology and biotechnology

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Ecotechnology</th>
<th>Biotechnology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic unit</td>
<td>Ecosystem</td>
<td>Cell</td>
</tr>
<tr>
<td>Basic principles</td>
<td>Ecology</td>
<td>Genetics; cell biology</td>
</tr>
<tr>
<td>Control</td>
<td>Forcing functions, organisms</td>
<td>Genetic structure</td>
</tr>
<tr>
<td>Design</td>
<td>Self-design with some human help</td>
<td>Human design</td>
</tr>
<tr>
<td>Biotic diversity</td>
<td>Protected</td>
<td>Changed</td>
</tr>
<tr>
<td>Maintenance and development costs</td>
<td>Reasonable</td>
<td>Enormous</td>
</tr>
<tr>
<td>Energy basis</td>
<td>Solar based</td>
<td>Fossil fuel based</td>
</tr>
</tbody>
</table>
Contrasts with Other Fields

- Environmental engineering
- Biotechnology
- Ecology
The design, restoration and creation of ecosystems
Contrasts with Other Fields

- Environmental engineering
- Biotechnology
- Ecology
- Ecotechniques/Cleaner Technology
  - Industrial Ecology
Ecological Engineering Principles
Self-design

The application of self-organization in the design of ecosystems
Systems categorized by types of organization (modified from Pahl-Wostl, 1995)

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Imposed organization</th>
<th>Self-organization</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>externally imposed;</td>
<td>endogenously imposed;</td>
</tr>
<tr>
<td></td>
<td>centralized control</td>
<td>distributed control</td>
</tr>
<tr>
<td>Rigidity</td>
<td>rigid networks</td>
<td>flexible networks</td>
</tr>
<tr>
<td>Potential for adaptation</td>
<td>little potential</td>
<td>high potential</td>
</tr>
<tr>
<td>Application</td>
<td>conventional engineering</td>
<td>ecological engineering</td>
</tr>
<tr>
<td>Examples</td>
<td>machine</td>
<td>organism</td>
</tr>
<tr>
<td></td>
<td>fascist or socialist society</td>
<td>democratic society</td>
</tr>
<tr>
<td></td>
<td>agriculture</td>
<td>natural ecosystem</td>
</tr>
</tbody>
</table>
whole-ecosystem experiment in self-design

Atmospheric

Biotic (including human)

Hydrologic

self-design

Sources of Biotic Propagules for Self-Design
The Acid Test
A Systems Approach
Nonrenewable Resource Conservation
Conventional Engineering

- Fossil Fuels
- Conventional Engineer
- Natural Energies
- Services to Society
Ecological Engineering

Natural Energies

self design

Fossil Fuels

Ecological Engineer

Services to Society

Mitsch (1998)
Ecosystem Conservation

“To keep every cog and wheel is the first precaution of intelligent tinkering.”

Aldo Leopold
Ecological Design Principles

1. Ecosystem structure and function are determined by the forcing functions of the system.

2. Energy inputs to the ecosystem and available storage of matter are limited.

3. Ecosystems are open and dissipative systems.

4. Attention to a limited number of factors is most strategic in preventing pollution or restoring ecosystems.

5. Ecosystems have some homeostatic capability that results in smoothing out and depressing the effects of strongly variable inputs.

6. Match recycling pathways to the rates to ecosystems to reduce the effect of pollution.
Ecological Design Principles

7. Design for pulsing systems whenever possible.

8. Ecosystems are self-designing systems.

9. Processes of ecosystems have characteristic time and space scales that should be accounted for in environmental management.

10. Biodiversity should be championed to maintain an ecosystem self-design capacity.

11. Ecotones, transition zones, are as important for ecosystems as membranes are for cells.

12. Coupling between ecosystems should be utilized wherever possible.
Ecological Design Principles

13. The components of an ecosystem are interconnected, interrelated, and form a network, implying that direct as well as indirect effects of ecosystem development need to be considered.

14. An ecosystem has a history of development.

15. Ecosystems and species are most vulnerable at their geographical edges.

16. Ecosystems are hierarchical systems and are parts of a larger landscape.

17. Physical and biological processes are interactive. It is important to know both physical and biological interactions and to interpret them properly.

18. Ecotechnology requires a holistic approach that integrates all interacting parts and processes as far as possible.

19. Information in ecosystems is stored in structures.
Classification of Ecological Engineering
Classification According to Sustainability
Functional classification

- Ecosystems are used to reduce or solve a pollution problem
- Ecosystems are imitated or copies to reduce a resource problem
- The recover of ecosystems is supported
- Existing ecosystems are modified in an ecologically sound way
- Ecosystems are used for the benefit of humankind without destroying the ecological balance
Examples of ecological engineering approaches for terrestrial and aquatic systems according to types of applications.

<table>
<thead>
<tr>
<th>Ecological Engineering Approaches</th>
<th>Terrestrial Examples</th>
<th>Aquatic Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Ecosystems are used to solve a pollution problem</td>
<td>Phytoremediation</td>
<td>Wastewater wetland</td>
</tr>
<tr>
<td>2. Ecosystems are imitated or copied to reduce or solve a problem</td>
<td>Forest restoration</td>
<td>Replacement wetland</td>
</tr>
<tr>
<td>3. The recovery of an ecosystem is supported after disturbance</td>
<td>Mine land restoration</td>
<td>Lake restoration</td>
</tr>
<tr>
<td>4. Existing ecosystems are modified in an ecologically sound way</td>
<td>Selective timber harvest</td>
<td>Biomanipulation</td>
</tr>
<tr>
<td>5. Ecosystems are used for benefit without destroying ecological balance</td>
<td>Sustainable agroecosystems</td>
<td>Multi-species aquaculture</td>
</tr>
</tbody>
</table>
Solving or reducing a pollution problem

- non-point source of nutrients
- wetland
  - wastewater treatment
  - chemical precipitation
- lake
  - hypolimnion water withdrawal

Steps:
A. Non-point source of nutrients
B. Chemical precipitation
C. Hypolimnion water withdrawal
Solving or reducing a pollution problem

- Sludge filtration in urban regions (A)
- Incineration
- Recycling on agricultural land (B)
Solving or reducing a pollution problem

[Diagram showing processes]

A. Denitrification

B. Technological alternatives

C. Ecotechnology: treatment wetland
Imitating or copying ecosystems
Imitating or copying ecosystems
Supporting ecosystem recovery

- Planted marsh
- Unplanted marsh

Criterion for success

5-yr monitoring period

"Success"
Supporting ecosystem recovery

The graph illustrates the percentage cover over time for different scenarios:
- **Undisturbed marsh**
- **Best case**
- **Average case**
- **Worst case**

The y-axis represents the percentage cover, ranging from 0 to 100, while the x-axis represents years, ranging from 0 to 20. The graph shows the expected range of cover over time, with a bound of expectation outlining the average case scenario.
Modifying existing ecosystems in an ecologically sound way—Biomanipulation

Source: Hosper and Meijer, 1992
Classification According to Scale

• Mesocosm scale
• Ecosystem scale
• Regional scale
When to Use Ecotechnology

1. The parts of nature affected, directly and indirectly, must be determined.
2. Quantitative assessment of impact of all alternatives must be carried out.
3. Project needs to include entire system, including human impacts and affected ecosystem.
4. Optimization should include short and long-term effects.
5. Renewable and nonrenewable resource use should be quantified.
6. Uncertainty should be accounted for in ecological and economic components.
American Ecological Engineering Society: http://aeesociety.org
Thank you!

Information on the book: http://swamp.osu.edu

American Ecological Engineering Society: http://aeesociety.org
Some major references