LOICZ: Land-Ocean Interactions in the Coastal Zone

International Geosphere Biosphere Programme

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http://ian.umces.edu
LOICZ is a core project of IGBP

- JGOFS  Joint Global Ocean Flux Studies
- IGAC   International Global Atmospheric Chemistry
- GCTE   Global Change and Terrestrial Ecosystems
- BAHC   Biospheric Aspects of the Hydrological Cycle
- PAGES  Past Global Change
- LOICZ  Land-Ocean Interactions in the Coastal Zone
- LUCC   Land Use and Cover Change
- GLOBEC Global Ocean Ecosystem Dynamics
- GAIM   Global Analysis, Integration and Modelling
- START  System for Analysis, Research, and Training
Land-sea interfaces are regions of strong gradients and major human impacts.
Primary foci for new LOICZ

Global: Direct disturbance (e.g., altered hydrology, sea level rise)
  Polar: Climate change
  Tropical: Coastal Development
  Temperate: Eutrophication

Polar (<4°C)
Tropical (24°C+)
Temperate (4-24°C)
Temperate issues: Eutrophication

- Intensive land use - high yield
  - Nutrients from fossil fuel burning,
  - intensified agriculture,
  - manure/fertilizer runoff

- Historically degraded waterways
  - Nutrient enhanced runoff;
    high NO₃, P limitation in freshwater
  - Sediment deposition & nutrient flux

- Eutrophication with shifting sources
  - Harmful algal blooms;
    hypoxia/anoxia;
    seagrass loss
  - Variable limiting factors;
    expanding reforestation & aquaculture

- Productive coastal ecosystems
  - Phytoplankton; nutrient ratio sensitive,
    generally N limited,
    deposition leading to hypoxia
  - Salt marsh accretion;
    persistent upwelling

Integration of these processes leads to application and development of network solutions to mitigate eutrophication.
Tropical issues: Coastal development

- Catchment / Watershed
- River / Estuary
- Coastal
- Reef
- Ocean

Rapidly degrading ecosystems
- Monsoonal rains; more dams
- Deforestation, intensified fertilization, grazing, aquaculture, & burning

Impacted by coastal development
- Pulsed sediment-laden runoff, deposition/scouring, resuspension & light limitation
- Urban development & mangrove deforestation

Pulsed runoff
- Mud deposition & resuspension
- Harmful algal blooms; tropical seagrasses & macrograzers; benthic microalgae; fisheries declines

Oligotrophic ecosystems
- Mangroves, seagrasses and corals responsive to pulsed runoff
- Low nutrient concentrations; co-limitation of nitrogen & phosphorus
- Atmospheric iron inputs; seasonal upwelling
Hydrosphere

Integration application network

Jeffery Hanson
Johns Hopkins University
Biosphere
LOICZ distributed scientific network

The image shows a map of the world with various symbols and markers indicating different locations. The legend at the bottom of the map indicates symbols for different ranges (1-5, 5-10, 10-50, 50-150).
LOICZ addresses several questions:

- What are the mass balances of carbon, nitrogen, and phosphorus?
- How can knowledge of the processes and impacts of biogeochemical and socio-economic changes be applied to improve Integrated Environmental and Economic Management of the Coastal Areas, ICZM?
- How are humans altering these mass balances, and what are the consequences?
- How do changes in land use, climate, and sea level alter the fluxes and retention of water and particulate matter in the coastal zone, and affect coastal morphodynamics?
- What is the role of the coastal zone in trace gas emissions (e.g., DMS, NOx)?
- Is the coastal zone a sink or source of CO₂?
The new LOICZ themes

- River basins and human dimensions
- Coastal footprint: implications of land use change
- Fate and transformation of materials in coastal and shelf waters
- Towards system sustainability and resource management issues
- Risk and safety
River basins and human dimensions

Goal: Assess magnitude and variations in land-derived material loads to the coastal seas and atmosphere, and implications of these fluxes and changes on coastal functioning and human use

- ‘Hit lists’ (regional drivers & pressures)
- Impacts & critical loads
- Scenario development
- Global upscaling
- Typology
Coastal footprint: implications of land use change

Goal: Determine the temporal and spatial scales of land based coastal change (habitats, biodiversity, ecological economics)

The disappearing pristine coast: Global typology of low (<10/km²) population density and low (<5%) cropland use (polar regions cropped)
Biogeochemical budgets: CNP fluxes & net system metabolism

Water and Salt Budgets
- Water budget
  - Freshwater flows known.
  - System residual flow ($V_R$) conserves volume.
- Salt budget
  - Net flows known.
  - Mixing ($V_x$) conserves salt content.

Nutrient Budgets
- Nutrient (Y) budgets
  - Internal dissolved nutrient net source or sink ($\Delta Y$) to conserve Y.
- Calculations based on simple system stoichiometry
  - Assume Redfield C:N:P ratio (106:16:1)
    - $\left( \text{production} - \text{respiration} \right) = -106 \times \Delta \text{DIP}$
    - $\left( \text{Nitrogen fixation} - \text{denitrification} \right) = \Delta \text{DIN}_{\text{obs}} - 16 \times \Delta \text{DIP}$

LINGAYEN GULF
DIN Budget (fluxes in 10$^6$ moles/yr)

- Ocean
  - Upper Gulf (84% area)
    - $\Delta \text{DIN} = -180$
    - $V_i \text{DIN}_i = 0.5\mu$M
    - $V_x \text{DIN}_x = -7$
  - Bolinao (6% area)
    - $\text{DIN}_B = 3.9\mu$M
    - $V_x \text{DIN}_x = -10$
    - $V_i \text{DIN}_i = -10$
  - Nearshore (10% area)
    - $\text{DIN}_N = 1.7\mu$M
    - $V_x \text{DIN}_x = -282$
    - $V_i \text{DIN}_i = -282$

LOICZ budget sites
Fate and transformation of materials in coastal and shelf waters

Goal: Determine fate of land-derived and atmospheric loads and ramification of load changes in the coastal and continental shelf seas, and implications for earth function

- Shelf processes
- Coastal aquifer system
- Open ocean exchange
- Submarine groundwater discharge
- Pore water reservoir
Towards system sustainability and resource management issues

Goal: Provide the integrative indicators and scaling tools & develop scenarios of probable and “desirable” future response options
Risk and safety

Goal: Improve knowledge and understanding of vulnerability of society and ecosystems to global change hazards in the coastal zone.

Coastal vulnerability maps

Global typology of high (>60/km²) population density and (>10%) cropland use (polar regions cropped)
The new LOICZ: A process-based common approach, not a 'project'
The new LOICZ: Role and users/clients

Earth System
Global Drivers/Pressures
Climate change, Population Pressure, International trade

Global Science results

LOICZ
Continental or Subcontinental

Regional & National Scale
Integrated Coastal Zone Management

Some Users/Clients
UNESCO-IOC, UNEP, SCOR, IGBP
EU, OSPAR, HELCOM, ICES, ASEAN, SADC, MERCOSUR
National: CZM- Organizations, Authorities, River Commissions, City Councils
The new LOICZ: Structure

Sponsors Group
IGBP/ IHDP...
Sponsoring agencies
National governments

LOICZ Scientific Steering Committee:
Executive Group, 6 Members
10-14 Corresponding Members

LOICZ distributed International Project Office, IPO

IPO Node, central executive functions and Theme A

IPO Research Node, Theme B
IPO Research Node, Theme C
IPO Research Node, Theme N
LOICZ

Robert Buddemeier
Robert Costanza
Chris Crossland
Hartwig Kremer
Stephen Smith
James Syvitski

www.nioz.nl/loicz
Now is the time for a global scientific focus on environmental problem solving.

- Paradigm shifts occur when scientific discovery is effectively communicated to society.
- Societal needs provide impetus for discovery.
- The next paradigm shift needed is that we can solve ‘intractable’ environmental problems.
Focus on solving environmental problems when importance and uncertainty are high.
Studying environmental problems

- **Scientific rigor**
- **Total commitment**
- **Understanding complexity**
- **Developing methodologies**
- **Yearning for truth**
Solving environmental problems

- **Shared vision**
- **Organized participation**
- **Leadership**
- **Varied communication**
- **Effective actions**
In order to both study and solve problems, credibility, tenacity, creativity and virtue are needed

“Wisdom is knowing what to do next; virtue is doing it.”

David S. Jordan
Observation Revolution

Data gathering capabilities dramatically increasing

Remote sensing

In situ sensing
Information Generation

Capacity for data analysis increasing

Quantitative models

Spatial analysis

Airshed model → Watershed model → Estuarine model
Knowledge Building

Synthesis and visualization techniques not utilized enough

Integration application network
Problem Solving

Need integrated and applied approach

Management
- Informed decisions, not knee-jerk reactions

Monitoring
- Feedback for management actions, not well documented declines

Research
- Research for problem solving, not just curiosity-driven research

Integration, Application, Network
Challenge: "It will cost too much"

Response: Investments in protection & restoration are cheapest now & can stimulate local economies

Case Study: Mersey Basin Campaign

- 6 million people; world’s 1st industrial region
- 25 yr. campaign
- Negative value land turned into 5 star hotel
- In 1985 3 raw sewage discharges; now swimmable water

www.merseybasin.org.uk
Challenge: “There are too many different jurisdictions & stakeholders with divergent views”

Response: A participatory process can create a shared vision among a variety of stakeholders.

Case Study: Mekong River Commission

Cambodia, Lao PDR, Thailand, Vietnam

Large river system (8th in volume globally)

Major fisheries

17 million people; 70 ethnic minorities

High rice production

www.mrcmekong.org
**Challenge:** “Population growth counteracts any progress made with management interventions”

**Response:** A proactive program that accounts for population growth and new development.

**Case Study: Healthy Waterways Campaign**

<table>
<thead>
<tr>
<th>Rank</th>
<th>Urban Region</th>
<th>1995 Popn (‘000s)</th>
<th>Ave Annual Growth 1990-95 (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Toronto, Canada</td>
<td>4,084</td>
<td>3.66</td>
</tr>
<tr>
<td>2</td>
<td>Vancouver, Canada</td>
<td>1,678</td>
<td>3.46</td>
</tr>
<tr>
<td>3</td>
<td>Atlanta, USA</td>
<td>3,432</td>
<td>2.88</td>
</tr>
<tr>
<td>4</td>
<td>Brisbane, Australia</td>
<td>2,109</td>
<td>2.86</td>
</tr>
<tr>
<td>5</td>
<td>Phoenix, USA</td>
<td>2,564</td>
<td>2.68</td>
</tr>
<tr>
<td>6</td>
<td>Denver, USA</td>
<td>2,233</td>
<td>2.37</td>
</tr>
<tr>
<td>7</td>
<td>Lisbon, Portugal</td>
<td>1,863</td>
<td>2.33</td>
</tr>
<tr>
<td>7</td>
<td>Orlando, USA</td>
<td>1,391</td>
<td>2.33</td>
</tr>
<tr>
<td>9</td>
<td>Dusseldorf, Germany</td>
<td>3,031</td>
<td>2.31</td>
</tr>
<tr>
<td>10</td>
<td>Portland, USA</td>
<td>2,022</td>
<td>2.28</td>
</tr>
</tbody>
</table>

[www.healthywaterways.org](http://www.healthywaterways.org)
Human health is linked to ecosystem health

- Medical geology: human disturbances can accelerate natural geological processes

- Biodiversity affects ecosystem function & health

- Pathogen pollution: unintentionally spreading disease

- Endocrine disrupters leading to increased human diseases

- Disease emergence as a function of ecosystem alteration
  
  e.g., AIDS, SARS
Social change in S. China has led to ecosystem alternation and disease emergence.
**Constructed wetlands are used to treat raw sewage (Shatian, S. China)**

<table>
<thead>
<tr>
<th>INPUT (mg/L)</th>
<th>OUTPUT (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total N 28.7</td>
<td>Total N 9.3</td>
</tr>
<tr>
<td>Total P 3.9</td>
<td>Total P 0.3</td>
</tr>
<tr>
<td>BOD$_5$ 36.9</td>
<td>BOD$_5$ 9.6</td>
</tr>
<tr>
<td>Suspended Solids 63</td>
<td>Suspended solids 2</td>
</tr>
</tbody>
</table>

5,000 tonnes/d
Constructed wetlands that treat raw sewage are used in conjunction with public parks (Hongku, S. China)

**INPUT (mg/L)**
- Dissolved $O_2$: 1.6
- Total P: 3.1
- $BOD_5$: 38.6

**OUTPUT (mg/L)**
- Dissolved $O_2$: 6.8
- Total P: 0.4
- $BOD_5$: 5.5
Ecosystem health can be measured and improved.
Problem: Sewage nutrients leading to algal blooms

= Sewage N
Research: Sewage plumes assessed & mapped

Sewage plume map ($\delta^{15}N$)

(Moreton Bay Study, 1999)
Solution: Sewage treatment upgrades (biological nutrient removal)

Murrumba Downs Wastewater Treatment Plant - Total Nitrogen Discharge

Big steps towards a healthier Bay

The Brendale Wastewater Treatment Plant has undergone a $7 million upgrade, funded by the Queensland Government and Pine Rivers Shire Council. The upgrade includes the addition of a new biological nutrient removal system, which will significantly reduce the amount of nitrogen discharged into the bay.

Summer, 1998

Summer, 2001
**Problem:** Fine grained sediments causing turbidity, killing seagrass

Fine grained sediments:
- Enter the bay
- are deposited
- & resuspended, killing seagrass

<table>
<thead>
<tr>
<th>Sediment mud content (%)</th>
<th>Suspended sediment concentration (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red &gt; 90%</td>
<td>Red &gt; 100 mg/L</td>
</tr>
</tbody>
</table>

- Moreton Bay Study, 1999

- Secchi depth (m): Pink/red < 1 m
- Seagrass area (green) and loss (red)
Research: Sediment comes from channel erosion in agricultural regions

Evidence for channel erosion

70% of sediment in the Bay comes from 30% of catchment

(Healthy Catchments – Healthy Waterways, in press)
Solution: Rehabilitate channels in eroding regions (fencing and replanting)
Problem: Blooms of *Lyngbya majuscula* (cyanobacterium) causing human and ecosystem health problems
Research findings: *Lyngbya* bloom initiation linked to forestry practices

Photosynthetic pigment concentration (mg/g)

- Phycoerythrin
- Chlorophyll a

Pumicestone Region watershed plantation Clearfelling 1991-1999
Solution: Monitoring & revised forestry practices
Management objective

- Clear water
- Maintain seagrass
- Reduce sewage inputs
- Reduce nutrients
- Reduce phytoplankton
- Reduce harmful algal bloom

Ecosystem health indicator

- Turbidity
- Seagrass area
- Sewage plume mapping
- Total phosphorus
- Chlorophyll $a$
- Extent of *Lyngbya* bloom

Reference value

- Secchi < 1.7 m
- Historical distribution
- $d^{15}N < 4$ ppt
- Total $P < 1.6$ mM
- Chl $a < 1$ mg/L
- Historical distribution
Maps of ecosystem health indicators

Maps of reference values

Secchi
- >2.5 m
- 1.7-2.5 m
- 1-1.7 m
- 0-1 m

Chl a
- 0 -- 0.5 micr/L
- 0.5 -- 1 micr/L
- 1 -- 2.5 micr/L
- 2.5 -- 5 micr/L
- 5 -- 10 micr/L

Bramble Bay
North Deception Bay
Central Bay
South Deception Bay
North Deception Bay
Central Bay
South Deception Bay
Central Bay

Compliant
Non-compliant

integration  application  network
Ecosystem health map created by combining reference value maps (area-weighted averaging)

Ecosystem health index (2001)

\[ EH_R = \frac{1}{N_I} \sum_{i=1}^{N_I} \frac{1}{N_{p,i}} \sum_{p=1}^{N_{p,i}} A_p T_I(P_i(S_I(I_p)))) \]

**Areas and their Ecosystem Health Indexes (2001):**

- Eastern Bay: 0.89
- Central Bay: 0.86
- N. Deception Bay: 0.74
- Eastern Banks: 0.66
- Southern Bay: 0.65
- Waterloo Bay: 0.58
- S. Deception Bay: 0.48
- Bramble Bay: 0.27
- **Moreton Bay**: 0.74
Ecosystem health values converted into report card values (A – F)
Monitoring results and methods synthesized and communicated

- Books
- Newsletters
- Video
Net result: Ecosystem health of Moreton Bay improving

Ecosystem health index (2002)

Ecosystem health index change (2001-2002)
Key Lessons

- **Tracers** useful in source identification
- **Environmental report cards** provide focus & feedback
- **Conceptual diagrams** useful in stakeholder dialogue
- **Communication** elicits effective actions
- **Cultural celebrations** build awareness & support
Chesapeake Bay

Extremely well studied
Intensively managed
Heightened awareness
Well funded

BUT
Continuing to degrade
Recommendations

- Ecological economics can provide key indicators for assessment and monitoring.
- The next major global scientific effort, environmental problem solving, will require the type of transdisciplinary science that ecological economics practices.
- Both human and ecosystem health are rapidly changing and creative solutions are possible.
- The well resourced countries need to become world leaders in environmental problem solving.
Salmon are returning to the Rhine River

- Rhine River
  Major European river system; Long history of human intervention (Roman dykes; currently 50 million people in watershed); Navigable & industrialized from North Sea to Switzerland; Major ecological disaster in 1986 (chemical company fire led to 500,000 dead fish); 50 native fish spp.; only 29 spp. in 1975

- International Commission for the Protection of the Rhine
  5 nations (Switzerland, France, Luxembourg, Germany, Netherlands; Pollution reduction throughout watershed; Initial goal for Rhine Action Plan is return of salmon; Flooding partially restored; Return of invertebrates, algae, bats and salmon
Problem: Nutrient over-enrichment leading to more extensive hypoxia/anoxia

- Volume of Chesapeake Bay with dissolved oxygen deficiencies (< 2 mg/L)
- Walter Boynton data

Walter Boynton data
Research findings: Decomposing phytoplankton in bottom waters leads to oxygen depletion.

Predicted vs Observed Hypoxic Volumes Droughts and Floods 1950 - 2000

Predicted Hypoxic Volume = f (TN conc, River Flow)

• Walter Boynton data
Solution: Nutrient reduction strategies for point and diffuse sources

• Walter Boynton data
Problem: Critical habitat loss (oyster reefs and seagrass beds)

Skipjacks

Oyster reefs

Seagrass - 1933

Oyster catch 1840-2000

1840 1860 1880 1900 1920 1940 1960 1980 2000

2 4 6 8 10 12 14 16

Marine Bush (pounds)
Research findings: Filtration by oysters and seagrasses historically significant

- Shallow water volume filtration by oysters:
  
  Pre-1870  2.5 d
  Current   245 d
  (Newell, 1988)

- Denitrification enhancement by oysters
  (Newell et al., 2002)

- Seagrass sediment baffling:
  Historic seagrass captured 125% sediment load
  (Kemp et al., 1988)
Solution: Oyster restocking and seagrass restoration programs

Caveats:
- Disease
- Hatchery limitations (2000 vs. 20 acres)
- Degraded habitat
- Location of food varies

Caveats:
- Water quality
- Propagule limitations
- Degraded habitat
Problem: Dams and riparian degradation leading to less coarse but more fine grained sediments.
Research findings: Extensive salt marsh and island loss with rising sea level

- Eroding salt marsh
- Disappearing island
- Salt marsh loss at Blackwater
- Groundwater depression

Rapid sea level rise in N. Atlantic

Images: E.W. Koch, UMCES; Douglas Hanks Jr.; Maryland Sea Grant

Solution: Possible use of dredge spoil to augment marshes and islands

- Poplar Island
- Chesapeake salt marsh
- Sediment stabilization
Net result: Chesapeake Bay ecosystem health not improving

Chesapeake Bay Foundation annual report card rankings
Biogeochemical budgets: CNP fluxes & net system metabolism

\[
\log(\text{mol DIP km}^{-2} \text{ yr}^{-1}) = 2.72 + 0.36 \log(\text{persons/km}^2) + 0.78 \log(\text{m/yr})
\]

\[ R^2 = 0.58 \]