Predicting the unpredictable - a macroecological approach towards future ecosystem scenarios

Thomas Brey, AWI
Predicting the unpredictable -

**A macroecological approach towards future ecosystem scenarios**

Macroecology = study of relationships between organisms and their environment at large spatial scales to characterise and explain statistical patterns of abundance, distribution and diversity (Brown 1989)

**Thomas Brey, AWI**
Predicting the unpredictable - a macroecological approach towards future ecosystem scenarios

... a preview on years to come

Thomas Brey, AWI
Predicting the unpredictable - a macroecological approach towards future ecosystem scenarios

... a preview on years to come

... with focus on the benthic compartment

Thomas Brey, AWI
What are we expected to deliver?

Management

ECOSYSTEM FUNCTIONING

Goods & Services

Sustainable Use
What are we expected to deliver?

Stakeholders → Management

? → !

Science

Analysis

Model

Prediction

ECOSYSTEM FUNCTIONING

Goods & Services

Sustainable Use

Fisheries

Marine Drugs

Genetic Heritage

Recreation

Bio-Reactor

Monday, 17 December 12
What are we expected to deliver?

Stakeholders → Management

Science → Analysis → Model → Prediction

Sustainable Use

Goods & Services

Ecosystem Functioning

Stakeholders

Science

Analysis

Model

Prediction

Global Warming Projections

Mean Sea Level

pH Value

Sea Ice Cover

Coastal Erosion

Bio-Reactor

Monday, 17 December 12
Why is ecosystem modeling so difficult?
Why is ecosystem modeling so difficult?

• Non-deterministic ecological processes

Chaos in a long-term experiment with a plankton community

Prediction time (d)

Predictability

Benincá et al. 2008 Nature 451
Why is ecosystem modeling so difficult?

- Non-deterministic ecological processes
- The players: genetic, taxonomic, functional diversity?
Why is ecosystem modeling so difficult?

- Non-deterministic ecological processes
- The players: genetic, taxonomic, functional diversity?
- The rules: “1st Principles” in ecophysiology & ecology?

![Secondary Extinction Models](image)

Jacob et al. 2011

Number of species removed
Why is ecosystem modeling so difficult?

- Non-deterministic ecological processes
- The players: genetic, taxonomic, functional diversity?
- The rules: “1st Principles” in ecophysiology & ecology?
- Spatial heterogeneity of state & change

Arctica islandica

in the southern North Sea

Witbaard et al. 1994
Why is ecosystem modeling so difficult?

- Non-deterministic ecological processes
- The players: genetic, taxonomic, functional diversity?
- The rules: “1st Principles” in ecophysiology & ecology?
- Spatial heterogeneity of state & change

Spatially explicit approach:

Who is doing what, where and why?

Witbaard et al. 1994
Is the whole > the sum of its parts?

- Dynamic Habitat Models
- Geo-Referenced Ecological Niche Models
- Species Performance Models
- Species Interaction Models

ECOSYSTEM FUNCTIONING
Goods & Services

Monday, 17 December 12
Is the whole > the sum of its parts?

Implicit chapter headings...
Is the whole > the sum of its parts?

Implicit chapter headings...

- Geostatistics + niche models = game changer
Is the whole > the sum of its parts?

Implicit chapter headings...

• Geostatistics + niche models = game changer

• Measuring performance of benthic biota
Is the whole > the sum of its parts?

Implicit chapter headings...

- Geostatistics + niche models = game changer
- Measuring performance of benthic biota
- Linking the biosphere to its drivers
Is the whole > the sum of its parts?

Implicit chapter headings...

- Geostatistics + niche models = game changer
- Measuring performance of benthic biota
- Linking the biosphere to its drivers
- A holistic view from the service side
Is the whole > the sum of its parts?

Implicit chapter headings...

• Geostatistics + niche models = game changer
• Measuring performance of benthic biota
• Linking the biosphere to its drivers
• A holistic view from the service side
• Our regional focus
Geostatistics - Spatial pattern analysis

Spatial patterns in species numbers
Geostatistics - Spatial pattern analysis

Benthos and demersal fish habitats in the German Exclusive Economic Zone (EEZ) of the North Sea

Hermann Neumann · Henning Reiss · Siegfried Ehrich · Anne Sell · Kay Penten · Matthias Kloppmann · Ingo Wilhelms · Ingrid Kröncke

Spatial patterns in species numbers
Benthic habitat modeling

Habitat information

Depth & sediment type for each (grid) cell of the raster map
Benthic habitat modeling &

Species preferences

Habitat information

Species information

Depth & sediment type for each (grid) cell of the raster map

Probability of species occurrence in the depth & sediment continua
Dynamic habitat models

Spatial probability model of species occurrence

Probability of species occurrence in raster cell

(Dannheim 2011 unpubl)
Dynamic habitat models

Spatial probability model of species occurrence

Pleuronectes platessa

Mapping parameters for Pleuronectes platessa (European plaice)

<table>
<thead>
<tr>
<th>Area restrictions:</th>
<th>FAQ Areas: 21, 27, 34</th>
<th>Pelagic: False</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bounding Box (NSWE):</td>
<td>72 36 -47 45</td>
<td></td>
</tr>
</tbody>
</table>

Environmental envelope:

<table>
<thead>
<tr>
<th></th>
<th>Min</th>
<th>Pref Min (10th)</th>
<th>Pref Max (90th)</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth (m)</td>
<td>0</td>
<td>10</td>
<td>50</td>
<td>200</td>
</tr>
<tr>
<td>Water temp. (°C)</td>
<td>-1.77</td>
<td>8.8</td>
<td>13.4</td>
<td>18</td>
</tr>
<tr>
<td>Salinity (psu)</td>
<td>6.25</td>
<td>28.7</td>
<td>35.37</td>
<td>36</td>
</tr>
<tr>
<td>Primary Production</td>
<td>559</td>
<td>1742</td>
<td>2669</td>
<td></td>
</tr>
<tr>
<td>Sea Ice Concentration (% cover)</td>
<td>-0.981077376</td>
<td>0</td>
<td>0.03</td>
<td>0.81</td>
</tr>
<tr>
<td>Distance to Land (km)</td>
<td>0</td>
<td>4</td>
<td>166</td>
<td>594</td>
</tr>
</tbody>
</table>

Relative probabilities of occurrence

- Red: 0.80 - 1.00
- Pink: 0.60 - 0.79
- Orange: 0.40 - 0.59
- Yellow: 0.20 - 0.39
- Light Yellow: 0.01 - 0.19

1 km²

Probability of species occurrence

Monday, 17 December 12
Dynamic habitat models

Spatial probability model of species occurrence

-> Validation! Suitable habitat <-> Realized niche

platessa

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Ecophysiological niche modeling

Thermal tolerance model

Pörtner & Peck 2010
Ecophysiological niche modeling

Thermal tolerance model

Species thermal niche model

Pörtner & Peck 2010

Monday, 17 December 12
Ecophysiological niche modeling

Species thermal niche model

-> Validation! Functional niche <-> Realized niche

Pörtner & Peck 2010
Performance modeling -> Services

- Primary Production
- O₂
- CO₂
- Respiration
- Gonad Production
- Somatic Production
- Bioturbation
- Bioirrigation
- Food Web

Benthic Animal / Population

Monday, 17 December 12
Performance modeling -> Services

We need performance models!

- AWI data
- UVS data

Monday, 17 December 12
Performance modeling -> Services

Primary Production

Consumption

O₂

CO₂

Respiration

Gonad Production

Somatic Production

Bioturbation

Bioirrigation

Food Web

Benthic Animal / Population

Monday, 17 December 12
Performance modeling -> Services

Primary Production

O₂  CO₂

Consumption  Respiration  Bioturbation  Bioirrigation

Gonad Production  Food Web

Somatic Production

Benthic Animal / Population

Respiration model

An empirical model for estimating aquatic invertebrate respiration
Performance modeling -> Services

Primary Production

Respiration

Consumption

Gonad Production

Somatic Production

Bioturbation

Bioirrigation

Benthic Animal / Population

Food Web

Production model

A multi-parameter artificial neural network model to estimate macrobenthic invertebrate productivity and production
Performance modeling -> Services

Primary Production

Consumption

O₂

CO₂

Respiration

Gonad Production

Somatic Production

Bioturbation

Bioirrigation

Somatic Production

Food Web

Benthic Animal / Population

Bioturbation model

Role of macrofauna functional traits and density in biogeochemical fluxes and bioturbation

Ulrike Braeckman¹*, Pieter Provoost², Britta Gribsholt³, Dirk Van Gansbeke¹, Jack J. Middelburg², Karline Soetaert², Magda Vincx¹, Jan Vanaverbeke¹
Species interaction modeling
Species interaction modeling

Food web model

Jacob et al. 2006
Species interaction modeling

Food web model

The Role of Body Size in Complex Food Webs: A Cold Case

UTE JACOB, AARON THIERRY, ULRICH BROSE, WOLF E. ARNTZ, SOFIA BERG, THOMAS BREY, INGO FETZER, TOMAS JONSSON, KATJA MINTENBECK, CHRISTIAN MOLLMANN, OWEN L. PETCHY, JENS O. RIEDE, AND JENNIFER A. DUNNE

Adv. Ecological Res. 45; 2011

Jacob et al. 2006
Environmental drivers & system response
Environmental drivers & system response

- Land
- Ocean
- Atmosphere

Drivers
Models
Environmental drivers & system response

Finite Element Ocean Model (FEOM)
Finite Element Sea Ice Ocean Model (FESOM)

Land-
Ocean-
Atmosphere

Drivers

Models
Environmental drivers & system response

- Land-Ocean-Atmosphere Drivers
- Models

Finite Element Ocean Model (FEOM)
Finite Element Sea Ice Ocean Model (FESOM)
Environmental drivers & system response

Finite Element Ocean Model (FEOM)
Finite Element Sea Ice Ocean Model (FESOM)

Land-Ocean-Atmosphere

Drivers

Models

Long-Term Ecolog. Data

Paleo-Record & Bioarchives

Theoretical Ecology

Macrobenthic diversity 1969-2000
(Schröder 2005)
Environmental drivers & system response

Land-Ocean-Atmosphere Drivers Models

Long-Term Ecolog. Data Paleo-Record & Bioarchives Theoretical Ecology

Finite Element Ocean Model (FEOM)
Finite Element Sea Ice Ocean Model (FESOM)

Macrobenthic diversity 1969-2000
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Arctica islandica growth variability 1770-2005
(Brey & Schöne unpubl)
Environmental drivers & system response

Land-Ocean-Atmosphere Drivers Models

Long-Term Ecolog. Data

Paleo-Record & Bioarchives

Theoretical Ecology

A Post-Invasion Weddell Sea Food Web (Woodward et al. 2010)

Macrobenthic diversity 1969-2000 (Schröder 2005)

Arctica islandica growth variability 1770-2005 (Brey & Schöne unpubl)

Finite Element Ocean Model (FEOM)

Finite Element Sea Ice Ocean Model (FESOM)

Sleepershark Somniosus microcephalus (a. 6.4 m)

Porbeagle Lamna nasus (a. 2.5 m)

Spurdog Squalus acanthias (a. 0.8–1.6 m)

Lanternshark Etmopterus granulosus (a. 0.6 m)

Monday, 17 December 12
Environmental drivers & system response

Finite Element Ocean Model (FEOM)
Finite Element Sea Ice Ocean Model (FESOM)

Macrobenthic diversity 1969-2000
(Schröder 2005)

Arctica islandica growth variability 1770-2005
(Brey & Schöne unpubl)

A Post-Invasion Weddell Sea Food Web
(Woodward et al. 2010)
Macroecological-/physiological Scenario Generator

- Actual system state
- Cause & effect relationships
- Future scenarios
- Hypothesis testing
The sediment-water interface challenge

**Ecosystem Goods & Services**

- Nutrient Remineralization
  - $\rightarrow$ Primary Production
- Carbon Metabolization
  - $\rightarrow$ Higher Trophic Levels
- Processing & Neutralization of Anthropogenic Substances
The sediment-water interface challenge

Ecosystem Goods & Services

- Nutrient Remineralization
  -> Primary Production
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The sediment-water interface challenge

Ecosystem Goods & Services

- Nutrient Remineralization
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  -> Higher Trophic Levels
- Processing & Neutralization of Anthropogenic Substances

Sediment Oxygen Profile

D. Sevilgen unpubl.
The sediment-water interface challenge

Benthic macrofauna impact on biogeochemical processes

Ecosystem Goods & Services
- Nutrient Remineralization -> Primary Production
- Carbon Metabolization -> Higher Trophic Levels
- Processing & Neutralization of Anthropogenic Substances

Sediment Oxygen Profile

- no infauna
- infauna

D. Sevilgen unpubl.
The Shelf Sea Benthic Biogeochemical Reactor

Macrobenthic Community

Ecosystem Goods & Services

- Nutrient Remineralization -> Primary Production
- Carbon Metabolization -> Higher Trophic Levels
- Processing & Neutralization of Anthropogenic Substances
The Shelf Sea
Benthic
Biogeochemical
Reactor

Ecosystem Goods & Services

- Nutrient Remineralization
  -> Primary Production
- Carbon Metabolization
  -> Higher Trophic Levels
- Processing & Neutralization
  of Anthropogenic Substances

Macrobenthic Community
The Shelf Sea Benthic Biogeochemical Reactor

Ecosystem Goods & Services

- Nutrient Remineralization
  -> Primary Production
- Carbon Metabolization
  -> Higher Trophic Levels
- Processing & Neutralization of Anthropogenic Substances

Biogeochemical Cycling

- POM Turnover & Metabolism
- Sediment Bioirrigation
- Bioturbation

POM & DOM Dynamics

System Metabolism

Macrobenthic Community

- Land-Ocean-Atmosphere
- Drivers
- Models
- Long-Term Ecology
- Paleo-Records & Bioarchives
- Theoretical Ecology

Dynamic Habitat Models

Species Performance Models

Geo-Referenced Ecological Niche Models

ECOSYSTEM FUNCTIONING
Goods & Services

Monday, 17 December 12
The Shelf Sea Benthic Biogeochemical Reactor

Ecosystem Goods & Services

- Nutrient Remineralization
  -> Primary Production
- Carbon Metabolization
  -> Higher Trophic Levels
- Processing & Neutralization of Anthropogenic Substances

System Metabolism

- POM & DOM Dynamics
- Sediment Bioirrigation
- Bioturbation
- Macrobenthic Community

Drivers
Models
Long-Term Ecology, Data
Paleo-Record & Bioarchives
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Land-Ocean-Atmosphere

Dynamic Habitat Models
Species Performance Models
Species Interaction Models

Geo-Referenced Ecological Niche Models

ECOSYSTEM FUNCTIONING Goods & Services

POM Turnover & Metabolism

Anthropogenic Impact

Fisheries
Windfarms

Monday, 17 December 12
The Shelf Sea Benthic Biogeochemical Reactor

Ecosystem Goods & Services
- Nutrient Remineralization
- Carbon Metabolization
- Higher Trophic Levels
- Processing & Neutralization of Anthropogenic Substances

Biogeochemical Cycling
- Biogeochemical Reactor
- Carbonate System
- Primary Production
- Respiration
- Organic Matter
- Food Web
- Biogenic Sediments
- Biomineralization
- Solution
- CaCO₃
- CO₂ + H₂O
<= H⁺ + HCO₃⁻
<= 2 H⁺ + CO₃²⁻

POM & DOM Dynamics
System Metabolism

Monday, 17 December 12
Ecosystem Goods & Services

- Carbon Metabolization → Higher Trophic Levels
- Nutrient Remineralization → Primary Production
- Processing & Neutralization of Anthropogenic Substances

The Shelf Sea Benthic Biogeochemical Reactor

- Biogeochemical Cycling
- POM & DOM Dynamics
- System Metabolism
- Regional / Global Biogeochemical Models

Carbonate System

\[ \text{CO}_2 + \text{H}_2\text{O} \Leftrightarrow \text{H}^+ + \text{HCO}_3^- \Leftrightarrow 2 \text{H}^+ + \text{CO}_3^{2-} \]

Primary Production

Respiration

Organic Matter

Food Web

Biogenic Sediments

Sediment Bioirrigation

Macrobenthic Community

Windfarms

Anthropogenic Impact

CO\(_2\) and CO\(_3^{2-}\)

Primary Production

CaCO\(_3\)

Bioturbation

Solution

Regional / Global Biogeochemical Models

Monday, 17 December 12
Regions of interest
Regions of interest

North Sea
Regions of interest

Arctic Ocean

North Sea
Regions of interest:

- Arctic Ocean
- North Sea
- Weddell Sea
Regions of interest

Research Field Earth and Environment
Proposal for a Helmholtz Research Programme

Marine, Coastal and Polar Systems
PACES II: Polar regions And Coasts in the changing Earth System
Regions of interest

Research Field Earth and Environment
Proposal for a Helmholtz Research Programme

Marine, Coastal and Polar Systems

PACES II: Polar regions And Coasts in the changing Earth System

Workpackage 6: Large scale variability and change in polar benthic biota and ecosystem functions

Coordinators: T. Brey (AWI), H.O. Pörtner (AWI)

Mission statement

To identify, understand, and anticipate large scale and long-term change in ecosystem function and services provided by benthic and demersal biota of Arctic and Antarctic marine habitats.
Regions of interest

Research Field Earth and Environment
Proposal for a Helmholtz Research Programme

Marine, Coastal and Polar Systems
PACES II: Polar regions And Coasts in the changing Earth System

Workpackage 6: Large scale variability and change in polar benthic biota and ecosystem functions
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Workpackage 4: Biogeochemical provinces of sea floors in the German North Sea sector
Coordinators: Ralf Ebinghaus (HZG), Michael Schlüter (AWI)

Mission statement
To provide a comprehensive georeferenced inventory of biogeochemical seafloor properties in the German Bight of the North Sea as a basis to assess their pollution status and functions in material cycling.
Antarctic Weddell Sea
Antarctic Weddell Sea

Pressemitteilung Nr. 318 vom 29.10.12 Deutschland plant Meeresschutzgebiete in der Antarktis
Aigner: "Einzigartige Ökosysteme müssen wirksam geschützt werden"

Die Bundesrepublik Deutschland wird für die "Internationale Kommission zum Schutz lebender Ressourcen in der Antarktis" (CCAMLR: Commission for the Conservation of Antarctic Living Resources) die Vorbereitungen zur Errichtung von Meeresschutzgebieten im Weddellmeer übernehmen.
Antarctic Weddell Sea

Data (1982 – 2012)
11,142 stations
5,742 data sets

Neumayer III Station

Weddell Sea
Antarctic Weddell Sea

MPA Working Group

Weddell Sea
Antarctic Weddell Sea

Weddell Sea

MPA Working Group

Identification of biogeochemical provinces in the Southern Ocean: spatial modeling of biological, geochemical and sedimentological data

Dr. Kerstin Jerosch

Monday, 17 December 12
Arctic Ocean

Vision:

pan-Arctic approach:
1st step: geo-referenced benthic data bank
**Vision:**

pan-Arctic approach: 1st step: geo-referenced benthic data bank

*Mar Biodiv* (2011) 41:51–70
DOI 10.1007/s12526-010-0059-7

**ARCTIC OCEAN DIVERSITY SYNTHESIS**

Towards a pan-Arctic inventory of the species diversity of the macro- and megabenthic fauna of the Arctic shelf seas

Dieter Piepenburg · Philippe Archambault · William G. Ambrose Jr. · Arny L. Blanchard · Bodil A. Bluhm · Michael L. Carroll · Kathleen E. Conlan · Mathieu Cusson · Howard M. Feder · Jacqueline M. Grebmeier · Stephen C. Jewett · Mélanie Lévesque · Victor V. Petryashev · Mikael K. Sejr · Boris I. Sirenko · Maria Włodarska-Kowalczyk
Vision:
pan-Arctic approach:
1st step: geo-referenced benthic data bank

Barents Sea macrobenthic production
Cooperation IMR Tromsø - AWI
North Sea

Trawling frequency

Offshore wind farms

Monday, 17 December 12
North Sea

Trawl frequency (times trawled per year)
0 - 0.01
0.01 - 1
1 - 2
2 - 3
3 - 5
5 - 7
7 - 10
10 - 15
15 - 21

Infaunal biomass

Rave Research at Alpha Ventus
Eine Forschungsinitiative des Bundesumweltministeriums

Monday, 17 December 12