Estimation of bacterial growth efficiency by a coupled experimental-modelling approach

Influence of substrate regime

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The oceanic carbon cycle
The oceanic carbon cycle

Dissolved organic carbon (DOC)

2nd stock of bioreactive carbon in the oceans (Williams & Druffel 1987)

3 pools (Kirchman et al. 1993):
- Labile DOC (L-DOC)
- Semi-labile DOC (SL-DOC)
- Refractory DOC (R-DOC)

Heterotrophic bacteria

Major DOC consumers (Pomeroy 1974)
DOC producers (Kaiser and Benner 2008)

≈ 50% of total respiration in ocean interior (del Giorgio & Duarte 2002)

Central component of the microbial loop (Legendre & Rassoulzadegan 1995)

BGE = bacterial growth efficiency
quantifies carbon fluxes through bacterioplankton

L-DOC

BGE
growth

(1-BGE)
respiration

CO₂

?

Δbiomass

Δsubstrate

DEB Symposium
Brest 20-22 April 2009
### The oceanic carbon cycle

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<thead>
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**BGE** = bacterial growth efficiency

- quantifies carbon fluxes through bacterioplankton

**BGE varies greatly according to numerous factors:**

- chemical nature (Cherrier et al. 1996)
- molecular weight (Amon and Benner 1996)
- elemental ratios (Goldman et al. 1987)
- distance from seashore (La Ferla et al. 2005)
- season (Romthaler & Herndl 2005)
- temperature (Rivkin & Legendre 2001)
- UV exposure (Abboudi et al. 2007)

Heterotrophic bacteria

- Major DOC consumers (Pomeroy 1974)
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≈ 50% of total respiration in ocean interior (del Giorgio & Duarte 2002)

Central component of the microbial loop (Legendre & Rassoulzadegan 1995)

**Objectives**

**Influence of DOC availability on BGE estimation**

**Consequences for ecosystem modelling**

- DOC degradation experiments: one load vs pulsed load
- construction of a DEB model
- comparison with empirical models
- BGE estimation
- impact for biogeochemical modelling

**BGE** = \( \frac{\Delta \text{biomass}}{\Delta \text{substrate}} \)
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DOC degradation experiments

Experiment B
Batch

Experiment P
Pulsed

Typical experiment
Mimic natural DOC dynamic

unique L-DOC source: Pyruvic acid
unique bacterial strain: Alteromonas infernus

Same experimental conditions
Same total amount of substrate
Nutrients in excess

Effects of substrate regime on DOC and bacterial dynamics?
DOC degradation experiments

Experiment B
Batch
Typical experiment

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Pulsed
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unique L-DOC source: Pyruvic acid
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Same total amount of substrate
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Effects of substrate regime on DOC and bacterial dynamics?

DOC = dissolved organic carbon
POC = particulate organic carbon (bacterial biomass)
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Construction of a DEB model

Case 1: growth

- 3 state variables
  - $L = L\text{-DOC}$
  - $M_E = \text{reserve mass}$
  - $M_V = \text{structural body mass}$

- 3 processes

![Diagram of DEB model for Case 1: growth]

Case 2: reduction

- 3 state variables
  - $L = L\text{-DOC}$
  - $M_E = \text{reserve mass}$
  - $M_V = \text{structural body mass}$

- 3 processes

![Diagram of DEB model for Case 2: reduction]

Kooijman 2000
Tolla et al. 2007

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Construction of a DEB model

Case 1: growth

- 4 state variables
  - \( L \) = L-DOC
  - \( R \) = unlabile-DOC
  - \( M_E \) = reserve mass
  - \( M_V \) = structural body mass

- 4 processes
  - \( M_E \) = assimilation
  - \( M_V \) = maintenance
  - Growth
  - \( POC = M_V + M_E \)
  - \( DOC = L + R \)

Case 2: reduction

- 2 new parameters:
  - \( j_{MV} \) = maintenance from structure
  - \( y_{RV} \) = yield coefficient from structure to unlabile-DOC

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### Comparison with empirical models

<table>
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<tr>
<th>Processes</th>
<th>DEB</th>
<th>Marr-Pirt</th>
<th>Monod</th>
</tr>
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<tr>
<td>reserve</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>2 maintenances ($M_E + M_V$)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R-DOC production</td>
<td></td>
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Special cases of the DEB model with particular parameter values

#### Processes

**Pulse**

- DEB:
  - Reserve
  - 2 maintenances ($M_E + M_V$)
  - R-DOC production

**Batch**

- DEB:
  - Reserve
  - 2 maintenances ($M_E + M_V$)
  - R-DOC production

- Marr-Pirt:
  - 1 maintenance ($M_v$)
  - R-DOC production

- Monod:
  - 1 maintenance ($M_v$)
  - R-DOC production
Objectives

Influence of DOC availability on BGE estimation
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BGE estimation

\[ \frac{dl}{dt} = -\alpha lM_L \]
\[ \frac{dM}{dt} = \alpha y_{LM}M_L - j_{gD}M_v - y_{LV}M_v + \frac{k_{LM}M_L - j_{M}M_L}{M_L + y_{LV}M_v} \]
\[ d\left( \frac{M_L}{y_{LV} + M_L} \right) = \frac{y_{LM} - j_{gD}}{y_{LV} \alpha L} \]

\[ \frac{dM_L}{dt} = \text{BGE}_L \]

\[ \frac{dM_v}{dt} = \text{BGE}_v \]

\[ \frac{dM_j}{dt} = \text{BGE}_j \]
BGE estimation

**DEB**
\[
\frac{dL}{dt} = -\alpha L M_v
\]
\[
\frac{dM}{dt} = \alpha y_{L,M_v} L M_v - j_{M_v} M_v
- y_{L,M_v} \frac{k_2 M_v - j_{M_v} M_v}{M_v + y_{L,M_v} M_v}
\]
\[
\frac{dM_v}{dt} = y_{L,M_v} \frac{k_2 M_v - j_{M_v} M_v}{M_v + y_{L,M_v} M_v} - y_{L,m} M_v
\]
\[
\frac{d(M/L)}{-dL} = y_{L,M_v} \frac{j_{M_v}}{y_{L,M_v}} \alpha L
\]

**Marr-Pirt**
\[
\frac{dL}{dt} = -\alpha L M_v
\]
\[
\frac{dM}{dt} = BGE_s \alpha L M_v - j_{M_v} M_v
\]
\[
\frac{dM_v}{dt} = y_{L,M_v} \frac{j_{M_v}}{M_v}
\]
\[
\frac{d(M/L)}{-dL} = BGE_s \frac{j_{M_v}}{\alpha L}
\]

**Monod**
\[
\frac{dL}{dt} = -\alpha L M_v
\]
\[
\frac{dM}{dt} = BGE_s \alpha L M_v
\]
\[
\frac{dM_v}{dt} = BGE_s \alpha L M_v
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\[
\frac{d(M/L)}{-dL} = BGE_s \frac{j_{M_v}}{\alpha L}
\]
### BGE estimation

<table>
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<tr>
<td>Batch</td>
<td>0.14</td>
<td>0.20</td>
<td>0.21</td>
</tr>
<tr>
<td>Pulse</td>
<td>0.23</td>
<td>0.38</td>
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BGE for model including maintenance are higher than without maintenance.

BGE estimated from the Marr-Pirt and DEB models are equivalent.
BGE estimation

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BGE for model including maintenance are higher than without maintenance

BGE estimated from the Marr-Pirt and DEB models are equivalent

BGE estimated experimentally and from the Monod model are equivalent

Bacterial growth on pulse load is more efficient
Objectives

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Impact for biogeochemical modelling

• Bacterial DOC production
  new DEB bacterial model
  only 2 more parameters
Impact for biogeochemical modelling

• BGE (pulse) > BGE (batch)

- Bacterial DOC production
  - should be taken into account in biogeochemical models (Eichinger et al., accepted)
  - impact on the carbon cycle?

• BGE (pulse) > BGE (batch)
  - incorporation of a better DOC dynamic → higher BGE

• BGE (maintenance) > BGE (without maintenance)
  - maintenance was experimentally demonstrated
  - under-estimation of the BGE with the typical methods?
  - over-estimation of bacteria as CO₂ producer?
Thank you for your attention !!!