Seasonal hypoxia of the Amurskiy Bay (Japan/East Sea)

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**Study area: Amurskiy Bay - part of Peter the Great Bay, the Japan/East Sea**

Amurskiy Bay is a semiclosed basin. It is located in the northwestern part of Peter the Great Bay. Its length is about 70 km and depth varies from 0 up to 53 m (average depth is about 15 m). Square of the bay is about 1000 km². Annual river-runoff is 2.5 km³. Population around Amurskiy Bay is 300,000. Northern part of the Bay is covered by ice in winter time.
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Motivation

Hypoxia is a below critical content of DO, when heterotrophic life is not possible

(30% in RF, 75 uM commonly)

Hypoxia is a form of ecosystem instability which leads to significant changes and may cause negative consequences

Hypoxia became a world wide phenomena for coastal waters recently (e.g. Diaz, 2001; Diaz and Rosenberg, 2010)
Goals of this study

Mechanisms of hypoxia formation and destruction in the Amurskiy Bay, Japan/East Sea

Contribution of natural and anthropogenic factors

Inter-annual tendencies
Observations in four seasons during 1999-2010

Measured parameters:
Profiles: CTD, Oxygen, Fluorescence, turbidity – RBR XR-620, SBE-19+

Samples from surface and from near-bottom: Dissolved Oxygen, Nutrients (Silicate, Nitrite, Nitrate, Ammonium, Phosphate), pH, Total Alkalinity, Chlorophyll, Humic Substances, Transparency by disc Secci.
In total:
- Stations - >1000
- Taken samples - >2600
- Measurements - > 20 000

Winter – 197
Spring – 144
Summer – 456
Autumn - 152
Data

Special seasonal surveys in 2008

Feb
65

May
103

Aug
140

Oct
132
Severe hypoxia of near-bottom layer in the Amurskiy Bay

Lowest oxygen concentration was $4 \mu\text{mol/kg}$. (1.5%)
Seasonal variations of DO at bottom layer, 2008
Seasonal variations of DIP at bottom layer, 2008

Feb

May

Aug

Oct
Seasonal variations of DIN at bottom layer, 2008
Seasonal variations of DISi at bottom layer, 2008
Seasonal variations of NDIC at bottom layer, 2008
Summer is a period of hypoxia formation

- coincidence of hypoxia areas and areas of maximum of nutrients and DIC suggests microbial destruction of large amount of organic matter in the areas of hypoxia;

- formation of hypoxia is related to excess of phytoplankton biomass caused by eutrophication of the bay;

- there are 2 main sources of nutrients: Vladivostok city waste waters and Razdolnaya River discharge
Load of nutrients by Razdolnaya River and Vladivostok City waste waters

(a) (b)
## Monthly load of nitrogen (TN) and phosphorus (TP) into Amurskiy Bay in 2008

<table>
<thead>
<tr>
<th>Period of the year</th>
<th>Jan-Dec</th>
<th>May-Aug</th>
<th>Sep-Apr</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sources</strong></td>
<td>City</td>
<td>River</td>
<td>City</td>
</tr>
<tr>
<td><strong>TN: τ/(km²/month)</strong></td>
<td>0.1</td>
<td>0.35</td>
<td>0.1</td>
</tr>
<tr>
<td>Portion from total</td>
<td>22%</td>
<td>78%</td>
<td>11%</td>
</tr>
<tr>
<td><strong>TP: τ/(km²/month)</strong></td>
<td>0.01</td>
<td>0.04</td>
<td>0.01</td>
</tr>
<tr>
<td>Portion from total</td>
<td>24%</td>
<td>76%</td>
<td>11%</td>
</tr>
</tbody>
</table>

River – ¾, Vladivostok City – ¼ of total load

- **Main source of eutrophication is Razdolnaya River**
- **City discharge is stable while river discharge is variable**
Nutrients fluxes into Amurskiy Bay by Razdolnaya River in 2008:

a – DIN  
b – DIP  
c – DISi

Annual fluxes (T/year) of nutrients into Amurskiy Bay by river runoff

<table>
<thead>
<tr>
<th>Nutrients</th>
<th>DIN</th>
<th>N-tot</th>
<th>DIP</th>
<th>P-tot</th>
<th>DISi</th>
</tr>
</thead>
<tbody>
<tr>
<td>River runoff</td>
<td>1800</td>
<td>4200</td>
<td>120</td>
<td>450</td>
<td>17040</td>
</tr>
</tbody>
</table>
Seasonal variation of plankton bloom events 1991-2007

Number of bloom events by month in Amurskyi Bay (1991–2007).
Source: Center of Monitoring of HABs & Biotoxins of the Institute of Marine Biology FEB RAS http://www.imb.dvo.ru/misc/toxicalgae/index.htm (Tatiana ORLOVA)
Scenario of near-bottom hypoxia formation:

1. **Eutrophication hit** - due to heavy precipitations at June and July in watershed of Razdolnaya River, high water of the River supplies nutrients and suspension matter into surface of Amursky Bay

2. **Diatoms bloom** - after settling of suspension matter, diatoms bloom is occurred at 14 June, and 25 July, 2008

3. Due to short time changes, zooplankton and fishes are excluded from food chain, therefore diatoms died and settled on the bottom
4. **High water turbidity** - decay of diatoms is going under deficit light conditions for most of the Amursky Bay area because turbidity of waters. Then hypoxia of near-bottom waters is occurred through microbiological processes such as:

**Ammonification or denitrification -**

\[
(CH_2O)_{106}(NH_3)_{16}H_3PO_4 + 84.8NO_3^- + 99.8H^+ \rightarrow 106CO_2 + 148.4H_2O + 16NH_4^+ + 42.4N_2 + H_2PO_4^-, \tag{1}
\]

**and sulfatereduction -**

\[
(CH_2O)_{106}(NH_3)_{16}H_3PO_4 + 53SO_4^{2-} \rightarrow 38H_2S + 16NH_4^+ + H_2PO_4^- + 106HCQ^+ + 15HS^{-} \tag{2}
\]
Small fishes mortality event in Amurskiy Bay on September 14, 2008

Died fishes on 14th September 2008 at the coast of Amurskiy Bay. Most part of the fishes were junior smelt and had a specific smell.

Photo: Vladimir Kolesnikov
5. Strong stratification and calm weather in Summer over last years prevent vertical mixing of hypoxic bottom layer.
Autumn is a period of hypoxia destruction

- coastal upwelling during season of monsoon shift and horizontal advection of open sea water up into the bay;

- vertical mixing caused by stronger winds and convection

<table>
<thead>
<tr>
<th>№</th>
<th>Период</th>
<th>Место</th>
<th>Продолжительность</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>16.06-26.10.09</td>
<td>Токаревский прол.</td>
<td>132</td>
</tr>
<tr>
<td>2</td>
<td>14-22.09.09</td>
<td>м. Назимова</td>
<td>8</td>
</tr>
<tr>
<td>3</td>
<td>28.10-22.11.09</td>
<td>б. Золотой Рог</td>
<td>26</td>
</tr>
<tr>
<td>4</td>
<td>4-20.06.10</td>
<td>м. Назимова</td>
<td>15</td>
</tr>
<tr>
<td>5</td>
<td>4-20.06.10</td>
<td>м. Назимова</td>
<td>15</td>
</tr>
</tbody>
</table>

H=48 m
RDCP-600

Advection of sea water

Hypoxia maximum

22-25.08

Shift of mean transport

Current speed

Current direction

0-30 m

31-46 m
Removal of hypoxia in the Amurskiy Bay

изменение T, S и DO на разрезе через Амурский и Уссурийский заливы 1-7 октября 2011
Removal of hypoxia in the Amurskiy Bay

изменение T, S и DO на разрезе через Амурский и Уссурийский заливы 1-7 и 27-30 октября 2011
Winter is a period of DO regeneration

- high primary production;

- vertical mixing by thermo-haline convection
Winter AOU – oxygen oversaturation

High biological productivity of Amursky Bay in winter season which utilizes nutrients due to primary production and including of zooplankton and fishes into food chain.
Winter pCO$_2$ – undersaturated

Distribution of CO$_2$ partial pressure surface (a) and bottom (b) waters. It is demonstrated that most part of Amursky Bay area is undersaturated by carbon dioxide. Green line notes equilibrium state.
Winter Chl-a and PP – highly productive area

Highest production area is associated with non-consolidate ice area “ice-edge effect”

Distribution of chlorophyll-a concentration and primary production (gC/(m² day)) in surface waters. It is demonstrated that Amursky Bay area is highly productivity area.
Seasonal variation of DO
(based on 18 cruise data 1999-2010)

Mean DO Surf
Mean DO Bot
Min DO Bot
Critical level
75 uM
Variation of DO min value in the Amurskiy Bay over 85 years

Decreased by 30 times
Conclusion:

1. Hypoxia in the Amurskiy Bay has a seasonal occurrence. Strong decrease of DO is observed in Summer and is associated with eutrophication hits caused by fluctuation of Razdolnaya River. Autumn upwelling and advection of deep sea water onto shelf removes hypoxia. High PP in winter regenerates DO and makes whole water column oversaturated.

2. Strong hypoxia (below in Summer became a permanent feature of the Amurskiy Bay bottom layer over last 5 years at least.

3. Retrospective analyses of available data over 85 years shows gradual decrease of DO minimum in bottom layer.
Thank you for attention!