Floating University course

Use bio-optical parameters as convenient tool to study marine biogeochemical processes
Piotr Kowalczuk, Waldemar Walczewski

Introduction to Baltic Sea hydrography
Baltic Sea – basic facts

Baltic Sea is very young – it has been formed during last deglaciation ca. 10000 y. ago and the present form reached only ca. 3000 y. ago

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area</td>
<td>392 978 km(^2)</td>
</tr>
<tr>
<td>Volume</td>
<td>21 205 km(^3)</td>
</tr>
<tr>
<td>Mean/max. depth</td>
<td>54 / 459 m</td>
</tr>
<tr>
<td>Drainage basin area</td>
<td>1 633 290 km(^2)</td>
</tr>
<tr>
<td>Water renewal time</td>
<td>33 – 50 years</td>
</tr>
<tr>
<td>Mean salinity</td>
<td>7.4</td>
</tr>
<tr>
<td>Primary production</td>
<td>30 -250 g C m(^2)yr(^-1)</td>
</tr>
<tr>
<td>Coastal countries</td>
<td>9</td>
</tr>
<tr>
<td>Countries in the drainage basin area</td>
<td>14</td>
</tr>
<tr>
<td>Population in drainage basin area</td>
<td>85 mln</td>
</tr>
</tbody>
</table>

Lepparanta and Myberg, 2009
### Baltic Sea – unique marine basin

#### ESTUARY
- High volume of terrstrila inflow
- Low salinity
- Brackish surface water
- Strong stratification with picnocline
- Intensive mixing across picnocline

#### BIG LAKE
- Shallow depth
- Complex bathymetry
- Dominating wind circulation
- Presence of side borders influences circulation

#### SMALL OCEAN
- Mesoscale eddies
- Upwelling
- Internal waves
- Seiches

**Semi-Enclosed Basin ⇒ No Tides**
Block diagram presenting hydrological budget and exchange of water between Baltic Sea basins and the North Sea. The volume transport in km³.
Baltic Sea – unique marine basin

- Baltic – shallow inland sea;
- Baltic - mesohaline sea
  averaged oceanic salinity ca. 35
  averaged Baltic Sea salinity ca. 7
- Strong stratification – high gradient between low salinity surface layer and high salinity deep waters;
- Rapid change of salinity with depth (halocline);
- This results with rapid density gradients (picnocline);
- Significant difference in salinity along main Baltic Sea axis – salinity decreases with distance from Danish Straits
Baltic Sea – unique marine basin

Fig. 3. Section from the Kattegat to Bothnian Bay showing salinity stratification

Carstensen, et al., 2014 PNAS 111 (15) 5628-563

EUROFLEETS+ - An alliance of European marine research infrastructure to meet the evolving needs of the research and industrial communities

www.eurofleets.eu

The consequence of vertical stratification and stagnation of bottom waters – hydrogen sulfide deserts

Exciting forces and processes controlling water circulation in the Baltic Sea
Types of inflows of saline water into the Baltic Sea

**Barotropic inflow**
- The barotropic inflow is forced by the difference in water level between Kattegat and Arkona basin;
- Those inflow usually occur during fall and winter storms;
- To initiate the barotropic inflow the specific atmospheric circulation is necessary:
  - in the first phase long lasting easterly winds (associated with high atmospheric pressure over Russia) that intensify the Surface oligohaline water outflow and lowering water level in Arkona Basin are required,
  - in the second phase rapid reverse of atmospheric circulation from easterly to westerly winds is required what causes the compensating inflow through the Danish Straits.

**Baroclinic inflows**
- the exciting force initiating baroclinic inflows is difference in water density between Baltic Sea and the North Sea waters;
- baroclinic inflows carried much smaller water volume compared to barotropic ones;
- they are much frequent;
- they propagate over Stolpe sill in the forms of overflow.
Categorization of inflows of saline water into the Baltic Sea according to volume transport measured at Danish Strait gateway

- **Weak** <100 km³
- **Moderate** 100-200 km³: 41 moderate inflows since 1898
- **Very strong** >300 km³: 1897 (330 km³), 1906 (300 km³), 1922 (510 km³), 1951 (510 km³), and 1993/94 (300 km³).
Significance of inflows

- Inflows of saline water prevent Baltic Sea to became fresh water lake;
- Inflows are the main source of oxygen in deep waters below picnicline;
- Inflows impact the biogeochemical cycle of dissolved organic matter in deep waters;
- Inflows have direct impact on benthic communities and cod stock spawning.
The overflow sequence of baroclinic inflow over Stolpe Sill

- The pulsating overflow of dense water over the sill ⇒ propagation of isolated lenses in the Słupsk Channel
  - maximal currents velocities up 40 cm/s
  - maximal propagation of the lense up to 10-20 cm/s
- Duration period – from several to 24 hours
- Volume transport of saline waters (S>13) ca. 1 km³
Two last major inflows into Baltic Sea – February 2003 and November 2014

The vertical distribution of temperature, salinity and density along main axis of inflow propagation – December 2002

The vertical distribution of temperature, salinity and density along main axis of inflow propagation – February 2003

The vertical distribution of temperature, salinity and density along main axis of inflow propagation – December 2002
Two last major inflows into Baltic Sea – February 2003 and November 2014

2014/2015 inflow propagation and dissipation sequence

The vertical distribution of temperature, salinity, density and dissolved oxygen along main axis of inflow propagation, November 2014, left, January 2015 right.
Two last major inflows into Baltic Sea – February 2003 and November 2014

2014/2015 inflow propagation and dissipation sequence

The vertical distribution of temperature, salinity, integrated currents velocities, and dissolved oxygen along main axis of inflow propagation in February 2015

The vertical distribution of temperature, salinity, integrated currents velocities, and dissolved oxygen along main axis of inflow propagation in October 2015
The Baltic Sea is very young inland water, which hydrology is dominated by the fresh water discharge from vast drainage area;

Surface and bottom waters in the Baltic Sea are separated by the density boundary – the picnocline

The Baltic Sea bottom water is under sever oxygen deficit resulting in creation of the hydrogen sulfide dead zones;

Inflows of the saline water from the North Sea is the only mechanism of renewal of bottom waters and supply of dissolved oxygen

The strongest inflows to the Baltic Sea are the barotropic inflows;

The frequency of strongest inflows decreased from, 5-7/decade to 1/decade;

It is projected the frequency of strongest inflows will continue to decreased due to climate change;

The strong inflow observed in 2014-2015 has been significant (ca. 200 km³ saline water and ca. 4 GT of salt), but did not remediated the oxygen deficit in the deep waters;

The irregular barotropic inflows are becoming significant for bottom water renewal in the Baltic Sea;