Ship-of-opportunity observations of mesoscale eddies

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Mesoscale eddies form around the rim of the North Pacific. They influence plankton distributions and may act as a ‘Hot-Spot’ for upper trophic levels.
Eddies are thought to impact lower trophic levels by:

- Advecting chlorophyll, nutrients and organisms from shelf to open ocean \cite{Brickley2004}.

- By supplying nutrients to the euphotic zone through vertical processes within the eddy \cite{Ladd2005}.

- Colonisation by oceanic zooplankton and then aggregation and retention through vertical migration behaviour \cite{Mackas2005}.

- There is interannual variability in eddy strength and frequency with El Niño years producing larger, longer-lived eddies – climate change is likely to affect eddy frequency and intensity.
Eddies are readily visible as sea surface height anomalies:

http://argo.colorado.edu/~realtime/welcome/
The Continuous Plankton Recorder Survey uses ships-of-opportunity to sample the oceanic North Pacific on regular routes:

Ship tracks often passed through eddies
Since the survey started in 2000, eddies have been sampled 47 times (whole N Pacific), 34 times in the Gulf of Alaska

<table>
<thead>
<tr>
<th>Variable</th>
<th># sampled in GoA</th>
<th># sampled in whole N. Pacific</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phyto- and zooplankton</td>
<td>34</td>
<td>46</td>
</tr>
<tr>
<td>Chlorophyll a (from CTD on CPR)</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td>Bird and Mammal observations</td>
<td>5</td>
<td>14</td>
</tr>
</tbody>
</table>

But only 5 eddies have all variables sampled
June 2\textsuperscript{nd} 2005

Western GoA

All variables measured
Two questions to examine:

1. Is there evidence that the eddies enhance the ‘productivity’ of the water within them with responses at multiple trophic levels, in all areas?

2. Do eddy properties visible from SSH anomaly images (size, age and intensity) determine biological properties?
6 regions where eddies were sampled by the ship transects:
Selected variables:

- Number of phytoplankton taxa
- Number of mesozooplankton taxa
- Biomass of mesozooplankton
- Number of bird species
- Bird density
- Mammal density

(chlorophyll a sampled too infrequently)

Calculated mean value of each variable within each eddy and monthly mean value for the region when eddies were not present

Then for each eddy calculated the anomalies for each variable
Lower trophic level anomalies

Columns show mean sample anomaly per eddy and white bars show one standard deviation of the monthly regional mean.
Focus on bird species that may be associated with eddies

Horned Puffin
Tufted Puffin
Parakeet Auklet
Black-footed Albatross
Leach’s Storm Petrel
Mottled Petrel
Sooty Shearwater
Higher trophic level anomalies

Bird density is only those species thought to be associated with eddies
### Percentage of anomalies that are positive, positive by > 1 st dev or negative by > 1 st dev

<table>
<thead>
<tr>
<th>Category</th>
<th>W GoA</th>
<th>NC GoA</th>
<th>NE GoA</th>
<th>E GoA</th>
<th>Bering Sea</th>
<th>W. Pacific</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phyto taxa</td>
<td>80, 30</td>
<td>57, 14</td>
<td>56, 0</td>
<td>75, 50</td>
<td>0, 0</td>
<td>60, 33</td>
</tr>
<tr>
<td>Zoo taxa</td>
<td>78, 57</td>
<td>57, 20</td>
<td>56, 25</td>
<td>38, 0</td>
<td>0, 0</td>
<td>50, 0</td>
</tr>
<tr>
<td>Zoo biomass</td>
<td>70, 29</td>
<td>57, 0</td>
<td>56, 25</td>
<td>0, 0</td>
<td>50, 0</td>
<td>30, 0</td>
</tr>
<tr>
<td>Bird taxa</td>
<td>75, 0</td>
<td>0</td>
<td>0</td>
<td>0, 0</td>
<td>33, 0</td>
<td>17, 0</td>
</tr>
<tr>
<td>Bird density</td>
<td>50, 0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>67, 33</td>
<td>33, 17</td>
</tr>
<tr>
<td>Mammal density</td>
<td>25, 0</td>
<td>0</td>
<td>0</td>
<td>100, 0</td>
<td>33, 0</td>
<td>0, 0</td>
</tr>
</tbody>
</table>

Only 1 eddy
Not all eddies enhance productivity….

“in August 2007 …a chlorophyll desert in the centre of a Haida Eddy in the eastern GoA” Bill Crawford pers. com.

……but some regions consistently do (W GoA) or sometimes do (E GoA)
Formation regions, formation conditions, time of year, eddy track will all affect the biology.

- Eddies formed here are transported in Alaska Stream and may stay associated with shelf.
- Eddies here may be from oligotrophic Kuroshio.
- Bering Sea is already productive and not Fe limited. Eddy structure may inhibit horizontal advection.
- Eddies formed here move westwards into open ocean.
Do eddy properties visible from SSH anomaly images affect biological properties?

1. Intensity (cm)

2. Size (km²)

3. Age (months)
### Multiple Linear Regression results – all areas combined

<table>
<thead>
<tr>
<th></th>
<th>Phyto taxa</th>
<th>Zoo taxa</th>
<th>Zoo Biomass</th>
<th>Bird taxa</th>
<th>Bird density</th>
<th>Mam. density</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intensity</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Area</td>
<td></td>
<td></td>
<td>+</td>
<td></td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>Age</td>
<td>+</td>
<td></td>
<td>+</td>
<td></td>
<td></td>
<td>+</td>
</tr>
<tr>
<td>Phyto taxa</td>
<td></td>
<td></td>
<td>+</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zoo taxa</td>
<td></td>
<td>+</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zoo Biomass</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>+</td>
</tr>
</tbody>
</table>
Species richness is positively correlated with species richness of the trophic level below

Mammals are possibly influenced by eddy characteristics
### By area (lower trophic levels and physical variables only)

<table>
<thead>
<tr>
<th></th>
<th>Phytoplankton taxa</th>
<th>Zooplankton taxa</th>
<th>Zooplankton Biomass</th>
</tr>
</thead>
<tbody>
<tr>
<td>W GoA</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C GoA</td>
<td></td>
<td>+Intensity</td>
<td>+Size</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>-Intensity</td>
</tr>
<tr>
<td>NE GoA</td>
<td>+Intensity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>E GoA</td>
<td></td>
<td>-Size</td>
<td></td>
</tr>
<tr>
<td>W Pacific</td>
<td></td>
<td>+Size</td>
<td>+Age</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>+Size</td>
</tr>
</tbody>
</table>
Summary

- Eddies influence the biology of the ocean, though not all eddies enhance productivity.

- Diversity is most influenced.

- Regional variations in biological enhancement dependent on formation region and to some extent physical properties.

- There are trophic linkages within the eddies, especially diversity.

- Measuring some physical properties is possible from satellites and Argo floats (Ueno et al., in prep) but biological and chemical properties require being in the water.

- FUTURE needs to account for these mesoscale features.
Thank you