Science Drivers - Chapter 2

Oxygen variability and change, oxygen minimum zones

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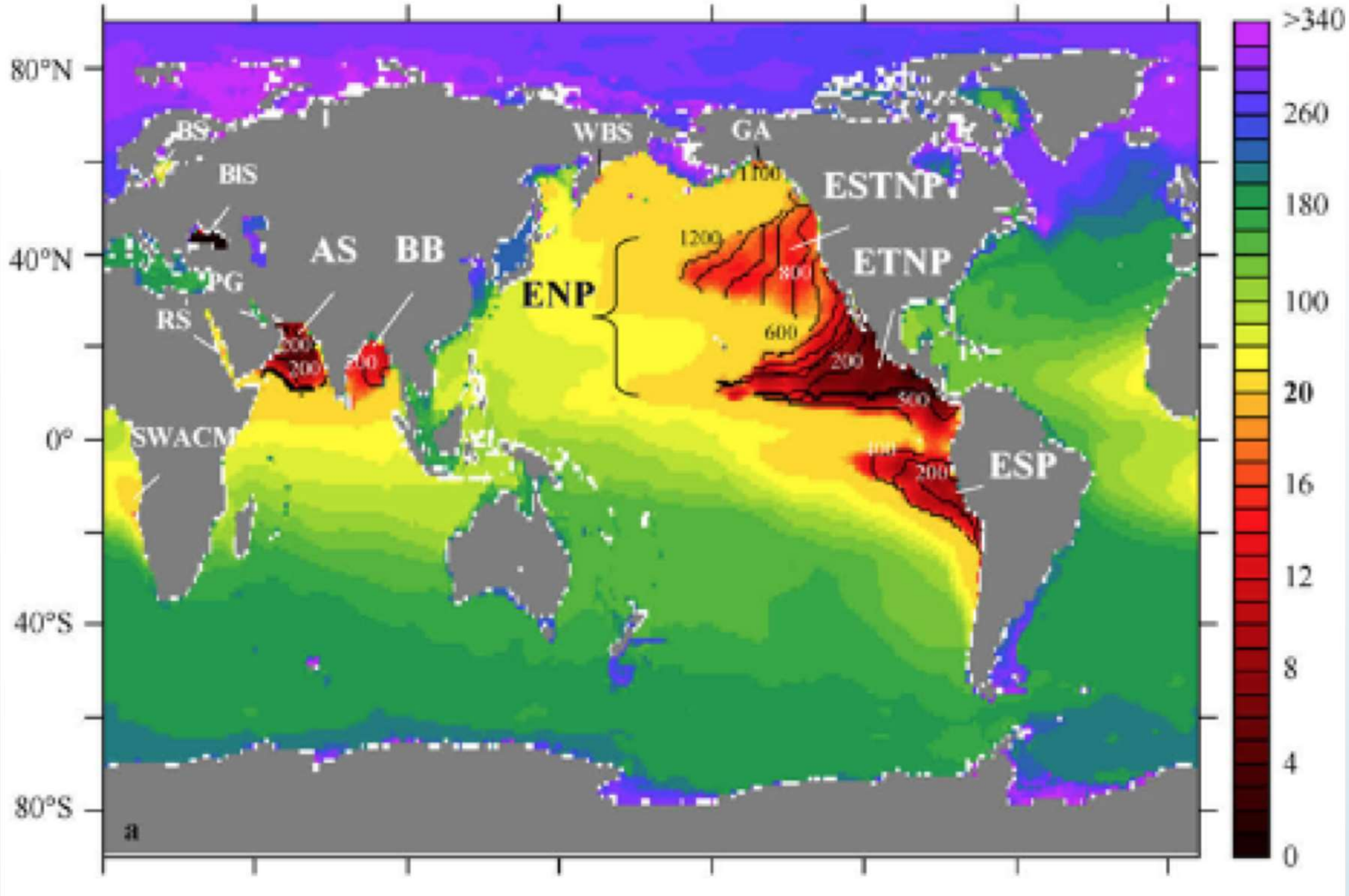
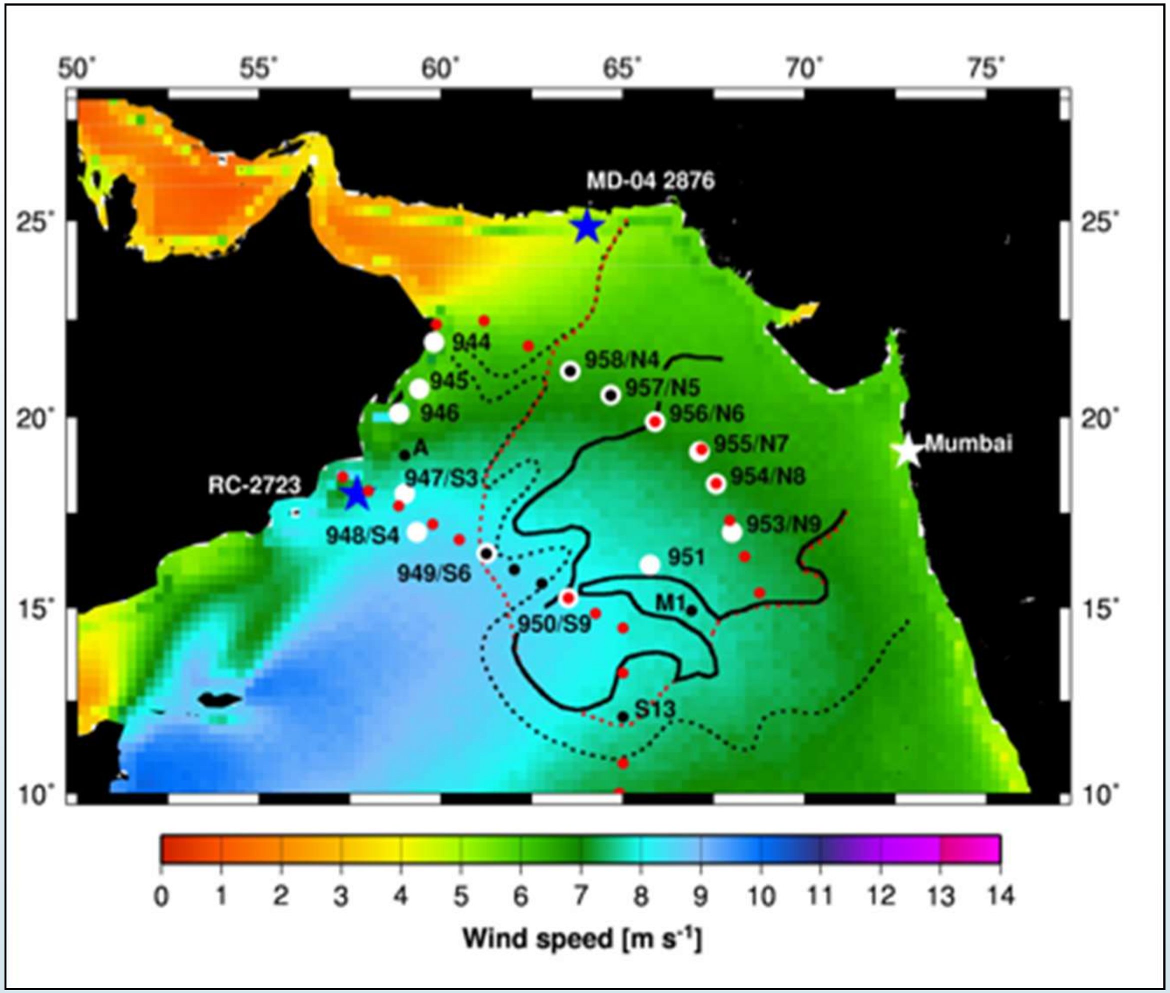
Global OMZ Distribution / Intensity



Deoxygenation is driven by global warming through

1) **Lower oxygen solubility as temperatures increase**
2) **Reduced ventilation as stratification increases.**

Extent of Denitrification Maximum in AS



Secondary Nitrite Maximum (SNM)

Naqvi and Shailaya 1996:

$NO_2 > 0.5$ µM

$NO_2 > 2$ µM

Rixen et al. 2014:

$NO_2 > 2$ µM

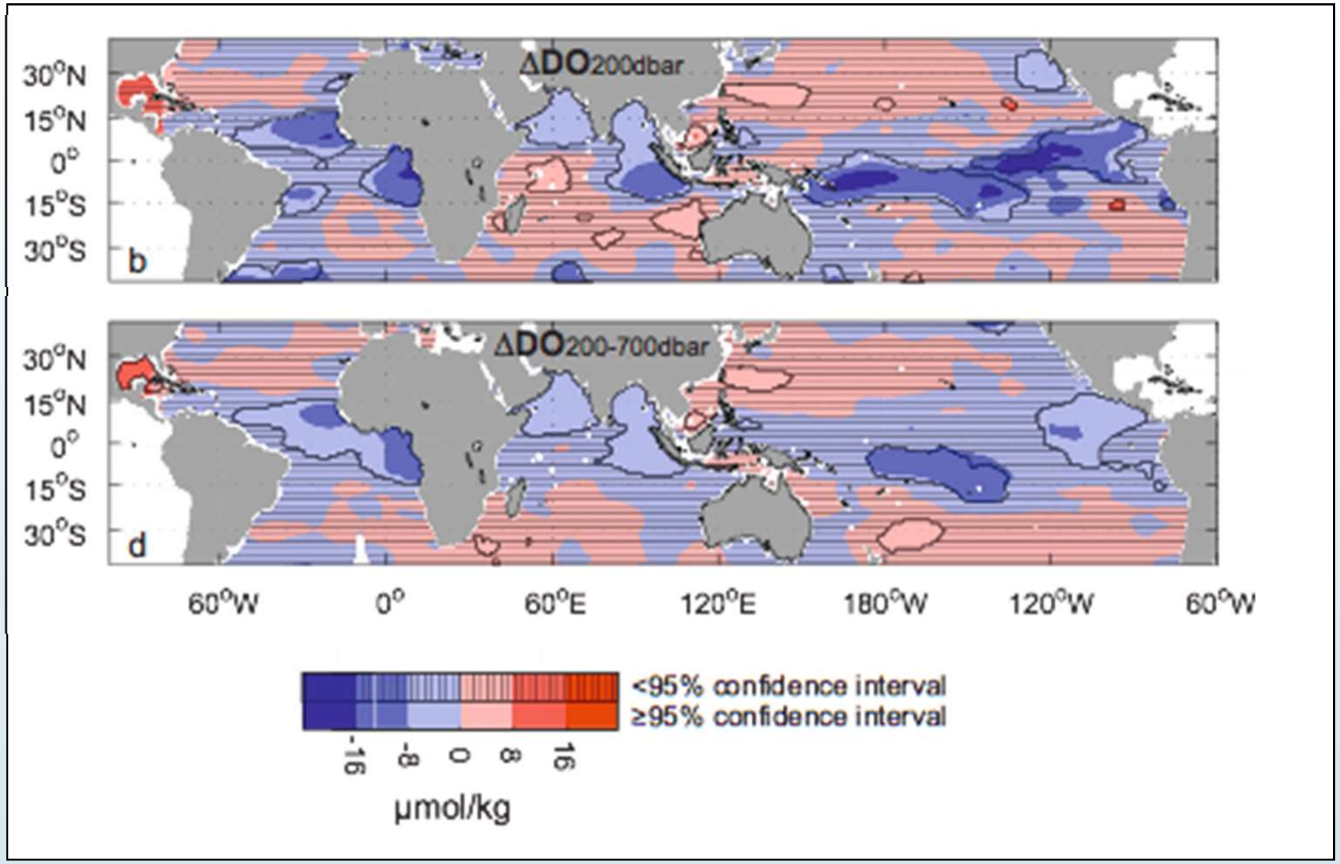
SNM area increased by 63% in 12 since JGOFS (1995 -> 2007)

SWM Mean Wind Speed

Black/Red Circles: AS JGOFS (1995)

White Circles: R/V Meteor (2007)

Deoxygenation Patterns (in Blue)
(1960-1974 ⇒ 1990-2008)



Changes in Dissolved Oxygen (DO) at 200 dbar (upper) and integrated 200-700 dbar (lower)

Comparison Periods
1960-1974 vs. 1990-2008

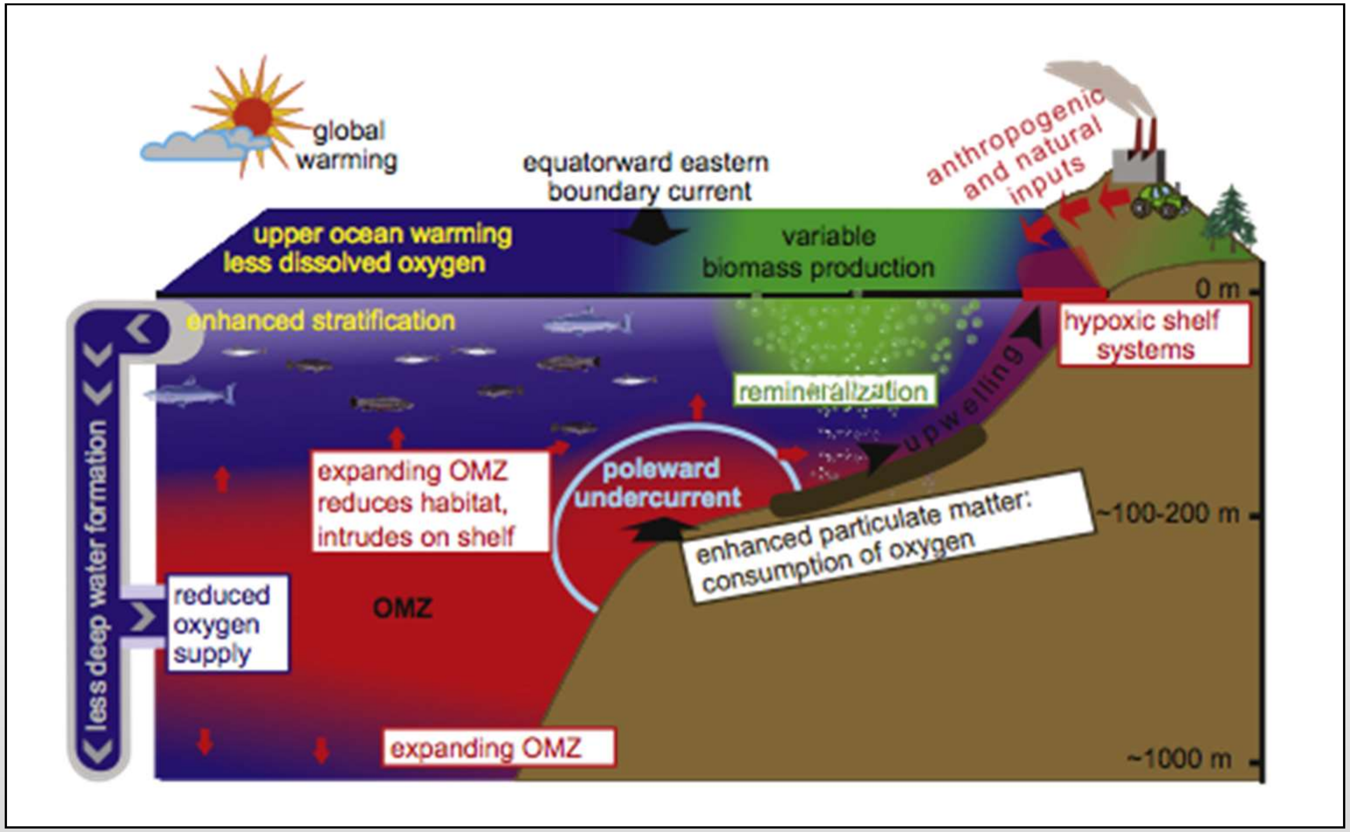
RED - DO increase
BLUE - DO decrease

Hatched regions indicate < 95% confidence interval

Data source: World Ocean Atlas

- **Spatial pattern of deoxygenation in EqIO and STIO aligns with IOD action centers**
  - **Suggestive of a biophysical linkage that should be explored**

Ecological Impact of Deoxygenation



- Under climate change, characterized by anthropogenic CO_2 emissions and global warming, OMZs are expanding / shoaling
- Consequences of OMZ expansion to the marine ecosystem include:
  - Loss of vertical habitat for high-oxygen-demand tropical pelagic billfishes and tunas
  - Associated increased risk of overfishing of these species by surface fishing gear
- High catch rates in habitat-compressed areas can be misinterpreted, leading to overly optimistic population condition assessments for both target (e.g., tuna) and by-catch (e.g., blue marlin) species
- Habitat compression should be accounted for in management decisions regarding harvest rates and fishing pressure

Stramma et al., (2010), Deep-Sea Res. I, 57(4), 10.1016/j.dsr.2010.01.005, 587-595.

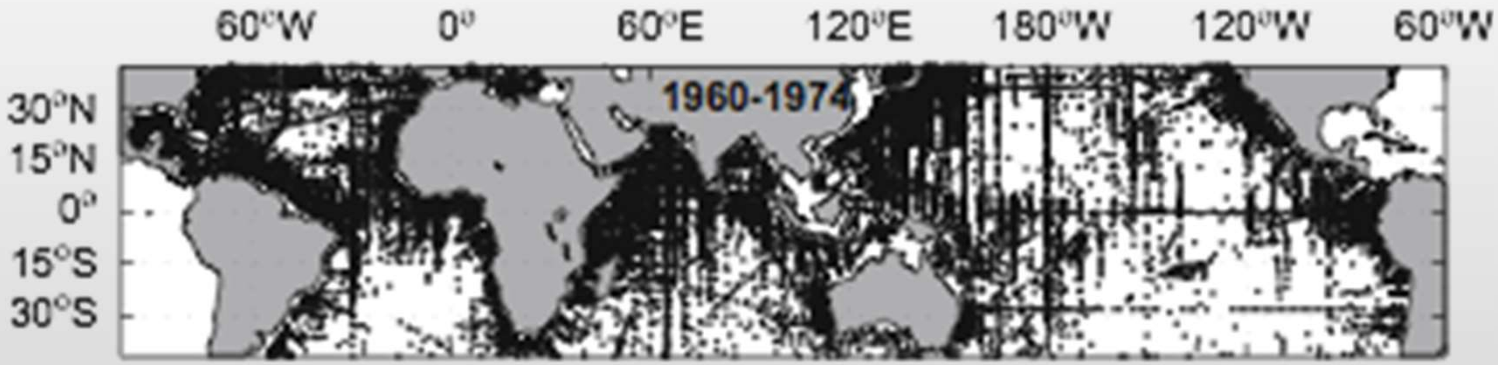
Deoxygenation - Advance Scientific Understanding to Better Assess Ecological & Societal Impacts

- OMZ Severity Contrast between Arabian Sea & Bay of Bengal
  - Distinctive buoyancy flux controls
    - Evaporative salinization vs. pronounced hydrologic inputs
  - Nature and extent of coastal upwelling
  - Varying impacts of seasonally reversing boundary currents
  - Mesoscale eddy impact on both ventilation & lateral advection of organic matter
  - Terrestrial inputs of organic and inorganic nutrients and particulates
    - Both atmospheric and river borne influences
    - Encompass desertification and increased usage of fertilizer in agricultural activities
- Organism response to sub-optimal oxygen availability
  - Energy conservation (e.g., reduced activity and/or cellular function)
  - Avoidance behaviors that impact growth, reproduction and survival
  - Habitat compression of planktonic and pelagic species could alter pelagic species distribution and their vulnerability to fisheries exploitation
- Vulnerability of Indian Ocean Rim Nations
  - Region's economies are the most vulnerable to climate change impacts on fisheries production
  - Region is home to approximately 2 billion people (~ 30% of global population)

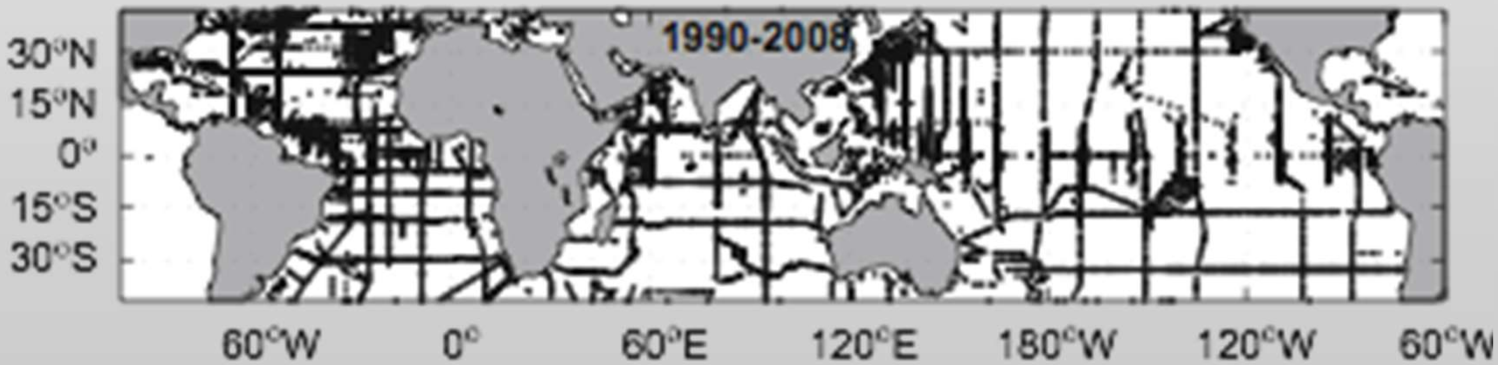
EOV Recommendations & Justification

- Critical need for expansion of the dissolved oxygen data availability for establishing the current state of the system
  - Stramma et al (2010) analysis demonstrates this striking contrast in current observational coverage relative to the historical baseline

1960 - 1974



1990 - 2008



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EOV Recommendations & Justification

- Complete suite of observations needed to comprehensively assess extent and function of biogeochemical processing within a fully reducing OMZ (hypoxic / anoxic)
  - NO_3, NO_2, NH_4, PO_4, and $\delta^{15N}NO_3$,
- Significantly expand the number of Bio-Argo float deployments
  - At a minimum, outfit these floats with dissolved oxygen sensors
  - As possible, deploy with more extensive capability to provide OMZ state characterization (as noted above)
- Deploy gliders and AUVs with oxygen and nutrient sensors in coastal ocean regions, where human influences are most pronounced and quickly evolving
- Leverage any ship-based activities (GEOTRACES, GO-SHIP, etc.) that could provide opportunity for more detailed rate experiments to develop deeper understanding of OMZ processes
- All of these activities will promote improving the skill of Earth System Models (ESMs) to simulate / project deoxygenation in oceanic environments stressed by climate change factors

Reviewer Feedback

- More specificity is required.
  - Does the global BGC Argo program design, parameters and accuracy meet the needs of this application?
  - Describe accuracy requirements for detecting long term trends
    - Essential to inform ongoing work on sensor improvement and calibration for autonomous instruments
- Fig 2 does not refer to observation density – is it a missing figure?
- Key recommendations are for bio-argo and gliders to monitor the OMZs and nutrients - this emphasis not well reflected in the executive summary.
- What is the importance of Air/Sea fluxes in regulating DO?
- Consider framing sampling design as recommending glider deployments at ocean boundaries and bio-argo floats in the ocean interior
- Acknowledge / illustrate linkages of ecosystem productivity more directly
  - E.g., map of tuna catches overlaid on chlorophyll measurements or the sites of biogeochemically-enhanced RAMA moorings