IMPLICATIONS OF SUBSURFACE NUTRIENT INCREASES IN THE SUBARCTIC PACIFIC OCEAN

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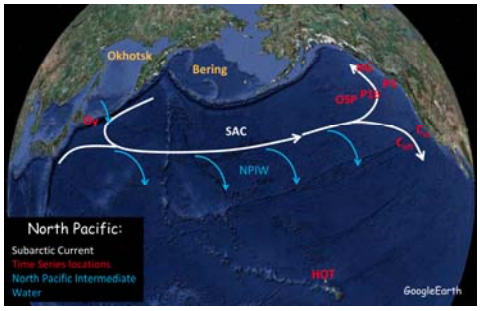
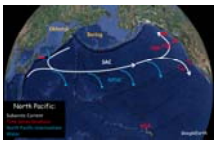
Temporal Trends of Inorganic Nutrients in the Subsurface North Pacific



- 9 nutrient time series stations available from 4 oceanic regions in North Pacific
- time period : 25-50 yr series (1960s-present)
- change in inventory from winter MLD to 500m depth

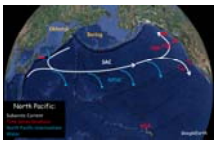
TAKE-HOME MESSAGES

- **Pan-Pacific trends to lower oxygen & higher nutrients below surface layer**
- **Nutrient accumulation in ocean pycnocline counteracts enhanced upper-ocean stratification**
- **Vertical compression of oxic habitat may exacerbate these trends**



OUTLINE

- **Characteristics & variability of California Current System**
  - California Undercurrent (CUC) structure and transport
  - Changes in source waters to California (O_2, NO_3)
- Pan-Pacific trends in dissolved oxygen, inorganic nutrients
  - NW Pacific (Oyashio region)
  - NE Pacific (Line P, Haida)
- Basin-scale comparisons and synthesis
- Mechanisms & ecological implications



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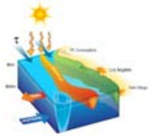

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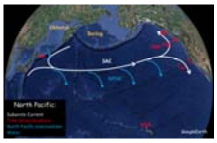

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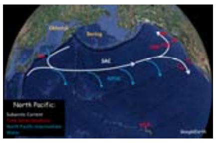

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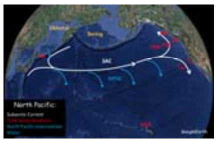
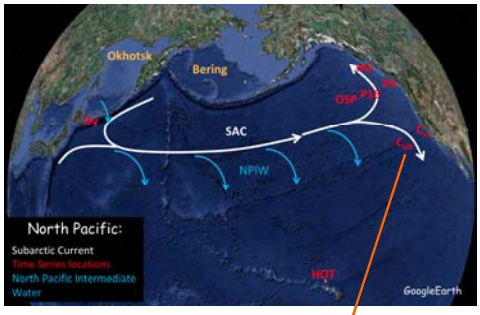
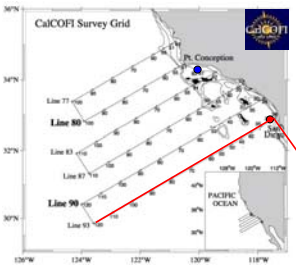


Temporal Trends of Inorganic Nutrients in the Subsurface North Pacific



CalCOFI

SOUTHERN CALIFORNIA CURRENT: CalCOFI

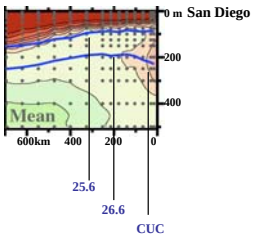


- 1984-present
- Quarterly Surveys
- consistent sampling
- 66 stations
- 0-500 m
- >100 Occupations

Station 93.30:
California Undercurrent

CALIFORNIA UNDERCURRENT TRENDS

Line 93 Mean Autumn Spiciness



CALIFORNIA UNDERCURRENT TRENDS: Nutrients & Nutrient Ratios

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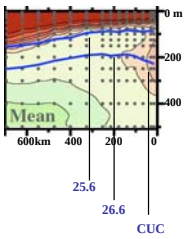
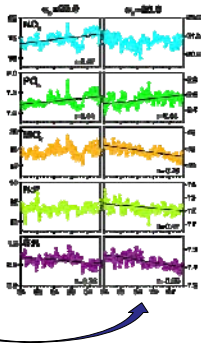
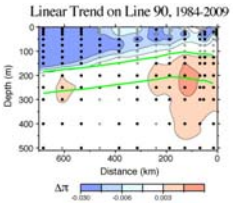
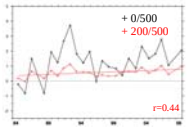




CALIFORNIA UNDERCURRENT TRENDS: Spiciness & Transport





Autumn Geostrophic Volume Transport, 93.30 – 93.60

1. Changes in water properties & transport of CUC
2. Tropical/Subtropical influence on California Current
3. CUC waters upwelled upstream (Chaak & Di Lorenzo, 2007)

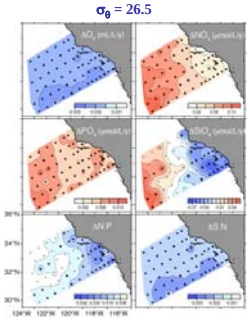
CalCOFI OXYGEN & NUTRIENT TRENDS on σ_θ=26.5

σ_θ = 26.5

⇩ Oxygen

⇧ Phosphate

⇩ N:P

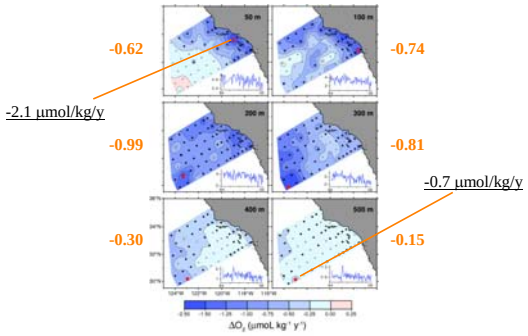


Nitrate ⇧

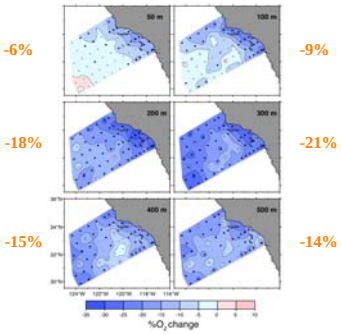
Silicate ⇧⇩

S:N ⇩

CalCOFI OXYGEN TRENDS: Magnitude



CalCOFI OXYGEN TRENDS: % Change



CalCOFI TRENDS SUMMARY

1. Oxygen declining at 0.2-1 µmol/kg/y *(mean)*
2. Largest mean declines at 200-300 m
3. Expansion of low-oxygen habitat
4. NO_3 and PO_4 increasing, at different rates
5. Strongest trends offshore, 100-300 m; shallower for NO_3
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What about the rest of the North Pacific …?

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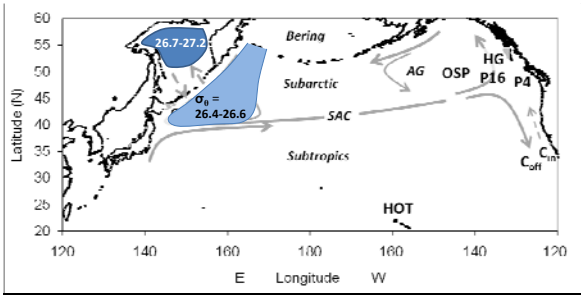
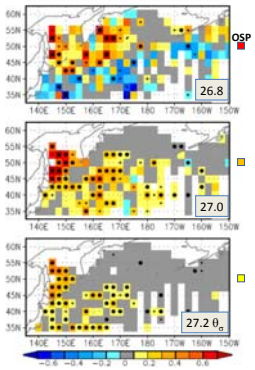


Oy – Oyashio (time series)
WSG – Western subarctic gyre
HOT – Hawaiian Ocean Time-series
SAC – subarctic current
AG – Alaska gyre
OSP – Ocean St. P Time-series (Stn P16 and P4)
HG – Haida Gwaii
C_{off}, C_{in} – CalCOFI Time-series

TEMPERATURE & SEA ICE TRENDS IN OKHOTSK SEA



Warming (°C), 1955-2004

(Nakowatari et al., 2007)

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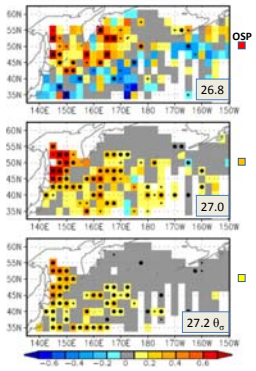

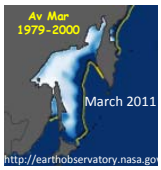

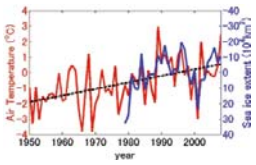

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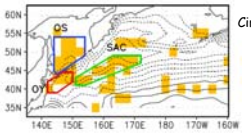
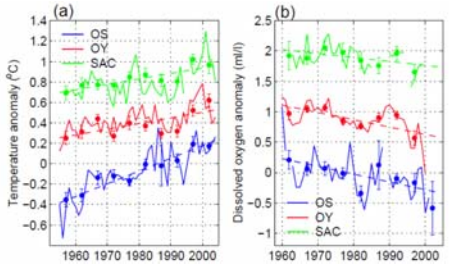
Temperature & Oxygen Trends in the NW Pacific on σ_θ=27.0



Circulation and warming at σ_θ=27.0

(Nakowatari et al., 2007)



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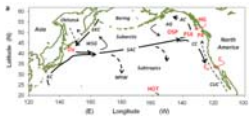
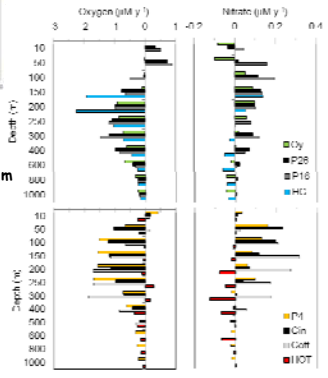


Subarctic trends
(time-series of ~25y)

- **O_2 loss >1 μM/y at 100-300 m**



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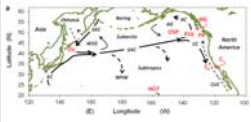

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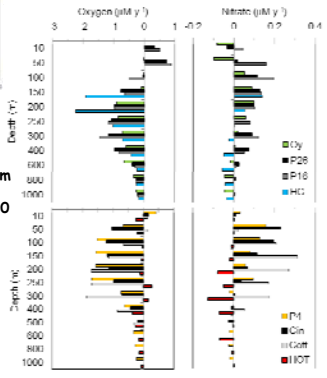

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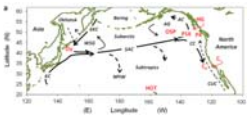

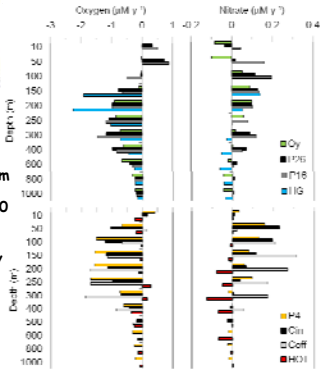

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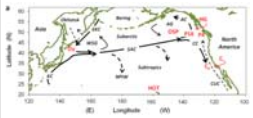

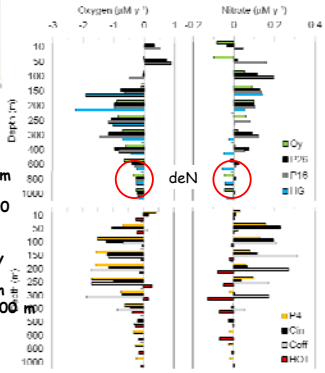

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- O_2 loss >1 μM/y at 100-300 m
- Integrated O_2 loss of 140-480 mmol/m²/y
- NO_3 gain 0f 15-60 mmol/m²/y
- Denitrification on N. American coast and Okhotsk Sea below 300 m

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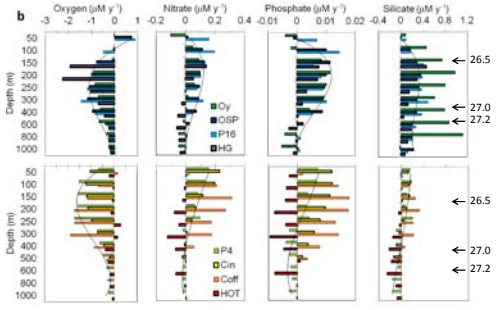
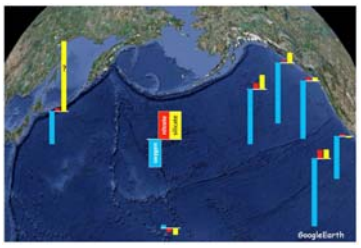


SUMMARY: Pan-Pacific Dissolved Oxygen & Nitrate Trends



1. Warming & reduced ice production in Okhotsk Sea
2. Freshening & increased stratification in Subarctic Pacific
3. Large declines in dissolved oxygen extending to eastern Pacific
4. Nutrient accumulation in the pycnocline

WHAT CAUSES VARIABILITY IN OXYGEN & NUTRIENTS?

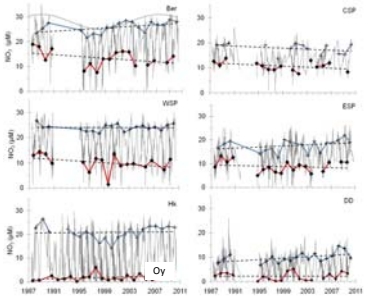
SUPPLY:

Winter mixing & ice formation along Asian margin, and subsequent transport along isopycnals

CONSUMPTION:

Depends on levels of primary production & ensuing export by sinking particles and migrating biota

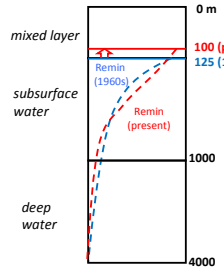
SURFACE NUTRIENTS ARE NOT DECLINING



Wintertime nutrient supply & seasonal drawdown stable

(Whitney, 2011)

WHAT CAUSES VARIABILITY IN OXYGEN & NUTRIENTS?



- Increased nitrate inventory at Station P can be achieved if remineralization in the waters above 1000m increases by 8%
- Balanced by decreased NO_3 concentration below 1000m
- HYPOTHESIS: Trends due to reduced ventilation & oxygen transport, shallower oxygen consumption & nutrient regeneration

IMPLICATIONS OF OXYGEN & NUTRIENT TRENDS

Three major issues arise from reduced ocean ventilation:

1. Increased nutrients in the pycnocline enrich winter resupply and upwelling sources

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… appears to be counteracting effects of increased upper-ocean stratification

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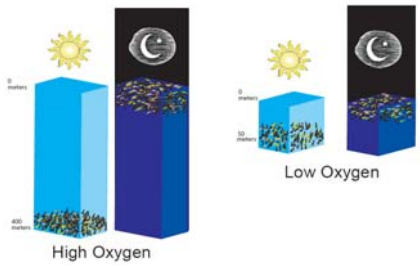
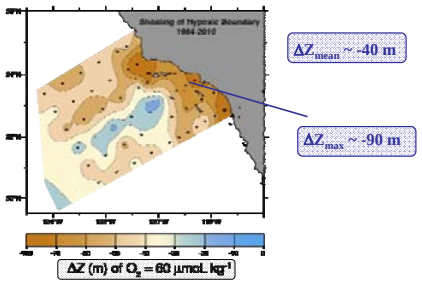
2. Expanding hypoxia limits continental slope habitat (also waters become more acidic)

ECOSYSTEM IMPLICATIONS: Shifts in Habitat & Community Structure

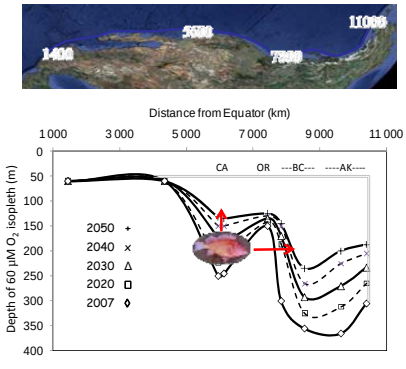


CalCOFI EXPANSION of LOW-OXYGEN HABITAT



NORTH AMERICAN SUMMER HABITAT CHANGE

(oxygen loss of 1.3% per year)



By summer 2050 only half the depth range may remain for groundfish needing >60 µM O_2

► Habitat compression, forced migration, less biomass.

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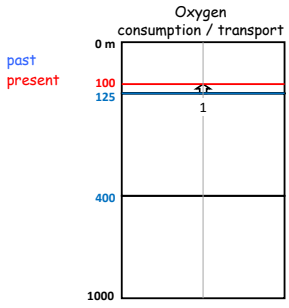
1. Increased nutrients in the pycnocline enrich winter resupply and upwelling sources

2. Expanding hypoxia limits continental slope habitat (also waters become more acidic)

3. Escalating eutrophication as low O_2 – high NO_3 waters upwelled

SUMMARY: What is Happening in the Subarctic Pacific?



1. Shoaling mixed layer

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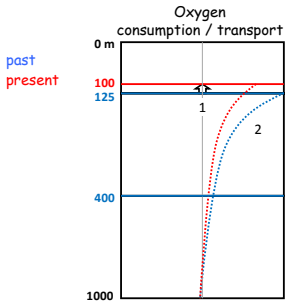

1. Shoaling mixed layer
2. And reduced ventilation (oxygen transport)

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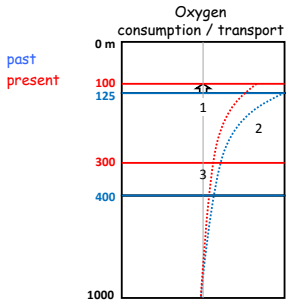

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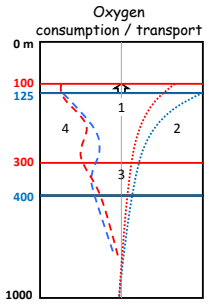

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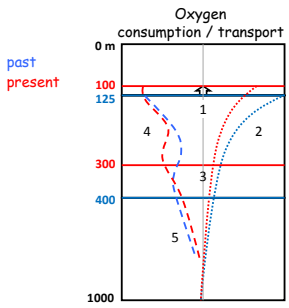

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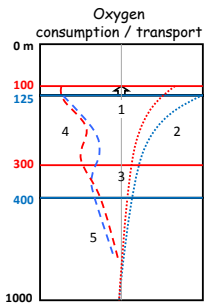

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Pycnocline waters are accumulating nitrate at ~20-40 mmol m^{-2} y^{-1} over an area of ~5 million km^2 = an increase of 100-200 Gmol y^{-1}

TAKE-HOME MESSAGES

- Pan-Pacific trends to lower oxygen & higher nutrients below surface layer
- Nutrient accumulation in ocean pycnocline counteracts enhanced upper-ocean stratification
- Vertical compression of oxic habitat may exacerbate these trends
- Do models capture these trends?

Thank You!