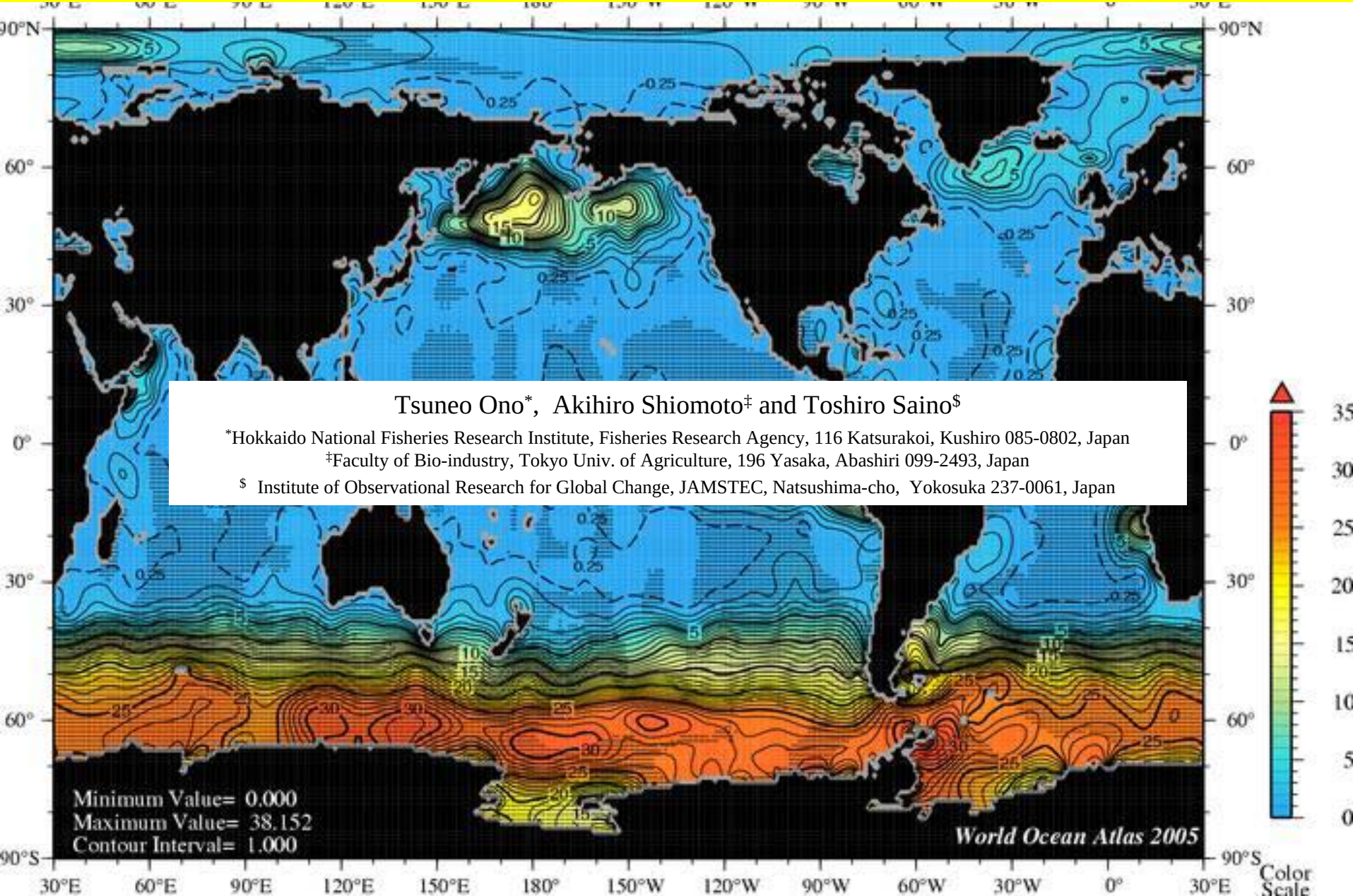
Recent decrease of summer time nutrients in the mixed layer of North Pacific HNLC region



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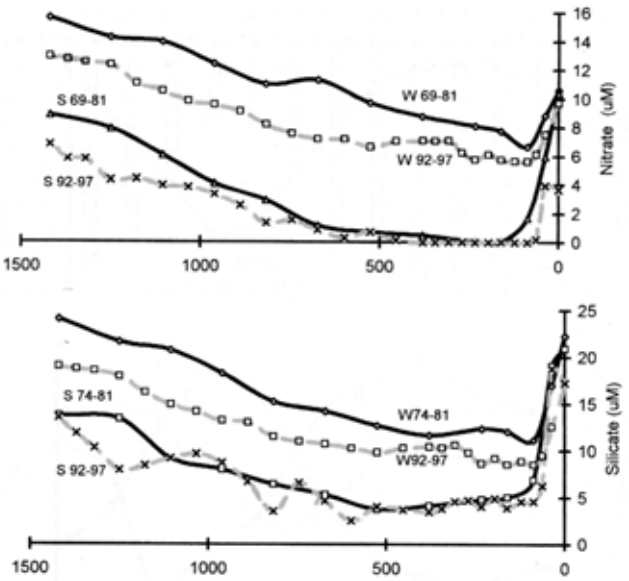
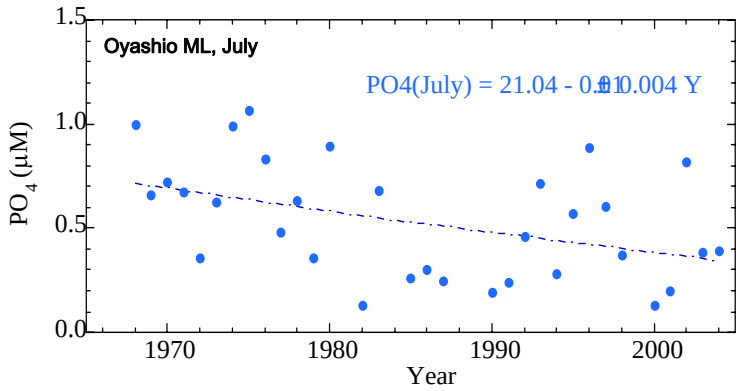
Background and Objectives

Oceanic stratification and surface nutrients decrease in the recent North Pacific

Eastern North Pacific
(Line P, Whitney & Freeland 1999)
ΔNO3 = 1.2 μM/15y



Western subarctic North Pacific
(west of 155E, Ono et al.,2002)
ΔPO4 = 0.1 μM/decade



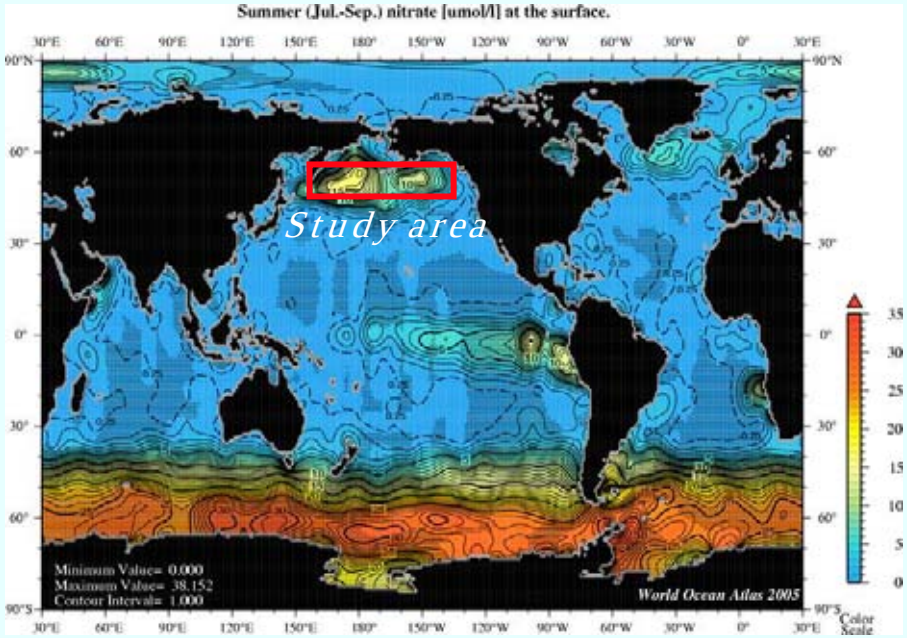
Objective of this study:

Assessment for basin-scale trend of nutrient in summertime mixed layer.....negative trend exist?
What is the cause of nutrient trend ?
What is the ecological consequence ?

Data

Data source:

- World Ocean Data base 2005 (http://www.nodc.noaa.gov/OC5/WOD05/pr_wod05.html)
- Japan Oceanographic Data Center / J-DOSS (http://jdoss1.jodc.go.jp/NEW_JDOSS_HP/FETI_scalar_doc_e.html)
- CDIAC WOCE-ODV collections (http://cdiac.ornl.gov/oceans/pacific_ODV.html)
- Line P Oceanographic data (http://www.pac.dfo mpo.gc.ca/sci/osap/data/linep/linepselectdata_e.htm)
- JGOFS-NPPS Data Set CD-ROM
- JMA data CD-ROM



Selection criteria:

Time span: 1975 - 2005
=>divided into 1975-1990 & 1991-2005 time groups

Month: July-Sept.

Area: rectangle 42.5N - 55N, 155E-135W
coastal data (Bottom depth <1000m) are excluded.

Depth: a single data nearest to 10m is selected as ML data for each station

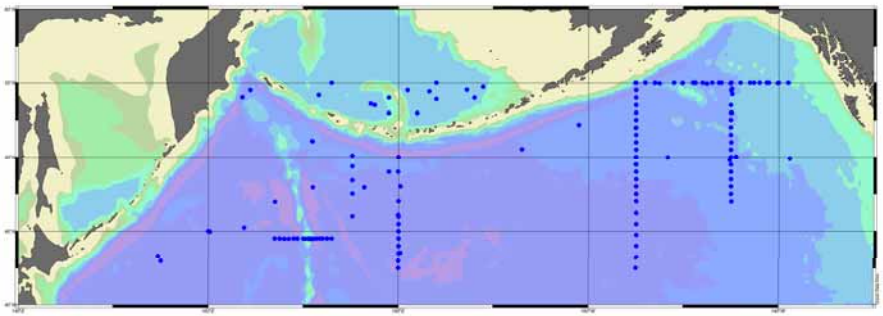
Unit: All data are adjusted to μM unit

Obtained data numbers:

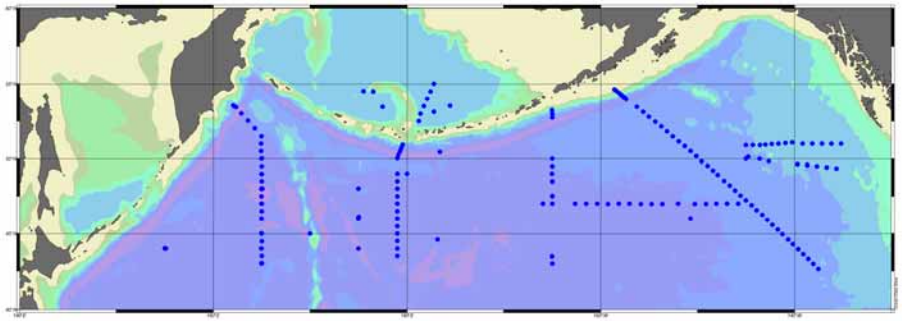
time_group		Phosphate	Silicate
1975- 1990		170	130
1991- 2005		181	148
total		351	278

Data distribution : geographical

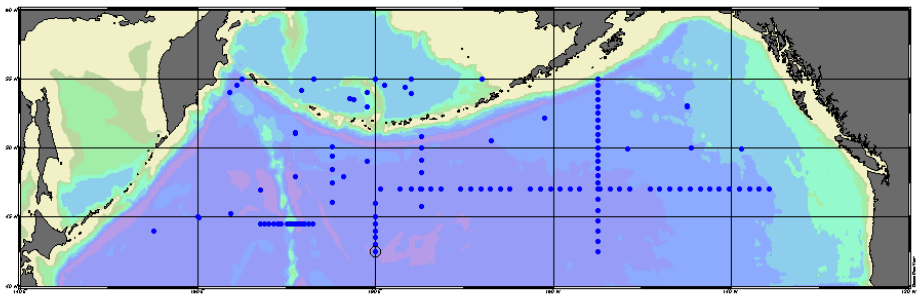
PO4: 1975-1990



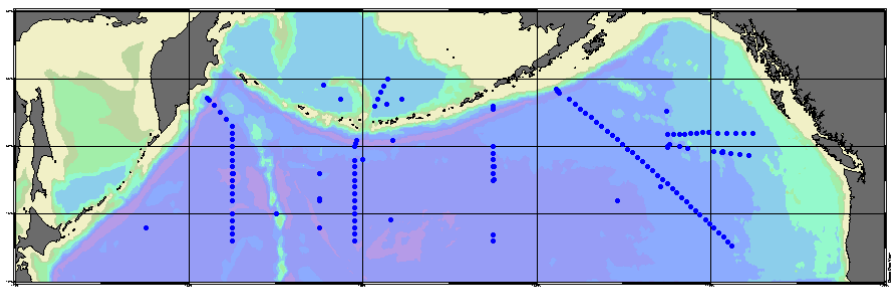
PO4: 1991-2005



Si: 1975-1990

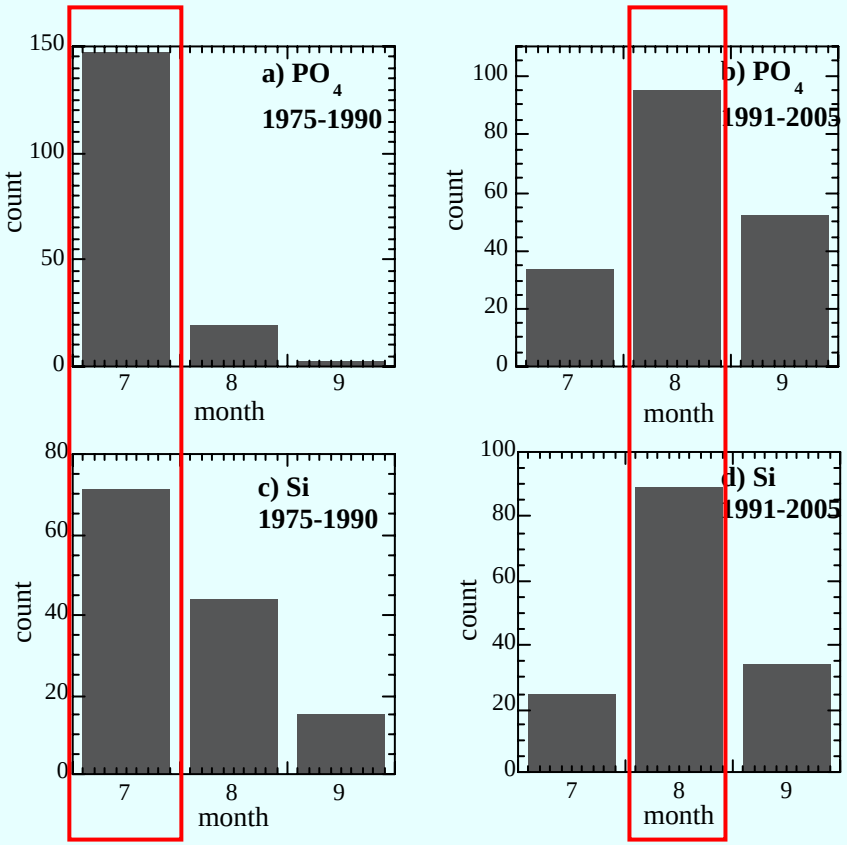


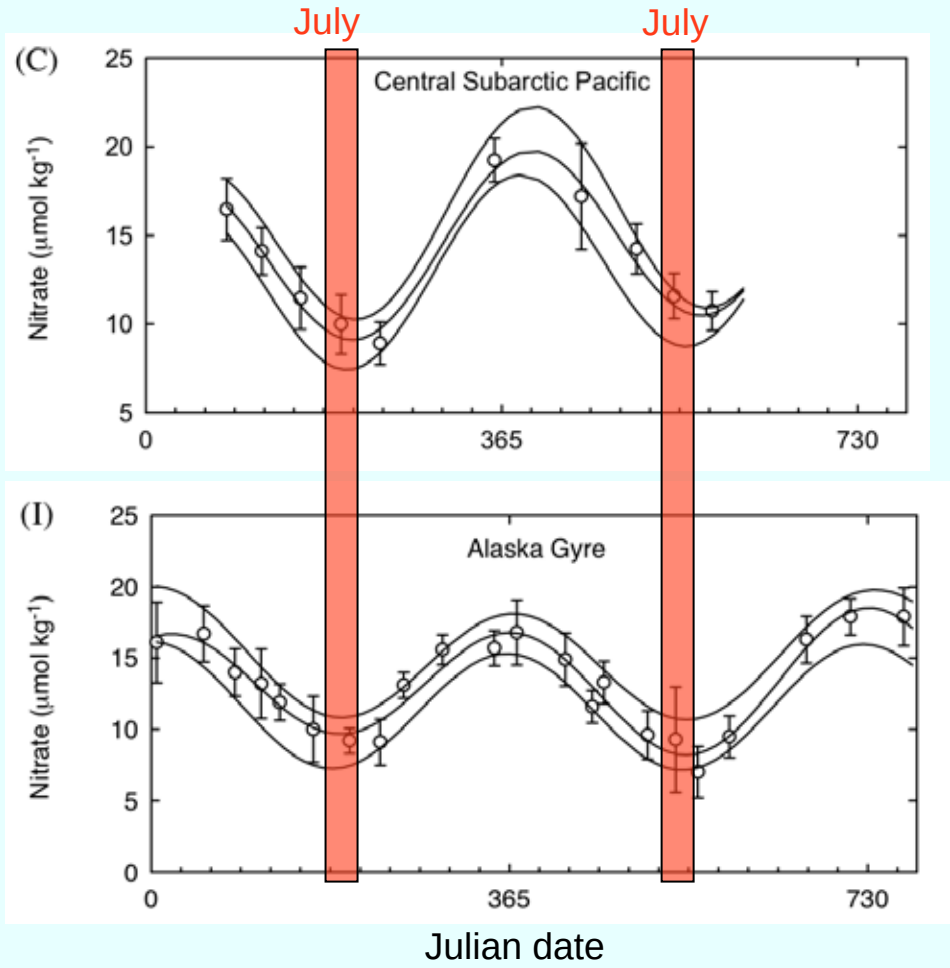
Si: 1991-2005



Data distribution : seasonal

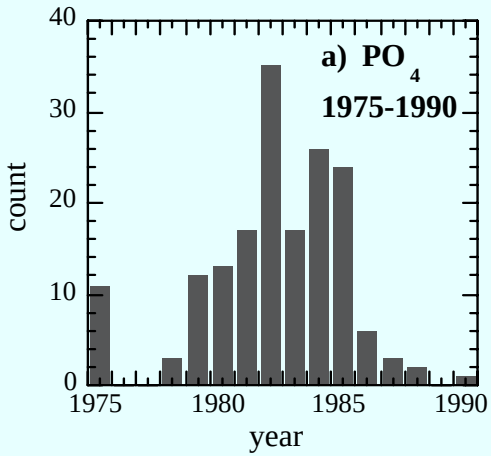
Climatology of surface nitrate in the central subarctic North Pacific and Alaskan Gyre [Wong et al., 2002]

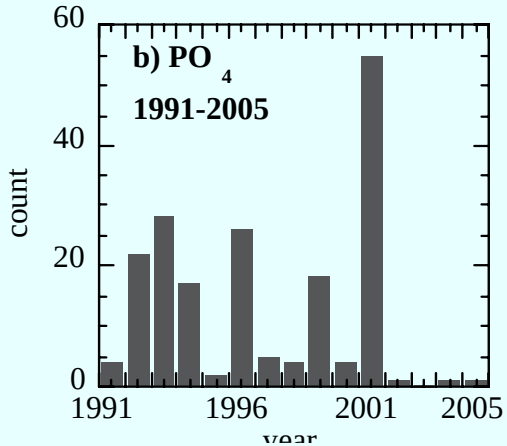


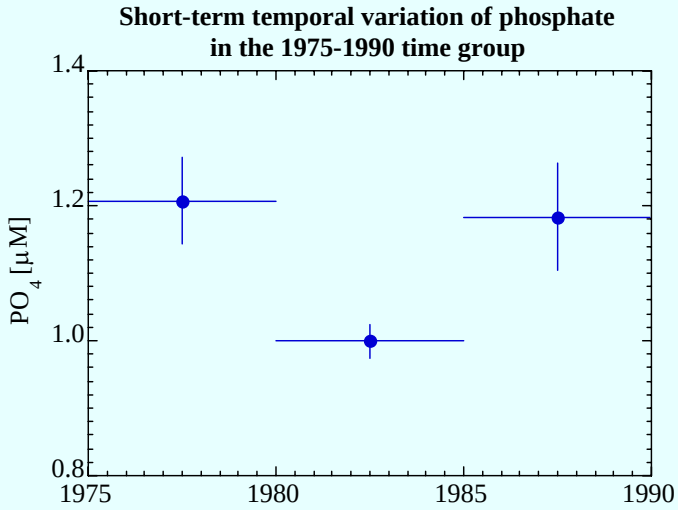


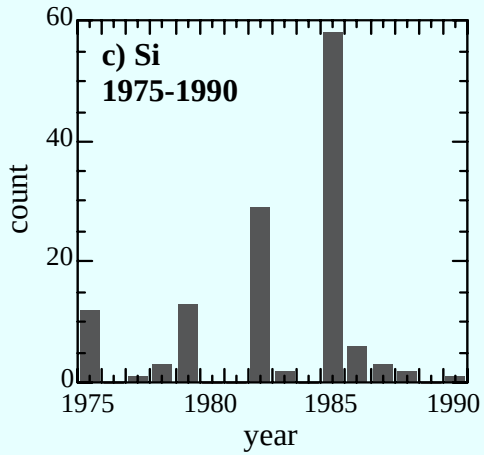
*potential overestimate in nutrients decrease
caused by peak-month shift from 1975-1990 group [July] to 1991-2005 group [Aug.]
=> ~0.03 μM (P) and ~0.4 μM (Si) at max.

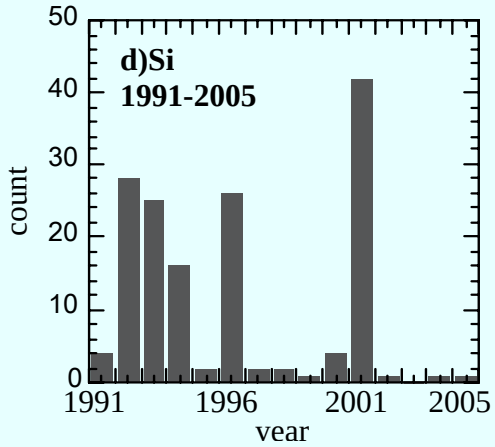
Data distribution : annual

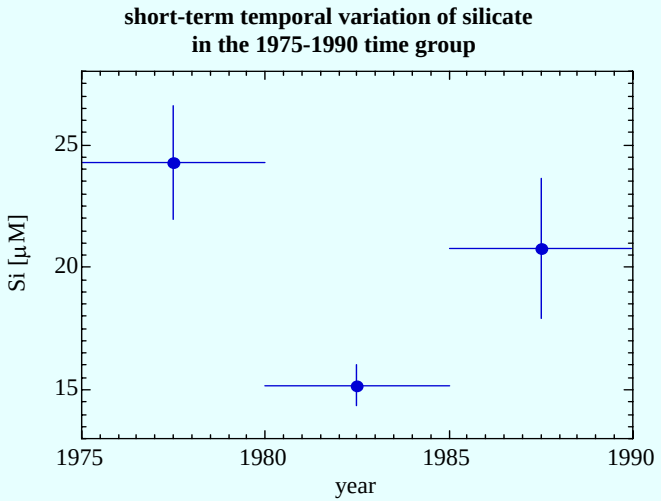






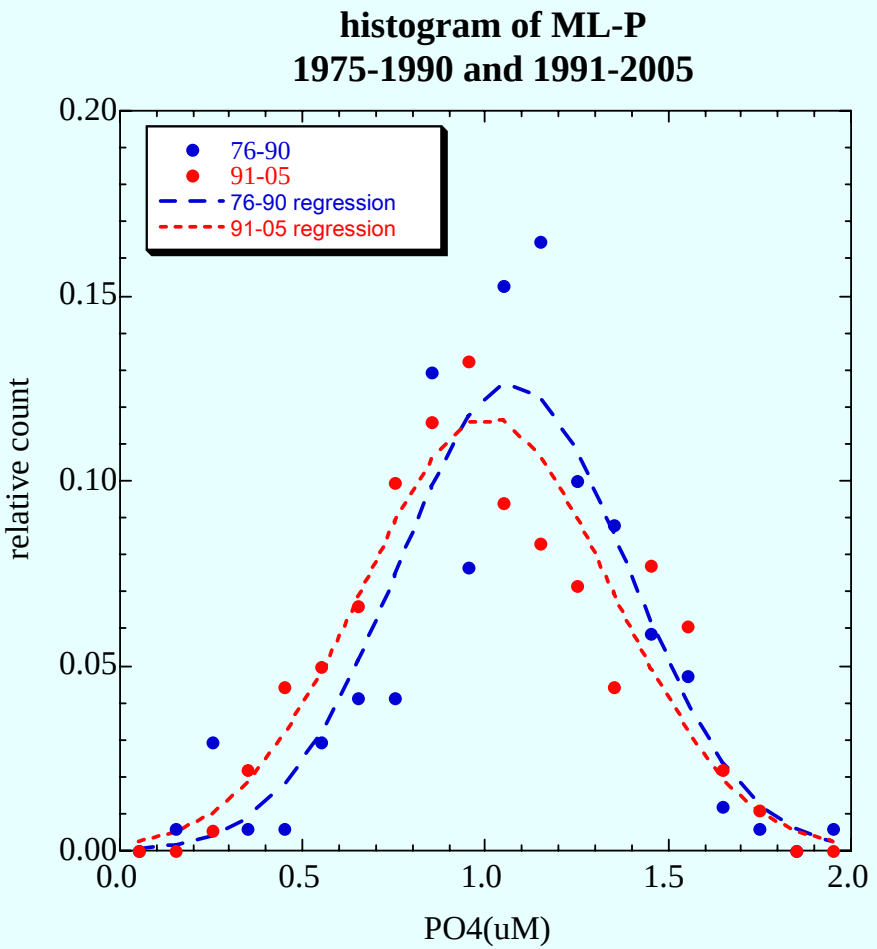




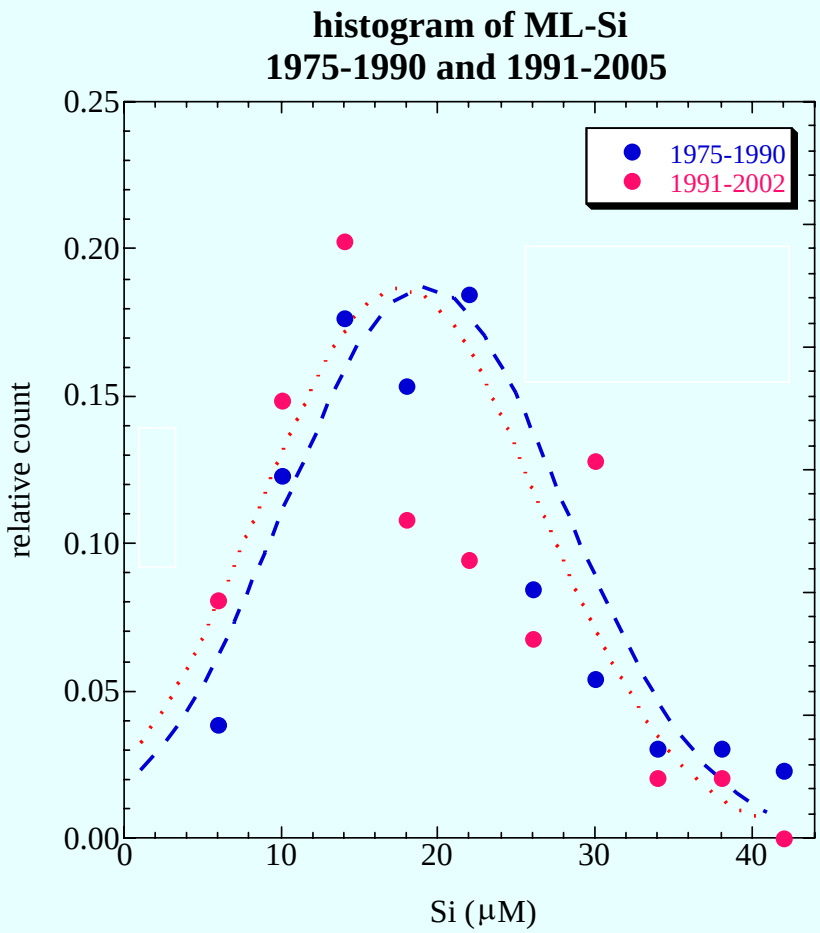


*data localization to mid-1980s in 1975-1990 group
=>may cause some underestimate of nutrients decrease from 1975-90 group to 1991-05 group

Temporal variation of nutrients: Difference in Time-Groups



ML-Pavg = 1.07± 0.02 μM [1975-1990]
1.00± 0.02 μM [1991-2005]
ΔML-Pavg = 0.07± 0.05 μM (α =0.05)

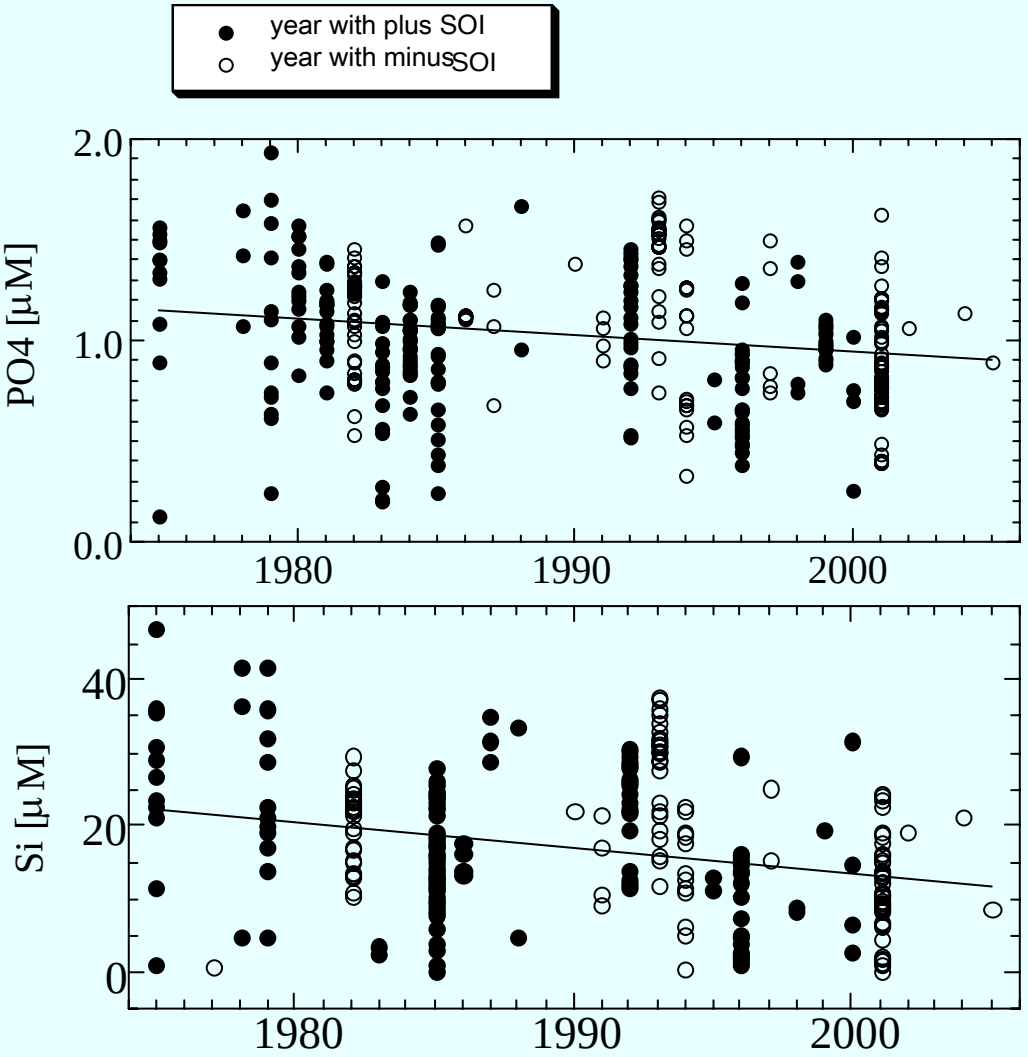


ML-Siavg = 19.16± 0.78 μM [1975-1990]
17.61± 0.77 μM [1991-2005]
ΔML-Siavg = 1.55± 1.55 μM (α =0.1)

statistically significant nutrient decrease between 1975-90 and 1991-05 time groups is observed both in P and Si.

*** ΔML-Si / ΔML-P = 22: corresponds to observed Si:P ratio in the subarctic NP surface water [Wong et al., 2002])**

Temporal variation of nutrients: Raw Data Analysis



* PO_4 = - 0.008±0.002 y + 17.82 (r = 0.25)

*Si = - 0.35±0.07 y + 722 (r = 0.27)

*even larger negative trend in the raw data analyses c/w the time-group comparison analyses
=> co-existence of spatial variation ?

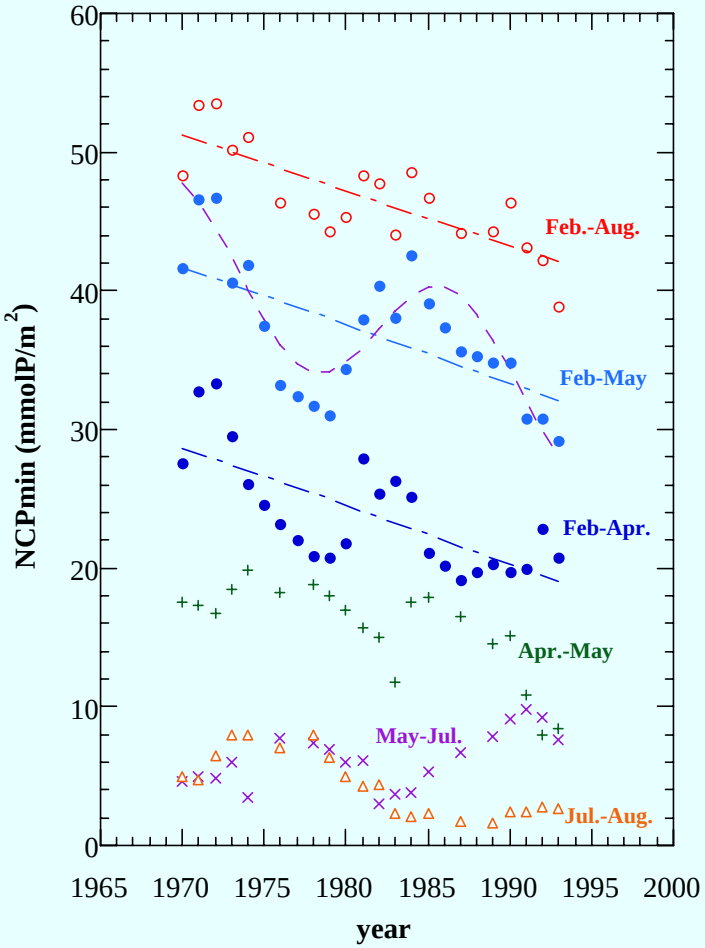
*trends are also detected even when data divided into +SOI & -SOI subsets
=>no effect of recent "-SOI" trend !

Cause of ML-P & ML-Si Trends

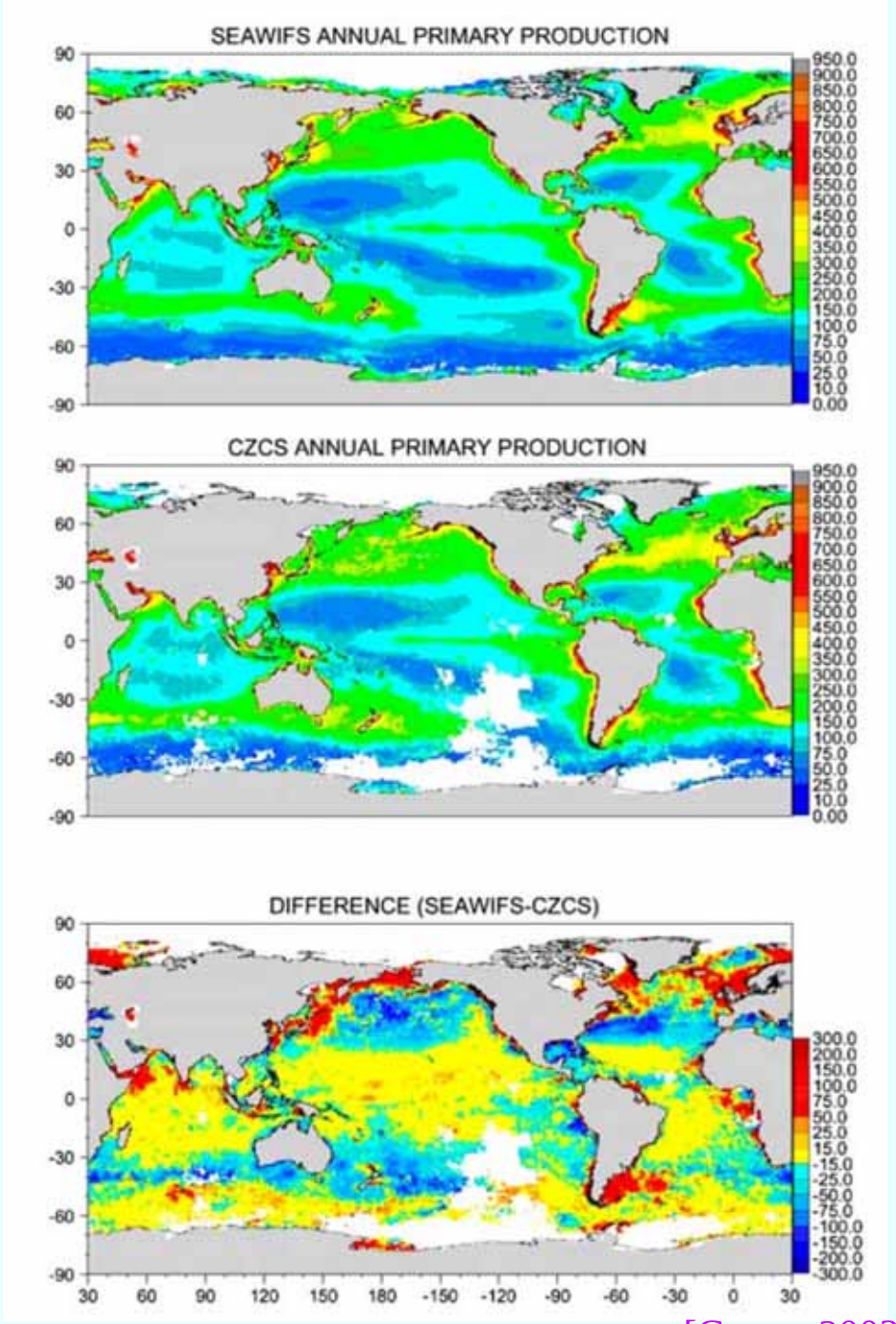
Possibility [1]: Increase in NPP

.....No !

Net Biological Consumption of ML Phosphate
(=minimum estimate of net community production)
at western subarctic North Pacifc west of 155E



[Ono et al., 2002]

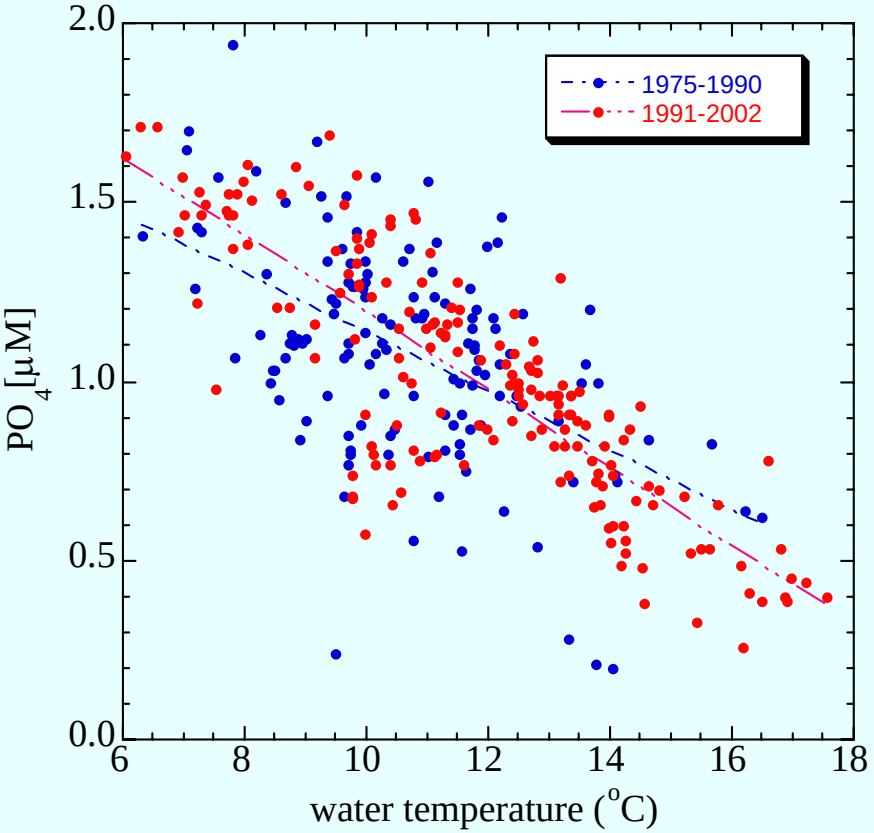


[Gregg, 2003]

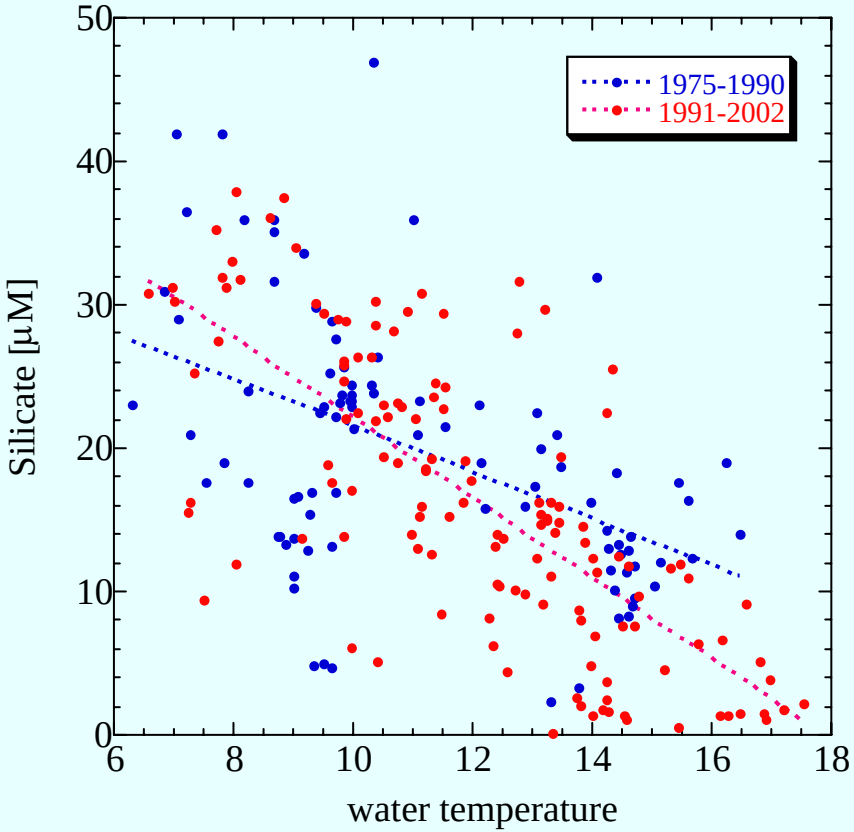
Cause of ML-P & ML-Si Trends

Possibility [2]: decrease of nutrient supply under constant NPP due to surface warming Yes!

ML-P distribution against SST
1975-1990 and 1991-2005



ML-Si distribution against SST
1975-1990 and 1991-2005

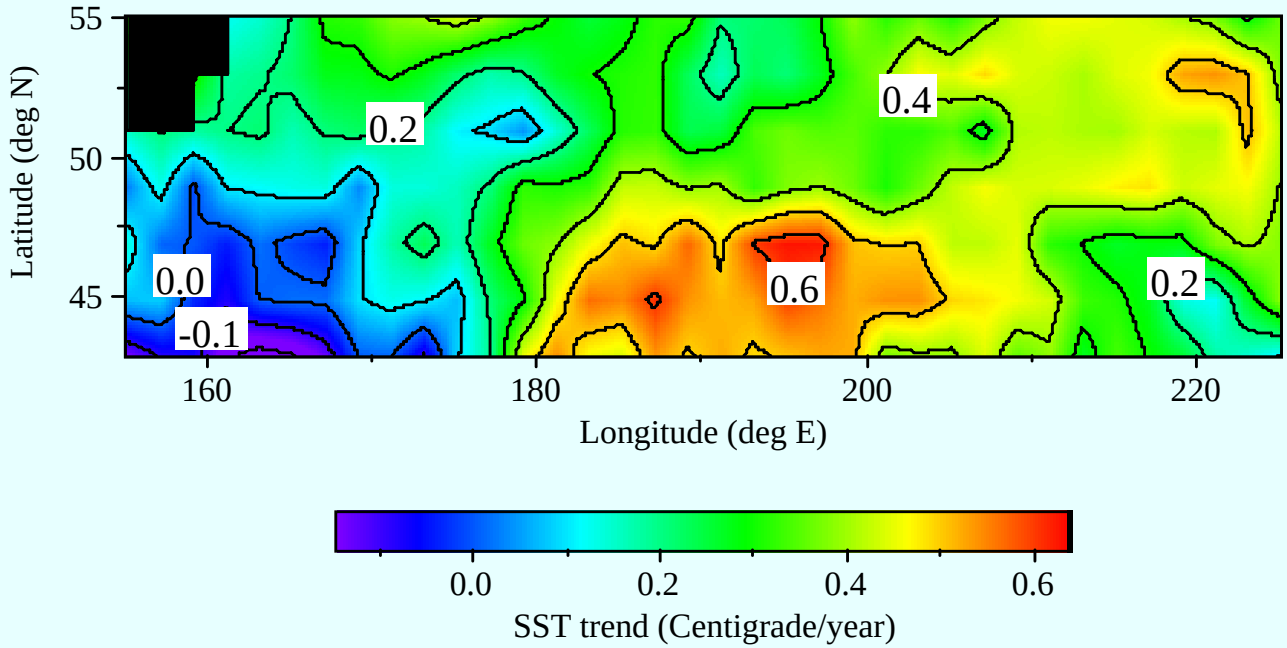


 # No significant change in SST vs. ML-P relationship before and after 1991

=>observed nutrient decrease must be associated with SST changes

Estimating Nutrients Decrease with Surface Warming

SST trend in the analyzed field from 1975 to 2005 based on the JMA $2^0 x 2^o$ gridded SST field [http://goos.kishou.go.jp/rrtdb/datainfo.html]



area-averaged SST trend : 0.30 ± 0.18 ^{0}C/decade
present nutrient-SST relationships in the subarctic NP: -0.095 μMP/°C and -2.34 μMSi/°C

=>expected nutrient trend under the constant nutrient-SST relationship:
-0.03 μMP/decade and -0.7 μMSi /decade
(observation: -0.047± 0.03 μMP/decade and 1.0± 1.0 μMSi/decade)

Consequence of the ML-P & ML-Si Decrease

Temporal CO_2 sequestration by imbalance between upward nutrient flux and export flux

...decrease of summer nutrient indicates that biological export production in the SANP HNLC region exceeds annual upward flux of regenerated nutrients during the recent decades. (as predicted by Sarmiento et al., 1998)

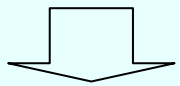
[estimation of amount of phosphate already-removed from the SANP-HNLC mixed layer]

*observed P concentration decrease: -0.07 μM

*effective ML depth of observed P decrease: 10m [assumption]

*area of SANP-HNLC: 6.8 x 10^6 km

=>transported P from summer ML to ocean interior: **4.8 x 10^9 mol P**

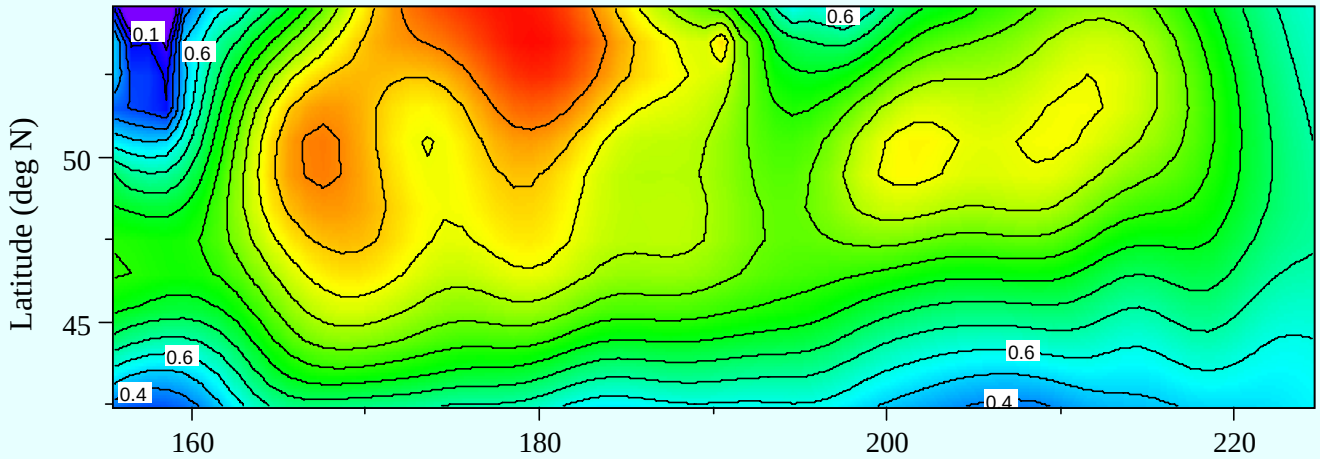


*observed C/P ratio in the nutrient variation in the SANP HNLC surface: 135 [Wong et al., 2002]

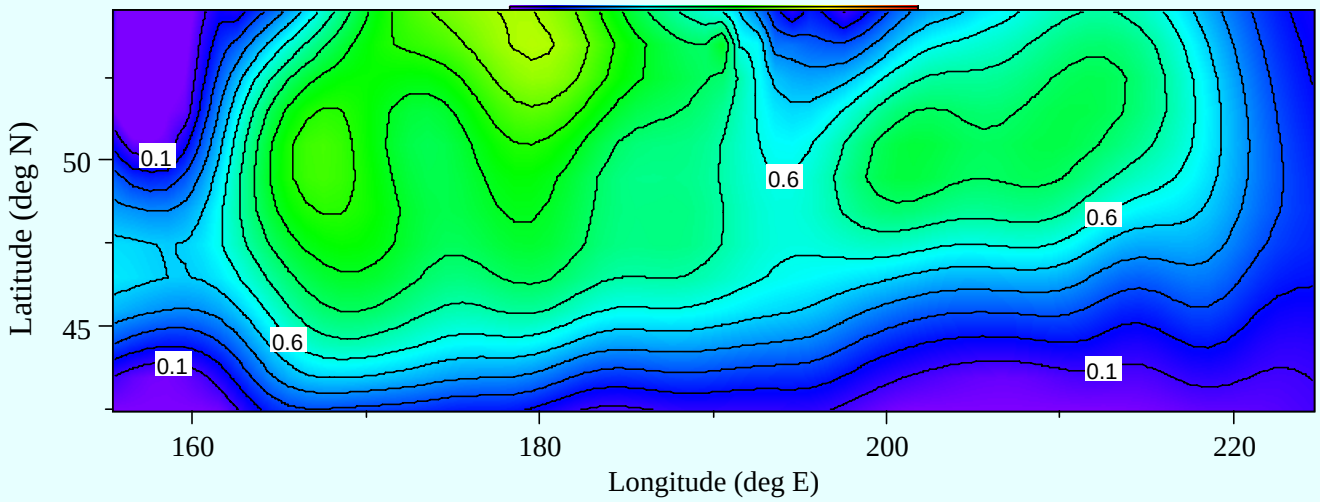
=>transported C along with SANP-HNLC P removal after 1975: **7.7 x 10^6 ton C**

If this trend persists to 2101.....

Present summer ML-P in NP (drawn after WOA 2001 grid data)



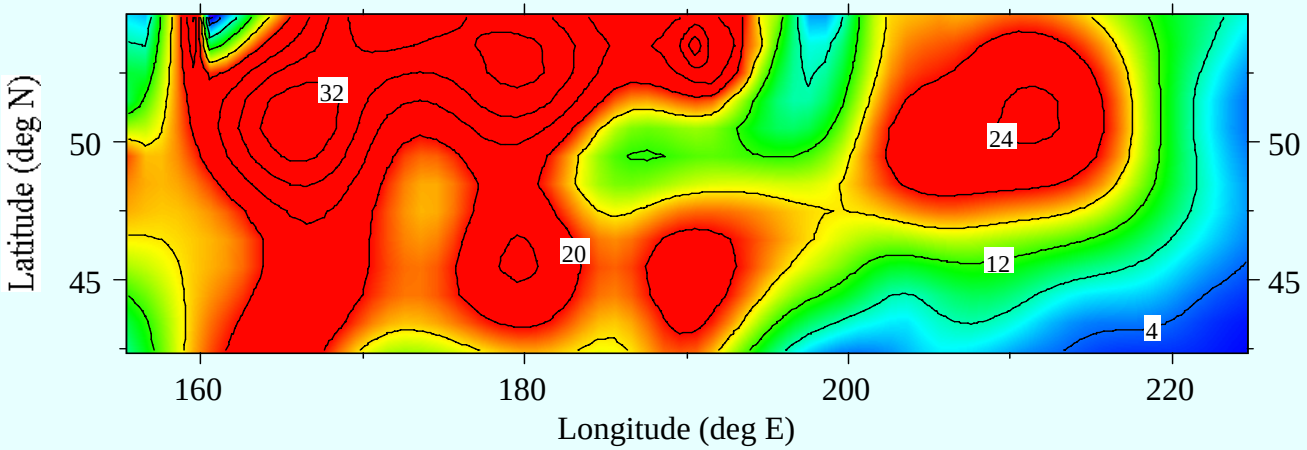
Predicted summer ML-P in 2101 [assuming -0.047μMP/decade decrease]



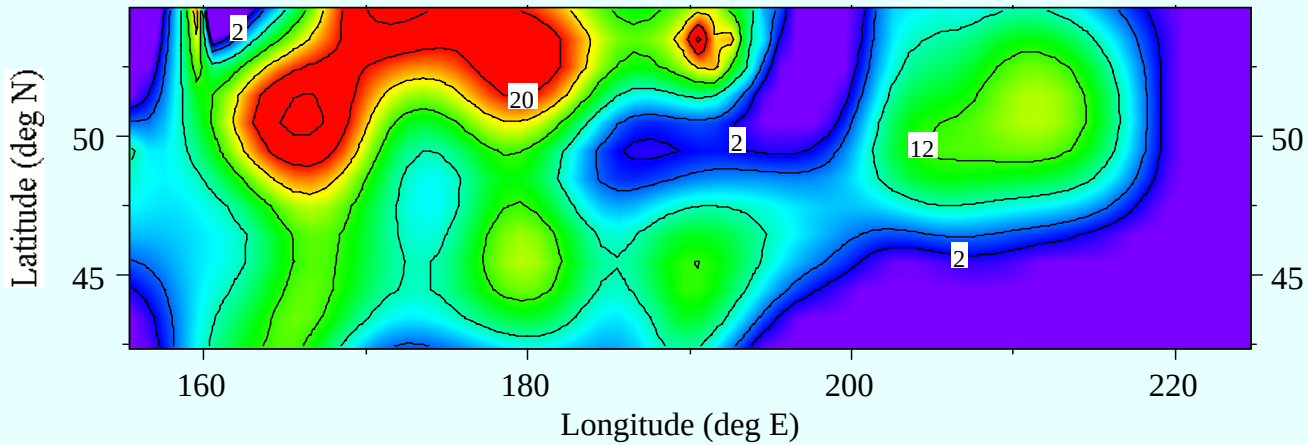
15% of present HNLC turns to non-HNLC (ca: P<0.2μM) in 2101

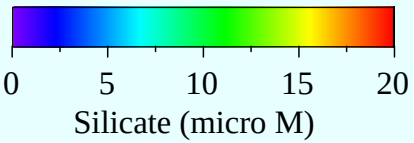
If this trend persists to 2101.....

Present summer ML-Si in NP (drawn after WOA 2001 grid data)



Predicted summer ML-Si in 2101 [assuming -1.0 μMSi/decade decrease]



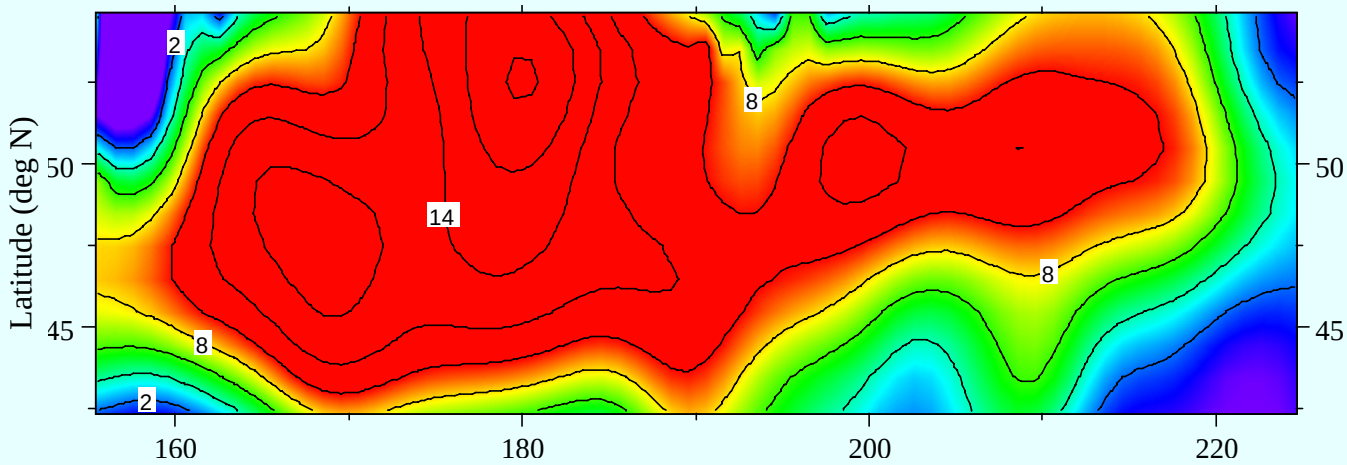


25% of present HNLC turns to non-HNLC (ca: SI<2μM) in 2101

*This process occurs mainly in spring!"

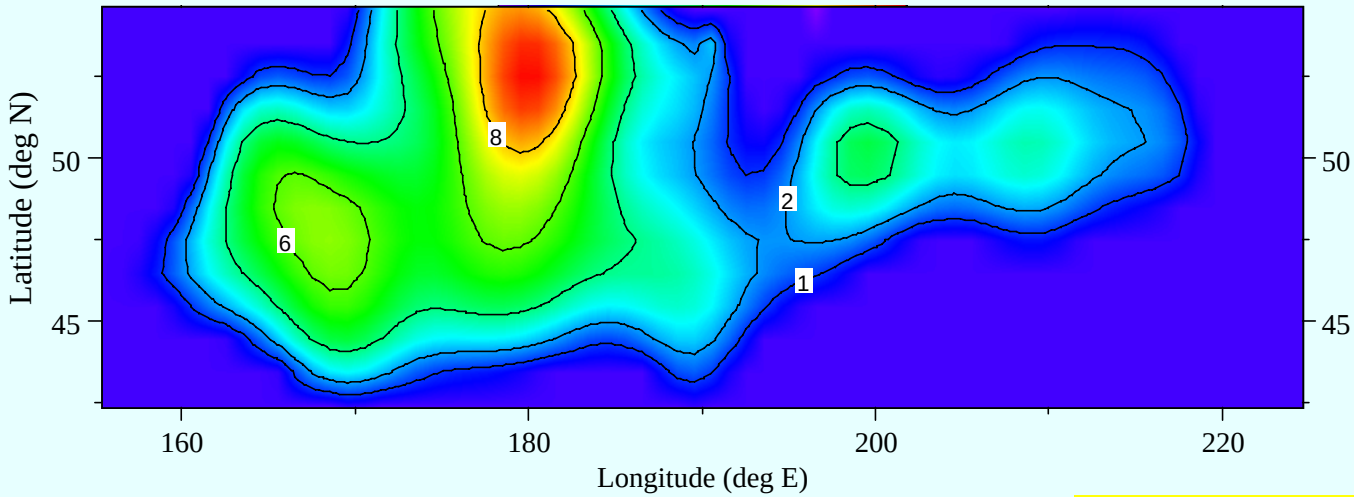
If N also decrease proportionally to P & Si .....

Present summer ML-N in NP (drown after WOA 2001 grid data)



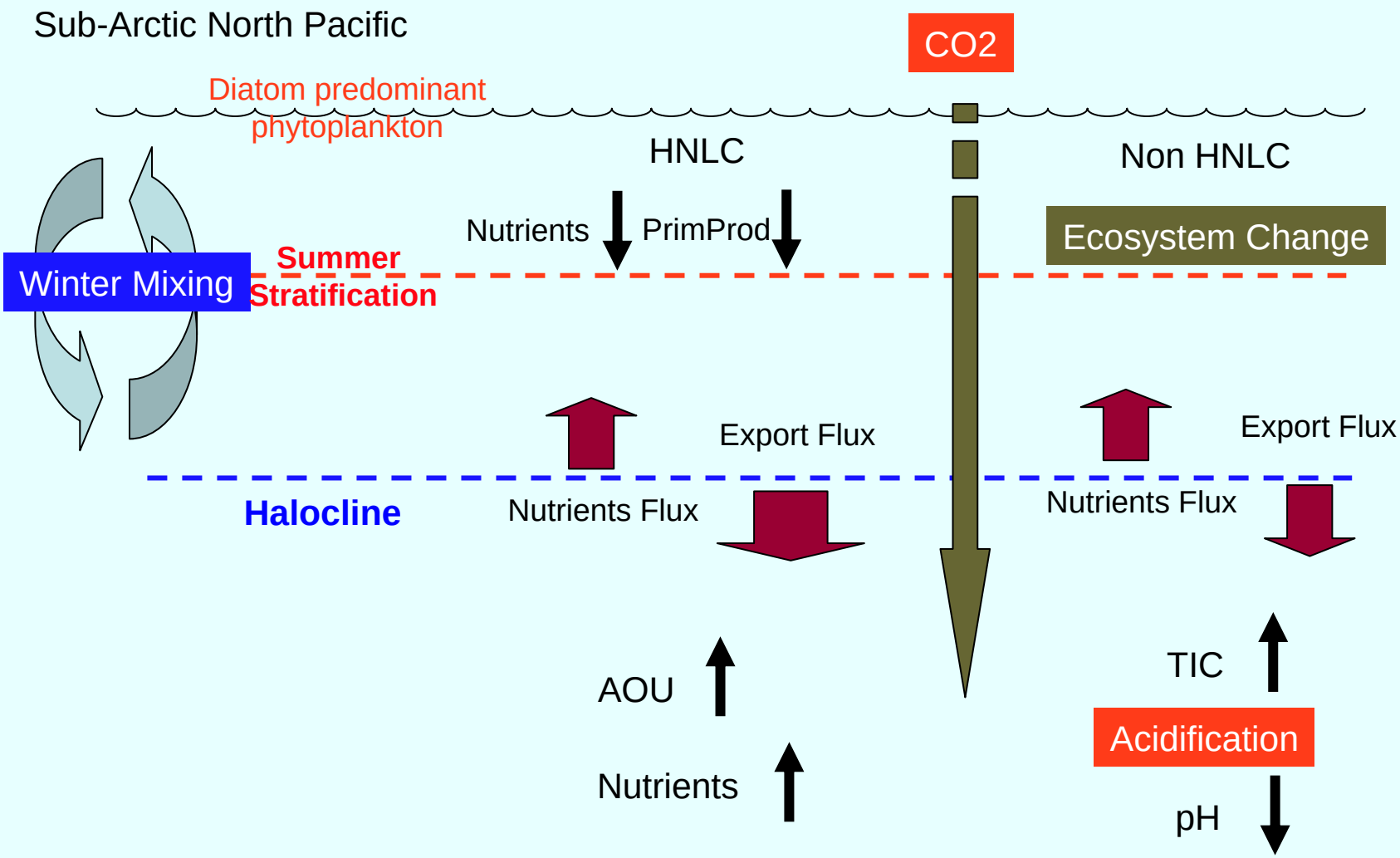
assumption:
$\Delta NO_3 = 18\Delta PO_4$
= -0.8 μM N/decade

Predicted summer ML-N in 2101 [assuming -0.8μM N/decade decrease]



conclusion:
48% of present HNLC turns to non-HNLC (ca: NO_3<1μM) in 2101

Ecological Significance



Summary

First basin-wide assessment for the decrease of summer ML nutrients in the North Pacific HNLC region is made;

*Significant decreasing trends in Mixed Layer Phosphate (-0.047± 0.03 μMP/decade) and Silicate (-1.0± 1.0 μMSi/decade) are detected between 1975-1990 and 1991-2005 time groups.

*SST vs. Phosphate plot doesn't change with time despite of significant changes in average phosphate concentration. This indicates that phosphate, and perhaps other nutrients, have been decreased with corresponding SST increase.

*NP-HNLC SST has been increased at the rate of 0.30 ± 0.18 ^{0}C/decade. From this result, corresponding decrease of phosphate and silicate (-0.03 μMP/decade and -0.7 μMSi /decade, respectively) are estimated based on the present SST-nutrients relationship. Those rates are close to the observed nutrient decrease, indicating that ocean warming and consequent near-surface stratification is the primary cause of nutrient decrease in the HNLC region.

*Hence, nutrient decrease will be continuing while the surface warming in the NP continues.

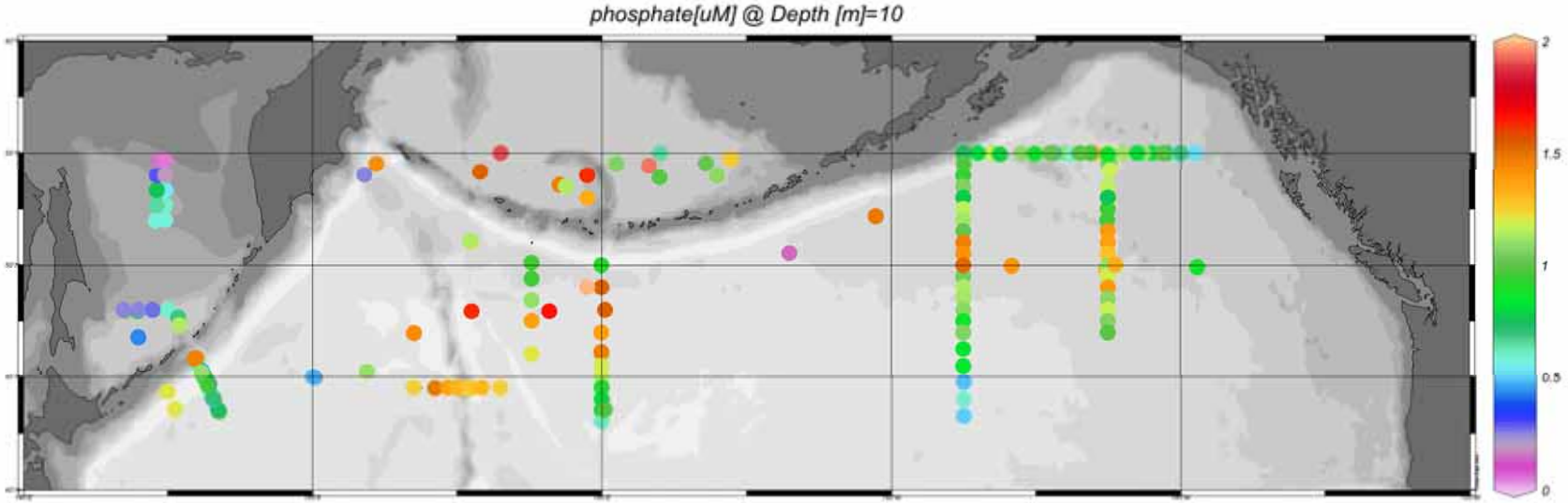
*Assuming that the observed rate of phosphate decrease persists until 2101, **~25% of the present HNLC region becomes P-limited or Si -limited** by that year.

*If we further assume that nitrate is similarly decreasing with the present Si/N/P ratio, **~48% of the present HNLC region will no longer be in HNLC condition in 2101.**

Further study:

*make assessment for the NP-HNLC nitrate, and any nutrients in other HNLC regions
*make assessment for the biological consequence of HNLC condition change.
*get more & more nutrient data to follow trends!

PO4 1975-1990 : raw data distribution



1991-2005