A Preliminary Look at Nitrate Sources and Sinks in the Shelf Waters of the Northern Gulf of Alaska

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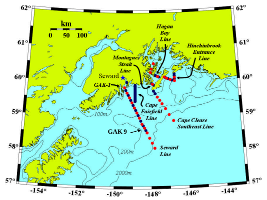
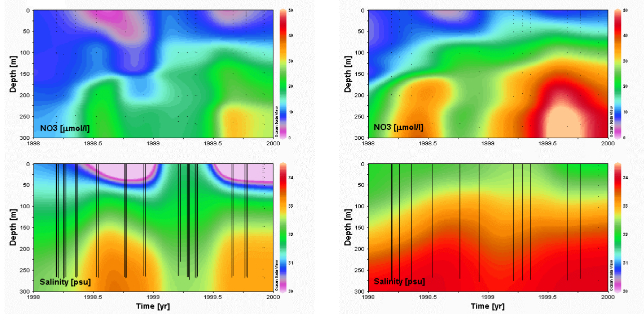


Abstract: Nutrient data collected in 1998, 1999 and 2000 from the northern Gulf of Alaska shelf as part of the Global Ocean Ecosystem Dynamics (GLOBEC) Gulf of Alaska Long Time Series Observation Program (LTOP) have provided preliminary data on the sources and sinks of nitrate to the shelf waters. Surface nitrate exhibited an annual cycle of spring and summer drawdown followed by replenishment throughout the winter months. First order new production estimates revealed that springtime nitrate utilization was similar between years within the shelf regimes (except over the shelf-break) with the highest rates over the inner shelf both years. Deep-water measurements provided evidence of a summer onshore flux of dense, nitrate-rich bottom water onto the shelf when the predominant downwelling regime relaxed. This seasonal flux created a reservoir over the inner shelf that was ultimately mixed into the upper water column through winter wind mixing.

In an effort to determine the source of nitrate to the euphotic zone after summer depletion, first order calculations of vertical diffusion and surface Ekman transport were made. These estimates indicated that vertical diffusion could potentially play a much larger role in transporting nitrate to the euphotic zone over the inner shelf. There were distinct interannual differences in the chemical and physical properties across the Gulf of Alaska shelf in 1998 (El Nino) and 1999 (La Nina). The water column in spring 1998 was more stratified and fresher due to high freshwater discharge and anomalously strong downwelling, consequently nitrate concentrations were notably lower in spring 1998 than those measured in spring 1999. Spring 1999 (May) experienced an eddy offshore of the shelf-break which elevated nitrate concentrations over the shelf due to shelf-break upwelling. Overall, it is apparent from this data that new production is an important element for supporting the phytoplankton community, however the underlying mechanisms in transporting nitrate to the euphotic zone remain unclear.

GAK 1: Inner Shelf / GAK 9: Shelf Break



Time Series (March 1998 – December 1999) at GAK 1 and GAK 9:

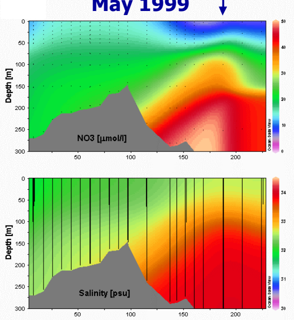
❖**Annual Cycle:** The data show an annual cycle with a well mixed water column in the spring with relatively high nitrate and high salinities in the upper water column. This is followed by nitrate drawdown throughout spring, summer, and fall accompanied by freshwater inputs evident at the surface in late summer and fall.

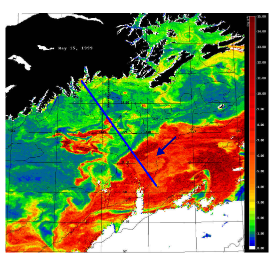
❖**Deep Inflow:** Nitrate and salinity reveal a deep onshore flux of high nitrate, high salinity water over the shelf break onto the shelf during the summer months. This seasonal flux creates a nutrient reservoir over the inner and middle shelf which is thought to be a major source of nitrate to the upper water column by way of winter mixing.

❖**Interannual Variability:** The water column had greater stratification, because of freshening, in spring 1998 thus fresher, lower nitrate shelf waters compared to a well mixed water column in spring 1999 (see poster by Weingartner et al.). Nitrate drawdown in summer and fall 1998 was more extensive than in 1999. The bottom onshore flux occurred earlier in 1998, however bottom nitrate concentrations were consistently higher in 1999.

•**Eddy in May 1999**: The presence of a large eddy offshore of the shelf break resulted in shelf break upwelling of high nitrate, high salinity water (see poster by Okkonen et al.).

May 1999





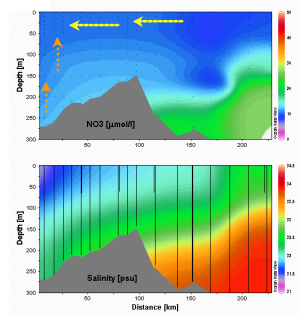
A SeaWifs false-color image of near-surface chlorophyll pigment concentration on **15 May 1999** shows high chlorophyll concentrations offshore of the shelf-break. (Cloud cover is white).

Nitrate supply to the shelf waters throughout the winter months:

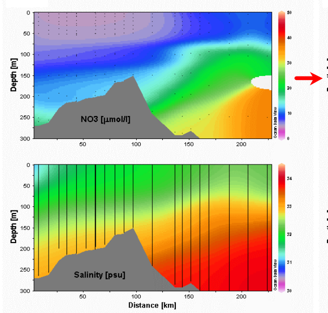
• Winter 97-98 (El Nino) was found to have anomalously strong downwelling, high freshwater discharge, and stronger stratification. On the other hand, winter 98-99 (La Nina), had anomalously weak downwelling, low discharge, and weak stratification. (see poster by Weingartner et al.)

• Nitrate concentrations in March 1998 were considerably lower than those measured in March 1999 and March 2000 (by 30-40%). This is possibly due to stronger Ekman transport and freshwater influx in winter 97-98 than winter 98-99.

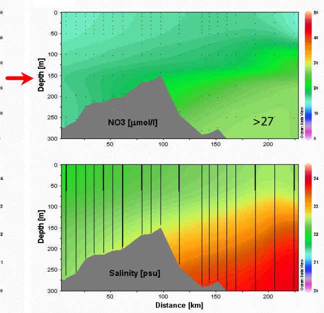
March 1998



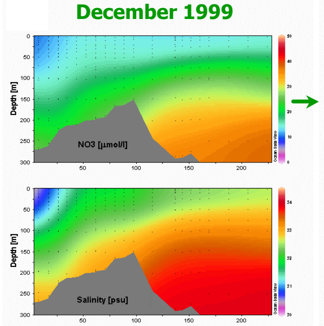
December 1998



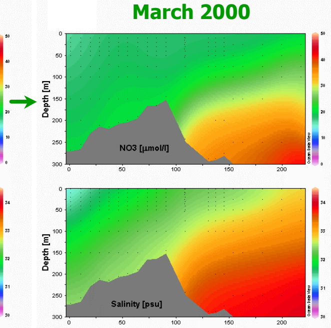
March 1999



December 1999



March 2000



Nitrate fluxes into the euphotic zone:

•Surface Ekman Transport: (yellow arrows)

Nitrate concentrations over the shelf in December 1998 and 1999 were used to estimate the amount of nitrate fluxed onto the inner shelf via surface Ekman transport. The following conditions were used:

• Along shore wind speed averaging 8 m sec^{-1},

• Thickness of the Ekman layer ~ 30 m

• Offshore gradient of 3 mmole nitrate m^{-3} over a distance of 150 km.

➢ Under these conditions, the onshore advection of nitrate onto the inner shelf within the surface Ekman layer was calculated to be $\underline{1.00 \times 10^{-3}\ \text{mmole nitrate}\ m^{-1}\ sec^{-1}}$.

•Vertical Diffusion: (orange arrows)

Nitrate diffusion rates were calculated for the inner shelf by splitting the water column into three layers: the upper layer (0-50 m), a middle layer (50-150 m), and a bottom layer (150 m to the bottom).

• Mean nitrate concentrations from stations GAK 1-3 in December 1998 and 1999 over these depth ranges were averaged over the two years.

• Diffusivities of 0.005 and 0.060 $m^2\ sec^{-1}$ were used to determine a range in diffusion rates (Williams and Weingartner, 1999).

➢ Using the weaker diffusivity estimate for nitrate diffusion from the middle layer to the upper layer within the frontal zone, which is approximately 10 km wide, the rate of nitrate diffusion was calculated to be $\underline{1.14\ \text{mmole nitrate}\ m^{-1}\ sec^{-1}}$ within the inner shelf under early winter conditions.

❖ Vertical diffusion could potentially play a much larger role in transporting nitrate to the upper shelf waters throughout the winter months.

❖ Winter (Dec.-Mar.) onshore Ekman transport cannot account for March 1999 nitrate concentrations. Other processes such as vertical diffusion must be have been involved. However, winter onshore Ekman transport could account for nitrate concentrations in March 2000.

❖ Other sources not considered here are along-shore transport, eddy events inducing upwelling, storm events, and up-stream sources such as Prince William Sound.

Nitrate fluxes out of the euphotic zone:

First Order New Production Estimates:

New production estimates were calculated from the differences in 0-50 m integrated nitrate concentrations within the four shelf regimes between March and July 1998, March and August 1999, and March and July 1999* (assuming nitrate concentrations were minimum by July). Units are mmole nitrate $m^{-2}\ day^{-1}$.

	Mar/Jul 1998	Mar/Aug 1999	Mar/Jul 1999*
Inner Shelf	2.26	1.89	2.52
Middle Shelf	1.76	1.36	1.81
Shelf-break	0.83	1.31	1.74
Oceanic	1.43	0.90	1.19

➢ Nitrate utilization was similar in spring 1998 and 1999, except within the shelf-break regime where estimates were higher in 1999, which may have been due to eddy activity.

➢ Nitrate utilization was highest over the inner shelf in both years compared to the other shelf regimes.

➢ These rates are similar the those measured in open Gulf of Alaska waters.

➢ These estimates are minimum values considering this shelf experiences advection and diffusion through various mechanisms including along-shelf and cross-shelf transport, coastal inputs, eddy activity, and storm events (see posters by Okkonen et al. and Musgrave et al.). It is also possible that nitrate utilization occurred over shorter time periods than evaluated here.

A few key questions:

✓ **How are nutrients supplied to this shelf in spring?**

- There is evidence of an annual summertime deep-water flux of nitrate-rich water onto the shelf, which created a reservoir over the inner shelf. But it is still uncertain how nitrate gets into the euphotic zone.

✓ **What are the relative roles of surface Ekman transport and vertical mixing/diffusion?**

- First order calculations indicate that vertical mixing plays a much larger role in transporting nitrate to the euphotic zone.

✓ **What are the effects of eddy activity and storm events on the nitrate distributions, consequently the phytoplankton community?**

✓ At this time, we really don't know.

References: Williams, W. J. and T. J. Weingartner (1999) The response of buoyancy driven coastal currents to downwelling favorable wind-stress. EOS, Transaction, AGU, OS262