6.2 Chemical Oceanography

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6.2.1 Contaminants

No measurements of chemical contaminant concentrations in the Gully, either water or sediments, are available. If a broader geographic area that includes adjacent parts of Sable Island Bank, Middle Bank and Banquereau is considered, some limited measurements of contaminants are encountered, including some measurements of contaminants in biota. Some of these data were collected on BIO cruises and other field surveys, and some by the companies involved in the Sable Bank offshore energy developments. This latter body of data has recently been reviewed in the Sable Offshore Energy Project Environmental Impact Statement. Some of the BIO cruise results have been published (*e.g.* Keizer *et al.*, 1978; Dalziel, 1992; Yeats, 1993; and Addison and Stobo, 1993). Additional data are stored in the BIO node of the National Contaminants Information System, a national DFO contaminants database, and in the AGC 'open file' system. Analytes that have been considered in one or more of these studies include heavy metals, PCBs, and PAHs in water, sediments and/or biota. As would probably have been expected for an offshore area such as the Gully, no particularly elevated levels of any of these contaminants were encountered in any of these studies.

The main routes for contaminant transport to the Gully would be long range atmospheric transport and water transport in surface currents flowing out of the Gulf of St. Lawrence and across the shelf. The importance of the St. Lawrence discharge on the Gully is indicated in the assessment of monthly mean salinity statistics (Section 6.1). Some indication of the transport of heavy metals out of the Gulf of St. Lawrence in this surface water discharge is available (Yeats, 1993). No information of organic contaminant discharges from the Gulf is available. The importance of long range atmospheric transport of several organic contaminants and mercury has been identified in studies by DOE of wildlife in the Kejimkujik area of southwestern Nova Scotia. DOE data on concentrations of organic contaminants in wet precipitation in Atlantic Canada have been summarized by Brun *et. al* (1991). A potential new source for contaminant transport to the Gully is the Sable Offshore Energy Project. Contaminants could be transported in solution or as particulates, and the magnitudes of the discharges could be quite large. The work that has been done to date on the zones of impacts of drilling muds discharged from offshore developments and the current regimes in the SOEP area as part of the SOEP EIS, however, suggest that this potential source is unlikely to impact the Gully. Development of drilling sites closer to the Gully may present a far greater risk.

6.2.2 Nutrients

By far the largest chemical oceanographic data sets for the Gully area exist for nutrients and oxygen. An extensive database of nutrient and oxygen data for eastern Canadian marine waters is maintained by the Marine Chemistry Section at BIO. This database has been used to develop the following picture of the nutrient distributions in the Gully area.

For this analysis, data were extracted from the nutrient and oxygen data from a polygon that encompasses the Gully plus some of the shelf areas immediately adjacent to the Gully, and from polygons for the shelf areas to the west (eastern Sable Island Bank), north (Middle Bank), and east (Banquereau). These areas plus the locations of stations with nutrient or oxygen data are shown in Fig. 6.2.1.

A nitrate vs. depth profile for all the data from stations in the Gully polygon is shown in Fig. 6.2.2. This representation gives a picture integrated over both space and time of the nitrate distribution. The two features that are most evident from this figure are the general picture of nutrient concentrations increasing with depth and the large range in nitrate concentrations that are seen in the surface mixed layer. The general profile shows an increase from non-detectable or very low levels at the surface to approximately 15 μM at 200 m depth - a level that is comparable to those generally found in intermediate depth slope waters off the Scotian Shelf. The variability in the surface layer reflects the seasonal cycle of nutrient concentrations decreasing from high concentrations in the winter to low concentrations in the spring and through the summer into the early part of the fall. The seasonal cycle for nitrate in the surface mixed layer is shown in Fig. 6.2.3. Similar pictures, both the vertical profiles and the seasonal cycles, are seen for phosphate and silicate.

This general picture of the nitrate (or phosphate) distribution in the Gully, averaged as it is over time and space, is indistinguishable from similar pictures developed for Sable Island Bank, Middle Bank or Banquereau. A comparison of the seasonal cycle of nitrate in the surface layer for the four regions is shown in Fig. 6.2.4. This figure shows the average monthly surface layer concentrations in each region. It is clear from this figure that there are no substantive differences in the seasonal concentrations in any of these regions. For the deeper waters a comparison of the nitrate profile for all Gully stations with soundings greater than 100 m with those from similar depth stations from the Sable Island Bank and Banquereau shelf edge (Fig. 6.2.5) shows that the profiles are indistinguishable. The picture for silicate is slightly different with the seasonal surface layer distributions (Fig. 6.2.6) showing higher concentrations in winter in the Middle Bank region. The source of this signal is probably the discharge from the Gulf of St. Lawrence. Otherwise, the silicate distributions are also substantively similar in all four regions.

A major problem with the previous description is that results from all the stations are combined. Only for the seasonal cycle in the surface layer are there enough data to investigate any trends. There are insufficient data to investigate long-term trends such as the decadal scale trends in oxygen seen in Emerald Basin (Petrie *et al.*, 1994). Important features associated with specific locations such as inflows on the eastern flank of the Gully associated with a counterclockwise circulation as suggested by some of the results summarized in Section 6.1 may also be lost in the general picture. Offshore to inshore gradients or cross-Gully gradients may be important components of our understanding of nutrient supply to the Gully, but there are insufficient data to investigate these gradients. One cruise in our database does have three stations lined up more or less along the main axis of the Gully and this line (approximately 50 km long) does show significant increases in nitrate and silicate concentrations at 100 m depth from offshore to inshore. Salinity decreases slightly along this line. There are no cross-gully transects in the nutrient database that could be investigated for evidence of doming of nutrient profiles like those seen for chlorophyll a in the Gully (see Section 6.3.1) or for nutrients elsewhere (*e.g.* Shea and Broenkow, 1982).

Sources of nutrients to the Gully will include the three general sources identified above in the section on contaminants. The Gulf of St. Lawrence outflow will be an important source, particularly in the winter as the nutrient discharge from the Gulf in winter is quite large (Yeats, 1988). Atmospheric inputs for nutrients are generally considered to be fairly minor but SOEP may be a significant source because produced waters usually contain very high ammonia concentrations. The most important source of nutrients, however, will be the input from offshore. The main source of these offshore waters that mix onto the shelf will be intermediate depth slope waters, either Warm Slope Water or Labrador Slope Water (Petrie and Drinkwater, 1993). Nutrient concentrations in Warm Slope Water are high (nitrate approximately 22 µM and silicate, 15 µM), while those in the Labrador Slope Water are less well defined based on the currently available data, but somewhat lower than those in the Warm Slope Water. In either case these intermediate depth slope waters will be a major contributor of nutrients to the shelf break region including the Gully.

6.2.3 Nutrient Fluxes through the Gully

The contributions of low frequency processes to the onshore-offshore exchange of heat and salt through the Gully are described in Chapter 6.1. Moreover, Houghton *et al.* (1978) stated that there was evidence in their data of enhanced cross-shelf exchange through the Gully and the Scotian Gulf. They did not present quantitative evidence for the former but did show detailed calculations of the heat, salt and nitrate fluxes for the latter. Their nitrate fluxes were based on current meter data from a mooring located at the 250 m isobath on the shelfbreak south of the Scotian Gulf from December 1975 to April 1976 (Smith 1978) and water bottle observations of dissolved oxygen and nitrate. The current meters measured current speed and direction, temperature and salinity. Regressions between water bottle temperature and salinity with dissolved oxygen (for depths $\geq$ 50 m) were used to convert the temperature and salinity fluxes from the current meters to a dissolved oxygen flux; then, a regression between dissolved oxygen and nitrate was used to transform the oxygen flux to a nitrate flux. The nitrate flux calculated by Houghton *et al.* represents the contribution to the shelf for low frequency motions with periods of 16.5 hours to 33 days. Most of the nitrate flux is concentrated in the band from 4 to 14 d, *i.e.,* motions generally caused by meteorological forcing. Neither Houghton *et al.* (1978) nor

Smith (1978) calculated the nitrate flux associated with the mean flow over the mooring period. Smith (1978) showed that the mean flow at 50 and 150 m was onshelf at 2.8 and 2.6 cm s^{-1}. Their calculations of nitrate fluxes, with a positive sign corresponding to onshelf transport, show 38.3 µmole m^{-2} s^{-1} at 50 m, -10.7 µmole m^{-2} s^{-1} at 150 m and 0 µmole m^{-2} s^{-1} at 230 m. If we take these measurements as representative of the entire Scotian Gulf and extend them to the surface, then the nitrate transport to 150 m = (Representative width*Representative depth*Flux),

Nitrate Transport = (50,000 m * 100 m * 38.3 µmole m^{-2} s^{-1})-(50,000*50*10.7 µmole m^{-2} s^{-1})
= $1.7*10^2$ moles s^{-1}

In order to evaluate the importance of the Gully in terms of transport of nutrients onto the Scotian Shelf, we have calculated the nitrate transport out of the Gulf of St. Lawrence and through the Gully and Scotian Gulf. We carried out the calculations for two periods, the months of December to February, representing high nutrient levels in shallower depths, and June to August, when upper level nutrients should be depleted.

Current meter data were taken from the Bedford Institute's archives and are summarized in Table 6.2.1. We only included data between 0 and 160 m from the western half of Cabot Strait, the mouth of the Gully, and between 43-43.25° N, 63-64°W for the Scotian Gulf. The Gully was the area least sampled.

Table 6.2.1. Current Meters Records.

Location	Number of Records Months - DJF	Months - JJA	Representative Width (km)
Cabot Strait	10	43	50
Gully	1	6	10
Scotian Gulf	11	11	50

Nitrate data for these months were extracted from the MCS database for the Cabot Strait region (46-48 °N, 59-61 °W), the Gully (43.8-44.5 °N, 58.5-60.5 °W), and the Scotian Gulf (43-43.8 °N, 63-64 °W). For each region the numbers of points (DJF, JJA) were: Cabot (347, 475), Gully (55,107) and the Scotian Gulf (71,73). The nitrate transports are tabulated in Table 6.2.2.

Table 6.2.2. Nitrate Transports.

Cabot Strait						
Width=50km for outflow						
	DJF			JJA		
Depth(m)	Current(m/s)	Nitrate(μM)	Flux(moles/s)	Current(m/s)	Nitrate(μM)	Flux(moles/s)
10	0.22	6.2	2046	0.12	0.4	72
50	0.21	5.54	1891	0.01	3.35	54
75	0.2	6.73	1682	0.06	6.04	453
100	0.14	9.16	2405	0.04	8.72	654
150	0.08	12.88	1288	0.05	14.72	920
Total(moles/s)			**9312**			**2153**

Gully						
Width=10km for inflow						
	DJF			JJA		
Depth(m)	Current(m/s)	Nitrate(μM)	Flux(moles/s)	Current(m/s)	Nitrate(μM)	Flux(moles/s)
10	0.019	10.52	60	0.028	0.43	3.6
50		13.32	82		4.73	63
75		15.3	73	0.054	7.7	104
100		19.16	137		12.64	256
150		21.73	103		20.72	280
Total(moles/s)			**455**			**707**

Scotian Gulf						
Width=50km						
	DJF			JJA		
Depth(m)	Current(m/s)	Nitrate(μM)	Flux(moles/s)	Current(m/s)	Nitrate(μM)	Flux(moles/s)
10	-0.091	8.46	-1155	-0.057	0.17	-15
50	-0.025	12.88	-523	-0.036	4.1	-240
75		16.83	-358		10.21	-313
100	-0.009	18.71	-316	-0.013	11.98	-292
150	-0.004	19.08	-95	0.006	15.15	114
Total(moles/s)			**-2447**			**-746**

In the winter, the nitrate transport from the Gulf of St. Lawrence is about 4 times that through the Scotian Gulf and nearly 20 times greater than the transport through the Gully. In summer, the nitrate transport from the Gulf is 3 times that through the Gully and the Scotian Gulf. The transport through the latter two are nearly equal and but the opposite sense. Note that the transport though the Scotian Gulf is in the opposite sense for winter as well, and to that determined by Houghton *et al.* (1978). Moreover, our December-February transport exceeds their December-April transport by a factor of nearly 15. The differences in their analysis compared to this one are that they used current data for only one period and from farther off the shelf, and they calculated the nutrient fluxes for periods of about 1 to 30 days, whereas, our calculation estimates seasonal fluxes. One earlier estimate of nitrate transport through Cabot Strait based on geostrophic calculations of the currents and BIO nutrient data collected in the 1970s (Yeats, 1988) gave an annual average of $5*10^3$ moles/s.

Our calculations are based on current meter data that were not collected at the same time as the nutrient data, assumptions about the horizontal scale that the current meter data represent *(e.g.,* half the width of the Gully at its narrowest point defined by the 100 m isobath), very few current meter observations with poor vertical resolution (particularly true for the Gully, where one winter current observation was taken as representative of the entire depth to 150 m), and in some cases few nutrient measurements from the regions (again particularly true for the Gully, where most of the data comes from the adjacent bank areas). With these weaknesses in mind, the overall indication is that the nitrate transport through the Gully could make a significant contribution to the eastern Scotian Shelf during the summer. In winter, the transport from the Gulf of St. Lawrence dominates.

6.2.4 Summary

There are no data on contaminant concentrations within the Gully. Extrapolation of data from adjacent areas would suggest that elevated concentrations of any of the common contaminants would not be anticipated in the water, sediments or biota of the Gully. Contaminant survey(s) to establish baseline levels would be worthwhile.

There are adequate measurements of nutrient and oxygen concentrations in the Gully to calculate monthly mean concentrations for these parameters. The general picture of nutrient distributions in the Gully averaged as it is over monthly time scales and Gully-wide space scales is very similar to analagous descriptions for adjacent areas. Estimates of nutrient transport through the Gully onto the Scotian Shelf based on these seasonally averaged descriptions of the distributions indicate that transport through the Gully can make a significant contribution to the nutrient pool on the eastern Scotian Shelf. There are inadequate data for an investigation of nutrient variability on smaller time or space scales. There is no indication in the available dataset of elevated nutrient levels that may have resulted from enhanced mixing or upwelling in the Gully. Mixing may be no greater in the Gully than on the adjacent regions of the shelf, it may be occurring on small time and space scales that were missed with the limited data coverage, or nutrients may be rapidly removed by biological uptake. A combined physical, chemical and biological study would be required to investigate these possibilities.

6.2.5 References

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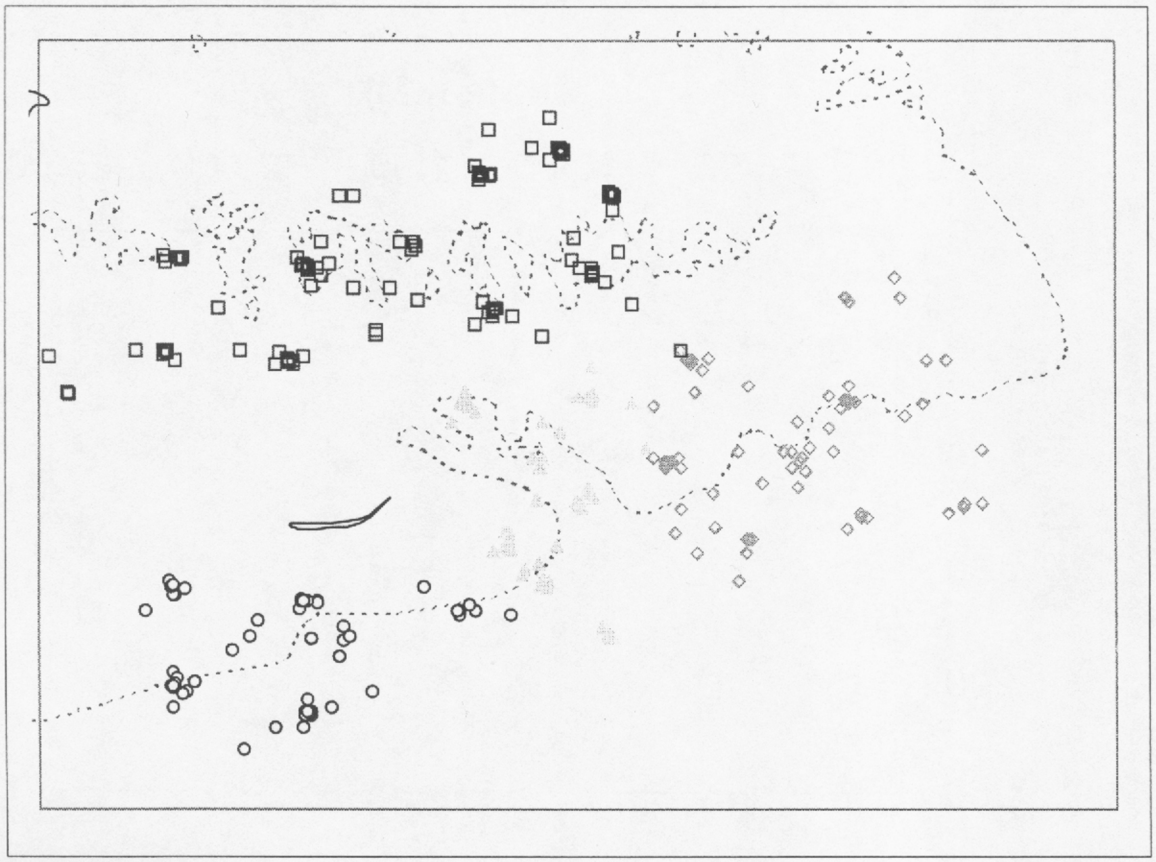

Fig 6.2.1. Locations of stations in the Marine Chemistry database with nutrient data. Triangles indicate stations from the Gully region; circles, squares and diamonds the adjacent western (Sable Island Bank), northern (Middle Bank) and eastern (Banquereau) regions.

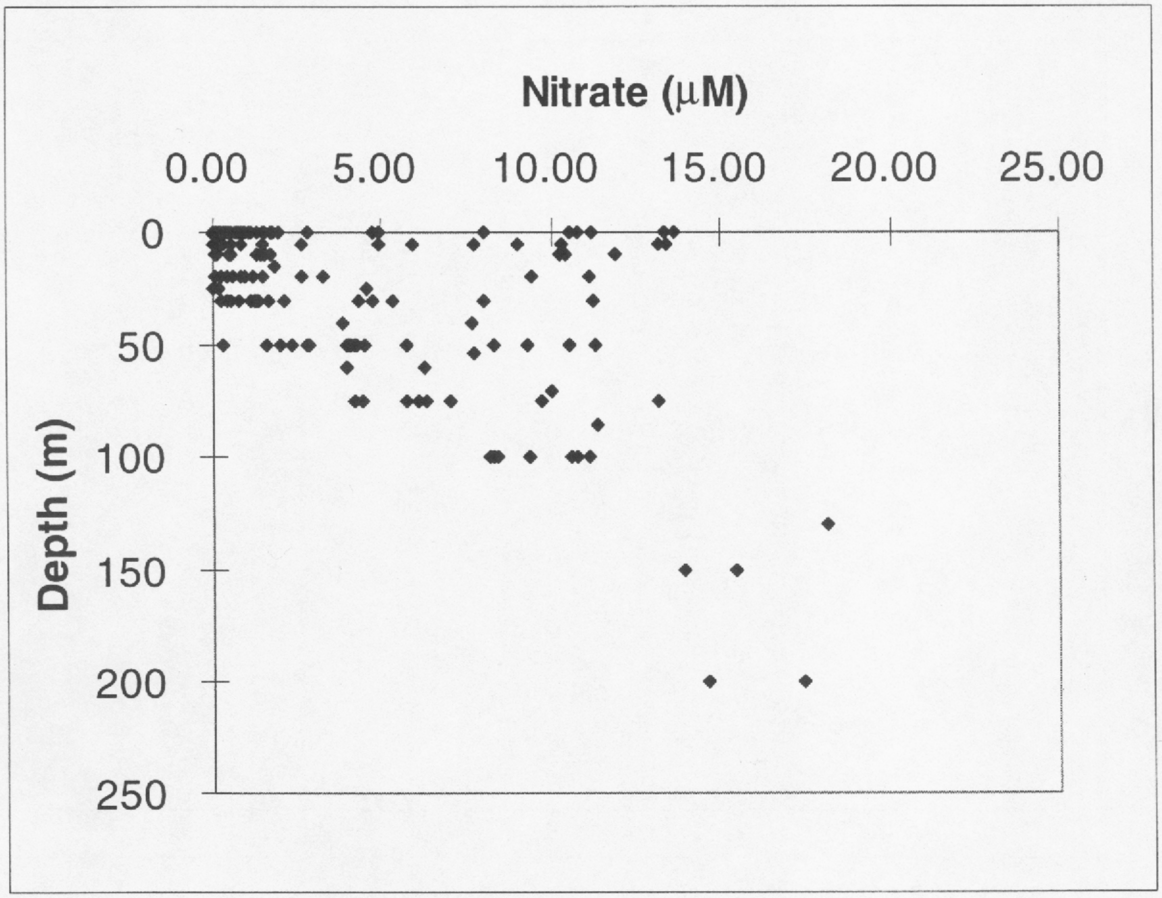

Fig 6.2.2. Nitrate versus depth for all Gully stations.

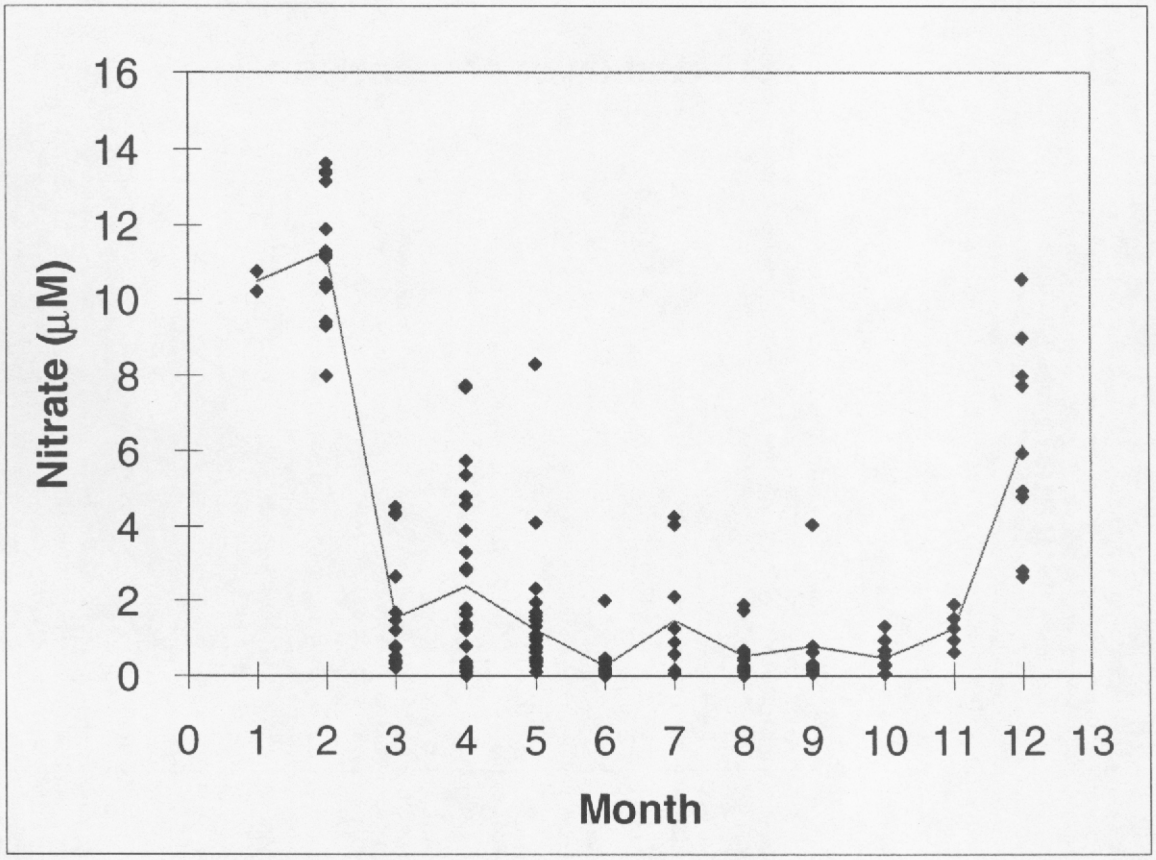

Fig 6.2.3. Gully nitrate concentrations for depths <50 m by month.

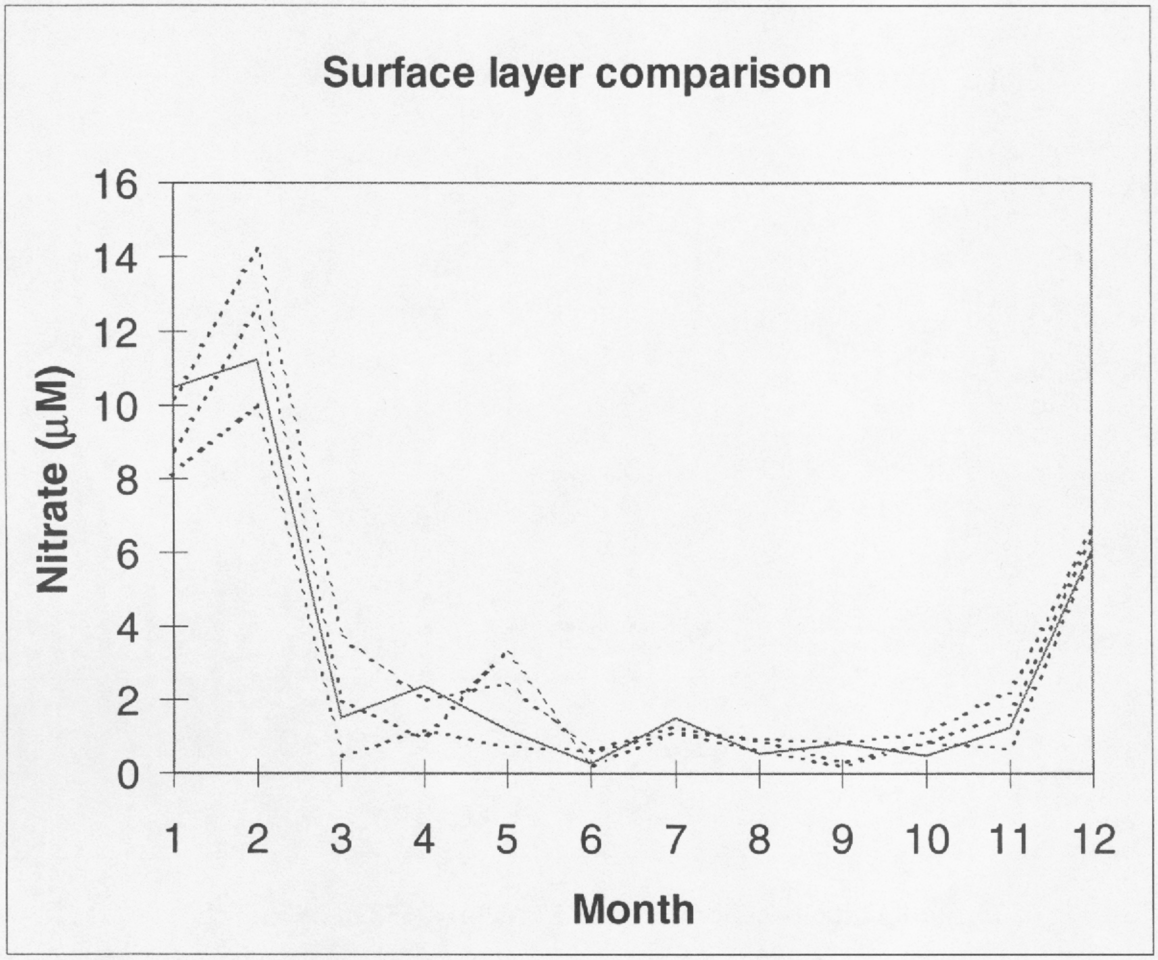

Fig 6.2.4. Average monthly nitrate concentrations for depths <50 m. Gully shown as solid line, adjacent shelf areas as broken lines.

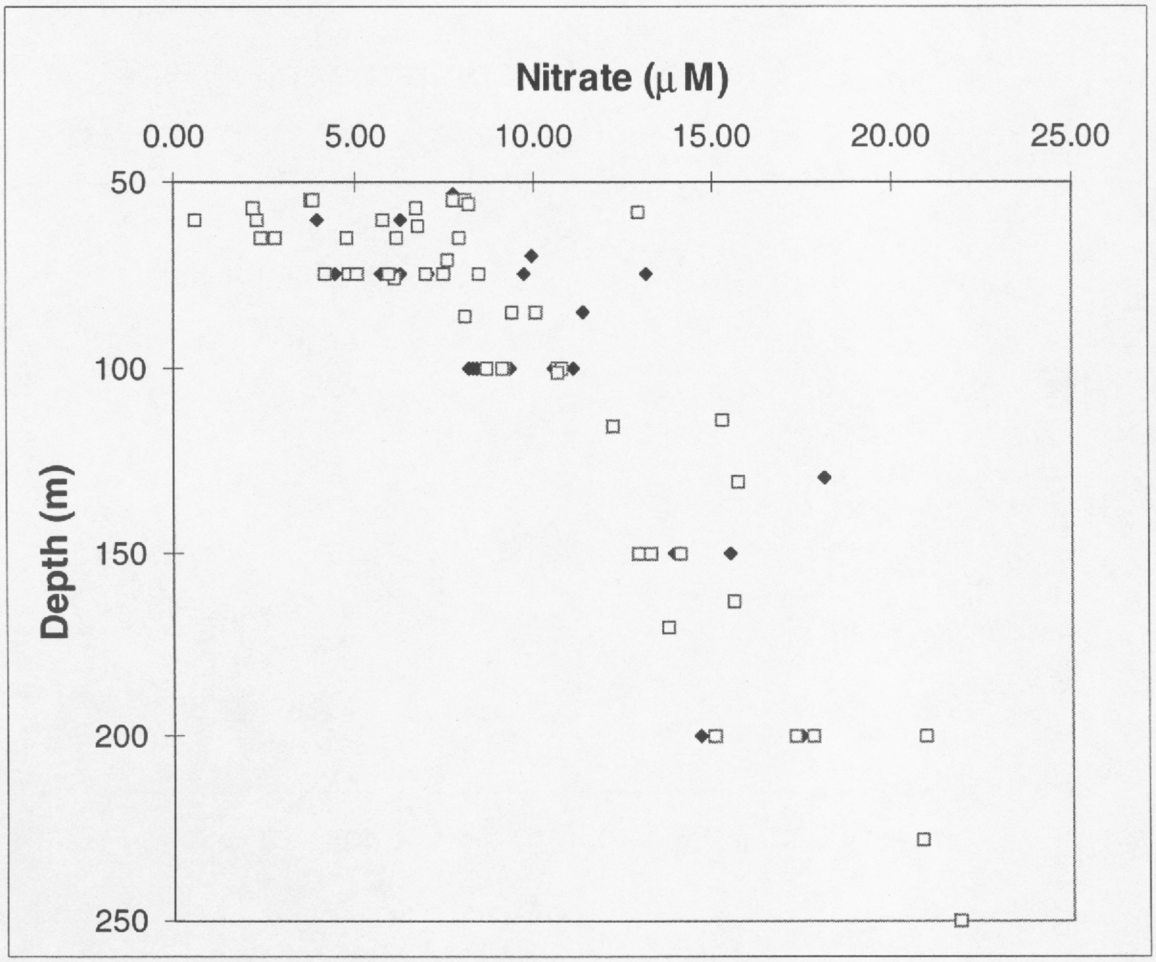

Fig 6.2.5. Nitrate versus depth (depths >50 m) for the Gully (diamonds) and adjacent shelf areas (squares).

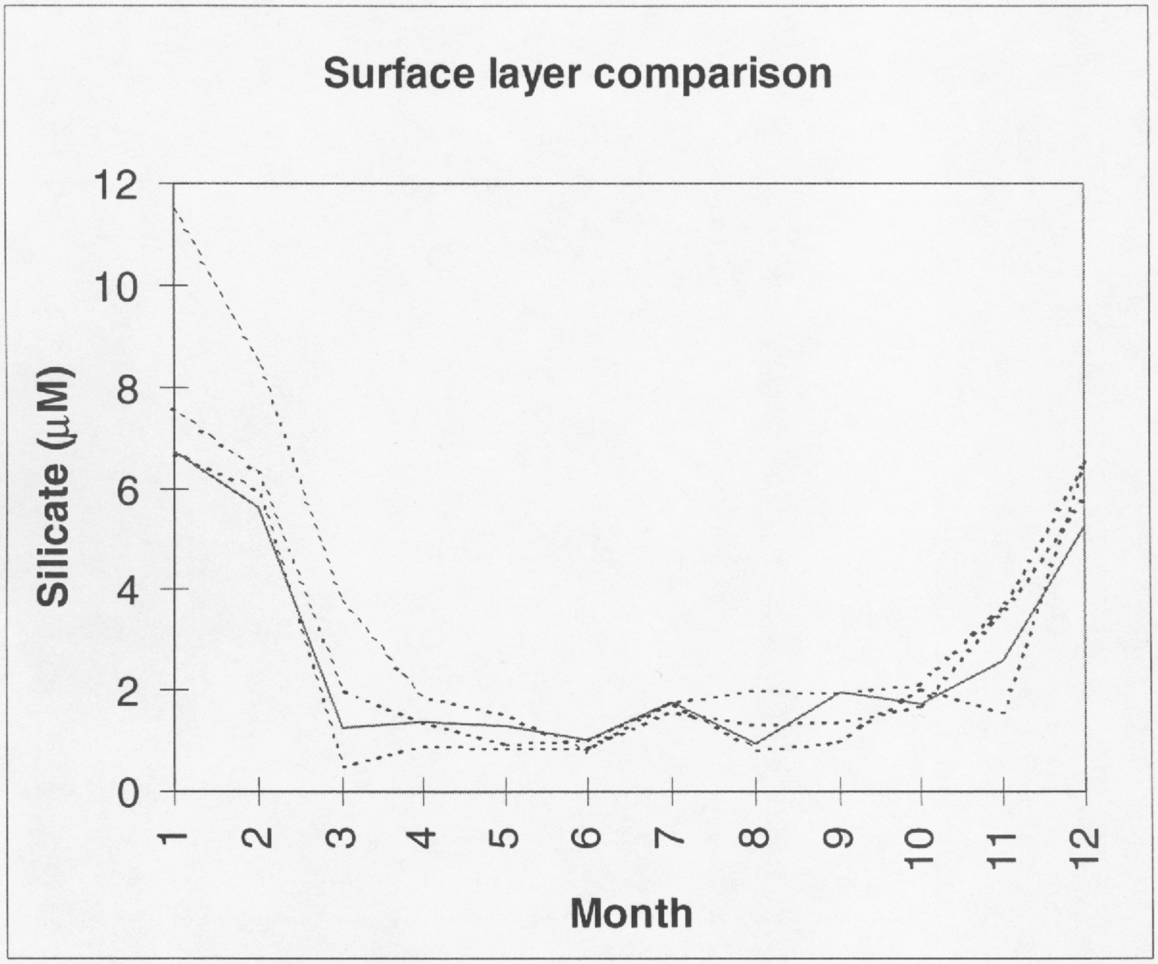

Fig 6.2.6. Average monthly silicate concentrations for depths <50 m. Gully shown as solid line, adjacent shelf areas as broken lines.