Biological Productivity in the Northeast Pacific: Comparing an *in-situ* method with incubation based methods

by

Karina Giesbrecht
B.Sc., University of Victoria, 2007

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of the Requirements for the Degree of

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in the School of Earth and Ocean Sciences

Supervisory Committee

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Abstract

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In-situ net community production (NCP) was measured on nine cruises along Line P in the subarctic Northeast Pacific during 2007-2009 and incubation based new, regenerated and carbon production on four cruises starting in August 2008. *In-situ* NCP, determined using the O_2/Ar gas ratio in the mixed layer, averaged 18.4±5.1 mmol O_2 m^{-2} d^{-1} for stations west of 130˚W in June and August. *In-situ* NCP was nearly equivalent to 24-h $^{15}NO_3^-$ based euphotic zone integrated new production (New-P) with an average NCP: New-P ratio of 1.3±0.4 that was consistent over a range of environmental conditions. The relationship between NCP and 24-h ^{13}C integrated production (C-PP) was variable, but with a consistent mean NCP:C-PP ratio of 0.42±0.27 even when historical measurements were included in the comparison. Two offshore high productivity events were observed in the HNLC region of Line P, one centered between 134˚W and 139˚W and the other west of 130˚W. Only one high productivity event shows conclusive evidence of being caused by iron deposition.

Table of Contents

List of Tables

List of Figures

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Chapter 1. Introduction

The biological production of organic carbon and its export from the surface to the deep ocean are important processes that regulate atmospheric CO_2 concentrations, a main contributor to global warming. This biological pump results in atmospheric CO_2 concentrations that are 2-3 times lower than the levels predicted if all marine life were extinct (*Sieganthaler and Sarmiento,* 1993). The rate of the pump has likely remained relatively unchanged since pre-industrial times (*Sieganthaler and Sarmiento,* 1993), because nutrients, light, and zooplankton grazing control biological productivity, rather than CO_2 concentrations (*Raven and Falkowski*, 1999). However, there is potential for significant changes to this export flux in the future as a result of warming induced stratification (*Sarmiento et al.,* 1998), making quantification and monitoring of the biological pump essential.

A wide variety of methods have been developed to quantify biological productivity, but methodological differences and the lack of a standard for flux measurements have brought their accuracy into question (e.g. *Platt et al.*, 1989). Thus, productivity may be best constrained by comparing several different methods (Table 1.1), with each method susceptible to different errors. Incubation-based methods suffer from isolation of the phytoplankton community within the incubation bottle, and potential mismatches in the physical conditions of incubation vs. the original environment, such as light levels and temperature (*Platt and Sathyendranath*, 1993; *Cullen,* 2001). *In-situ* methods do not suffer from these bottle effects, but are susceptible to other types of errors, such as approximately ±15% errors in air-sea gas exchange fluxes for the O_2 mass balance method (e.g. *Juranek and Quay*, 2010). A caveat to productivity method comparisons, especially between incubation and *in-situ* based techniques, is that different methods rarely directly measure the same type of productivity (*Falkowski et al.*, 2003). For example, although new production and net community production do not measure the same process (Table 1.1), their rates should be equivalent in a steady state system or averaged over large enough temporal and spatial scales (e.g. *Legendre and Gosselin*, 1989; *Laws*, 1991; *Falkowski et al.*, 2003). Available techniques can integrate over temporal and spatial scales ranging from milliseconds and single cells (Fast Repetition Rate Fluorometry) to hours and specific depths (incubation-based) to weeks and the mixed layer (O_2 mass balance) to years and globally (satellite-based). As a result, the temporal and spatial scales of each method must be considered when comparing different methods.

Though there have been a number of studies that compare incubation-based productivity estimates using different tracers (e.g. *Bender et al.*, 1987; *Bender et al.*, 1999; *Dickson et al.*, 2001), few studies have compared *in-situ* and incubation-based methods (e.g. *Emerson et al.,* 1993; *Hendricks et al.*, 2004; *Juranek and Quay*, 2005; *Reuer et al.*, 2007; *Quay et al.*, 2010). There are fewer still that compare *in-situ* estimates of net community productivity (NCP) with incubation-based estimates (*Emerson et al.,* 1993; *Reuer et al.*, 2007; *Quay et al.*, 2010) and only one of these studies that compared one month of measurements in the subarctic Northeast Pacific (*Emerson et al.,* 1993). In this study, *in-situ* estimates of net community productivity (O_2/Ar NCP) are compared with incubation-based estimates of new (New-P, based on $^{15}NO_3^-$), regenerated (Regen-P, based on $^{15}NH_4^+$), and carbon-based primary (C-PP, based on ^{13}C) productivity (Table 1.1) along a coastal-oceanic transect in the subarctic Northeast Pacific.

Table 1.1 Productivity Definitions and Methods

Carbon or Oxygen-based	
Net Community (NCP)	
Definition	Total amount of carbon available for export to the deep ocean. Takes entire planktonic community into account. For C: The net rate at which CO_2 is converted to particulate and dissolved organic carbon. For O_2 (also known as NOP): the difference between the rate of gross O_2 production by photosynthesis and the rate of all metabolic O_2 respiration. Includes biological export into biomass and via sinking/mixing to the deep ocean. Can be converted to C units via a stoichiometric ratio of 1.4 O_2:CO_2.
Tracer/Method used in this work	*In-situ* based O_2/Ar, estimates NCP using a mass balance of biological O_2 (*Craig and Hayward*, 1987; *Emerson et al.*, 1999)
Equivalent at steady state to	New production, Biological Carbon Export (*Legendre and Gosselin*, 1989; *Laws*, 1991; *Falkowski et al.*, 2003)
Nitrogen-based	
New (New-P)	
Definition	Assimilation rate of new nitrogen sources (primarily NO_3^-) during photosynthesis. Assumes no nitrification (bacterial oxidation of ammonium to nitrate) occurs within euphotic zone. Cab be converted to C units via a stoichiometric ratio of 6.6 C:N
Tracer/Method used in this work	$^{15}NO_3^-$ incubation (24 h) (*Dugdale and Goering*, 1967; *Slawyk et al.*, 1977; *Dugdale and Wilkerson*, 1986)
Equivalent at steady state to	Net Community Production, Biological Carbon Export (*Legendre and Gosselin*, 1989; *Laws*, 1991; *Falkowski et al.*, 2003)
Regenerated (Regen-P)	
Definition	Assimilation rate of recycled forms of nitrogen (NH_4^+ and urea)
Tracer/Method used in this work	$^{15}NH_4^-$ incubation (24 h) (*Dugdale and Goering*, 1967; *Slawyk et al.*, 1977; *Dugdale and Wilkerson*, 1986)
Carbon-based	
Carbon-based primary (C-PP)	
Definition	Falls between Gross Primary (fixation rate of CO_2 into organic carbon through photosynthesis, GPP) and Net Primary (Gross Primary less autotrophic/metabolic respiration, NPP) for 24 hr (*Marra*, 2002; 2009; *Marra and Barber*, 2004)
Tracer/Method used in this work	^{13}C incubation (24 h) (*Slawyk et al.*, 1977; *Hama et al*, 1983)
Equivalent at steady state to	^{14}C incubation (24 h) (*Slawyk et al.,* 1984)

With tri-annual cruises that cover a range of productivity regimes and a comprehensive historical dataset with several intensive studies, Line P is an ideal transect over which to compare estimates of productivity. Located in the subarctic North Pacific, Line P extends from the southern tip of Vancouver Island out to one of the longest running deep-ocean time series in the world, P26 (Ocean Station Papa, OSP, Station P, or P, at 50˚N 145˚W, Figure 1.1). The time series includes over five decades of measurements at P26, with additional stations added in 1959 and increasing in 1981 to the 27 sampled today (*Freeland*, 2007). Line P spans a range of physical (*Whitney et al.,* 2005), chemical (*Whitney et al.,* 1998; 2005; *Varela and Harrison*, 1999) and biological (*Boyd et al.,* 1998; *Whitney et al.*, 1998; *Boyd and Harrison*, 1999; *Varela and Harrison*, 1999) regimes, shifting from a highly productive coastal environment affected by seasonal upwelling (*Whitney et al.,* 1998) out to the High-Nutrient Low-Chlorophyll (HNLC) region of the subarctic gyre where iron limitation and microzooplankton grazing control phytoplankton standing stocks (*Miller et al*., 1991; *Boyd et al.*, 1996; *Whitney et al.,* 2005; *Whitney and Freeland,* 1999). Temporal and spatial variations in productivity along Line P are low (*Boyd and Harrison*, 1999; *Varela and Harrison*, 1999) making the subarctic North Pacific an ideal region to compare productivity methods that integrate over vastly different temporal and spatial scales. However, though productivity along Line P tends to be nearly constant, iron inputs have caused sporadic high productivity events in the offshore region throughout the time-series (*Parsons and Lalli*, 1988; *Wong et al.*, 1995; *Lam et al.*, 2006). Several methods have been used to estimate productivity along Line P (Table 1.2), though only one study (*Emerson et al.*, 1993) compared productivity from both *in-situ* (O_2, N_2 and Ar mass balance) and incubation ($^{15}NO_3^-$) techniques.

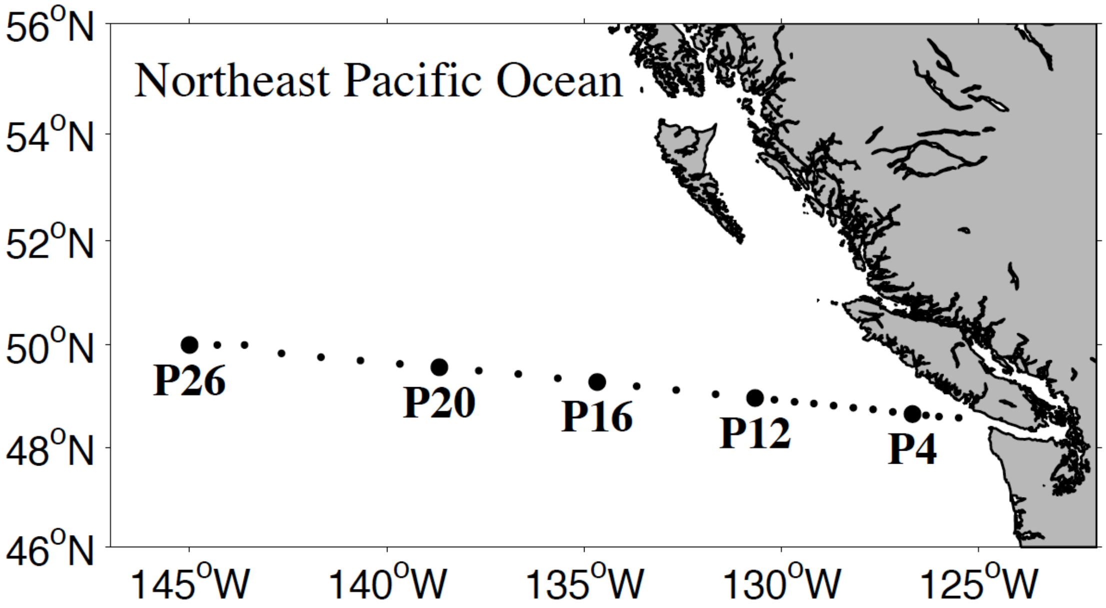

Figure 1.1. Map of the subarctic Northeast Pacific and Line P. Major stations are marked by larger circles. *In-situ* NCP samples were collected at all major stations. Incubation based measurements were made at stations P4, P16 and P26.

Table 1.2. Productivity studies at the major stations (P4, P12, P16, P20 and P26) along Line P and Station R (53˚N, 145˚W)

Tracer/Method	Years	Period	Stations	Reference
Carbon-based primary productivity				
^{14}C	1960-1990	Monthly	P26	*Wong et al.*, 1995
	1987-1988[†]	May-Aug	P26, R	*Welschmeyer et al.*, 1993
	1992-1997[*]	Feb-Sept	Major	*Boyd and Harrison*, 1999
^{13}C	2009 2008	Feb-Aug Aug	P4, P16, P26 P26	*This study*
Nitrogen-based primary productivity				
$^{15}NO_3^-$	1984, 1987-1988[†]	May-Oct	P26, R	*Wheeler et al.*, 1989; *Wheeler and Kokkinakis*, 1990; *Wheeler*, 1993; *Emerson et al.*, 1993
	1992-1997[*]	Feb-Sept	Major	*Varela and Harrison*, 1999; *Peña and Varela*, 2007
	2009 2008	Feb-Aug Aug	P4, P16, P26 P26	*This study*
$^{15}NH_4^+$	1984, 1987-1988[†]	Aug	P26, R	*Wheeler et al.*, 1989; *Wheeler and Kokkinakis*, 1990
	1992-1997[*]	Feb-Sept	Major	*Varela and Harrison*, 1999; *Peña and Varela*, 2007
	2009 2008	Feb-Aug Aug	P4, P16, P26 P26	*This study*
^{15}N-urea	1992-1994[*]	Feb-Sept	Major	*Varela and Harrison*, 1999
Bacterial productivity				
	1987-1988[†]	May-Aug	P26	*Kirchman et al.*, 1993
	1993-1994[*]	Feb-Mar	P23, P26	*Boyd et al.*, 1995a,b
	1995-1997[*]	Feb-Sept	Major	*Sherry et al.*, 1999
***In-situ* Net Community Productivity from a dissolved gas mass balance**				
O_2	1969-1978	May-Aug	P26	*Emerson*, 1987
$O_2/N_2/Ar$	1987-1988[†]	May-Aug	P26, R	*Emerson et al.*, 1991; 1993
	2007-2009	Feb-Aug	Major	*This study*
Particulate carbon export				
^{234}Th	1996-1997[*]	Feb-Sept	Major	*Charette et al.*, 1999
Sediment trap	1982-1993	Annual	P26	*Wong et al.*, 1999
Nitrate drawdown (ΔNO_3^-)				
0-100 m	1965-1970	May-Aug	P26	*Emerson*, 1987
euphotic zone	1996[*]	May-Aug	Major	*Charette et al.*, 1999
surface	1995-1996	Annual	N. Pacific (>35˚N)	*Wong et al.*, 2002a

[†] part of the Subarctic Upper Ocean Process and Ecosystem Research (SUPER) program
[*] part of the Canadian Joint Global Ocean Flux Studies (CJGOFS) program

This thesis presents a three-year dataset of dissolved O_2, N_2 and Ar measurements and a one-year dataset of $^{13}C/^{15}N$ dual tracer incubations along Line P from the tri-annual cruises between February 2007 and August 2009. The following results will show that O_2/Ar based NCP showed little variability at the offshore stations from early June to late August for 2007 – 2009 (excluding anomalous August 2008 measurements). Rates of New-P were nearly equivalent to NCP for all stations and seasons sampled. Rates of C-PP and NCP (or New-P) were strongly correlated in 2009, though comparison with historical data indicates that the ratios of these rates are subject to interannual variability. Finally, observations of two high productivity events along Line P are presented, one in winter (February 2007) and one in summer (August 2008), resulting from reduction of light (winter) or iron limitations on phytoplankton.

Chapter 2. Analytical Methods and Data Reduction

Samples for biological and chemical analyses were collected from 10L Niskin bottles on a 24 bottle rosette frame. Depth profiles of conductivity, temperature and pressure were collected using a SBE 911+ CTD mounted to the rosette. The CTD was also outfitted with a Chelsea/Seatech transmissometer, an SBE 43 dissolved oxygen sensor and a Seapoint Fluorometer that collected depth profiles of transmittance, dissolved oxygen and fluorescence respectively. Routine analyses of dissolved oxygen, salinity, nutrients (NO_3^-, PO_4^{3-}, SiO_4^-) and chlorophyll at the 5 major stations (depth profiles) and surface (5 m) samples at all stations along Line P were collected and analyzed by the Institute of Ocean Sciences (Fisheries and Oceans Canada, Sidney, BC) as part of the Line P program (see http://www.pac.dfo-mpo.gc.ca/science/oceans/data-donnees/line-p/index-eng.htm for details)

2.1. Dissolved gas sampling and analysis

Dissolved gas samples were collected on nine Line P cruises over a 3-year period (2007 – 2009, Table 2.1) at the five major stations (P4, P12, P16, P20 and P26). Samples were collected at 5-m for most stations, with a depth profile at P26 for every cruise and additional stations on the 2009 cruises. Duplicate samples for $O_2/N_2/Ar$ ratios were collected following the method of *Emerson et al.* (1999), directly after discrete O_2 samples. Briefly, seawater was collected into evacuated 180-mL glass flasks equipped with 9mm Louwers-Hapert valves with 2 sealing O-rings and containing a small amount of dried $HgCl_2$ to stop biological activity. Bubble-free seawater from Niskin bottles was added to half-fill the flasks using tubing flushed with CO_2 to ensure no atmospheric contamination. Samples were preserved by sealing CO_2 between the O-rings and within the flask necks using vinyl caps. Discrete O_2 samples were analyzed on-board using the Carpenter-modified Winkler titration (*Carpenter*, 1965).

Table 2.1. Cruise Dates

Season	**2007**	**2008**	**2009**
Winter	February 9 – 18	February 1 – 10	January 29 – February 5
Late spring	June 1 – 8	June 1 – 10	June 8 – 14
Summer	August 16 – 22	August 14 – 21	August 21 – 28

Back at the lab, samples were weighed and then equilibrated for 8 hrs in a rotating rack within a constant temperature bath to equilibrate the dissolved gases with the headspace. Following equilibration, the seawater was removed under vacuum leaving the headspace intact. Samples not immediately run at this point were stored under a CO_2 atmosphere in gas-tight bags. The gas sample was purified of H_2O and CO_2 with liquid N_2 and frozen into a stainless steel tube immersed in liquid He. After the sample was removed from the liquid He and allowed to come to room temperature, the $O_2/N_2/Ar$ ratios were measured against a standard of similar ratios on a dual-inlet mass spectrometer (Finnigan Delta X/L at Univ. of Wash. or MAT 253 at Univ. of Victoria). Though the $O_2/N_2/Ar$ ratios in the standard are matched quite closely to the samples, the ratios in this standard are ultimately determined relative to an air sample, with significantly different O_2/N_2 ratios. To correct for different gas ionization efficiencies when the sample and standard gases have different O_2 concentrations, the mass spectrometer was calibrated with a standard set containing known $O_2/N_2/Ar$ ratios (*Emerson et al.*, 1999; *Hamme*, 2003). Corrections to the measured O_2/Ar ratios were on the order of 0.05 %, mainly due to the O_2/N_2 mismatch between the mixed-layer standard and air.

2.1.1. Net Community Production (NCP) from dissolved O_2/Ar measurements

The O_2/Ar ratio in the mixed layer is a tracer of net community O_2 production. Argon has a similar solubility and temperature dependence to O_2, but is not affected by biological processes, thus acting as an abiotic analogue to O_2. For the O_2/Ar ratio, these similarities normalize the O_2 signal for physical processes, such as temperature changes and bubble-mediated gas exchange, which have an approximately equivalent effect on O_2 and Ar. The biological oxygen supersaturation, ΔO_2/Ar, is defined as

$$\Delta \mathrm{O}_2/\mathrm{Ar} = \left[\frac{(\mathrm{O}_2/\mathrm{Ar})_{sample}}{(\mathrm{O}_2/\mathrm{Ar})_{eq}} - 1\right] \tag{2.1}$$

where $(O_2/Ar)_{sample}$ is the measured ratio in seawater, and $(O_2/Ar)_{eq}$ is the ratio at equilibrium with the atmosphere for the potential temperature and salinity of the water mass (*Garcia and Gordon,* 1992; 1993; *Hamme and Emerson*, 2004).

In a simple steady state, net production of O_2 by photosynthesis in the mixed layer is balanced by diffusive gas exchange. Following *Reuer et al.* (2007), this flux can be quantified as

$$\mathrm{NCP} = \Delta(\mathrm{O}_2/\mathrm{Ar})\,[\mathrm{O}_2]_{eq}\; k\,\rho \tag{2.2}$$

where $[O_2]_{eq}$ is the equilibrium concentration of O_2 in the mixed layer (μmol kg^{-1}), k is the gas exchange coefficient (m d^{-1}), and ρ is the density of the mixed layer (kg m^{-3}). The gas exchange coefficient, k, is estimated using the quadratic wind speed parameterization of *Ho et al.* (2006) and the 6-hourly NCEP/QuikSCAT blended wind product provided by Colorado Research Associates (http://dss.ucar.edu/datasets/ds744.4/). The wind speed weighting scheme of *Reuer et al.* (2007) can be used to account for wind speed variability over the weeks preceding the sampling date. This method, which weights and averages gas exchange coefficients over a 60-day period and assumes constant values for net production and mixed layer thickness, yields robust estimates of NCP even when wind speeds are variable. A photosynthetic quotient (PQ, ΔO_2:ΔCO_2) of 1.4 (*Laws*, 1991) was used to convert O_2/Ar based NCP into carbon-based units, which is based on the PQ of nitrate assimilation.

I estimate the uncertainty associated with the wind-speed parameterization of the gas exchange coefficient, *k*, to be ±14%. This value is a conservative estimate representing twice the % difference between the value of *k* calculated using *Sweeney et al.* (2007), which is an update of the global bomb ^{14}C-derived wind speed parameterization of *Wanninkhof* (1992), and *Nightingale et al.* (2000), which is based on multiple dual-tracer experiments. The *Ho et al.* (2006) parameterization falls midway between. These parameterizations span the reasonable values expected from the calculation of *k* from wind speed. The small uncertainties in the equilibrium concentration of O_2 (±0.2%) and in the measurements of ΔO_2/Ar (±0.1% mean difference between duplicates) are negligible compared to errors associated with gas exchange. However, though diffusive gas exchange is typically the dominant physical process affecting dissolved O_2 concentrations in the mixed layer, both diapycnal mixing (vertical mixing across the base of the mixed layer) and horizontal advection can complicate this O_2 mass balance of NCP with diffusive gas exchange.

Few measurements of diapycnal mixing at the base of the mixed layer are available along Line P, so the diapycnal mixing flux cannot be accurately quantified. Instead, its importance to the mass balance can be diagnosed by estimating the magnitude of the eddy diffusion coefficient that would be needed if diapycnal mixing at the base of the mixed layer were to balance the surface gas exchange flux.

$$\left[\frac{\mathrm{d}[\mathrm{O}_2]}{\mathrm{dz}} - \frac{\mathrm{d}[\mathrm{Ar}]}{\mathrm{dz}}\left(\frac{[\mathrm{O}_2]_{eq}}{[\mathrm{Ar}]_{eq}}\right)\right] K_z\, \rho = \Delta(\mathrm{O}_2/\mathrm{Ar})\, [\mathrm{O}_2]_{eq}\, k\, \rho \tag{2.3}$$

where $d[O_2]/dz$ and $d[Ar]/dz$ are the gradients in the O_2 and Ar concentrations below the mixed layer (μmol kg^{-1} m^{-1}), K_z is the eddy diffusion coefficient (m^2 d^{-1}), and the right-hand side of the equation is the same as equation (2.2). The O_2 and Ar depth gradients are calculated using depth profiles of dissolved O_2 from the O_2 CTD sensor and the equilibrium concentration of Ar from potential temperature and salinity profiles. Although the CTD O_2 sensor reading may contain bias, the accuracy of the O_2 concentrations is less important because I am calculating the change in concentration over depth. Argon supersaturations (as determined from my discrete O_2/Ar and O_2 measurements) are essentially constant (± 0.5%) above and directly below the mixed layer, so the gradient in the equilibrium concentration of Ar approximates the true Ar gradient. I calculate the concentration gradients (and thus K_z) averaged over a depth from the bottom of the mixed layer to about 5 to 10 meters below.

The impact of diapycnal mixing on O_2/Ar based NCP can be generalized into three months (February, June and August), characterized by the magnitude and direction of the dissolved O_2 and Ar gradients below the mixed layer. In February, dissolved O_2 depth gradients (Figure 2.1a) were typically large and negative (lower O_2 concentrations below the mixed layer), a result of cooler temperatures and strong winds mixing the surface layer to the depth of the permanent halocline that exists along Line P (*Whitney and Freeland*, 1999). Measurements of $\Delta O_2/Ar$ in the mixed layer were predominantly undersaturated at this time (-0.4 ± 0.7 %, n = 13). For these circumstances, I calculated that eddy diffusivity values of ≤ 0.2 cm^2 s^{-1} would be sufficient to generate a mixing flux that balanced air-sea gas exchange. These values are well within the reasonable range (0.1 – 10 cm^2 s^{-1}) determined from previous measurements of K_z below the mixed layer (e.g. *Large et al.,* 1986; *Gregg*, 1989; *Ledwell et al.,* 1993; *Rousseau et al.*, 2010). This indicates that diapycnal mixing likely plays an important role in the February gas mass balance and thus, I cannot constrain NCP by the O_2/Ar mass balance method under these conditions. These very small values of K_z estimated for February also indicate that I would unlikely be able to constrain NCP under these conditions even with accurate estimates of K_z, as the uncertainty in measurements of K_z would be sufficient enough to overwhelm the mass balance.

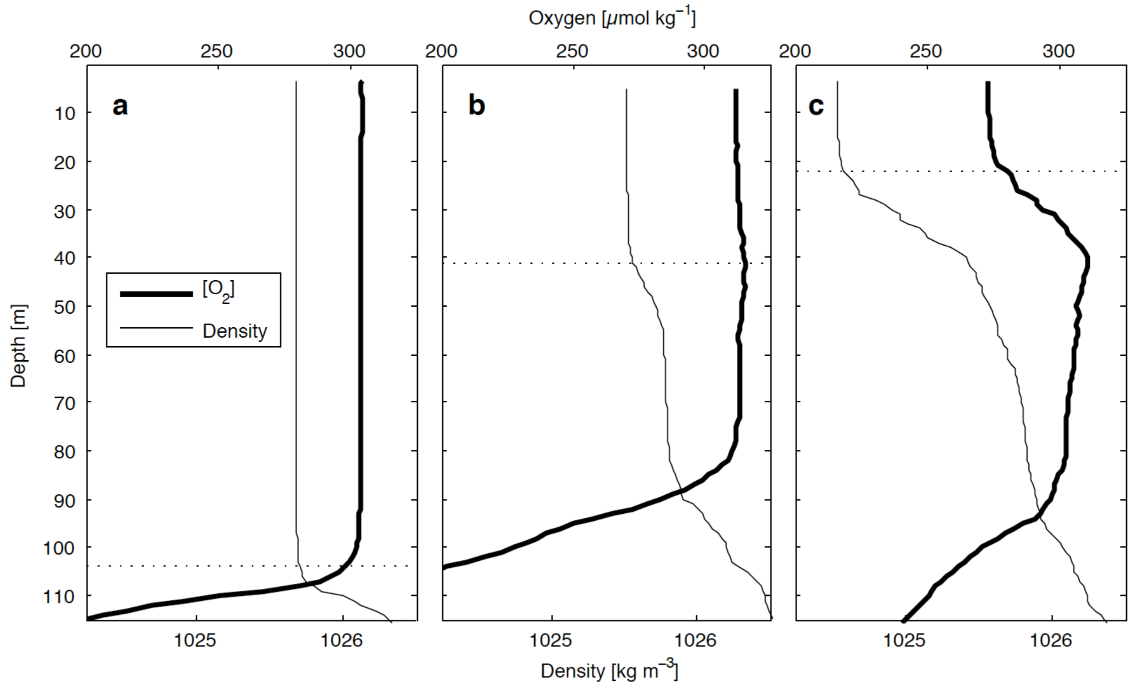

Figure 2.1. Depth profiles of oxygen concentrations and density at P26 in (a) February, (b) June and (c) August 2007. Dashed lines indicate mixed layer depths.

In June, the mixed layer depth has shoaled, the result of decreasing wind speeds and increasing temperatures creating a shallow seasonal thermocline (*Whitney and Freeland*, 1999). Dissolved gas concentration gradients are virtually non-existent below the mixed layer (Figure 2.1b) and $\Delta O_2/Ar$ in the mixed layer is always supersaturated (4.0 ± 3.1 %, n = 15). Calculated eddy diffusivities needed to balance the gas exchange flux in these conditions were extremely large and sometimes negative ($\pm 10^3$ cm^2 s^{-1}), because the diapycnal mixing flux is proportional to the O_2 and Ar gradients. Thus, because actual K_z values are likely less than 0.1 cm^2 s^{-1} (*Rousseau et al., 2010*), the contribution of diapycnal mixing to the mixed layer mass balance in June must be negligible.

By August, a subsurface O_2 maximum (Figure 2.1c) results in positive O_2 gradients (higher O_2 concentrations below the mixed layer) across the fully formed seasonal thermocline. Eddy diffusivity values of 2-5 $cm^2\ s^{-1}$ would be needed for vertical mixing to balance gas exchange in August. Thus, because these values for K_z are still within the reasonable range (0.1 – 10 $cm^2\ s^{-1}$) determined by previous studies, I cannot assume a negligible mixing flux as I do in spring and the positive O_2 gradients indicate that I overestimate NCP if I exclude diapycnal mixing from the mass balance. It is likely, however, that the degree of this overestimation is generally small as recent estimates of K_z below the mixed layer in June 2007 at P26 average between 0.05 – 0.08 $cm^2\ s^{-1}$ (*Rousseau et al., 2010*) though *Large et al.* (1986) found K_z values can increase to >10 $cm^2\ s^{-1}$ on short time-scales during storms. Even if I assume a conservative value for K_z of 0.1 $cm^2\ s^{-1}$ in August, the diapycnal mixing flux accounts for less than 1 mmol $O_2\ m^{-2}\ d^{-1}$, or ~6 % of the gas exchange flux. Thus, though I cannot quantify the mixing flux in the summer, excluding it from my mass balance likely only overestimates NCP by ~6%.

Here, I ignore horizontal advection in the O_2 mass balance, because its contribution in this region is usually small. To demonstrate this, I estimate the contribution of the horizontal fluxes to my mass balance using

$$-\frac{d[O_2]}{dx}\, v_c\, h\, \rho \tag{2.4}$$

where $d[O_2]/dx$ is the horizontal gradient in the O_2 concentration in the mixed layer ($\mu mol\ kg^{-1}\ m^{-1}$) between two adjacent stations, v_c is the current speed ($m\ d^{-1}$), and h is the depth of the mixed layer (m). Horizontal gradients along Line P are generally 10^{-6} to 10^{-5} $\mu mol\ O_2\ kg^{-1}\ m^{-1}$ and variable in sign between stations (based on surface (5 m) O_2 concentrations). Average surface current speeds at P26 are ~ 5×10^3 $m\ d^{-1}$ and can be variable in direction (based on current speeds at 5 and 35 m depth from the NOAA Station P mooring at http://www.pmel.noaa.gov/stnP/index.html). For an average mixed layer depth of 40 m, the horizontal flux of O_2 could be 0.2 to 2 mmol O_2 m^{-2} d^{-1} or about 1-10% of the usual gas exchange flux. Variability in both the horizontal O_2 concentration gradients and the direction of the surface currents make this estimate an upper limit.

2.2. Dual-tracer $^{13}C/^{15}N$ experiments

2.2.1. Sample collection and ancillary measurements

Samples for ^{13}C and ^{15}N uptake rate experiments were collected on the same cruises as the dissolved gases starting in August 2008 at station P26, and starting in February 2009 at stations P4 and P16. Water was collected at 5 depths determined by light levels (100%, 55%, 30%, 10% and 1% of the photosynthetically active radiation (PAR)), as measured by a spherical PAR sensor (Biospherical Instruments QSP-200 LS4) on the rosette. At each depth, water for the dual-tracer incubation experiments was collected into two acid-washed 1-L polycarbonate bottles. Blanks were collected at either the 100% or 1% light depth. Samples for dissolved inorganic carbon (DIC), NO_3^-, and NH_4^+ concentrations were collected from the same Niskin, except NH_4^+ samples for the 2009 cruises. In February 2009, NH_4^+ samples collected for the incubations were contaminated at all stations sampled. As the mixed layer was deeper than the euphotic zone at this time, NH_4^+ values collected at other depths within the euphotic zone were used to calculate uptake rates. For the June and August 2009 cruises, NH_4^+ samples were collected at the same sampling depths as the incubations, but from a different Niskin bottle. Water samples for dissolved NO_3^- and NH_4^+ concentrations were kept at 4˚C until analysis. Samples were analyzed on-board shortly after collection using a Technicon II

Autoanalyzer® (*Barwell-Clark and Whitney*, 1996) for dissolved NO_3^- and using the manual fluorometric method of *Holmes et al.* (1999) for dissolved NH_4^+. DIC samples were collected before other samples into 500-mL borosilicate bottles, preserved with 200 µL of a saturated $HgCl_2$ solution and kept at 4˚C until analysis onshore using a SOMMA-Coulometer system following the methods of *Dickson and Goyet* (1994).

2.2.2. Incubation and analysis

Nitrogen and carbon uptake rates were measured using a dual tracer method with the stable isotopes ^{15}N and ^{13}C (*Dugdale and Goering*, 1967; *Slawyk et al.* 1977). Samples were kept under low light conditions and at low temperatures (4˚C) for no more than 2 h prior to incubation and after removal from the on-deck incubator until termination by gentle filtration. For each depth, both samples were enriched with ^{13}C labeled $NaHCO_3$ (Cambridge Isotope Laboratories, 99 atom % ^{13}C) and a ^{15}N labeled solution of either KNO_3 or NH_4Cl (Cambridge Isotope Laboratories, 99 atom % ^{15}N). Isotopic additions were made at ~10% of the ambient concentration of DIC and NO_3^- or NH_4^+. When NO_3^- or NH_4^+ concentrations were below the detection limit (0.05 µmol L^{-1}), which was always the case for NH_4^+ and only at P4 in June for NO_3^-, ^{15}N additions were 0.05 µmol L^{-1}. Seawater blanks were inoculated according to their ambient concentration and filtered immediately after the start of incubation to account for initially adsorbed ^{13}C and ^{15}N on the filter and/or cell membranes.

Samples were placed in an on-deck incubator for 24 hrs under a pre-determined amount of neutral density screening that simulated the *in-situ* light conditions of the sampling depth. Incubation temperature was controlled by continuously flowing surface seawater from the ship's intake through the incubator. After 24 hrs, samples were filtered under gentle vacuum through pre-combusted Whatman® GF/F filters. Filters were kept at -80˚C until the end of the cruise and then dried at 60˚C for 3 days. The Stable Isotope Facility at the University of California, Davis analyzed the filters for atom % ^{13}C and ^{15}N, and particulate carbon (PC) and nitrogen (PN) concentrations.

2.2.3. Carbon and nitrogen uptake rates from $^{13}C/^{15}N$ dual-tracer incubations

Carbon, nitrate and ammonium uptake rates were calculated using the PC or PN measured at the end of the incubation and the following equation (adapted from equations (6) and (3) from *Dugdale and Wilkerson* (1986))

$$\text{New - P} = \ln\left[\frac{^{15}N_{enr} - {}^{15}N_{blank}}{^{15}N_{enr} - {}^{15}N_{sample}}\right]\frac{PN_t}{t} \tag{2.5}$$

where $^{15}N_{enr}$ is the atom % ^{15}N in the initially labeled fraction, $^{15}N_{blank}$ is the atom % ^{15}N of the blank (ca. 0.366 at%), $^{15}N_{sample}$ is the measured atom % ^{15}N in the sample, PN_t is the PN concentration at the end of the incubation (µmol L^{-1}), and t is the time duration of the incubation (d). For carbon, ^{15}N in the equation above is replaced with ^{13}C and PN_t with PC_t. Though equation (2.5) is based on nitrogen physiology, calculating C-PP using equations based on carbon physiology (*Hama et al.*, 1983) resulted in only a mean difference of 0.5%, much smaller than the average difference (15%) between duplicate samples. When the initial concentration of nitrogen was below the limit of detection (0.05 µmol L^{-1}), ambient nitrogen concentrations, which are included in the $^{15}N_{enr}$ term, were given a value of 0 for the rate calculations. Ammonium uptake rates should be considered a lower estimate because no corrections were made for isotope dilution of the dissolved NH_4^+ pool from remineralization of PON (*Kanda et al.*, 1987). Carbon and nitrogen uptake rates were also not corrected for loss of ^{13}C as $DO^{13}C$ (e.g. *Karl et al.*, 1998; *Williams and Lefévre*, 2008) or ^{15}N as $DO^{15}N$ (e.g. *Bronk et al.*, 1994). The stoichiometric ratio of PC:PN measured at the end of the incubation was used to convert nitrogen-based rates to carbon-based rates in each bottle before depth integrating the results, though using the Redfield ratio (106 C:16 N) instead changes the rates by a maximum of ± 3%. I estimate the errors associated with my incubation-based measurements to be ±15%, which represents the mean % difference between duplicate samples for C-PP. I assume similar errors for $^{15}NO_3^-$ based New-P and $^{15}NH_4^+$ based Regen-P.

Chapter 3. Results and Discussion

3.1. Biological Productivity along Line P: Results and Comparisons to previous studies

3.1.1. Oceanographic Conditions along Line P from 2007 to 2009

Routine measurements of surface temperature, salinity and nitrate and silicate concentrations along Line P (sample collection and analysis by the Institute of Ocean Sciences: Fisheries and Oceans Canada, Sidney, BC) exhibited some significant variability between 2007 to 2009. Surface salinity along Line P ranged from 31.1 to 32.7 from February 2007 to August 2009. Sea-surface Temperature (SST; Figure 3.1) in February 2008 was much cooler compared to the long term mean (1988 – 2009), a feature that persisted into June and August (Figure 3.1). In contrast, SST in June 2009 was much warmer compared to previous years. Nitrate and silicate concentrations also exhibited some variability, with nitrate concentrations being lower in June 2009 compared to previous years, especially past P16 (Figure 3.1). Silicate, which is associated with diatom growth and export, was strongly drawn down along Line P and nearly depleted at P26 in August 2008 (Figure 3.1). Silicate concentrations were depleted around P20 in August 2007 and between P16 and P20 in February 2007, all of which suggests the existence of a diatom bloom. In general, however, the average seasonal variability of nitrate and silicate concentrations along Line P is much greater at stations east of P4 (more coastal), a result of more variable coastal processes such as seasonal upwelling, tidal mixing and river discharge affecting nutrient concentration (*Whitney et al.*, 2005), whereas at stations west of P4, nutrients are primarily affected by offshore transport of coastal waters via mesoscale eddies or gyre recirculation, processes which can only occur under special circumstances (*Whitney et al.*, 2005).

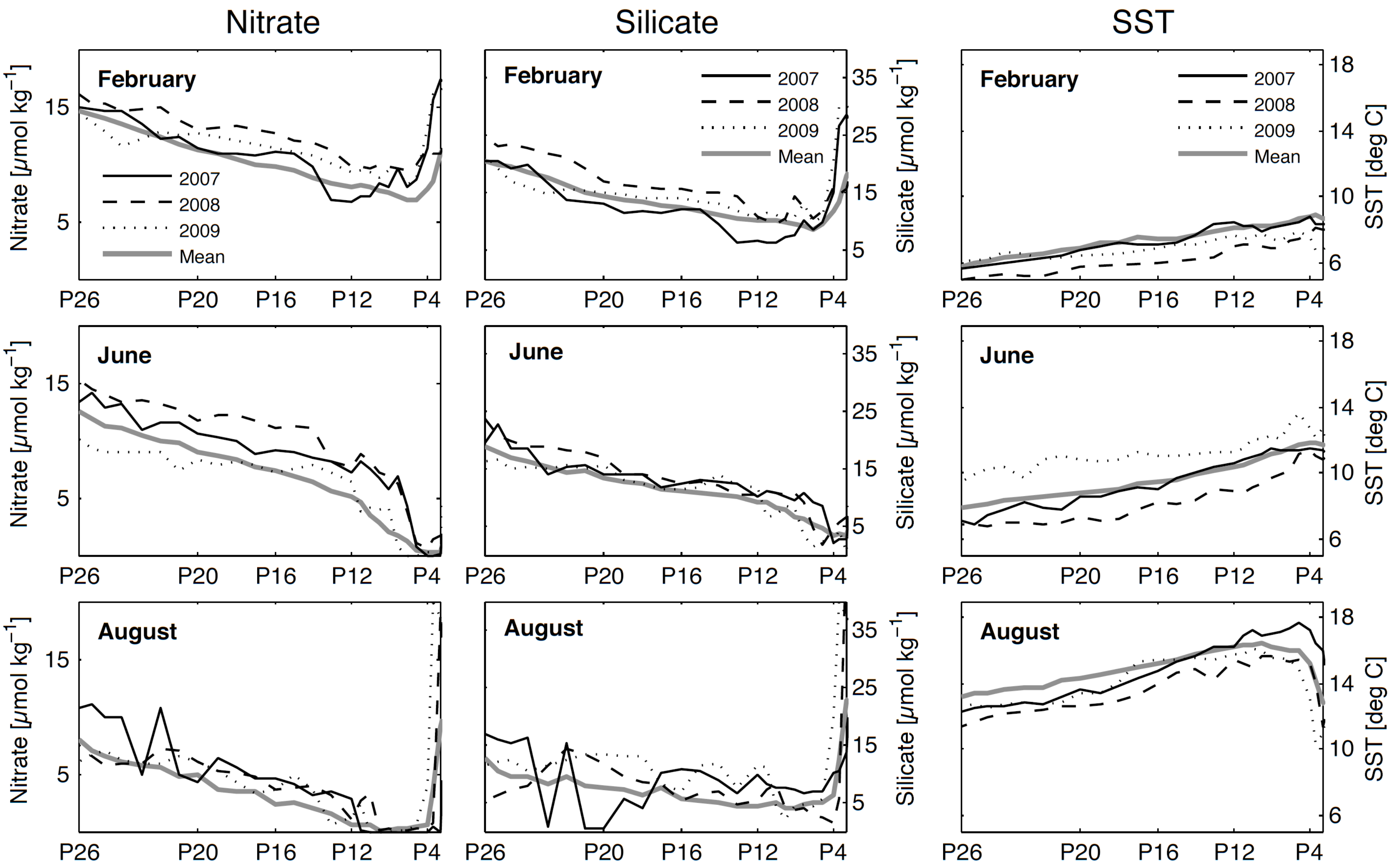

Figure 3.1. Sea surface nitrate, silicate and temperature measured along Line P (samples collected from the underway system. Sample collection and analysis by the Institute of Ocean Sciences: Fisheries and Oceans Canada, Sidney, BC) for the nine cruises between 2007 and 2009. The mean represents an average for either February, June or August for each measurement from 1988 to 2009.

3.1.2. Productivity regimes and variability

Based on both my *in-situ* and incubation-based measurements of productivity, Line P can be split into two productivity regimes: coastal and offshore. Rates measured at the offshore stations (P12-P26) were generally lower and exhibited less seasonal and interannual variability compared to the more coastal station (P4). Yet, despite the generally low offshore variability, I observed two high productivity events where measured rates offshore were significantly higher than those measured during previous studies or similar time periods in this study. In general, however, measurements of productivity throughout this study were comparable to, though on the lower end of, rates measured during previous studies.

3.1.3. Net Community Production (NCP) from O_2/Ar measurements

Apart from the most coastal station (P4), my estimates of NCP along Line P in June and August showed little temporal variation from 2007 to 2009 (Figure 3.2). I do not calculate NCP in February 2007 – 2009 (apart from the high productivity event discussed in Section 3.3.1), as I am unable to constrain NCP during these cruises due to high diapycnal mixing fluxes. In June, I estimate the error in my NCP measurements as ±14%, mainly a result of the uncertainty in the gas exchange coefficient. In August, an additional bias of +5-10% results from diapycnal mixing and higher O_2 concentrations below the mixed layer. Unlike Whitney et al. (1998), who separate Line P into three regions (Coastal, Transition and Offshore) according to macronutrient supply and utilization, the mean June-August NCP measured for the 2007-2009 period (Table 3.1) suggests only two productivity regimes: coastal (P4) and offshore (P12 – P26).

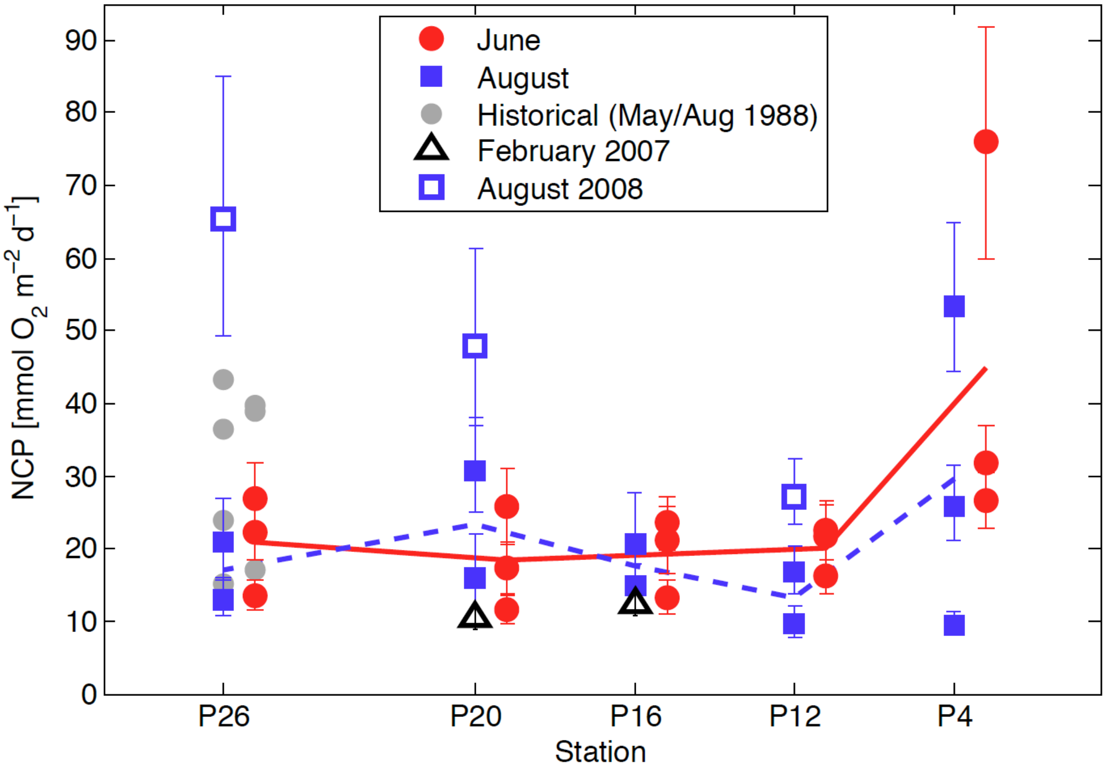

Figure 3.2. Net Community Production along Line P derived from O_2/Ar measurements in the mixed layer. Open points indicate measurements taken during high productivity events. Points for each station are slightly offset to avoid overlap of points.

Table 3.1. Means of O_2/Ar based NCP along Line P.

	Net Community O_2 Production (mmol O_2/m^2/d)	
	Coastal (P4)	**Offshore (P12 – P26)**
Interannual Means (2007 – 2009)		
June	44.4 ± 26.5 (n = 3)[*]	19.7 ± 5.1 (n = 12)
August	26.2 ± 22.4 (n = 2)	17.8 ± 6.4 (n = 8)
High Productivity Events		
February 2007		11.4 ± 1.5 (n = 2)
August 2008	25.7 (n = 1)	46.9 ± 19.2 (n = 3)[†]
Re-calculated historical data (from Quay et al., 1993)		
	Stn 'R' (53°N, 145°W)	**P26 (50°N, 145°W)**
May 1988		31.9 ± 12.9 (n = 3)
August 1988	19.5 ± 6.1 (n = 2)	39.8 ± 4.8 (n = 2)[†]

Paired *t*-tests were used to test for significant differences between seasons in each region (Coastal, Transition, Offshore). Unpaired *t*-tests were used to test for significant differences between stations in each season and between seasonal means and either high productivity events or recalculated historical data.
* denotes statistically significant difference between regions ($p < 0.05$).
† denotes statistically significant difference from the offshore August 2007/09 mean ($p < 0.005$)

Rates of O_2/Ar based NCP at P4 had the most interannual variability, with particularly high values measured in June 2007 (76 mmol O_2 m^{-2} d^{-1}) and August 2009 (53 mmol O_2 m^{-2} d^{-1}) (Figure 3.2). Coastal waters along southern Vancouver Island are highly productive due to winds from the north driving coastal upwelling from April to September and bringing high-nutrient/low-oxygen waters to the surface, enhancing offshore transport of these nutrient rich waters (*Ianson et al.*, 2003; *Whitney et al.*, 2005). A high degree of positive correlation ($R^2 > 0.83$) exists between the June and August estimates of NCP at P4 and a mean of the daily Upwelling Index (Pacific Fisheries and Environmental Laboratory, NOAA) at 48˚N, 125˚W. Though a strong correlation subsists if the upwelling index is averaged between the sampling date and anywhere from 5 to 10 days prior, the 10-day mean exhibited the strongest correlation ($R^2 = 0.90$, $p < 0.01$; Figure 3.3).

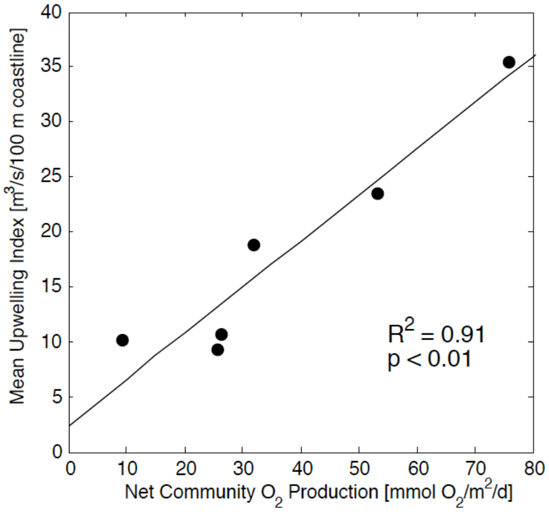

Figure 3.3. Correlation between Net Community O_2 Production at P4 and the Bakun Upwelling Index at 48˚N, 125˚W in the spring and summer 2007-2009. The solid line is a linear regression.

This positive correlation between O_2/Ar NCP and the Upwelling Index may seem surprising, not only given the temporal and spatial variability in upwelling, but also because newly upwelled waters should have low O_2 content. The correlation we observe must be a result of productivity fuelled by the offshore transport of upwelled nutrients over the shelf or brouth to the surface by tidal mixing in the Strait of Juan de Fuca (*Whitney et al.*, 2005). The lag found in the correlation between NCP and Upwelling Index (5-10 days) is similar to the residence time of O2 in the mixed layer with respect to air-sea gas exchange.

The mean June – August NCP for the offshore stations was 18.4 ± 5.1 mmol O_2 m^{-2} d^{-1} (n = 20) for 2007 – 2009 (excluding August 2008), showing little spatial or seasonal variation during these months. The two offshore high productivity events (February 2007 and August 2008 are excluded from the offshore mean, leaving discussion of these results to Section 3.3. I compare my results to those of *Emerson et al.* (1991), who reported the only previous measurements of *in-situ* NCP made in this region. *Emerson et al.* (1991) estimated NCP using an O_2 mass balance and measurements of the $O_2/N_2/Ar$ ratios in June/September 1987 and May/August 1988 at stations P26 and R (53˚N, 145˚W). Using the raw O_2/Ar ratios and temperature and salinity measurements in the mixed layer (from *Quay et al.*, 1993), I recalculated NCP for May/August 1988 using my methods and 6-h wind speeds derived from NCEP reanalysis data (provided by the NOAA/OAR/ERSL PSD, Boulder, Colorado, USA: http://www.esrl.noaa.gov/psd) (Table 3.1). These recalculated estimates of NCP are nearly twice those reported by *Emerson et al.* (1991), with most of this difference resulting from the much higher gas exchange coefficient I calculate (4.6 m d^{-1}) compared to what *Emerson et al.* (1991) calculate (2.3 m d^{-1}) using the parameterization of *Liss and Merlivat* (1986), ship-board wind speeds and a 5-day even weighted mean. The recalculated rates for NCP at Station R in August 1988 were nearly identical to NCP in June and August 2007-2009. However, rates measured in May/Aug 1988 at P26 were nearly twice those measured in this study (Figure 3.2), though this difference was only significant for August 1988 (Table 3.1).

3.1.4. Incubation-based estimates of productivity: $^{13}C/^{15}N$ dual-tracer incubations

My measurements of the depth-integrated (100 – 1% light levels) rates of carbon (C-PP), nitrate (New-P) and ammonium (Regen-P) uptake in 2009 were of similar magnitude and exhibited similar weak seasonal and spatial trends to previous studies along Line P (Figure 3.4). In August 2008, rates of New-P and Regen-P at P26 were nearly ten times those measured the following August, though C-PP did not show a similar difference (Figure 3.4, open points). Like O_2/Ar NCP, I leave discussion of these results to Section 3.3.2.

Incubation based results are compared with previous studies conducted using similar tracers (Table 1.2) and incubation times (24 h) either along Line P as part of the Canadian JGOFS program or at P26 as part of the SUPER program. For the CJGOFS data, discrete depth measurements of ^{14}C-based C-PP (*Boyd*, 2000) were integrated to the bottom of the euphotic zone for those rates not included in *Boyd and Harrison* (1999). $^{15}NO_3^-$ based New-P (*Varela et al.*, 2000) was integrated over the depth of the euphotic zone for the period between 1995 – 1997, because previously published results (*Peña and Varela*, 2007) were integrated only to 15 m depth. *Varela and Harrison* (1999) reported integrated rates for $^{15}NO_3^-$ based New-P to the bottom of the euphotic zone for the period between 1992 - 1994. Reported measurements of C-PP (*Welschmeyer et al.*, 1993) and

New-P (*Emerson et al.*, 1993; *Wheeler*, 1993) for May and August 1988 at P26 and Station R (53˚N, 145˚W) during the SUPER program were already integrated to the bottom of the euphotic zone. Though measurements of C-PP have been made at P26 since the early 1960s (*Wong et al.*, 1995), I compare my results only to the measurements during CJGOFS and the SUPER program because as the main objective of this study is to compare different productivity methods, and these programs measured rates of New-P and Regen-P (and during the SUPER program O_2/Ar NCP), often concurrently with C-PP measurements.

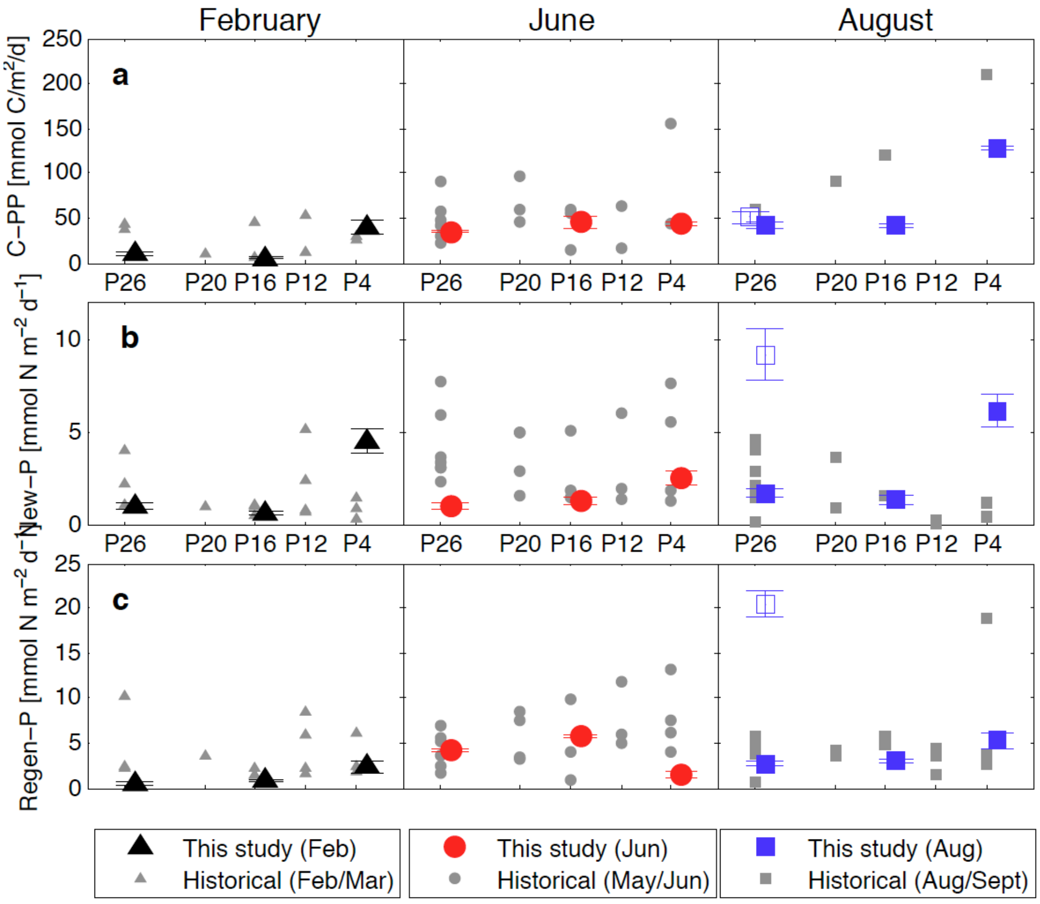

Figure 3.4. Incubation-based estimates of (a) ^{13}C-based C-PP, (b) $^{15}NO_3^-$ based New-P and (c) $^{15}NH_4^+$ based Regen-P in February (left panels), June (middle panels) and August (right panels) 2009. Open points indicate measurements at P26 in August 2008. Grey points mark historical data collected at P26 in May/Aug 1988 and along Line P from Sept 1992 – Jun 1997 (see Table 1.2 for sources).

In general, rates of C-PP from this study increased from February to June and, like NCP, were similar between June and August at the offshore stations (Figure 3.4a). P4 was the most variable, with the highest rate measured in August 2009, though C-PP was similar at P4, P16 and P26 in June (Figure 3.4a, middle panel). As noted for NCP, upwelling favourable winds and the subsequent offshore transport of upwelled nutrients significantly influences P4 (*Whitney et al.*, 2005), which creates both spatial and temporal variability. Rates of C-PP measured during this study were comparable to previous studies at P26 (May/Aug 1988: *Welschmeyer et al.*, 1993) and along Line P (Sept 1992 – Jun 1997: *Boyd et al.*, 1999; *Boyd*, 2000) conducted during similar months (Feb/Mar, May/Jun and Aug/Sept).

Similar seasonal and spatial trends were observed for the $^{15}NO_3^-$ based New-P measured during this study as for C-PP (Figure 3.4b). Again, measurements of New-P at P4 were the most seasonally variable, with the maximum productivity measured in August 2009. Differences in New-P at P4 may be related to increased upwelling (which brings high-nutrient/low-oxygen water to the surface) given that New-P rates were higher when an upwelling event occurred only a few days prior to sampling (Figure 3.5). Similar to *Peña and Varela* (2007), there was a small increase in New-P from February to August at the offshore stations (P16/P26). Rates of New-P were at the lower end of the range but comparable to New-P measured during previous studies at P26 and along Line P (Table 1.2 , Figure 3.4).

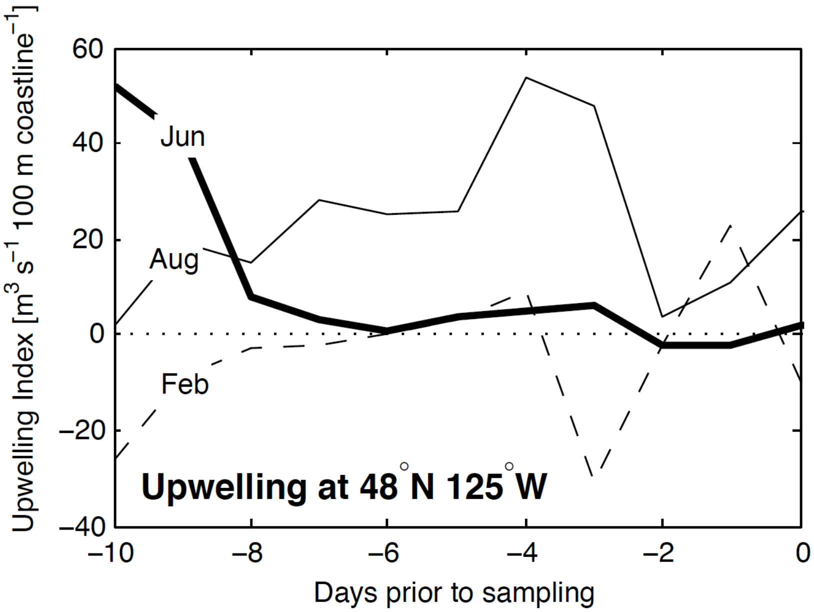

Figure 3.5. Bakun Coastal Upwelling Index at 48˚N 125˚W (on the southwest coast of Vancouver Island) for February, June and August 2009. Sampling date is 0. Calculated by NOAA Pacific Fisheries Environmental Laboratory (PFEL)

Though measurements of $^{15}NH_4^+$ based regenerated production (Regen-P) from this study were more seasonally variable compared to the other methods, differences between P16 and P26 were still small in both June and August (Figure 3.4c). Regen-P was highest in June at P16 and P26, but remained relatively low and constant at P4 for all three 2009 cruises. Overall, rates of Regen-P were within the range or slightly lower than rates measured during previous studies (Figure 3.4c). Regen-P was greater than New-P at P16 and P26 in June and August; however, at P4, New-P always exceeded Regen-P. In contrast, *Varela and Harrison* (1999) found that rates of NH_4^+ based Regen-P exceeded that of New-P in all seasons and at all stations sampled along Line P for the period 1992 – 1994. *Peña and Varela* (2007), however, observed several instances where New-P exceeded NH_4^+ based Regen-P during 1995 – 1997. Estimates of NH_4^+ based Regen-P are not corrected for isotope dilution, which occurs when regenerative processes (such as heterotrophic bacterial respiration) return unlabelled (^{14}N) ammonium back into the dissolved pool. This lowers the atom % of dissolved $^{15}NH_4^+$, causing a bias in my measurements towards low Regen-P. Isotope dilution likely has more of an effect at the coastal station (e.g. *Kanda et al.*, 1987). *Wheeler et al.* (1989) found that, at P26, the atom % $^{15}NH_4^+$ decreased from 96 to 71% during the first 24 hours of incubation with regeneration occurring only at night. As rates of NH_4^+ based Regen-P measured during CJGOFS (*Varela and Harrison*, 1999; *Peña and Varela*, 2007) were also not corrected for isotope dilution, it is not expected that this process would account for any significant differences between this study and theirs, though it may have an effect on calculation of the f_N ratio.

Using the measurements of new and regenerated production, I calculate a mean (±SD) f_N ratio, which represents the ratio of new production (New-P) to total production (New-P + Regen-P), of 0.43 ± 0.18 (n = 9) for Feb-Aug 2009. I underestimate regenerated production (and thus total production) and overestimate f_N by not including urea-based primary production (urea-P) (Table 3.2), another form of regenerated nitrogen taken up by phytoplankton. *Varela and Harrison* (1999) found excluding urea-P overestimated f_N by an average of 24%. The f_N ratio calculated for this study is higher, but not significantly different (*t-test*, $P > 0.10$) from the average f_N-ratio calculated (0.34 ± 0.19, n = 51) using only the New-P and NH_4-based Regen-P rates measured during CJGOFS (*Varela et al.*, 2000).

Table 3.2. Physical and biological processes affecting productivity measurements

Process	**Overestimate**	**Underestimate**
O_2/Ar based NCP		
Large O_2, Ar gradients at the base of the mixed layer	O_2/Ar NCP (negative gradients)	O_2/Ar NCP (positive gradients)
Gas Exchange parameterization	O_2/Ar	O_2/Ar
Nitrogen based		
Isotope dilution		Regen-P
Heterotrophic Bacterial uptake of DIN in conjunction with retention of bacterial biomass on filter	New-P, Regen-P	
Uptake of other regenerated N sources	f_N-ratio	Regen-P, Total N
Nitrification	New-P	Regen-P
Other new sources of N		New-P
Carbon based		
Selective respiration of the new POC pool	NPP (from C-PP)	GPP (from C-PP)
DOC production/exudation		C-PP

3.2. Method Comparisons

3.2.1. Net Community Production vs. New Production

O_2/Ar based NCP and $^{15}NO_3^-$-based New-P measure the rates of different processes (Table 1.1), but averaged over large enough temporal and spatial scales, or at true steady state, these rates should yield equivalent results (*Falkowski et al.*, 2003). Typically, this equivalence is only expected on seasonal to annual time scales, especially in regions like the macronutrient-limited subtropical gyres, where there is significant short-term variability in productivity (*Karl et al.*, 2003). In the subarctic North Pacific, however, the decrease in nitrate over the course of the spring/summer growing season (Mar-Sept) at the offshore stations (P12 – P26) along Line P is slow and steady (*Peña and Varela*, 2007) meaning that rates of New-P are more likely to represent the long-term mean. Rates of nitrate drawdown are steadier in this offshore region because iron-limitation inhibits total depletion of macronutrients in the surface waters.

A very strong correlation (r = 0.91) was found between estimates of new (New-P) and net community productivity (O_2/Ar NCP) at P4, P16 and P26 in Jun-Aug 2009 and at P26 in Aug 2008 and May-Aug 1988 (Figure 3.6). The average NCP:New-P ratio for these measurements was 1.3 ± 0.4 (mol C:mol C ± SD, n = 14) and a Wilcoxon rank sum non-parametric test indicates there is less than 30% probability that New-P and NCP are from different distributions. There is no significant difference (*t-test*, P > 0.35) between the coastal (1.1 ± 0.1, n = 2) and offshore stations (1.4 ± 0.4, n = 5) for the 2008/09 period, nor is there any difference between the NCP:New-P ratio from just this study (1.3 ± 0.4, n = 7) to that of the recalculated NCP:New-P during May/August 1988 (1.3 ± 0.5, n = 7). Rates of O_2/Ar NCP and New-P were much higher during May/Aug 1988 compared to Jun/Aug 2009 (Table 3.1), indicating that variability in NCP and New-P does not affect the ratio of these rates. That I see no significant difference in the NCP:New-P ratio at the coastal station or even during the high productivity event in August 2008 also suggests that this relationship is not affected by episodic bursts of productivity. *Emerson et al.* (1993) found a significant difference between the rates of NCP and New-P for August 1988 that I do not find based on my recalculation of 1988 NCP. The relationship between NCP and New-P is robust both temporally and over the range of rates measured (Figure 3.6).

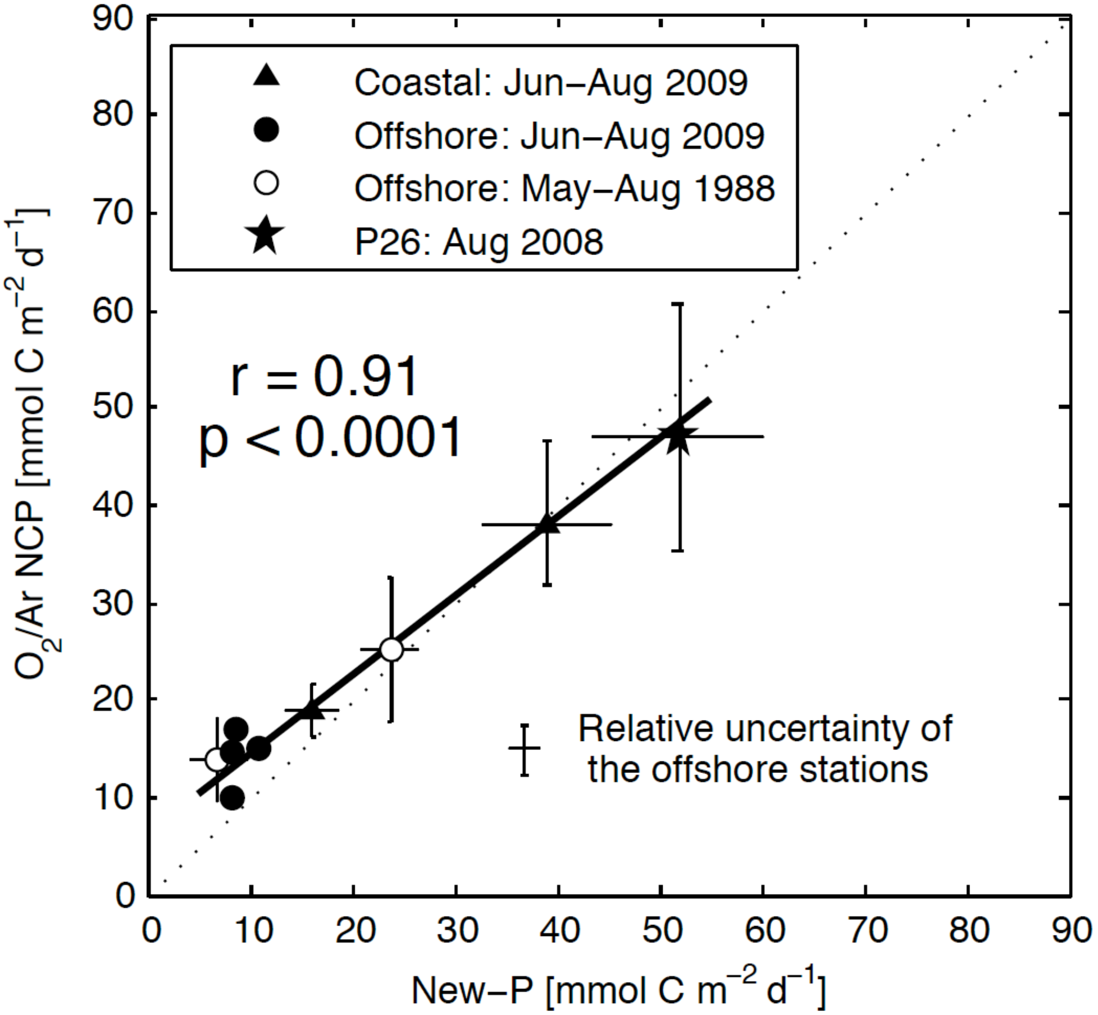

Figure 3.6. Comparison between Net Community Production from measurements of O_2/Ar in the mixed layer and 24-h $^{15}NO_3^-$ based new production (New-P) throughout the euphotic zone. Measurements made in February are not included as NCP cannot be constrained due to diapycnal mixing. Error bars on historical data represent ±1 SD of the mean. The dotted line has a slope of 1. The thick black line represents a linear regression through the data with the equation: NCP = 0.81 * New-P + 6.41 ($R^2 = 0.84$) A regression forced through the origin gives the relationship NCP = 1.3(±0.4)*New-P.

This relationship is consistent in other regions of the oceans. *Reuer et al.* (2007) reported concurrent measurements of O_2/Ar NCP with New-P from 24-h incubations in the Southern Ocean, another major HNLC region. Though the mean rate of O_2/Ar NCP they measured in the subantarctic and polar frontal zones is higher compared to this study (average of 39.2 mmol O_2 m^{-2} d^{-1} for 46˚S-60˚S compared to 18.4 mmol O_2 m^{-2} d^{-1} for this study), the mean NCP:New-P ratio (1.4 ± 0.3, n = 2) was not significantly different ($p > 0.74$) from my relationship for the subarctic North Pacific.

The significance of this nearly equivalent relationship of NCP and New-P on the order of a day is even more extraordinary considering all of the processes and methodological uncertainties that affect measurements of O_2/Ar NCP and New-P. As previously discussed, the dominant uncertainties in my estimates of NCP from O_2/Ar ratios are from the parameterization of gas exchange and potential bias due to diapycnal mixing. I underestimate NCP, which integrates over the mixed layer, relative to New-P, which is integrated over the euphotic zone, given that, between May and September, the depth of the seasonal mixed layer is generally shallower than the euphotic zone. However, considering that my discrete incubation based rates decrease with depth, with >60% of the incubation-based productivity occurring in the mixed layer, the magnitude of this bias is likely much smaller than the uncertainty in the mean NCP:New-P ratio. One potential source of bias for both O_2/Ar NCP and $^{15}NO_3^-$ based New-P results from using stoichiometric ratios of photosynthesis and respiration to convert these rates to carbon-based units. I minimize this uncertainty for New-P by converting my discrete rates using the in-bottle PC:PN ratio, though the mean C:N ratio (7.0 ± 1.0, n = 48) for my incubations did not deviate far from Redfield (C:N = 6.6).

Heterotrophic bacterial uptake of NO_3^- and oxidation of NH_4^+ into NO_3^- (nitrification) in the euphotic zone can both bias New-P measurements high (Table 3.2). During May-Aug 1987-1988 at P26, bacterial uptake of labeled nitrate accounted for 5-60% of the total measured New-P *(Kirchman and Wheeler* 1998), causing an overestimate of new production if any bacterial biomass was retained on the GF/F filter. The degree of this overestimation should depend on both the abundance and activity of captured bacteria. Assuming that ≤50% of the bacterial biomass is retained on the filter (e.g., *Kirchman et al.*, 1994), this could cause a +16% bias in New-P, however, considering that bacterial specific growth rates along Line P were always lower than those of phytoplankton (*Varela and Harrison* 1999; *Sherry et al.*, 1999), this overestimation is probably smaller. In addition, *Kirchman et al.* (1990) found some evidence that heterotrophic bacteria at P26 may be limited by the supply of dissolved organic carbon. This may explain why rates of New-P are slightly greater than those of NCP during the August 2008 wide-scale phytoplankton bloom. My estimate of $^{15}NO_3^-$ based New-P could exceed NCP at this time if, as a result of the iron-mediated bloom (*Hamme et al.*, 2010), there was an increase in heterotrophic bacterial uptake of labeled NO_3^- in conjunction with either increased DOC concentrations from spring to summer (*Wong et al.*, 2002b) or increased turnover of the DOC pool (e.g. *Kirchman et al.*, 1991). Nitrification can occur within the euphotic zone and may account for about half of the nitrate consumed by growing phytoplankton (*Yool et al.*, 2007). If euphotic zone nitrification is important along Line P, New-P will reflect other sources of nitrate than from the deep ocean, leading to an overestimate of new production. The degree of this overestimation is dependant on the rates of nitrification in the euphotic zone. Previous studies have shown that nitrification rates are undetectable at the surface (where nitrifying bacteria are completely photoinhibited), but increase with depth (*Ward et al.*, 1982; *Dore and Karl*, 1996). Given that my discrete measurements of New-P decrease with depth, nitrification likely had little effect on my depth-integrated rates of New-P. In spite of all these potential uncertainties and biases that may affect estimates of NCP and New-P, I still find that the average NCP:New-P ratio is very close to one, further illustrating that the equivalence observed between NCP and New-P on very short time scales is robust both temporally and over a range of environmental conditions.

3.2.2. Net Community Production vs. Carbon Production

Net Community Production, which represents the amount of biologically produced carbon available for export, is an important part of the global carbon cycle, especially considering how rising atmospheric CO_2 levels may affect this process. However, productivity estimates in most regions of the world are dominated by measurements of ^{14}C-based C-PP, with relatively few measurements of NCP. Thus, identifying a relationship between NCP and C-PP would be valuable in allowing one to convert between these rates and obtain a better estimate of NCP when no direct measurements are available.

In June and August 2009, rates of NCP and ^{13}C-based C-PP along Line P were very strongly correlated ($r = 0.98$) compared to the correlation of the total dataset along Line P from May to August ($r = 0.80$), which includes measurements made during the SUPER program (Figure 3.7). The mean ratio of net community productivity (O_2/Ar NCP) to carbon-based primary productivity (C-PP) in 2009 was 0.35 ± 0.05 (mol C:mol C ± SD, $n = 6$), which is not significantly different ($p > 0.80$) from the mean f_N-ratio (0.37 ± 0.18, $n = 6$) calculated for the same period. Rates measured during the August 2008 bloom conditions were very different and are excluded from this comparison (Section 3.3.2).

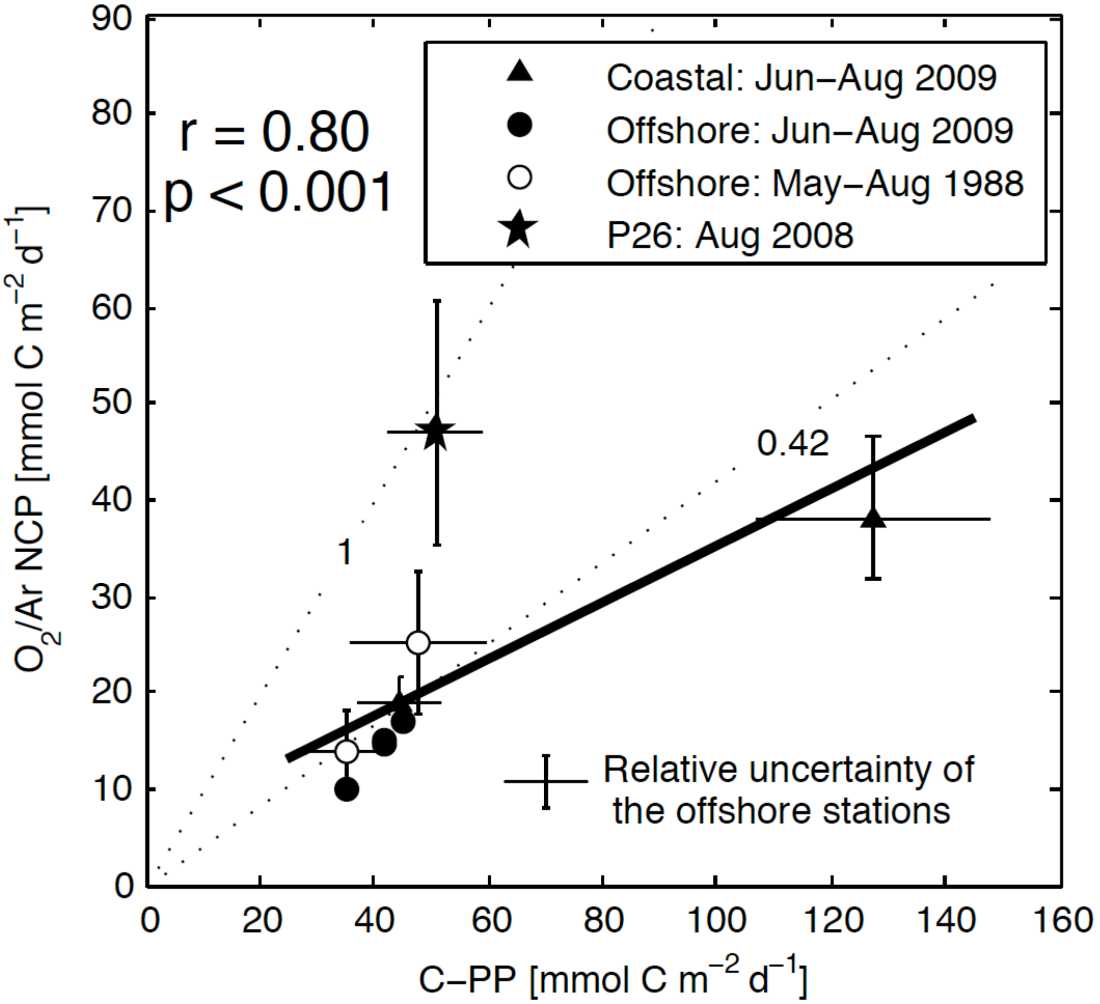

Figure 3.7. Comparison between O_2/Ar based Net Community Production in the mixed layer and ^{13}C-based primary productivity throughout the euphotic zone (C-PP) in June and August 2009 and ^{14}C-based C-PP in May and August 1988. Error bars on historical data represent ±1 SD of the mean. The August 2008 measurements are not included in the correlation. The solid black line represents a linear regression through the entire dataset (excluding August 2008) with the equation: C-PP = 0.29 * NCP + 5.91 ($R^2 = 0.64$) A regression forced through the origin gives the relationship NCP = 0.42(±0.11)*C-PP.

This comparison can be extended to include May and August 1988 as measurements of 24-h ^{14}C-based C-PP were made at P26 and Station R (*Welschmeyer et al.*, 1993) concurrently with the O_2/Ar NCP. I assume that estimates of carbon-based productivity are equivalent for 24-h ^{13}C and ^{14}C incubations (*Slawyk et al.*, 1984). The mean ratio of net community productivity (O_2/Ar NCP) to carbon-based primary productivity (C-PP) for both the Jun/Aug 2009 and May/Aug 1988 cruises was 0.42 ± 0.11 (n = 13), which, again, is not significantly different ($p > 0.38$) from the mean f_N-ratio for the same time periods (0.37 ± 0.17). Though rates of NCP and C-PP are strongly correlated ($r = 0.80$, Figure 3.7), stronger correlations exist if I consider 1988 and 2009 separately ($r = 0.88$ and 0.98 respectively), because NCP:C-PP ratios were significantly higher ($p < 0.05$) in 1988 (0.48 ± 0.11, n = 7) compared to 2009. Higher integrated chlorophyll concentrations in Aug 1988 at P26 (23.0 ± 5.4 mg m^{-3}) compared to station R (16.9 ± 2.8 mg m^{-3}) from *Welschmeyer et al,* (1993) suggest that P26 may have been sampled during a bloom event, raising the NCP:C-PP ratio in a manner similar to August 2008, though similar integrated chlorophyll concentrations were measured in August 2009 at P16 and P26 (21.1 ± 2.1 mg m^{-3}, chlorophyll *a* sample collection and analysis by the Institute of Ocean Sciences: Fisheries and Oceans Canada, Sidney, BC). The strong La Niña conditions during 1988 (*Hare and Mantua*, 2000; *Wong et al.*, 2007) may also have contributed to this difference; however, there is not enough data to elucidate if these differences arise from a long-term trend, interannual variability or simply from methodological differences between each study.

At Station ALOHA (23˚N 158˚W), *in-situ* mixed layer measurements of O_2/Ar NCP were compared with 12-h (dawn-dusk), incubation-based, 0-100 m integrated estimates of ^{14}C-based C-PP to yield a mean annual NCP to C-PP ratio of 0.24 ± 0.08 (*Juranek and Quay*, 2005; *Quay et al.*, 2010). My observed NCP:^{13}C-PP ratio along Line P was nearly twice this value, but the difference is comparable to the difference between the typical f-ratios observed in each region (~0.1 at ALOHA (*Karl*, 1999) and ~0.2 along Line P

(*Varela and Harrison* (1999), includes urea-based production). The difference may also partly result from differences in incubation time for the $^{13}C/^{14}C$ based measurements in each region.

The main difficulty with interpreting measurements of C-PP is determining, depending on incubation length, what kind of primary productivity the rates approximate (Table 1.1). There has been significant debate over whether ^{14}C (and ^{13}C) incubations estimate Gross Primary Production (GPP), Net Primary Production (NPP) or something in between and on what time-scales. The general consensus is that 24 hr incubations approximate a rate somewhere between GPP and NPP (*Marra*, 2009). In brief, once internal CO_2 is fixed by photosynthesis, it enters into an organic pool, a portion of which will be respired back to CO_2. If phytoplankton preferentially respire the newly fixed organic matter (with a higher isotopic enrichment) instead of older organic matter (with a lower isotopic composition) already present at the start of the incubation (e.g. the q factor of *Dring and Jewson*, 1982), and all or part of this 'new' CO_2 pool were excreted by the cell (*Williams and Lefévre*, 2008), respiration would reduce the isotopic composition of the 'bulk' organic matter captured at the end of incubation. In this case, measurements of C-PP would estimate rates somewhere between GPP and NPP.

The production and excretion of $DO^{13}C$ may also lead to underestimates of C-PP, though this bias will be reduced by the proportion taken up by bacteria that are subsequently retained on the filter (*Bjornsen*, 1988). One of the inherent assumptions in using the ^{13}C (or ^{14}C) based method is that $DO^{13}C$ ($DO^{14}C$) production is negligible. The commonly accepted range for labeled DOC production is 5-15% of measured C-PP (*Williams and Lefévre*, 2008), though some studies have reported a much larger proportion (e.g. 30-50%, *Karl et al.*, 1998). Considering that *Kirchman et al.* (1990) found evidence of DOC limitation on bacterial communities at P26, it seems likely that, under normal conditions, production of labelled DOC would not significantly affect my measurements of C-PP.

3.2.3. New Production vs. Carbon Production

I can extend my comparison of NCP and C-PP to include the Canadian JGOFS data (1992 – 1997) since, as shown in section 3.2.1, rates of NCP and New-P are approximately equivalent. Comparisons of New-P and C-PP in winter can also be included, as the incubation-based estimates are not directly affected by mixing across the thermocline. During CJGOFS, carbon and nitrogen incubations were conducted at all of the major stations along Line P during similar months as for this study, usually concurrently or within 1 day of each other.

Rates of new production and carbon-based production measured during SUPER, CJGOFS, and this study were strongly correlated (Figure 3.8, r = 0.82) for Feb-Sept, though a noticeable difference exists between the mean Feb/Mar and May-Sept New-P:C-PP ratios. Again, the estimates from August 2008 are excluded due to the anomalous biological state at this time (Section 3.3.2). The mean New-P:C-PP ratio for May-Sept (0.32 ± 0.16, n = 22) is equivalent to the mean May-Aug NCP:C-PP ratio if New-P is converted to NCP (NCP = 1.3 × New-P). In February and March, the mean New-P:C-PP ratio along Line P was highly variable (0.50 ± 0.25, n = 12) and larger than both the mean

May-Sept ratio and the mean f_N-ratio (0.35 ± 0.17). This variability may be the result of the relative depths of the mixed layer and euphotic zone. Unlike in spring and summer, where the euphotic zone depth always exceeds that of the mixed layer, strong winds and cooler temperatures in the winter mix the surface layer down to the permanent thermocline, exceeding the euphotic zone depth. New-P may be biased high during these periods, if there is significant nitrification occurring within the euphotic zone or mixed layer. Though the highest discrete rates of New-P occur at the surface in winter, regenerated nitrate produced below the euphotic zone but in the mixed layer will constitute a source of nitrate at the surface that is not “new”.

That the May-Sept New-P:C-PP ratio based on an extended dataset compares well to my May-Aug NCP:C-PP ratio (after converting New-P to NCP) further supports the conclusion that 0.42±0.25 is the most appropriate value to convert summertime measurements of C-PP to NCP in the subarctic NE Pacific. However, as the inclusion of the JGOFS data illustrates, the NCP:C-PP ratio is subject to significant seasonal and interannual variability, much more than the NCP:New-P ratio, so this conversion ratio should only be used with care. The error in the NCP:C-PP ratio is also much larger in comparison, again indicative of greater variability. I found that, unlike the NCP:New-P ratio, anomalous events significantly affect the NCP:C-PP ratio, as demonstrated by the measurements in August 2008. The mean NCP:C-PP ratio calculated for Feb-Mar (using New-P:C-PP and a conversion factor of 1.3) was 0.74±0.51, much higher than the May-Sept mean. Whether this is a result of overestimation of New-P or an actual difference in the mean ratio during this time of year is difficult to discern without constrained measurements of O_2/Ar NCP.

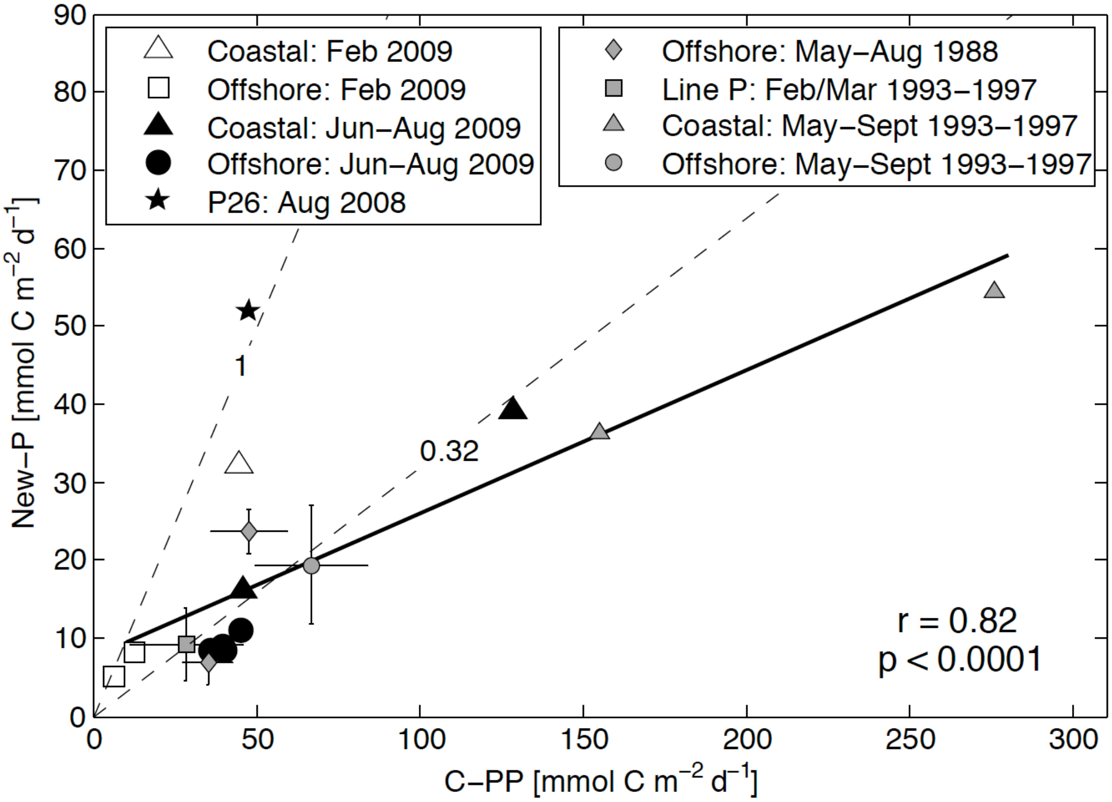

Figure 3.8. Comparison between $^{15}NO_3^-$ based new production (New-P) and ^{13}C-based primary production (C-PP) throughout the euphotic zone along Line P. A linear regression through the data from this study (excluding February) gives the relationship: C-PP = 0.33 * New-P – 3.33 (R^2 = 0.97). A linear regression through the February 2009 data gives the relationship: C-PP = 0.73 * New-P – 0.08 (R^2 = 0.998). Historical measurements along Line P (CJGOFS: 1992-1997) and at stations P26 and R (SUPER: 1988) are included when New-P and ^{14}C-based C-PP were measured concurrently or within 1 day of the other. Historical offshore and Feb/Mar values are represented as mean rates (error bars are ±1 SD). A linear regression through the entire data set for May to September gives the relationship: C-PP = 0.18 * New-P + 7.52 (R^2 = 0.68) represented by the thick black line. A regression forced through the origin for this time period gives the relationship C-PP = 0.32(±0.16)*New-P. A linear regression through all the February to March data gives the relationship: C-PP = 0.34 * New-P + 1.90 (R^2 = 0.40). Rates measured in August 2008 are not included in the correlations or regressions.

3.2.4. Net Community Production vs. other estimates of New Production

Though I used my rates of $^{15}NO_3^-$ based New-P to compare with NCP, I also measured ammonium and carbon uptake rates, which I could use to determine carbon-based new production by scaling my measurements of C-PP using the f_N-ratio. There are, however, several processes that affect estimates of either C-PP (Section 3.2.2), Regen-P or the f_N

ratio, which complicate the interpretation of these rates and thus a calculation of new production based on these quantities.

Measurements of Regen-P are affected mainly by heterotrophic bacterial uptake of $^{15}NH_4^+$ (similar to nitrate) and by isotope dilution (Table 5). Like New-P with labeled nitrate, *Kirchman and Wheeler* (1998) found that bacterial uptake of labeled ammonium accounted for 5-40% of the total measured Regen-PP. I overestimate Regen-P if any significant fraction of the bacterial biomass was retained on the filter, though this would depend on the abundance and activity of the captured bacteria. Heterotrophic bacteria also contribute to isotope dilution, which occurs when regenerative processes (such as heterotrophic bacterial respiration) return unlabelled (^{14}N) ammonium back into the dissolved pool. This lowers the atom % $^{15}NH_4^+$ causing an underestimation of NH_4-PP.

Using the f_N ratio and C-PP to calculate new production also depends on the assumption that total production from nitrogen based measurements (Total-P) is equivalent to production measured by C-PP. However, as I did not measure urea-based production, I underestimate Total-P and thus, overestimate the f_N-ratio. I show in Section 3.2.1 that rates of NCP and New-P are approximately equivalent indicating that New-P represents NPP less autotrophic and heterotrophic respiration (Table 1.1). If I assume that Regen-P is equivalent to the rate of heterotrophic respiration (*Williams*, 1993), then Total-P (New-P + Regen-P) should be equivalent to NCP + heterotrophic respiration, or NPP. If I assume that my measurements of 24 h C-PP incubations estimate a rate somewhere between GPP and NPP (Section 3.2.2; *Marra*, 2009), I could significantly overestimate new production since I are overestimating both the f_N ratio and NPP. Thus, I only compare my estimates of O_2/Ar NCP to my $^{15}NO_3^-$ based New-P.

3.3. High Productivity Events

Though I generally observed low interannual variability in NCP offshore along Line P in 2007 – 2009, this iron-limited HNLC region is often subject to episodic high productivity events evidenced by higher chlorophyll *a* concentrations (e.g. *Parsons and Lalli*, 1988) attributed to periodic iron inputs (*Boyd et al.*, 1998). In my 3-years of O_2/Ar measurements, I observed two high productivity events (unfilled markers in Figure 3.2 and Figure 3.4), in February 2007 at P16 and P20 and in August 2008 at P12-P26 (*Hamme et al.*, 2010).

3.3.1. Reducing the light limitation: February 2007

In February 2007, productivity and chlorophyll *a* concentrations at stations P16 and P20 were approximately twice their mean winter values. Mixed layer ΔO_2/Ar at stations P16 and P20 were supersaturated, with calculated NCP at the low end of measurements during June or August (Table 3.1, Figure 3.2), but about twice the rate of New-P measured at P16 in February 2009 (Figure 3.4). Unlike the usual February case along Line P, dissolved O_2 gradients below the mixed layer in February 2007 were very small (Figure 3.9), such that diapycnal mixing fluxes were negligible and NCP could be constrained by a simple mass balance. Mean surface chlorophyll *a* concentrations between P16 and P20 in February 2007 (0.55 ± 0.13 mg m^{-3}, n = 5) were nearly twice the 1989 – 2006 wintertime average (0.31 ± 0.02 mg m^{-3}, n = 70), a significant difference ($P < 0.0001$) (Figure 3.10; chlorophyll *a* sample collection and analysis by the Institute of Ocean Sciences: Fisheries and Oceans Canada, Sidney, BC).

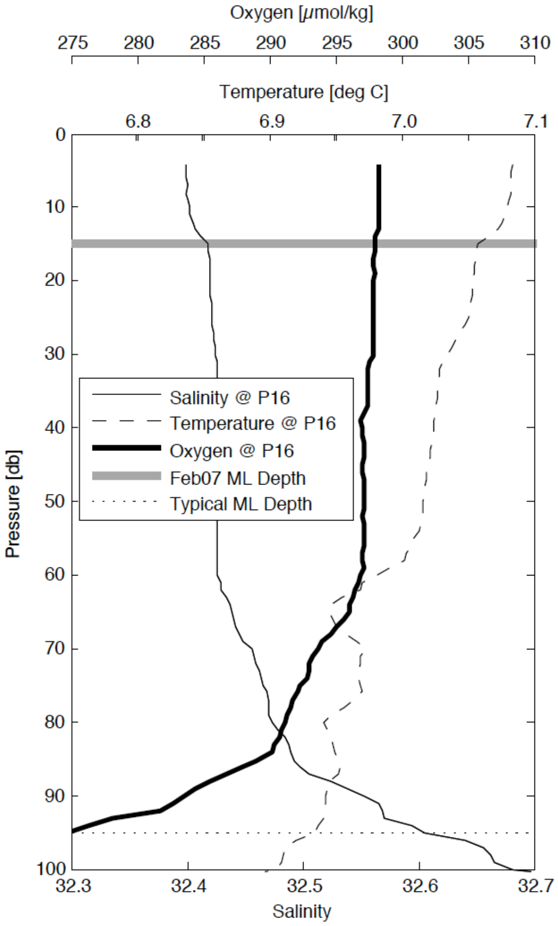

Figure 3.9. Depth profiles of Temperature, Salinity and Oxygen at P16 in February 2007. The thick grey line indicates the depth of precipitation-induced mixed layer in February 2007 (15 m) and the small dotted line the typical depth of the winter mixed layer at P16 (95 m).

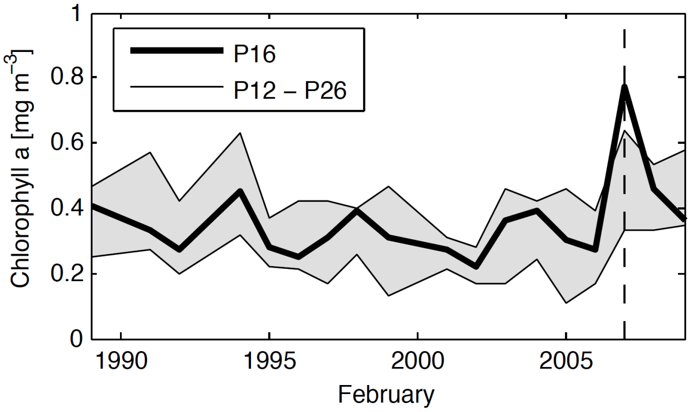

Figure 3.10. Time series of wintertime surface chlorophyll a concentrations at P16 (thick black line) with the range of chlorophyll a concentrations measured from P12 – P26 (greyed area). The vertical dashed line indicates the timing of the high productivity event.

A comparison of the location of these high productivity measurements with the location of eddies in the region indicate that an anticyclonic eddy was not responsible for this event. Instead, ancillary data show that these increases in NCP and chlorophyll *a* were likely due to a relief of light and possibly iron limitation on the phytoplankton, a result of rain-induced stratification between stations P16 and P20 in the days leading up to sampling. At these stations, the stratified surface waters were warmer and fresher (Figure 3.9). Prior to sampling, the NCEP/NCAR mean daily precipitation rate was significantly higher in the region surrounding stations P16 and P20 compared to the surrounding area (Figure 3.11). Increased precipitation is also supported by high precipitation rate (Figure 3.12a) and a drop in atmospheric pressure recorded at a Canadian NOMAD buoy located near P16 (Buoy C46036, 48˚19N 133˚57W, data maintained by Integrated Science Data Management (ISDM), Fisheries and Oceans Canada) (Figure 3.12b). Lower wind speeds observed prior to sampling (Figure 3.12c) would have helped to maintain the new stratification and shallower mixed layer.

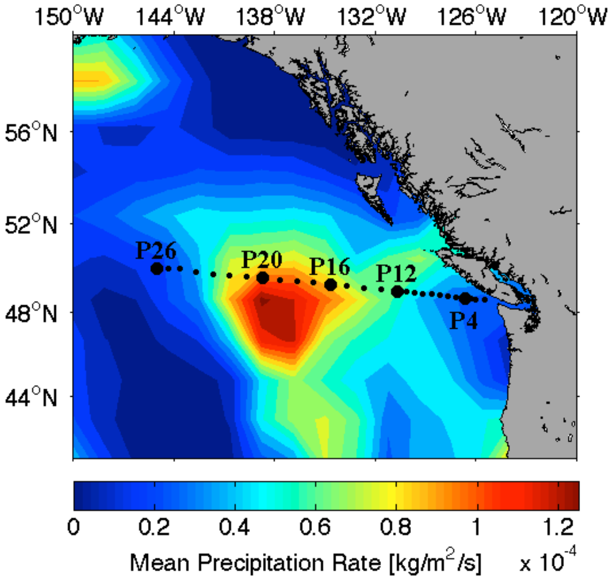

Figure 3.11. Mean daily precipitation rate (in kg m^2 s^{-1}) averaged between February 5 – 9, 2007 (P16/P20 sampling occurred February 11-12, 2007) from NCEP/NCAR reanalysis data.

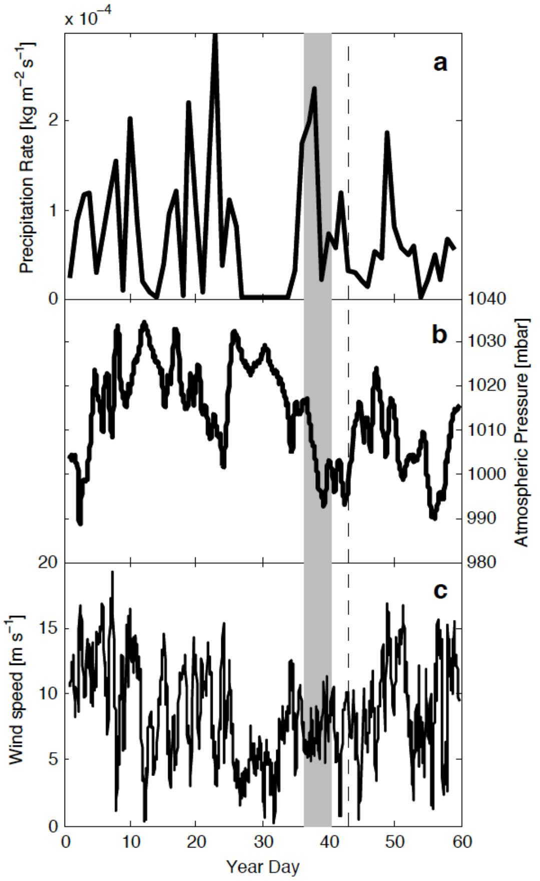

Figure 3.12. Atmospheric data near P16 for the period between January 1 – February 28, 2007. (a) Mean daily precipitation rate from NCEP/NCAR reanalysis data (b) Atmospheric pressure measured by Canadian NOMAD buoy C46036 (located at 48°21'9" N 133°57'0" W) (c) Wind speed measured by Canadian NOMAD buoy C46036. The shaded grey lines indicate the period averaged in **Figure 3.11**. The dashed vertical line indicates the time of sampling at P16.

In winter, phytoplankton communities at the offshore stations along Line P (typically P16 and beyond) are limited by both light and iron due to a decrease in solar irradiance, increased mixed layer depth, and, as a result of the light limitation, increased cellular demand for iron by the phytoplankton (*Maldonado et al.*, 1999). Thus, the temporary stratification of the surface waters induced by increased precipitation in February 2007 could have relieved the light stress on the phytoplankton since the mixed layer depth (15 m) was much shallower than the euphotic zone (75 m). The increased precipitation may also have facilitated an input of iron through wet deposition of iron-rich dust particles from the atmosphere (*Jickells and Spokes*, 2001), thus potentially relieving both light and iron limitation on the phytoplankton. The precipitation-induced stratification also allowed us to constrain NCP in this special February case, since the O_2 gradients below the newly stratified, shallower mixed layer were extremely small (Figure 3.9).

Two to seven days passed between the precipitation event and when the samples were collected, which agrees well with a potential stratification-induced event. *Maldonado et al.* (1999) observed that phytoplankton samples collected from P26 in winter, that were exposed to high light levels during a 7-day on-deck incubation, experienced a 20-fold increase in carbon fixation rates by day 3 and a measurable increase in chlorophyll *a* concentrations between days 3 and 7. This increase was even more pronounced when samples exposed to high light levels were also enriched with iron. This timing fits well with my higher measurements of NCP, especially considering that the O_2/Ar based method estimates a rate for NCP integrated over the residence time of O_2/Ar in the mixed layer (~7 days after the mixed layer shoals). That there is also a significant increase in the chlorophyll *a* concentrations suggests that I sampled stations P16 and P20 at least three days after the bloom initiated.

3.3.2. Wide-scale iron fertilization: August 2008

In 2008, the August 8-9 eruption of Kasatochi volcano in the Aleutian Islands may have fueled a wide-scale iron fertilization and anomalous plankton bloom in the subarctic Northeast Pacific and drove biological productivity to rates nearly three-times their normal values (Table 3.1; Figure 3.2; Figure 3.4). Evidence in support of this natural iron fertilization by volcanic ash deposition is discussed in detail in *Hamme et al.* (2010). I briefly summarize their findings. The volcanic ash was caught in a forming low-pressure system and transported southeast of the volcano and then farther to the north and east. Particle transport models based on prevailing winds indicate that the ash was likely deposited along Line P on August 11-12, 2008. Satellite chlorophyll levels were the highest ever recorded by satellite in the wider region, while changes in pCO_2 and pH of the surface water measured by the mooring at P26 established that the bloom initiated about two days after ash deposition. My measurements of O_2/Ar NCP, included in *Hamme et al* (2010), were 2-3 times greater at P20 and P26 than the mean August 2007/09 measurements for these stations.

Compared to my significantly higher offshore measurements, NCP at the inshore stations (P4/P12, Table 3.1) were either similar (at P4) or only slightly higher (at P12) than the August 2007/09 mean, whereas mean surface (0 – 15 m) chlorophyll concentrations at P12 were nearly 5 times higher in August 2008 (1.17 ± 0.22 mg m^{-3}, n = 4) compared to August 07/09 (0.25 ± 0.01 mg m^{-3}, n = 8). Though the waters east of P16 do not typically show signs of iron stress (*La Roche et al.*, 1996), iron measurements made as part of the Line P program in June 2008 show that surface iron concentrations at P12 were similar to the stations further offshore and much lower than those measured at P4 (K. Johnson, personal communication). It seems likely that transported volcanic ash may have fueled the increased productivity I observe (Table 3.1) given that (1) particle model studies of the ash dispersal (*Hamme et al.*, 2010) indicate that deposition of volcanic ash would have occurred at most 4-5 days prior to my sample collection at P12, (2) both *in-situ* (*Boyd et al.*, 2004) and incubation-based (*Boyd et al.*, 1996; *Maldonado et* *al.*, 1999) iron enrichment experiments at P26 have shown that there is a 3-4 day lag between iron enrichment and measureable increase in chlorophyll *a,* and (3) the O_2/Ar NCP method integrates over the residence time of O_2 in the mixed layer (~8 days for P12 in August 2008). If the bloom initiated, at most, 4-5 days prior to sampling at P12, the NCP I measure will include a pre-bloom signal, which explains why the increase in NCP measured at this station is not as dramatic as that measured at the offshore stations (where the high O_2/Ar had more time to build up).

All of the incubation-based measurements at P26 in August 2008 were greater than those measured in August 2009, but the intensification in nitrogen-based rates was much greater than the carbon-based rates (Figure 3.4). Rates of New-P and Regen-P were nearly 10-times greater than measurements in August 2009. These extremely high rates may partially result from increased euphotic zone nitrification and heterotrophic bacterial uptake of NO_3^- and NH_4^+. Surface ammonium concentrations and oxidation rates at P26 were at least three times higher in August 2008 than those measured in August 2009 (*Hamme et al.*, 2010), indicative of intense recycling and euphotic zone nitrification. High recycling and nitrification rates would have overestimated $^{15}NO_3^-$ based New-P, but underestimated $^{15}NH_4^+$ based Regen-P (through oxidation of $^{15}NH_4^+$ and isotope dilution). However, intense recycling by heterotrophic bacteria may also decouple the turnover times of the DOC and DON pools (Kirchman et al., 1991). Assuming some portion of the bacterial biomass is retained on the filter paper, this would lead to an overestimation of New-P and Regen-P if bacteria preferentially took up dissolved NO_3^- or NH_4^+ (DIN) instead of DON (e.g. urea). The bacterial preference of DIN sources over

DON sources has been shown for the bacteria communities in August at P26 (*Kirchman and Wheeler,* 1998). Evidence of this overestimation can be seen in the slightly lower than average NCP:New-P ratio in August 2008 (Figure 3.6, Section 3.2.1). *Dickson et al.* (1999) observed a similar disparity between rates of total production ($^{15}NO_3^-$ based New-P + $^{15}NH_4^+$ based Regen-P) and 24-h ^{14}C-based C-PP in the Arabian Sea that they also attribute to heterotrophic bacterial uptake of NO_3^- and NH_4^+.

In contrast to the nitrogen-based rates, rates of C-PP in August 2008 were higher, but not significantly different from those measured the following August (Figure 3.4). That significantly higher rates of C-PP are not seen compared to estimates the following year could be due to an increased loss of the ^{13}C-label as $DO^{13}C$ in this case. In an experimental mesocosm diatom bloom, DOC and $DO^{13}C$ concentrations increased throughout the experiment, though these changes were minimal until the bloom began to decline (*Norrman et al.*, 1995). Significantly higher surface ammonium concentrations and oxidation rates measured at P26 in August 2008 (*Hamme et al.*, 2010) indicate that P26 was sampled at least during mid-bloom conditions. If the bloom had already begun to decline when sampling occurred, it seems very likely that the small difference I see when comparing C-PP in August 2008 to 2009 results from an increased loss of ^{13}C as $DO^{13}C$ in 2008, rather than C-PP actually being so low in comparison to my other August 2008 measurements.

Chapter 4. Conclusions

Measurements of *in-situ* O_2/Ar NCP coupled with incubation-based measurements of organic carbon and nitrogen along Line P during this study and including previous studies along Line P indicates the following:

1. *In-situ* O_2/Ar NCP along Line P (excluding August 2008 and the most coastal station, P4) does not show marked seasonal or longitudinal variability between June and August for the period 2007 – 2009.

2. Typically, the contribution of diapycnal mixing is neglected when using measurements of O_2/Ar with the O_2 mass balance method. This allows for a simple calculation of *in-situ* NCP by equating NCP to diffusive gas exchange. My results show that when concentration gradients of O_2 and Ar below the mixed layer are large and measurements of ΔO_2/Ar close to equilibrium (as generally seen in February) the contribution of diapycnal mixing can significantly affect the O_2/Ar mass balance. In these cases, NCP cannot be constrained without measurements of the eddy diffusion coefficient at the base of the mixed layer. However, I also found that, when ΔO_2/Ar is largely supersaturated (as measured for June and August), the O_2/Ar mass balance can be constrained even with sizeable O_2 and Ar gradients below the mixed layer (as generally seen in August). I conclude that whenever and wherever mixed layer measurements of O_2/Ar are used to estimate NCP, the contribution of diapycnal mixing should be critically examined before excluding it from the O_2 mass balance.

3. In-situ estimates of NCP and 24-h incubations of New-P from May-Aug were nearly equivalent along Line P, with a mean NCP:New-P ratio of 1.3±0.4. This ratio is similar to that observed in the Southern Ocean, suggesting that new production may be broadly equivalent to NCP in HNLC regions, even on very short time-scales.

4. The mean NCP:^{13}C-PP ratio for May-Sept along Line P was 0.42±0.25, using measurements of 24-h ^{13}C/^{14}C-PP and either O_2/Ar NCP or New-P converted to NCP. This value, though far more variable than the NCP:New-P ratio, was, excluding August 2008, consistent across the entire available dataset along Line P (1988 – 2009). This ratio is likely only appropriate in non-bloom conditions for the May-Sept period as the New-P:C-PP ratio was higher in Feb-Mar. Whether this wintertime difference results from seasonal variability or from an overestimation of New-P is unclear.

5. Of the two offshore high productivity events observed (February 2007 and August 2008), only the August 2008 event shows conclusive evidence that the high productivity observed in both the *in-situ* and incubation-based measurements is the result of iron deposition. Precipitation rates and temperature and salinity profiles indicate that the high productivity observed in February 2007 was related to the stratification of surface waters and reduction in the light limitation, though wet deposition of iron may have also played a role.

The comparisons in this study between *in-situ* and incubation based methods used to quantify biological carbon cycling in the surface ocean demonstrate the importance of evaluating the relationships between productivity methods. My results show that consistent relationships can be found over a range of productivity regimes and environmental conditions, even between methods that integrate on very different temporal and spatial scales. Better understanding of these relationships and the processes which affect them will improve our understanding of the mechanisms responsible for biological carbon export to the deep ocean and predictions of the response of the ocean biological pump to future climate change.

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Appendix A. Dissolved Gas Measurements along Line P

Description of variable names:

Cruise – Line P cruises are typically numbered in the format YEAR-XX (eg. 2007-01). Cruise numbers shown here correspond to the last 3 digits of these official cruise numbers, so 2007-01 becomes 701.

Date – Sampling date

Station – Major station (4, 12, 16, 20, or 26) along Line P where samples were collected

Lat – Latitude in degrees North

Long – Longitude in degrees East

Cast – Cast number

Depth – Depth in meters

Ptmp – Potential Temperature in degrees Celsius and referenced to the surface.

Sal – Salinity expressed on the Practical salinity scale. These are CTD salinities.

Dens – Density of the seawater referenced to the surface.

O_2 – O_2 concentration in umol/kg determined by Winkler titration measurements with a visual endpoint.

ΔO_2 – Supersaturation of O_2 in percent. 0% indicates that the O2 concentration is in equilibrium for the potential temperature and salinity of the water. ie. $\Delta O_2 = (O_2 - O_{2eq})/O_{2eq} * 100$. O_2 supersaturation is calculated relative to the solubility curve of *Garcia and Gordon* (1992)

O_2/Ar – O_2/Ar concentration in umol/kg determined from O_2/Ar mass spectrometry measurements.

ΔO_2/Ar – Supersaturation of O_2/Ar in percent. O2 supersaturation is calculated relative to the solubility curve of *Garcia and Gordon* (1992). Ar supersaturation is calculated relative to the solubility curve of *Hamme and Emerson* (2004).

N_2/Ar – N_2/Ar concentration in umol/kg determined determined from N_2/Ar mass spectrometry measurements.

ΔN_2/Ar – Supersaturation of N_2/Ar in percent. N_2 and Ar supersaturations are calculated relative to the solubility curves of *Hamme and Emerson* (2004).

NaN = missing data

Station 26.1 indicates samples collected near the NOAA Station Papa mooring (http://www.pmel.noaa.gov/stnP/index.html)

Table A1. Dissolved Gas Measurements along Line P from February 2007 to August 2009.

Cruise	Date	Station	Lat	Long	Cast	Depth	Ptmp	Sal	Dens	O_2	ΔO_2	O_2/Ar	Δ O_2/Ar	N_2/Ar	ΔN_2/Ar
701	9-Feb-07	4	48.65	-126.67	9.00	7.63	8.79	32.41	1025.12	283.85	-1.19	20.20	-1.02	38.21	2.79
701	9-Feb-07	4	48.65	-126.67	9.00	7.63	8.79	32.41	1025.12	285.91	-0.47	20.16	-1.21	38.16	2.66
701	10-Feb-07	12	48.97	-130.67	30.00	5.55	8.41	32.44	1025.20	289.82	0.06	20.46	0.25	38.09	2.54
701	11-Feb-07	16	49.28	-134.67	36.00	5.35	7.09	32.41	1025.37	300.97	0.84	20.67	1.25	37.90	2.27
701	11-Feb-07	16	49.28	-134.67	36.00	5.35	7.09	32.41	1025.37	300.77	0.77	20.64	1.11	37.76	1.90
701	12-Feb-07	20	49.57	-138.67	46.00	6.15	6.73	32.51	1025.49	301.87	0.38	20.58	0.80	37.79	2.05
701	15-Feb-07	26	50.00	-145.00	69.00	5.35	5.68	32.58	1025.68	304.76	-1.05	20.31	-0.54	37.95	2.66
701	15-Feb-07	26	50.00	-145.00	69.00	5.35	5.68	32.58	1025.68	306.38	-0.52	20.38	-0.20	37.94	2.64
701	15-Feb-07	26	50.00	-145.00	69.00	31.33	5.66	32.58	1025.68	304.87	-1.06	20.28	-0.69	37.95	2.68
701	15-Feb-07	26	50.00	-145.00	69.00	75.14	5.65	32.58	1025.68	304.17	-1.28	20.27	-0.74	37.98	2.76
701	15-Feb-07	26	50.00	-145.00	69.00	75.14	5.65	32.58	1025.68	305.23	-0.94	20.30	-0.59	38.03	2.88
701	15-Feb-07	26	50.00	-145.00	69.00	123.59	6.02	33.69	1026.51	124.00	-59.07	8.35	-59.10	37.89	2.50
701	15-Feb-07	26	50.00	-145.00	69.00	123.59	6.02	33.69	1026.51	123.71	-59.17	8.33	-59.20	37.90	2.52
701	15-Feb-07	26	50.00	-145.00	69.00	197.89	4.91	33.80	1026.73	122.16	-60.67	8.02	-60.73	37.86	2.61
701	15-Feb-07	26	50.00	-145.00	69.00	197.89	4.91	33.80	1026.73	122.03	-60.72	8.01	-60.78	37.82	2.51
701	15-Feb-07	26	50.00	-145.00	66.00	248.80	4.73	33.83	1026.78	98.24	-68.50	6.42	-68.56	37.84	2.61
701	15-Feb-07	26	50.00	-145.00	66.00	248.80	4.73	33.83	1026.78	97.61	-68.71	6.39	-68.71	37.94	2.86
701	15-Feb-07	26	50.00	-145.00	66.00	297.91	4.56	33.90	1026.85	65.14	-79.19	4.24	-79.24	37.75	2.38
701	15-Feb-07	26	50.00	-145.00	66.00	990.33	2.86	34.38	1027.40	13.58	-95.82	0.86	-95.79	38.01	3.42
701	15-Feb-07	26	50.00	-145.00	66.00	990.33	2.86	34.38	1027.40	45.68	-85.93	2.78	-86.39	42.08	14.50
701	15-Feb-07	26	50.00	-145.00	66.00	2953.45	1.36	34.66	1027.73	108.54	-67.60	6.68	-67.31	37.84	3.22
701	15-Feb-07	26	50.00	-145.00	66.00	3930.83	1.18	34.68	1027.75	135.78	-59.54	8.32	-59.29	37.76	3.02

Cruise	Date	Station	Lat	Long	Cast	Depth	Ptmp	Sal	Dens	O_2	ΔO_2	O_2/Ar	ΔO_2/Ar	N_2/Ar	ΔN_2/Ar
701	15-Feb-07	26	50.00	-145.00	66.00	3930.83	1.18	34.68	1027.75	135.78	-59.54	8.32	-59.29	37.68	2.81
713	1-Jun-07	4	48.65	-126.67	11.00	6.10	11.49	31.53	1023.98	308.01	12.96	22.68	11.20	37.35	-0.04
713	1-Jun-07	4	48.65	-126.67	11.00	6.10	11.49	31.53	1023.98	308.01	12.96	22.65	11.05	37.38	0.02
713	2-Jun-07	8	48.82	-128.67	17.00	6.59	11.44	32.48	1024.74	294.95	8.79	21.10	3.46	37.30	-0.14
713	2-Jun-07	8	48.82	-128.67	17.00	6.59	11.44	32.48	1024.74	294.95	8.79	21.14	3.66	37.31	-0.11
713	2-Jun-07	12	48.97	-130.67	21.00	6.00	10.60	32.49	1024.89	295.47	7.06	21.09	3.40	37.29	-0.02
713	2-Jun-07	12	48.97	-130.67	21.00	6.00	10.60	32.49	1024.89	295.47	7.06	21.13	3.60	37.28	-0.05
713	3-Jun-07	16	49.29	-134.68	30.00	6.88	9.01	32.52	1025.18	297.21	4.05	20.88	2.32	37.21	0.07
713	4-Jun-07	20	49.57	-138.67	39.00	6.68	8.46	32.41	1025.17	305.92	5.72	20.92	2.52	37.15	-0.01
713	4-Jun-07	20	49.57	-138.67	39.00	6.68	8.46	32.41	1025.17	305.92	5.72	20.89	2.35	37.16	0.02
713	7-Jun-07	26.1	50.13	-144.85	62.00	2.06	7.02	32.58	1025.51	308.45	3.32	20.89	2.31	37.11	0.15
713	7-Jun-07	26.1	50.13	-144.85	62.00	2.06	7.02	32.58	1025.51	308.45	3.32	20.93	2.53	37.11	0.16
713	7-Jun-07	26.1	50.13	-144.85	62.00	6.59	7.02	32.58	1025.51	309.41	3.64	20.94	2.60	37.09	0.11
713	7-Jun-07	26.1	50.13	-144.85	62.00	6.59	7.02	32.58	1025.51	309.41	3.64	20.93	2.50	37.09	0.10
713	7-Jun-07	26.1	50.13	-144.85	62.00	11.50	7.01	32.59	1025.52	308.77	3.40	20.96	2.67	37.08	0.08
713	7-Jun-07	26.1	50.13	-144.85	62.00	11.50	7.01	32.59	1025.52	308.77	3.40	20.93	2.54	37.09	0.11
713	7-Jun-07	26.1	50.13	-144.85	62.00	21.33	7.00	32.59	1025.52	310.41	3.94	20.95	2.64	37.08	0.09
713	7-Jun-07	26.1	50.13	-144.85	62.00	21.33	7.00	32.59	1025.52	310.41	3.94	20.91	2.42	37.09	0.11
713	7-Jun-07	26.1	50.13	-144.85	62.00	30.17	6.98	32.63	1025.55	310.65	4.01	20.89	2.35	37.12	0.20
713	7-Jun-07	26.1	50.13	-144.85	62.00	30.17	6.98	32.63	1025.55	310.65	4.01	20.94	2.57	37.11	0.17
713	8-Jun-07	26	50.00	-145.00	66.00	6.59	7.06	32.65	1025.56	312.18	4.71	20.87	2.25	37.07	0.05
713	8-Jun-07	26	50.00	-145.00	66.00	6.59	7.06	32.65	1025.56	312.18	4.71	21.18	3.74	45.88	23.83

Cruise	**Date**	**Station**	**Lat**	**Long**	**Cast**	**Depth**	**Ptmp**	**Sal**	**Dens**	**O_2**	**ΔO_2**	**O_2/Ar**	**$\Delta O_2/Ar$**	**N_2/Ar**	**$\Delta N_2/Ar$**
713	8-Jun-07	26	50.00	-145.00	66.00	20.93	7.06	32.60	1025.52	305.92	2.56	20.89	2.32	37.10	0.13
713	8-Jun-07	26	50.00	-145.00	66.00	20.93	7.06	32.60	1025.52	305.92	2.56	20.91	2.40	37.12	0.17
713	8-Jun-07	26	50.00	-145.00	66.00	49.92	5.88	32.65	1025.71	312.87	2.12	20.58	0.77	37.09	0.31
713	8-Jun-07	26	50.00	-145.00	66.00	49.92	5.88	32.65	1025.71	312.87	2.12	20.58	0.79	37.10	0.33
713	8-Jun-07	26	50.00	-145.00	66.00	98.83	5.60	33.26	1026.23	194.70	-36.57	12.90	-36.83	37.23	0.76
713	8-Jun-07	26	50.00	-145.00	66.00	98.83	5.60	33.26	1026.23	194.70	-36.57	12.96	-36.53	37.20	0.70
713	8-Jun-07	26	50.00	-145.00	66.00	246.91	4.62	33.91	1026.85	85.06	-72.78	5.46	-73.26	37.26	1.05
713	8-Jun-07	26	50.00	-145.00	66.00	246.91	4.62	33.91	1026.85	85.06	-72.78	5.47	-73.22	37.17	0.82
713	8-Jun-07	26	50.00	-145.00	67.00	493.12	3.79	34.13	1027.11	24.97	-92.15	1.48	-92.77	37.21	1.09
713	8-Jun-07	26	50.00	-145.00	67.00	493.12	3.79	34.13	1027.11	24.97	-92.15	1.55	-92.43	37.28	1.27
713	8-Jun-07	26	50.00	-145.00	67.00	980.28	2.75	34.42	1027.44	15.04	-95.38	0.82	-96.00	37.25	1.38
713	8-Jun-07	26	50.00	-145.00	67.00	980.28	2.75	34.42	1027.44	15.04	-95.38	0.83	-95.94	37.21	1.26
713	8-Jun-07	26	50.00	-145.00	67.00	1948.57	1.66	34.60	1027.67	55.67	-83.30	3.46	-83.09	37.26	1.60
713	8-Jun-07	26	50.00	-145.00	67.00	1948.57	1.66	34.60	1027.67	55.67	-83.30	3.46	-83.05	37.24	1.55
713	8-Jun-07	26	50.00	-145.00	67.00	2909.08	1.15	34.66	1027.75	108.78	-67.71	6.68	-67.32	37.18	1.45
713	8-Jun-07	26	50.00	-145.00	67.00	2909.08	1.15	34.66	1027.75	108.78	-67.71	6.68	-67.31	37.20	1.52
713	8-Jun-07	26	50.00	-145.00	67.00	3860.78	0.88	34.76	1027.84	136.50	-59.63	8.30	-59.41	37.14	1.40
713	8-Jun-07	26	50.00	-145.00	67.00	3860.78	0.88	34.76	1027.84	136.50	-59.63	8.32	-59.31	37.21	1.58
715	16-Aug-07	4	48.65	-126.66	8.00	5.31	17.34	31.76	1022.95	254.78	5.23	20.78	2.00	37.67	-0.27
715	16-Aug-07	4	48.65	-126.66	8.00	5.31	17.34	31.76	1022.95	254.78	5.23	20.83	2.24	37.66	-0.29
715	18-Aug-07	12	48.97	-130.67	22.00	5.21	16.22	32.15	1023.51	255.07	3.37	20.78	1.95	37.63	-0.15
715	18-Aug-07	12	48.97	-130.67	22.00	5.21	16.22	32.15	1023.51	255.07	3.37	20.80	2.04	37.64	-0.13

Cruise	Date	Station	Lat	Long	Cast	Depth	Ptmp	Sal	Dens	O_2	ΔO_2	O_2/Ar	Δ O_2/Ar	N_2/Ar	ΔN_2/Ar
715	19-Aug-07	16	49.28	-134.67	28.00	2.46	15.11	32.35	1023.91	268.77	6.72	21.16	3.79	37.53	-0.21
715	19-Aug-07	16	49.28	-134.67	28.00	2.46	15.11	32.35	1023.91	268.77	6.72	21.19	3.93	37.54	-0.18
715	20-Aug-07	20	49.57	-138.66	35.00	3.64	13.60	32.37	1024.24	274.79	5.90	21.37	4.81	37.48	-0.05
715	20-Aug-07	20	49.57	-138.66	35.00	3.64	13.60	32.37	1024.24	274.79	5.90	21.31	4.51	37.47	-0.07
715	22-Aug-07	26	50.00	-145.00	51.00	0.79	12.43	32.47	1024.54	275.74	3.82	20.81	2.03	37.43	0.03
715	22-Aug-07	26	50.00	-145.00	51.00	0.79	12.43	32.47	1024.54	275.74	3.82	20.80	2.00	37.41	-0.01
715	22-Aug-07	26	50.00	-145.00	51.00	10.42	12.43	32.47	1024.54	276.96	4.28	20.84	2.18	37.41	-0.02
715	22-Aug-07	26	50.00	-145.00	51.00	10.42	12.43	32.47	1024.54	276.96	4.28	20.82	2.11	37.41	-0.02
715	22-Aug-07	26	50.00	-145.00	51.00	19.17	12.37	32.46	1024.55	275.13	3.46	20.85	2.25	37.38	-0.09
715	22-Aug-07	26	50.00	-145.00	51.00	19.17	12.37	32.46	1024.55	275.13	3.46	20.86	2.28	37.38	-0.10
715	22-Aug-07	26	50.00	-145.00	51.00	28.21	11.75	32.47	1024.67	281.73	4.58	21.01	3.03	37.39	0.04
715	22-Aug-07	26	50.00	-145.00	51.00	28.21	11.75	32.47	1024.67	281.73	4.58	21.07	3.28	37.36	-0.03
715	22-Aug-07	26	50.00	-145.00	52.00	392.90	3.98	34.04	1027.02	31.98	-89.91	2.18	-89.35	37.23	1.08
715	22-Aug-07	26	50.00	-145.00	52.00	392.90	3.98	34.04	1027.02	31.98	-89.91	2.22	-89.13	37.21	1.05
715	22-Aug-07	26	50.00	-145.00	52.00	978.92	2.76	34.39	1027.41	13.09	-95.98	0.84	-95.87	37.25	1.37
715	22-Aug-07	26	50.00	-145.00	52.00	978.92	2.76	34.39	1027.41	13.09	-95.98	0.87	-95.76	37.23	1.33
715	22-Aug-07	26	50.00	-145.00	52.00	1946.35	1.67	34.59	1027.66	55.98	-83.21	3.40	-83.37	37.20	1.43
715	22-Aug-07	26	50.00	-145.00	52.00	1946.35	1.67	34.59	1027.66	55.98	-83.21	3.45	-83.11	37.24	1.55
715	22-Aug-07	26	50.00	-145.00	52.00	2906.88	1.15	34.66	1027.74	106.35	-68.43	6.72	-67.13	37.19	1.50
715	22-Aug-07	26	50.00	-145.00	52.00	3859.45	0.88	34.83	1027.89	135.90	-59.79	8.34	-59.18	37.15	1.42
715	22-Aug-07	26	50.00	-145.00	52.00	3859.45	0.88	34.83	1027.89	135.90	-59.79	13.25	-35.18	52.45	43.20
715	22-Aug-07	26.1	50.13	-144.83	54.00	10.52	12.45	32.46	1024.53	278.29	4.80	20.98	2.88	37.41	-0.03

Cruise	Date	Station	Lat	Long	Cast	Depth	Ptmp	Sal	Dens	O_2	ΔO_2	O_2/Ar	Δ O_2/Ar	N_2/Ar	ΔN_2/Ar
715	22-Aug-07	26.1	50.13	-144.83	54.00	10.52	12.45	32.46	1024.53	278.29	4.80	20.98	2.87	37.37	-0.12
715	22-Aug-07	26.1	50.13	-144.83	54.00	21.72	12.10	32.46	1024.60	290.66	8.69	21.04	3.16	37.36	-0.08
715	22-Aug-07	26.1	50.13	-144.83	54.00	21.72	12.10	32.46	1024.60	290.66	8.69	21.05	3.23	37.37	-0.07
801	2-Feb-08	4	48.65	-126.67	6.00	6.00	7.81	32.43	1025.29	288.74	-1.65	20.22	-0.96	37.27	0.45
801	2-Feb-08	4	48.65	-126.67	6.00	6.00	7.81	32.43	1025.29	288.74	-1.65	20.22	-0.96	37.29	0.48
801	3-Feb-08	8	48.82	-128.67	18.00	6.49	6.83	32.48	1025.46	296.31	-1.26	20.24	-0.87	37.20	0.42
801	3-Feb-08	8	48.82	-128.67	18.00	6.49	6.83	32.48	1025.46	296.31	-1.26	20.24	-0.88	37.19	0.41
801	4-Feb-08	12	48.97	-130.67	27.00	4.62	6.94	32.49	1025.45	294.69	-1.55	20.26	-0.78	37.24	0.51
801	4-Feb-08	12	48.97	-130.67	27.00	4.62	6.94	32.49	1025.45	294.69	-1.55	20.27	-0.70	37.29	0.66
801	5-Feb-08	16	49.28	-134.67	31.00	5.60	5.98	32.53	1025.60	300.74	-1.71	20.14	-1.37	37.28	0.80
801	5-Feb-08	16	49.28	-134.67	31.00	5.60	5.98	32.53	1025.60	300.74	-1.71	20.15	-1.34	37.22	0.63
801	7-Feb-08	20	49.57	-138.67	37.00	6.98	5.79	32.59	1025.68	304.64	-0.83	20.27	-0.74	37.20	0.61
801	7-Feb-08	20	49.57	-138.67	37.00	6.98	5.79	32.59	1025.68	304.64	-0.83	20.24	-0.87	37.27	0.82
801	9-Feb-08	26	50.00	-145.00	45.00	2.46	4.90	32.63	1025.81	311.82	-0.57	20.25	-0.84	37.15	0.64
801	9-Feb-08	26	50.00	-145.00	45.00	2.46	4.90	32.63	1025.81	311.82	-0.57	20.26	-0.80	37.08	0.45
801	9-Feb-08	26	50.00	-145.00	45.00	5.70	4.89	32.63	1025.81	311.42	-0.70	20.24	-0.88	37.13	0.59
801	9-Feb-08	26	50.00	-145.00	45.00	5.70	4.89	32.63	1025.81	311.42	-0.70	20.26	-0.82	37.09	0.49
801	9-Feb-08	26	50.00	-145.00	45.00	10.22	4.89	32.63	1025.81	310.88	-0.87	20.25	-0.87	37.13	0.58
801	9-Feb-08	26	50.00	-145.00	45.00	10.22	4.89	32.63	1025.81	310.88	-0.87	20.27	-0.76	37.10	0.52
801	9-Feb-08	26	50.00	-145.00	45.00	20.54	4.89	32.63	1025.81	311.13	-0.81	20.25	-0.87	37.10	0.51
801	9-Feb-08	26	50.00	-145.00	45.00	20.54	4.89	32.63	1025.81	311.13	-0.81	20.25	-0.83	37.09	0.49
801	9-Feb-08	26	50.00	-145.00	45.00	29.58	4.90	32.63	1025.81	310.45	-1.00	20.26	-0.80	37.08	0.46

Cruise	Date	Station	Lat	Long	Cast	Depth	Ptmp	Sal	Dens	O_2	ΔO_2	O_2/Ar	Δ O_2/Ar	N_2/Ar	ΔN_2/Ar
801	9-Feb-08	26	50.00	-145.00	45.00	29.58	4.90	32.63	1025.81	310.45	-1.00	20.24	-0.90	37.14	0.62
801	11-Feb-08	26	50.00	-145.00	47.00	985.83	2.71	34.39	1027.42	15.15	-95.35	1.32	-93.52	37.17	1.18
801	11-Feb-08	26	50.00	-145.00	47.00	985.83	2.71	34.39	1027.42	15.15	-95.35	1.20	-94.13	37.18	1.19
801	11-Feb-08	26	50.00	-145.00	47.00	985.83	2.71	34.39	1027.42	15.10	-95.37	1.11	-94.59	37.21	1.29
801	11-Feb-08	26	50.00	-145.00	47.00	985.83	2.71	34.39	1027.42	15.10	-95.37	1.48	-92.75	37.18	1.18
801	11-Feb-08	26	50.00	-145.00	47.00	1948.37	1.64	34.59	1027.66	59.75	-82.09	3.89	-80.95	37.17	1.35
801	11-Feb-08	26	50.00	-145.00	47.00	1948.37	1.64	34.59	1027.66	59.75	-82.09	3.75	-81.67	37.19	1.41
801	11-Feb-08	26	50.00	-145.00	47.00	2907.93	1.14	34.66	1027.74	110.57	-67.18	7.03	-65.62	37.12	1.30
801	11-Feb-08	26	50.00	-145.00	47.00	3860.40	0.88	34.68	1027.78	138.07	-59.19	8.55	-58.16	37.12	1.33
801	11-Feb-08	26	50.00	-145.00	47.00	3860.40	0.88	34.68	1027.78	138.07	-59.19	8.64	-57.72	37.10	1.28
801	11-Feb-08	26.1	50.14	-144.83	51.00	1.38	5.07	32.59	1025.76	309.19	-1.03	20.20	-1.09	37.16	0.64
801	11-Feb-08	26.1	50.14	-144.83	51.00	1.38	5.07	32.59	1025.76	309.19	-1.03	20.20	-1.11	37.20	0.73
801	11-Feb-08	26.1	50.14	-144.83	51.00	5.31	5.07	32.62	1025.78	308.25	-1.32	20.16	-1.30	37.16	0.64
801	11-Feb-08	26.1	50.14	-144.83	51.00	5.31	5.07	32.62	1025.78	308.25	-1.32	20.20	-1.08	37.11	0.51
801	11-Feb-08	26.1	50.14	-144.83	51.00	9.93	5.07	32.62	1025.78	308.24	-1.32	20.18	-1.21	37.15	0.61
801	11-Feb-08	26.1	50.14	-144.83	51.00	9.93	5.07	32.62	1025.78	308.24	-1.32	20.18	-1.20	37.17	0.67
801	11-Feb-08	26.1	50.14	-144.83	51.00	22.90	5.07	32.62	1025.78	309.21	-1.02	20.21	-1.04	37.12	0.53
801	11-Feb-08	26.1	50.14	-144.83	51.00	22.90	5.07	32.62	1025.78	309.21	-1.02	20.18	-1.20	37.10	0.48
801	11-Feb-08	26.1	50.14	-144.83	51.00	29.97	5.06	32.62	1025.78	309.29	-0.99	20.16	-1.29	37.15	0.61
801	11-Feb-08	26.1	50.14	-144.83	51.00	29.97	5.06	32.62	1025.78	309.29	-0.99	20.16	-1.31	37.17	0.68
826	1-Jun-08	4	48.65	-126.67	7.00	5.16	11.48	31.98	1024.34	308.50	13.47	22.39	9.77	37.26	-0.27
826	1-Jun-08	4	48.65	-126.67	7.00	5.16	11.48	31.98	1024.34	308.50	13.47	22.39	9.77	37.28	-0.22

Cruise	Date	Station	Lat	Long	Cast	Depth	Ptmp	Sal	Dens	O_2	ΔO_2	O_2/Ar	Δ O_2/Ar	N_2/Ar	ΔN_2/Ar
826	2-Jun-08	8	49.83	-129.68	18.00	6.64	9.65	32.47	1025.03	295.27	4.79	20.97	2.78	37.18	-0.13
826	2-Jun-08	8	49.83	-129.68	18.00	6.64	9.65	32.47	1025.03	295.27	4.79	20.95	2.68	37.19	-0.11
826	3-Jun-08	12	49.97	-131.67	28.00	5.16	8.86	32.49	1025.18	298.09	3.99	20.96	2.71	37.14	-0.10
826	3-Jun-08	12	49.97	-131.67	28.00	5.16	8.86	32.49	1025.18	298.09	3.99	20.92	2.51	37.15	-0.07
826	4-Jun-08	16	49.28	-134.68	37.00	4.56	8.23	32.52	1025.29	299.32	2.99	20.73	1.57	37.06	-0.20
826	4-Jun-08	16	49.28	-134.68	37.00	4.56	8.23	32.52	1025.29	299.32	2.99	20.69	1.37	37.08	-0.14
826	5-Jun-08	20	49.58	-138.67	45.00	6.35	7.30	32.57	1025.46	299.32	0.89	20.77	1.75	37.06	-0.03
826	5-Jun-08	20	49.58	-138.67	45.00	6.35	7.30	32.57	1025.46	299.32	0.89	20.74	1.60	37.08	0.02
826	9-Jun-08	26	50.14	-144.84	75.00	4.76	7.17	32.65	1025.55	57.72	-80.59	20.92	2.48	37.00	-0.16
826	9-Jun-08	26	50.14	-144.84	75.00	4.76	7.17	32.65	1025.55	57.72	-80.59	20.92	2.48	37.00	-0.16
826	9-Jun-08	26	50.14	-144.84	75.00	20.03	6.39	32.67	1025.66	108.22	-64.25	21.01	2.90	36.98	-0.08
826	9-Jun-08	26	48.65	-126.67	75.00	20.03	6.39	32.67	1025.66	22.68	-92.51	21.05	3.10	36.97	-0.11
826	9-Jun-08	26	50.14	-144.84	75.00	29.84	6.34	32.67	1025.67	15.18	-94.99	20.95	2.61	36.96	-0.12
826	9-Jun-08	26	50.14	-144.84	75.00	29.84	6.34	32.67	1025.67	108.22	-64.29	20.91	2.41	36.98	-0.07
826	9-Jun-08	26	50.14	-144.84	75.00	49.66	5.53	32.67	1025.77	15.18	-95.09	20.71	1.42	36.96	0.02
826	9-Jun-08	26	50.14	-144.84	75.00	49.66	5.53	32.67	1025.77	137.37	-55.52	20.68	1.27	36.98	0.07
826	10-Jun-08	26	50.14	-144.84	62.00	74.74	5.06	32.68	1025.83	305.24	-2.23	20.51	0.43	36.98	0.16
826	10-Jun-08	26	50.14	-144.84	62.00	74.74	5.06	32.68	1025.83	315.39	1.02	20.47	0.23	36.99	0.18
826	10-Jun-08	26	50.14	-144.84	62.00	98.82	4.92	32.69	1025.85	312.99	-0.08	20.33	-0.46	36.99	0.21
826	10-Jun-08	26	50.14	-144.84	62.00	98.82	4.92	32.69	1025.85	315.09	0.59	20.30	-0.60	36.98	0.18
826	10-Jun-08	26	50.14	-144.84	62.00	148.96	4.24	33.59	1026.64	316.30	0.02	10.08	-50.65	37.12	0.73
826	10-Jun-08	26	50.14	-144.84	62.00	148.96	4.24	33.59	1026.64	315.09	-0.36	10.13	-50.40	37.06	0.56

Cruise	Date	Station	Lat	Long	Cast	Depth	Ptmp	Sal	Dens	O_2	ΔO_2	O_2/Ar	Δ O_2/Ar	N_2/Ar	ΔN_2/Ar
826	10-Jun-08	26	50.14	-144.84	62.00	197.30	4.05	33.78	1026.81	316.30	-0.29	6.71	-67.15	37.16	0.88
826	8-Jun-08	26	50.14	-144.84	62.00	197.30	4.05	33.78	1026.81	313.64	-1.13	6.76	-66.90	37.08	0.66
826	10-Jun-08	26	50.14	-144.84	62.00	247.90	3.99	33.85	1026.87	315.39	-0.64	4.97	-75.67	37.19	0.97
826	8-Jun-08	26	50.14	-144.84	62.00	247.90	3.99	33.85	1026.87	313.64	-1.20	5.04	-75.33	37.10	0.73
826	8-Jun-08	26	50.14	-144.84	63.00	494.81	3.67	34.16	1027.15	311.66	-2.33	1.40	-93.15	37.26	1.24
826	8-Jun-08	26	50.14	-144.84	63.00	494.81	3.67	34.16	1027.15	105.22	-67.02	1.33	-93.49	37.15	0.94
826	8-Jun-08	26	50.14	-144.84	63.00	989.33	2.82	34.38	1027.40	311.66	-4.08	0.91	-95.55	37.28	1.45
826	8-Jun-08	26	50.14	-144.84	63.00	989.33	2.82	34.38	1027.40	105.22	-67.62	0.86	-95.79	37.17	1.15
826	8-Jun-08	26	50.14	-144.84	63.00	1972.90	1.80	34.58	1027.64	156.85	-52.78	3.33	-83.70	37.23	1.49
826	8-Jun-08	26	50.14	-144.84	63.00	1972.90	1.80	34.58	1027.64	77.19	-76.76	3.29	-83.90	37.13	1.22
826	8-Jun-08	26	50.14	-144.84	63.00	2952.73	1.37	34.65	1027.72	156.85	-53.17	6.58	-67.80	37.17	1.39
826	8-Jun-08	26	50.14	-144.84	63.00	2952.73	1.37	34.65	1027.72	77.19	-76.95	6.57	-67.85	37.12	1.26
826	9-Jun-08	26	50.14	-144.84	63.00	3928.44	1.18	34.68	1027.75	22.68	-93.24	8.35	-59.14	37.09	1.19
827	14-Aug-08	4	48.65	-126.67	13.00	4.94	15.18	32.18	1023.76	272.37	8.18	21.43	5.13	37.50	-0.30
827	14-Aug-08	4	48.65	-126.67	13.00	4.94	15.18	32.18	1023.76	272.37	8.18	21.42	5.08	37.49	-0.32
827	16-Aug-08	12	49.97	-131.67	39.00	5.46	15.44	32.39	1023.87	277.44	10.92	21.97	7.79	37.51	-0.31
827	16-Aug-08	12	49.97	-131.67	39.00	5.46	15.44	32.39	1023.87	277.44	10.92	21.98	7.84	37.51	-0.31
827	19-Aug-08	20	49.28	-134.68	62.00	4.60	12.65	32.42	1024.46	285.69	8.01	21.78	6.80	37.37	-0.17
827	19-Aug-08	20	49.28	-134.68	62.00	4.60	12.65	32.42	1024.46	285.69	8.01	21.78	6.80	37.37	-0.17
827	21-Aug-08	26	50.14	-144.84	85.00	5.68	11.27	32.49	1024.77	289.42	6.36	21.59	5.85	37.29	-0.13
827	21-Aug-08	26	50.14	-144.84	85.00	5.68	11.27	32.49	1024.77	289.42	6.36	21.63	6.04	37.28	-0.16
827	21-Aug-08	26	50.14	-144.84	85.00	10.35	11.26	32.49	1024.78	289.51	6.37	21.58	5.80	37.32	-0.05

Cruise	Date	Station	Lat	Long	Cast	Depth	Ptmp	Sal	Dens	O_2	ΔO_2	O_2/Ar	Δ O_2/Ar	N_2/Ar	ΔN_2/Ar
827	21-Aug-08	26	50.14	-144.84	85.00	18.76	11.23	32.49	1024.78	289.83	6.42	21.60	5.89	37.31	-0.07
827	21-Aug-08	26	50.14	-144.84	85.00	18.76	11.23	32.49	1024.78	289.83	6.42	21.58	5.80	37.32	-0.04
827	21-Aug-08	26	50.14	-144.84	85.00	30.00	11.06	32.50	1024.82	286.96	5.00	21.34	4.62	37.32	-0.01
827	21-Aug-08	26	50.14	-144.84	85.00	30.00	11.06	32.50	1024.82	286.96	5.00	21.34	4.62	37.32	-0.01
827	21-Aug-08	26	50.14	-144.84	85.00	49.25	5.50	32.62	1025.73	308.44	-0.24	20.26	-0.79	36.99	0.10
827	21-Aug-08	26	50.14	-144.84	85.00	49.25	5.50	32.62	1025.73	308.44	-0.24	20.25	-0.84	36.99	0.10
827	21-Aug-08	26	50.14	-144.84	85.00	75.11	4.99	32.66	1025.82	309.36	-1.09	20.06	-1.78	36.98	0.17
827	21-Aug-08	26	50.14	-144.84	85.00	75.11	4.99	32.66	1025.82	309.36	-1.09	20.07	-1.73	36.98	0.17
827	21-Aug-08	26	50.14	-144.84	75.00	99.54	4.63	32.71	1025.90	304.60	-3.41	19.72	-3.45	36.99	0.26
827	21-Aug-08	26	50.14	-144.84	75.00	99.54	4.63	32.71	1025.90	304.60	-3.41	19.72	-3.45	37.00	0.29
827	21-Aug-08	26	50.14	-144.84	75.00	149.15	4.47	33.62	1026.64	157.35	-49.95	10.16	-50.25	37.13	0.72
827	21-Aug-08	26	50.14	-144.84	75.00	149.15	4.47	33.62	1026.64	157.35	-49.95	10.16	-50.25	37.12	0.69
827	21-Aug-08	26	50.14	-144.84	75.00	197.79	4.23	33.79	1026.80	105.01	-66.75	6.74	-67.00	37.16	0.85
827	21-Aug-08	26	50.14	-144.84	75.00	197.79	4.23	33.79	1026.80	105.01	-66.75	6.75	-66.95	37.15	0.82
827	21-Aug-08	26	50.14	-144.84	75.00	249.85	4.15	33.86	1026.86	72.81	-76.97	4.65	-77.23	37.15	0.84
827	21-Aug-08	26	50.14	-144.84	75.00	249.85	4.15	33.86	1026.86	72.81	-76.97	4.66	-77.18	37.16	0.86
827	21-Aug-08	26	50.14	-144.84	75.00	494.18	3.76	34.12	1027.11	21.95	-93.11	1.45	-92.90	37.21	1.08
827	21-Aug-08	26	50.14	-144.84	75.00	494.18	3.76	34.12	1027.11	21.95	-93.11	1.49	-92.71	37.19	1.03
827	21-Aug-08	26	50.14	-144.84	75.00	987.37	2.82	34.38	1027.40	13.88	-95.73	1.01	-95.06	37.23	1.31
827	21-Aug-08	26	50.14	-144.84	75.00	987.37	2.82	34.38	1027.40	13.88	-95.73	0.98	-95.20	37.23	1.31
903	29-Jan-09	4	48.66	-126.67	9.00	4.73	7.50	31.69	1024.75	292.01	-1.76	19.88	-2.61	37.19	0.24
903	29-Jan-09	4	48.66	-126.67	9.00	4.73	7.50	31.69	1024.75	292.01	-1.76	20.07	-1.68	37.17	0.19

Cruise	**Date**	**Station**	**Lat**	**Long**	**Cast**	**Depth**	**Ptmp**	**Sal**	**Dens**	**O_2**	**ΔO_2**	**O_2/Ar**	**Δ O_2/Ar**	**N_2/Ar**	**ΔN_2/Ar**
903	29-Jan-09	4	48.66	-126.67	9.00	29.38	7.66	32.36	1025.25	293.08	-0.56	20.38	-0.16	37.19	0.25
903	29-Jan-09	4	48.66	-126.67	9.00	48.48	7.59	32.40	1025.29	293.88	-0.42	20.41	-0.01	37.18	0.23
903	29-Jan-09	4	48.66	-126.67	9.00	74.56	7.39	33.05	1025.83	212.44	-27.98	14.68	-28.08	36.94	-0.35
903	29-Jan-09	4	48.66	-126.67	9.00	74.56	7.39	33.05	1025.83	212.44	-27.98	14.69	-28.03	37.22	0.41
903	29-Jan-09	4	48.66	-126.67	9.00	247.18	6.30	33.93	1026.67	95.91	-68.07	6.43	-68.50	37.38	1.08
903	29-Jan-09	4	48.66	-126.67	9.00	247.18	6.30	33.93	1026.67	95.91	-68.07	6.41	-68.60	37.27	0.78
903	1-Feb-09	12	48.97	-130.68	31.00	4.16	7.64	32.45	1025.32	296.02	0.46	20.54	0.63	37.26	0.44
903	1-Feb-09	12	48.97	-130.68	31.00	4.16	7.64	32.45	1025.32	296.02	0.46	20.51	0.48	37.16	0.17
903	2-Feb-09	16	49.28	-134.68	34.00	5.35	6.90	32.41	1025.39	301.17	0.47	20.50	0.42	37.11	0.17
903	2-Feb-09	16	49.28	-134.68	34.00	5.35	6.90	32.41	1025.39	301.17	0.47	20.51	0.46	37.12	0.20
903	2-Feb-09	20	49.57	-138.67	37.00	4.66	6.40	32.45	1025.49	301.18	-0.65	20.52	0.50	37.09	0.21
903	2-Feb-09	20	49.57	-138.67	37.00	4.66	6.40	32.45	1025.49	301.18	-0.65	20.46	0.21	37.10	0.23
903	5-Feb-09	26	50.01	-145.01	44.00	3.53	6.05	32.58	1025.63	305.86	0.17	20.50	0.40	37.17	0.49
903	5-Feb-09	26	50.01	-145.01	44.00	3.53	6.05	32.58	1025.63	305.86	0.17	20.49	0.35	37.09	0.27
903	5-Feb-09	26	50.01	-145.01	44.00	38.29	6.04	32.57	1025.63	305.43	0.00	20.48	0.30	37.08	0.25
903	5-Feb-09	26	50.01	-145.01	44.00	77.16	6.00	32.57	1025.63	305.30	-0.11	20.45	0.15	37.08	0.25
903	5-Feb-09	26	50.01	-145.01	44.00	77.16	6.00	32.57	1025.63	305.30	-0.11	20.44	0.10	37.07	0.23
903	5-Feb-09	26	50.01	-145.01	44.00	97.75	6.00	32.57	1025.63	305.59	-0.02	20.44	0.10	37.08	0.25
903	5-Feb-09	26	50.01	-145.01	44.00	97.75	6.00	32.57	1025.63	305.59	-0.02	20.44	0.10	37.08	0.25
903	5-Feb-09	26	50.01	-145.01	44.00	119.20	5.57	32.64	1025.74	300.85	-2.50	19.87	-2.70	37.05	0.25
903	5-Feb-09	26	50.01	-145.01	44.00	119.20	5.57	32.64	1025.74	300.85	-2.50	19.89	-2.60	37.05	0.25
903	5-Feb-09	26	50.00	-145.04	49.00	149.05	4.46	33.21	1026.31	242.75	-23.05	15.71	-23.08	37.07	0.53

Cruise	**Date**	**Station**	**Lat**	**Long**	**Cast**	**Depth**	**Ptmp**	**Sal**	**Dens**	**O_2**	**ΔO_2**	**O_2/Ar**	**$\Delta O_2/Ar$**	**N_2/Ar**	**$\Delta N_2/Ar$**
903	5-Feb-09	26	50.00	-145.04	49.00	149.05	4.46	33.21	1026.31	242.75	-23.05	15.72	-23.03	37.06	0.51
903	5-Feb-09	26	50.00	-145.04	49.00	171.02	4.70	33.59	1026.59	195.24	-37.58	12.62	-38.21	37.12	0.65
903	5-Feb-09	26	50.00	-145.04	49.00	171.02	4.70	33.59	1026.59	195.24	-37.58	12.62	-38.21	37.12	0.65
903	5-Feb-09	26	50.00	-145.04	49.00	196.84	4.41	33.71	1026.72	152.22	-51.62	9.81	-51.97	37.13	0.73
903	5-Feb-09	26	50.00	-145.04	49.00	246.90	4.11	33.81	1026.83	101.50	-67.94	6.47	-68.32	37.13	0.79
903	5-Feb-09	26	50.00	-145.04	49.00	246.90	4.11	33.81	1026.83	101.50	-67.94	6.47	-68.32	37.14	0.81
903	5-Feb-09	26	50.00	-145.04	49.00	300.05	4.03	33.87	1026.88	78.00	-75.40	4.99	-75.57	37.15	0.86
903	5-Feb-09	26	50.00	-145.04	49.00	300.05	4.03	33.87	1026.88	78.00	-75.40	5.05	-75.28	37.01	0.48
909	8-Jun-09	4	48.66	-126.68	10.00	73.73	7.28	32.51	1025.42	280.62	-5.48	19.02	-6.83	37.07	0.00
909	8-Jun-09	4	48.66	-126.68	10.00	73.73	7.28	32.51	1025.42	280.62	-5.48	19.09	-6.48	37.11	0.10
909	8-Jun-09	4	48.66	-126.68	10.00	39.70	8.28	32.37	1025.17	292.16	0.53	20.02	-1.91	36.80	-0.91
909	8-Jun-09	4	48.66	-126.68	10.00	39.70	8.28	32.37	1025.17	292.16	0.53	20.05	-1.76	37.08	-0.16
909	8-Jun-09	4	48.66	-126.68	10.00	19.94	9.98	32.22	1024.79	304.45	8.63	21.91	7.39	37.13	-0.34
909	8-Jun-09	4	48.66	-126.68	10.00	19.94	9.98	32.22	1024.79	304.45	8.63	21.89	7.29	36.85	-1.09
909	8-Jun-09	4	48.66	-126.68	10.00	5.30	12.68	32.09	1024.20	299.45	13.02	22.12	8.47	37.21	-0.62
909	8-Jun-09	4	48.66	-126.68	10.00	5.30	12.68	32.09	1024.20	299.45	13.02	22.10	8.37	37.23	-0.56
909	8-Jun-09	12	48.97	-130.66	10.00	5.30	11.33	32.41	1024.70	286.21	5.26	21.04	3.15	37.17	-0.46
909	10-Jun-09	16	49.29	-134.68	40.00	73.91	6.38	32.49	1025.52	301.28	-0.61	20.29	-0.62	36.98	-0.09
909	10-Jun-09	16	49.29	-134.68	40.00	73.91	6.38	32.49	1025.52	301.28	-0.61	20.26	-0.77	36.72	-0.79
909	10-Jun-09	16	49.29	-134.68	40.00	39.61	7.54	32.48	1025.36	308.53	4.49	21.13	3.52	37.00	-0.24
909	10-Jun-09	16	49.29	-134.68	40.00	39.61	7.54	32.48	1025.36	308.53	4.49	21.12	3.47	36.98	-0.29
909	10-Jun-09	16	49.29	-134.68	40.00	19.49	9.01	32.46	1025.13	308.51	7.96	21.58	5.75	36.81	-1.01

Cruise	Date	Station	Lat	Long	Cast	Depth	Ptmp	Sal	Dens	O_2	ΔO_2	O_2/Ar	Δ O_2/Ar	N_2/Ar	ΔN_2/Ar
909	10-Jun-09	16	49.29	-134.68	40.00	19.49	9.01	32.46	1025.13	308.51	7.96	21.61	5.90	37.02	-0.45
909	10-Jun-09	16	49.29	-134.68	40.00	5.22	10.97	32.44	1024.79	285.37	4.17	20.66	1.28	37.15	-0.45
909	12-Jun-09	20	49.57	-138.68	56.00	5.12	10.76	32.49	1024.86	292.32	6.27	21.00	2.94	37.10	-0.55
909	12-Jun-09	20	49.57	-138.68	56.00	5.12	10.76	32.49	1024.86	292.32	6.27	21.00	2.94	37.11	-0.52
909	14-Jun-09	26	50.01	-145.00	75.00	4.85	9.47	32.54	1025.12	294.54	4.17	20.80	1.94	37.04	-0.47
909	14-Jun-09	26	50.01	-145.00	75.00	4.85	9.47	32.54	1025.12	294.54	4.17	20.78	1.84	36.82	-1.06
909	14-Jun-09	26	50.01	-145.00	75.00	29.80	8.23	32.55	1025.32	307.80	5.93	21.19	3.82	36.96	-0.47
909	14-Jun-09	26	50.01	-145.00	75.00	50.48	6.63	32.57	1025.55	309.34	2.68	20.82	1.98	36.71	-0.86
909	14-Jun-09	26	50.01	-145.00	75.00	50.48	6.63	32.57	1025.55	309.34	2.68	20.82	1.98	36.72	-0.83
909	14-Jun-09	26	50.01	-145.00	75.00	74.36	5.88	32.59	1025.66	306.40	-0.02	20.38	-0.19	36.90	-0.21
909	14-Jun-09	26	50.01	-145.00	75.00	98.85	5.15	32.62	1025.77	303.37	-2.67	19.97	-2.22	36.63	-0.81
909	14-Jun-09	26	50.01	-145.00	75.00	98.85	5.15	32.62	1025.77	303.37	-2.67	20.05	-1.82	36.98	0.14
909	14-Jun-09	26	50.01	-145.00	75.00	123.35	4.82	32.87	1026.01	278.28	-11.25	18.23	-10.74	36.95	0.13
909	14-Jun-09	26	50.01	-145.00	75.00	123.35	4.82	32.87	1026.01	278.28	-11.25	18.27	-10.54	36.80	-0.28
909	14-Jun-09	26	50.01	-145.00	74.00	148.14	4.81	33.44	1026.46	214.92	-31.18	14.23	-30.32	36.85	-0.11
909	14-Jun-09	26	50.01	-145.00	74.00	148.14	4.81	33.44	1026.46	214.92	-31.18	13.84	-32.23	37.11	0.59
909	14-Jun-09	26	50.01	-145.00	74.00	174.00	4.61	33.69	1026.68	162.61	-48.08	10.69	-47.66	37.11	0.64
909	14-Jun-09	26	50.01	-145.00	74.00	174.00	4.61	33.69	1026.68	162.61	-48.08	10.73	-47.46	37.08	0.56
909	14-Jun-09	26	50.01	-145.00	74.00	198.31	4.42	33.73	1026.73	139.47	-55.66	9.13	-55.30	37.11	0.68
909	14-Jun-09	26	50.01	-145.00	74.00	198.31	4.42	33.73	1026.73	139.47	-55.66	9.19	-55.00	37.09	0.62
909	14-Jun-09	26	50.01	-145.00	74.00	246.28	4.16	33.79	1026.81	106.93	-66.19	6.92	-66.12	36.96	0.32
909	14-Jun-09	26	50.01	-145.00	74.00	495.25	3.90	34.09	1027.07	34.70	-89.07	2.06	-89.91	37.33	1.38

Cruise	Date	Station	Lat	Long	Cast	Depth	Ptmp	Sal	Dens	O_2	ΔO_2	O_2/Ar	Δ O_2/Ar	N_2/Ar	ΔN_2/Ar
909	14-Jun-09	26	50.01	-145.00	74.00	495.25	3.90	34.09	1027.07	34.70	-89.07	2.21	-89.18	36.97	0.40
910	21-Aug-09	4	48.66	-126.68	11.00	75.05	7.39	32.91	1025.72	233.96	-20.77	15.99	-21.66	37.22	0.40
910	21-Aug-09	4	48.66	-126.68	11.00	75.05	7.39	32.91	1025.72	233.96	-20.77	16.01	-21.57	37.21	0.37
910	21-Aug-09	4	48.66	-126.68	11.00	20.03	11.87	32.31	1024.53	281.44	4.61	20.58	0.91	37.33	-0.14
910	21-Aug-09	4	48.66	-126.68	11.00	20.03	11.87	32.31	1024.53	281.44	4.61	20.60	1.00	37.32	-0.17
910	21-Aug-09	4	48.66	-126.68	11.00	10.81	12.32	32.25	1024.39	285.65	7.13	21.07	3.32	37.39	-0.06
910	21-Aug-09	4	48.66	-126.68	11.00	10.81	12.32	32.25	1024.39	285.65	7.13	21.06	3.27	37.36	-0.14
910	21-Aug-09	4	48.66	-126.68	15.00	5.35	13.41	32.20	1024.14	291.02	11.58	22.23	9.02	37.42	-0.18
910	21-Aug-09	4	48.66	-126.68	15.00	5.35	13.41	32.20	1024.14	291.02	11.58	22.16	8.68	37.42	-0.18
910	23-Aug-09	12	48.97	-130.67	28.00	5.31	15.79	32.27	1023.70	257.79	3.69	20.76	1.86	37.65	-0.01
910	23-Aug-09	12	48.97	-130.67	28.00	5.31	15.79	32.27	1023.70	257.79	3.69	20.78	1.95	37.62	-0.09
910	31-Aug-09	16	49.29	-134.68	68.00	74.27	7.29	32.53	1025.43	302.48	1.92	20.51	0.47	37.11	0.10
910	31-Aug-09	16	49.29	-134.68	68.00	29.80	15.06	32.47	1024.01	259.14	2.89	20.76	1.85	37.66	0.16
910	31-Aug-09	16	49.29	-134.68	68.00	29.80	15.06	32.47	1024.01	259.14	2.89	20.73	1.70	37.62	0.06
910	31-Aug-09	16	49.29	-134.68	68.00	4.71	15.14	32.48	1024.00	257.95	2.59	20.69	1.50	37.67	0.18
910	31-Aug-09	16	49.29	-134.68	68.00	4.71	15.14	32.48	1024.00	257.95	2.59	20.71	1.60	37.64	0.10
910	29-Aug-09	20	49.57	-138.68	60.00	4.44	13.44	32.48	1024.35	263.43	1.26	20.62	1.13	37.48	-0.02
910	29-Aug-09	20	49.57	-138.68	60.00	4.44	13.44	32.48	1024.35	263.43	1.26	20.61	1.08	37.51	0.06
910	28-Aug-09	26	50.01	-145.01	49.00	4.95	12.67	32.47	1024.50	269.31	1.89	20.73	1.66	37.48	0.12
910	28-Aug-09	26	50.01	-145.01	49.00	4.95	12.67	32.47	1024.50	269.31	1.89	20.71	1.56	37.48	0.12
910	27-Aug-09	26	50.00	-145.01	47.00	9.92	12.54	32.46	1024.52	269.41	1.65	20.58	0.92	37.56	0.36
910	27-Aug-09	26	50.00	-145.01	47.00	9.92	12.54	32.46	1024.52	269.41	1.65	20.65	1.26	37.50	0.20

Cruise	**Date**	**Station**	**Lat**	**Long**	**Cast**	**Depth**	**Ptmp**	**Sal**	**Dens**	**O_2**	**ΔO_2**	**O_2/Ar**	**Δ O_2/Ar**	**N_2/Ar**	**ΔN_2/Ar**
910	27-Aug-09	26	50.00	-145.01	47.00	21.39	12.45	32.47	1024.54	271.62	2.30	20.68	1.41	37.51	0.24
910	27-Aug-09	26	50.00	-145.01	47.00	21.39	12.45	32.47	1024.54	271.62	2.30	20.60	1.01	37.49	0.19
910	27-Aug-09	26	50.00	-145.01	47.00	30.31	12.42	32.47	1024.55	270.91	1.97	20.66	1.31	37.49	0.20
910	27-Aug-09	26	50.00	-145.01	47.00	30.31	12.42	32.47	1024.55	270.91	1.97	20.66	1.31	37.32	-0.26
910	27-Aug-09	26	50.00	-145.01	47.00	49.76	8.51	32.59	1025.31	292.45	1.33	20.43	0.11	37.17	0.05
910	27-Aug-09	26	50.00	-145.01	47.00	49.76	8.51	32.59	1025.31	292.45	1.33	20.42	0.06	37.17	0.05
910	28-Aug-09	26	50.00	-145.01	51.00	75.61	6.09	32.64	1025.68	298.79	-1.98	19.89	-2.59	37.06	0.19
910	28-Aug-09	26	50.00	-145.01	51.00	75.61	6.09	32.64	1025.68	298.79	-1.98	19.88	-2.64	37.05	0.16
910	28-Aug-09	26	50.01	-145.01	49.00	100.82	5.66	32.66	1025.74	299.84	-2.61	19.77	-3.18	37.01	0.13
910	28-Aug-09	26	50.01	-145.01	49.00	100.82	5.66	32.66	1025.74	299.84	-2.61	19.77	-3.18	37.01	0.13
910	28-Aug-09	26	50.01	-145.01	49.00	149.83	5.33	33.44	1026.40	234.62	-23.94	15.53	-23.95	37.14	0.58
910	28-Aug-09	26	50.01	-145.01	49.00	149.83	5.33	33.44	1026.40	234.62	-23.94	15.56	-23.80	37.12	0.53
910	28-Aug-09	26	50.01	-145.01	49.00	195.89	4.64	33.67	1026.66	163.06	-47.91	10.59	-48.15	37.12	0.66
910	28-Aug-09	26	50.01	-145.01	49.00	195.89	4.64	33.67	1026.66	163.06	-47.91	10.60	-48.10	37.13	0.69
910	28-Aug-09	26	50.01	-145.01	49.00	246.53	4.25	33.70	1026.72	120.74	-61.77	7.65	-62.55	37.09	0.65
910	28-Aug-09	26	50.01	-145.01	49.00	246.53	4.25	33.70	1026.72	120.74	-61.77	7.65	-62.55	37.12	0.73

Appendix B. O_2/Ar based estimates of NCP along Line P

Description of variable names:

Cruise – Line P cruises are typically numbered in the format YEAR-XX (eg. 2007-01). Cruise numbers shown here correspond to the last 3 digits of these official cruise numbers, so 2007-01 becomes 701.

Date – Sampling date

Station – Major station (4, 12, 16, 20, or 26) along Line P where samples were collected

MLdpth – Mixed layer depth in meters

MLtmp – Longitude in degrees East

MLsal – Mixed layer salinity expressed on the Practical salinity scale.

MLdens – Depth in meters

O_2/Ar – O_2/Ar concentration in umol/kg determined from O_2/Ar mass spectrometry measurements.

ΔO_2/Ar – Supersaturation of O_2/Ar in percent. 0% indicates that the O_2/Ar concentration is in equilibrium for the potential temperature and salinity of the water. ie. $\Delta O_2/Ar = (O_2/Ar - O_{2eq}/Ar_{eq})/(O_{2eq}/Ar_{eq}) * 100$. O_2 supersaturation is calculated relative to the solubility curve of *Garcia and Gordon* (1992). Ar supersaturation is calculated relative to the solubility curve of *Hamme and Emerson* (2004).

k_{O2} – 60-day mean gas exchange coefficient for O_2 calculated from the wind speed parameterization of *Ho et al.* (2006) and the 6-hourly NCEP/QuikSCAT blended wind product provided by Colorado Research Associates (http://dss.ucar.edu/datasets/ds744.4/) and then averaged using the weighting scheme of *Reuer et al.* (2007).

NCP – Net Community O_2 Production calculated from the mean gas exchange coefficient and O_2/Ar supersaturation. See Section 2.1.1 for details on the calculation.

NaN = missing data.

Table B1. Estimates of Net Community Production at the major stations along Line P from February 2007 to August 2009.

Cruise	Date	Station	MLdpth	MLtmp	MLsal	MLdens	O_2/Ar	ΔO_2/Ar	k_{O2}	NCP
701	9-Feb-07	4	75	8.79	32.41	1025.12	20.18	-0.01	6.01	NaN
701	10-Feb-07	12	90	8.41	32.44	1025.20	20.46	0.00	7.23	3.48
701	11-Feb-07	16	80	7.09	32.41	1025.37	20.66	0.01	6.01	12.46
701	12-Feb-07	20	110	6.73	32.51	1025.49	20.58	0.01	6.18	10.39
701	15-Feb-07	26	110	5.67	32.58	1025.68	20.31	-0.01	6.97	NaN
713	1-Jun-07	4	15	11.50	31.53	1023.98	22.67	0.11	7.12	75.95
713	2-Jun-07	12	20	10.60	32.49	1024.89	21.11	0.03	5.78	16.16
713	3-Jun-07	16	35	9.01	32.52	1025.18	20.88	0.02	8.14	21.19
713	4-Jun-07	20	42	8.46	32.41	1025.17	20.91	0.02	7.84	25.83
713	8-Jun-07	26	45	7.06	32.63	1025.54	20.96	0.03	7.66	26.77
715	16-Aug-07	4	18	17.34	31.76	1022.95	20.81	0.02	5.28	9.47
715	18-Aug-07	12	12	16.22	32.15	1023.51	20.79	0.02	6.24	9.71
715	19-Aug-07	16	15	15.11	32.35	1023.90	21.17	0.04	5.02	14.76
715	20-Aug-07	20	17	13.60	32.37	1024.24	21.34	0.05	7.30	30.81
715	22-Aug-07	26	25	12.42	32.47	1024.54	20.83	0.02	6.83	13.06
801	2-Feb-08	4	75	7.81	32.43	1025.29	20.22	-0.01	6.50	NaN
801	4-Feb-08	12	97	6.94	32.49	1025.45	20.26	-0.01	7.67	NaN
801	5-Feb-08	16	90	5.98	32.53	1025.60	20.14	-0.01	8.82	NaN
801	7-Feb-08	20	112	5.79	32.59	1025.67	20.26	-0.01	9.28	NaN
801	9-Feb-08	26	91	4.89	32.63	1025.81	20.25	-0.01	8.75	NaN
826	1-Jun-08	4	8	11.48	31.98	1024.34	22.39	0.10	4.29	31.91
826	3-Jun-08	12	50	8.86	32.49	1025.17	20.94	0.03	7.03	22.40

Cruise	Date	Station	MLdpth	MLtmp	MLsal	MLdens	O_2/Ar	ΔO_2/Ar	k_{O2}	NCP
826	4-Jun-08	16	40	8.23	32.52	1025.29	20.71	0.01	6.95	13.35
826	5-Jun-08	20	46	7.30	32.57	1025.46	20.76	0.02	7.82	17.37
826	10-Jun-08	26	35	6.63	32.66	1025.63	20.96	0.03	6.84	22.26
827	14-Aug-08	4	12	15.18	32.18	1023.76	21.43	0.05	6.79	25.70
827	16-Aug-08	12	8	15.44	32.39	1023.87	21.98	0.08	4.95	27.19
827	19-Aug-08	20	22	12.65	32.42	1024.46	21.78	0.07	8.37	47.89
827	21-Aug-08	26	30	11.25	32.49	1024.78	21.60	0.06	9.03	65.47
903	29-Jan-09	4	30	7.55	31.91	1024.91	20.11	-0.01	6.35	NaN
903	1-Feb-09	12	75	7.64	32.45	1025.32	20.53	0.01	7.70	NaN
903	2-Feb-09	16	100	6.90	32.41	1025.39	20.51	0.00	7.62	NaN
903	2-Feb-09	20	100	6.40	32.45	1025.49	20.49	0.00	7.41	NaN
903	5-Feb-09	26	95	6.03	32.57	1025.63	20.47	0.00	8.47	NaN
909	8-Jun-09	4	11	12.68	32.09	1024.20	22.11	0.08	4.57	26.52
909	8-Jun-09	12	28	11.33	32.41	1024.70	21.04	0.03	7.30	21.70
909	10-Jun-09	16	20	9.66	32.45	1025.02	21.28	0.04	6.15	23.56
909	12-Jun-09	20	15	10.76	32.49	1024.86	21.00	0.03	5.40	11.68
909	14-Jun-09	26	31	9.06	32.54	1025.19	20.92	0.03	5.76	13.64
910	21-Aug-09	4	20	13.41	32.20	1024.14	22.20	0.09	5.52	53.30
910	23-Aug-09	12	35	15.79	32.27	1023.70	20.77	0.02	7.38	16.67
910	31-Aug-09	16	35	15.10	32.48	1024.00	20.72	0.02	8.75	20.63
910	29-Aug-09	20	35	13.44	32.48	1024.35	20.62	0.01	10.41	16.05
910	28-Aug-09	26	35	12.52	32.47	1024.52	20.66	0.01	8.86	20.85

Appendix C. Incubation-based estimates of productivity along Line P

Description of variable names:

Cruise – Line P cruises are typically numbered in the format YEAR-XX (eg. 2007-01). Cruise numbers shown here correspond to the last 3 digits of these official cruise numbers, so 2007-01 becomes 701.

Date – Sampling date

Station – Major station (4, 12, 16, 20, or 26) along Line P where samples were collected

Depth – Mixed layer depth in meters

%I_o – % Surface PAR (photosynthetically active radiation) as measured by the PAR sensor on the rosette

NO_3^-– Nitrate (and nitrite) concentration in µmol/L

NH_4^+ – Ammonium concentration in µmol/L

DIC – Dissolved inorganic carbon concentration in µmol/L

Chl *a* – Chlorophyll *a* concentration in µg/L

PN1 – Particulate Nitrogen concentration in µmol/L from NO_3^- incubation

PN2 – Particulate Nitrogen concentration in µmol/L from NH_4^+ incubation

PC – Average Particulate Carbon concentration in µmol/L

New – 24 hr Euphotic zone integrated $^{15}NO_3^-$ based new production

Regen – 24 hr Euphotic zone integrated $^{15}NH_4^+$ based regenerated production

CPP – 24 hr Euphotic zone integrated ^{13}C based carbon production

NaN = missing data.

Table C1. Estimates of 24-hr incubation based New, Regenerated and Carbon based production and associated biological and chemical measurements at the major stations along Line P from February 2007 to August 2009.

Cruise	Date	Stn	Dpth	%I_o	NO_3^-	NH_4^+	DIC	Chl *a*	PN1	PN2	PC	New	Regen	CPP
827	21-Aug-08	26	1.40	100	7.40	0.09	2035.71	NaN	NaN	4.21	59.04	NaN	613.62	1.88
827	21-Aug-08	26	7.00	55	7.70	0.09	2035.71	NaN	4.02	4.43	59.19	494.73	728.60	2.66
827	21-Aug-08	26	9.50	30	7.80	0.09	2036.46	NaN	4.32	4.05	58.58	436.43	697.16	2.26
827	21-Aug-08	26	18.80	10	7.80	0.15	2037.77	NaN	NaN	4.10	57.36	NaN	737.60	1.59
827	21-Aug-08	26	37.50	1	14.50	0.54	2104.21	NaN	1.07	0.96	14.22	11.08	57.07	0.01
903	30-Jan-09	4	1.50	100	13.40	0.08	2064.52	1.66	0.67	0.71	5.31	16.15	19.59	0.31
903	30-Jan-09	4	4.50	55	13.50	0.07	2064.92	1.64	1.41	1.48	10.19	182.55	62.70	2.07
903	30-Jan-09	4	7.50	30	13.50	0.08	2065.82	1.61	1.62	1.71	11.74	197.62	82.37	2.24
903	30-Jan-09	4	15.00	10	12.70	0.09	2070.87	1.45	1.55	1.52	10.82	136.32	66.05	1.00
903	30-Jan-09	4	47.00	1	9.30	0.12	2072.15	0.37	1.31	1.39	8.29	11.29	25.13	0.03
903	01-Feb-09	16	1.00	100	11.50	0.09	2070.67	0.34	0.79	0.74	6.11	16.36	34.19	0.32
903	01-Feb-09	16	9.00	55	11.60	0.03	2070.79	0.33	0.74	0.78	6.20	12.99	13.51	0.20
903	01-Feb-09	16	19.00	30	11.60	0.03	2070.16	0.34	0.85	0.90	5.93	10.53	16.34	0.09
903	01-Feb-09	16	38.00	10	11.70	0.03	2069.51	0.35	0.87	0.69	6.32	5.39	7.71	0.03
903	01-Feb-09	16	80.00	1	11.70	0.05	2077.92	0.35	0.89	0.74	6.43	6.51	4.37	0.00
903	05-Feb-09	26	2.74	100	14.50	0.09	2094.69	0.39	0.99	0.79	6.32	23.63	34.26	0.41
903	05-Feb-09	26	5.48	30	14.60	0.00	2094.01	0.37	1.04	0.76	6.87	22.96	7.34	0.22
903	05-Feb-09	26	29.22	10	14.70	0.00	2095.53	0.36	0.84	0.86	7.88	25.47	10.46	0.30
903	05-Feb-09	26	48.35	1	14.50	0.00	2095.56	0.37	0.64	0.88	6.54	4.97	3.70	0.01
909	07-Jun-09	4	1.51	100	0.00	0.00	1998.35	0.49	2.16	2.15	14.54	78.24	34.64	1.50
909	07-Jun-09	4	5.16	55	0.00	0.00	1998.61	0.52	1.81	2.69	15.71	73.60	35.34	1.81

Cruise	Date	Stn	Dpth	%I_o	NO_3^-	NH_4^+	DIC	Chl *a*	PN1	PN2	PC	New	Regen	CPP
909	07-Jun-09	4	8.21	30	0.00	0.00	2003.65	0.52	2.14	2.30	15.80	81.35	36.07	1.84
909	07-Jun-09	4	13.00	10	0.10	0.00	2013.12	0.67	2.35	2.34	15.42	164.14	36.82	2.06
909	07-Jun-09	4	27.68	1	4.20	0.53	2048.35	0.92	1.87	1.95	13.17	9.69	97.96	0.85
909	10-Jun-09	16	2.13	100	7.25	0.35	2048.30	0.32	1.20	1.31	9.49	18.81	138.06	0.88
909	10-Jun-09	16	6.07	55	7.30	0.34	2047.54	0.32	1.21	1.26	9.41	18.34	114.96	0.80
909	10-Jun-09	16	14.03	30	7.70	0.29	2051.87	0.33	1.28	1.30	9.49	38.04	125.79	1.06
909	10-Jun-09	16	31.10	10	8.55	0.31	2060.23	0.43	1.23	1.22	8.77	22.61	92.09	0.74
909	10-Jun-09	16	60.66	1	11.10	0.26	2078.78	0.51	1.14	0.96	8.22	3.35	53.63	0.43
909	14-Jun-09	26	2.43	100	9.90	0.27	2088.99	0.29	2.07	1.36	14.33	41.96	95.39	1.17
909	14-Jun-09	26	4.44	55	10.00	0.21	2088.21	0.28	1.46	1.45	13.05	39.83	128.99	1.24
909	14-Jun-09	26	27.72	10	10.40	0.27	2093.75	0.32	1.39	1.36	12.52	15.89	92.13	0.65
909	14-Jun-09	26	45.88	1	12.00	0.42	2107.77	0.38	1.15	1.01	10.04	1.28	36.96	0.18
910	21-Aug-09	4	2.51	100	3.00	0.41	2001.52	5.65	7.43	6.46	43.84	729.89	257.85	10.92
910	21-Aug-09	4	5.19	55	3.30	0.37	2004.64	4.73	6.63	6.76	42.98	729.05	279.00	11.94
910	21-Aug-09	4	7.04	30	4.40	0.32	2014.89	2.72	4.09	3.72	24.48	375.21	217.83	7.13
910	21-Aug-09	4	11.24	10	5.20	0.47	2027.12	1.24	2.88	2.82	17.96	54.44	321.11	3.94
910	21-Aug-09	4	24.36	1	6.50	0.90	2060.76	0.32	1.08	1.13	6.34	10.22	33.59	0.43
910	24-Aug-09	16	2.64	100	3.50	0.16	2020.78	0.32	1.54	1.61	10.39	56.65	77.76	1.50
910	24-Aug-09	16	5.61	55	3.60	0.14	2018.25	0.32	1.42	1.47	8.81	45.31	60.45	1.20
910	24-Aug-09	16	14.83	30	3.60	0.13	2018.95	0.32	1.48	1.61	9.56	42.14	61.31	1.15
910	24-Aug-09	16	33.91	10	3.60	0.15	2019.44	0.30	1.50	1.55	8.83	7.44	44.90	0.37
910	24-Aug-09	16	63.72	1	8.60	0.72	2075.75	0.29	0.88	1.18	5.63	2.60	19.02	0.20

Cruise	**Date**	**Stn**	**Dpth**	**%I$_o$**	**NO$_3^-$**	**NH$_4^+$**	**DIC**	**Chl *a***	**PN1**	**PN2**	**PC**	**New**	**Regen**	**CPP**
910	28-Aug-09	26	2.39	100	6.10	0.13	2036.74	0.39	1.66	1.90	10.98	64.66	93.51	1.21
910	28-Aug-09	26	8.53	55	6.20	0.10	2036.82	0.38	1.71	1.73	10.73	67.39	72.34	1.53
910	28-Aug-09	26	12.54	30	6.30	0.10	2039.06	0.40	2.38	1.65	14.18	42.46	62.68	0.91
910	28-Aug-09	26	30.45	10	6.40	0.17	2041.08	0.38	1.45	1.41	8.37	16.56	29.70	0.49
910	28-Aug-09	26	61.63	1	11.20	1.28	2102.79	0.30	1.00	0.87	5.78	6.77	26.57	0.36