Longterm trends in phytoplankton productivity in McMurdo Dry Valley lakes

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Introduction

The McMurdo Dry Valley LTER site (MCM) is located in the coldest, driest desert on Earth (Figure 1). Because of the delicate balance between frozen and liquid water, subtle changes in climate can have dramatic effects on the ecology of this system. Lakes are the only year-round liquid water environments in the MCM region (and on the continent), and phytoplankton growth in these lakes is light limited. <3% of incident irradiance penetrates the thick ice covers of the MCM lakes, and under-ice irradiance rarely exceeds 50 µmol photons/m^2/s. It has been suggested that light is the primary constraint on photosynthesis in these lakes. Here we use Generalized Additive Models (GAMs) and our 20 year LTER dataset to determine if photosynthetically available radiation (PAR) is the primary driver of phytoplankton productivity in the MCM lakes.

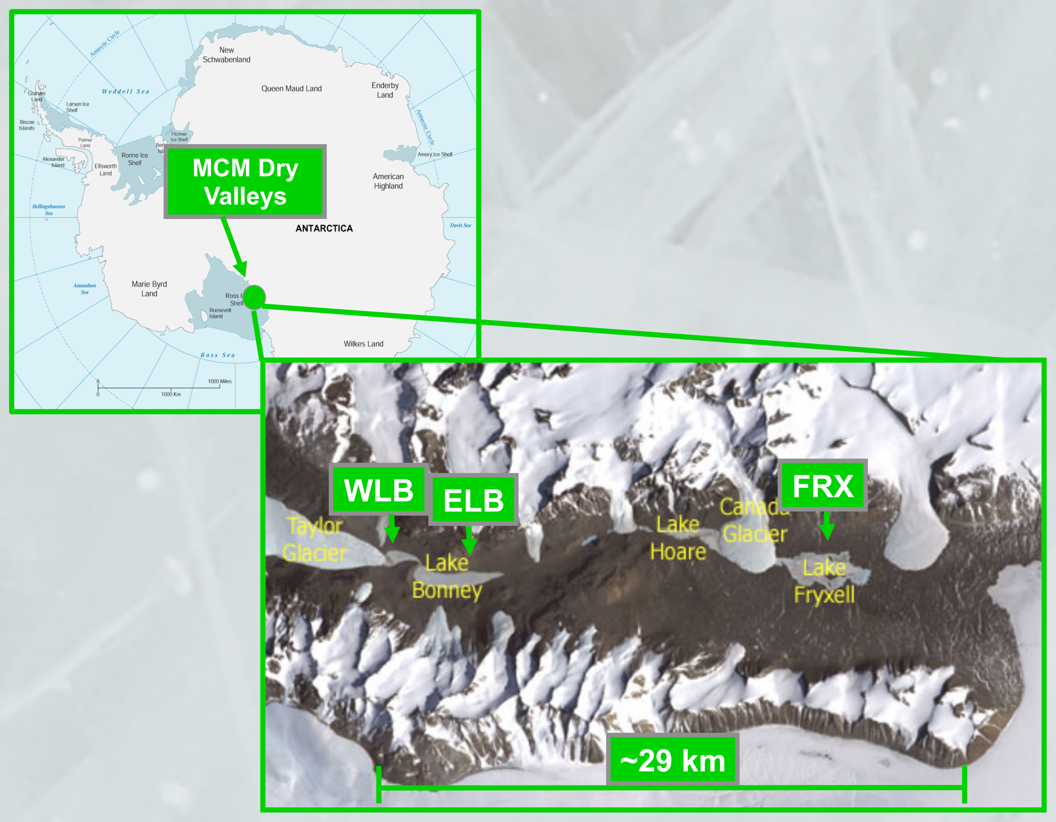


Figure 1. Location of the MCM Dry Valleys (77°S, 163°E) and the study lakes.

Methods

Sample collections were done 2-3 times annually during the austral spring and summer (Nov-Dec) from 1995-2014 in Lake Fryxell (FRX), East Lake Bonney (ELB), and West Lake Bonney (WLB).

- **PPR** was measured by ^{14}C uptake over 24 hours and integrated over the photic zone (µgC m^{-2} d^{-1}).
- **Photosynthetically Available Radiation (PAR)** was logged during PPR incubations using a LI-COR LI-193SA spherical underwater quantum sensor. PAR values were averaged over the incubation period and Beer's Law was used to calculate average incubation period PAR at each incubation depth using water column extinction coefficients calculated from vertical profiles of PAR. Average incubation period PAR was integrated over the photic zone (µmol photons m^{-1}d^{-1}).
- **Time series analysis:** Generalized Additive Models (GAMs) were used to estimate non-linear temporal trends of PPR and PAR. All temporal trend plots have a fitted trend (dark line), 95% confidence intervals (shadow areas) and raw observations (dots). At each lake, regression GAMs were used to estimate the relationship between PPR as the response variable and PAR as the predictor variable after adjusting for the time. To fit the GAMs, we used R programming (version 12.5.3) and mgcv package (Wood, 2006).

Results FRX

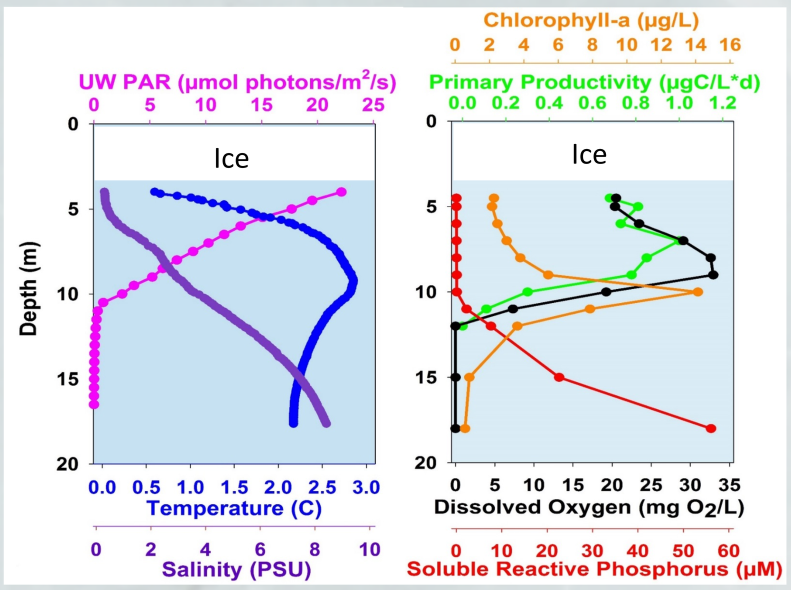
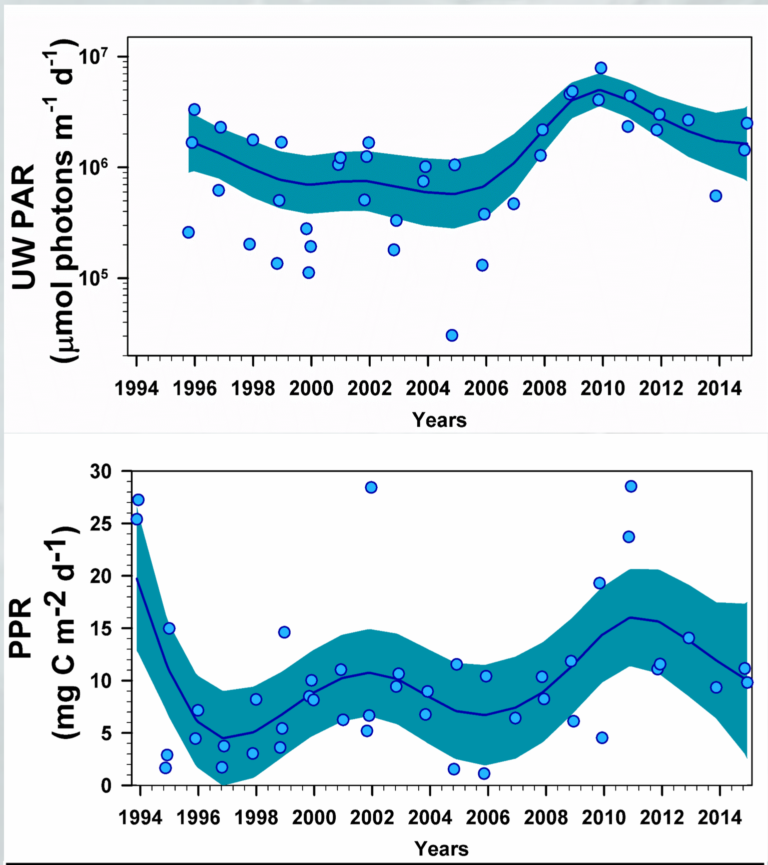


Figure 2a. Biological, chemical and physical characteristics in FRX during December 2009.

GAM Temporal Trends

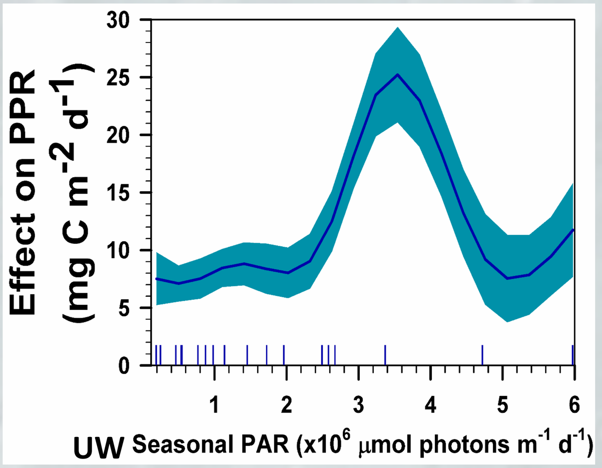


UW PAR and PPR showed significant trends over time. FRX had more complex trends compared to ELB and WLB in PAR and PPR (Figure 3a).

	edf	F	p-value	Deviance explained	Time Range
PAR	6.51	1.699	<0.0001	67.5%	1995 - 2014
PPR	6.45	1.610	0.004	42.3%	1993 - 2014

Figure 3a. UW PAR and PPR GAM trends over time for FRX.

GAM Regression: PPR vs UW PAR + time



PPR showed a positive correlation with UW PAR after adjusting for the time trend. The model explained 93.2% of the variability in PPR (Figure 4a).

Response variable	Predictor variables	edf	F	p-value	Deviance explained	Time Range
PPR	PAR	5.79	10.97	<0.001	93.2%	1995 - 2014
	Time	3.34	3.43	0.0044		

Figure 4a. PPR vs UW PAR GAM regression for FRX.

Results ELB

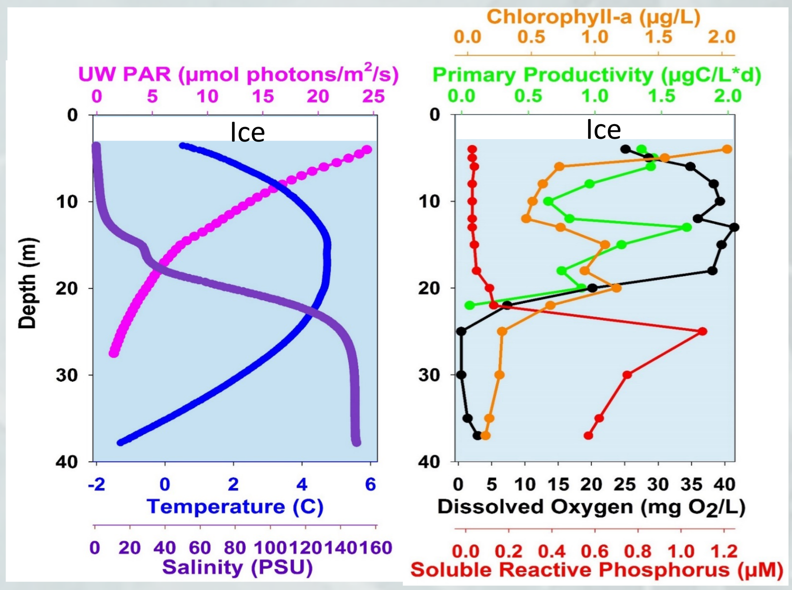
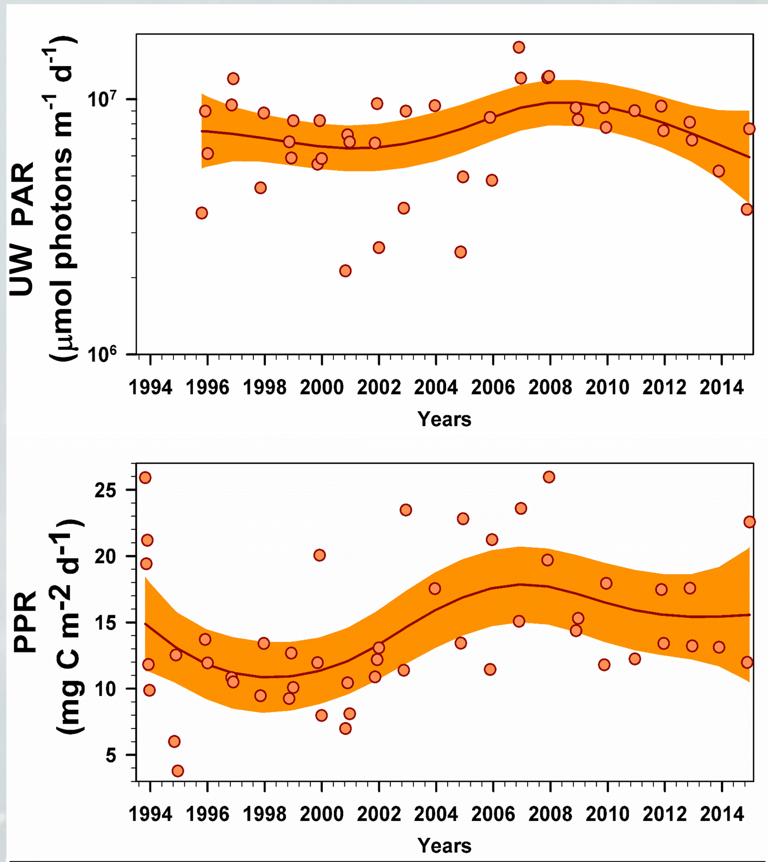


Figure 2b. Biological, chemical and physical characteristics in ELB during December 2009.

GAM Temporal Trends

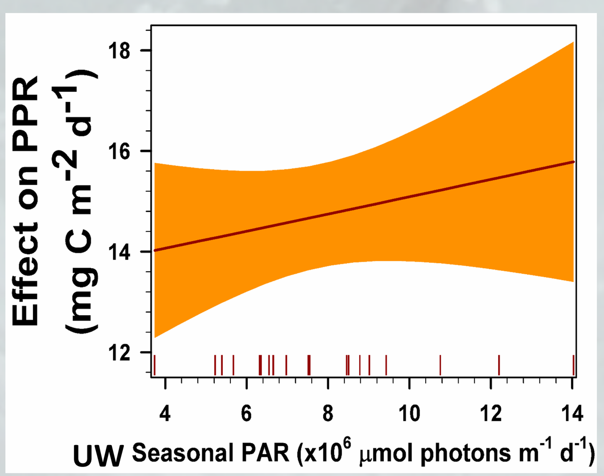


UW PAR and PPR showed significant trends over time. ELB had a more complex trend than WLB, but less than FRX, in PAR and PPR (Figure 3b).

	edf	F	p-value	Deviance explained	Time Range
PAR	3.54	0.262	0.033	24.9%	1995 - 2014
PPR	4.04	1.074	0.007	28.9%	1993 - 2014

Figure 3b. UW PAR and PPR GAM trends over time for ELB.

GAM Regression: PPR vs UW PAR + time



PPR did not show a positive correlation with UW PAR after adjusting for the time trend. The model explained only 70.3% of the variability in PPR (Figure 4b).

Response variable	Predictor variables	edf	F	p-value	Deviance explained	Time Range
PPR	PAR	0.48	0.626	0.124	70.3%	1995 - 2014
	Time	3.77	7.037	0.001		

Figure 4b. PPR vs UWPAR GAM regression for ELB.

Results WLB

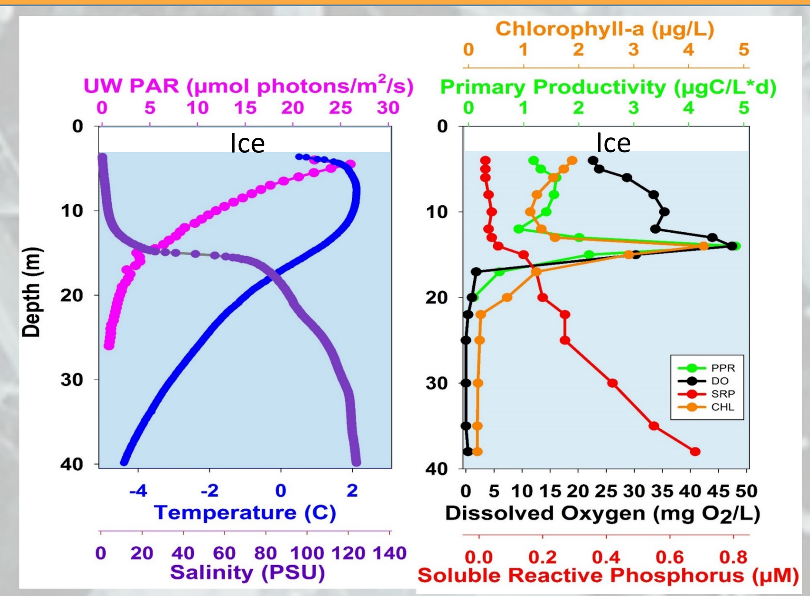
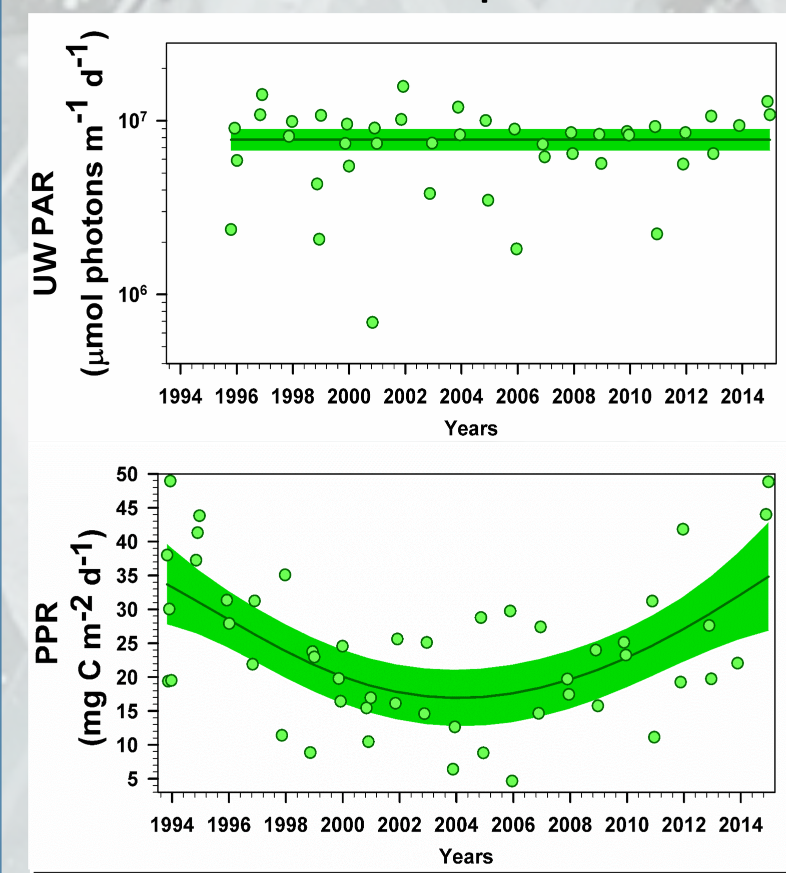


Figure 2c. Biological, chemical and physical characteristics in WLB during December 2009.

GAM Temporal Trends

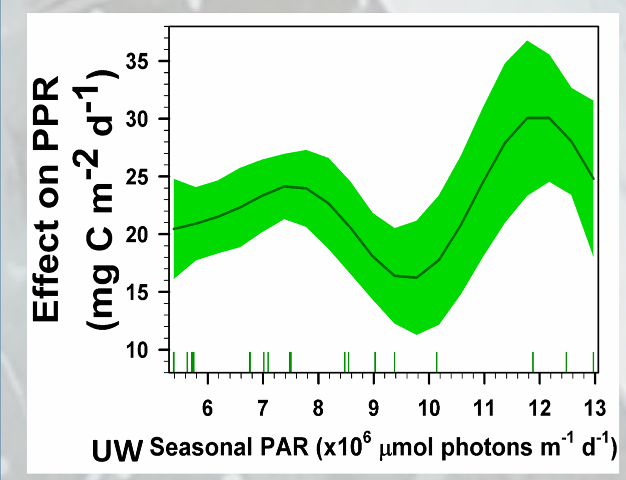


UW PAR did not show a significant trend over time. PPR showed a significant trend over time. WLB had the lowest complexity of the three lakes for PAR and PPR (Figure 3c).

	edf	F	p-value	Deviance explained	Time Range
PAR	0.00	0.000	0.629	0.0%	1995 - 2014
PPR	2.57	2.454	<0.001	40.1%	1993 - 2014

Figure 3c. UW PAR and PPR GAM trends over time for WLB.

GAM Regression: PPR vs UW PAR + time



PPR showed a positive correlation with UW PAR after adjusting for the time trend. The model explained 83.4% of the variability in PPR Figure 4c).

Response variable	Predictor variables	edf	F	p-value	Deviance explained	Time Range
PPR	PAR	4.44	3.45	0.022	83.4%	1995 - 2014
	Time	1.85	10.55	0.001		

Figure 4c. PPR vs UW PAR GAM regression for WLB.

Conclusions

UW PAR in FRX and ELB have significant trends. WLB, despite its location <1 km from ELB, does not show any trend in UW PAR, perhaps due to the high amounts of glacial till often observed in WLB.

All lakes show a significant trend in PPR, but, despite their close proximity and location in the same valley, PPR does not follow the same trend between lakes. Fryxell shows the most complex trend, followed by ELB, then WLB.

The higher complexity of the PPR and PAR trends in FRX may be explained by local climatic conditions. FRX receives higher and more uniform annual flux of incident PAR than ELB or WLB due to its open basin. However, FRX also receives more snowfall and has cloudier conditions than ELB or WLB, and has the thickest ice cover.

Our GAM regressions show that UWPAR is the primary driver of phytoplankton productivity in FRX and WLB, but not in ELB.

Phytoplankton in FRX are adapted to lower light and show less nutrient deficiency than phytoplankton in ELB or WLB, suggesting that primary productivity in FRX is more tightly coupled to light availability than phytoplankton in ELB or WLB.

Acknowledgements

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