# Air-sea exchange of $CO_2$ over a subantarctic macrocystis kelp bed

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***Figure 1: Macrocystis pyrifera***

*A substancial proportion of subantarctic coastlines is occupied by highly productive giant kelp bed Macrocystis pyrifera. This marine macroalagae is one of the largest and grows up to 50m in length, forming forest in hard-bottom subtidal area. Surface occupied by Macrocystis around kelp bed in the Kerguelen Archipelago would be about 1000 km$^2$.*


## Abstract:

**Macrophytes** has been reported to be a potential **sink of Carbon Dioxide** ($CO_2$) at a global scale in 1981. Two decades after, in the context of climate change, study of the contribution of Macrophytes to the biological pump of $CO_2$ have not advanced significantly. Diel and seasonal changes of partial pressure of $CO_2$ ($pCO_2$) and related biological parameters (phytoplankton and bacterioplankton) have been investigated during a two years survey (1996 and 1997) over some Macrocystis kelp beds surrounding the **Kerguelen Archipelago** (Indian sector of the Southern Ocean). The evolution of $pCO_2$ is regulated by kelp bed activity, phytoplanktonic and bacterial production, hydrodynamics and air-sea exchange. The contribution of each of these processes varies as a function of the considered season. Primary production has been estimated from Dissolved Inorganic Carbon (DIC). In summer, **Net Primary Production (NPP)** could reach **4.2 gC.m$^{-2}$.d$^{-1}$** and **gross primary production (GPP)** up to **40 gC.m$^2$.d$^{-1}$** have been observed. From August to April the primary production of kelp beds keeps $pCO_2$ below the threshold of saturation. Thereafter, **air-sea exchange** of $pCO_2$ over the year have been estimated to range from **–16 to –33 gC.m$^{-2}$.yr$^{-1}$** depending of the air-sea exchange coefficient considered.


## Objectives:

Macrophytes could contribute significantly to the sink of atmospheric $CO_2$ by primary production because of :

- a high biomass (about two-thirds of oceanic plant biomass)
- high primary production
- high turnover time compared to phytoplankton

We aim to asses the uptake of $CO_2$ by primary production of the Macrocystis kelp bed and budget the air-sea exchanges of $CO_2$.

## Method:

Measurements were carried out from December 1995 to December 1997 in the Kerguelen Archipelago, Southern Ocean (Indian sector). A substantial proportion of the coastlines of the archipelago are occupied by *Macrocystis pyrifera* kelp beds. Monitoring of diel cycles have been conducted in three sites around the Archipelago. The study consisted in the monitoring of both diel and seasonal variations of $pCO_2$ and related biological parameters (Nutrients, Chlorophyll and Bacterial abundance)

$pCO_2$ and DIC was calculated from pH and Total Alkalinity using the acidity constant of Mehrbach *et al.* $pCO_2$ and DIC measurements presented here have been normalized to a constant temperature and salinity respectively.

Gross primary production have been assessed from diel cycles of DIC (DIC change over 12 hours), while seasonal variations of DIC have been used to compute net primary production (DIC changes over weekly/monthly period).

Air-sea exchange of $CO_2$ has been computed from air-sea gradients of pCO2 using windspeed measurements made in the meteorolgical station of Kergelen and the algorithms of Liss et Merlivat (1986), Wanninkhof (1992), Wanninkhof and Mc Gillis (1999) and Nightingale *et al.* (2000).

## Results:

Depending of the considered season, waters above Macrocystis pyrifera can exhibit marked diel cycles of $pCO_2$ and DIC. Taking into account chlorophyll abundance - phytoplankton - and bacterial abundance and considering diel cycles outside the kelp bed (data non shown), Diel cycles appear to be essentially due to Macrocystis though the kelp bed seems to favour phytoplankton growth. Physical factors (temperature, air-sea exchange) act to play a leading role limited to winter while organic matter decay increases sharply DIC and $pCO_2$ in autumn.

Taking into account the reduced currents in Macrocystis kelp forest, diel cycles allow us to assess that **gross primary production** of the kelp through the change in DIC over the light period of the day. During our observations, this one ranged from **15 to 40 mgC.m$^{-2}$.d$^{-1}$** while it reached hardly **10 gC.m$^{-2}$.d$^{-1}$** during summer. Over several days or weeks, DIC changes gives us an indication of the **Net Primary Production.** DIC average changes over spring yield to NPP around 0.25 gC.m$^{-2}$.d$^{-1}$. However over shorter period (week) which are less biased by advection, NPP between **2** and **4 gC.m$^{-2}$.d$^{-1}$** were observed. These values are in the range of previous observations of productivity of Macrocystis in California (2.7-3.6 gC.m$^{-2}$.d$^{-1}$ ).

Air-sea exchange of $pCO_2$ have been computed from diel cycles of $pCO_2$ and integrated over the year. Depending of the algorithm used for the calculation of the exchange coefficient, overall fluxes range from **16 to 33 gC.m$^{-2}$.d$^{-1}$** . In spite of a large primary production, overall fluxes do not reflect diel uptake of $CO_2$ because of the advection of surrounding water in the kelp bed.

## Conclusion:

Growth of Macrocystis pyrifera kelp bed leads to a strong uptake of $CO_2$ reflected in the diel cycles of $pCO_2$. Hence, the kelp bed is likely to act as a strong sink of $CO_2$ with regard to atmospheric $CO_2$. However, advection processes bias computation of the annual budget of air-sea exchange of $CO_2$. Hence, other strategies are needed to assess the role played by Macrophytes with regard to atmospheric $CO_2$.

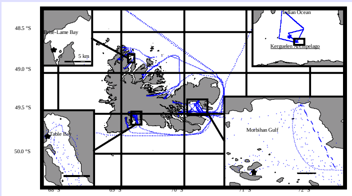


***Figure 2: Sampling sites***

*Measurements were carried out from December 1995 to December 1997 in the Kerguelen Archipelago, Southern Ocean (Indian sector). Usually, Kerguelen Archipelago is cited in the literature as a subantarctic island. However, from a strict oceanographic point of view, this archipelago is situated either in the Polar Frontal Zone or in the Antarctic Zone depending of the position of the Polar Front with regards to the Island.*

*Monitoring of diel cycles have been conducted in three sites around the Archipelago.*

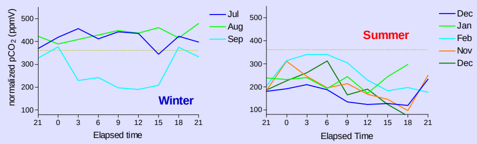



***Figure 3: Diel cycles of $pCO_2$***

*In winter, $pCO_2$ over Macrocystis kelp bed in the Morbiahn gulf is above the threshold of saturation and exhibits weak changes. These latter are due to physical factors as air-sea exchange and advection.*

*In summer, waters above kelp bed are strongly undersaturated. $pCO_2$ pattern exhibited an obvious diel cycle with a maximum at night and a minimum in the afternoon accordingly to photosynthetic activity. Large changes of $pCO_2$ are observed, and strong primary production leads to a sharp decrease of $pCO_2$ until 80 ppmV.*

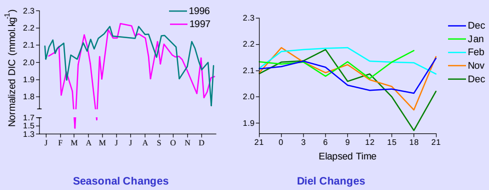



***Figure 4: Seasonal and Diel cycles of DIC***

*Left: Seasonal changes of DIC In the Morbihan gulf at 2 p.m.: Seasonal changes of DIC are well marked and exhibited a decrease which begins at the end of the winter to reach a minimum in summer well below winter value (between 0.4 and 0.6 mmol.kg$^{-1}$ less)*

*Right: Diel cycle of DIC in summer in the Morbihan Gulf: diel cycles appear obviously. DIC decreases steadily to reach a minimum in the afternoon and increases sharply at the sunset. Magnitudes of changes range between 0.1 and 0.3 mmol.kg$^{-1}$ over 12 hours.*

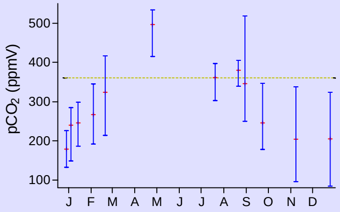
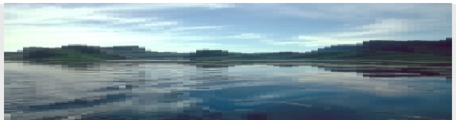



***Figure 5: Diel average of $pCO_2$ and magnitude of diel changes***

*Blue bars represent the range of diel changes (none the errors) whereas red dash represent the diel averages of $pCO_2$ for both the Morbihan gulf and Brise-lame Bay.*

*Waters above kelp beds appear to be a source of $CO_2$ from April to September, with weak diurnal changes. In spring, diurnal average $pCO_2$ is decreasing to reach a minimum in December-January. Then, magnitudes of diel cyles are the strongest, reaching 200 ppmV.*



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