2007 PICES workshop on "*Measuring and monitoring primary productivity in the North Pacific*"

by Paul J. Harrison and Sei-ichi Saitoh

Marine net primary productivity is a key metric of ecosystem health and carbon cycling, and is commonly a function of plant biomass, incident solar flux, and a scaling parameter that accounts for variations in algal physiology. Net primary productivity is defined as the amount of photosynthetically fixed carbon available to the first heterotrophic level, and is the relevant metric for addressing environmental questions ranging from trophic energy transfer to the influence of biological processes of carbon cycling. Long-term monitoring of primary productivity is a high priority for PICES member countries, because it is one of the essential parameters needed for the understanding of marine ecosystems and biogeochemistry. Recently, measurement technology of primary production has become extremely advanced through the application of fast repetition rate fluorometers, satellites, buoys, *etc*. However, inconsistencies between *in situ* measurements and satellites still exist, and there are some differences between the values obtained with ^{13}C and ^{14}C isotopic methodology. The workshop on "*Measuring and monitoring primary productivity in the North Pacific*" was developed by the BIO (Biological Oceanography) and MONITOR Committees and was held on October 27, 2007, at the PICES Sixteenth Annual Meeting in Victoria, Canada. The convenors were Drs. Paul J. Harrison (Hong Kong University of Science and Technology, Hong Kong) and Sei-ichi Saitoh (Hokkaido University, Japan).

Workshop convenors: Drs. Sei-ichi Saitoh (Japan) and Paul J. Harrison (Hong Kong).

The workshop aimed to discuss the state-of-the-art of primary productivity measurement technology and its application to understanding primary productivity in the North Pacific. There were 2 invited and 4 contributed talks and 1 poster. Presentations addressed techniques for measuring primary productivity, compared *in situ* and satellite measurements of primary productivity, demonstrated the utility of long time series measurements in understanding ecosystem variability, and described the application of primary productivity studies to marine ecosystems and biogeochemistry.

Our first invited speaker, Dr. Michael Behrenfeld (Oregon State University, U.S.A.), gave an excellent overview of the differing seasonal cycles in North Pacific phytoplankton discerned through changes in chlorophyll (Chl) and carbon (C) biomass, and discussed the implications of these two different viewpoints on uncertainties in net primary productivity estimates. Discrepancies between Chl and C biomass reflect physiological acclimations to light, nutrient and temperature variability. Light variability plays an important role in Chl:C changes throughout the North Pacific, but in the eastern subarctic, iron stress also has a major effect. He raised a number of questions for future studies which are highlighted in the recommendations.

In another invited talk, Dr. Toshiro Saino (Nagoya University, Japan) explained his new *in situ* ocean primary productivity profiling system that was developed to measure ocean primary productivity for real time validation of satellite-derived primary productivity estimations. The system uses a fast repetition rate flourometer (FRRF) installed on a profiling buoy tethered to an underwater winch. These FRRF measurements of gross primary productivity were compared with the oxygen-17 anomaly in dissolved oxygen, which measures gross primary productivity over time scales of a week to 10 days. It was also suggested that if the oxygen-17 anomaly method is combined with the oxygen/argon (or nitrogen) ratio, it can provide, in addition to gross primary production, net community production and total (algal + heterotrophic) respiration, which are parameters that are central in carbon cycle studies. The FRRF measurement could *objectively* be validated with that method, and hence the FRRF measurements could be a standard method of primary productivity measurement in place of ^{14}C incubations. The use of FRRF measurements for validation of satellite-based estimates of gross primary productivity was recommended.

Dr. Sinjae Yoo (Korean Ocean Research and Development Institute, Korea) reported on the challenges of measuring Chl and primary productivity in the very turbid Yellow Sea. He divided the Yellow Sea into different zones and different seasons. In the center of the Yellow Sea, estimates were more accurate in summer than in winter, because the Yellow Sea is very turbid in winter due to wind mixing which produces a large overestimate of chlorophyll.

Workshop invited speakers: Drs. Toshiro Saino (Japan) and Michael Behrenfeld (U.S.A.).

Dr. Sei-ichi Saitoh showed that primary productivity is increased several weeks after the passage of the typhoons, with slow passage of the typhoon and strongest winds giving the highest primary productivity. The number of typhoons has increased in the last 15 years and average primary productivity has increased also; these increases may be related to the warming of the sea surface. Typhoons appear to be more frequent in warmer El Niño years.

Drs. Akihiro Shiomoto (Tokyo University of Agriculture, Japan) and Paul Harrison discussed primary productivity in the North Pacific. Dr. Shiomoto reported that primary productivity in winter is 2 to 3 times lower at Station KNOT (NW Pacific) due to lower light, compared to Station P (NE Pacific). Also at Station P, the photic zone is deeper (80 m *vs*. 55 m at Station KNOT). Primary productivity saturates at about 3 Ein m^{-2} d^{-1} at Station P and around 18 Ein m^{-2} d^{-1} at Station KNOT. In summer, Station P has about 1.6 times greater primary productivity than Station KNOT.

Dr. Harrison reviewed the variability in chlorophyll and primary productivity in the NE Pacific. While Chl appears to be relatively constant at about 0.4 μg/L over the annual cycle, small blooms greater than 1 μg/L have been observed in June and August/September, and some of the blooms are sub-surface. Blooms of coccolithophores also occur and cause problems for remote sensing estimates of Chl. Although the NE Pacific appears to have a relatively constant Chl and only a factor of 2 or 3 seasonal increase in primary productivity, episodic larger variations could be caused by eddies moving offshore and injections of iron from dust deposition and some vertical mixing.

Discussion led to the following recommendations:

- The SeaWiFS operational lifespan is uncertain. MODIS could take over from SeaWiFS if it fails, but beyond MODIS there are no other satellites planned with capabilities similar to SeaWiFS and MODIS. Continuation of the ocean color climate–quality data record is of paramount importance for future advances in our understanding of ocean ecosystems and their link to climate. Given the long lead time from funding to launch, there is a serious immediate need to establish a new ocean color sensor as a priority for satellite earth observing systems. This new sensor should not simply reproduce the measurement suite of SeaWiFS and MODIS, but should reflect in its design scientific developments since these heritage sensors, including an expansion of the wavelength range (near UV to short-wave infrared) and resolution (5 nm from UV through visible). These expanded capabilities will ensure inter-comparison with heritage satellite data, support the more effective implementation of advanced spectral matching algorithms, and enable the application of future algorithms that address many of the scientific questions listed below.
- Chlorophyll alone can be a very poor proxy for net primary productivity. This conversion requires estimation of the light-saturated chlorophyll-specific carbon fixation efficiency (*i.e*., the "assimilation efficiency"), which is not readily retrieved from remote sensing. Sea surface temperature should not be used as a proxy for physiological variability in natural phytoplankton populations.
- The new "carbon-based approach" provides an avenue for addressing physiological variability from space. However, additional field studies are needed to further resolve the relationship between backscattering coefficients and phytoplankton carbon biomass, regional variations in this relationship, and the derivation of growth rates from Chl:C ratios.
- How much variability is occurring under the clouds and during the long periods when there are no images?
- Remotely sensed information of species/functional groups and their influence on the particle size spectrum is required to have a better understanding of phytoplankton carbon standing stocks and ecosystem functioning.
- We need to re-evaluate the use of FRRF measurements as a proxy for primary productivity measurements.
- We have to continue time series measurements on both the western and eastern sides of the Pacific since these data can provide valuable ground-truthing for satellites and observations of episodic events that may occur during cloud cover. There is a very strong need to develop techniques for routinely and accurately determining phytoplankton carbon standing stocks and growth rates (*i.e*., beyond microscopic analyses and dilution experiments).