Five LME Modules are used to assess the changing states of Large Marine Ecosystems. Each of the 5 modules has its own suite of indicators to assess changes in the LMEs and determine whether an LME is improving or deteriorating.

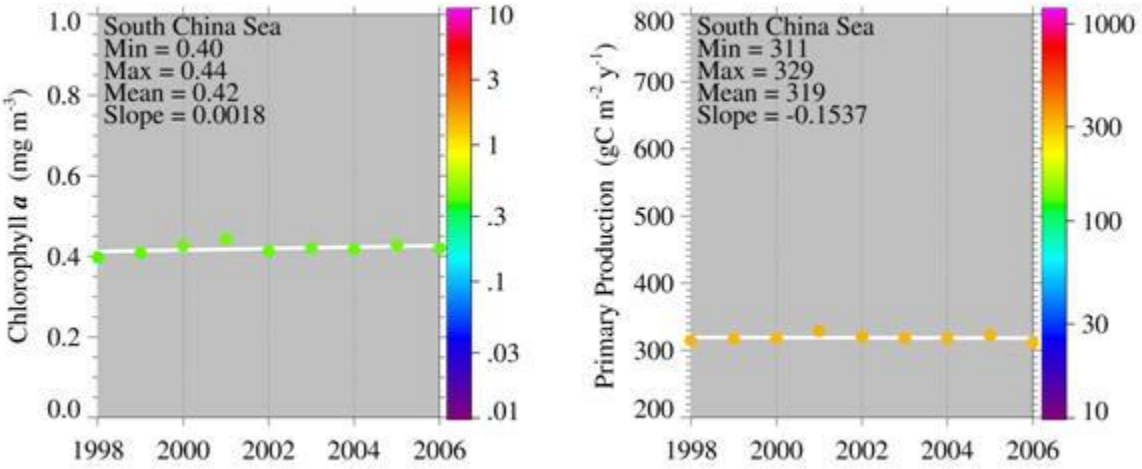
(i) The Productivity Module

PRODUCTIVITY MODULE INDICATORS

Primary productivity can be related to the carrying capacity of an ecosystem for supporting fish resources. It has been reported that the maximum global level of primary productivity for supporting the average annual world catch of fisheries has been reached, and that further large-scale un-managed increases in fisheries yields from marine ecosystems are likely to be at trophic levels below fish in the marine food web.

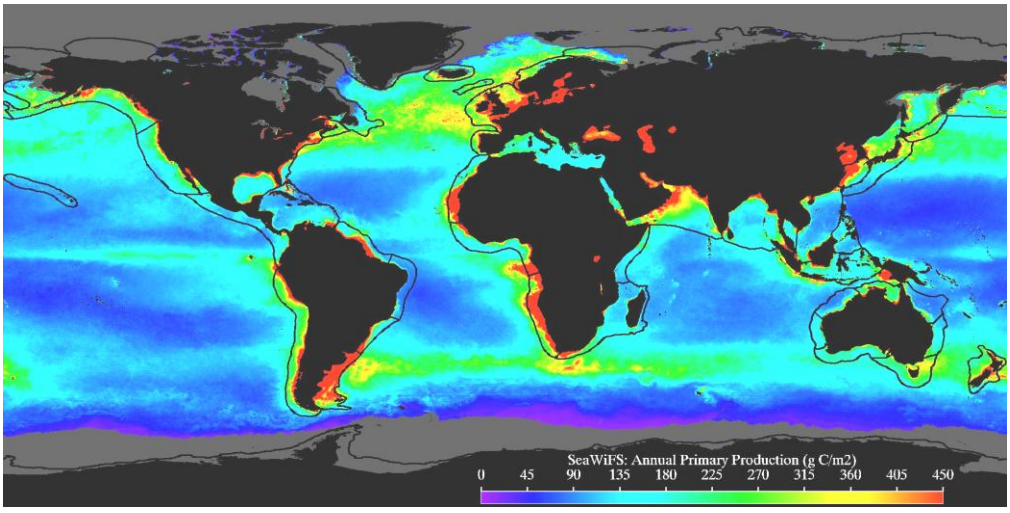
The ecosystem parameters measured and used as indicators of changing conditions in the productivity module are zooplankton biodiversity and species composition, zooplankton biomass, water-column structure, photosynthetically active radiation, transparency, chlorophyll-a, nitrate, and primary production. Plankton can be measured over decadal time scales by deploying continuous plankton recorder systems with sensors for temperature and salinity, in monthly transects across ecosystems from commercial vessels of opportunity. The Mariner Shuttle (annex 1), an advanced plankton recorder, provides the means for in-situ monitoring and for calibrating satellite-derived oceanographic data.

Applications of multi-annual satellite-derived time-series information on chlorophyll, primary production, sea surface temperature, and hydrographic gradients for each of the world's 64 LMEs are given in Sherman and Hempel (2008).



South China Sea LME trends in SeaWiFS-derived chlorophyll a (left) and primary productivity (right), 1998-2006. Values are colour coded to the right hand ordinate. Figure courtesy of J. O'Reilly and K. Hyde, NOAA-Fisheries, Narragansett Laboratory. Sources discussed p. 15, UNEP LME Report (Sherman and Hempel 2008) available from Reports on this website.

In the following global map showing average primary productivity and the boundaries of the 64 Large Marine Ecosystems (LMEs) of the world, annual productivity estimates are based on SeaWiFS satellite data collected between September 1998 and August 1999, and the model developed by M. Behrenfeld and P.G. Falkowski (1997). The color-enhanced image provided by Rutgers University depicts primary productivity from a high of 450 gCm^2yr^{-1} in red to less than 45 gCm^2yr^{-1} in purple. Primary productivity supporting marine populations is higher in LMEs than in the open ocean.



Average primary productivity and boundaries of the 64 Large Marine Ecosystems (LMEs) of the world. The red areas show the regions of highest primary productivity, and the blue, those with the lowest primary productivity.

Selected Productivity Indicator Module publications

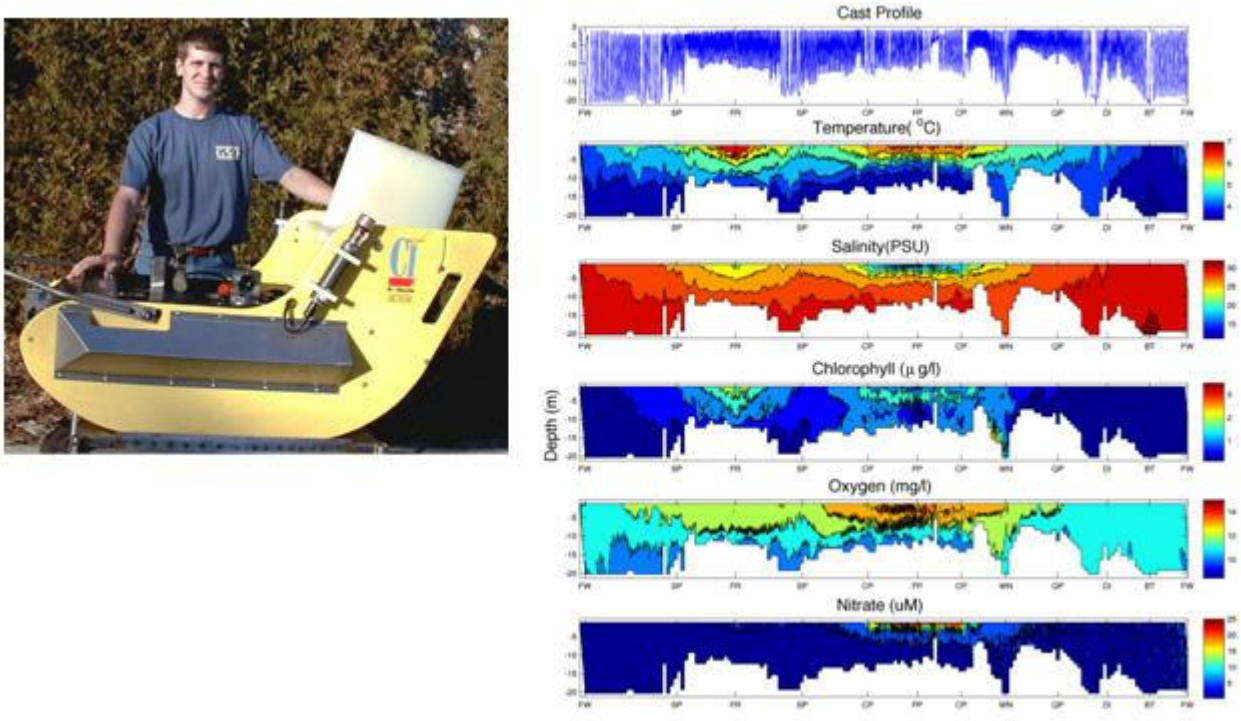
Behrenfeld MJ, Falkowski PG. 1997. Photosynthetic rates derived from satellite-based chlorophyll concentration. Limnology and Oceanography 42 (1):1-20.

Pauly D, Christensen V. 1995. Primary production required to sustain global fisheries. Nature 374:255-257.

Sherman K, Hempel G, eds. 2008. The UNEP Large Marine Ecosystem Report: A perspective on changing conditions in LMEs of the world's Regional Seas, UNEP Regional Seas Report and Studies No. 182. Nairobi, Kenya: UNEP. 872 p.

Annex 1

The **Mariner Shuttle,** an advanced plankton recorder, provides the means for in-situ monitoring and for calibrating satellite-derived oceanographic data. Properly calibrated sensors can provide information on ecosystem conditions including physical state (i.e., surface temperature), fast repetitious rate fluorescence chlorophyll characteristics, primary productivity, salinity, oxygen, nitrate, and zooplankton.



The Mariner Shuttle undulating oceanographic sampling system (left) carries sensors for temperature, salinity, chlorophyll, oxygen and nitrate. Payload output (right) of depth, temperature, salinity, chlorophyll, oxygen, and nitrate. The Shuttle also carries a continuous plankton recorder mechanism.

Selected Publications on the Mariner Shuttle:

Berman MS, Sherman K. 2001. A towed body sampler for monitoring marine ecosystems. Sea Technology 42(9):48-52.

Melrose DC, Oviatt CA, O'Reilly JE, Berman MS. 2006. Comparisons of fast repetition rate fluorescence estimated primary production and ^{14}C uptake by phytoplankton. Marine Ecology Progress Series 311:37-46.