Carbon cycle

Photosynthesis seen from above

from R.A. Warrick

ONE of the latest developments in remote sensing, reported by Tucker *et al.* on page 195 of this issue[1], is the capacity to estimate green-leaf biomass of plant canopies and, presumably, terrestrial photosynthesis and primary production, on a global scale with fine temporal and spatial resolution. This development has the potential to sharpen our understanding of the role of terrestrial biota in the carbon cycle and could allow the monitoring of important changes in global vegetation and productivity resulting from increasing atmospheric CO_2 and climatic changes.

As a result of fossil fuel burning, deforestation and other changes in land use, the atmospheric concentrations of CO_2 have risen from a pre-industrial (mid-nineteenth century) level of 275 ± 10 to 343 ± 1 parts per million by volume in 1984 (ref. 2). With a doubling of the pre-industrial CO_2 level the world could become considerably warmer, by 1.5–5.5°C according to climate modellers[3] — the much-debated greenhouse effect. A major issue is when will this happen. The answer depends largely on future rates of energy consumption and CO_2 emissions, together with the sources and sinks of CO_2 and the fluxes between the various carbon reservoirs, which are the subjects of global carbon-cycle modelling. The terrestrial biota is a major component of such models.

In the presence of light, atmospheric CO_2 is assimilated by plants and transformed into carbohydrates — the process of primary production. Through respiration and the decay of organic matter, CO_2 is released back into the atmosphere. Because the rates of assimilation and release are dependent on solar radiation and temperature, and because the distribution of the terrestrial biota is lop-sided in favour of the northern hemisphere, the atmospheric CO_2 concentration has a strong seasonal cycle whose amplitude varies spatially. It has long been suspected that global-scale CO_2 variations are due to variations in primary production of the terrestrial biota, but the empirical demonstration and quantification of this has been hindered by insufficient data coverage, in terms of both time and space.

The remote-sensing techniques discussed by Tucker and his colleagues[1] take a large step towards remedying this problem. Their method involves advanced very high-resolution radiometer (AVHRR) sensors carried by the National Oceanic and Atmospheric Administration's polar orbiting meterological satellites. The sensors collect radiance data daily, at 4 km spatial resolution with global coverage. Daily collection is important, as it allows for selection of data for cloud-free days to minimize the effects of cloud cover. Tucker *et al.* have used these data to estimate the amount of intercepted photosynthetically active radiation (IPAR), the radiation in the spectral range that is strongly absorbed by leaves for driving photosynthesis. From this they estimate the green-leaf densities of plant canopies. If these factors provide an accurate measure of terrestrial photosynthesis, and if the annual CO_2 cycle is due mainly to photosynthesis variations, the satellite data should correlate well with atmospheric CO_2 variations.

The monthly, latitudinally-averaged values of a vegetation index derived from the data for the period 1982–84 have been compared with atmospheric CO_2 concentrations by Tucker *et al.* The patterns match well and show the expected inverse relationship: the higher the vegetation index, the lower the CO_2 concentration with a 1–2-month lag.

These remote-sensing techniques could potentially contribute to our understanding of the greenhouse problem in at least two ways. First, they could help in refining and validating global carbon-cycle models[4-6]. There is considerable uncertainty about how well the terrestrial biota is represented by these models; few detailed validations have been performed[2]. The global-wide data from the AVHRR sensors could provide an additional, independent data source against which CO_2 assimilation and release could be compared.

Second, they could be valuable for monitoring long-term effects of higher CO_2 concentrations and climatic change on the global vegetation. It is very uncertain whether and how the productivity of global ecosystems will be affected directly by higher CO_2 levels[7] — the CO_2-fertilization effect. In carbon-cycle models this effect is often represented by a simple one-parameter equation in which the assumed value of the biotic growth factor is estimated from results of greenhouse experiments. But scaling up the controlled experimental results from leaf or plant level to the real world of highly dynamic, interactive plant communities and ecosystems is fraught with difficulties[8]. The technique for monitoring changes in the productivity of global ecosystems could provide the empirical data with which to test the assumption of CO_2 fertilization.

Change in species composition or areal distribution of ecosystems could also be caused directly by increasing CO_2 levels and by climatic change. Such vegetation changes have obvious feedbacks to carbon reservoirs and fluxes as well. Again, the satellite data could prove useful for detecting any such shifts.

But the state-of-the-art in using the remote-sensing methods for relating reflected radiation, green-leaf biomass, primary production and atmospheric CO_2 levels is still immature. Tucker *et al.* note that unexplained variance and uncertainty exist at each link of this chain of relationships. How much confidence can we place in the approach? How much of an improvement over existing methods of measurement does it actually represent? Its biggest advantage is the global coverage, with fine resolution. But the sceptic must be convinced that we are not being sold sophisticated technology to address questions for which we largely know the answers.

Further careful comparisons of the satellite data with model results and ground-based data would help to establish the validity of the approach. Nevertheless, we have been given an enticing glimpse of a method with potentially far-reaching applications to the important global problems of the greenhouse effect and climatic change. □

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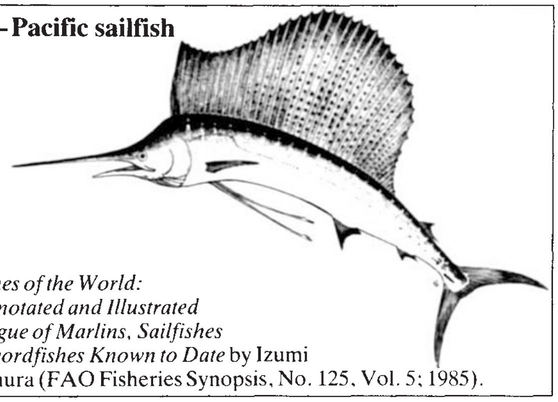
Indo–Pacific sailfish



From *Billfishes of the World: An Annotated and Illustrated Catalogue of Marlins, Sailfishes and Swordfishes Known to Date* by Izumi Nakamura (FAO Fisheries Synopsis, No. 125, Vol. 5; 1985).