Phytoplankton Production Biology

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Grant Number: N00014-97-1-0120
http://www.onr.mil/sci_tech/ocean/onrpgahj.htm

LONG-TERM GOALS

I continue to critically and creatively review knowledge about interactions between bulk marine phytoplankton and zooplankton with the hydrographic and chemical environment, as well as the feedback from the biological processes to the abiotic environment. The emphasis is on general principles, as well as regional oceanography in the Arabian Sea.

OBJECTIVES

1. *To stress again that understanding the change of phytoplankton concentrations should be one of the principal goals of biological oceanography and limnology*. Both are parts of the earth sciences, as well as of ecology. Hence they ought to be able to predict the abundance of organisms and the rate of temporal change. By and large, however, phytoplankton is still being studied as if its population dynamics are driven by the interplay of its physiology and the resources (so-called bottom-up approach). Actually, aside from the physical aspects (e.g., dilution by mixing), full understanding is possible only by including also the mortality (so-called top-down effect), which is an emergent property accurately measurable only in the field. The geochemical aspect is the degree of draw-down of CO_2 in surface water.

2. *To study sources of variability in satellite-derived estimates of phytoplankton production*. A major goal for using maps of satellite-derived plankton chlorophyll is to estimate primary production, with the biogeochemical implications for estimating downward transport of organic matter and carbon dioxide exchange with the atmosphere. The satellite-based estimates, however, do not yet achieve a really useful accuracy as shown by comparison with in-situ measurements of photosynthesis. One issue is that the chlorophyll-normalized light-saturated photosynthetic rate is required for accuracy, which, however, cannot yet be determined from space. Our approach is to simulate satellite pigment and correlate it with simultaneously determined, existing in-situ photosynthesis.

3. *To study the ventilation of the upper thermocline in the northernmost Arabian Sea.* A hitherto not widely recognized high-density (sigma-t about 25 g dm^{-3}) water poleward of 21˚-22˚N is caused by convective overturn during the dry and cold northwest monsoon, which leads to sinking to up to about 150 m depth and ventilates the upper thermocline, whereas the famous oxygen minimum prevails in the same density range to the south in the central Arabian Sea. Existing data are being used.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 AUG 2003**	2. REPORT TYPE	3. DATES COVERED **00-00-2003 to 00-00-2003**
4. TITLE AND SUBTITLE **Phytoplankton Production Biology**		5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **University of Washington,,School of Oceanography,,Seattle,,WA,98195**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**6**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

4. *To study the long-term (four decades) stability and short-term (days) variability of the oxygen minimum in the central Arabian Sea* along 65˚E, with the goal, among others, of commenting on the difficulty of budgeting the nitrogen budget from single sections. Existing and newly collected data are being used.

5. *Continue the attempt to open windows to the Russian oceanographic literature* by arranging for publications of translations of small monographs by Russian-language authors, as well as of a newly commissioned work on a comprehensive 1990 expedition to the Arabian Sea, also by Russian-language (Ukrainian) authors, but written in English from the outset.

WORK COMPLETED

A paper reviewing E. Steemann Nielsen's view of the role of zooplankton also presents three sets of data on phytoplankton mortality in the field based on revisited water bodies (Banse 2002a; see further under Results, below). A presumably widely occurring systematic error source in estimating photosynthesis from satellite-derived pigment is demonstrated for five open-sea observations (Banse and Postel 2002; see also under Results, below). The need to address the reasons for changes of phytoplankton concentrations has been raised again but apparently, again, unsuccessfully so. The comments by the four respondents to Banse (2002b) have avoided the issue (see *Limnology and Oceanography Bulletin* 11:45 and 75, 2002; *ibid*., 12:1 and 39, 2003). Manuscripts about the hydrography of the northernmost Arabian Sea and about the decadal stability and day-to-day variability of the oxygen minimum in the central Arabian Sea are being prepared for publication. The printing of the monographs translated from the Russian language, however, has progressed little. The first monograph by L.I. Sazhina (Russian original, 1987), *Reproduction, Growth, and Production of Marine Copepods* (with 55 figures and 55 tables), has advanced to the galley proofs.

RESULTS

The role of the top-down effect: Over much of the open sea, phytoplankton concentrations do not change for months on end in spite of division rates of approximately one per day. Since physical losses including of sinking of live cells are known to amount to a few percent per day, the principal loss maintaining the balance is grazing. Among the results achieved during the reporting period, Banse (2002a) presented the first mortality data for phytoplankton *blooms* in water revisited in the open sea, with losses from mixing being accounted for, so that essentially, the grazing losses were determined (see table below and Figure 1).

Phytoplankton production lost from grazing in blooms
(from cumulative growth minus actual change of concentrations)

	CUSHING'S *CALANUS* PATCH	IronExI	IronExII
year	1954*	1993	1997*
loses	3/4	9/10	total, 4/5 diatoms, 2/3

(*by the time the peak of the bloom was reached)

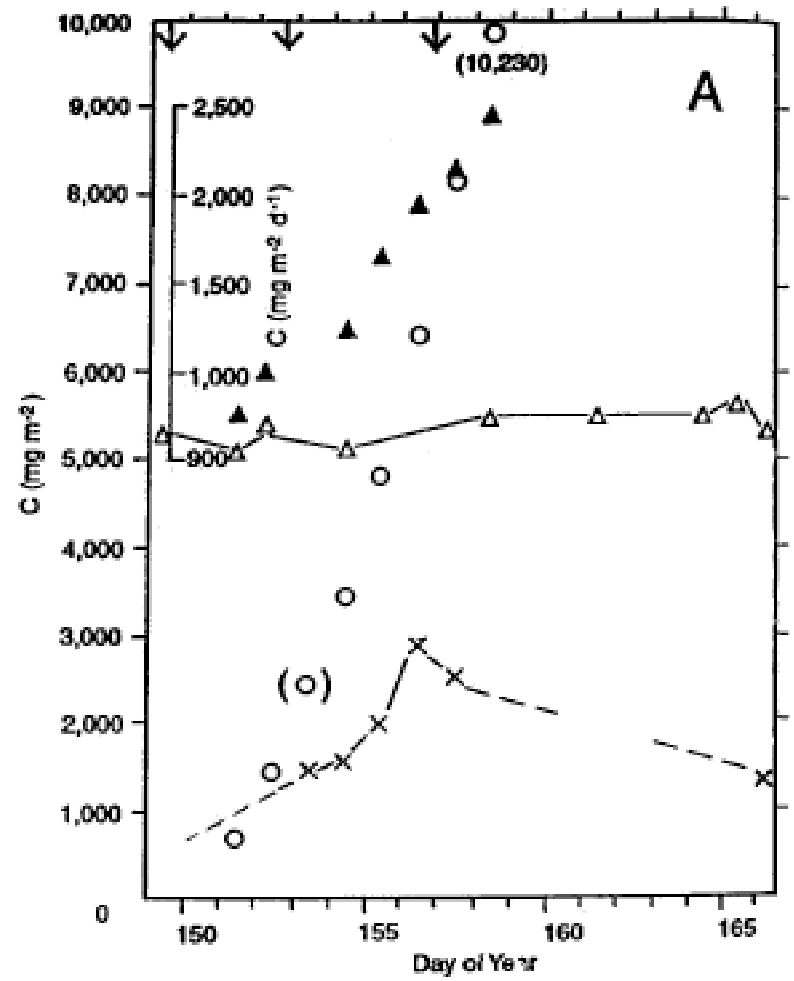

Figure 1: Phytoplankton dynamics during IronExII after fertilization with iron (arrows on top) of a large patch in the perennially high nutrient-low chlorophyll water of the eastern equatorial Pacific (modified from Banse 2002a). Top (inside ordinate): Daily phytoplankton carbon uptake (^{14}C) inside and outside of fertilized patch (filled and open triangles, respectively) integrated through the euphotic zone. The increase inside the patch is due to enhanced division rates from the iron addition and increased biomass of algae not grazed. Bottom: Cumulative integrated carbon uptake (circles) versus actual concentration change (crosses). On Day 157, when the sign of the latter changed (peak of the bloom), > 60% (in Fig. 1; 80% in another concurrently run experiment) of the newly formed plant carbon had been removed by grazing of microzooplankton, to which losses from macrozooplankton need to be added.

An error source in satellite-derived estimates of phytoplankton production. Observed column photosynthesis (P_t, mg C m^{-2} d^{-1}, from ^{14}C-uptake) may correlate only loosely with satellite-estimated phytoplankton pigment content at the same stations (Fig. 2, column A), but the accuracy and precision of the P_t estimates often improves greatly when the rate of C-uptake near the depth of light saturation, estimated for each of the same stations (Pb_{opt}, mg C [mg chlor. a] $^{-1}$ d^{-1}), is incorporated (Fig. 2, B). Pb_{opt} cannot be determined from space, but using geographic or seasonal means for the same data sets leads to imprecise and inaccurate correlations between predicted and observed P_t (Fig.

2, C), principally because P^b_{opt} and P_t are often correlated. We expect this error source to be widespread, although we did not observed the P^b_{opt} effect in coastal upwelling regions (Banse and Postel 2003).

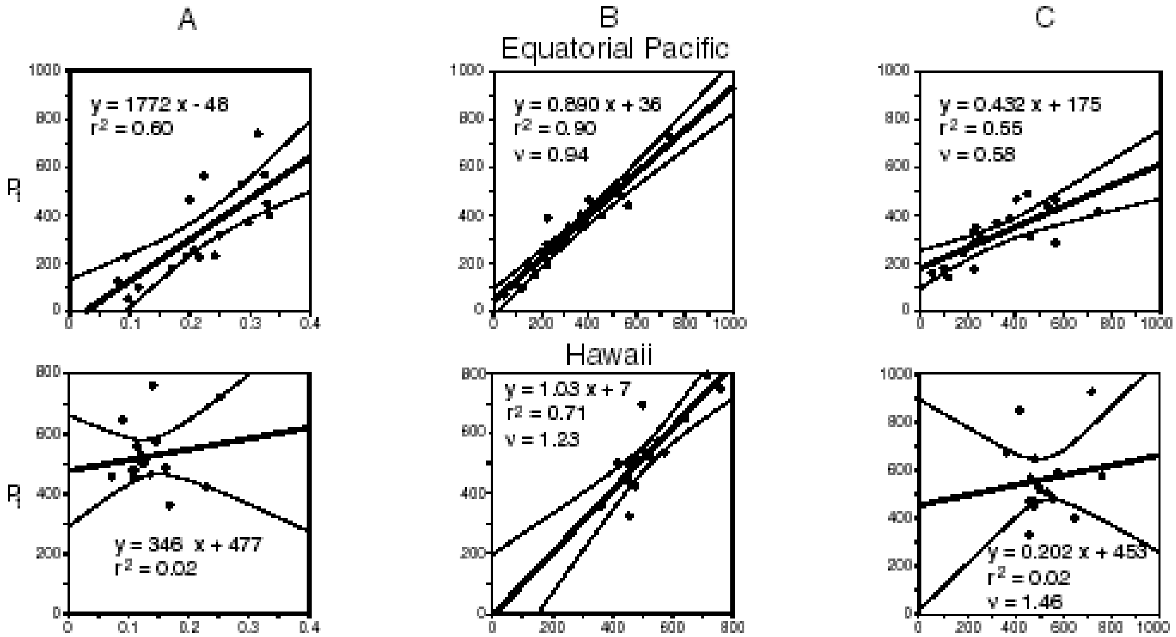

Fig. 2: Illustration of the effect on slope, intercept, and r^2 from plotting observed column production on simulated satellite pigment (A), after incorporating P^b_{opt} for the individual stations (B), and after incorporating P^b_{opt} as overall mean (C) as is currently needed in satellite application. The third line in the middle and right-hand panels is the slope for the model -II regression (Banse and Postel 2003). Confidence intervals at p = 0.05.

Should we continue to measure 14-C uptake by phytoplankton for another 50 years? A principal goal of ecology and, hence, biological oceanography and limnology is to understand and be able to predict the abundance of organisms and the rate of temporal change. Can we achieve this goal for the phytoplankton by only measuring photosynthesis by ^{14}C-uptake? Considering time scales of $\geq$24 h, my answer was NO, because (1) the rate of photosynthesis does not equal cell division, (2) phytoplankton is always accompanied by grazing zooplankton, and (3) the predictive power of measured ^{14}C-uptake toward the stated goal is small (Banse 2002b). (Parenthetically, the biologically-caused CO_2 flux into or out of the water cannot be found from photosynthesis alone either). Presumably being misled by the intentionally provocative headline, the responses by four colleagues did not address the issue raised in the first line herein and the cited article (see Banse 2003).

IMPACTS

1. The two papers (Banse 2002a, b) about the role of zooplankton grazing are another attempt to get the notion across that mechanistic explanations and the prediction of the concentrations and the temporal changes of phytoplankton, as well as the draw-down of carbon dioxide during blooms, must be sought in the context of the plankton as a community. Since phytoplankton is never met without grazers, the grazers are always a part of the community, but they are exposed to their predators at the

same time. Therefore, it is rarely, if ever, appropriate to study purely bottom-up (resource-) control or top-down (predation-) control of phytoplankton in the open sea.

2. The demonstration of a partially unsatisfactory (inaccurate) correlation of phytoplankton production with satellite-derived pigment (Banse and Postel 2003) is another example of the needed continual testing of our canonical views.

RELATED PROJECTS

Instruction at India's National Institute (NIO) of Oceanography in Goa. From mid-December 2002 to mid-March 2003, financed this time by India, I taught 15 newly hired scientists about biogeochemical oceanography along the JOGFS paradigms, focusing on the Arabian Sea and starting, of course, with the hydrography. Included was a two-month exercise of drafting a research proposal based on individual subjects suggested by me to hone writing skills. I was assured by my charges, as well as by the director of NIO, that the efforts were successful, but it is to be seen how many of the group will remain fired up in the long run. In addition, I talked with more senior colleagues but found little time for my own research.

PUBLICATIONS

K. Banse (2002a) *Steemann Nielsen and the zooplankton.* Hydrobiologia **480**: 15-28 [refereed].

K. Banse (2002b) *Should we continue to measure ^{14}C-uptake by phytoplankton for another 50 years?* Limnology and Oceanography Bulletin **11**: 45-46 [refereed].

K. Banse (2003) *One more reply by Karl Banse about measurements of ^{14}C-uptake during the next 50 years*. Limnology and Oceanography Bulletin **12**: 39, 2003 [refereed].

K. Banse and J.R. Postel (2003) *On using pigment-normalized, light-saturated carbon uptake with satellite-derived pigment for estimating column photosynthesis.* Global Biochemical Cycles. **17**, doi: 10.1029/2002/GB002021, 11 pp. [refereed].