Primary Production Calculations in the Mid-Atlantic Bight, Including Effects of Phytoplankton Community Size Structure

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Introduction

An absorption based primary production model that includes the effects of phytoplankton community size structure was developed for continental margin and adjoining Gulf Stream waters of the Mid-Atlantic Bight (MAB). The calculations included both light-limited and nutrient-limited conditions of the MAB seasonal cycle. Absorption is characterized by cell size seasonality, adding ecological information to a physiological and theoretical based model. Satellite-based estimates allow unprecedented temporal and spatial coverage but are limited to observing the surface of the ocean, whereas production extends at least three times deeper. Using a separate calculation based on in situ chlorophyll profiles, primary production missed by satellite estimates are quantified.

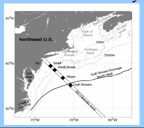


Fig. 1. Location of shelf, shelf break, slope and Gulf Stream study areas within the Mid-Atlantic Bight and adjoining waters.

Materials and Methods

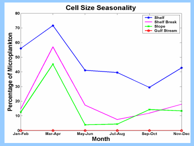
Satellite-Derived Observations:

Individual SeaWiFS chlorophyll, PAR and AVHRR sea-surface temperature images were composited monthly at 1km/pixel resolution and averaged over the area of each study area.

In Situ Observations:

XBT temperature profiles, collected during MV Oleander cruises were used to determine the depth of the mixed layer. Surface and vertical profiles of seasonal cycles of phytoplankton community size structure, chlorophyll, and nitrate concentration were obtained from published results.

Production estimates were calculated every month for 5-years for study areas representing shelf, shelf-break, slope and Gulf Stream waters assuming that SeaWiFS chlorophyll concentrations extended to the depth of the mixed layer (or euphotic zone). The same model was applied to published chlorophyll profiles for these regions and the difference between this second estimate and that based only on SeaWiFS chlorophyll was used as a measure of "missed production."



(O'Reilly and Zetlin, 1998; Olson *et al*., 1985; Olson *et al*., 1990; Cavender-Bares *et al*., 2001)

Fig. 2. Seasonal phytoplankton community size structure as the percentage of microplankton (>20 µm). Gulf Stream cells are assumed to be nanoplankton (< 20 µm) size or smaller.

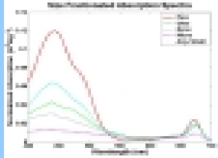


Fig. 3. Size fractionated absorption spectra for pico-, ultra-, nano-, and microplankton. Average small absorption spectra represents the average pico-, ultra- and nanoplankton size classes used for Gulf Stream calculations.

(Ciotti et al., 2002)

Production Model Calculations:

1) $PP = \int \bar{a}^*_{ph} * \Phi * E_k * \tanh(E_z/E_k) * chl\,dz$

2) $\bar{a}^*_{ph} = [(1-S) * \bar{a}^*_{pico}] + [(S) * \bar{a}^*_{micro}]$ (Ciotti et al., 2002)

3) $\Phi = \Phi_{max} * f_a * f_\Delta * f_{c(N)} * f_{c(\tau)} * f_{c(PAR,inh)} * f_{E,t}$ (Wozniak et al., 2002)

4) $E_k = P^b_{max}/\alpha$ (Sakshaug et al., 1997)

4a) $P^b_{max} = f(T)$ (P^b_{opt}, Behrenfeld and Falkowski, 1997)

4b) $\alpha = \bar{a}^*_{ph} * \Phi$ (Sakshaug et al., 1997)

Depth Dependence:

5) $K_{PAR} = 0.04+0.00888(chl)+0.054*((chl)2/3)$ (Nelson and Smith, 1991)

6) $Z_{eu} = 4.6/K_{PAR}$ (Morel and Berthon, 1989)

7) $Z_{MLD} = \pm 0.5°C$

8) $E_z = E_o \exp(-K_{PAR} * Z)$

Community Loss:

9) $R = (E_c * PP)/E_o$ (Siegel et al., 2002)

10) $(E_c/E_o) = (1/(K_{PAR} * Z_{CR})) * (1-e^{-KPAR*ZCR})$ (Sverdrup, 1953)

Results

Production and Community Loss Estimates:

The depth of integration (Fig. 4) influences relative production estimates (Fig. 5a, Table 1). As would be expected, production estimates based on actual chlorophyll profiles were greater than satellite based estimates. The in situ profile estimates displayed decreasing production with distance offshore, while the satellite estimates yielded moderate production on the shelf and shelf break, increasing at the slope and significantly declining at the Gulf Stream. The high slope production is due to the anomalously high chlorophyll concentration observed. The spring production peak is delayed by 2 – 3 months in the in situ profile estimates, likely due to the bloom initiation in shallow waters followed by propagation at depth, which could not be detected remotely.

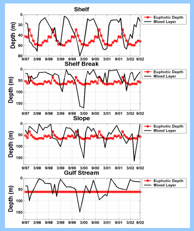


Fig. 4. The mixed layer depth, determined from XBT profile, and euphotic depth determined from in situ chlorophyll profiles for each study area. The constant Gulf Stream euphotic depth is due to the use of a single generalized chlorophyll profile for the annual cycle.

The community loss rates (Fig. 5B) tended to be greatest in the fall and spring corresponding to bloom periods, however loss rates in the fall were equal to or slightly greater than spring loss rates while fall production was significantly less than spring production. This observation suggests heterotrophic processes play a larger role in regulating the fall bloom than the spring bloom.

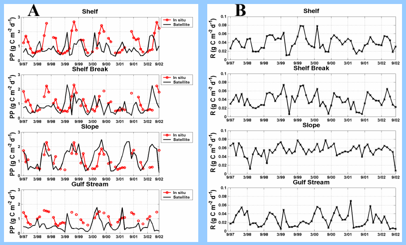


Fig. (5 A-B). A) The satellite based production estimates integrated to the depth of the mixed layer and the in situ estimates integrated to the base of the euphotic zone. The missing data in the in situ profile dataset results from no XBT profiles within the study area for that month. **B)** Community respiration estimated from remote data sets.

Temporal and Spatial Variability:

A variability index (standard deviation associated with the 5-year monthly means divided by the mean daily primary production for each month) was used to determine interannual variability in monthly production. Generally highest interannual variability occurred in the spring and summer, corresponding to bloom periods (Fig 6).

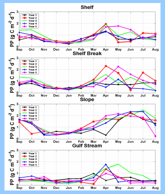


Fig. 6. Average daily satellite based estimates of primary production for each month of the time series, five years overlaid.

Production Missed by Satellite Estimates

Over the 5-year time series, 46%, 48%, 40%, and 38% of the in situ primary production was missed by satellite based estimates for the 4 study areas (Table 1). Of these, the least amount of confidence is placed in the Gulf Stream estimates due to the use of a single generalized chlorophyll profile.

Table. 1. Daily and annual primary production estimated remotely. Percent missed production indicates how much production was missed by satellite estimates in comparison to estimates made with the same model but applied to published in situ profile data.

year	Daily Production (gCm-2d-1)	Annual Production (gCm-2yr-1)	Missed Production
Shelf			
1	0.68	248	45%
2	0.84	307	49%
3	0.90	330	45%
4	0.76	278	47%
5	0.89	326	44%
Shelf Break			
1	0.66	239	47%
2	0.99	361	43%
3	0.85	310	50%
4	0.55	200	63%
5	0.93	341	41%
Slope			
1	1.09	399	39%
2	1.23	447	41%
3	1.38	503	34%
4	1.25	455	44%
5	1.21	443	49%
Gulf Stream			
1	0.51	186	43%
2	0.46	168	37%
3	0.63	231	34%
4	0.54	197	35%
5	0.43	156	42%

Sensitivity Analysis

A factorial experimental design was used to understand the relative contribution each parameter makes to primary production estimates. The parameters ranked from most influential to least influential were: chlorophyll, PAR, quantum yield, depth of integration, cell size, and SST (Fig. 7). To further understand the importance of cell size, production was calculated in 3 scenarios: cell size seasonality, assuming all microplankton and assuming all picoplankton. The all microplankton scenario decreased production by 70%, while the all picoplankton scenario increased production by 30%.

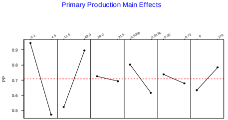


Fig 7. The main effect of the parameters were determined in relation to productivity by calculating the adjusted least squares mean of all combinations of the minimum and maximum value of each model parameter.

Conclusions

- Adding an ecological term (cell size) to the model allowed for greater understanding of the relative importance of light acquisition in photosynthesis.
- Productivity calculated from chlorophyll profiles decreased across the shelf into continental margin waters, while productivity calculations that assumed SeaWiFS chlorophyll concentrations extended to the base of the mixed layer increased at the slope and decreased into Gulf Stream waters.
- Interannual variability was related to intensity of wind mixing. Years when mixing was more intense, annual production was greater than years characterized by mild mixing.
- Highest interannual variability generally occurred in spring and fall owing to differences in bloom magnitude and timing.
- Production trends relative to the cell size seasonal cycle were regulated more by biomass than light acquisition capability. Large cells common during the winter-spring bloom are inefficient absorbers, however production was greatest when they were in dominance.
- **We estimate that approximately 40% of production was missed by satellite-based estimates.**

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For further information

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