20th February 2025
Department of Physics, Faculty of Science, University of Split

PHOTOCLIM 2nd Annual meeting
PRESENTATION OF THE RESULTS ACHIEVED DURING THE FIRST PROJECT YEAR

Project funded by the Croatian Science Foundation IP-2022-10-8859

HRZZ

Croatian Science Foundation

Fragility of primary production under climate change

Project logo created

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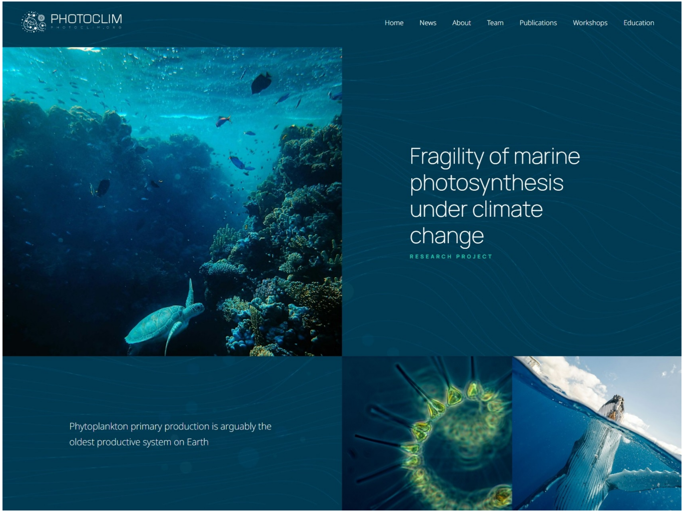
Project website created: photoclim.org



Fragility of marine photosynthesis under climate change

RESEARCH PROJECT

Phytoplankton primary production is arguably the oldest productive system on Earth

First year work plan

List of deliverables:

D1. Annual project work meeting
D2. Primary production time series data acquired
D3. Global marine phytoplankton production dataset accessed
D4. Local data repository created
D5. Primary production measurements in the Adriatic
D6. Modern capital theory applied to the study of marine photosynthesis
D7. Measuring primary production workshop
D8. Educational material on primary production measurements
D9. Training (Training in primary production measurements at the Plymouth Marine Laboratory)
D10. Training (Attendance of Summer Lecture Series Frontiers in Ocean Optics and Ocean Colour)
D11. Attendance at conferences
D12. Scientific publications

D1. Annual project work meeting

On the **23rd February 2024** we had our Kickoff meeting at the Faculty of Science in Split.

Meeting agenda

09:15 – 09:25 Opening Remarks
09:25 – 09:45 Project Presentation
09:45 – 10:00 Planning of Project Activities
  Presentation of the work plan for the entire project period
  Presentation of the financial plan for the entire project period
10:00 – 10:30 Coffee & Discussion
10:30 – 11:30 Planning of Project Activities for the First Year
  Data Collection
  Data Digitization
  Local Data Storage
  Data Processing
11:30 – 12:00 Coffee & Discussion
12:00 – 12:30 **Lecture: Assoc. Prof. Dr. Davor Mance: Ecological Economics**
12:30 – 13:00 Planning of Project Workshop: Measurement of Primary Production
13:00 – 15:00 Lunch

D2. Primary production time series data acquired

Stončica	1962	
Kaštelanski zaljev	1962	
Bermuda Atlantic Time Series	1988	bats.bios.edu
Hawaii Ocean Time Series	1988	hahana.soest.hawaii.edu/hot/hot-dogs
Cariaco	1996	imars.marine.usf.edu/car
Monterey Bay	1988	www.mbari.org/bog
La Coruña	1990	www.seriestemporales-ieo.com
Western Channel Observatory	1992	www.westernchannelobservatory.org.uk

+ 1148 annual time series from 483 locations (Cloern et al., 2014)

+ 125 time series longer than 8 years with more than 10 measurements per year (Winder & Cloern, 2010)

D2. Primary production time series data acquired

Such data are mostly publicly available.

Data typically comes in the form which requires **significant effort** to prepare the data for analysis.

The production data also come with **optical data**, which requires significantly **more processing**.

An example from BATS

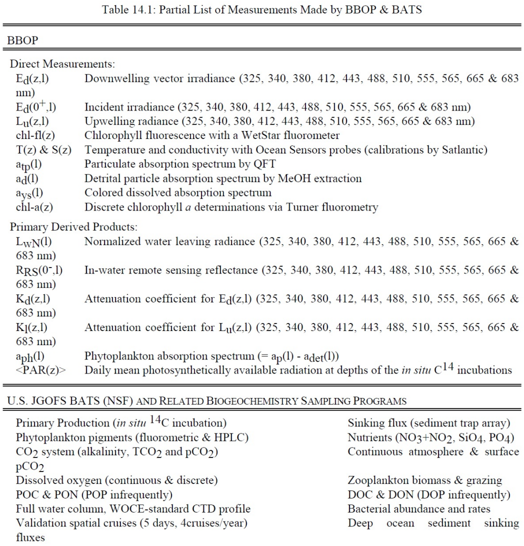
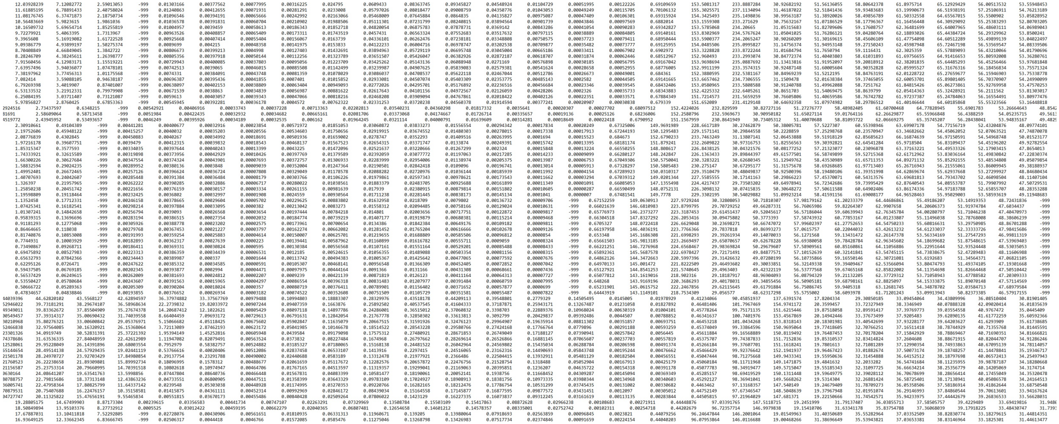


Table 14.1: Partial List of Measurements Made by BBOP & BATS

BBOP	
Direct Measurements:	
$E_d(z,l)$	Downwelling vector irradiance (325, 340, 380, 412, 443, 488, 510, 555, 565, 665 & 683 nm)
$E_d(0^+,l)$	Incident irradiance (325, 340, 380, 412, 443, 488, 510, 555, 565, 665 & 683 nm)
$L_u(z,l)$	Upwelling radiance (325, 340, 380, 412, 443, 488, 510, 555, 565, 665 & 683 nm)
chl-fl(z)	Chlorophyll fluorescence with a WetStar fluorometer
T(z) & S(z)	Temperature and conductivity with Ocean Sensors probes (calibrations by Satlantic)
$a_{tp}(l)$	Particulate absorption spectrum by QFT
$a_d(l)$	Detrital particle absorption spectrum by MeOH extraction
$a_{ys}(l)$	Colored dissolved absorption spectrum
chl-a(z)	Discrete chlorophyll *a* determinations via Turner fluorometry
Primary Derived Products:	
$L_{wN}(l)$	Normalized water leaving radiance (325, 340, 380, 412, 443, 488, 510, 555, 565, 665 & 683 nm)
$R_{RS}(0^-,l)$	In-water remote sensing reflectance (325, 340, 380, 412, 443, 488, 510, 555, 565, 665 & 683 nm)
$K_d(z,l)$	Attenuation coefficient for $E_d(z,l)$ (325, 340, 380, 412, 443, 488, 510, 555, 565, 665 & 683 nm)
$K_l(z,l)$	Attenuation coefficient for $L_u(z,l)$ (325, 340, 380, 412, 443, 488, 510, 555, 565, 665 & 683 nm)
$a_{ph}(l)$	Phytoplankton absorption spectrum (= $a_p(l)$ - $a_{det}(l)$)
<PAR(z)>	Daily mean photosynthetically available radiation at depths of the *in situ* C^{14} incubations
U.S. JGOFS BATS (NSF) AND RELATED BIOGEOCHEMISTRY SAMPLING PROGRAMS	
Primary Production (*in situ* ^{14}C incubation)	Sinking flux (sediment trap array)
Phytoplankton pigments (fluorometric & HPLC)	Nutrients (NO_3+NO_2, SiO_4, PO_4)
CO_2 system (alkalinity, TCO_2 and pCO_2)	Continuous atmosphere & surface pCO_2
Dissolved oxygen (continuous & discrete)	Zooplankton biomass & grazing
POC & PON (POP infrequently)	DOC & DON (DOP infrequently)
Full water column, WOCE-standard CTD profile	Bacterial abundance and rates
Validation spatial cruises (5 days, 4cruises/year)	Deep ocean sediment sinking fluxes

An example of optical data from BATS



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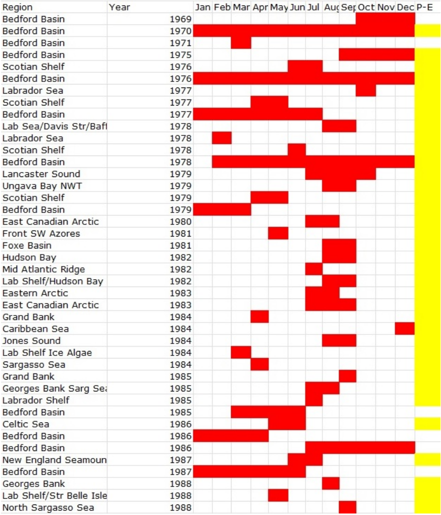
```

D2. Collecting data from lesser-known sources

Archived data from Platt and Irwin



Region	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	P-E
Bedford Basin	1969										🟥	🟥	🟥	
Bedford Basin	1970	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟨
Bedford Basin	1971			🟥										
Bedford Basin	1975									🟥	🟥	🟥	🟥	🟨
Scotian Shelf	1976						🟥	🟥						🟨
Bedford Basin	1976	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟨
Labrador Sea	1977										🟥			🟨
Scotian Shelf	1977				🟥	🟥								🟨
Bedford Basin	1977	🟥	🟥	🟥	🟥	🟥	🟥	🟥						🟨
Lab Sea/Davis Str/Baf	1978								🟥	🟥				🟨
Labrador Sea	1978		🟥											🟨
Scotian Shelf	1978						🟥							🟨
Bedford Basin	1978		🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟨
Lancaster Sound	1979							🟥	🟥	🟥	🟥			🟨
Ungava Bay NWT	1979								🟥	🟥				🟨
Scotian Shelf	1979				🟥	🟥								🟨
Bedford Basin	1979	🟥	🟥	🟥										🟨
East Canadian Arctic	1980							🟥	🟥					🟨
Front SW Azores	1981					🟥								🟨
Foxe Basin	1981								🟥	🟥				🟨
Hudson Bay	1982								🟥	🟥				🟨
Mid Atlantic Ridge	1982							🟥						🟨
Lab Shelf/Hudson Bay	1982								🟥	🟥				🟨
Eastern Arctic	1983							🟥	🟥					🟨
East Canadian Arctic	1983							🟥	🟥	🟥				🟨
Grand Bank	1984				🟥									🟨
Caribbean Sea	1984												🟥	🟨
Jones Sound	1984								🟥	🟥				🟨
Lab Shelf Ice Algae	1984			🟥										🟨
Sargasso Sea	1984				🟥									🟨
Grand Bank	1985									🟥				🟨
Georges Bank Sarg Se	1985							🟥	🟥					🟨
Labrador Shelf	1985							🟥						🟨
Bedford Basin	1985			🟥	🟥	🟥	🟥							
Celtic Sea	1986					🟥	🟥							🟨
Bedford Basin	1986	🟥	🟥	🟥	🟥									
Bedford Basin	1986							🟥	🟥	🟥	🟥	🟥	🟥	
New England Seamoun	1987						🟥	🟥						🟨
Bedford Basin	1987	🟥	🟥	🟥	🟥	🟥	🟥							
Georges Bank	1988								🟥					🟨
Lab Shelf/Str Belle Isle	1988					🟥								🟨
North Sargasso Sea	1988									🟥				🟨

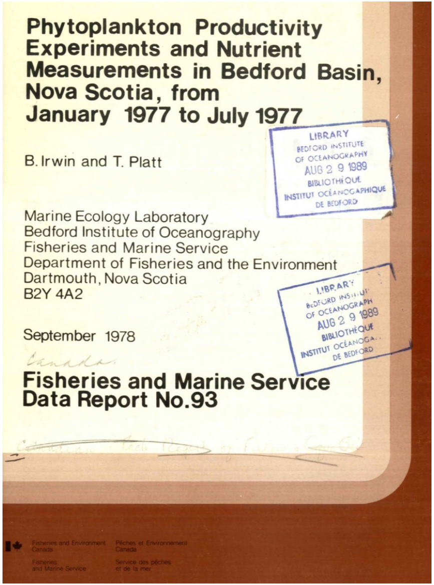
D2. Collecting data from lesser-known sources

Such data come in the form of reports, which have to be digitized **by hand!**

Thus far **we have digitized some 20%** of the entire dataset.

We estimate the entire dataset to have around **50 000 incubations**, which ammounts to around **100 000 datapoints** which have to be typed in.

An example from Bedford Basin



Phytoplankton Productivity Experiments and Nutrient Measurements in Bedford Basin, Nova Scotia, from January 1977 to July 1977

B. Irwin and T. Platt

Marine Ecology Laboratory
Bedford Institute of Oceanography
Fisheries and Marine Service
Department of Fisheries and the Environment
Dartmouth, Nova Scotia
B2Y 4A2

September 1978

Canada.

**Fisheries and Marine Service
Data Report No.93**

~~Canadian Tech Report of Fisheries & [illegible]~~

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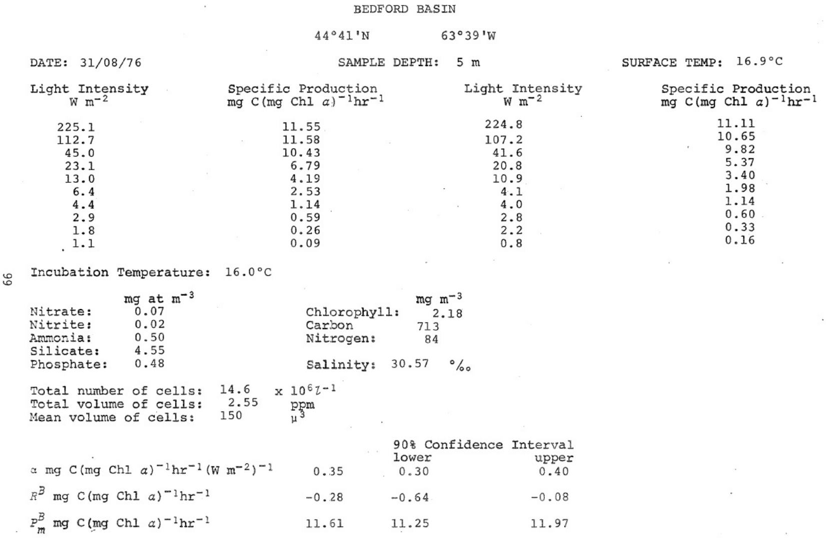
Fisheries and Environment Canada | Pêches et Environnement Canada
Fisheries and Marine Service | Service des pêches et de la mer

An example from Bedford Basin



BEDFORD BASIN

44°41'N 63°39'W

DATE: 31/08/76 SAMPLE DEPTH: 5 m SURFACE TEMP: 16.9°C

Light Intensity W m^{-2}	Specific Production mg C(mg Chl a)$^{-1}$hr^{-1}	Light Intensity W m^{-2}	Specific Production mg C(mg Chl a)$^{-1}$hr^{-1}
225.1	11.55	224.8	11.11
112.7	11.58	107.2	10.65
45.0	10.43	41.6	9.82
23.1	6.79	20.8	5.37
13.0	4.19	10.9	3.40
6.4	2.53	4.1	1.98
4.4	1.14	4.0	1.14
2.9	0.59	2.8	0.60
1.8	0.26	2.2	0.33
1.1	0.09	0.8	0.16

Incubation Temperature: 16.0°C

	mg at m^{-3}
Nitrate:	0.07
Nitrite:	0.02
Ammonia:	0.50
Silicate:	4.55
Phosphate:	0.48

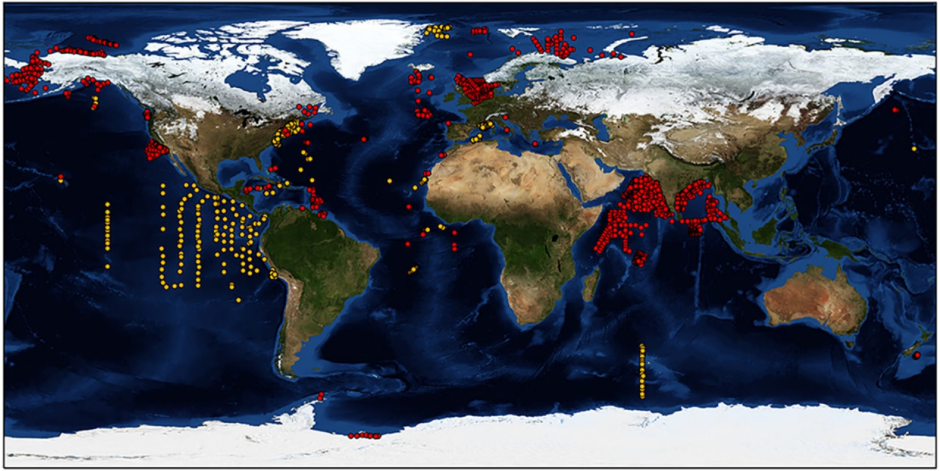
	mg m^{-3}
Chlorophyll:	2.18
Carbon	713
Nitrogen:	84

Salinity: 30.57 ‰

Total number of cells:	14.6	x $10^6 l^{-1}$
Total volume of cells:	2.55	ppm
Mean volume of cells:	150	μ^3

		90% Confidence Interval lower	upper
α mg C(mg Chl a)$^{-1}$hr^{-1}(W m^{-2})$^{-1}$	0.35	0.30	0.40
R^B mg C(mg Chl a)$^{-1}$hr^{-1}	-0.28	-0.64	-0.08
P_m^B mg C(mg Chl a)$^{-1}$hr^{-1}	11.61	11.25	11.97

D3. Global marine phytoplankton production dataset accessed (Mattei & Scardi, 2021)



D3. Global marine phytoplankton production dataset accessed (Mattei & Scardi, 2021)

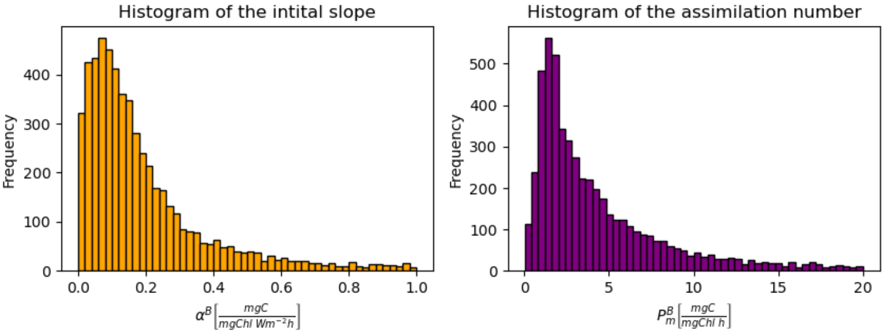
This dataset has **6084 production profiles**.

There are around **50 000 primary production incubations**.

There are around **50 000 chlorophyll measurements**.

D4. Local data repository created

An example of parameter estimation from Mattei & Scardi (2021) dataset



D5. Primary production measurements in the Adriatic

In situ primary production measurements were conducted at the following stations:

Kašetla bay:
23.1.2024., 16.2.2024., 15.3.2024., 2.4.2024., 9.10.2024., 16.11.2024., 10.12.2024.

Stončica station:
24.1.2024., 17.2.2024., 17.3.2024., 3.4.2024., 14.10.2024., 17.11.2024., 11.12.2024.

D6. Modern capital theory applied to the study of marine photosynthesis

Bioeconomic interpretation of primary production models

Žarko Kovač[1], Davor Mance[2], Diana Mance[3,*], Shubha Sathyendranath[4], Anja Kovač [5]

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[2] *University of Rijeka, Faculty of Economics, Ivana Filipovića 4, 51000 Rijeka, Croatia*
[3] *University of Rijeka, Faculty of Physics, Radmile Matejčić 2, 51000 Rijeka, Croatia*
[4] *Plymouth Marine Laboratory, Prospect Place, The Hoe, Plymouth PL1 3DH, UK*
[5] *Institute of Oceanography and Fisheries, Šetalište Ivana Meštrovića 63, 21000 Split, Croatia*
[*] **corresponding author: diana.mance@uniri.hr**

Abstract

Mathematical models of marine primary production have long since been established in the oceanographic literature. They are based on biophysical principles expressing the relation between the rate of carbon assimilation by photosynthesis in the presence of light, via mathematical functions called photosynthesis-irradiance functions. Here we make the case that marine primary production can also be studied using economic theory, by employing similarities in the mathematical apparatus used in biophysical and economic models. By using economic theory we provide a bioeconomic interpretation to the canonical model of primary production and derive a set of bioeconomic indicators for marine primary production. It is shown that the photosynthesis-irradiance function can be interpreted as the marginal product of phytoplankton biomass and that the initial slope of the photosynthesis irradiance function equals the marginal product of light. It is also demonstrated that saturation of photosynthesis with respect to light is in line with the law of diminishing returns. Watercolumn production and mixed-layer production are studied using the notions of marginal product and elasticity. Marginal mixed-layer production is defined with respect to nutrients and its relation with respect to mixed layer depth is studied. Exact expressions for elasticity of output with respect to surface irradiance and mixed layer depth are derived and interpreted using the lens of economic theory. Finally, the theoretical significance of the approach is examined, highlighting instances in the literature where interactions between the disciplines of primary production modelling and economics would have been beneficial for both.

A paper under review

D7. Measuring primary production workshop

The first project workshop took place in Split in from **14th to 18th October**.

D7. Measuring primary production workshop

The theme of the workshop was the creation of a database of quality-checked in situ primary production time series along with programming tools for handling such data sets.A detalied report from the workshop can be found here:

https://www.photoclim.org/workshops/measuring-primary-production/

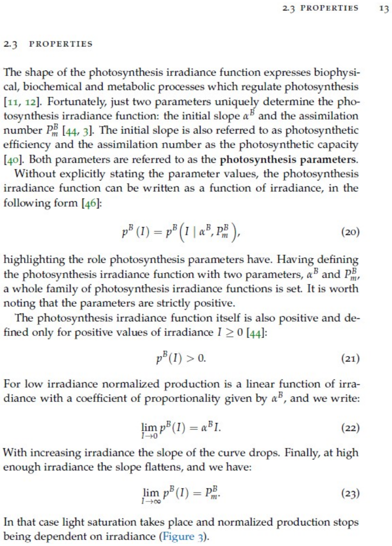
D8. Educational material on primary production theory

Our first educational material is now available for download!

Modelling Primary Production

https://www.photoclim.org/education/

D8. Educational material on primary production theory



2.3 PROPERTIES

The shape of the photosynthesis irradiance function expresses biophysical, biochemical and metabolic processes which regulate photosynthesis [11, 12]. Fortunately, just two parameters uniquely determine the photosynthesis irradiance function: the initial slope α^B and the assimilation number P_m^B [44, 3]. The initial slope is also referred to as photosynthetic efficiency and the assimilation number as the photosynthetic capacity [40]. Both parameters are referred to as the **photosynthesis parameters**.

Without explicitly stating the parameter values, the photosynthesis irradiance function can be written as a function of irradiance, in the following form [46]:

$$p^B(I) = p^B\left(I \mid \alpha^B, P_m^B\right), \tag{20}$$

highlighting the role photosynthesis parameters have. Having defining the photosynthesis irradiance function with two parameters, α^B and P_m^B, a whole family of photosynthesis irradiance functions is set. It is worth noting that the parameters are strictly positive.

The photosynthesis irradiance function itself is also positive and defined only for positive values of irradiance $I \geq 0$ [44]:

$$p^B(I) > 0. \tag{21}$$

For low irradiance normalized production is a linear function of irradiance with a coefficient of proportionality given by α^B, and we write:

$$\lim_{I\to 0} p^B(I) = \alpha^B I. \tag{22}$$

With increasing irradiance the slope of the curve drops. Finally, at high enough irradiance the slope flattens, and we have:

$$\lim_{I\to\infty} p^B(I) = P_m^B. \tag{23}$$

In that case light saturation takes place and normalized production stops being dependent on irradiance (Figure 3).

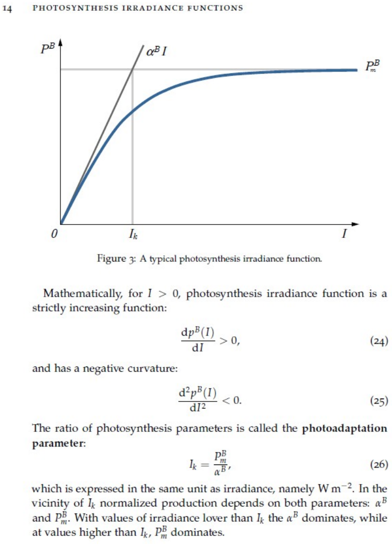


Figure 3: A typical photosynthesis irradiance function.

Mathematically, for $I > 0$, photosynthesis irradiance function is a strictly increasing function:

$$\frac{\mathrm{d}p^B(I)}{\mathrm{d}I} > 0, \tag{24}$$

and has a negative curvature:

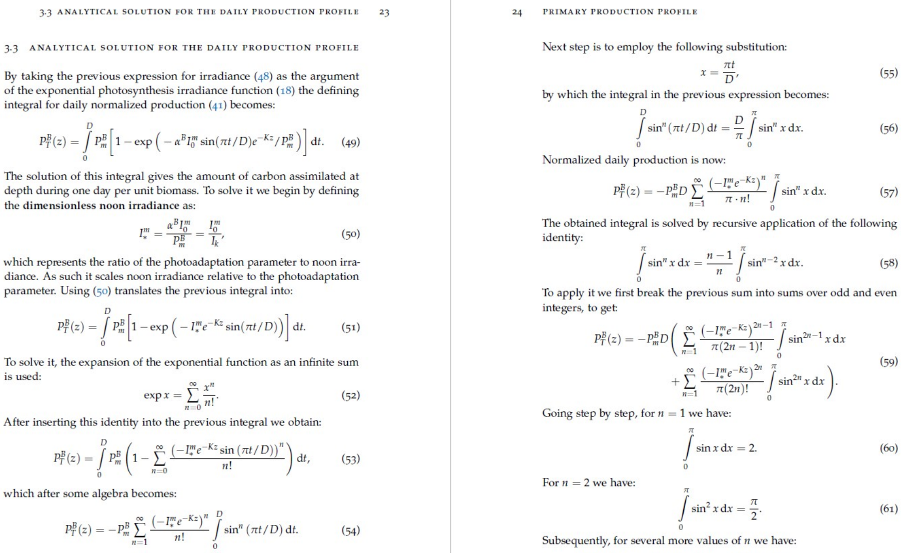
$$\frac{\mathrm{d}^2 p^B(I)}{\mathrm{d}I^2} < 0. \tag{25}$$

The ratio of photosynthesis parameters is called the **photoadaptation parameter**:

$$I_k = \frac{P_m^B}{\alpha^B}, \tag{26}$$

which is expressed in the same unit as irradiance, namely W m^{-2}. In the vicinity of I_k normalized production depends on both parameters: α^B and P_m^B. With values of irradiance lover than I_k the α^B dominates, while at values higher than I_k, P_m^B dominates.

D8. Educational material on primary production theory



3.3 ANALYTICAL SOLUTION FOR THE DAILY PRODUCTION PROFILE

By taking the previous expression for irradiance (48) as the argument of the exponential photosynthesis irradiance function (18) the defining integral for daily normalized production (41) becomes:

$$P_T^B(z) = \int_0^D P_m^B\left[1-\exp\left(-\alpha^B I_0^m \sin(\pi t/D)e^{-Kz}/P_m^B\right)\right]\mathrm{d}t. \tag{49}$$

The solution of this integral gives the amount of carbon assimilated at depth during one day per unit biomass. To solve it we begin by defining the **dimensionless noon irradiance** as:

$$I_*^m = \frac{\alpha^B I_0^m}{P_m^B} = \frac{I_0^m}{I_k}, \tag{50}$$

which represents the ratio of the photoadaptation parameter to noon irradiance. As such it scales noon irradiance relative to the photoadaptation parameter. Using (50) translates the previous integral into:

$$P_T^B(z) = \int_0^D P_m^B\left[1-\exp\left(-I_*^m e^{-Kz}\sin(\pi t/D)\right)\right]\mathrm{d}t. \tag{51}$$

To solve it, the expansion of the exponential function as an infinite sum is used:

$$\exp x = \sum_{n=0}^{\infty}\frac{x^n}{n!}. \tag{52}$$

After inserting this identity into the previous integral we obtain:

$$P_T^B(z) = \int_0^D P_m^B\left(1-\sum_{n=0}^{\infty}\frac{\left(-I_*^m e^{-Kz}\sin\left(\pi t/D\right)\right)^n}{n!}\right)\mathrm{d}t, \tag{53}$$

which after some algebra becomes:

$$P_T^B(z) = -P_m^B\sum_{n=1}^{\infty}\frac{\left(-I_*^m e^{-Kz}\right)^n}{n!}\int_0^D \sin^n\left(\pi t/D\right)\mathrm{d}t. \tag{54}$$

Next step is to employ the following substitution:

$$x = \frac{\pi t}{D}, \tag{55}$$

by which the integral in the previous expression becomes:

$$\int_0^D \sin^n(\pi t/D)\,\mathrm{d}t = \frac{D}{\pi}\int_0^\pi \sin^n x\,\mathrm{d}x. \tag{56}$$

Normalized daily production is now:

$$P_T^B(z) = -P_m^B D\sum_{n=1}^{\infty}\frac{\left(-I_*^m e^{-Kz}\right)^n}{\pi\cdot n!}\int_0^\pi \sin^n x\,\mathrm{d}x. \tag{57}$$

The obtained integral is solved by recursive application of the following identity:

$$\int_0^\pi \sin^n x\,\mathrm{d}x = \frac{n-1}{n}\int_0^\pi \sin^{n-2}x\,\mathrm{d}x. \tag{58}$$

To apply it we first break the previous sum into sums over odd and even integers, to get:

$$\begin{aligned} P_T^B(z) = -P_m^B D\Bigg(&\sum_{n=1}^{\infty}\frac{\left(-I_*^m e^{-Kz}\right)^{2n-1}}{\pi(2n-1)!}\int_0^\pi \sin^{2n-1}x\,\mathrm{d}x \\ &+\sum_{n=1}^{\infty}\frac{\left(-I_*^m e^{-Kz}\right)^{2n}}{\pi(2n)!}\int_0^\pi \sin^{2n}x\,\mathrm{d}x\Bigg). \end{aligned} \tag{59}$$

Going step by step, for $n=1$ we have:

$$\int_0^\pi \sin x\,\mathrm{d}x = 2. \tag{60}$$

For $n=2$ we have:

$$\int_0^\pi \sin^2 x\,\mathrm{d}x = \frac{\pi}{2}. \tag{61}$$

Subsequently, for several more values of n we have:

D9. & D10. Training

The 6th edition of the advanced **IOCCG Summer Lecture Series: Frontiers in Ocean Optics and Ocean Colour Science** was held during 4-16 November 2024 in Hyderabad, India. Our team member **Shubha Sathyendranath** was part of the organization committee and our team member **Leon Ćatipović** was one of the attendees.

D11. Attendance at conferences

Leon Ćatipović and **Žarko Kovač** attended the **Ocean Optics** conference in Las Palmas, Gran Canaria. The six day conference started on the 6 October and was held at the Palacio de Congresos located along Playa de Las Canteras. It is considered the leading conference in the filed of ocean optics. In total there were over 350 attendees from around the globe.

Leon presented his work on validation of gap-filled satellite-detected surface chlorophyll concentration in the Adriatic and Ionian basin. **Žarko** served as a planning committee member.

D12. Scientific publications

Critical Times for the Critical Depth Theory

Žarko Kovač[1,*] & Shubha Sathyendranath[2]

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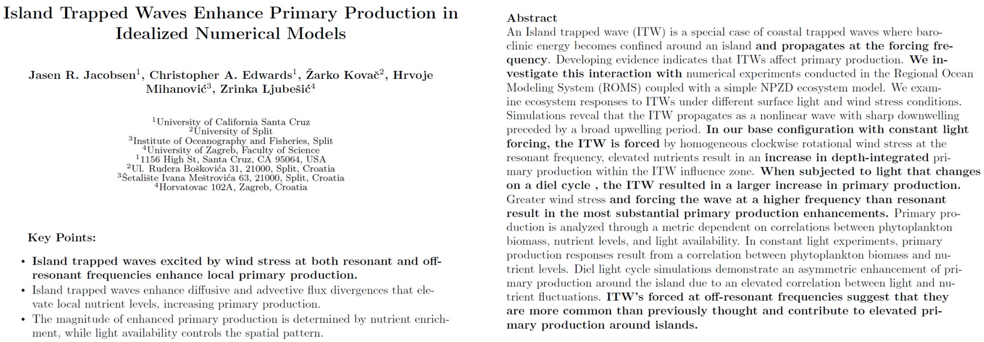
Abstract

Critical Depth Hypothesis is arguably one of the longest standing biophysical theories in oceanography and is the earliest mathematically formulated theory aimed at explaining the phenomenon of phytoplankton blooms. It introduces a depth horizon, termed the critical depth, at which the integrated primary production from the surface to that depth equals the integrated loss terms within the same layer. If the mixed layer is deeper than the critical depth, average light level in the mixed layer falls below that required to maintain photosynthesis at a level that equals losses. A related horizon in case of week mixing is the compensation depth, where the rate of photosynthesis matches the loss rate. In this paper the effect of phytoplankton light attenuation on the critical depth is examined, showing that it creates a bio-optical feedback in the model. A new differential equation, derived for the time evolution of the compensation depth reveals that the light intensities at both the compensation depth and the critical depth are constants of motion. A common model assumption of zero biomass below the mixed layer is derived as a consequence of the bio-optical feedback in the mixed layer. Exact solutions for average and total mixed layer biomass at steady state are derived and their stability properties analysed. It is demonstrated that the system has a trivial and a non-trivial steady state. An existence of a bio-optical bifurcation is shown, in which the mixed layer depth acts as the bifurcation parameter. The critical depth is identified as the bifurcation point at which the trivial and the non-trivial steady state exchange stability properties. Transients between steady states are also explored and it is shown that the relation between the initial condition and the final steady state is paramount in determining whether a shallowing or deepening of the mixed layer will lead to a rise or a decline in biomass over time.

A paper under review

D12. Scientific publications



Island Trapped Waves Enhance Primary Production in Idealized Numerical Models

Jasen R. Jacobsen[1], Christopher A. Edwards[1], Žarko Kovač[2], Hrvoje Mihanović[3], Zrinka Ljubešić[4]

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Key Points:

- **Island trapped waves excited by wind stress at both resonant and off-resonant frequencies enhance local primary production.**
- Island trapped waves enhance diffusive and advective flux divergences that elevate local nutrient levels, increasing primary production.
- The magnitude of enhanced primary production is determined by nutrient enrichment, while light availability controls the spatial pattern.

Abstract

An Island trapped wave (ITW) is a special case of coastal trapped waves where baroclinic energy becomes confined around an island **and propagates at the forcing frequency**. Developing evidence indicates that ITWs affect primary production. **We investigate this interaction with** numerical experiments conducted in the Regional Ocean Modeling System (ROMS) coupled with a simple NPZD ecosystem model. We examine ecosystem responses to ITWs under different surface light and wind stress conditions. Simulations reveal that the ITW propagates as a nonlinear wave with sharp downwelling preceded by a broad upwelling period. **In our base configuration with constant light forcing, the ITW is forced** by homogeneous clockwise rotational wind stress at the resonant frequency, elevated nutrients result in an **increase in depth-integrated** primary production within the ITW influence zone. **When subjected to light that changes on a diel cycle , the ITW resulted in a larger increase in primary production.** Greater wind stress **and forcing the wave at a higher frequency than resonant result in the most substantial primary production enhancements.** Primary production is analyzed through a metric dependent on correlations between phytoplankton biomass, nutrient levels, and light availability. In constant light experiments, primary production responses result from a correlation between phytoplankton biomass and nutrient levels. Diel light cycle simulations demonstrate an asymmetric enhancement of primary production around the island due to an elevated correlation between light and nutrient fluctuations. **ITW's forced at off-resonant frequencies suggest that they are more common than previously thought and contribute to elevated primary production around islands.**

A paper under review

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Thank you!