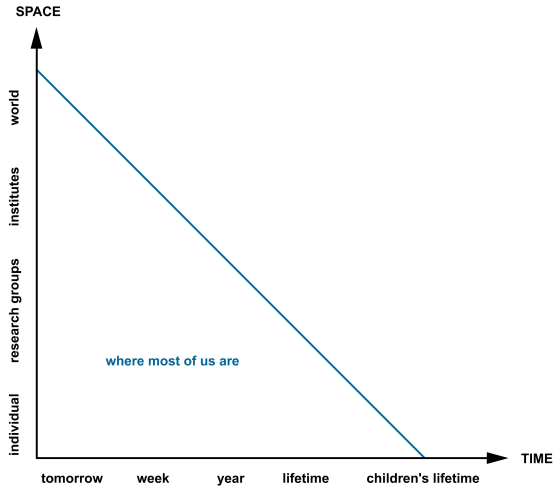
22nd February 2024
Department of Physics, Faculty of Science, University of Split

PHOTOCLIM Kickoff meeting

FRAGILITY OF MARINE PHOTOSYNTHESIS UNDER CLIMATE CHANGE

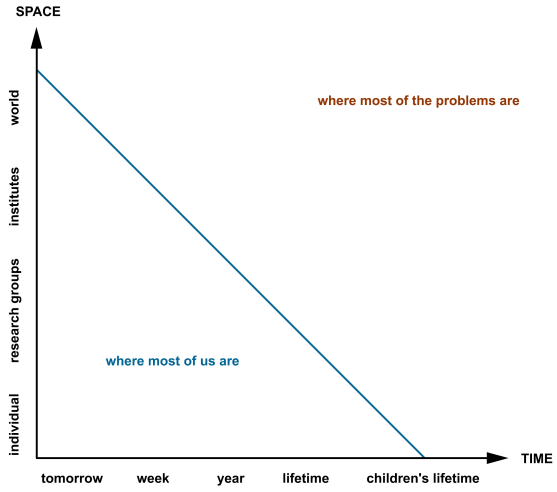
Project funded by the Croatian Science Foundation IP-2022-10-8859

Motivation



Adopted from Limits to growth (1972)

Motivation



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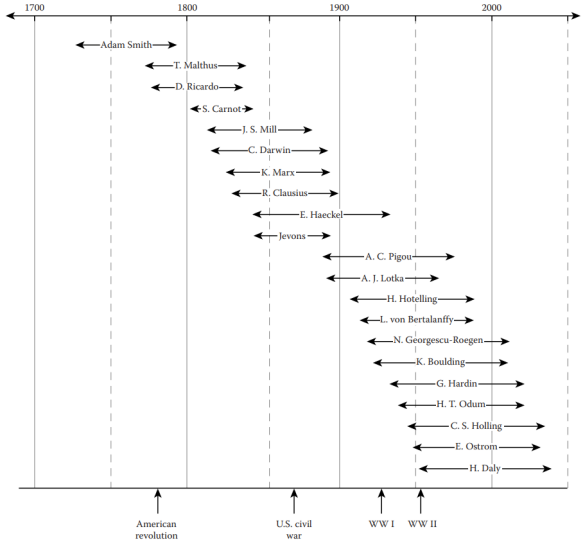
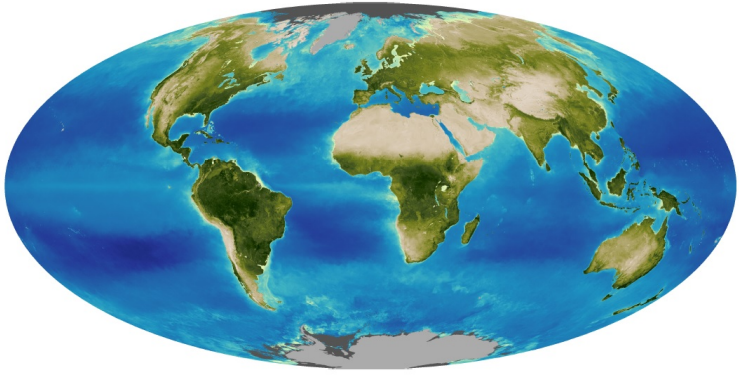
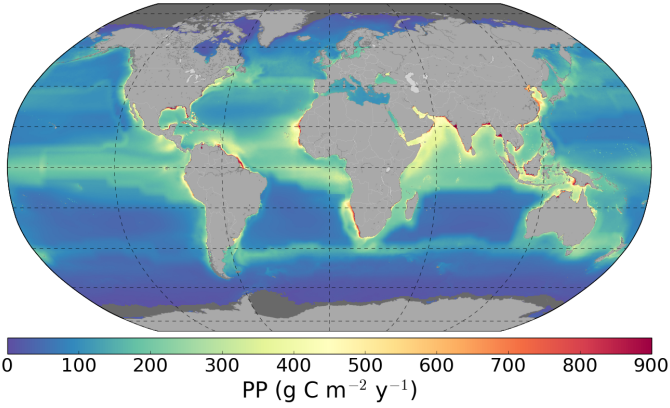

1700
1800
1900
2000
Adam Smith
T. Malthus
D. Ricardo
S. Carnot
J. S. Mill
C. Darwin
K. Marx
R. Clausius
E. Haeckel
Jevons
A. C. Pigou
A. J. Lotka
H. Hotelling
L. von Bertalanffy
N. Georgescu-Roegen
K. Boulding
G. Hardin
H. T. Odum
C. S. Holling
E. Ostrom
H. Daly
American revolution
U.S. civil war
WW I
WW II

Where we are now



Anthropogenic carbon emissions per year 10 Gt C
Carbon assimilated by the biosphere per year 100 Gt C
Carbon assimilated by phytoplankton 50% of total
Phytoplankton biomass 1% of total land biomass

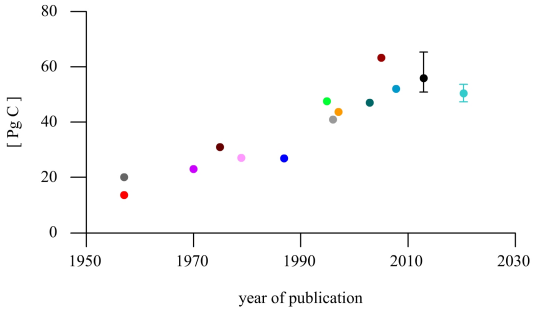
Global annual primary production from Kulk et al. (2021)



48.7 to 52.5 Gt C per year between 1998 and 2018

How we got here

Global annual marine primary production from the literature



- *Steeman Nielsen & Jensen, 1957*
- *Gessner, 1957*
- *Koblenz-Mishke, 1970*
- *Platt & Subba Rao, 1975*
- *Eppley & Peterson, 1979*
- *Berger et al., 1987*
- *Longhurst et al., 1995*
- *Antoine et al., 1996*
- *Behrenfeld & Falkowski, 1997*
- *Melin, 2003*
- *Behrenfeld et al., 2005*
- *Westberry et al., 2008*
- *Buitenhuis et al., 2013*
- *Kulk et al., 2021*

Adopted from Buitenhuis et al. (2013)

Where are we going?

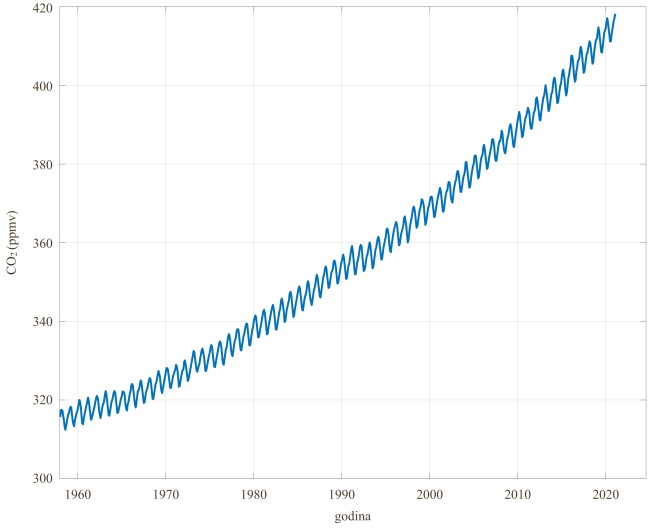
Tragedy of the commons

If decisions about the use of renewable natural resources are based exclusively on profits, even long-term profits, **renewable natural resources will be used on a sustainable basis only if their biological growth rate is greater than the expected growth rate of alternative investments.** Because the growth rate of the world economy today is greater than the biological growth rate of most renewable resources, there are powerful economic incentives not to use renewable natural resources on a sustainable basis. **If people accept the rules of the game in a free market economy, it is rational to use renewable resources unsustainably whenever biological production fails to compete with alternative forms of investment.**

(Marnet, 2001)

Considerations of sustainable growth are particulary problematic in the context of climate change. The stress on marine primary production comes from exploitation as well as from environmental changes.

The Keeling curve



Valuation: a hard problem

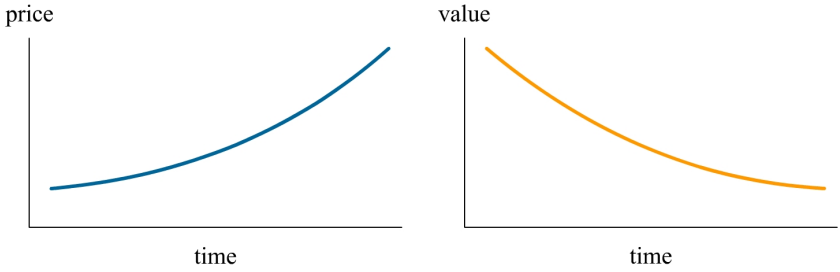
What would you rather: a tree today or two trees tomorrow?

Valuation: a hard problem

What would you rather: a tree today or two trees tomorrow?

Depends on how fast the trees grow!

Discounting



$$P = P_0 e^{\gamma t} \qquad \rightarrow \qquad P_0 = P e^{-\gamma t}$$

The process of converting value received in the future to value received now.

Do we properly value primary production?

Approaches to studying primary production

In situ

Incubation at sea under natural light conditions.
(Steemann Nielsen, 1952)

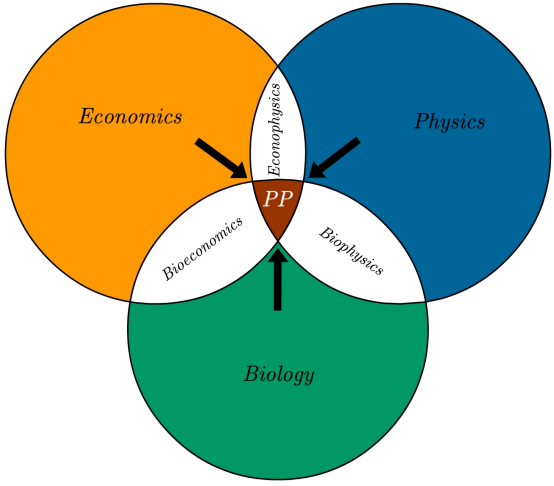
In vitro

Incubation under controlled light conditions.
(Platt i Jassby, 1976)

In silico

Computer implementation of primary production models.
(Gentleman, 2002)

The main project idea



A long standing question: What limits primary production?

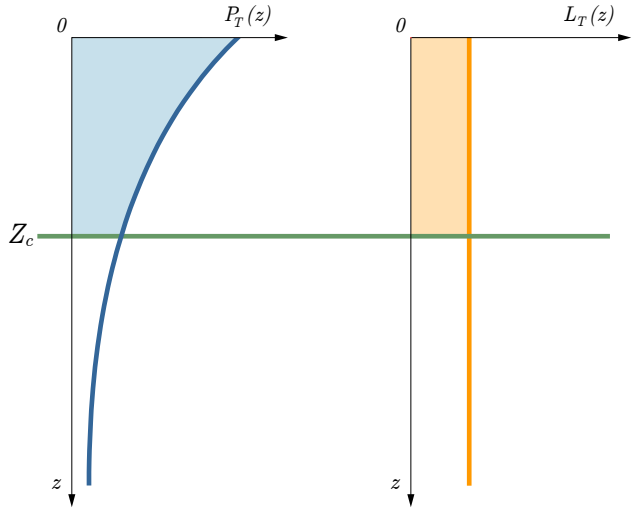
Going back to 1935!

...vertical movements of the water must favour new growth of phytoplankton through the mixing which carries nutritive substances to the illuminated zone from deep waters.

On the other hand a series of facts observed in recent years indicates that vertical mixing, besides having a favourable effect, may have an unfavourable influence on the growth of the phytoqlankton, because it prevents the living cells from accumulating in the illuminated zone where they may utilize the light for photosynthesis, and the nitrates and phosphates for growth and propagation.

(Gran & Braarud, 1935)

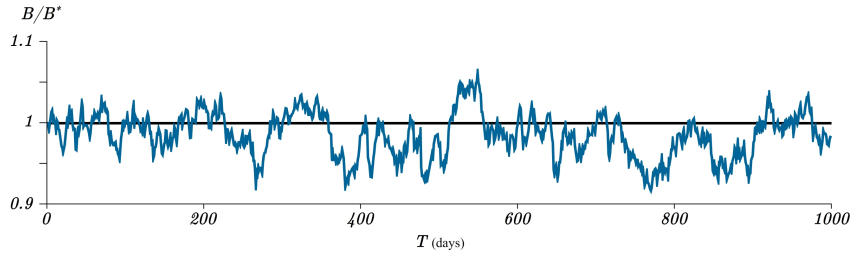
The classical Critical Depth Criterion (Sverdrup, 1953)



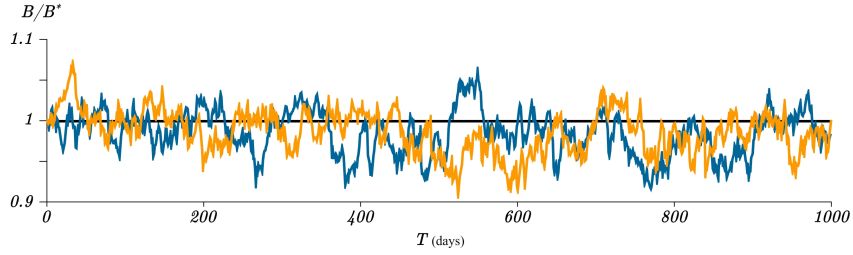
What happens when we add noise to surface irradiance?

$$I_0^m(t) = \langle I_0^m \rangle + \delta I_0^m$$

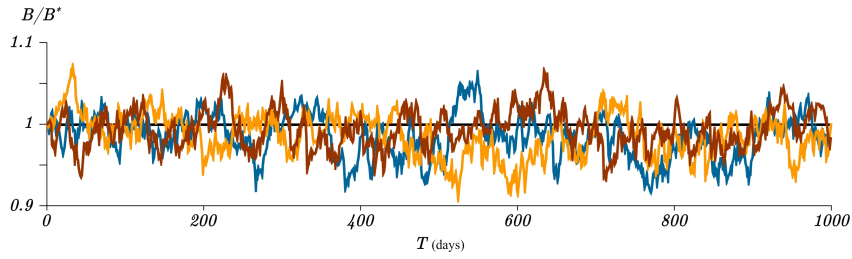
Dynamics



Dynamics



Dynamics

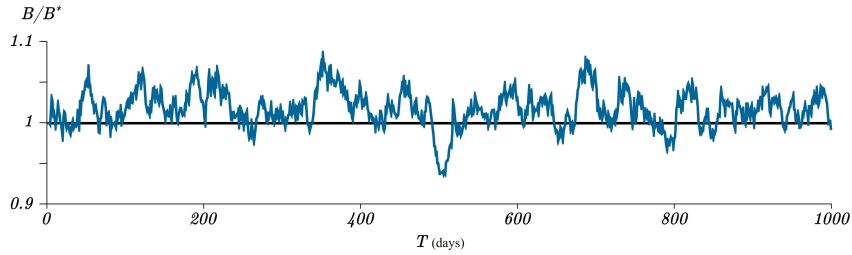


Biomass is suppressed despite having received same total energy.

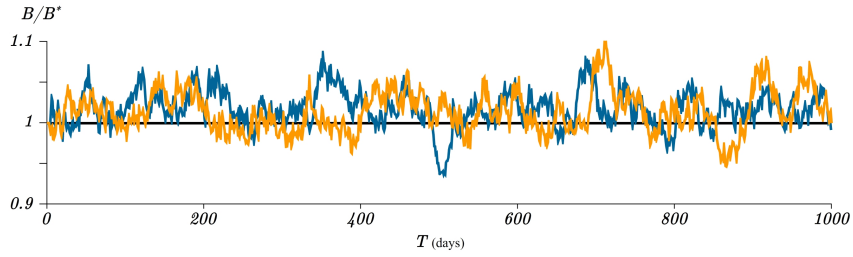
What happens when we add noise to mixed-layer depth?

$$Z_m(t) = \langle Z_m \rangle + \delta Z_m$$

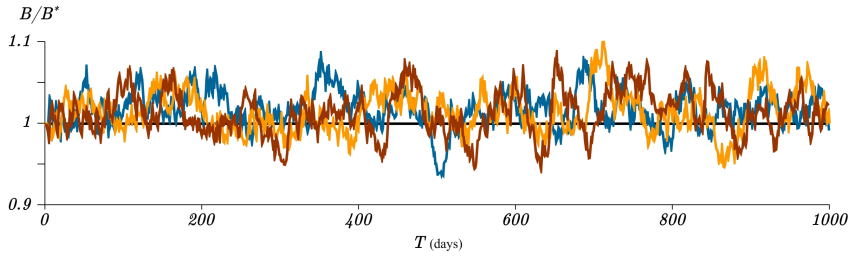
Dynamics



Dynamics



Dynamics

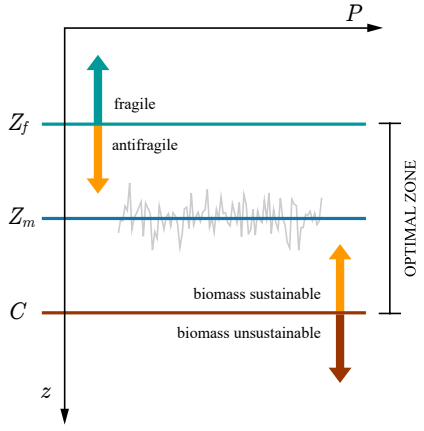


In this case the opposite holds: biomass is increased on average.

An analogy to illustrate the concept

FRAGILE	ROBUST	ANTIFRAGILE
suffers from disorder	stays the same	gains from disorder

Interpreting the model behaviour



Even though the critical depth criterion is met, biomass can be suppressed due to high frequency variability. Is there an optimal zone for the phytoplankton to thrive and production to be sustained in the long run? Can we speak of tipping points in primary production?

Thank you!