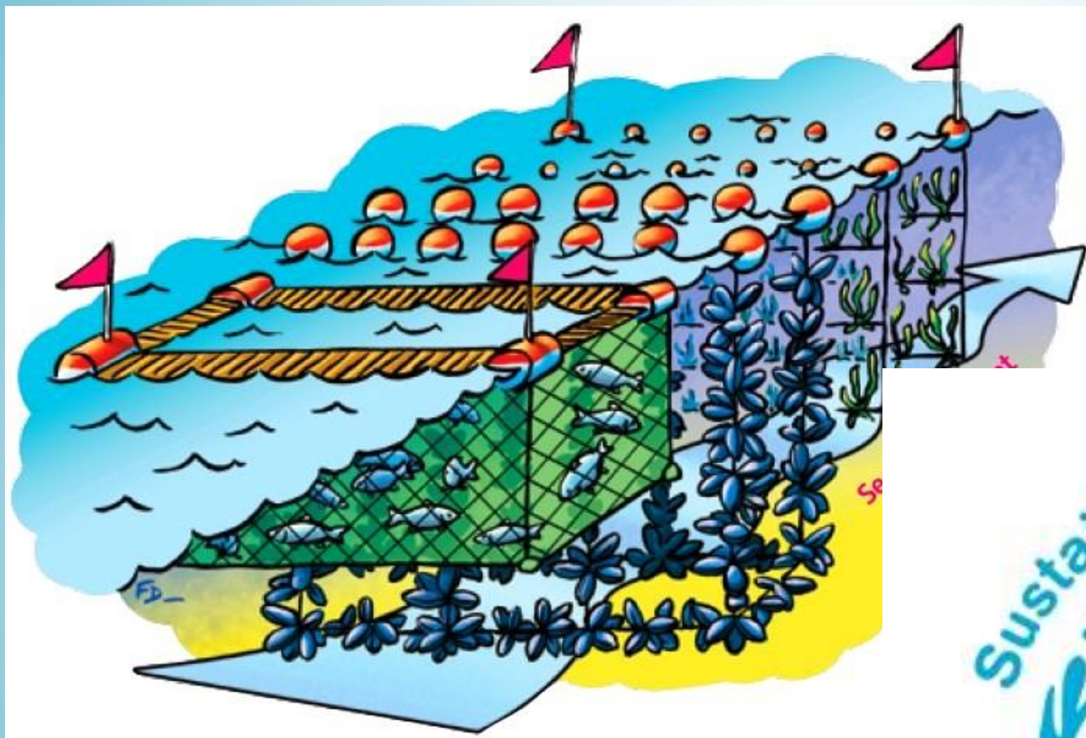
IMTA as a mass-production and mitigation tool in stress-prone coastal environments



Sustainable Aquaculture

CHOOSE WELL FOR THE FUTURE

Planetary boundaries

Science   Home   News   Journals   Topics   Careers

PERSPECTIVE | OCEANS

Nitrogen pollution knows no bounds

Edward Boyle

+ See all authors and affiliations

Science 19 May 2017:

Science
Vol 356, Issue 6339
19 May 2017

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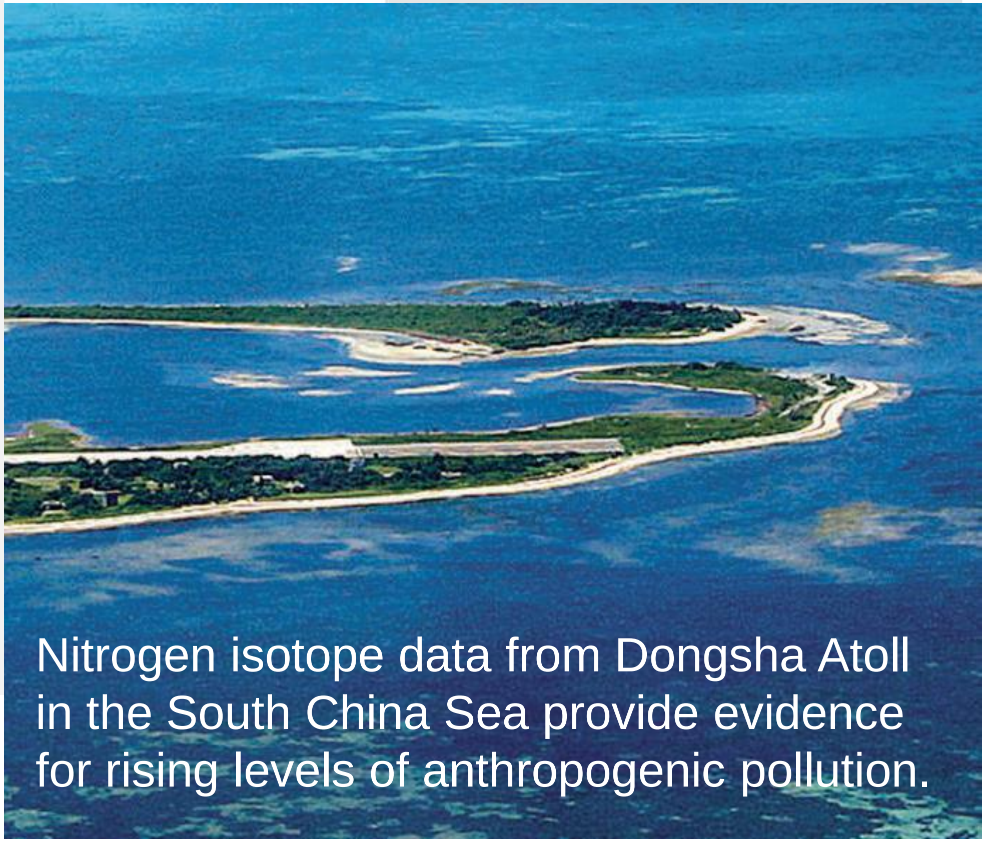
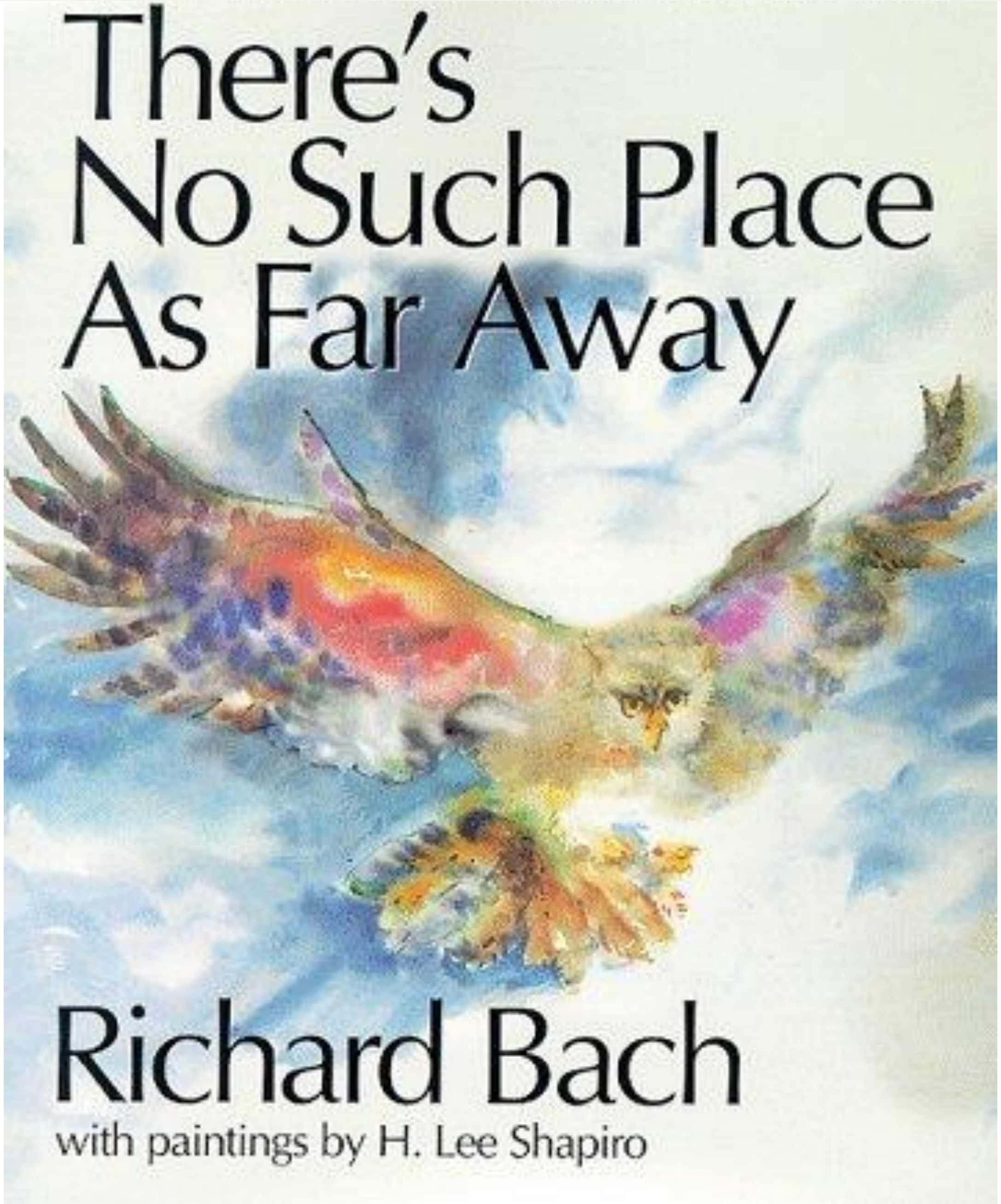
Advertising (PDF)
Classified (PDF)
Masthead (PDF)

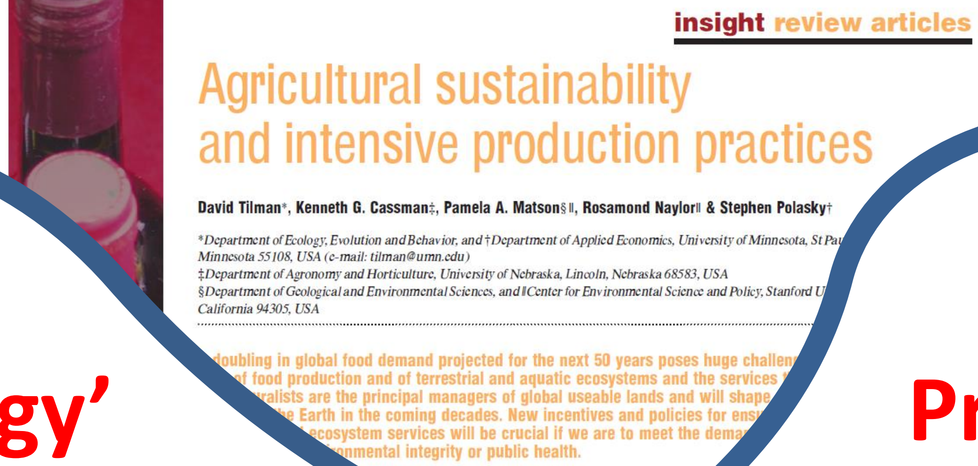
Anthropogenic nitrogen flux into the ocean may approach the magnitude of natural sources. This pathway now **supplies nearly one quarter of the annual nitrogen input to the ocean**.



Nitrogen isotope data from Dongsha Atoll in the South China Sea provide evidence for rising levels of anthropogenic pollution.

Planetary boundaries – Anthropogenic Nitrogen





insight review articles

Agricultural sustainability and intensive production practices

David Tilman*, Kenneth G. Cassman‡, Pamela A. Matson§ ‖, Rosamond Naylor‖ & Stephen Polasky†

*Department of Ecology, Evolution and Behavior, and †Department of Applied Economics, University of Minnesota, St Pau
Minnesota 55108, USA (e-mail: tilman@umn.edu)
‡Department of Agronomy and Horticulture, University of Nebraska, Lincoln, Nebraska 68583, USA
§Department of Geological and Environmental Sciences, and ‖Center for Environmental Science and Policy, Stanford U
California 94305, USA

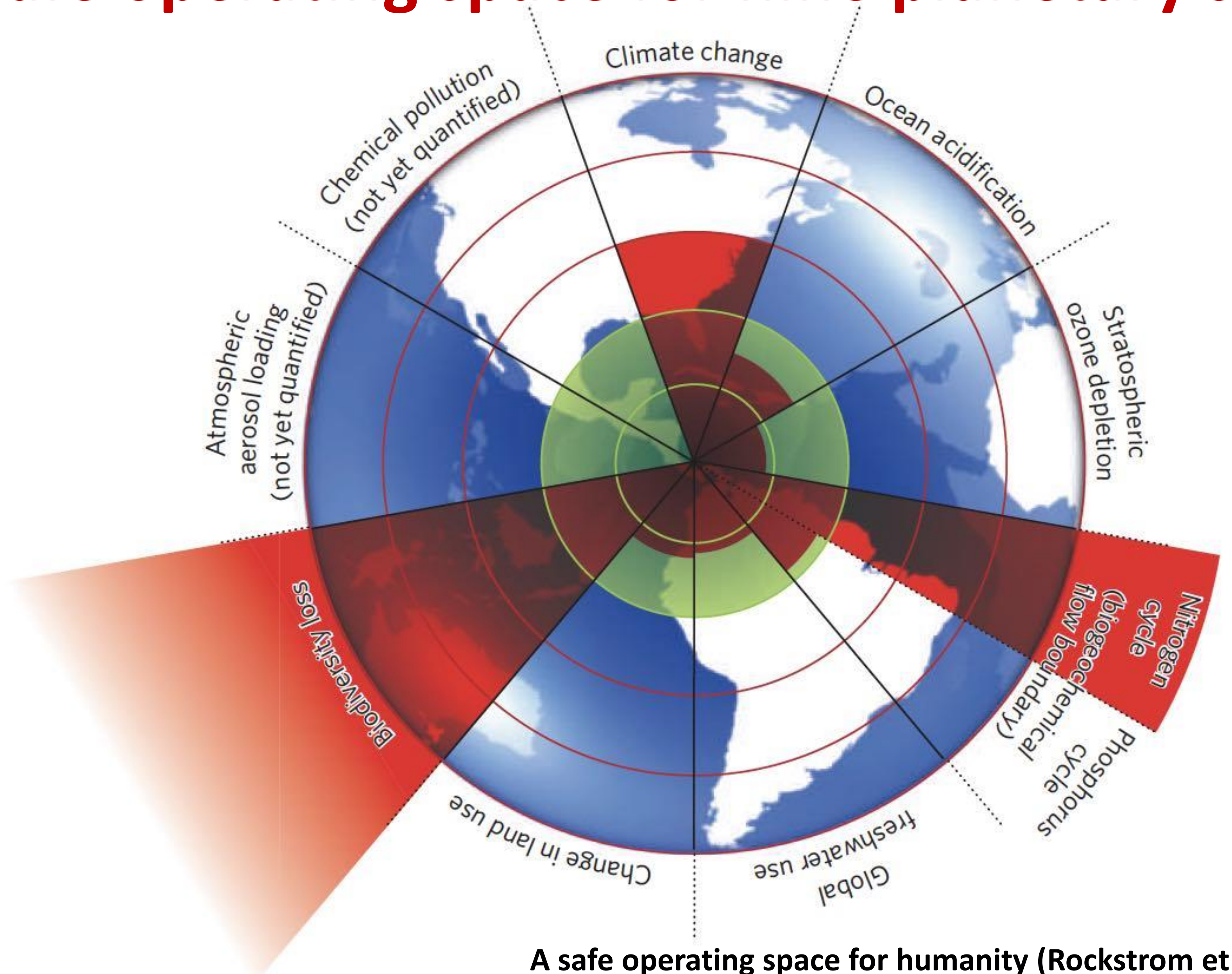
doubling in global food demand projected for the next 50 years poses huge challen
of food production and of terrestrial and aquatic ecosystems and the services
ralists are the principal managers of global useable lands and will shape
he Earth in the coming decades. New incentives and policies for ens
ecosystem services will be crucial if we are to meet the dema
onmental integrity or public health.

‘Energy’

Food Production

Healthy Environment

Planetary boundaries
Safe operating space for nine planetary systems



A safe operating space for humanity (Rockstrom et al. 2009 Nature)

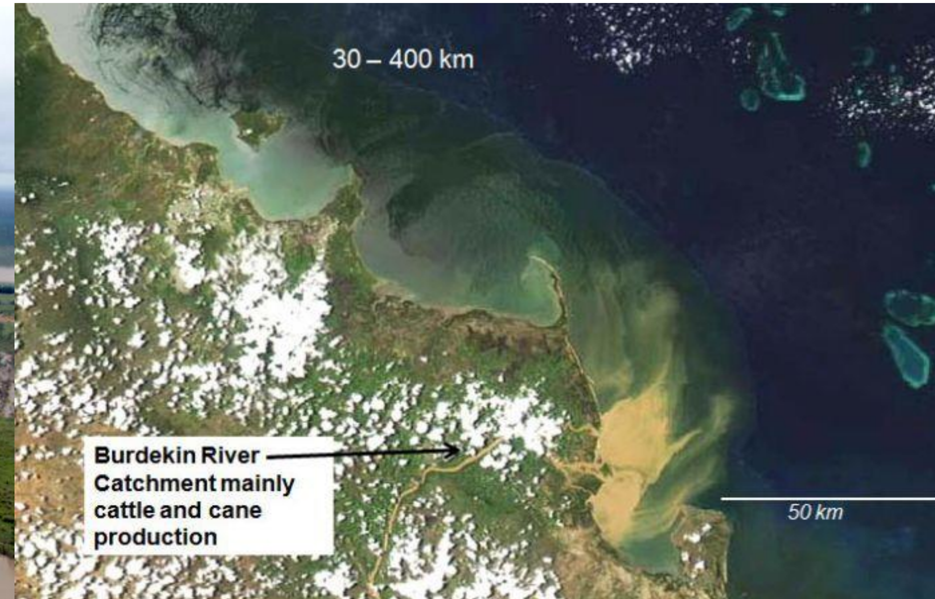
Can we feed the world and sustain the Planet?

By clearing tropical forests, farming marginal lands, and intensifying industrial farming in sensitive landscapes and watersheds, humankind has made agriculture the planet's dominant environmental threat. **Agriculture already consumes a large percentage of the earth's land surface and is destroying habitats, using up freshwater, polluting rivers and oceans, and emitting greenhouse gases more extensively than almost any other human activity**. To guarantee the globe's long-term health, we must dramatically reduce agriculture's adverse impacts.

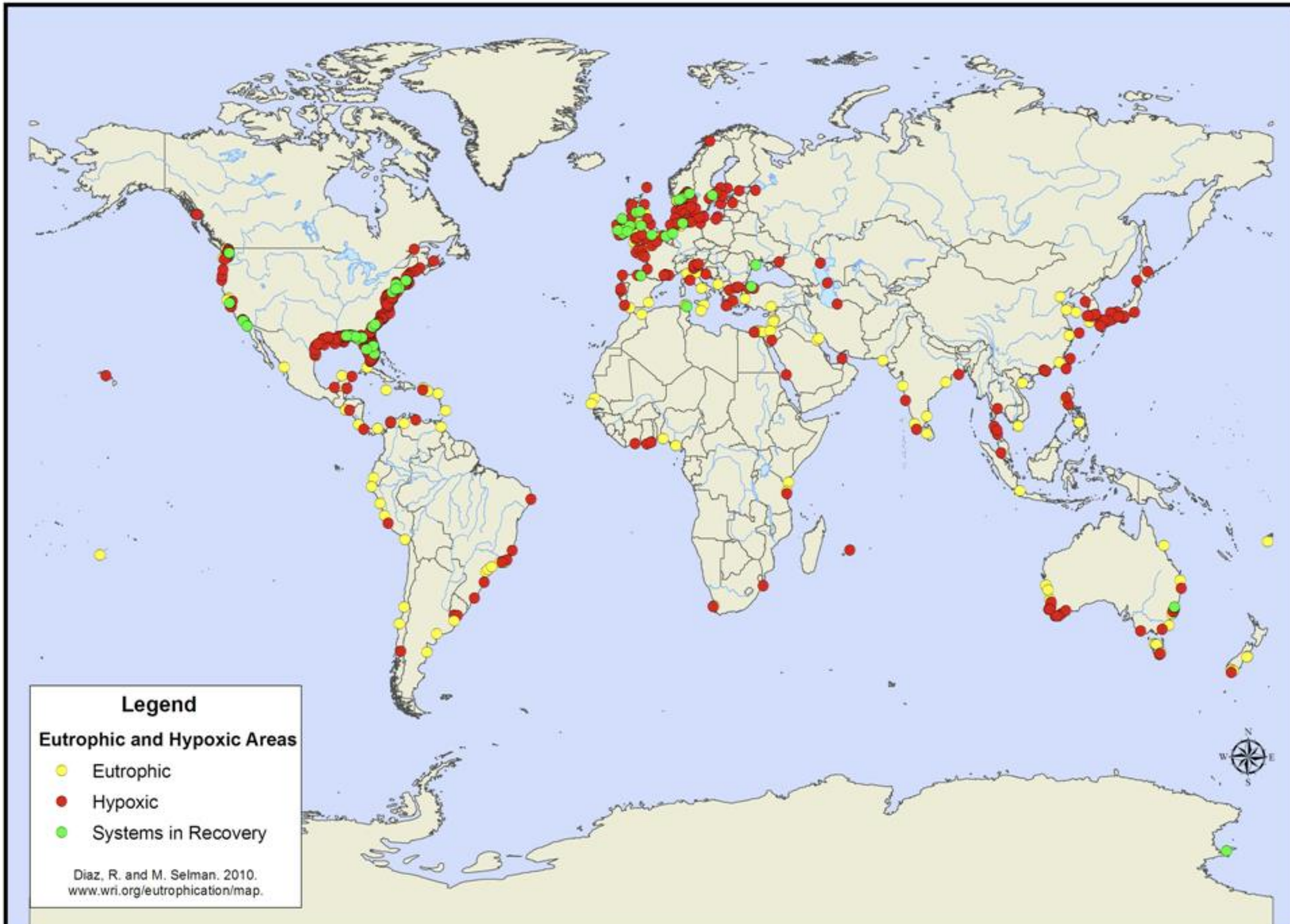
The world's food system faces three incredible, interwoven challenges. It must guarantee that all seven billion people alive today are adequately fed; it must double food production in the next 40 years; and it must achieve both goals while becoming truly environmentally sustainable.

(Foley 2011; Sci.Am.)

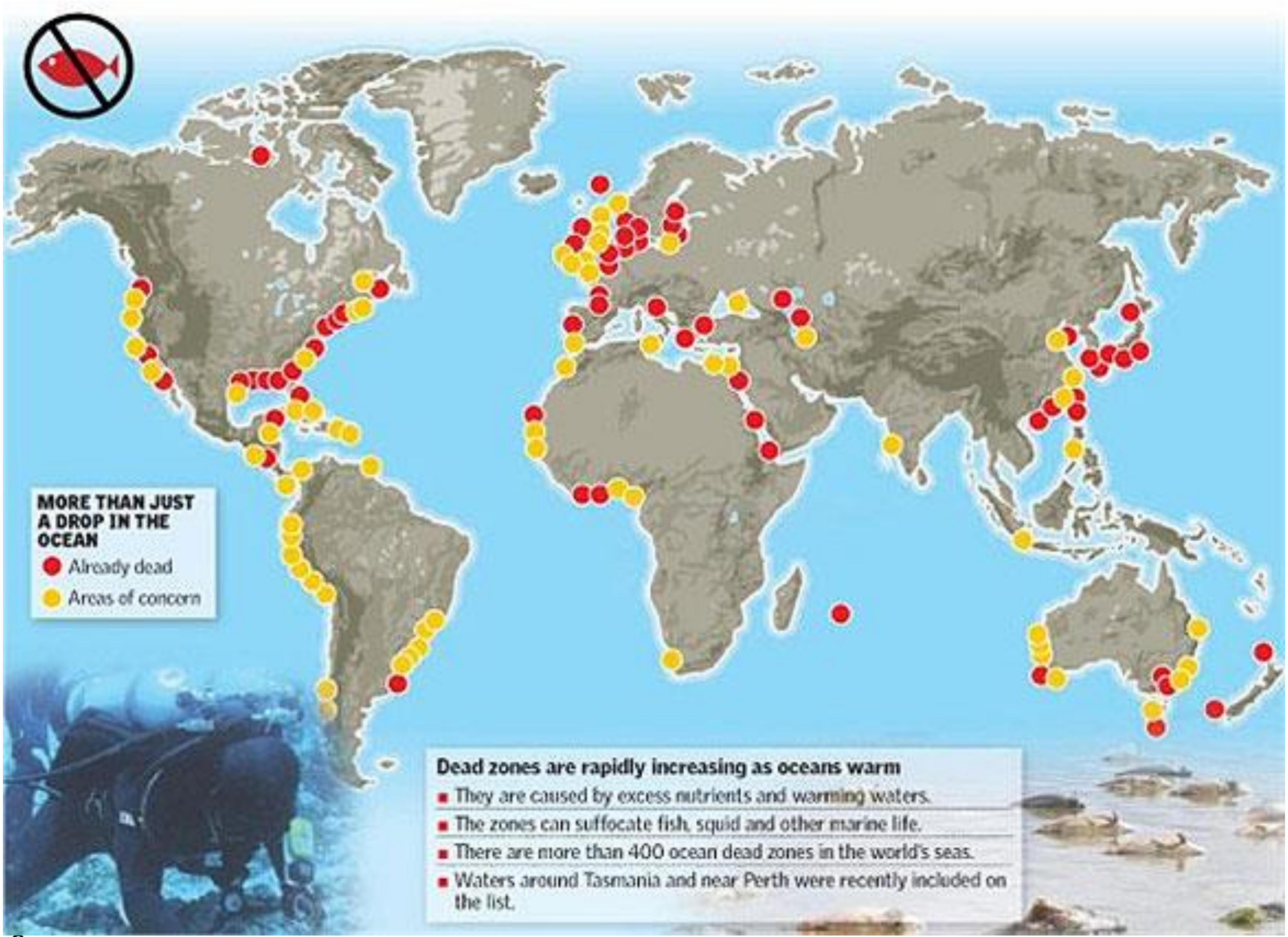
Coastal environments are degrading…



World Hypoxic and Eutrophic Coastal Areas

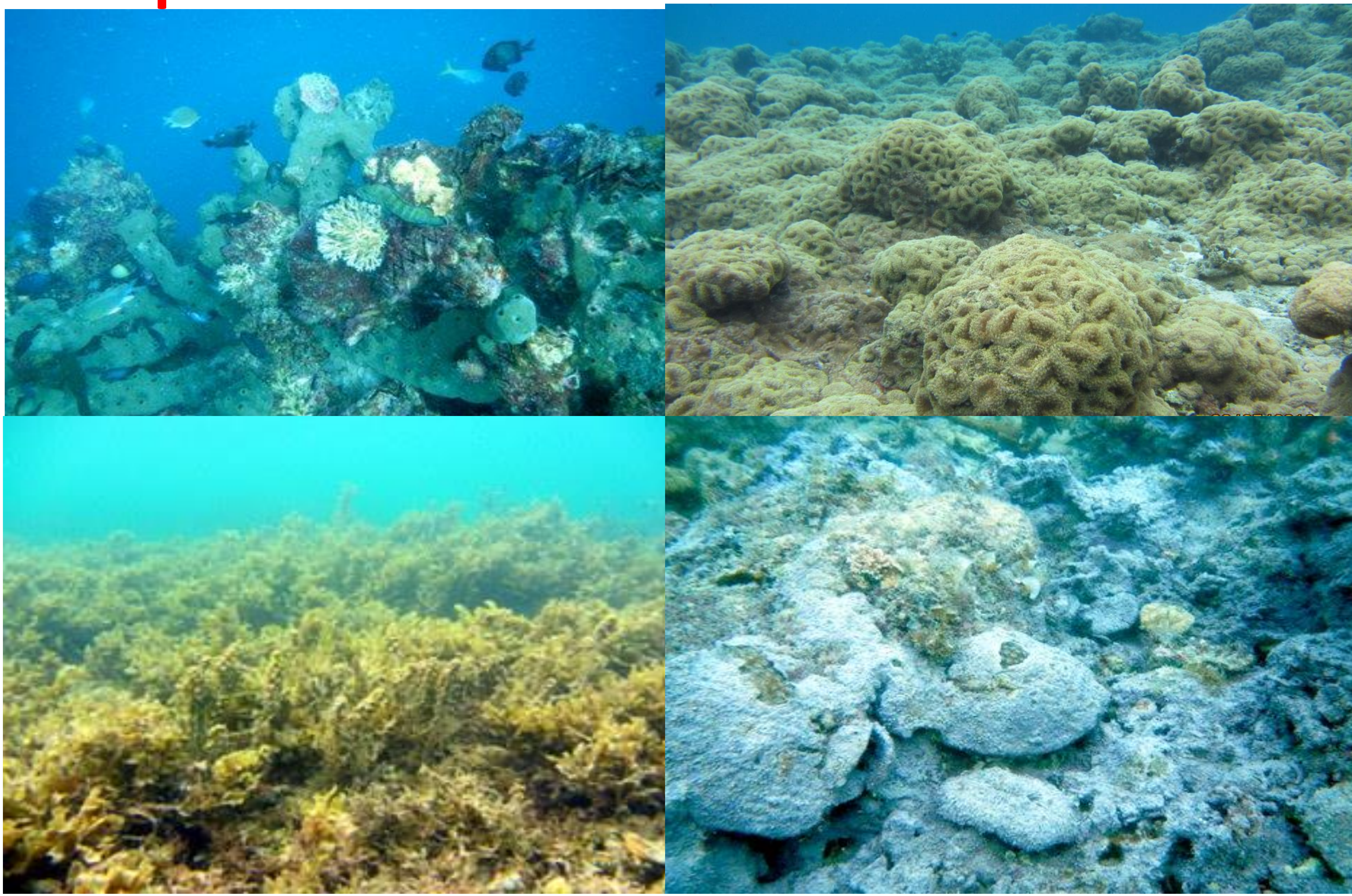


Marine 'Dead Zones'

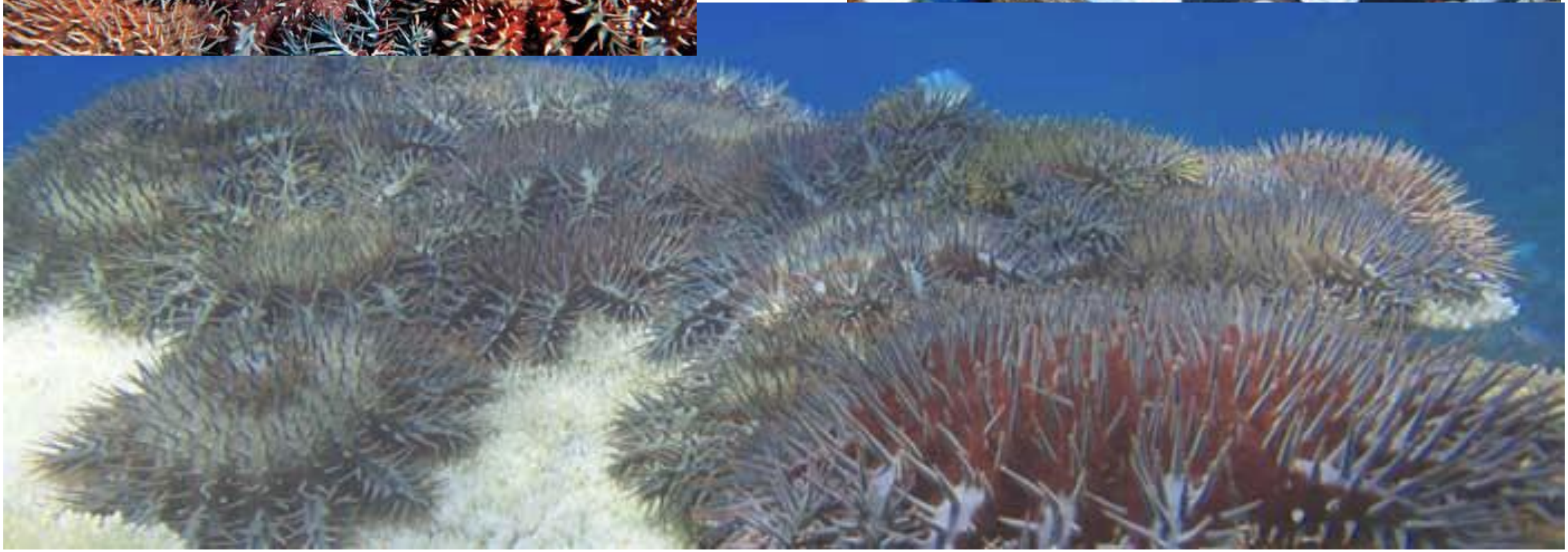


Algal blooms - China

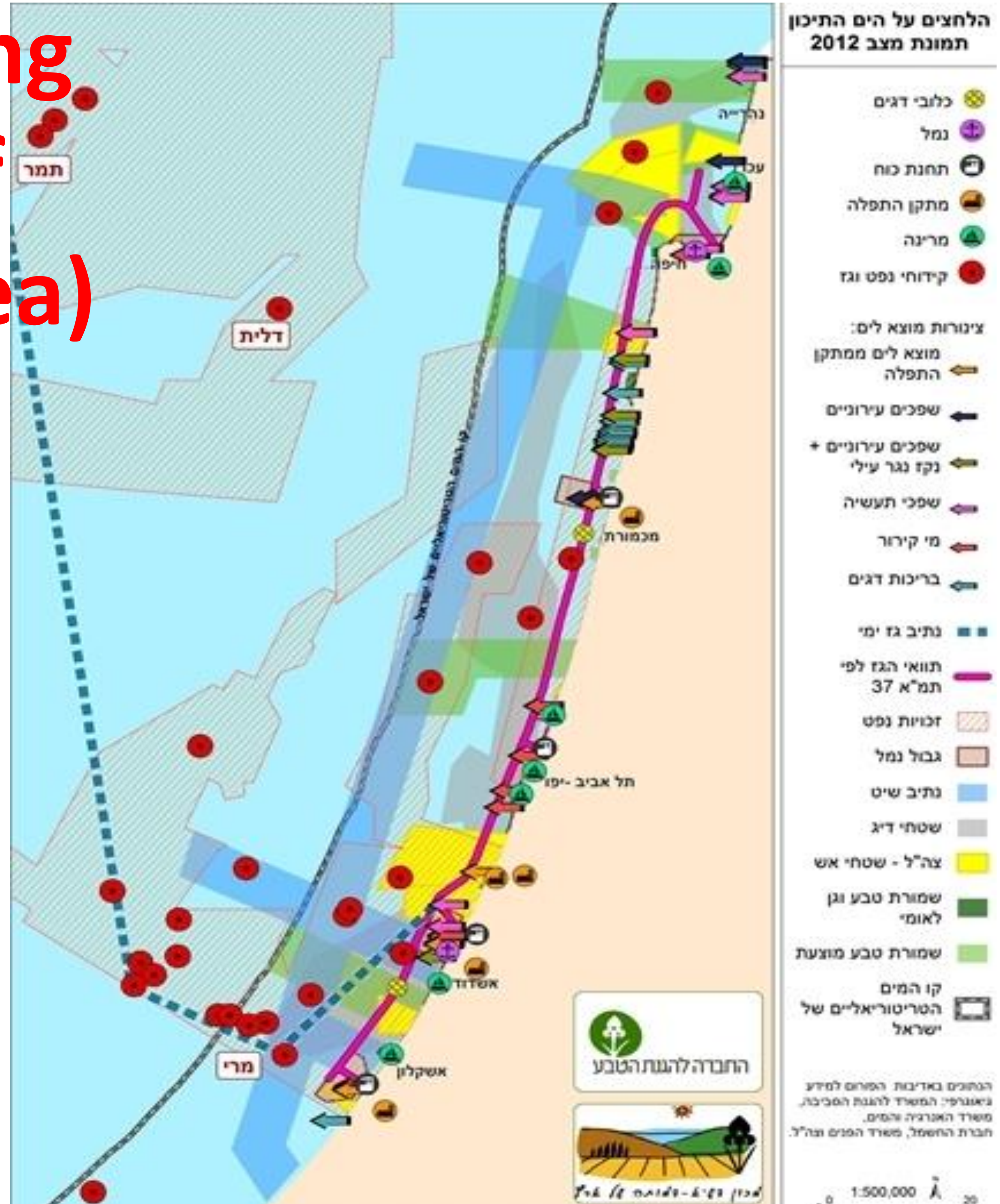
…and
phase-shifts of benthic communities

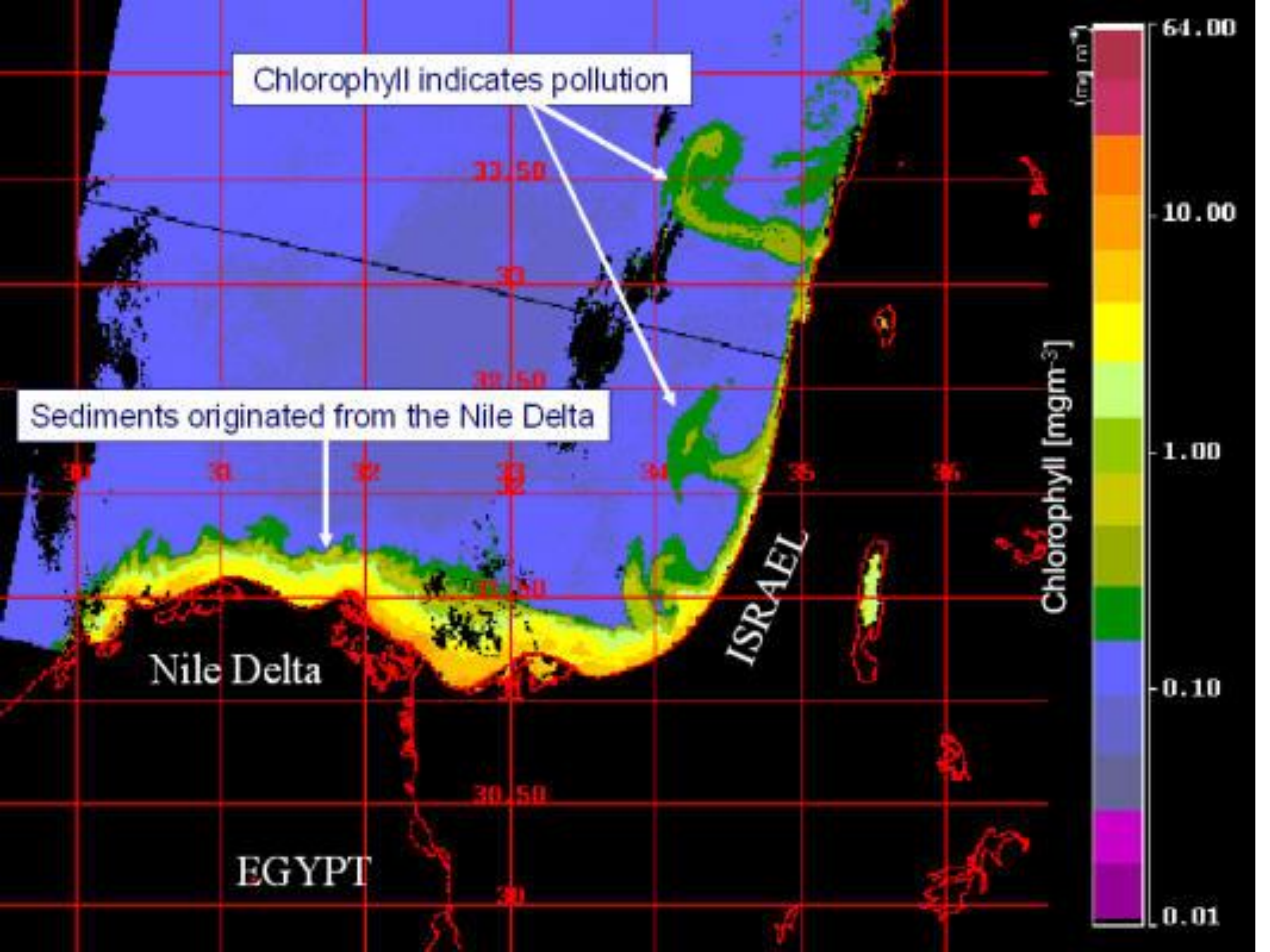


Detrimental outbreaks



Stressors along the coast of Israel (Med Sea)





Chlorophyll indicates pollution
Sediments originated from the Nile Delta
Nile Delta
EGYPT
ISRAEL
Chlorophyll [mgm-3]
64.00
10.00
1.00
0.10
0.01

Stressed coastal environments
Invasive bivalve species – East Med

Brachidontes pharaonis

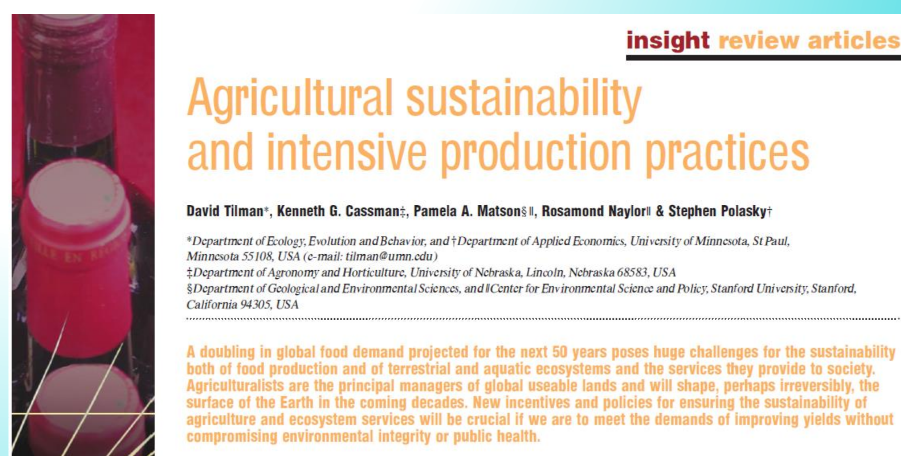
Spondylus spinosus

Chama pacifica

Solutions…

- *Improve efficiency of agriculture*
- *Use of agriculture waste (and cellulose)*
- *Use of abandoned lands*
- *Change our nutrition habits (plant-rich diet)*

➔ *Go to the sea…!*



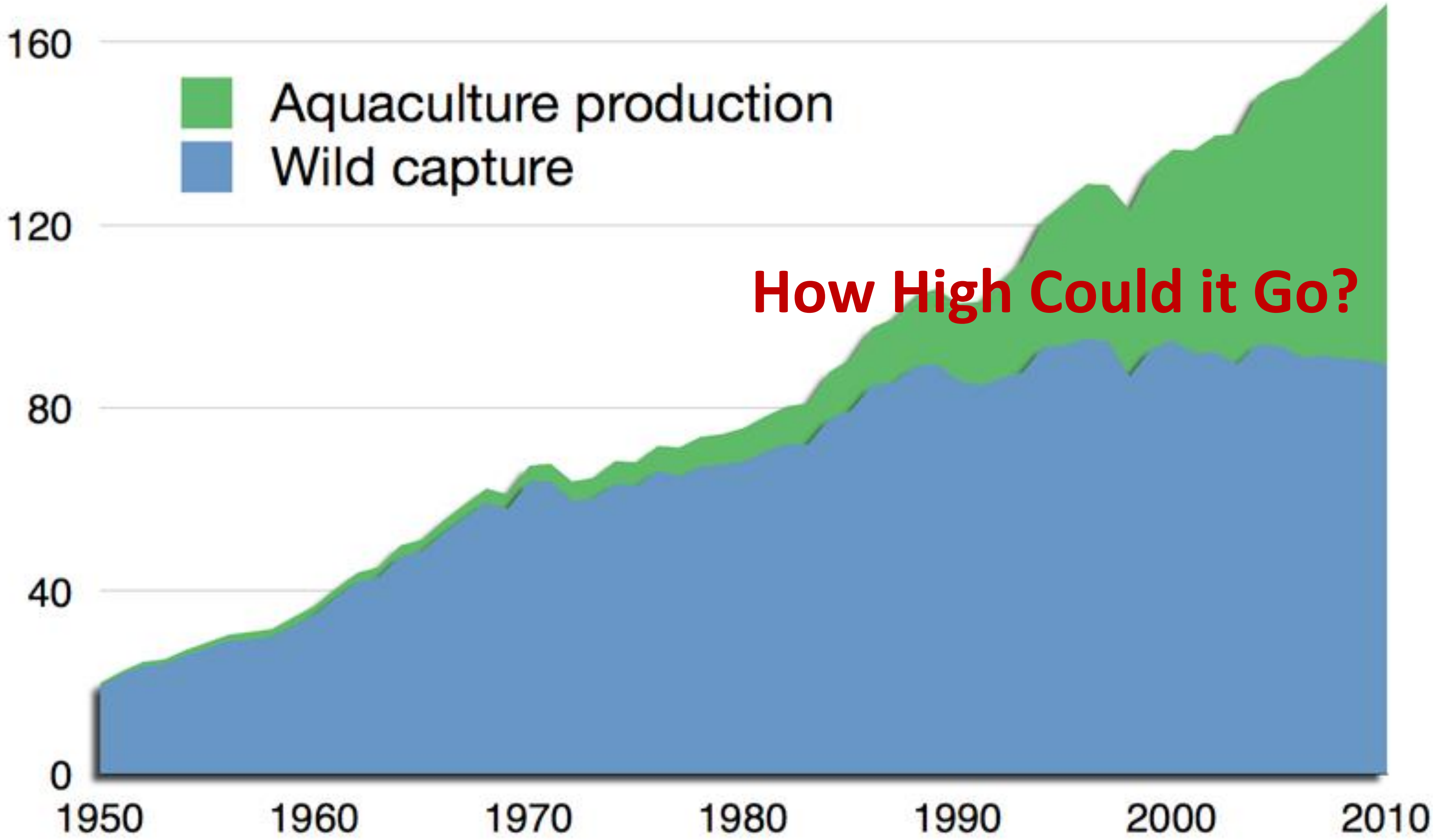
insight review articles

Agricultural sustainability and intensive production practices

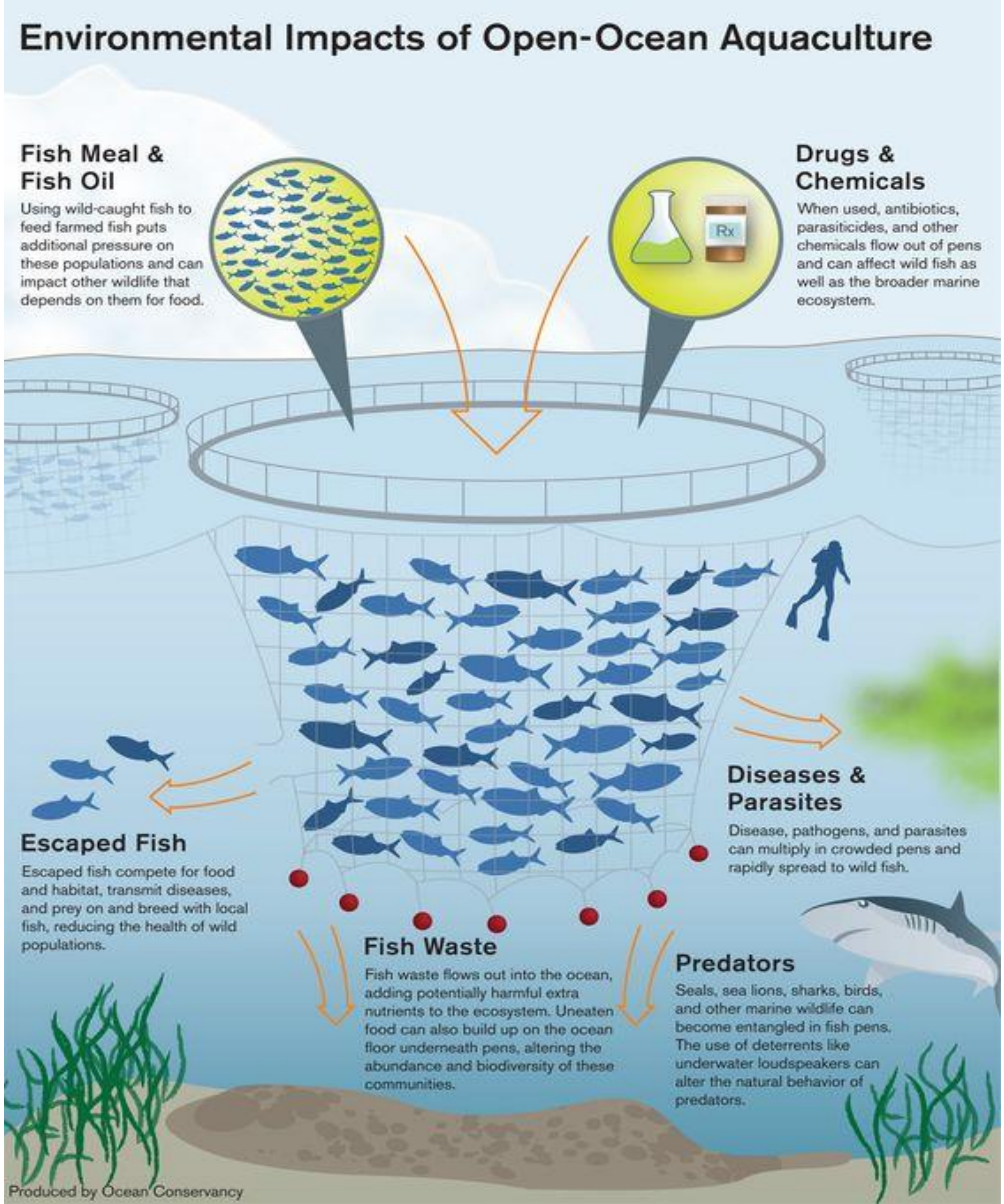
David Tilman*, Kenneth G. Cassman‡, Pamela A. Matson§‖, Rosamond Naylor‖ & Stephen Polasky†

*Department of Ecology, Evolution and Behavior, and †Department of Applied Economics, University of Minnesota, St Paul, Minnesota 55108, USA (e-mail: tilman@umn.edu)
‡Department of Agronomy and Horticulture, University of Nebraska, Lincoln, Nebraska 68583, USA
§Department of Geological and Environmental Sciences, and ‖Center for Environmental Science and Policy, Stanford University, Stanford, California 94305, USA

A doubling in global food demand projected for the next 50 years poses huge challenges for the sustainability both of food production and of terrestrial and aquatic ecosystems and the services they provide to society. Agriculturalists are the principal managers of global useable lands and will shape, perhaps irreversibly, the surface of the Earth in the coming decades. New incentives and policies for ensuring the sustainability of agriculture and ecosystem services will be crucial if we are to meet the demands of improving yields without compromising environmental integrity or public health.

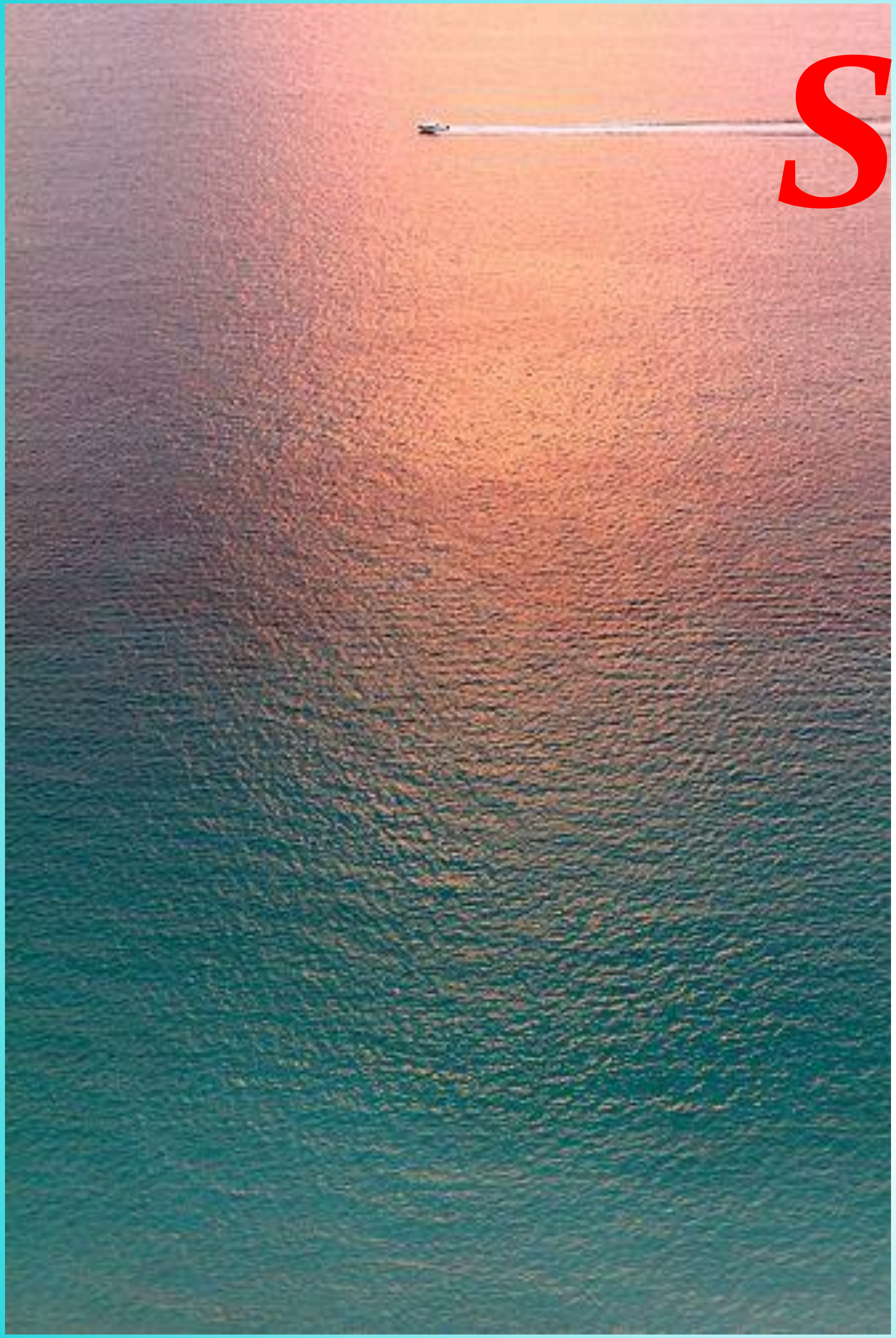


Aquaculture production
Wild capture
How High Could it Go?
160
120
80
40
0
1950
1960
1970
1980
1990
2000
2010


Environmental Impacts of Open-Ocean Aquaculture
Fish Meal & Fish Oil
Using wild-caught fish to feed farmed fish puts additional pressure on these populations and can impact other wildlife that depends on them for food.
Drugs & Chemicals
Rx
When used, antibiotics, parasiticides, and other chemicals flow out of pens and can affect wild fish as well as the broader marine ecosystem.
Diseases & Parasites
Disease, pathogens, and parasites can multiply in crowded pens and rapidly spread to wild fish.
Escaped Fish
Escaped fish compete for food and habitat, transmit diseases, and prey on and breed with local fish, reducing the health of wild populations.
Fish Waste
Fish waste flows out into the ocean, adding potentially harmful extra nutrients to the ecosystem. Uneaten food can also build up on the ocean floor underneath pens, altering the abundance and biodiversity of these communities.
Predators
Seals, sea lions, sharks, birds, and other marine wildlife can become entangled in fish pens. The use of deterrents like underwater loudspeakers can alter the natural behavior of predators.
Produced by Ocean Conservancy

Environmental Impact of Aquaculture

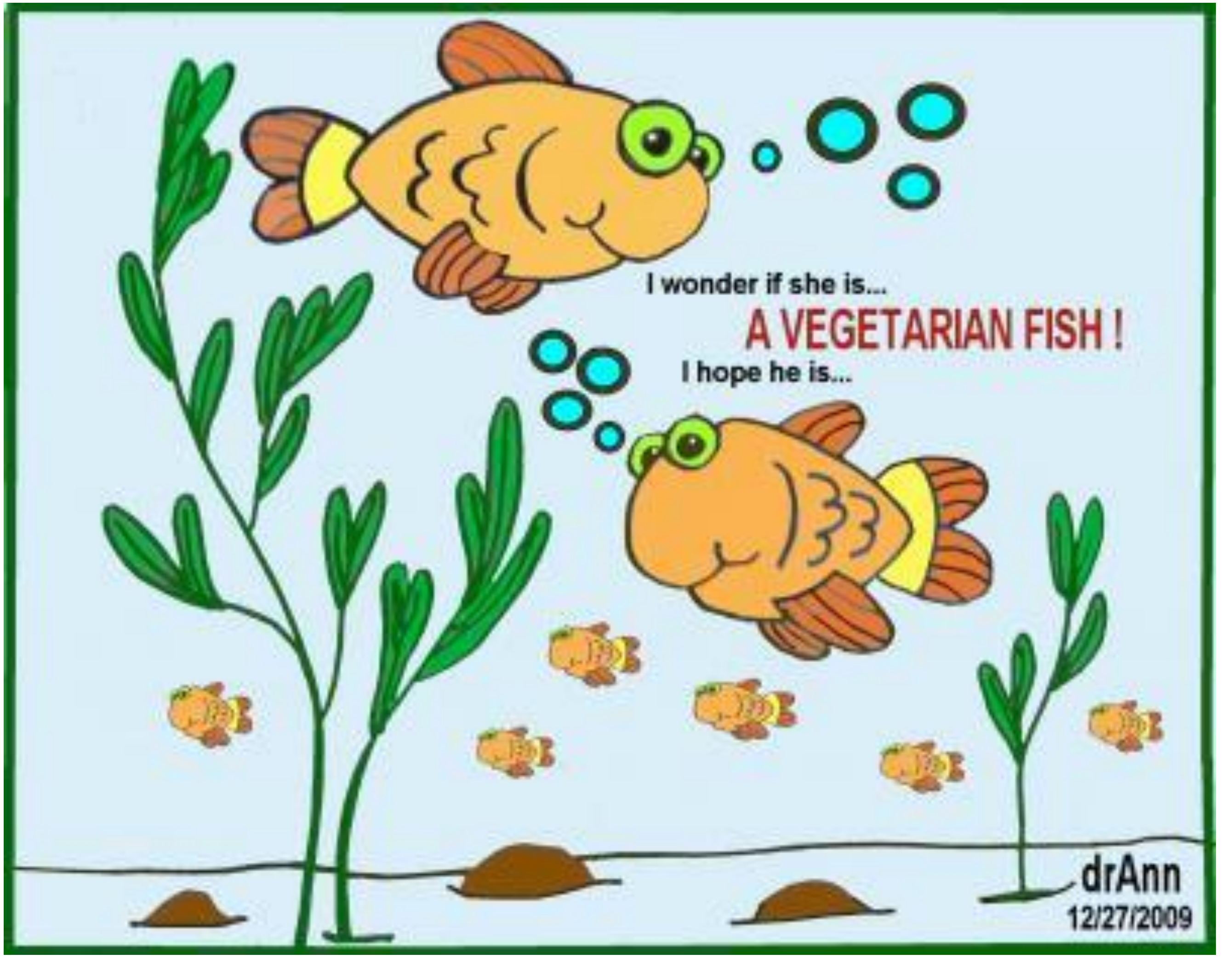
Solutions



Integrated Multi-Trophic Aquaculture (IMTA)

http://www.dfo-mpo.gc.ca/aquaculture/sci-res/imta-amti/index-eng.htm

IMTA: Fish meals

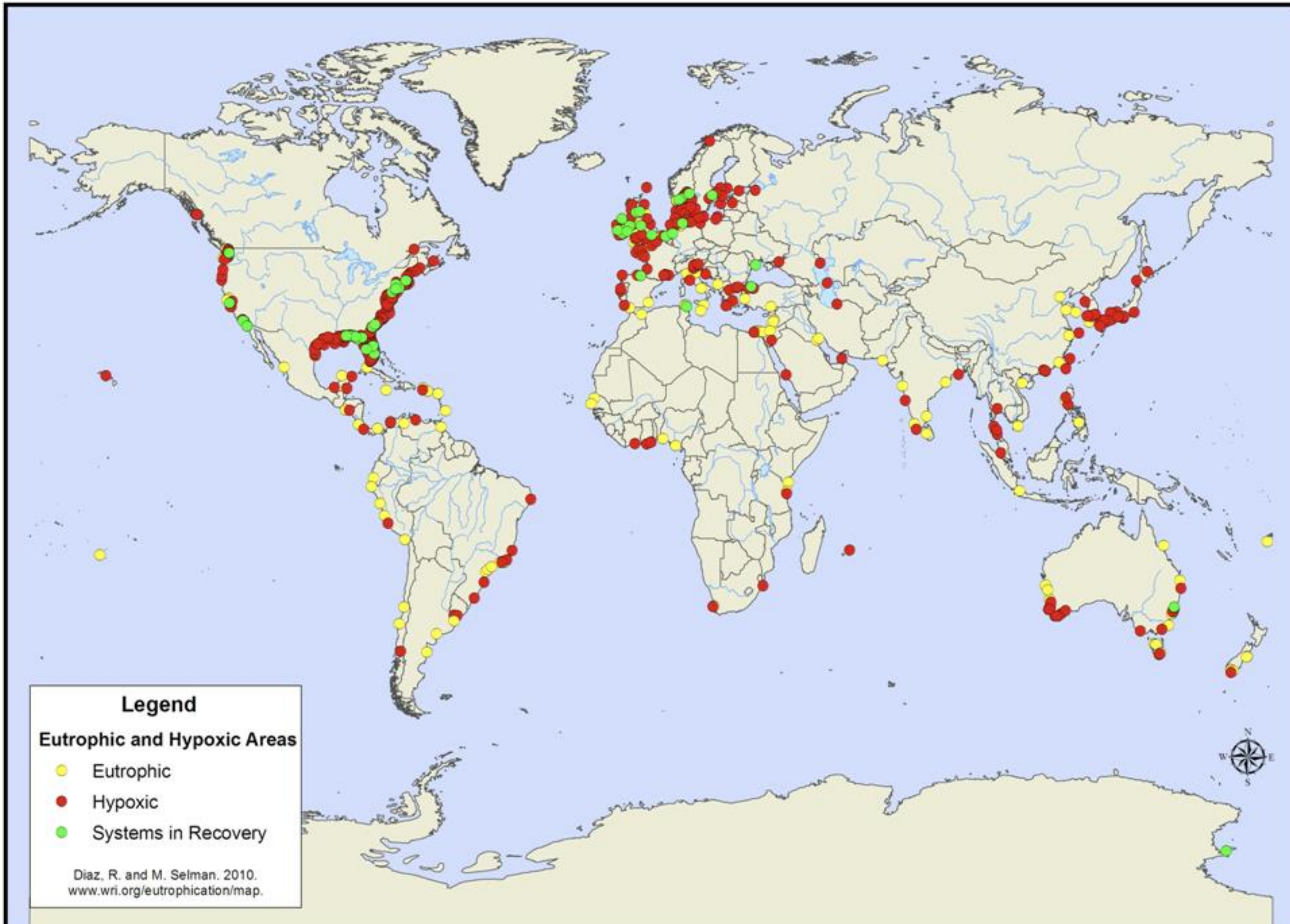


Is <u>fed culture</u> needed for mass production of <u>food</u> and <u>biofuel</u>?

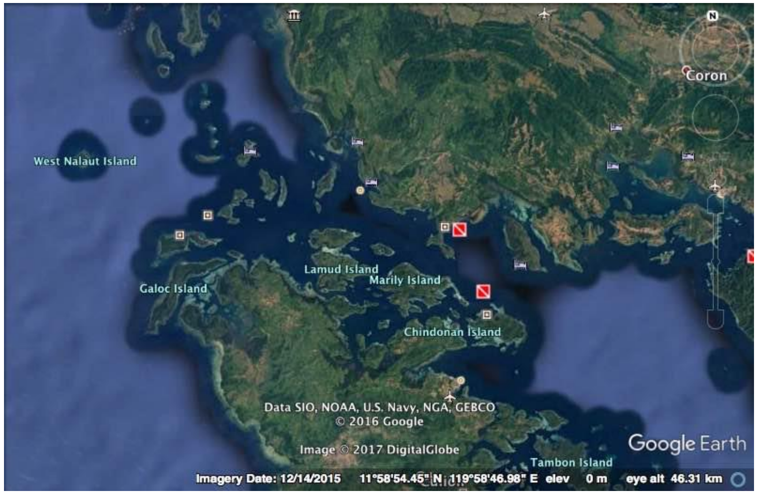
Harness the 'low-quality water' conditions for high-production, extractive culture

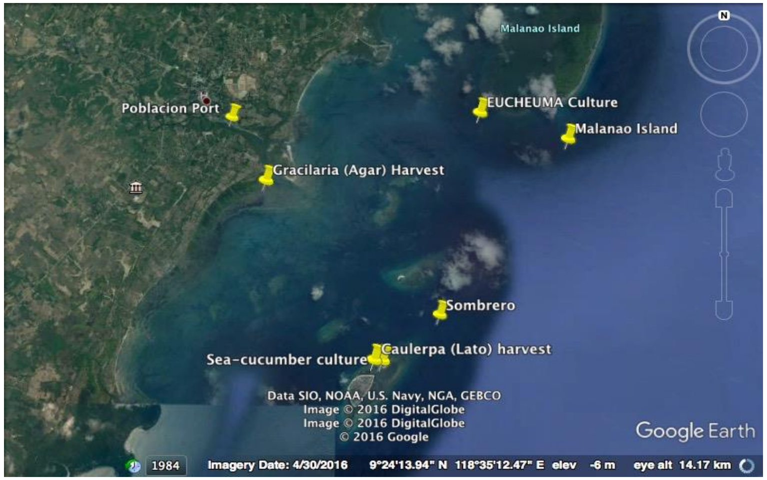
Integrated Multi-Trophic Aquaculture (e-IMTA)

World Hypoxic and Eutrophic Coastal Areas

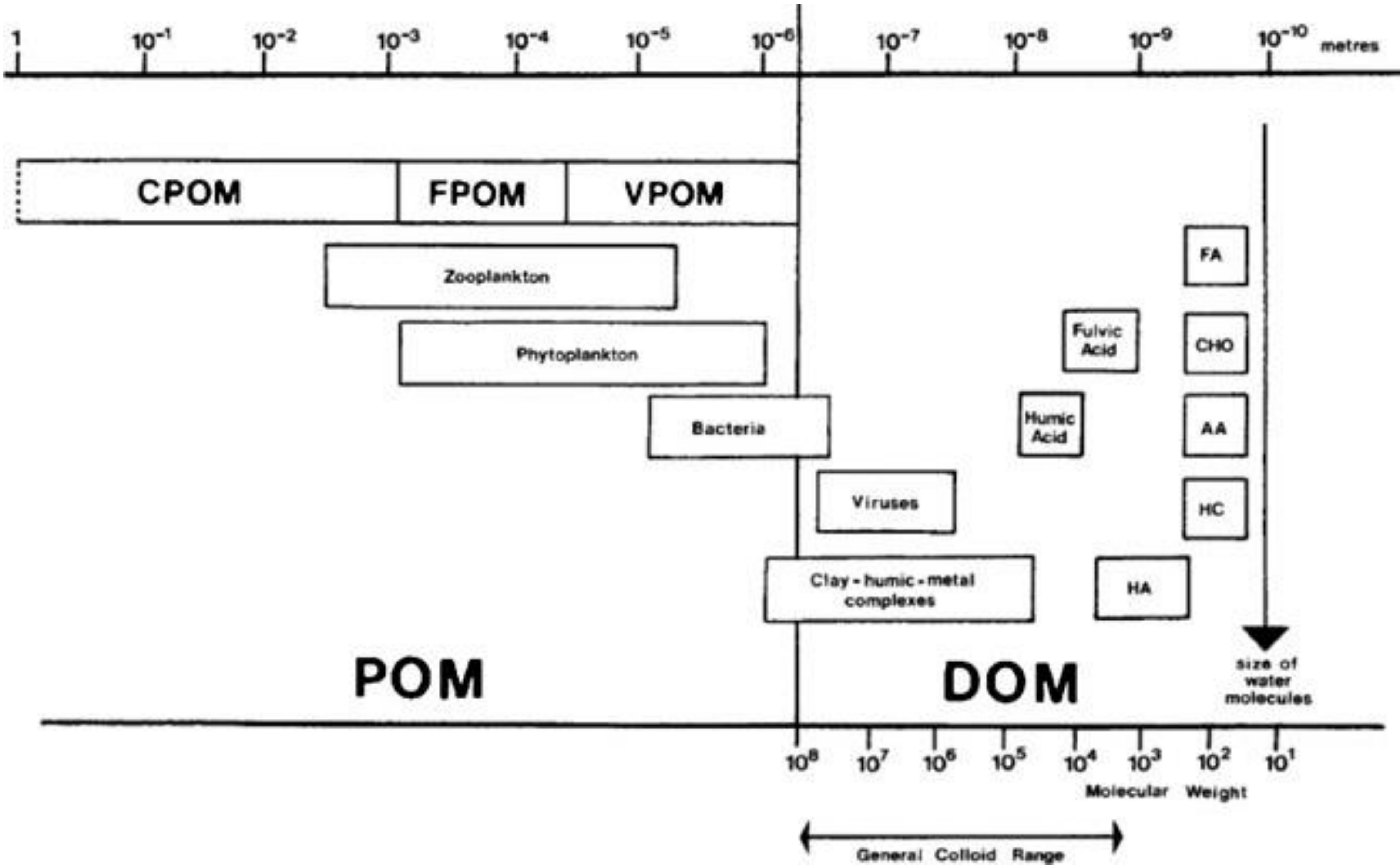


Improve water quality

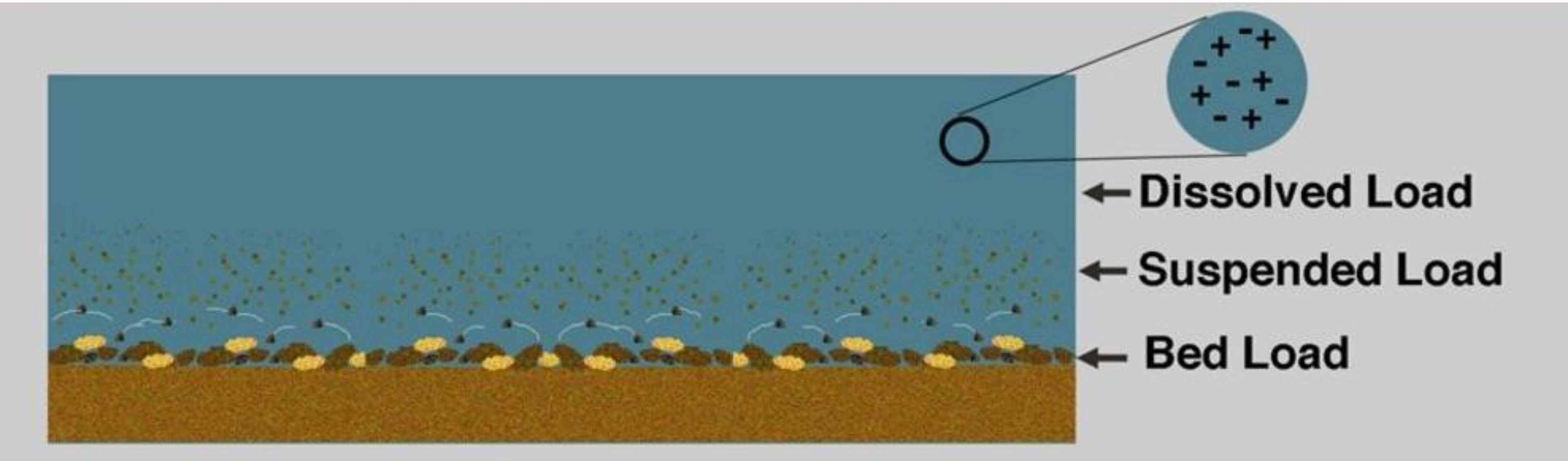


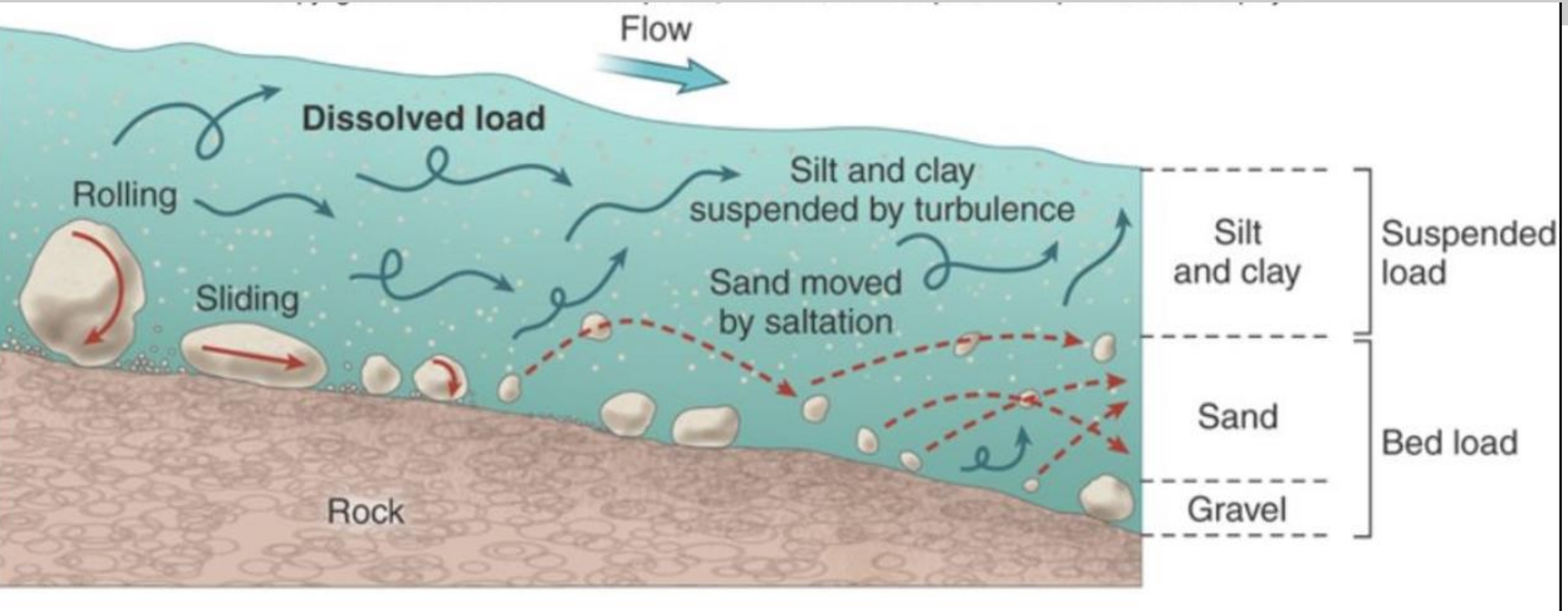


Marine food sources: DOM-POM

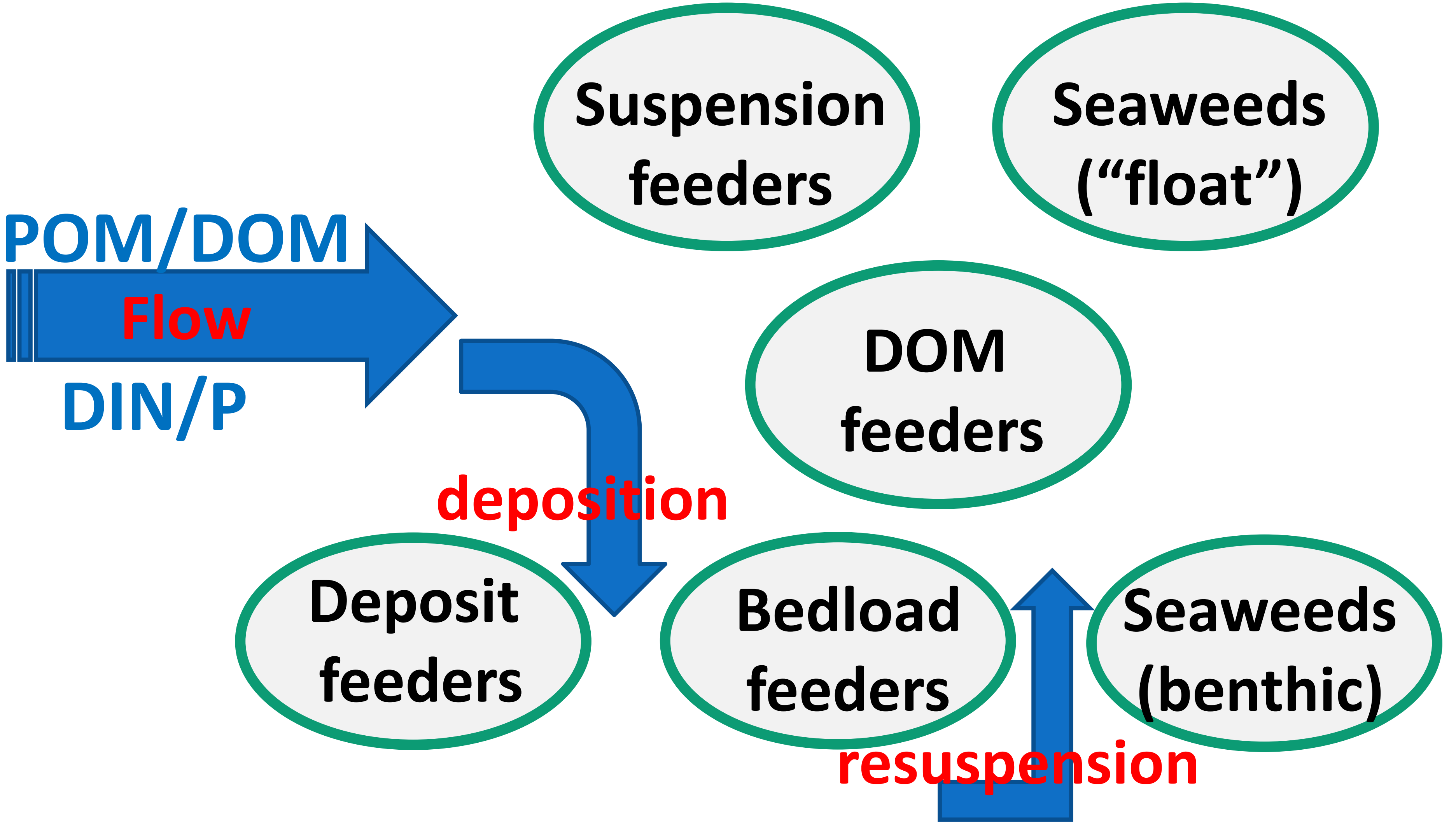


Marine food sources



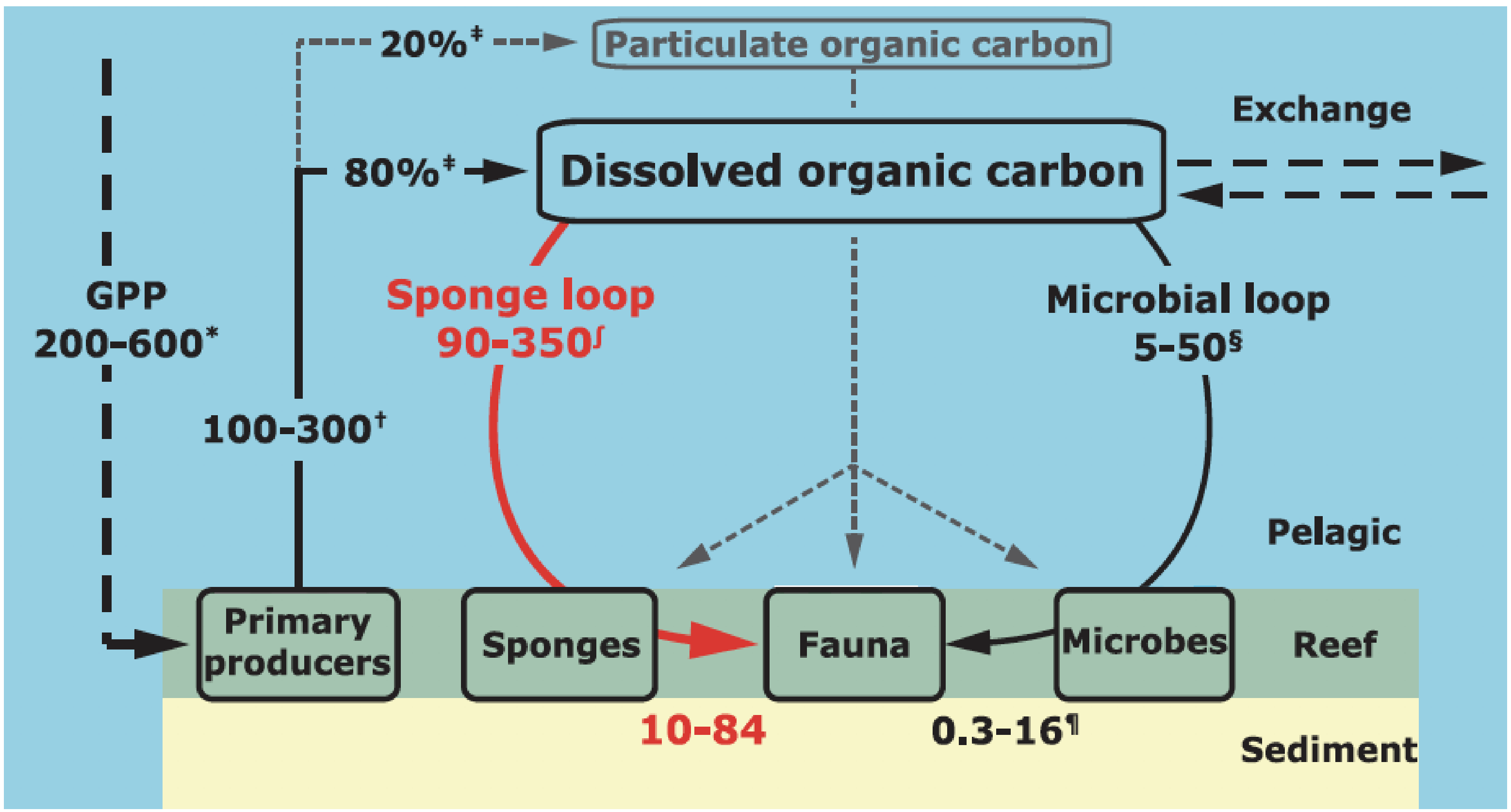


Extractive Integrated Multi-Trophic Aquaculture (e-IMTA)



POM/DOM to benthic communities

Primary producers such as **macro-algae** release up to 50% of their fixed carbon, of which up to 80% immediately dissolves in seawater. **Sponges** can transform the majority of DOM into particulate detritus (POM).

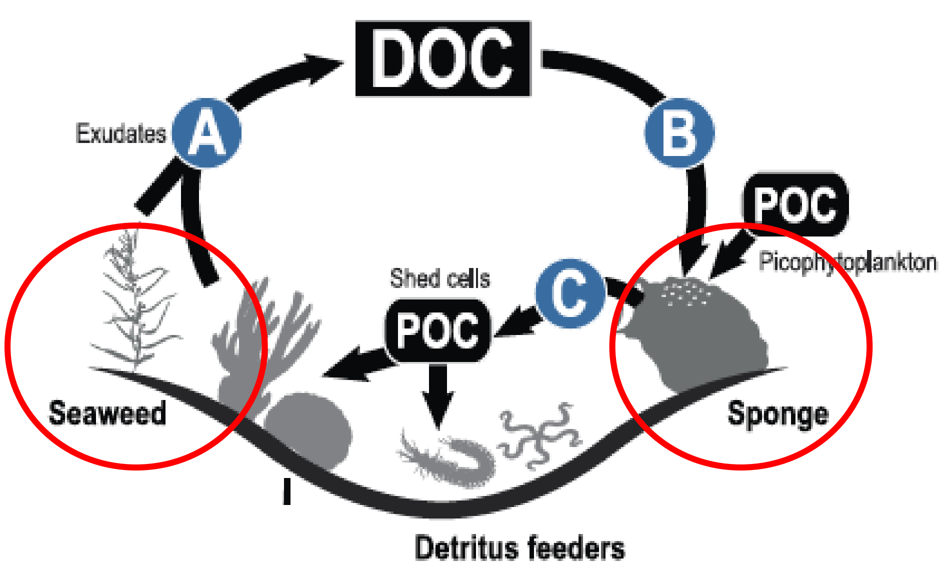


(millimoles of C m−2 day−1)

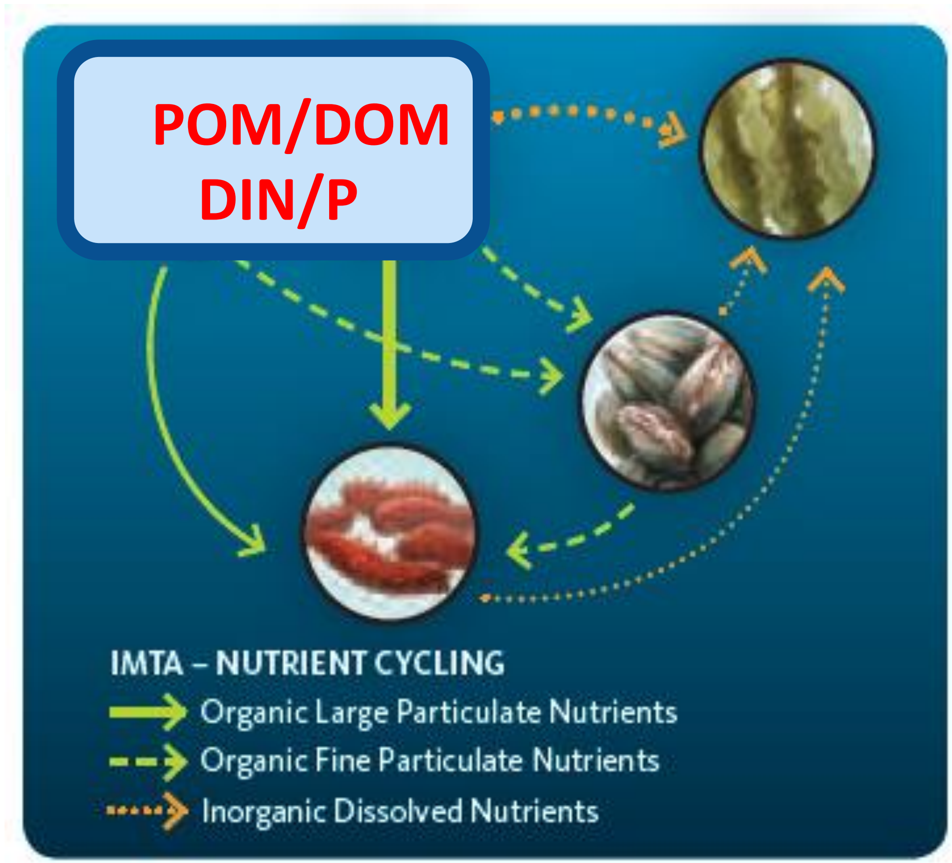
(de Goeij et al. 2013, Science)

Primary producers such as **macro-algae** release up to 50% of their fixed carbon, of which up to 80% immediately dissolves in seawater (DOM). **Sponges** can transform the majority of DOM into particulate detritus (POM).

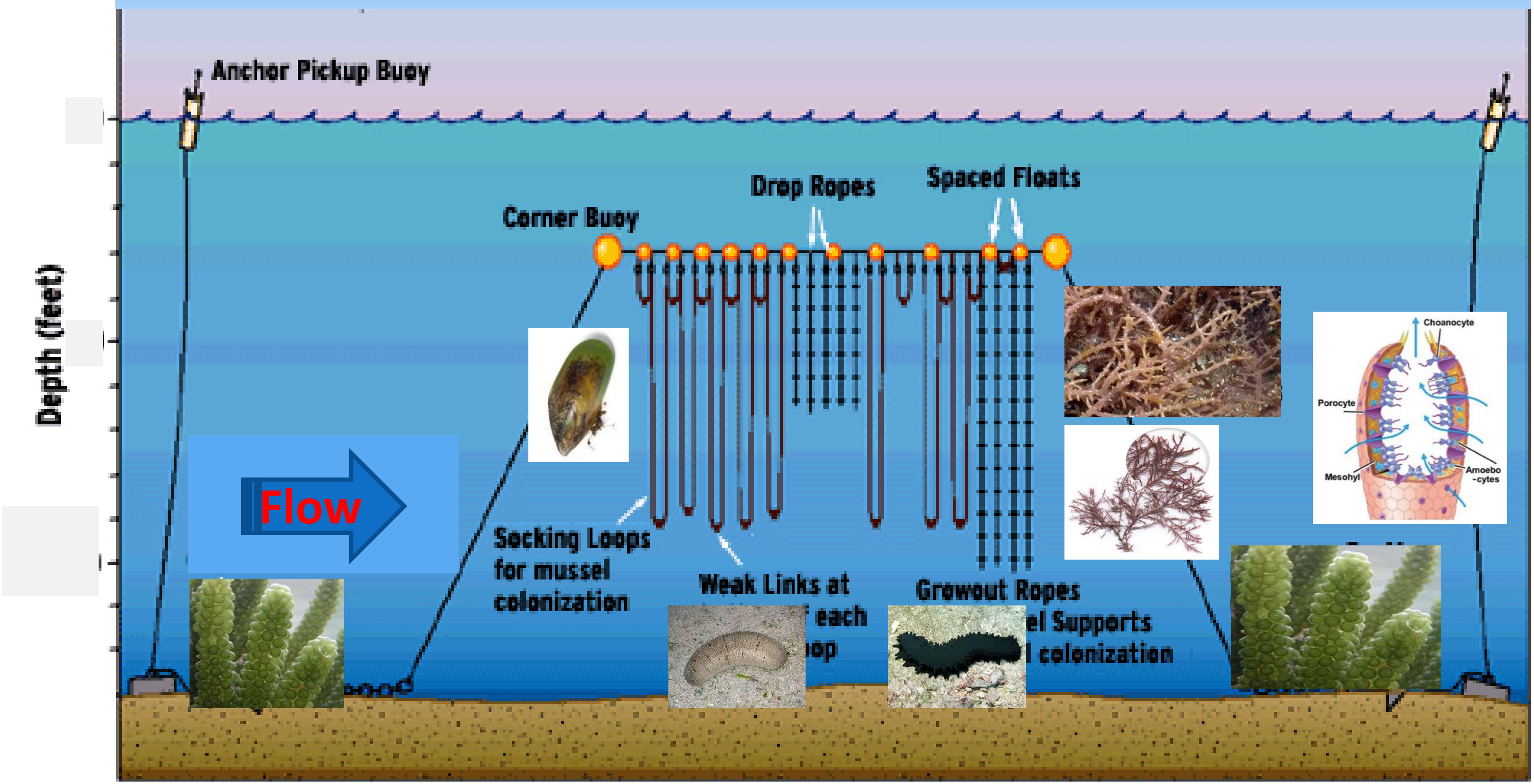
(de Goeij et al. 2013, Science)



(Pawlik et al. 2016; BioScience)



The e-IMTA system



The e-IMTA system

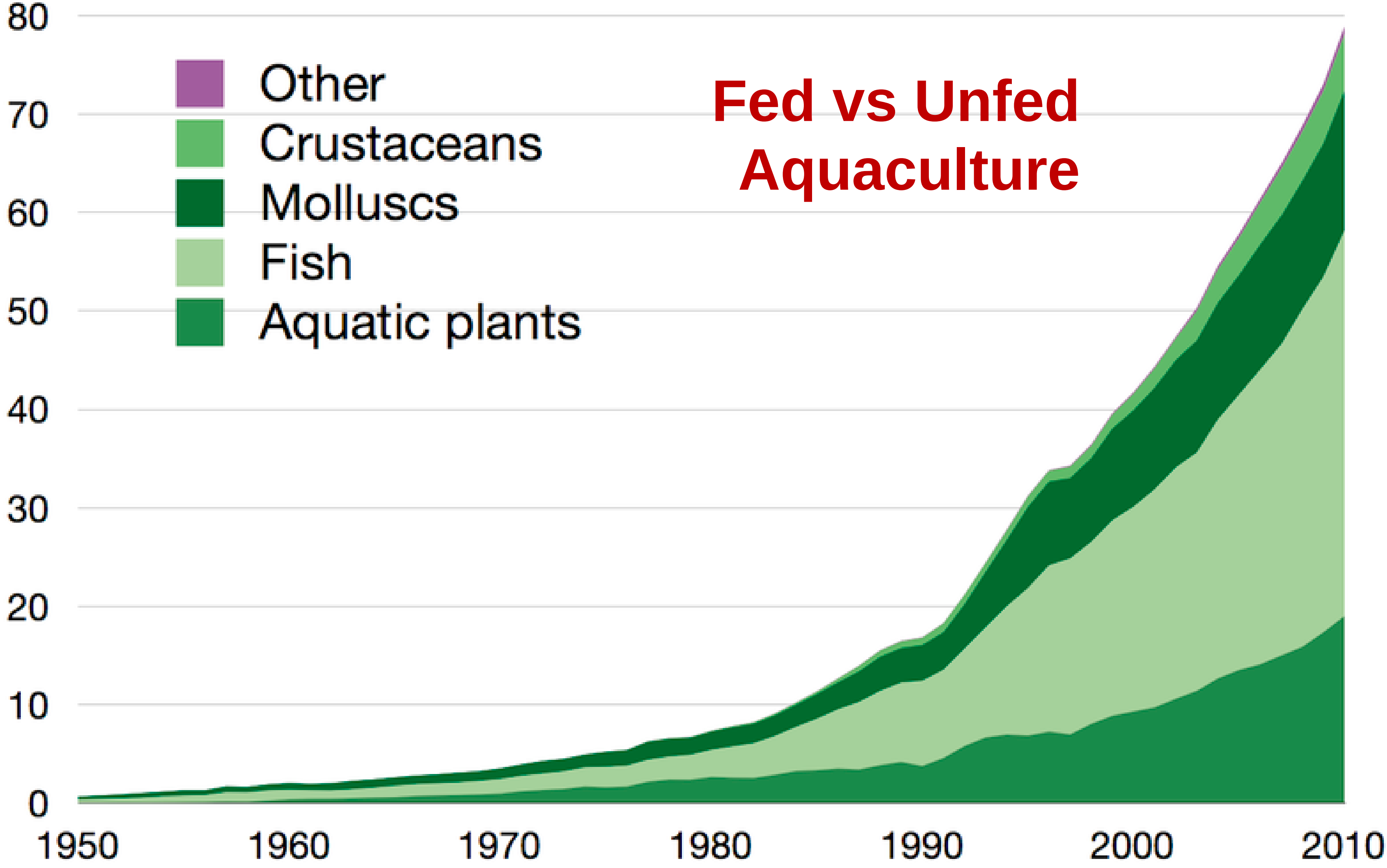
Advantages

- Diverse, abundant food for benthic species
- High production rates
- Diverse species
- **Supports mass production without feeding**
- **High versatility (site-spcific)**
- **Relatively low costs**
- **Portfolio approach investment**

Challenges

- Accurate designs for optimal function and maximum efficiencies
- Control and monitoring over spacious areas
- Fluctuated food supply
- Pest/predation prevention
- Multidisciplinary expertise
- **Funding!**


THANK
YOU!



80
70
60
50
40
30
20
10
0
Other
Crustaceans
Molluscs
Fish
Aquatic plants
Fed vs Unfed
Aquaculture
1950
1960
1970
1980
1990
2000
2010

Factors to be considered

- Flow regime; storms; bathymetry
- Nutrient and organic matter input
- Siltation rates
- Particles’ SFD (size frequency distribution)
- Particles’ quality (organic/inorganic ratio)
- Species interactions (combinations)
- Optimal setups (efficiency; extreme events)
- Potential predators and pathogens

The e-IMTA system components

Eucheuma sp

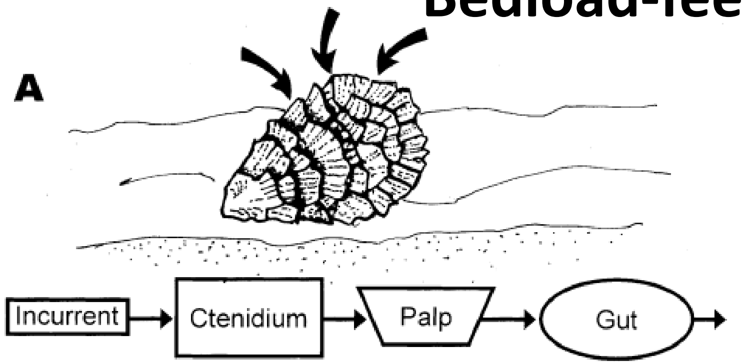
Gracilaria sp

Caulerpa lentillifera

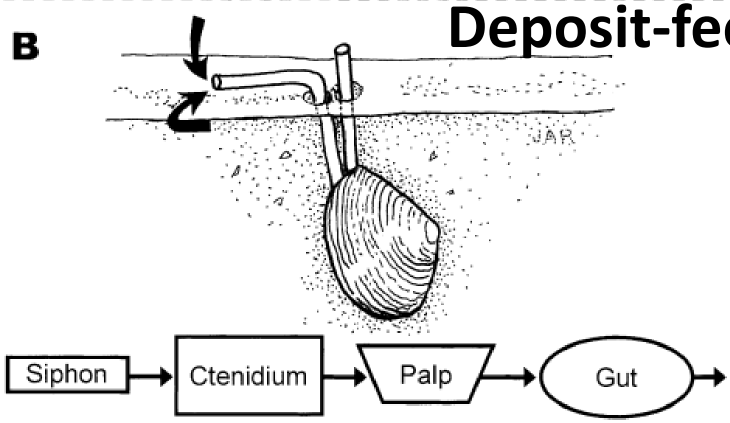
Gelidiella acerosa

The e-IMTA system components

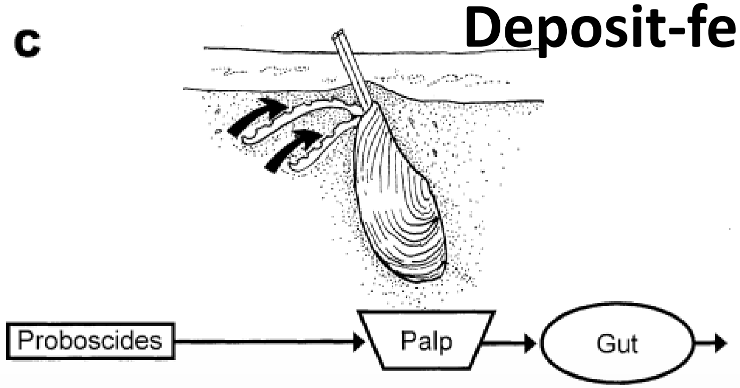
Bedload-feeders



Deposit-feeders

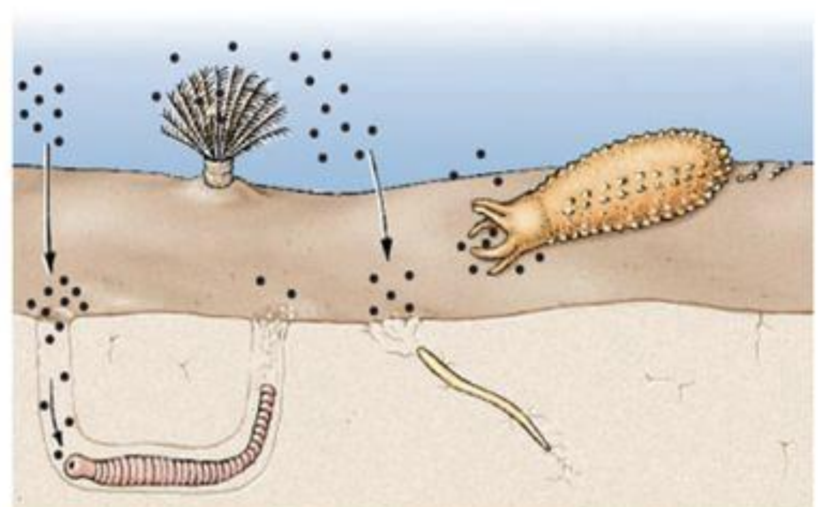


Deposit-feeders

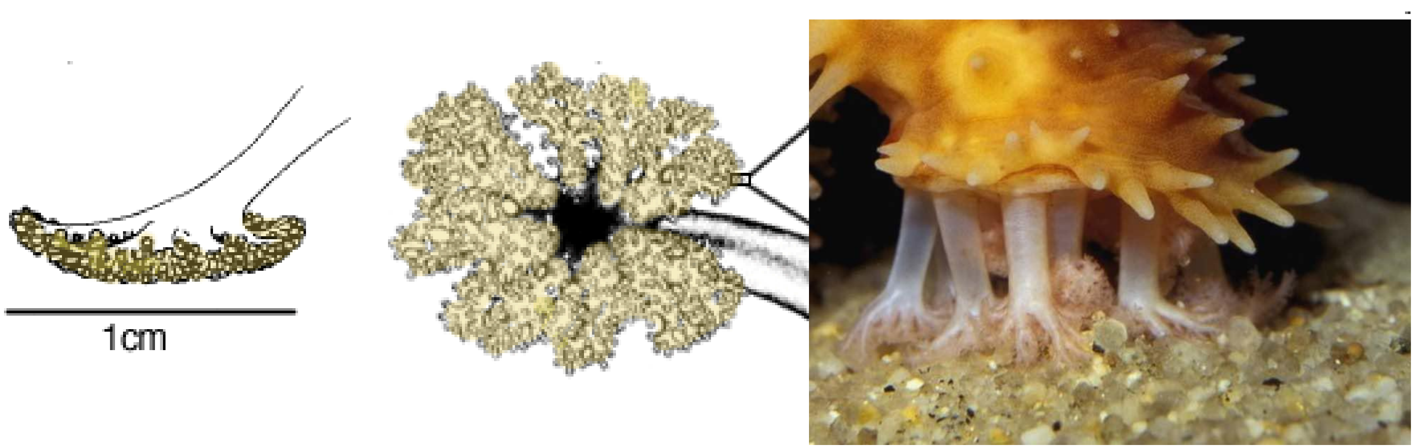


DEPOSIT FEEDING

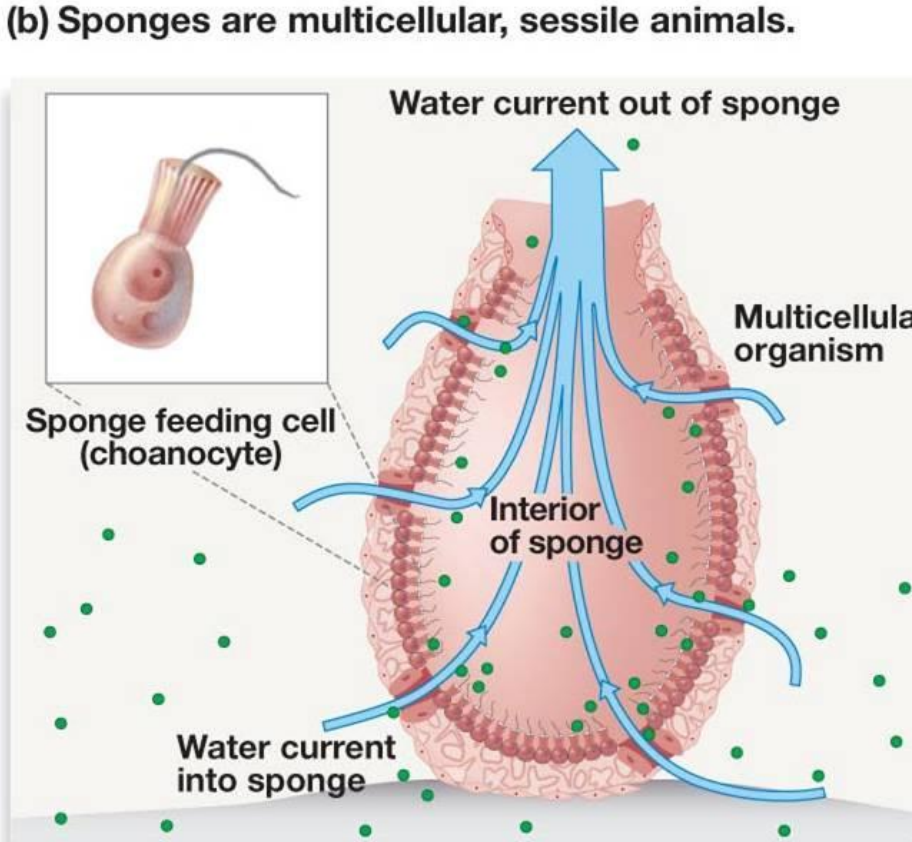
Feeding on particulate organic matter that settles on the bottom



The e-IMTA system components
Deposit feeders



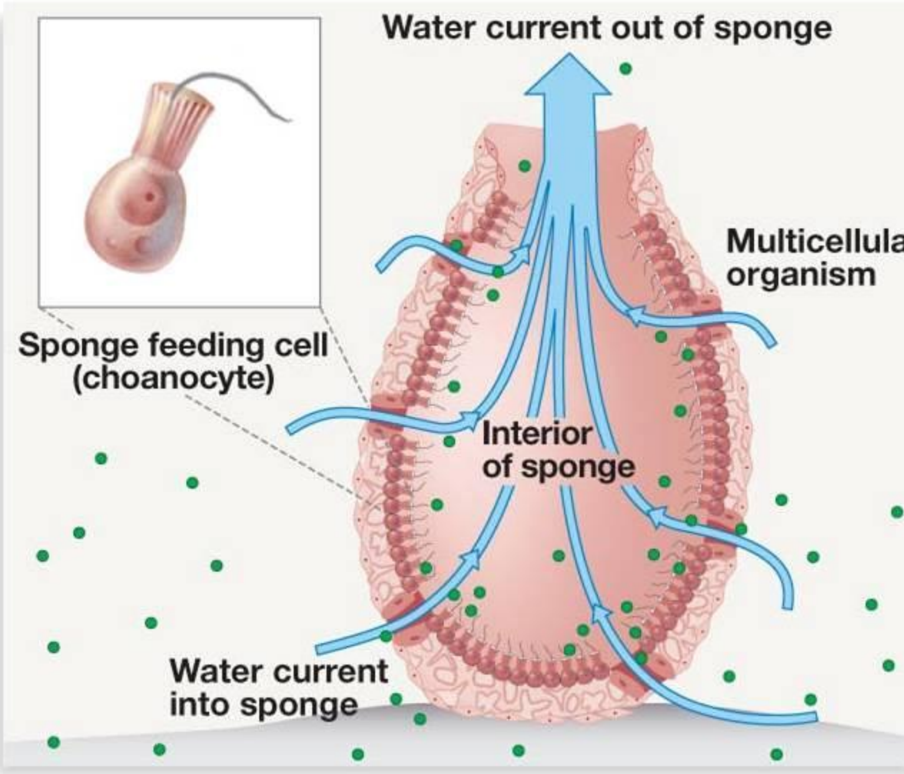
The e-IMTA system components
Suspension feeders



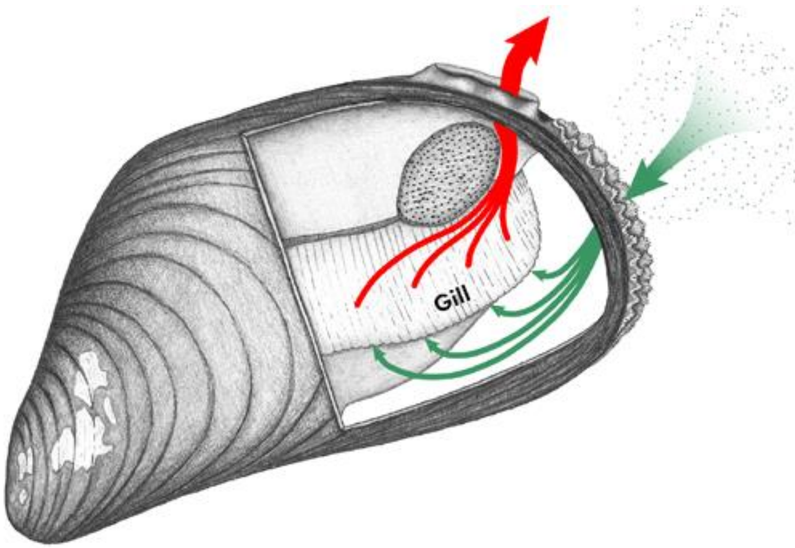
(Cresson et al. 2016)

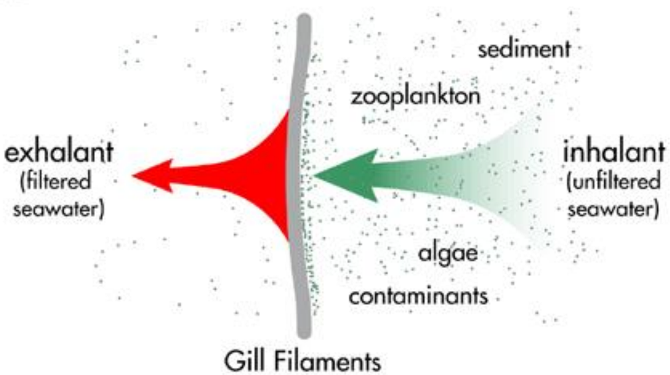
The e-IMTA system components
POM/DOM feeders - Sponges

(b) Sponges are multicellular, sessile animals.



The e-IMTA system components
Suspension feeders

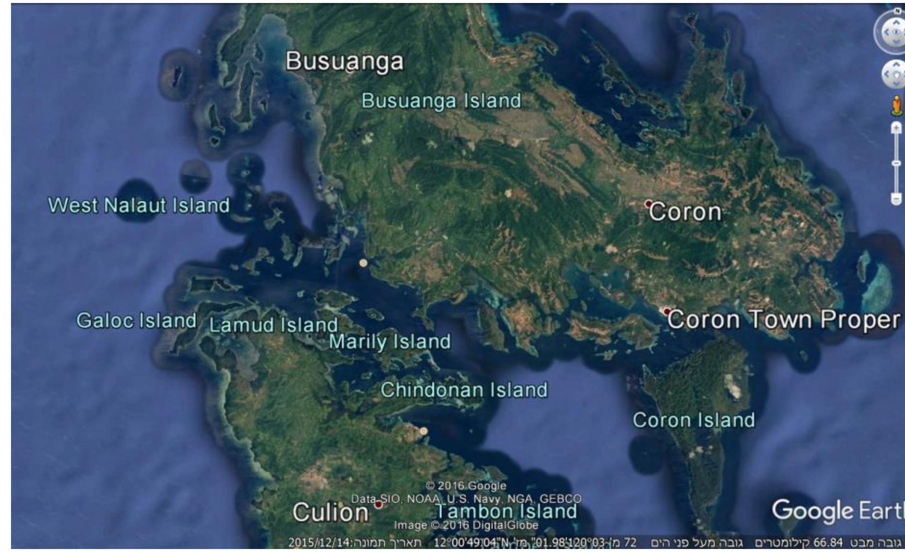


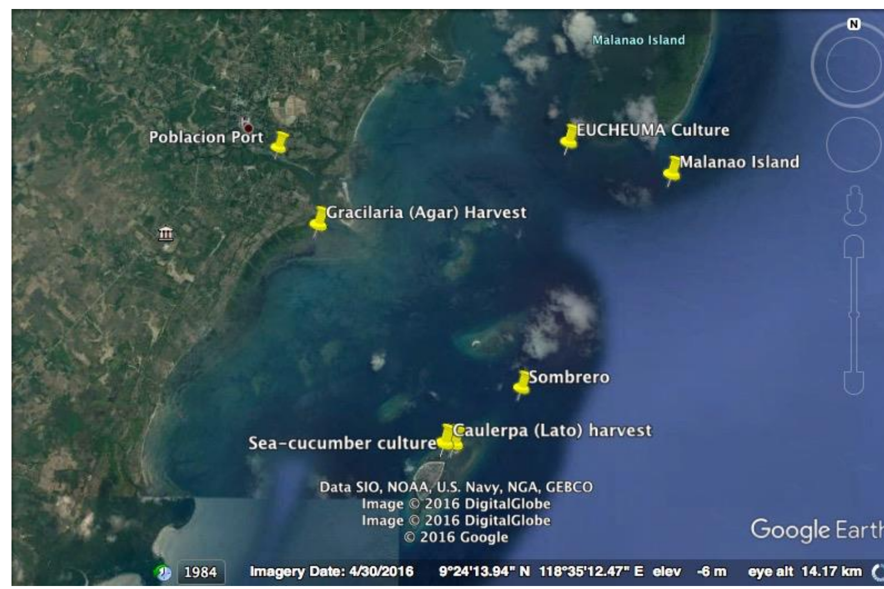


Factors to be considered

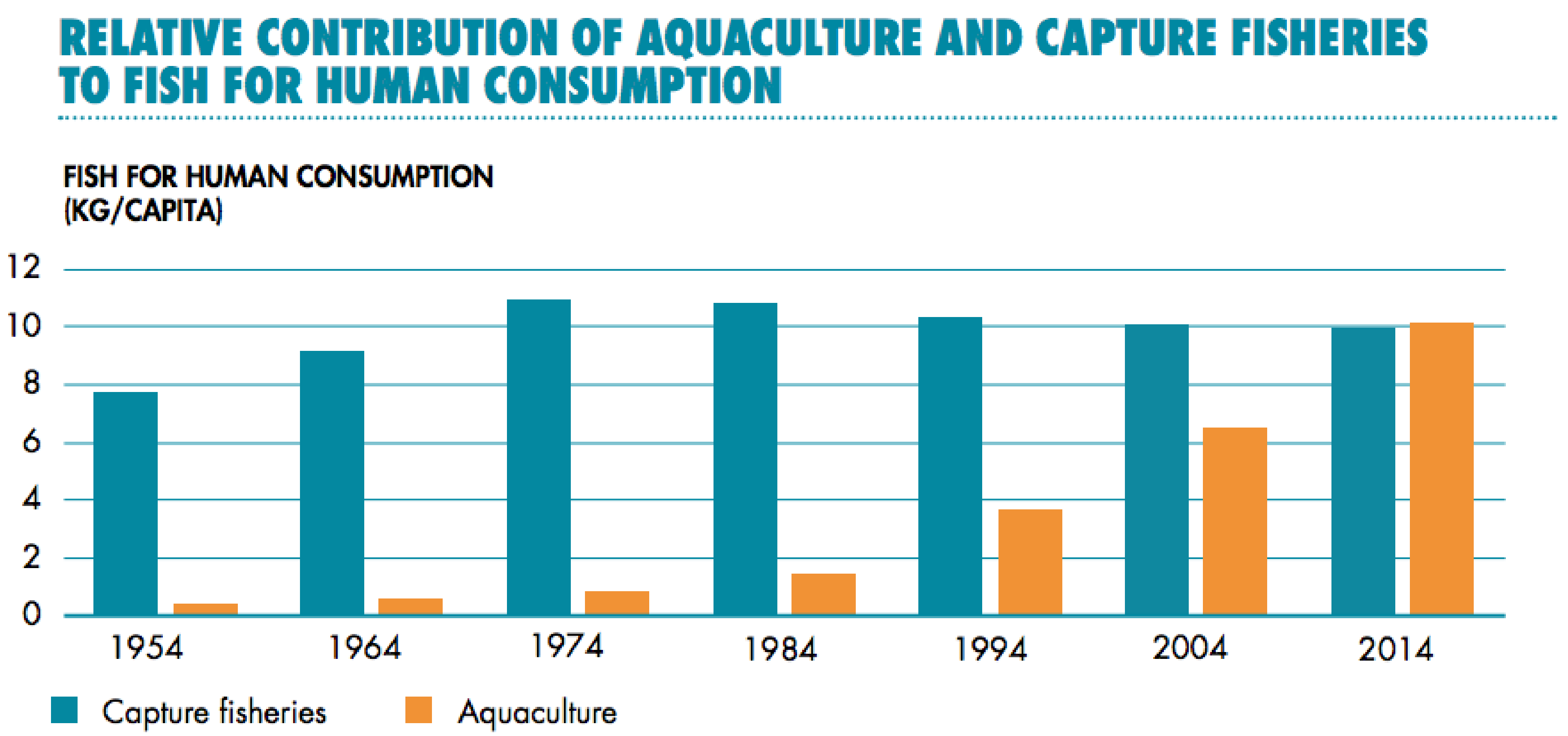
- Flow regime; storms; bathymetry
- Nutrient and organic matter input
- Siltation rates
- Particle size frequency distribution
- Particle organic/inorganic ratio (fluxes)
- Species combinations
- Optimal setups (efficiency; extreme events)

Siltation - Eutrophication

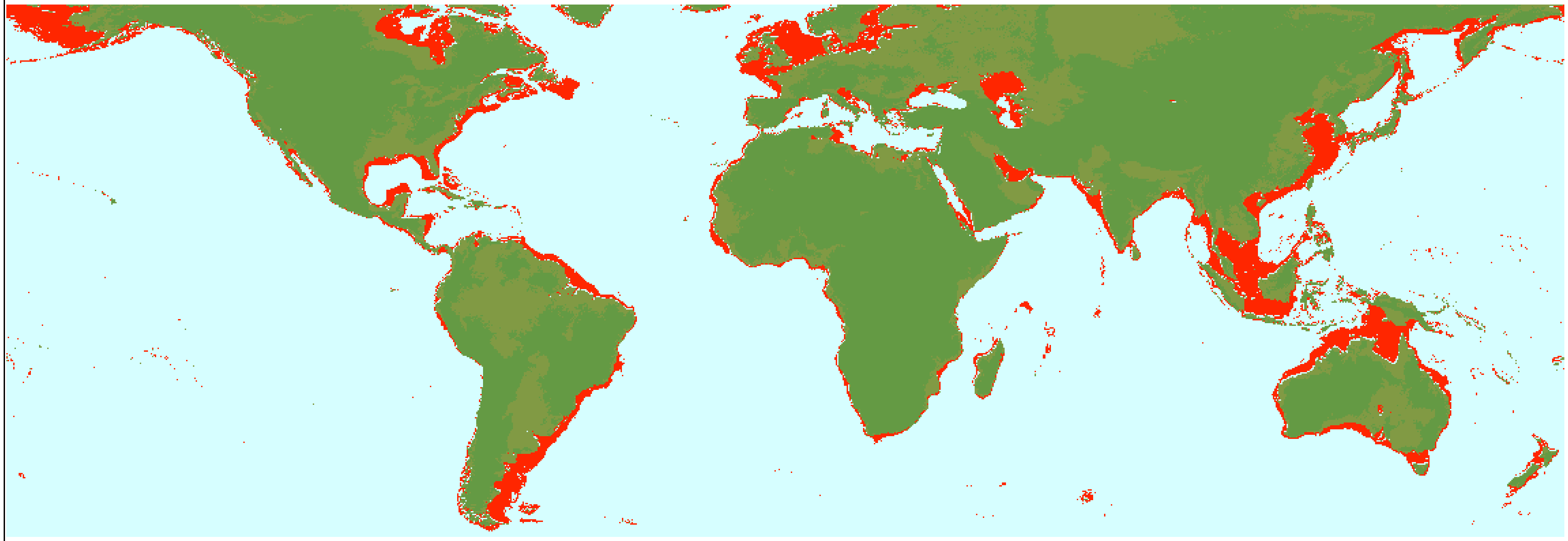


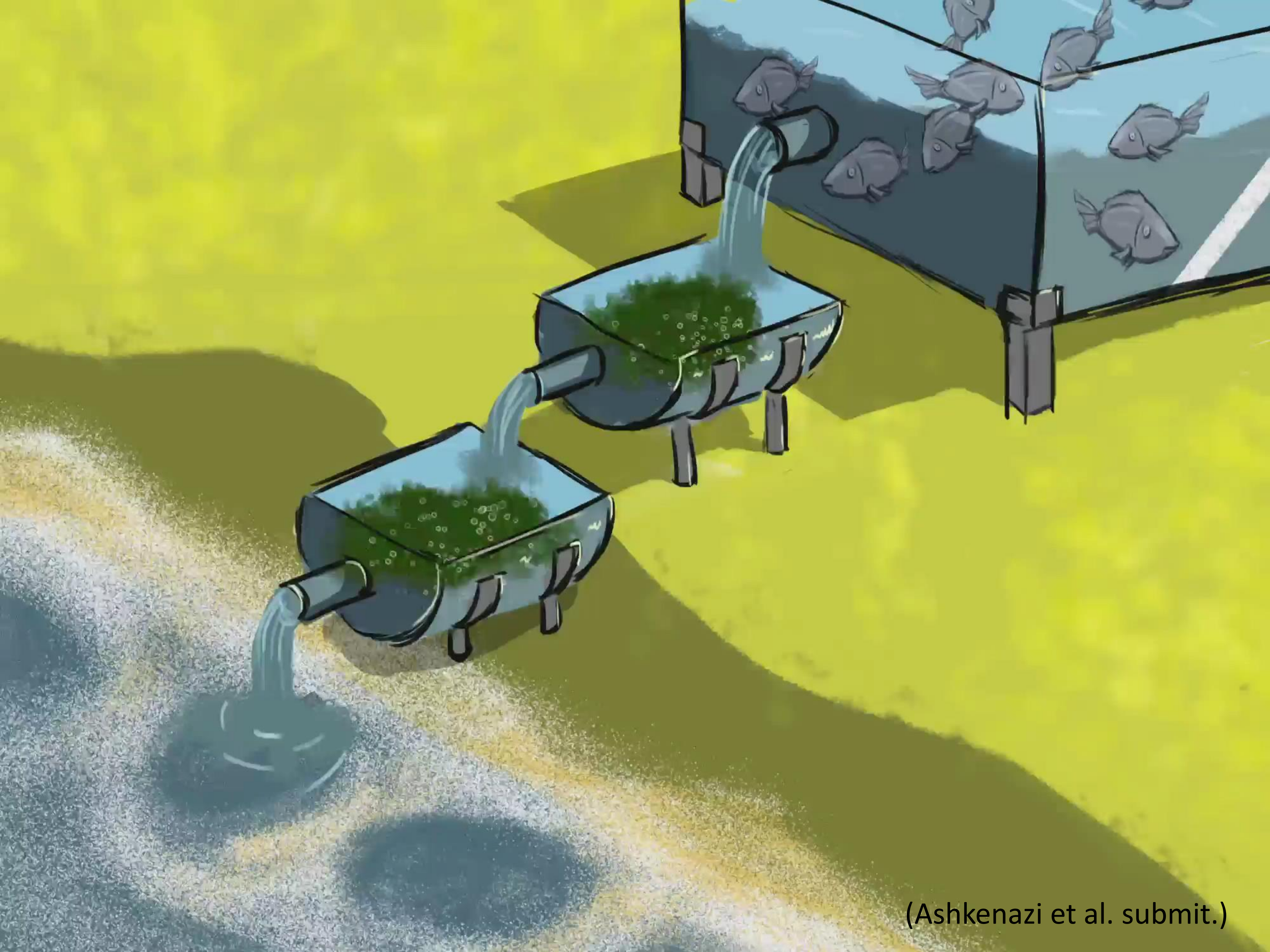


The State of World's Fisheries and Aquaculture 2016 - FAO

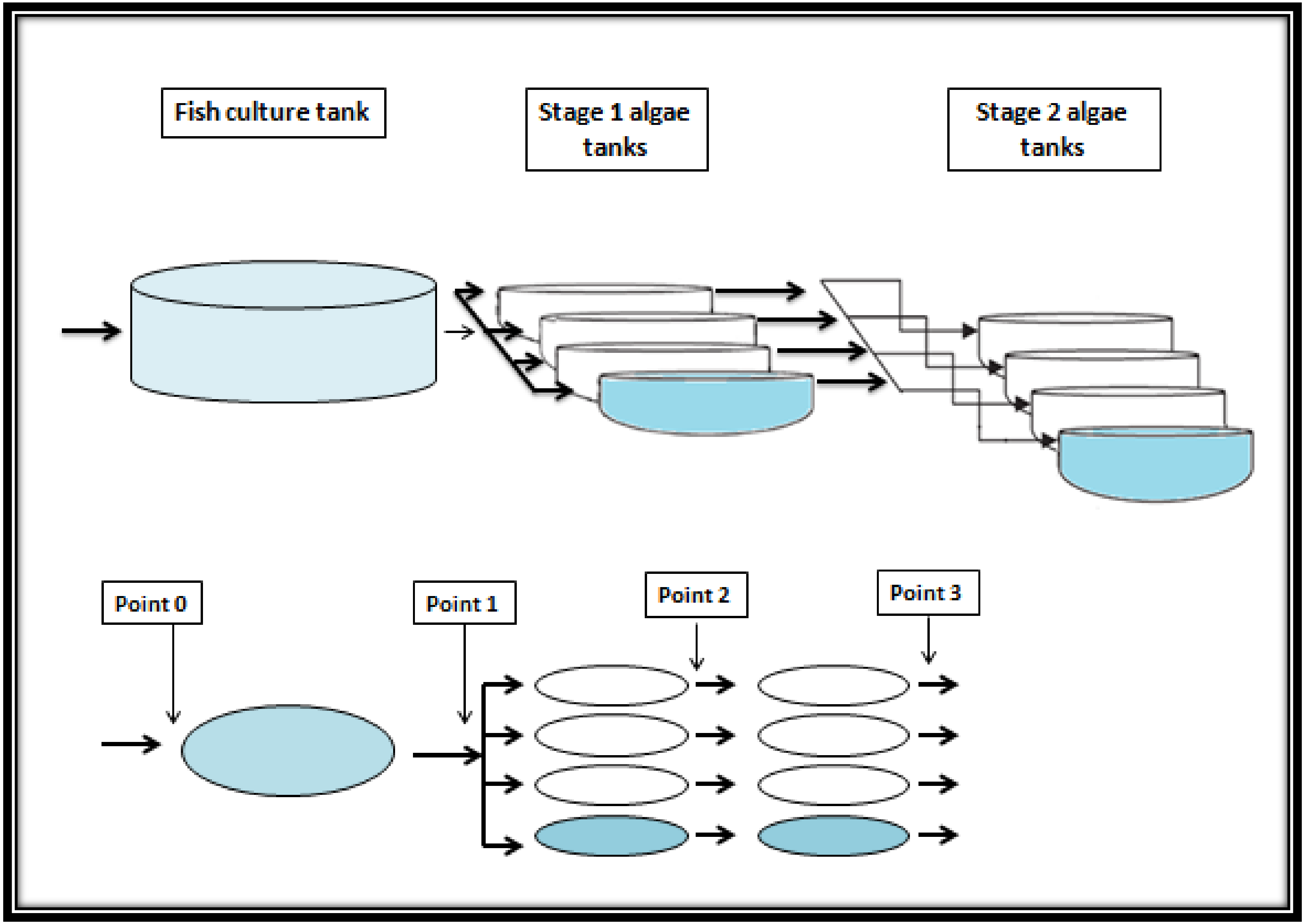


Global Shelf Area (> -150m between 65N and 55S)




(Ashkenazi et al. submit.)

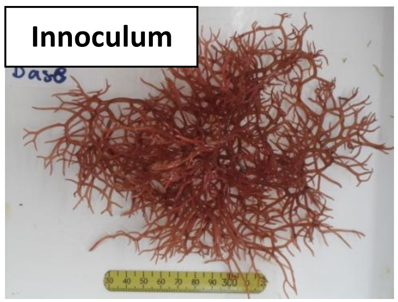
Land-based IMTA system

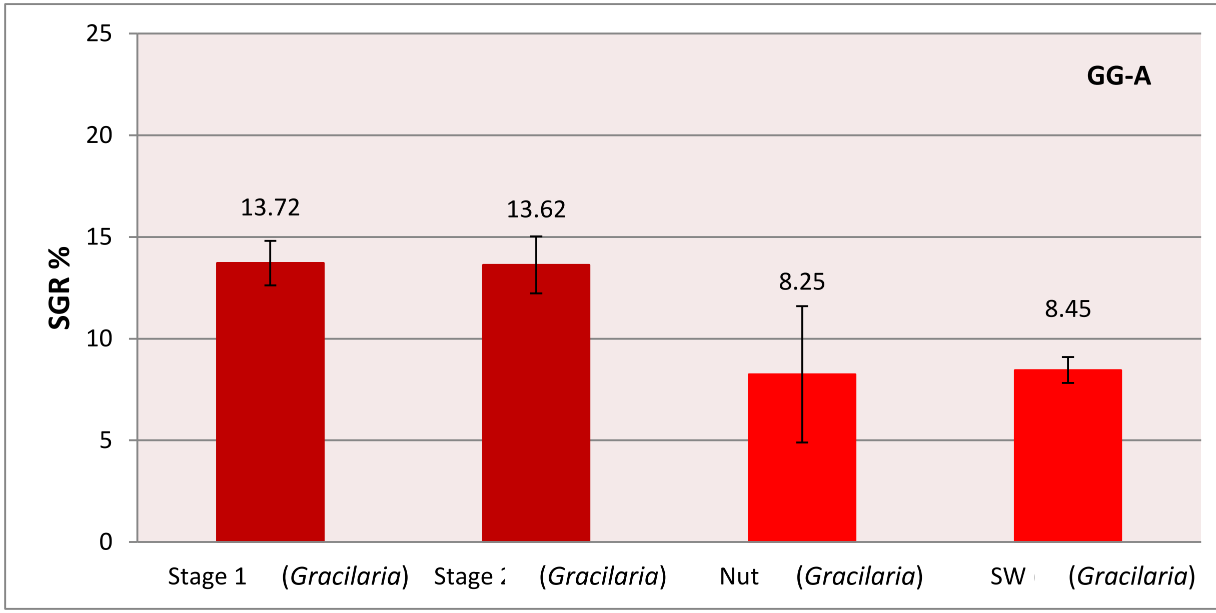


(Ashkenazi et al. submit.)

Results: Growth rates

- ***Gracilaria - Gracilaria***

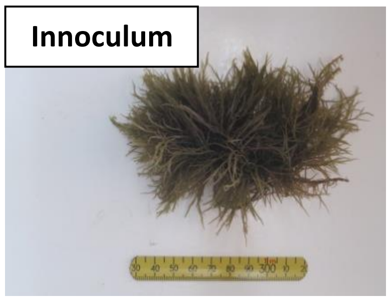


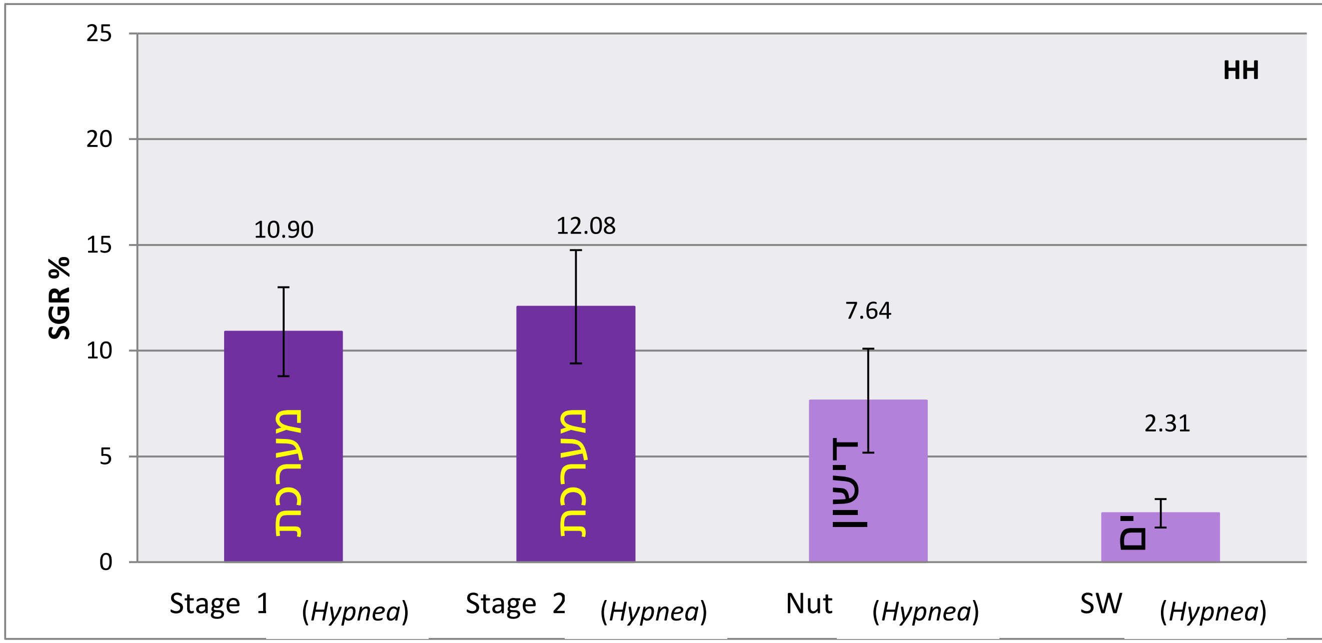


(Ashkenazi et al. submit.)

Results: Growth rates

- ***Hypnea - Hypnea***



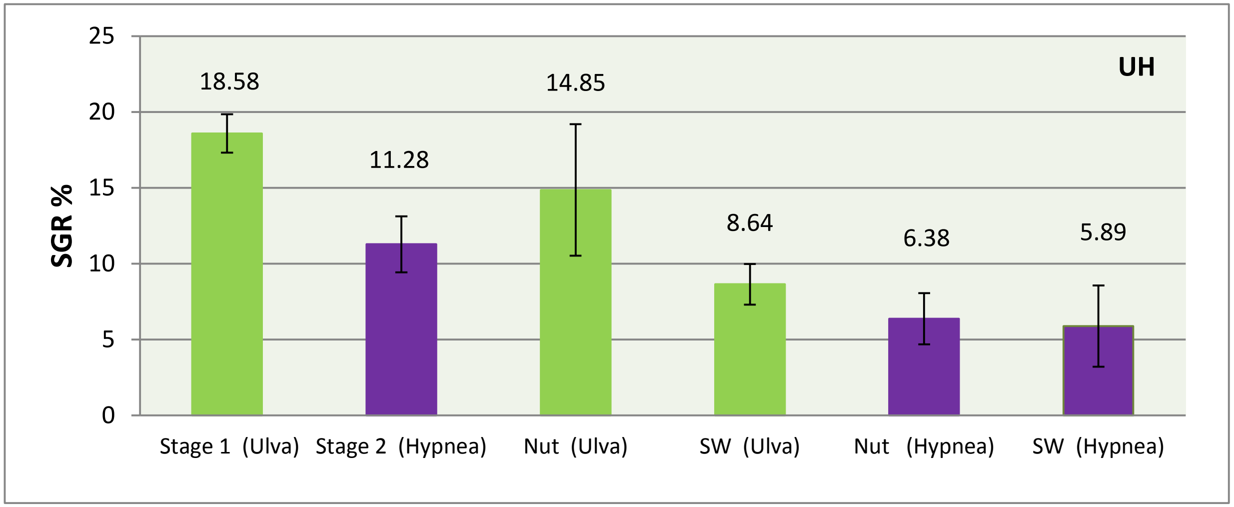


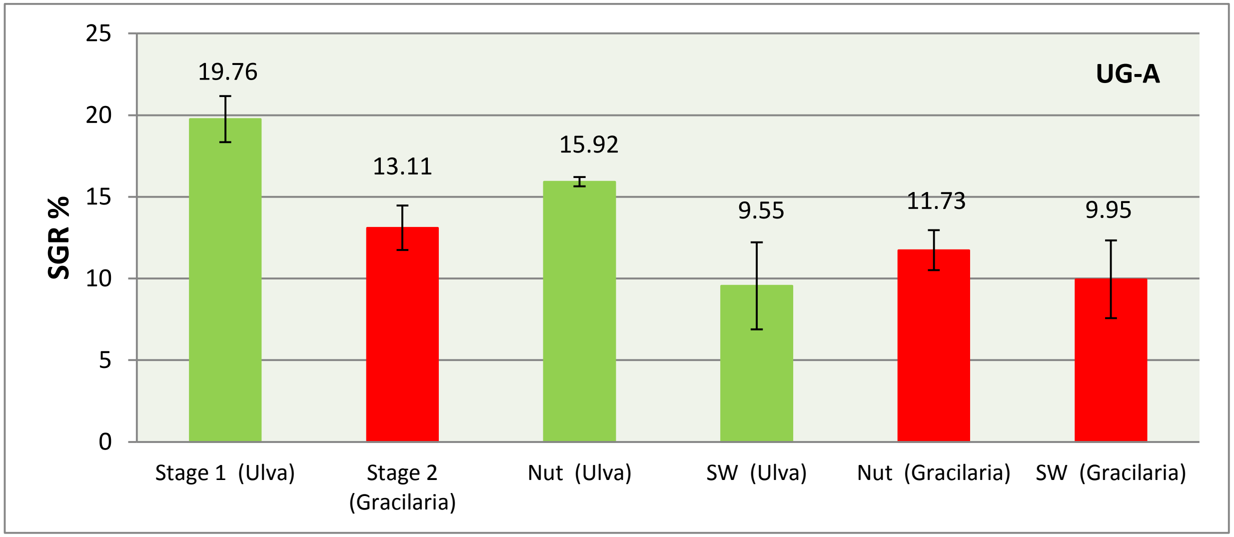
(Ashkenazi et al. submit.)

Results: Growth rates

- *Ulva - Hypnea , Ulva - Gracilaria*

- דפוס דומה.
- לא נראה ששילוב ה *Ulva* מעקב.



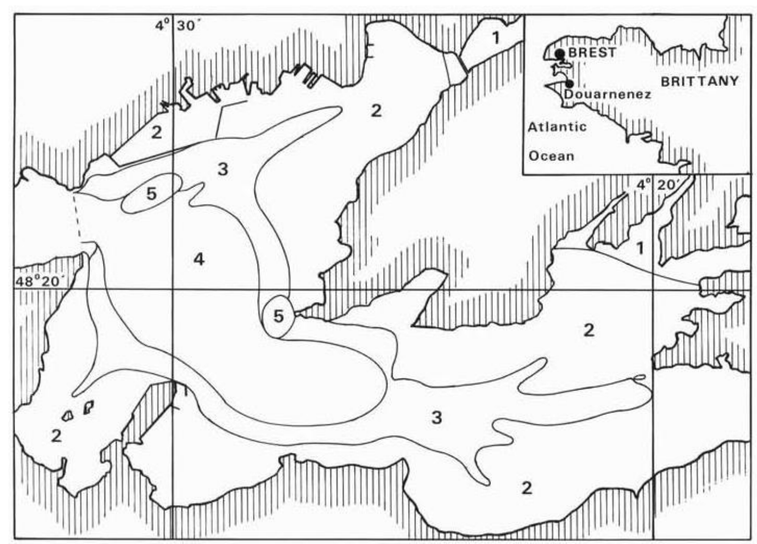


(Ashkenazi et al. submit.)

Is the activity of benthic suspension feeders a factor controlling water quality in the Bay of Brest (France)?

Fertilization of the bay by streams (2 rivers) loaded with nutrients induces a very high primary production (280 g C m-' yr-l). The annual mean flow of these rivers combined is 37.95 m^3 S-' ➔ Benthic suspension feeders can filter **7.18 X 10^8 m^3** daily, which is ca <u>30% of the total volume of the bay</u>.

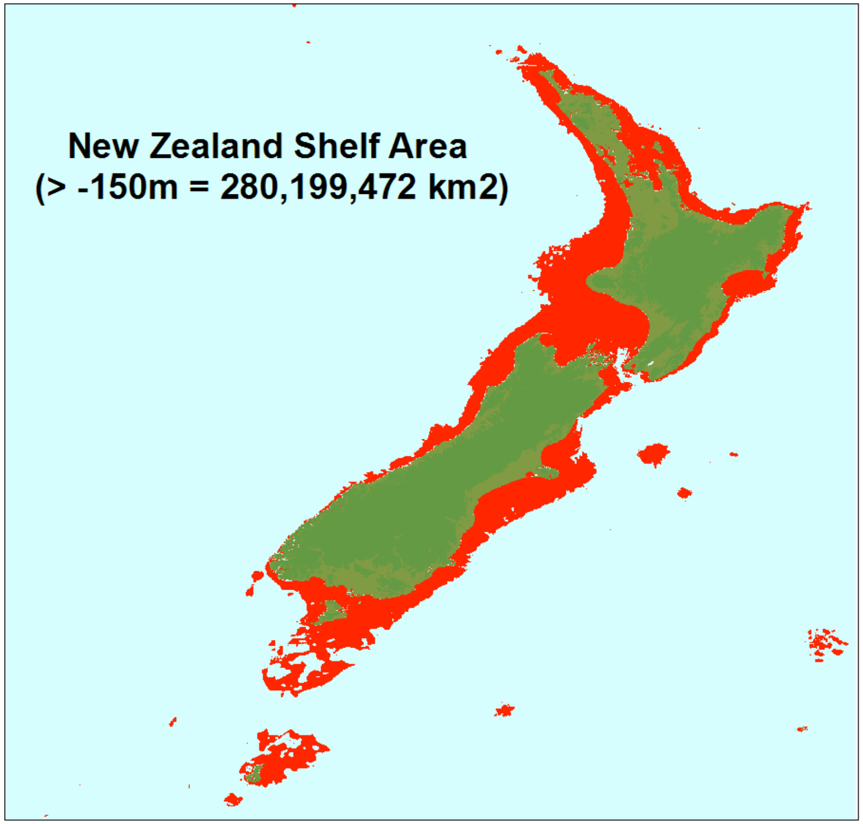
(Hily 1991)



Filtration ability - up to 100 m^3 d^{-1} m^{-2}

(Gil-Coma 1998)

Unfed Aquaculture



Summary: expected benefits

- The above described advantages of food production
- Carbon credit
- Nutrient Trading Credit (NTC)
- Diverse industrial products
- Bio-filtration systems for coastal-water upgrade
- Source for coral reef restoration
- Potential biofuel production
- Sustainable aquaculture modules as alternative livelihood

Additional significant benefits

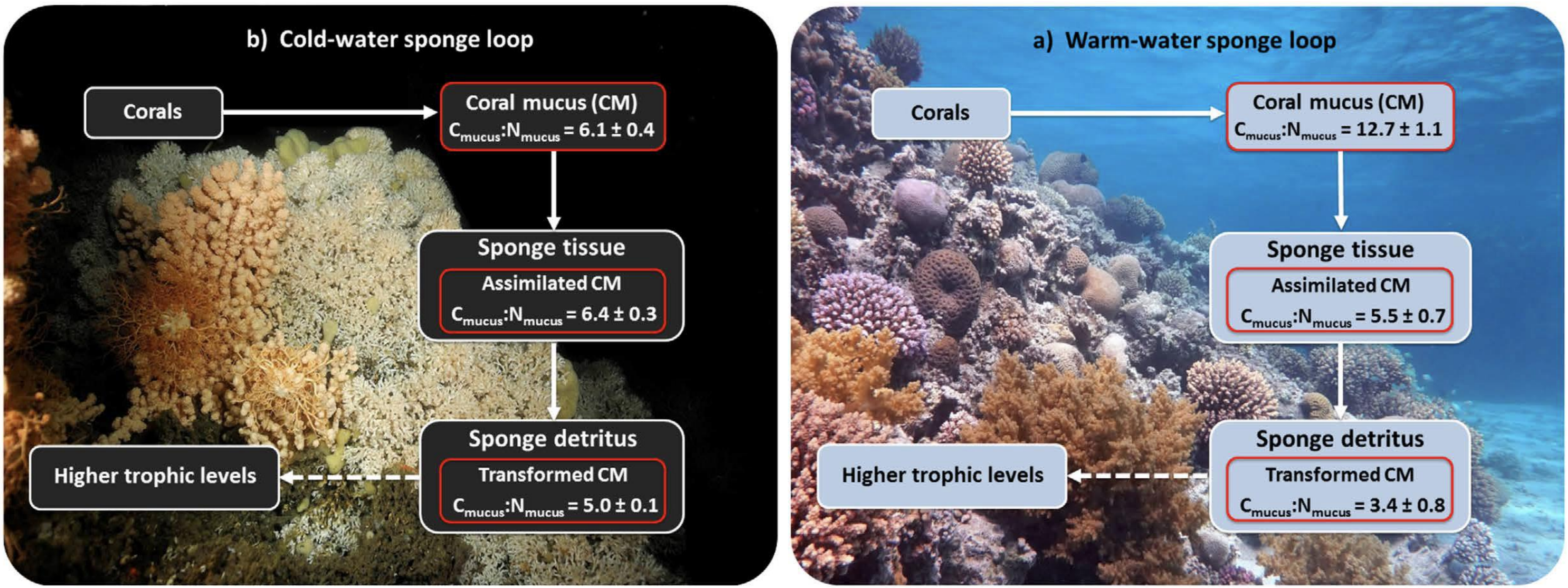
Ambient pollution treatment (eutrophication reduction)

Carbon sequestration

Mass production of biomass (notably macroalgae)

Contaminant absorption

Coral-reef restoration via re-introduction of grazing species


b) Cold-water sponge loop
Corals
Coral mucus (CM)
$C_{mucus}:N_{mucus} = 6.1 \pm 0.4$
Sponge tissue
Assimilated CM
$C_{mucus}:N_{mucus} = 6.4 \pm 0.3$
Sponge detritus
Transformed CM
$C_{mucus}:N_{mucus} = 5.0 \pm 0.1$
Higher trophic levels
a) Warm-water sponge loop
Corals
Coral mucus (CM)
$C_{mucus}:N_{mucus} = 12.7 \pm 1.1$
Sponge tissue
Assimilated CM
$C_{mucus}:N_{mucus} = 5.5 \pm 0.7$
Sponge detritus
Transformed CM
$C_{mucus}:N_{mucus} = 3.4 \pm 0.8$
Higher trophic levels

THANK YOU!