Use of algae and fungi in WWT

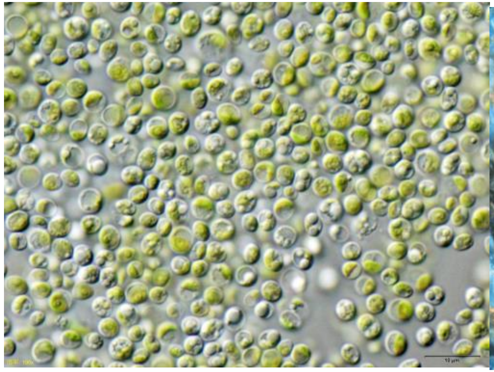
Danielle Bansfield
17.3.2020

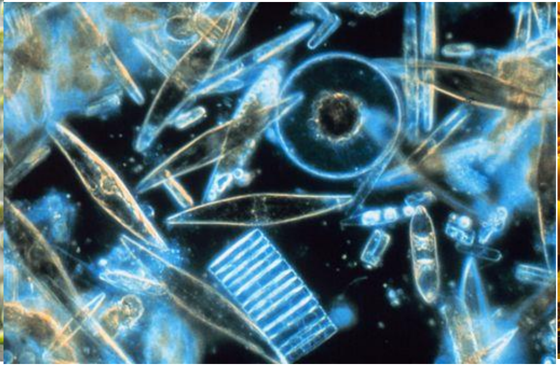
Aalto University
School of Engineering

Algae

Are a diverse collection of photosynthetic eukaryotes
They differ in form, and function

e.g.





kelp

Most are aquatic and produce own energy (autotrophic) via photsynthesis

Some like dinoflagellates consume organics (heterotrophs)

Some terrestrial and aerial

Some undergo asexual and some sexual reproduction

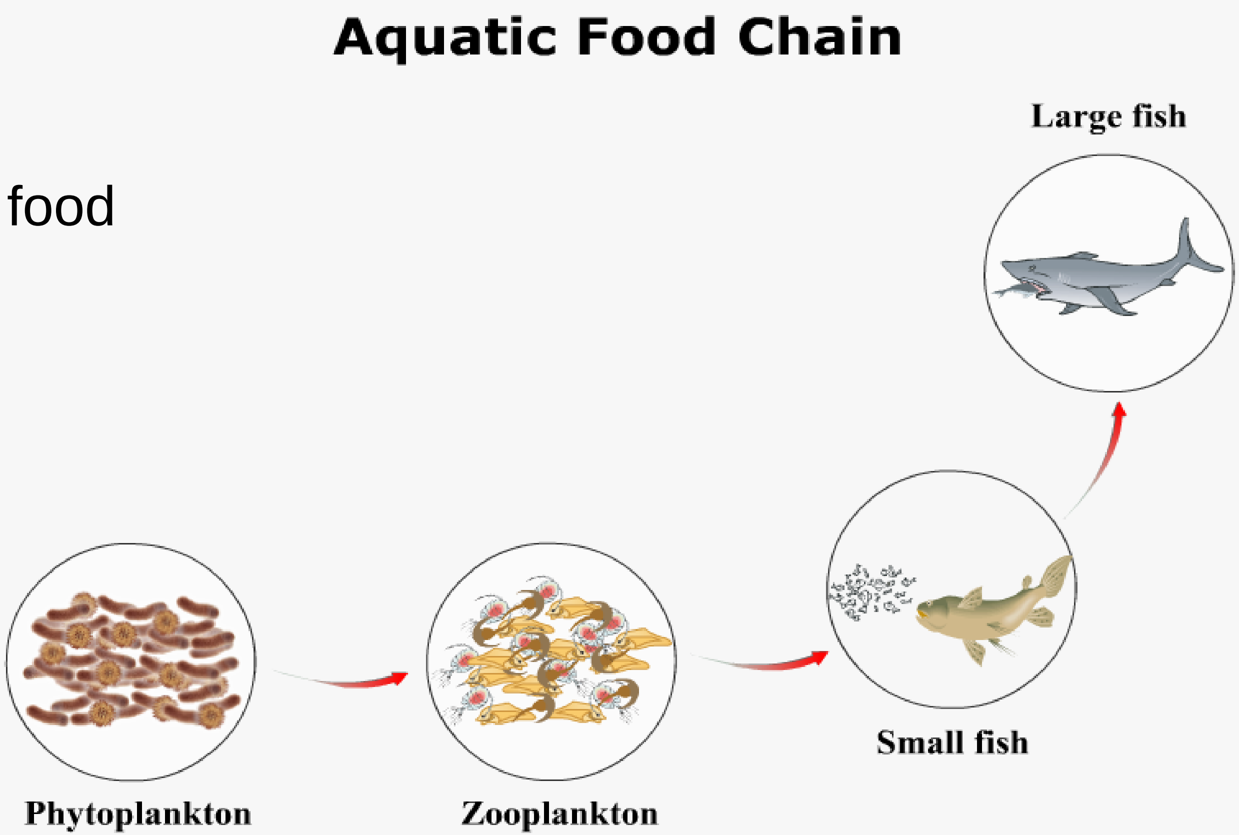
Importance in aquatic food chain

Very important

Form base of aquatic food chain

Produce own energy

Providing food for heterotrophs



Phycoremediation

Removal or biotransformation of nutrients/pollutants

Algae is used for:

1. Nutrient removal (namely N, P)
2. Transformation, conversion and degradation of xenobiotics (hydrocarbons, dyes, phenols)
3. Treatment of pH and metallic removal
4. Sequestration of CO_2
5. Detection of xenobiotics by algae based biosensors

Why not just use bacteria?

Better candidate than bacteria, yeast and plants because of their:

1. Fast growth
2. Higher nutritional value than bacteria
3. Production of valuable biochemicals (bio oils, vitamins)
4. Don’t compete for arable land
5. Less affected by seasonal changes

Wastewater treatment and Nutrient removal

They are ideal for WWT because they are aquatic and phototrophic (produce energy via sunlight)

Especially microalgae which grow quickly (double every 8hrs)

Good phycoremediators (removal/biotransformation of nutrients or toxins)

Algal base WWT was first developed by Professor William J. Oswald, University of California, Berkley in 50’s

He developed the high rate pond (HRP) system still in use today to produce feed, supplements, biochemicals and biomass for fuel production

Later immprovements -> Advanced integrated wastewater pond system (AIWPS)

AIWPS

Sewage goes through various series of ponds with various stages of ”clean up”

1st: anaerobic bacteria break down solids

2nd: shallower ponds so sunlight penetrates maximizing algal growth to outcompete bacteria

3rd: settling pond from which algal biomass is harvested

4th: maturation or settling to remove fecal coliform bacteria

-removes organics up to 1000mg/L of BOD5

-used around the world, especially suited to developing countries because:

1. Cheap to construct and maintain
2. Easy to maintain and operate (no need for engineering skills and lots of money)
3. Customizable

The technology has been refined by Oswald’s students

In 60’s they started large scale Algal WWTP in Califonia

Case study: Delhi, CA Municipal Algae WWTP

Location: Delhi, California,
Population: 10 000
Latitude: 37.4N

Headworks
(screns remove large debris)

2 Facultative ponds
Solids are settled and digested
Depth=4m, HRT=29 days

Inner high rate pond
Growth of algae
Depth= <1m, HRT= 4-5days

Outer high rate pond
Growth of algae
Depth= <1m, HRT= 4-5days

*1/8

*1/3

Rapid mix tank
Dosed with chlorohydrate coagulant

Algal settling pond
Depth= 4m, HRT=1 day

Maturation pond
polishing
HRT=14 days

to perculation basin -> aquifer

*recirculation of aerated sewage to curb odor

Case study: Aqualia, All-gas

Location: Chiclana-de la Frontera, Southern Spain.

Population: ~54 000. Latitude: 36.4N

10 yrs from lab -> pilot -> large scale

Treats the domestic WW of the city

Algal biomass digested -> methane for use in cars

Clean water discharged -> local river and agricultural use

Also feutured in the Netflix documentary ”Brave Blue World”

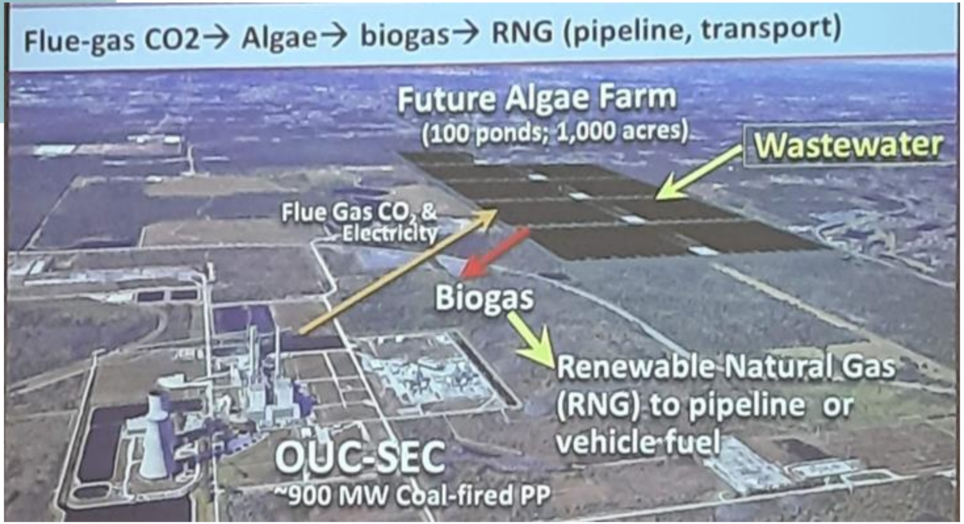
Pros

Municipal Wastewater Treatment Technologies

Technology	Number of Facilities	Total Flow MGD	Energy Intensity MWh/MG
Activated Sludge	6,800	25,000	1.3 - 2.5
Biofilm Systems	2,500	6,000	0.8 -1.8
Algae Ponds	5,000	2,000	0.4 – 1.4

Low energy use
And others mentioned in slide 10

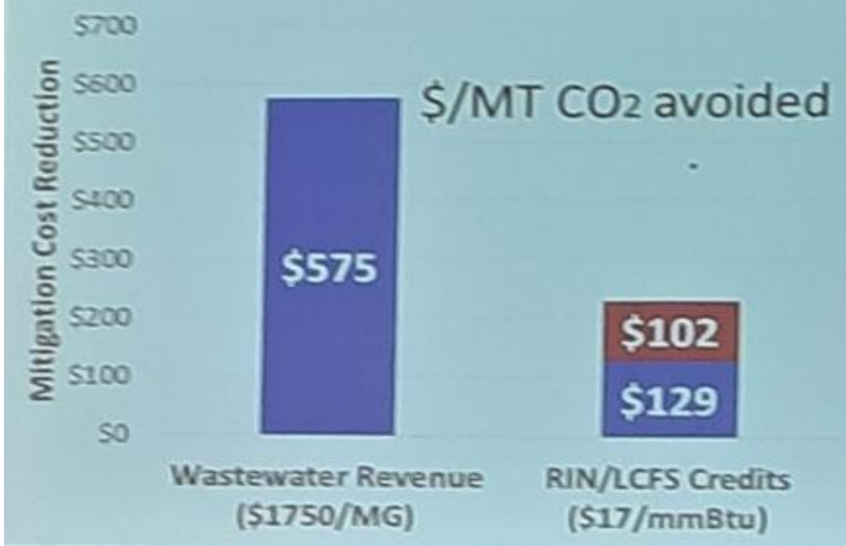
Can provide energy by digestion of algal biomass -> biogas
While mitigating CO2 emissions



Aalto University
School of Engineering

Alternative Case - RNG: Biogas production + Wastewater Treatment for economics need 30 million gallons/day, ~300,000 population

Also: upgrade to RNG ('Renewable Natural Gas') for pipelines, vehicles.



Costs $816/mt CO_2

Revenues: $806/mt CO_2

Net : $10 /mt of CO_2 emissions avoided

CONCLUSIONS: Biogas/ RNG, not a flue gas CO2 utilization case - it is a wastewater treatment process; most carbon from wastewater

Cons

The algal biomass is rarely harvested for used

Many now fail new treatment standards

Need relatively large land area

Low performance in winter

Pond systems limited to small population centers in warm climates

Fungi

Yeasts, rusts, smuts, mildews, molds, and mushrooms

*slime molds and water molds are not fungi!

Eukaryotic i.e. have membrane bound organelles and defined nuclei

Differ from plants:

- lack of chlorophyll
- different components in their cell walls and membranes
- Different mode of growth and nutrition

Fungi

Grow from tips of filaments (hyphae) -> mycelia network -> thallus (mushroom cap)

Secrete enzymes which breakdown organic matter externally then absorbed

Found everywhere

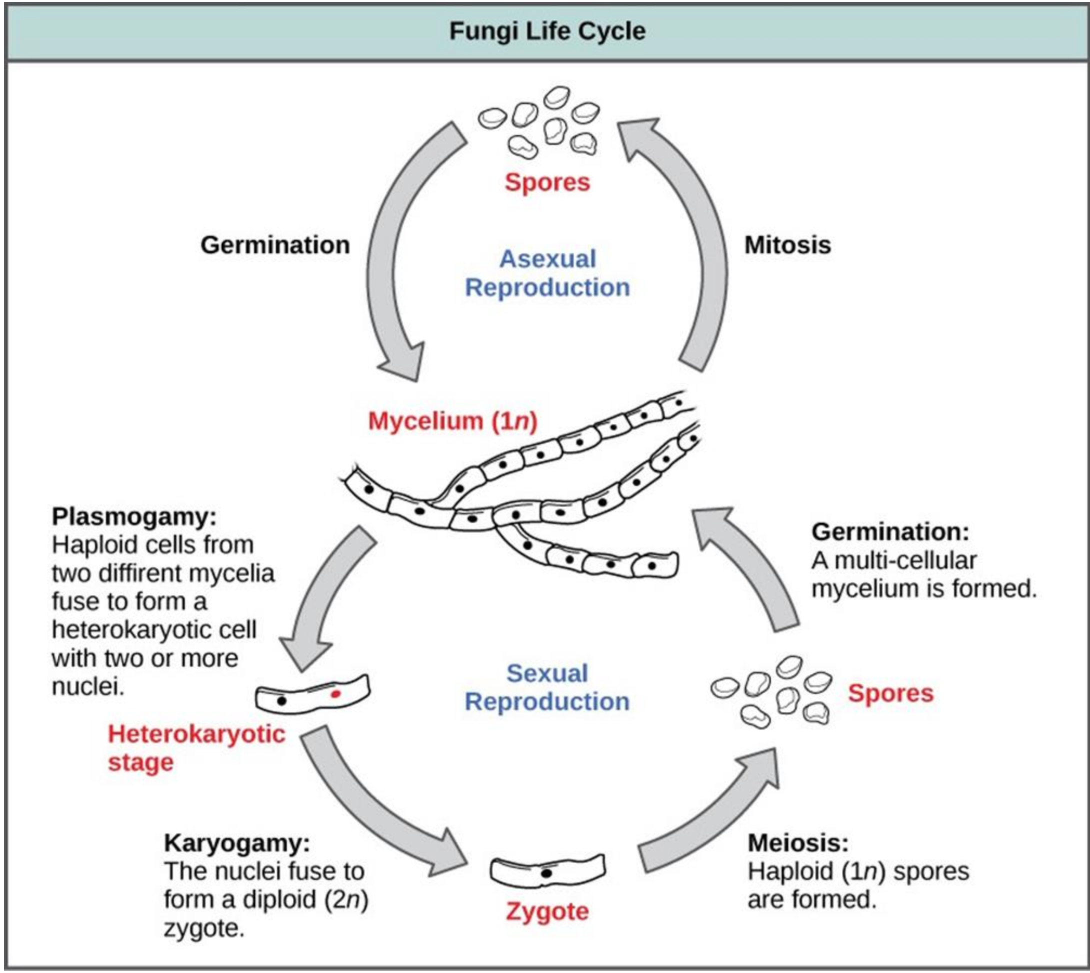
Yeasts do not form mycelium but bud into individual cells

Fungi

Reproduction

1) Asexual: cell division or fragmentation of the thallus, budding in yeasts

2) And sexual: cells of 2 hyphae fuse



Importance

Important for decomposition of organic matter

And therefore the realease of C, O, N and P back into the soil and atmosphere

Produce numerous industrailly important biochemicals e.g.

Laccase and cellulose (paper industry)

Medicines (antibiotics, statin)

Fatty acids

Vitamins

lipids

Fungi in WWT

Well are well suited to WWT because:

The are excellent at aborbing and degrading matter

Degradation is non-specific and broad

Ease of separation from water

Resistant

Used to treat difficult to remove toxins from industrial WW such as dyes (tecxtile industry) , heavy metals (mining, printing) and phenolics

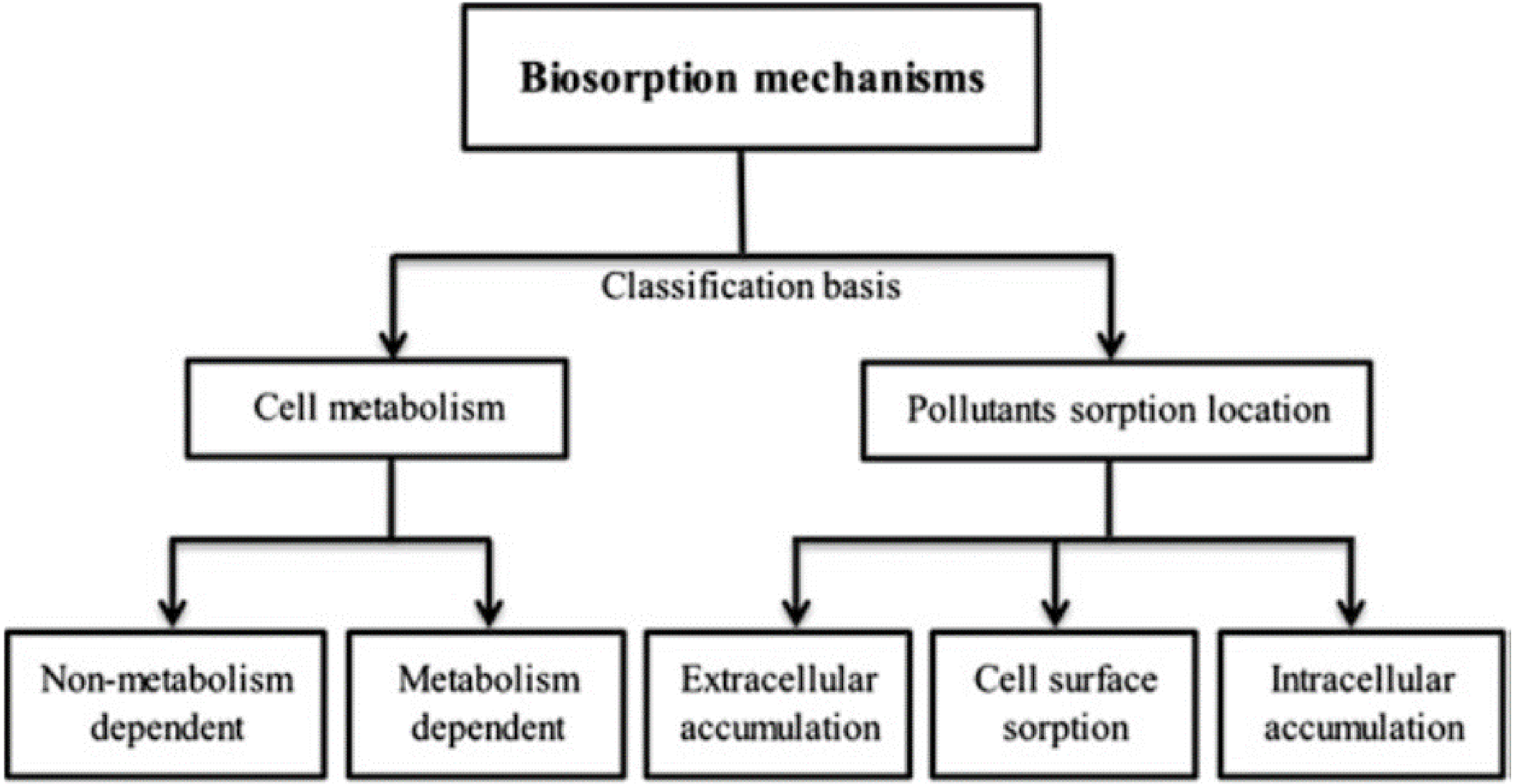
Biosorption

Various functional groups on cell walls such as carboxyl, hydroxyl, amino, sulfonate, and phosphonate, which adsorb compounds

Employ a variety of absorption mechanisms which are not fully understood

Two types:

1. Non-metabolism dependent (passive uptake)—ion exchange, precipitation, complexation, physical adsorption
2. Metabolism dependent (active uptake)—energy-driven


Biosorption mechanisms
Classification basis
Cell metabolism
Pollutants sorption location
Non-metabolism dependent
Metabolism dependent
Extracellular accumulation
Cell surface sorption
Intracellular accumulation

Degradation

Fungi produce non-specific degradative enzymes

e.g. laccase, lignase, cellulase

Meaning molecules of similar structure to its substrate can be degraded

e.g. organic pollutants: phenols, dyes (textile and paper making industry), pharmaceuticals, endocrine disruptors and many other xenobiotics

Filamentous fungi have especially great potential for sludge treatment such as:

- Organic solids reduction
- Bioflocculation
- Pathogens removal
- Dewaterability
- Detoxification

*As living organisms their efficacy is affected by:

Temperature, pH, nutrient content and salinity of the WW

Fungi/algae associations in WWT

Fungi is usually combined with algae for:

- **Improvement of the biomass (increased lipids -> better biofuel production, increased nutrients –> better fertilizer and feed, added biochemicals)**

fungi/alage pellets can be used to remove nutrients (namely N,P,) of up to 80 and 70% respectively

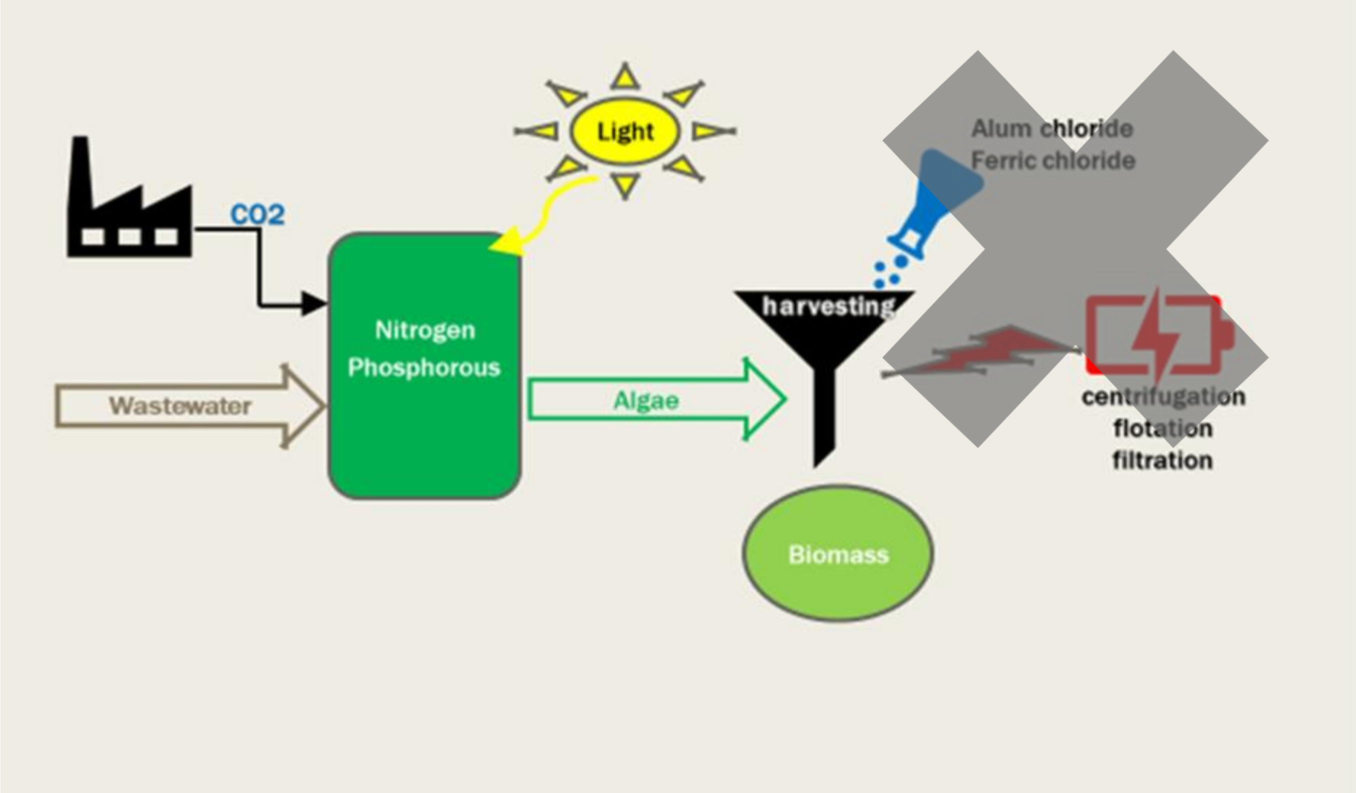
This is species dependent of course

- **Easier/cheaper/more biofriendly harvesting of algal biomass**

Traditional algal harvesting is chemical and energy intensive

Fungal-assisted bioflocculation

-> cost effective, environemtaly friendly algal harvesting method.



Our project at SYKE

(LEVARBIO-project/Leväsieppari project by my colleague Jonna Piiparinen

Investigating growth and removal of nutrients by

Euglena gracilis (algae) in biogas RW

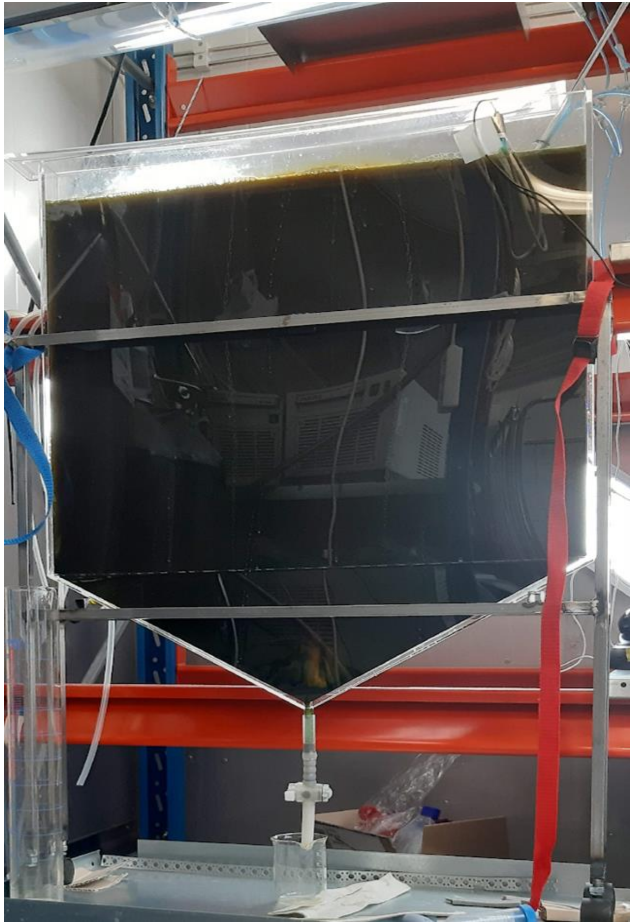
E. gracilis grew in a 50% dilution

Biomass yield: 1.0 g L-1

Nutrient removal: 13% N, 72% P

Protein content: 24% of the biomass.

Lipid content: low (22-24 mg g-1)



My project

Idea : to add fungi to Jonna's algal WWT system to improve organic removal and possibly ease harvesting

Chose 8 filamentous species and 2 yeast based on lit.

Found the RW was too nutrient limiting for fungal growth

Refocused my project to investigate other industrial waste streams (food/beverage production and digestate)

In the meantime I did harvesting studies using free *Pleurotus ostreatus* filaments in suspension combined with *E. gracilis*

Method:

ideal conditions

rotation at 90RPM (fungal self-flocculation induction method)

At RT (23C)

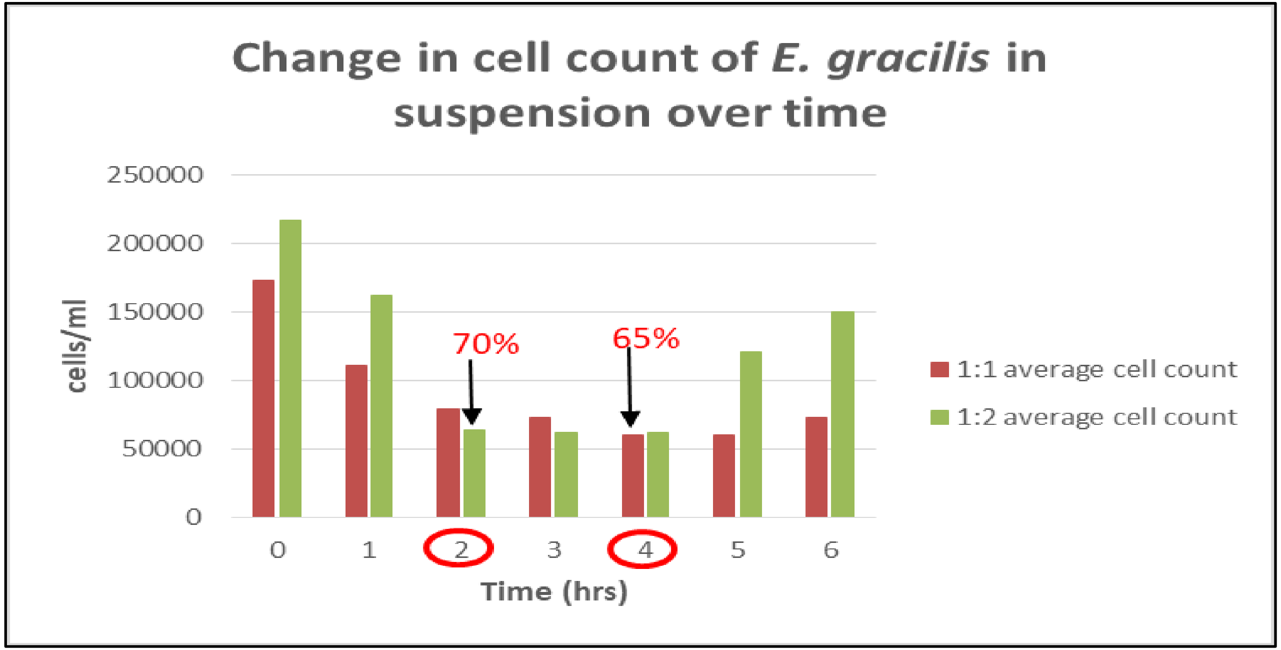
Measured concentration of microalgal cells (cells/ml) in suspension over time

What did I find?...

…that PO was able to harvest Euglena by up to 70% in 2hrs in a ratio of 1 part PO to 2 parts EG (ideal conditions)

Dosage affected harvesting

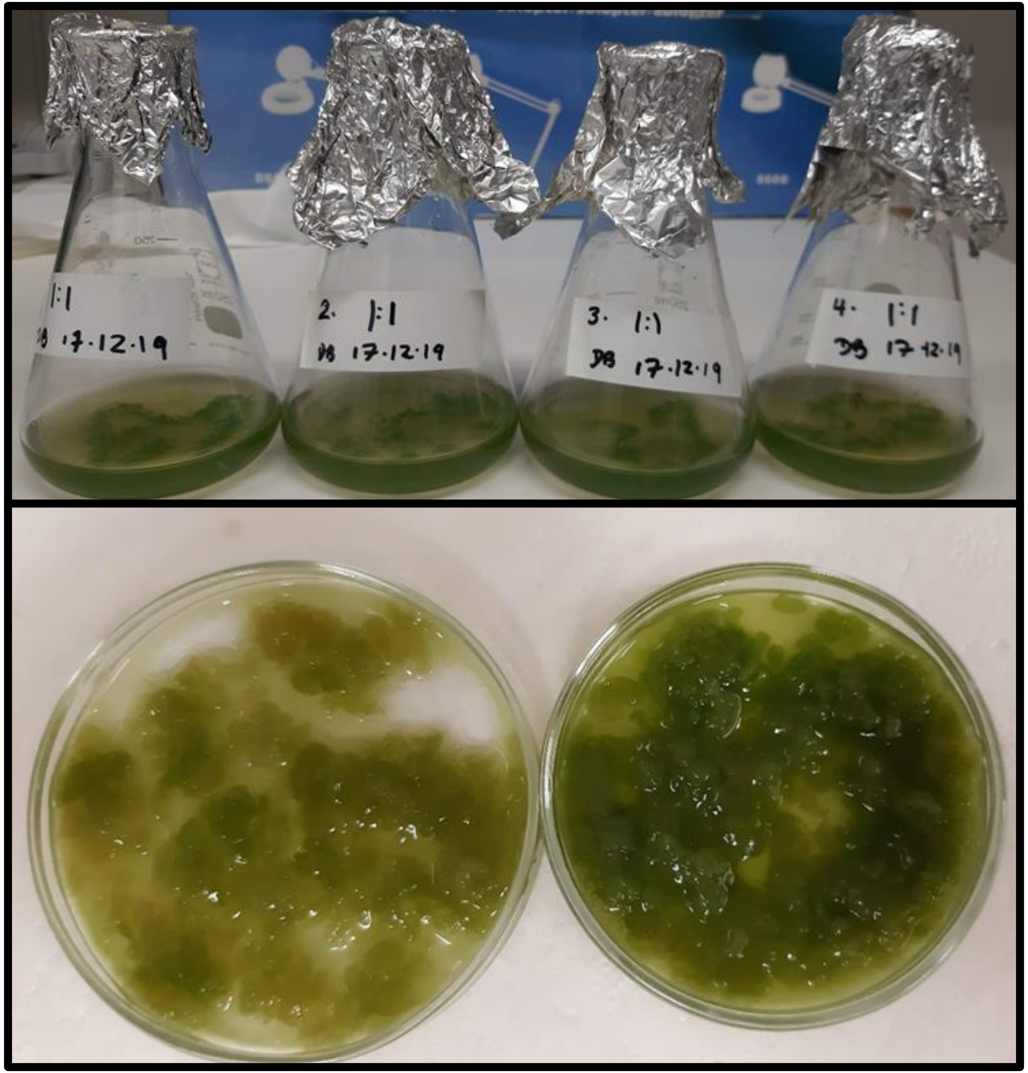
Larger proportion of fungi to algae -> higher removal of algal cells



*ratio = fungi: algae

Aggregates large enough to be collected with common household strainer

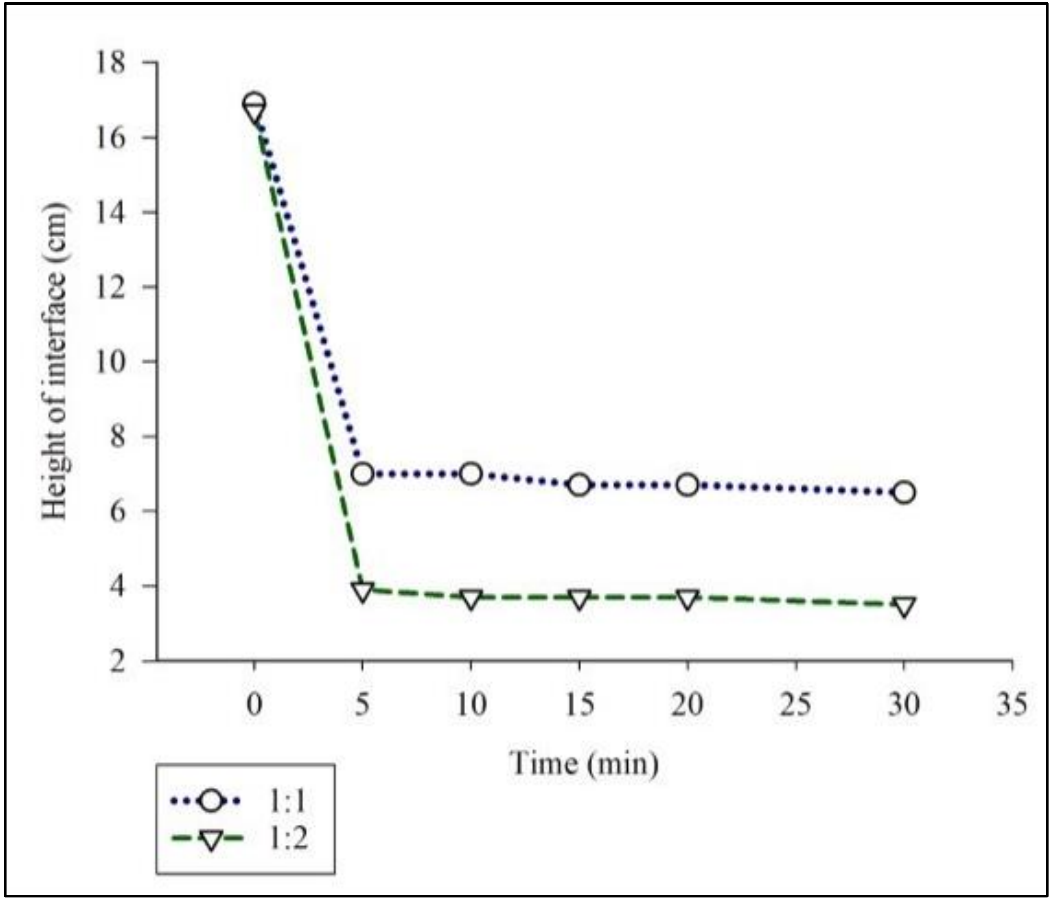
Also tested their settling ability using batch settling test



Also tested their settling ability

Dosage of fungi affected settling ability

Larger proportion of algae to fungi -> faster and more compact settling of flocs



*ratio = fungi: algae

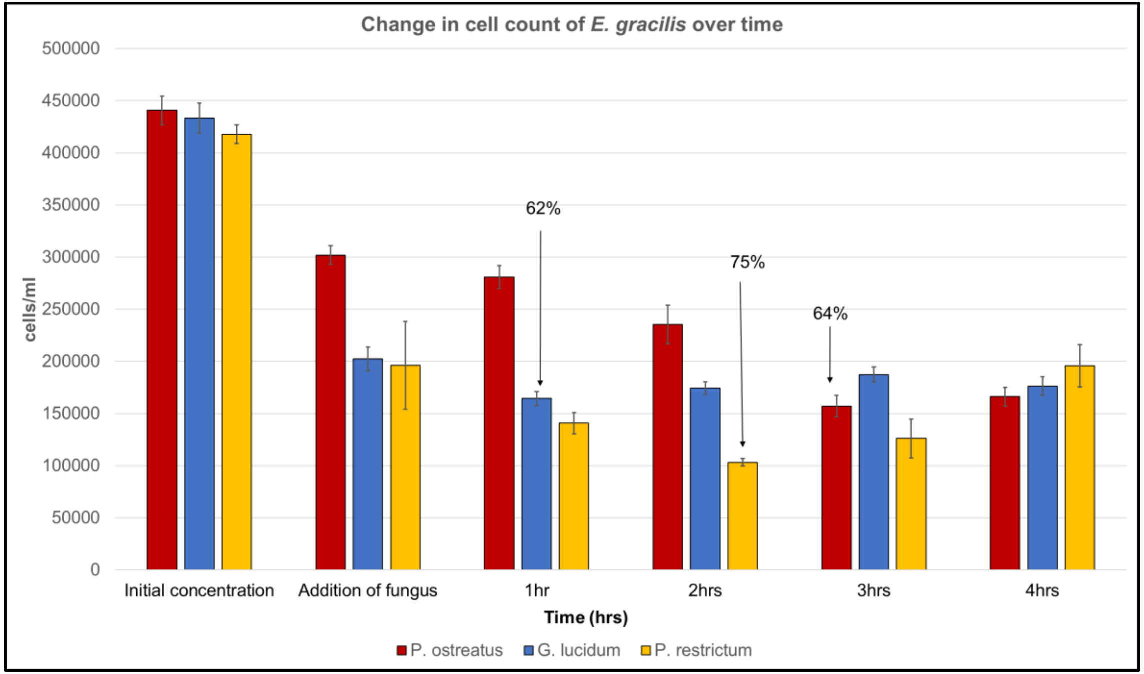
Tested harvesting of *E. gracilis* with other species

Used same set up conditions

Two other species were also able to harvest the algae rapidly (1 - 3 hrs)

by 62 - 75 %

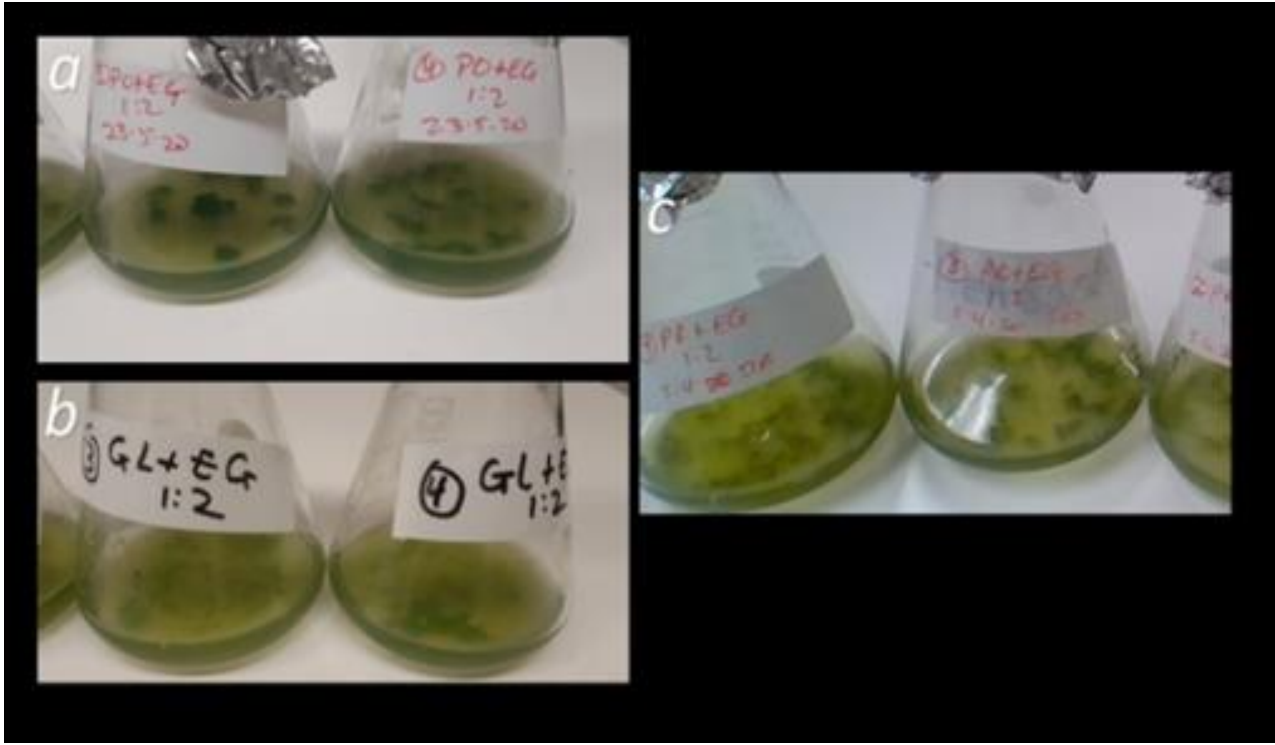
P. restrictum gave the highest harvesting results



*ratio = fungi: algae

Aalto University
School of Engineering

These aggregates were also large enough to be collected by screening

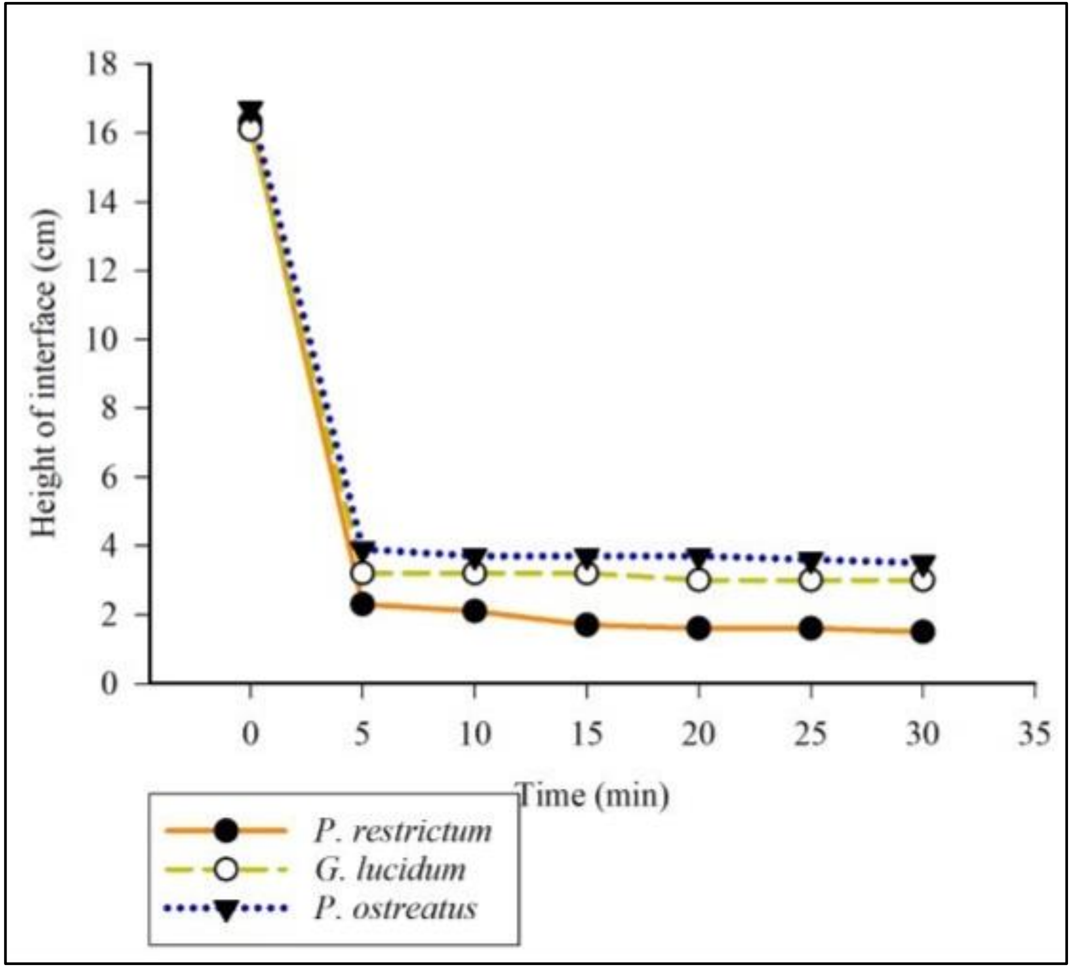


Also conducted batch settling tests on these flocs

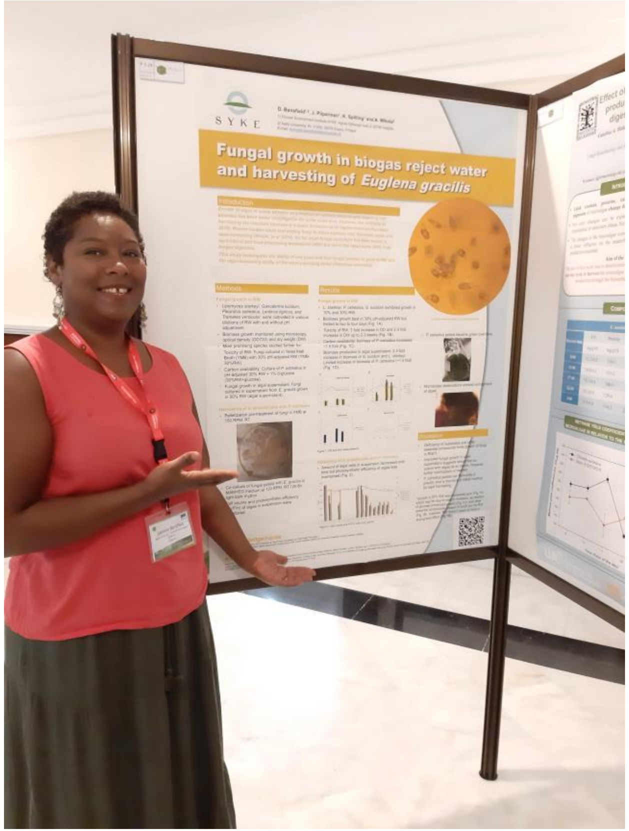
P. restrictum also settled fastest and most compactly

Proving to be the best species

These results prove that fungal filaments canbe used to harvest microalgae in suspension



Thanks for your attention



Aalto University
School of Engineering

References

Pics

1) By ja:User:NEON / User:NEON_ja - Own work, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=35450226
2) <ahref="https://commons.wikimedia.org/wiki/File:Diatoms_through_the_microscope.jpg" title="via Wikimedia Commons">Prof. Gordon T. Taylor, Stony Brook University / Public domain
3) By Bjørn Christian Tørrissen - Own work by uploader, http://bjornfree.com/galleries.html, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=6515137
4) https://www.pngitem.com/pimgs/m/406-4061561_aquatic-food-chain-hd-png-download.png
5) https://www.osti.gov/servlets/purl/1475450
6) OpenStax
7) Fungal Applications in Sustainable Environmental Biotechnology. Editors: Purchase, Diane (Ed.) Springer 2016

Videos

https://www.youtube.com/watch?v=ARonDwYtKU0&t=77s

Lit. sources

https://en.wikipedia.org/wiki/Algae

https://www.latimes.com/archives/la-xpm-2005-dec-17-me-oswald17-story.html

https://en.wikipedia.org/wiki/William_J._Oswald

http://ponce.sdsu.edu/aiwps.html

https://microbioengineering.com/wastewater

Industrial BiotechnologyVol. 14, No. 1

Autotrophic Microalgae Biomass Production: From Niche Markets to Commodities, John R. Benemann, Ian Woertz, and Tryg Lundquist. Published Online:1 Feb 2018https://doi.org/10.1089/ind.2018.29118.jrb
https://www.osti.gov/servlets/purl/1475450

Fungal Applications in Sustainable Environmental Biotechnology

Editors: Purchase, Diane (Ed.) Springer 2016

https://www.britannica.com/science/fungus/Life-cycle-of-fungi

Georgia Tech Biological Sciences http://bio1520.biology.gatech.edu/biodiversity/fungi-2/