Use of Marine Macroalgae for the Treatment of Municipal Wastewaters and Biomass Production for Animal Feed

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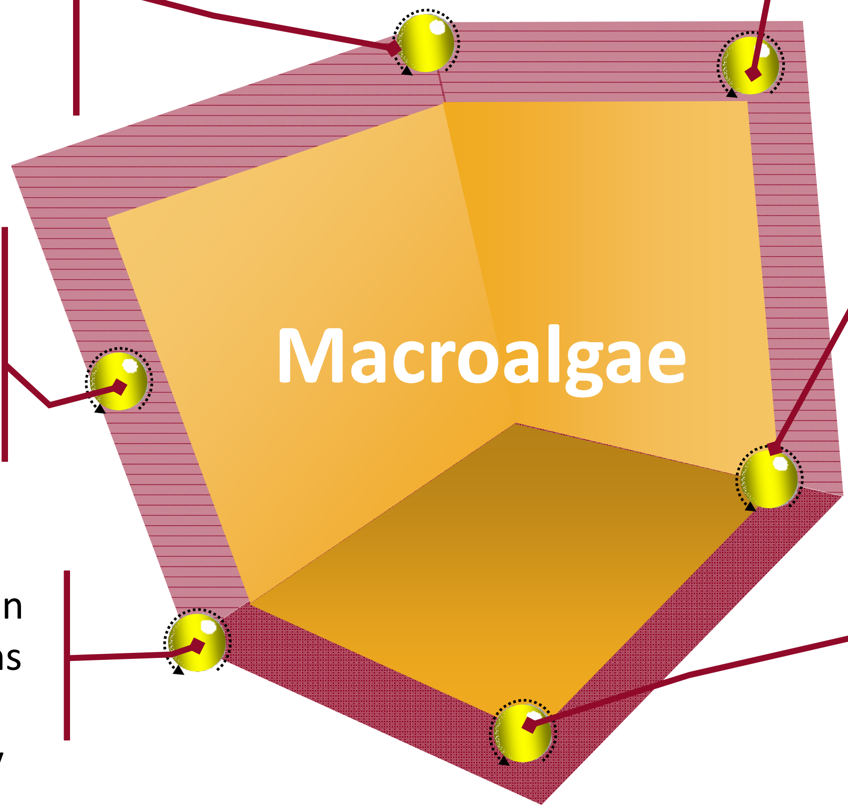
Macroalgae

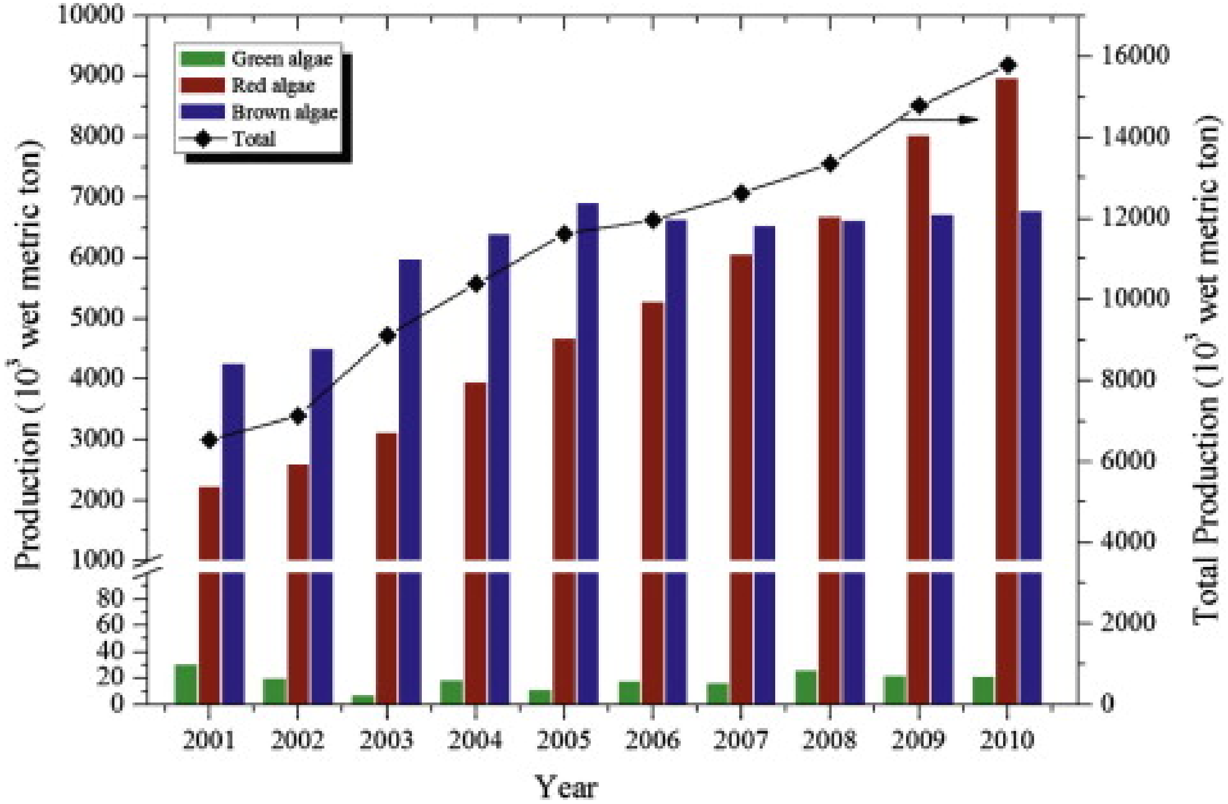
Compared to microalgae,

- Use of non-arable land or freshwater to grow. **Grow well with wastewater and waste gas containing CO_2**.
- Grow faster than most productive crops.
- **Chemical compounds** used in several applications in food, fodder or chemistry industry



- **Rich in carbohydrates,** which well suited for biofuel production
- Only a few species contain lignin.
- **Cost-efficient harvesting and dewatering**

Mass-cultivation of macroalga in the world (2001-2010)



The amount of macroalgal biomass cultivated in the world has increased consistently in the last 15 years. The 10 year span (2001-2010) showed an average of 10%.

Jung et al. Bioresource Technology, 2013, 135, 182-190.

Macroalgae classification

3 Phylum (Based on color, Chlorophyll type, food storage substance and cell wall composition)

❖ **Green Algae (Chlorophyta)**

- Freshwater species mostly (～700 marine species).
- Dominance: Chlorophyll *a* and *b.*
- Structurally simple.

❖ **Brown Algae (Phaeophyta)**

- Mostly marine (～1800 species), including most largest complex algae –kelps.
- Dominance: Xanthophyll pigment.
- Structurally simple (flat thalli) to complex (holdfast, stipe, blade, pneumatocyst).

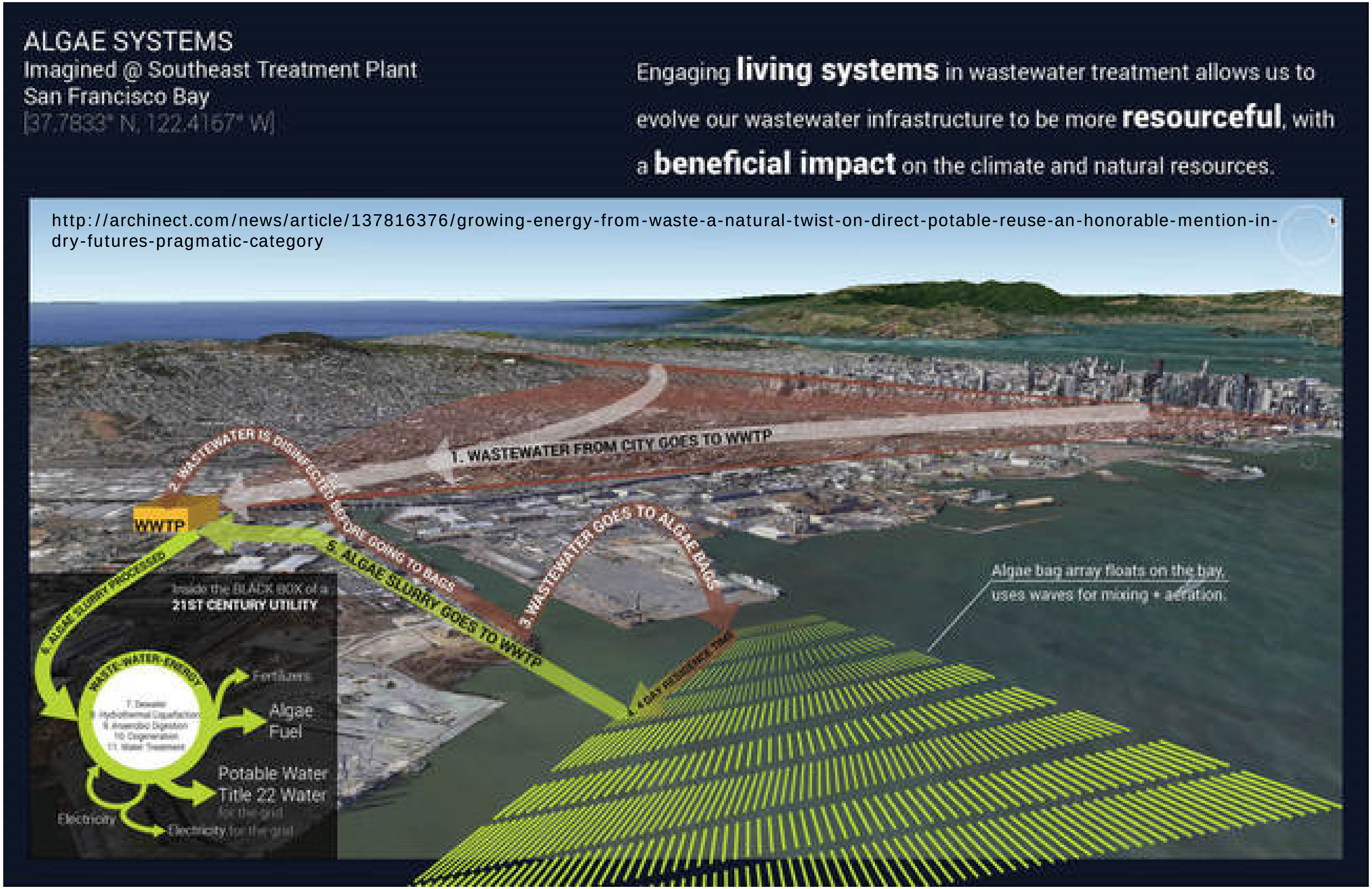
❖ **Red Algae (Rhodophyta)**

- Mostly marine (～4000 species).
- Dominance: phycoerythrin and phycocyanin.
- Most are filamentous.

RÉSEAU BIOFUELNET CANADA

"Growing Energy from Waste:
A Natural Twist on Direct Potable Reuse"

http://archinect.com/news/article/137816376/growing-energy-from-waste-a-natural-twist-on-direct-potable-reuse-an-honorable-mention-in-dry-futures-pragmatic-category



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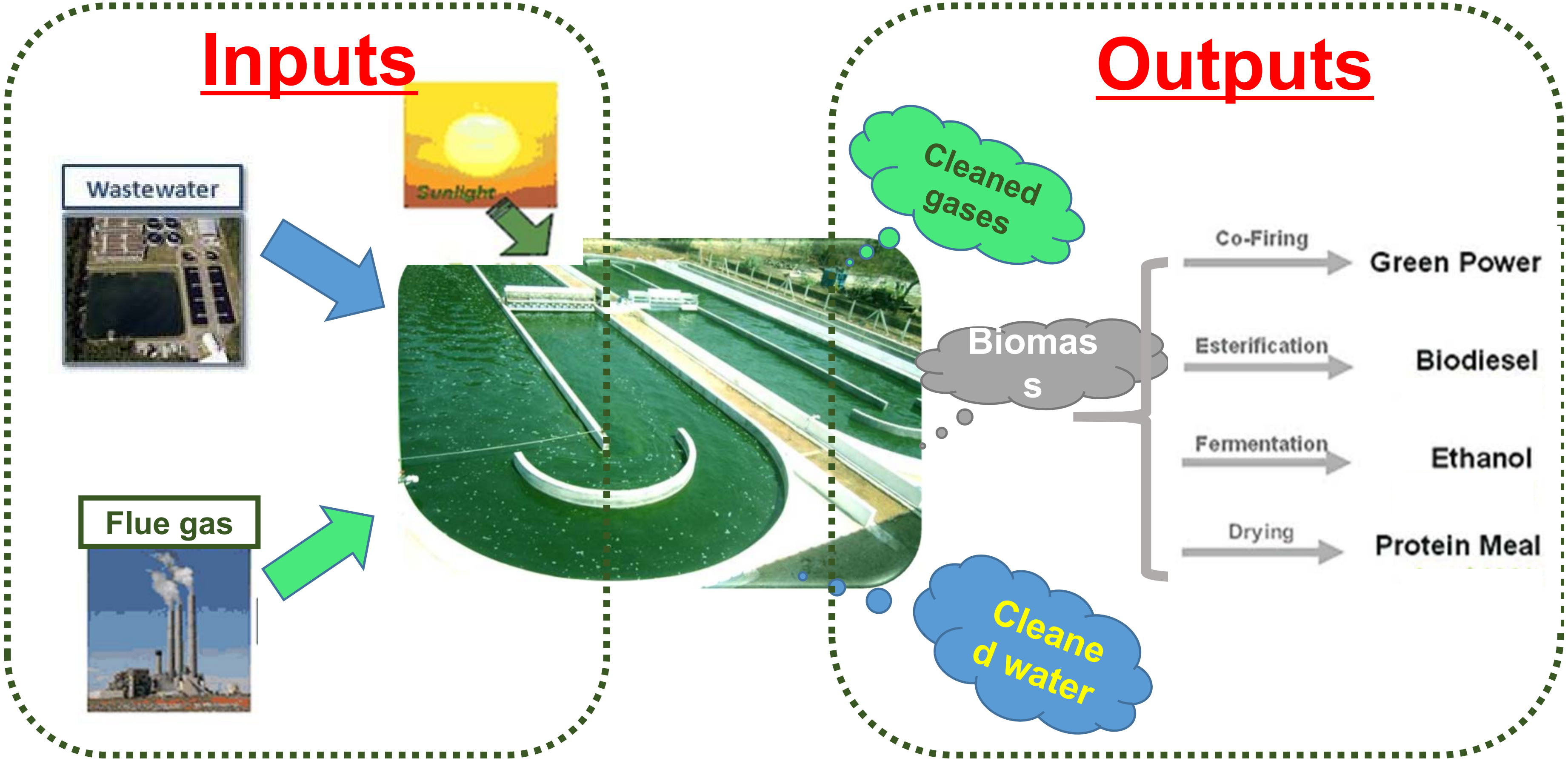
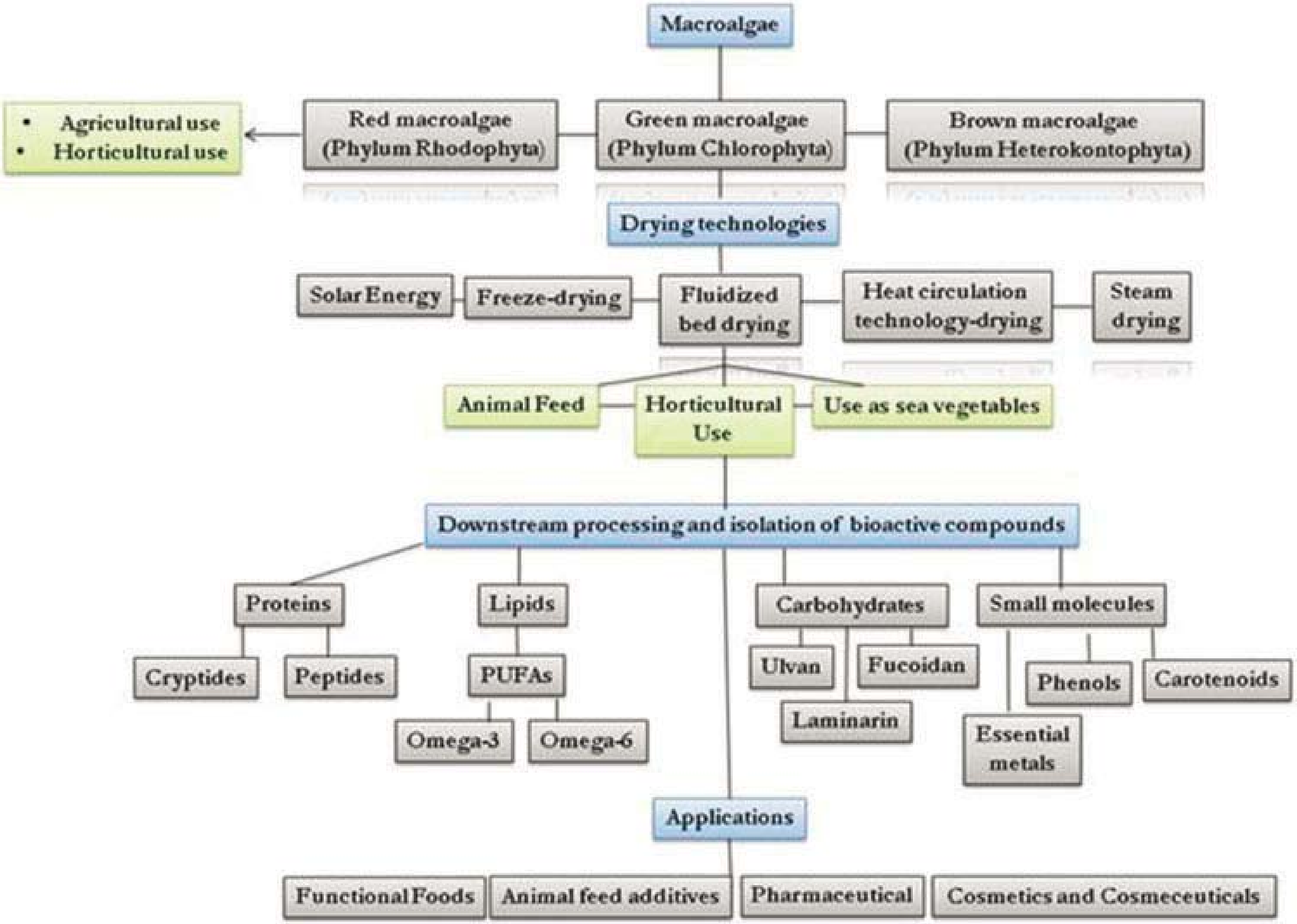
Algae (micro- and macroalgae) are emerging as a renewable feedstock for biofuel, bioenergy and other products production.



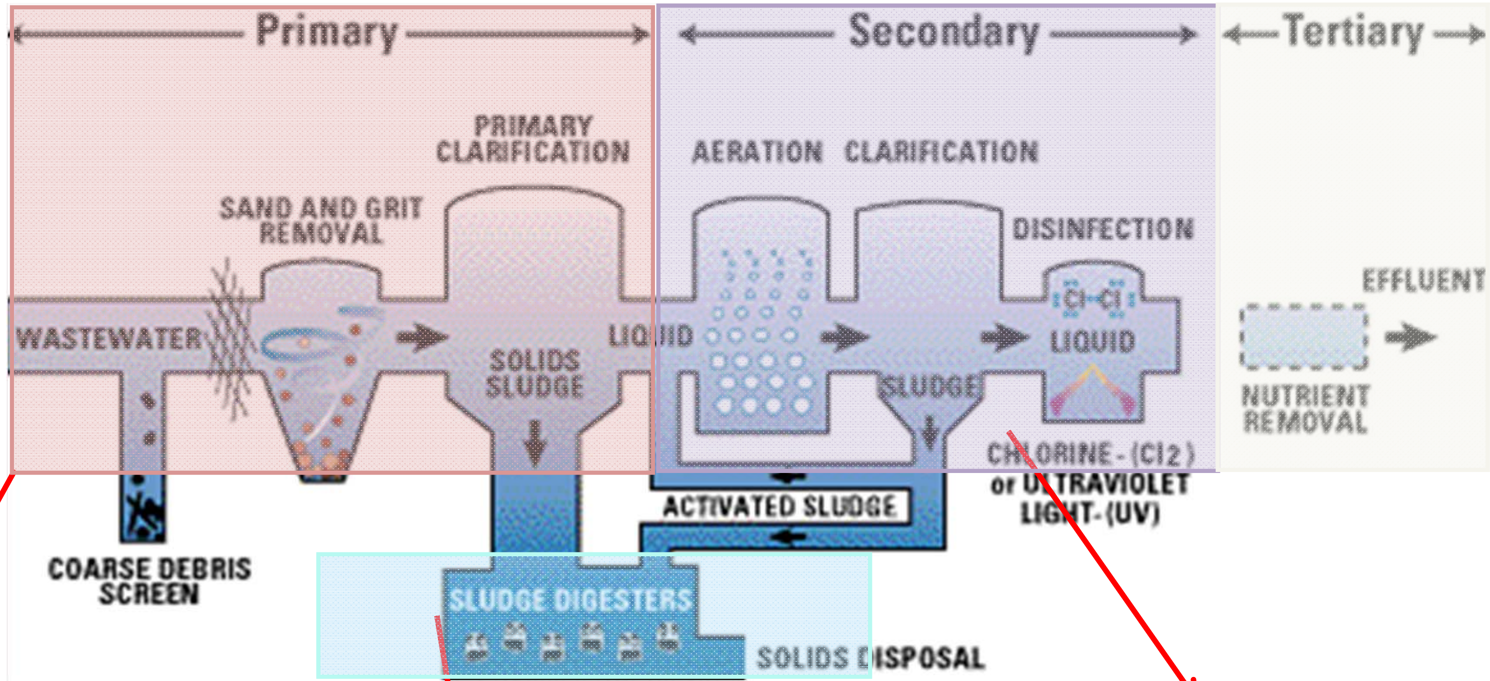
Macroalgae offer a potential resource for use as animal feed and human food.



Garcia-Vaquero et al. Food reviews international, 2016, 32, 15-45.

Nutrient sources in Wastewater from WWTPs

Simplified process flow diagram for a typical large-scale treatment plant



http://www.sheffy6marketing.com/index.php?page=test-child-page

- **Primary WW**

  organic N,
  NH_4^+-N(mostly)
  NO_3^--N
  Phosphate

- **Centrate WW**

  NH_4^+-N (mostly)
  NO_3^--N
  Phosphate

- **Secondary WW**

  NO_3^--N (mostly)
  NH_4^+- N
  Phosphate

The purpose of this study is to:

- investigate the possibility of using macroalgae (*Ulva lactuca*) for phosphorus and nitrogen recovery from municipal wastewater.
- provide a proof of principle that macroalgal cultivation could be considered as a technology for wastewater treatment and biomass production for animal food.

Macroalgae species

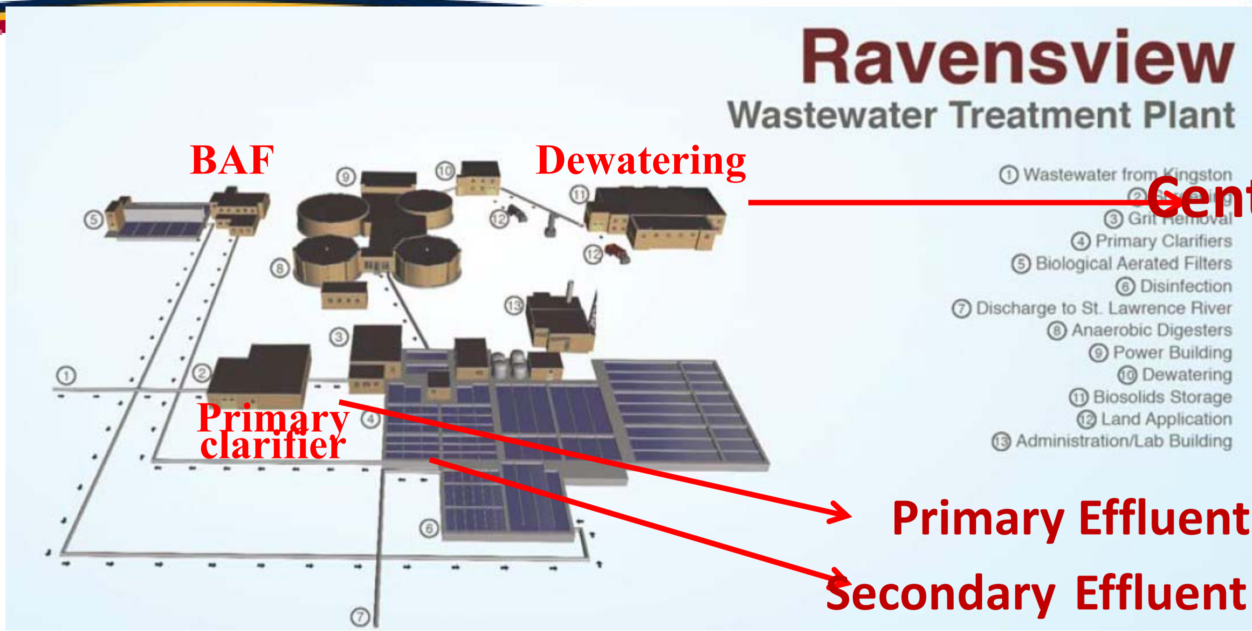
Ulva lactuca

- Green marine algae, Sea lettuce.
- Leaves most rounded or oval.
- Both free-floating and attached.
- **Tolerant of nutrient loading.**
- Indicator of high levels of pollutions

Glass Aquarium

- 5.5 gallon, flat-plate type.
- Orphek Atlantik Aquarium LED lighting (4 channels).
- Air pump with filtered air (i.e., 0.039% CO_2).

Wastewater---Ravensview WWTPs



Wastewater Characteristics

Parameters	Wastewater for macroalgae cultivation		
	PW	SW	CW
pH	7.28-7.54	6.72-7.13	7.88-8.35
COD (mg/L)	102.4-307.6	14.5-29.6	304-446
NH_4^+-N (mg/L)	**8.9-24.5**	0-0.85	**632-896**
NO_3^--N(mg/L)	0-0.83	**9.56-17.98**	0-0.15
NO_2^--N(mg/L)	<0.1	<0.1	0-0.09
TP(mg/L)	0.75-2.35	0.13-0.54	**15.5-20.6**

Experimental 1——macroalgae growth on wastewater

Jar test 250 mL Erlenmeyer flasks

- **WW sources:**

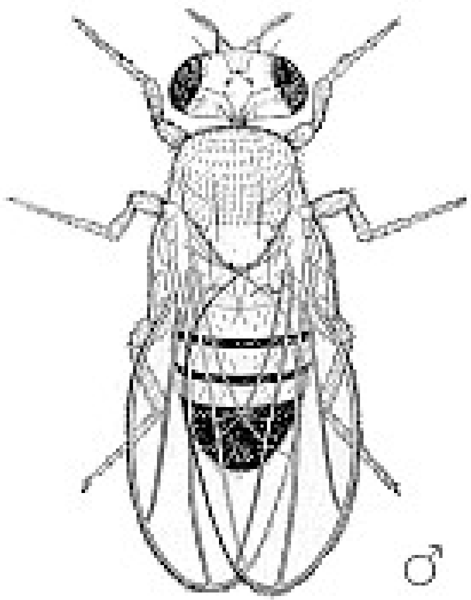
  PW, SW, 3% CW and 4% CW (autoclaved)

- **Salinity**: 32‰
- **LED** light source
- **24 h** light cycle
- No mixing
- Room temperature (24.0-27.5℃)
- **6 replicates** for each treatment

Experimental 2——fly feeding study

- **Animal model:**

  Drosophila melanogaster



- **3 Food sources**

  (1) 100% Standard medium (SM)

  (2) 80% SM+20% unwashed macroalgae

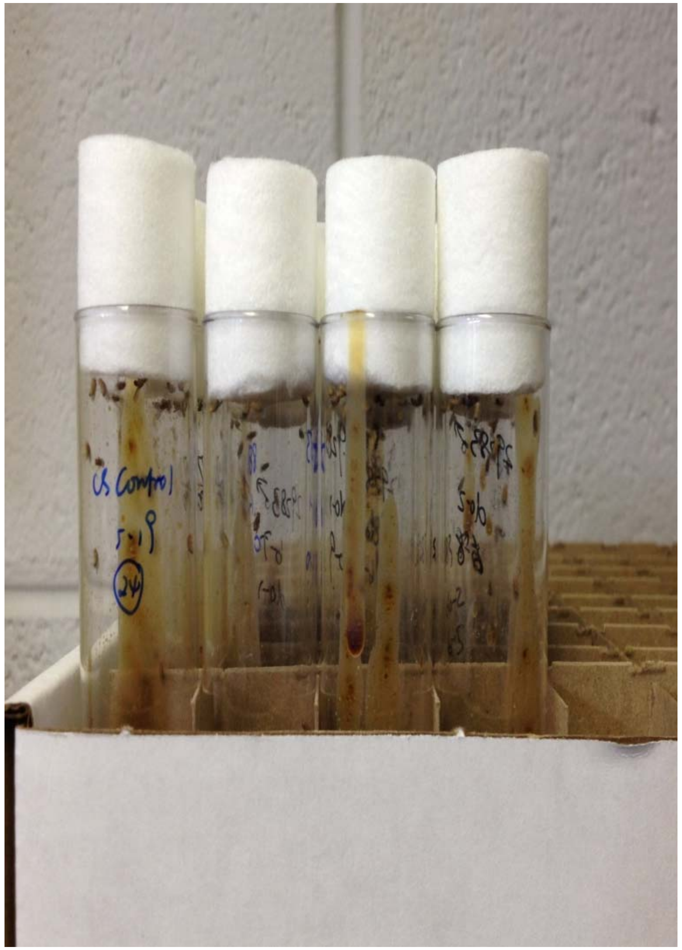
  (3) 80% SM+20% washed macroalgae

- **Raised in 10 ml plastic vials**
- **Growth conditions**

  21-23° C, 60-70% humidity, 12h/12 h light/dark cycle

Experimental 2——fly feeding study

Queen's UNIVERSITY



- **Lifespan experiment**

  Parameters: counting alive fly numbers

  Intervals: 10 days until Day 50

  Replicates: 5 vials (25 flies in each vial)

- **Body weight experiment**

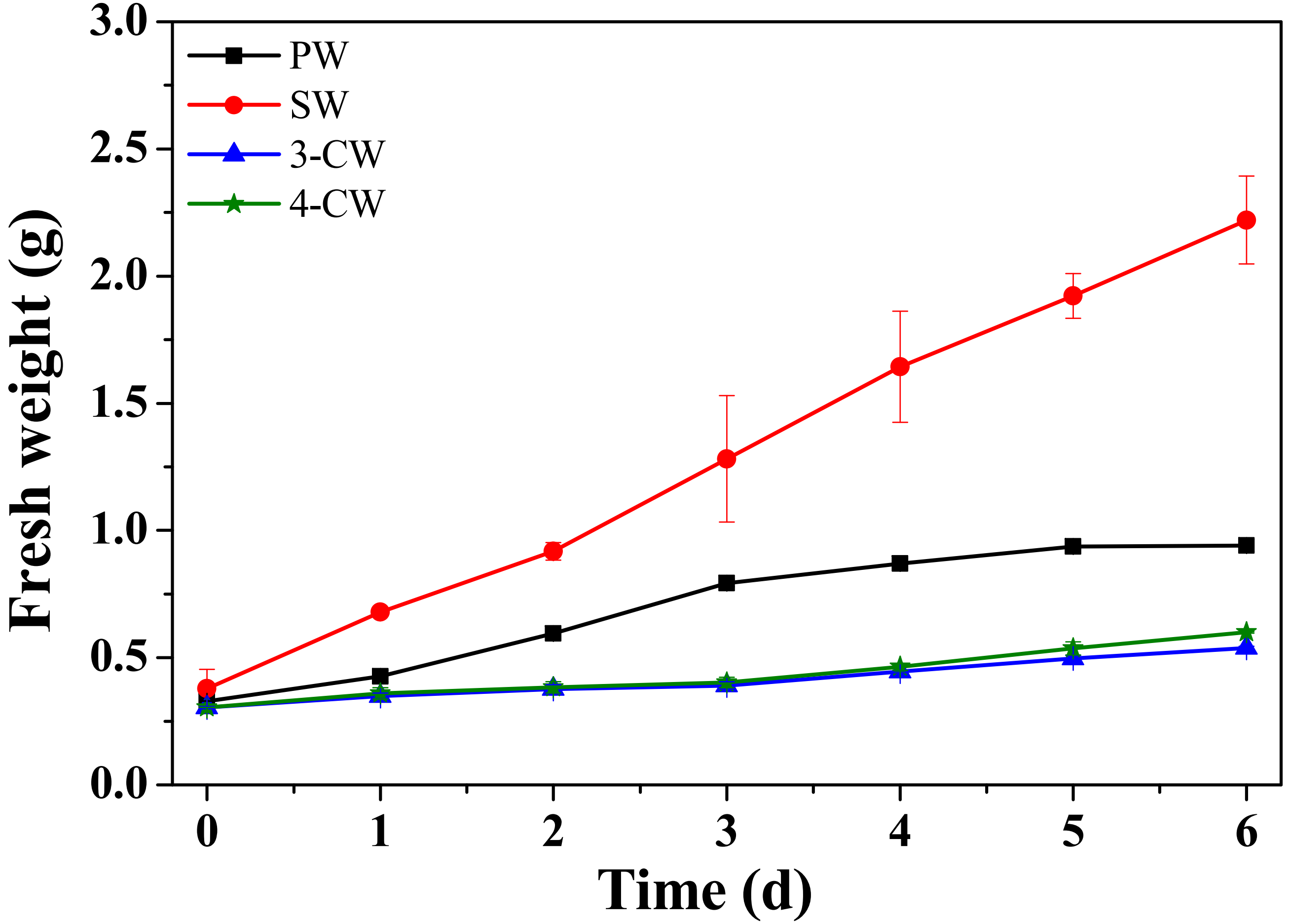
  Parameters: body weight

  Intervals: 10 days until Day 40

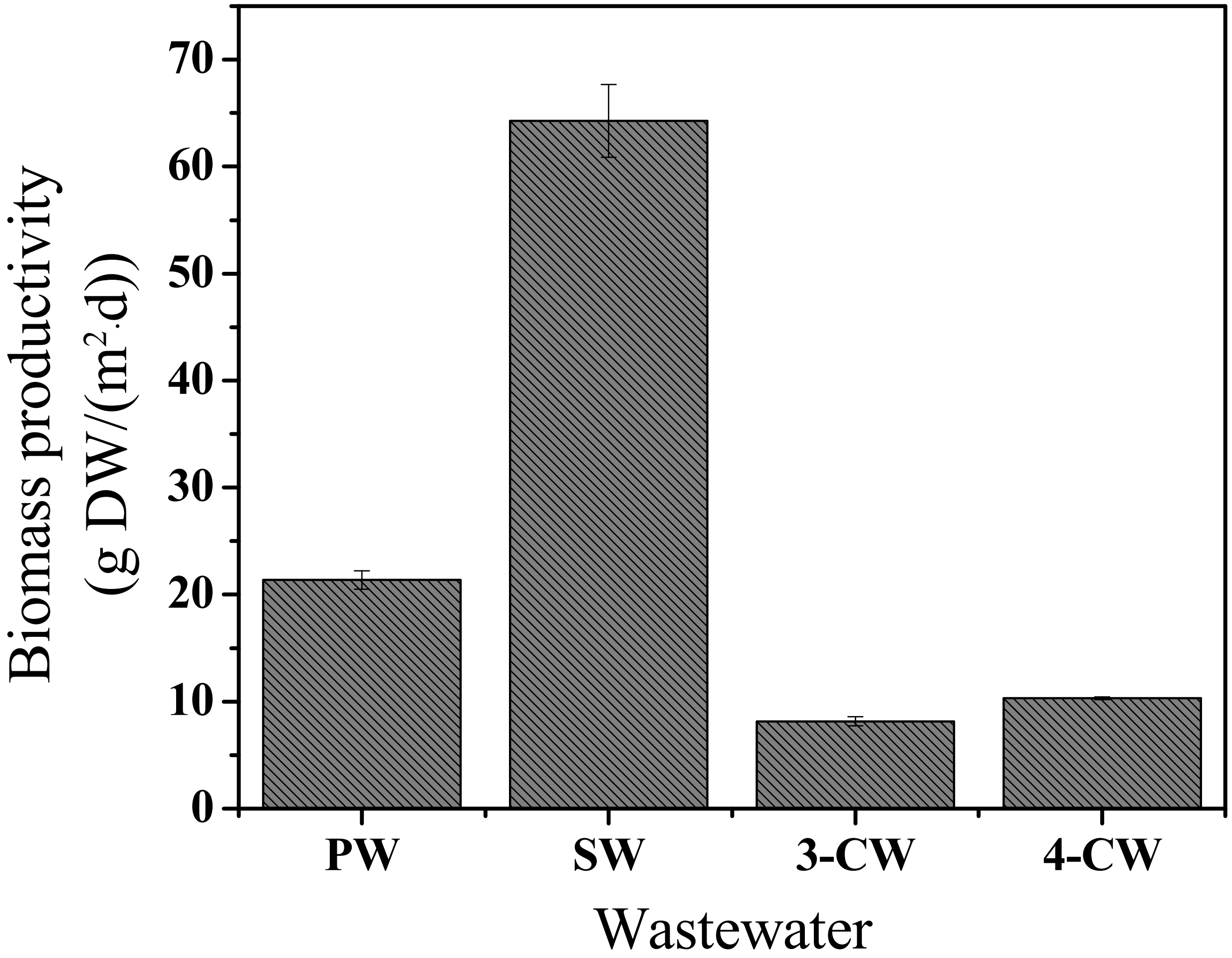
  Replicates: 5 vials (25 flies in each vial)

  Equipment: Denver Instrument SI-234 balance (accuracy 0.0001 g).

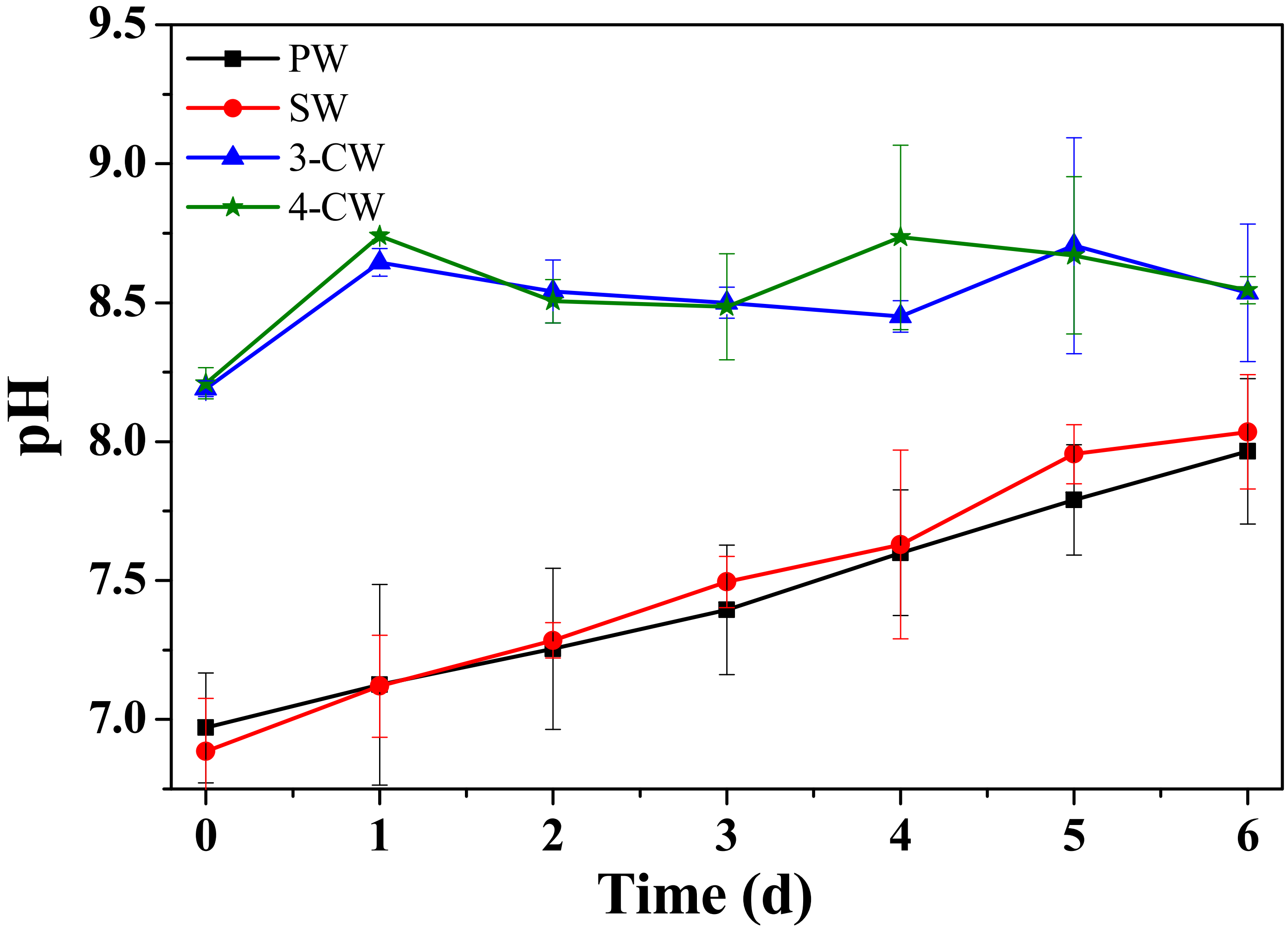
1. Fresh weights of *U. lactuca* grown on different WWs



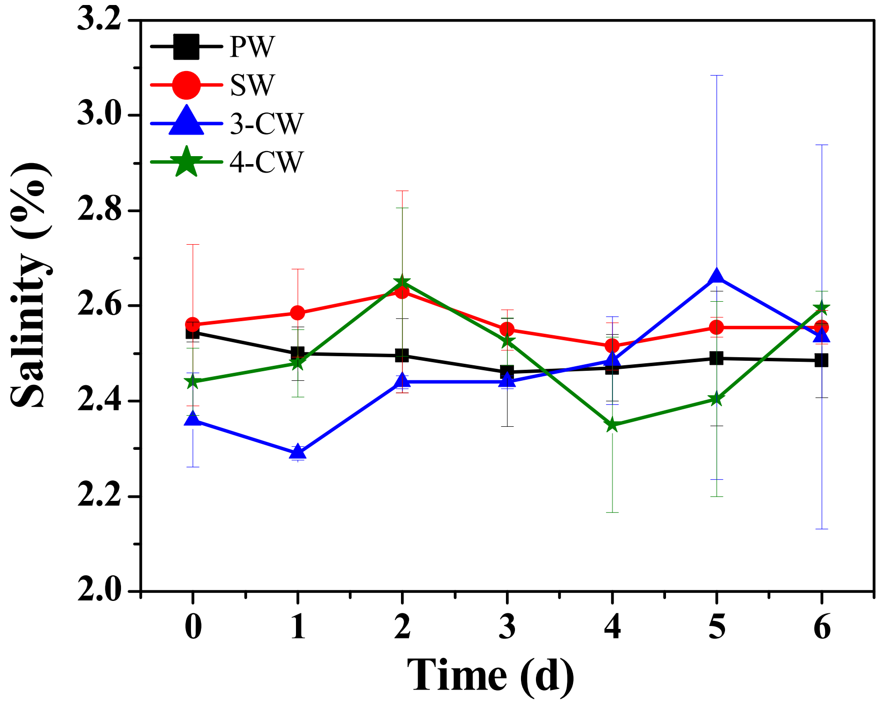
2. Biomass productivities of *U. lactuca* grown on different WWs

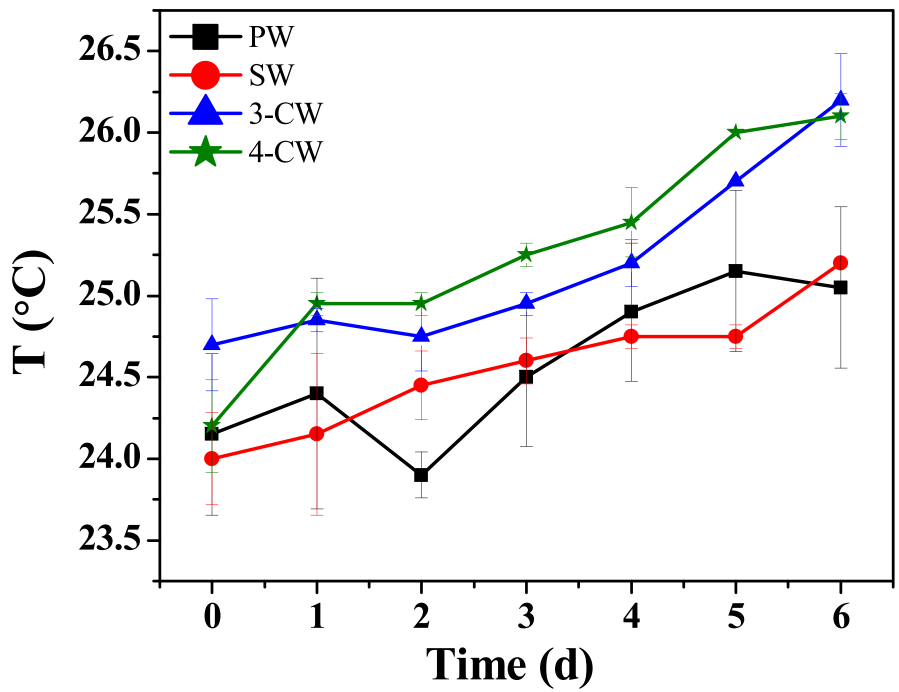


3. pH changes



4. Changes of T and salinities





5. Nutrient removal

Table 1. Nutrient removal and treatment efficiencies and removal rates in *U.lactuca* after exposure to different types of wastewaters for 12 days. The ratio of FW to DW is 3.8.

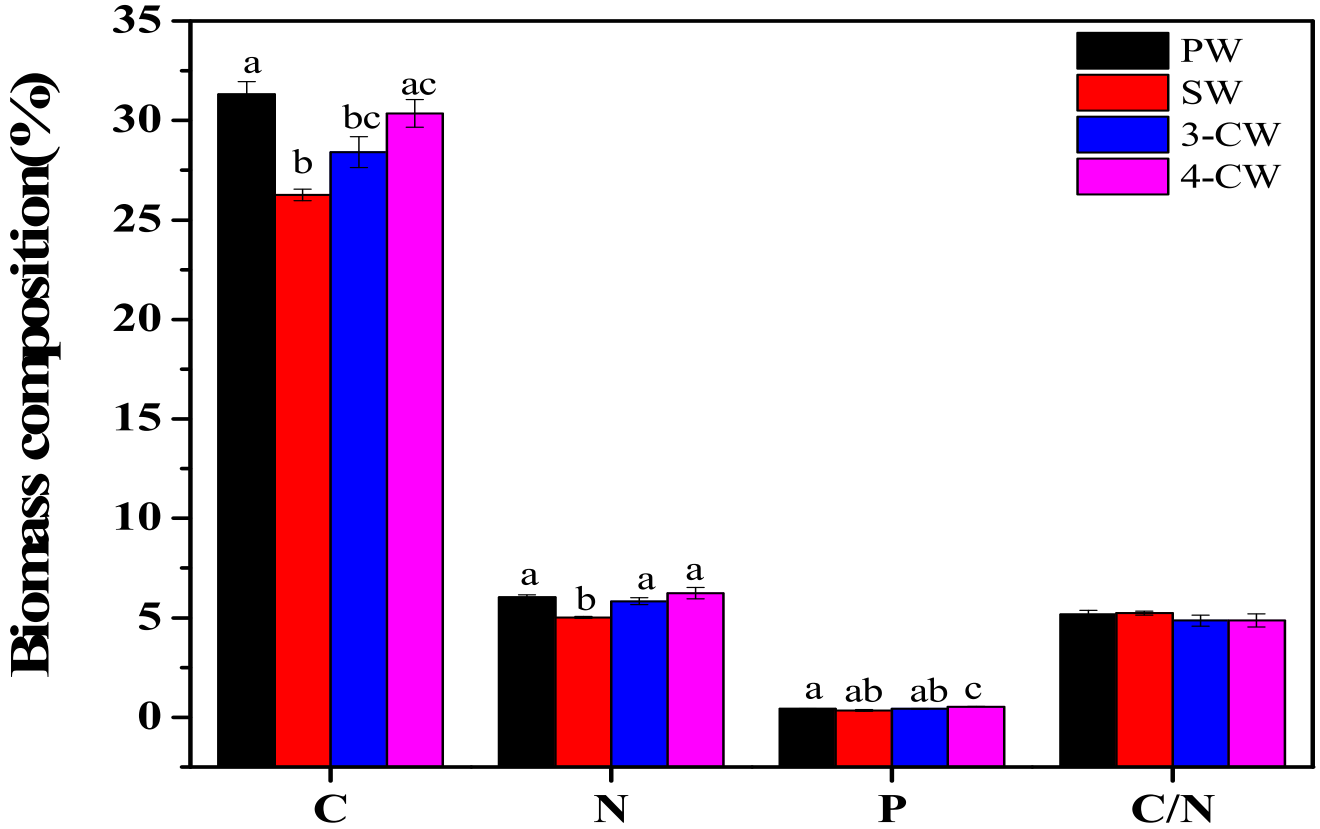
WWs	RE (%)		TE (%/d)		RR (mg/(g DW·d))	
	N	P	N	P	N	P
PW	98.7±0.6	88.6±1.2	12.3±0.1	11.1±0.2	4.51±0.05	0.44±0.01
SW	98.9±0.2	77.7±14.1	12.4±0.1	9.72±1.8	1.09±0.10	0.04±0.01
3-CW	92.5±1.7	64.5±3.9	11.6±0.2	8.07±0.5	24.7±1.0	0.69±0.01
4-CW	98.8±0.3	66.8±4.5	12.4±0.1	8.34±0.6	16.8±0.3	0.38±0.07

$$\text{RE }(\%) = \frac{C_0 - C_t}{C_0} \times 100\%$$

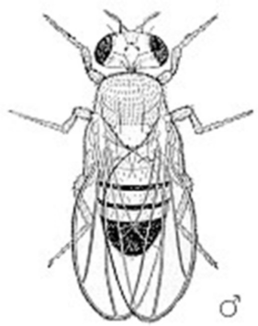
$$\text{TE }(\% \cdot d^{-1}) = \frac{C_0 - C_t}{C_0 \cdot d} \times 100\%$$

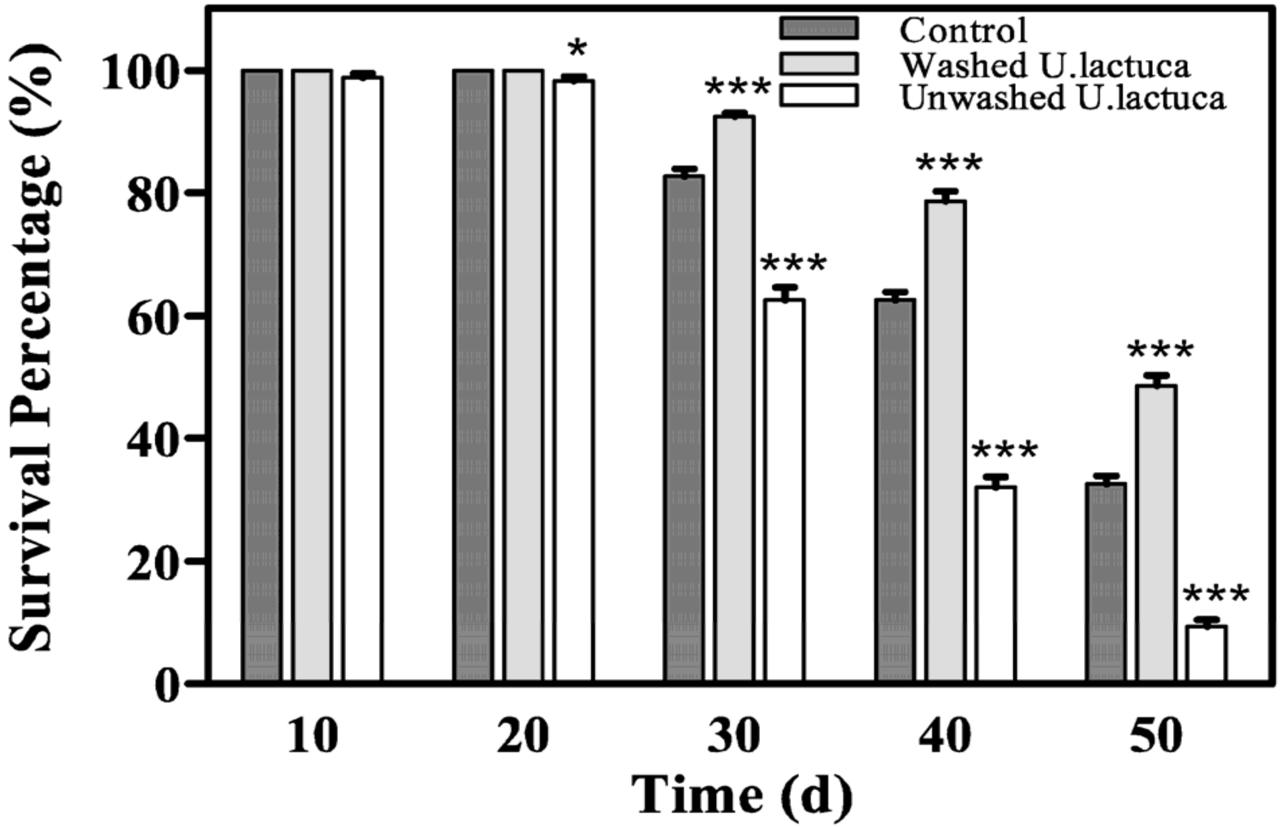
$$\text{RR }(\text{mg} \cdot \text{g}^{-1}\text{DW} \cdot d^{-1}) = \frac{C_0 - C_t}{m_t \cdot d}$$

6. Biomass composition

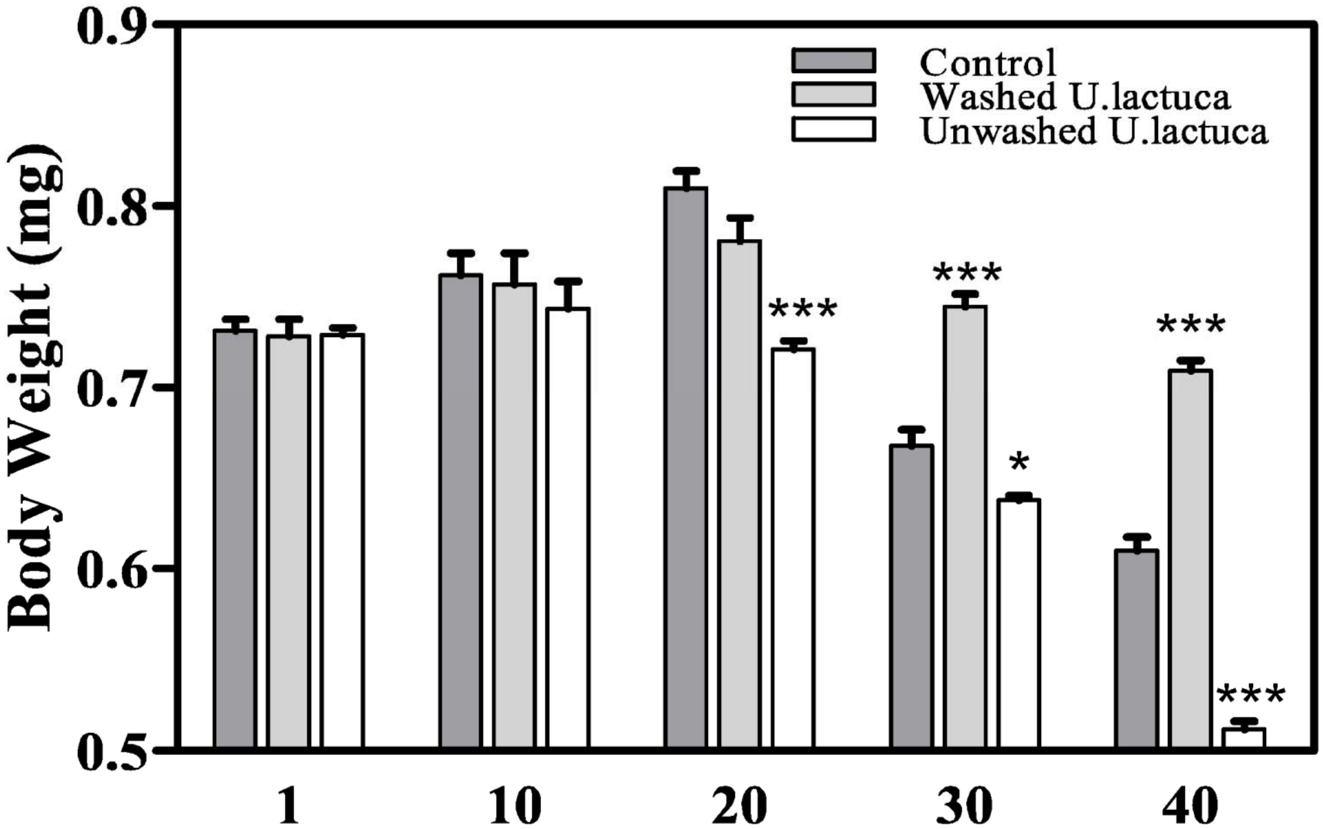


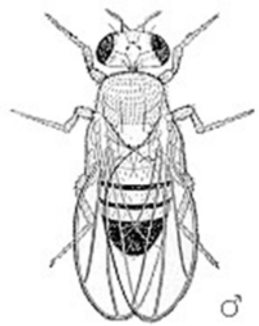
7. Fly lifespan experiment





body weight


0.9
0.8
0.7
0.6
0.5
Body Weight (mg)
Control
Washed U.lactuca
Unwashed U.lactuca
***
***
*
***
***
1
10
20
30
40


♂

Effective nitrogen and phosphorus removal was observed for *U. lactuca* cultivation in three types of municipal wastewaters.

The growth of *U. lactuca* may be an effective wastewater remediation technique with the added benefit of being a strong candidate for downstream use such as animal feed.

The survival percentages and body weights of macroalgae-treated flies indicated that washed rather than unwashed *U. lactuca* could be applied as a partial substitution of traditional fly food.

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