Life Cycle Assessment (LCA) of an Artisan Freshwater Aquaculture System Coupled to a Microalgae Pond in Colombia: Study Case

Lorena Duran Ortiz [1]*, Sebastián Muñoz Chinome [2]*, Tatiana C. Guarín C. [3]*, Alexander Meneses-Jácome [4]*

*Circular Bioeconomy Research Center (ε-BiO): Biotechnology and Environment Group. Universidad Autónoma de Bucaramanga (UNAB), Avenida 42 No. 48 – 11, Campus El Jardín, Bucaramanga, Colombia.

jduran697@unab.edu.co [1]/ smunoz65@unab.edu.co [2]/ tguarin23@unab.edu.co [3]/ ameneses2@unab.edu.co [4]

1. INTRODUCTION

This pilot project is developed at the Zapatosa's swamp, a waterbody embedded in the Magdalena´s river basin (Colombia), that is considered an ecosystem of special value for conservation. It addresses the environmental improvement of existing small and low-tech freshwater aquaculture systems in this territory by incorporating microalgae as bioremediation technology and circularity strategy. Microalgae cultivation allows nutrient recovery from fish farms effluents and reduces eutrophication. Besides, microalgae applied on-site as feed for fingerlings can replace a part of the commercial fishmeal used in the breeding process. By means a LCA approach is intended to provide a more comprehensive picture of the ecological trade-offs and co-benefits associated with this proof-of-concept and guide the continuous technological upgrade and the sustainable development of the current "artisan" fish farms.

2. METHODS

2.1 LCA STATUS & METHODOLOGICAL TRENDS IN THE FIELD OF FRESH-WATER FISHFARMING ON CLOSED-PONDS

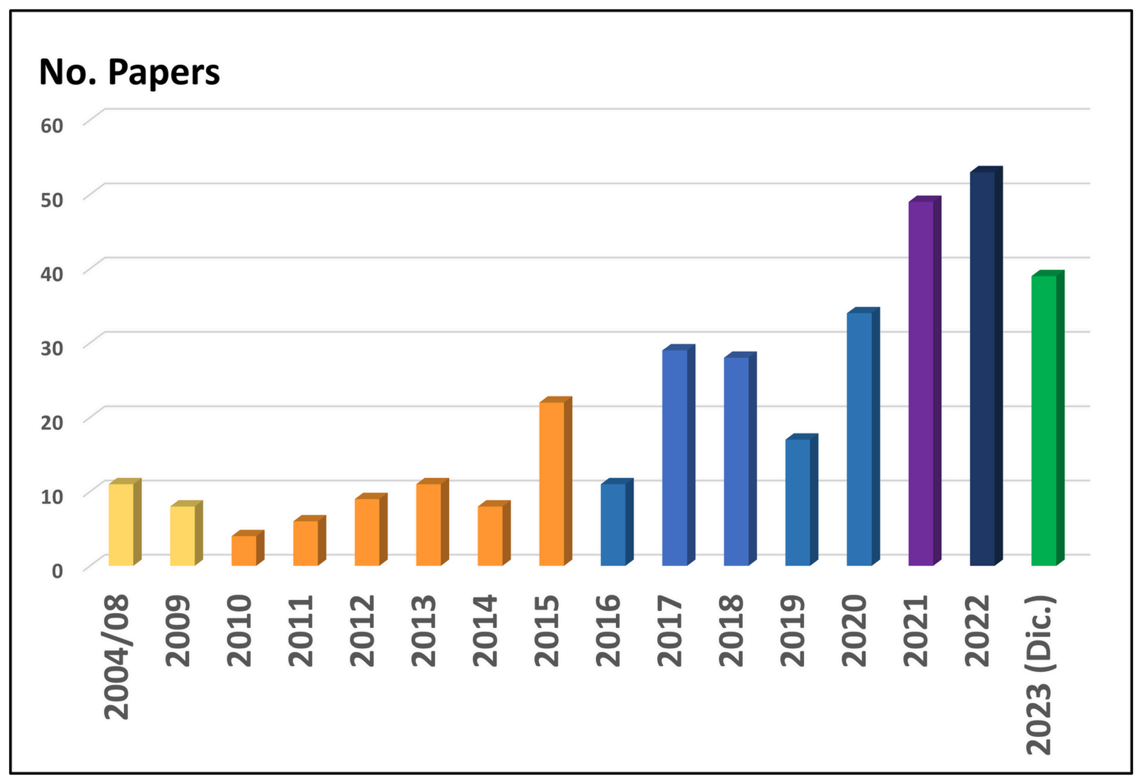


Fig. 1 Scientific publication on LCA applied to aquaculture and fish farming systems

Table 1. LCA applied to aquaculture and FISH FARMING systems integrated with MICROALGAE cultivation processes

First publication integrating Aquaculture and Microalgae	2013
No. Papers about Aquaculture + Microalgae for circular economy	24
No. Papers about Freshwater Fish Farming + Microalgae	12
No. Papers about Microalgae from circular process for feed	20

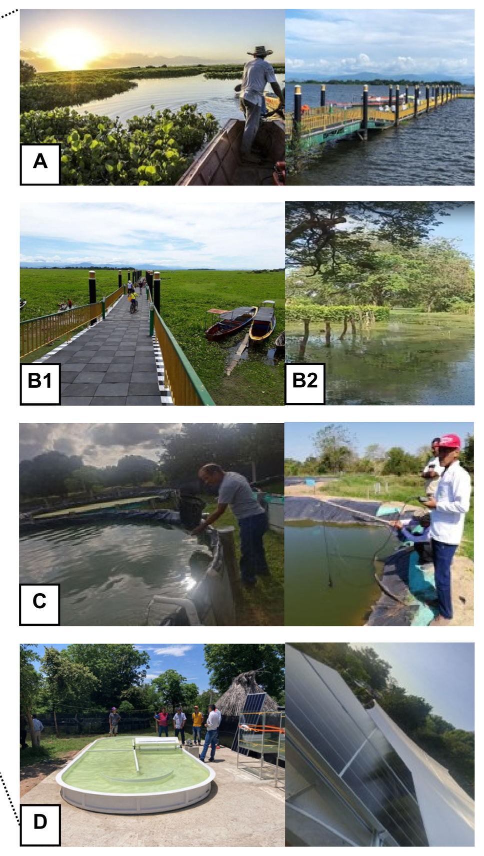
*Information from the ISI Web of Science, period 01/2004 - 12/2023 - Research equation: [TOPIC (aquaculture or pisciculture or "fish farming") AND TOPIC ("life cycle assessment" or "life cycle analysis" or LCA] – Only research papers were considered.

Author- Year	Farmed Fish Species (Scientific Name)	Country	functional unit	Mid-point environmental Impact Category (2)						Process in the system boundaries (I: Included or Not)				
				EP	GWP	AP	FWT*	WD	EnI	Feed Prod.	Transp. Insumos	Infra.	Incub	Slaughtering
(Bosma et al., 2011)	Striped catfish (Pangasianodon hypophthalmus)	Vietnam	1 ton FFEG	ReCiPe-2008	ReCiPe-2008	ReCiPe-2008	ReCiPe-2008	X	X	X	X	Not	Not	Not
(Pelletier and Tyedmers, 2010)	Indonesian tilapia (Oreochromis niloticus)	Indonesia	1 ton frozen fish	CML 2001	CML 2001	CML 2001	Not	Not	X	X	X	Not	X	X
(Avadí et al., 2015)	Red tilapia (Oreochromis spp.) black pacu (*Colossoma macropomum*)	Perú	1 ton FFEG	CML 2	CML2	CML 2	CML 2	ReCiPe-2008	X	X	X	X	X	Not
(Liu et al., 2016)	Atlantic salmon (Salmo salar)	Norway	Kg FRG	Not	IPCC	Not	Not	X	X	X	X	X	X	X
(Medeiros et al., 2017)	fish tambaqui (*Colossoma macropomum*)	Brazil		CML-IA	CML-IA	CML-IA	Not	X	X	X	X	X	X	Not
(Wilfart et al., 2013)	Carpa, tenca, rutilo, perca, lucioperca, lucio *(Common carp, tench, roach, perch, sander, and pike)*	Francia	1 ton FFEG	CML 2001	CML 2001	CML 2001	Not	Not	X	X	X	X	X	Not
(Yacout et al., 2016)	*Nile Tilapia (Oreochromis niloticus)*	Egypt	1 kg FFEG	CML 2001	CML 2001	CML 2001	Not	Not	X	X	Not	Not	X	Not
(Biermann y Geist 2019)	Carpa *(Cyprinus carpio L.)*	Alemania	1 kg FFEG	ILCD	ILCD	ILCD	ILCD	Not	Not	X	X	X	X	Not
(Bergman et al., 2020)	Nile tilapia (Oreochromis niloticus), African Clarias catfish (Clarias gar-iepinus)	Sweden	1 kg Fillet fish without skin	ILCD	IPCC 2013	Not	Not	Not	X	X	X	X	X	X
(Bohnes and Laurent, 2021)	catfish and Tilapia (generic farms)	Singapore	1 kg FFEG-Filleted	CML-IA	IPCC 2019	CML-IA	USEtox v2.0	X	X	X	X	X	X	X

Table 2. Methodological Trends in LCA Studies of Freshwater Fish Farming in Closed-Ponds Systems

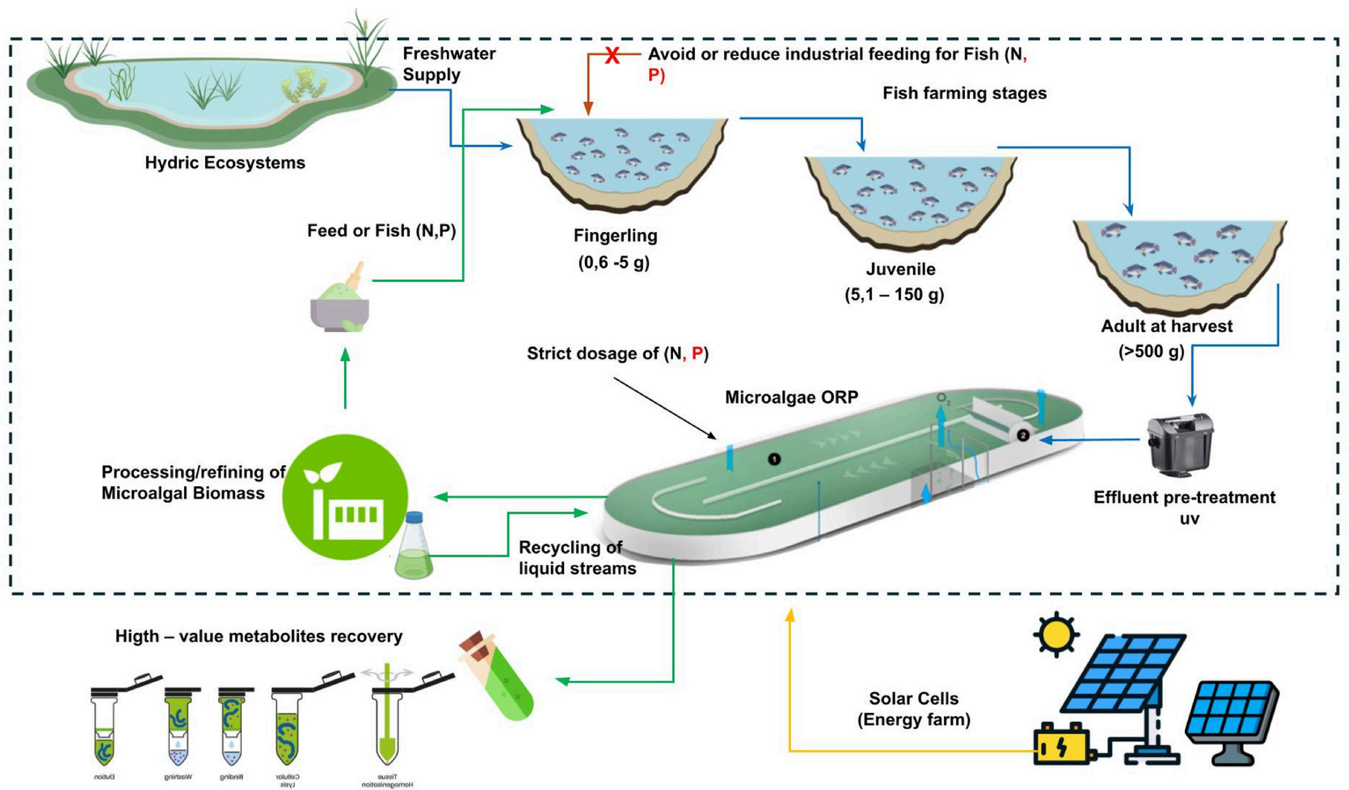
((1) Functional units (FFEG: Fish in farm exit-gate; (2) EP, eutrophication potential; AP, acidification potential; GWP, global warming potential 100 years; FWT*, Freshwater toxicity or other toxicity-related indicator; EnI: Some type or energy indicator is evaluated (eg. CED, CExD, NRE, etc.)

Context and location of the study case: "Project history"



A.Ciénaga Zapatosa. Ramsar wetland, largest freshwater wetland in the country.
B1. Tarulla (Eichhornia crassipes) limits contact with air oxygen.
B2. Crop Floods.
C. Fish farming in land ponds with geomembrane.
D. Raceway – solar panels – Sustainable fish farming

2.2 CIRCULAR BIOECONOMY APPROACH STATEMENT



3. RESULTS

- FU: 1 kg of fish in farm exit-gate. Microalgae production will be estimated on the number of batch cycles (6 – 7 weeks) of fingerlings raised during a complete processing cycle to obtain "redtilapia" adults (500 -600 g in 30 – 32 weeks).

- LCA Comparative and "Gate to gate" approach
- Scenario 1 – Business as usual (linear system without effluents treatment and without microalgae process integration VS. Scenario 2 – Circular Bioeconomy Concept)

3.1 System Boundaries

- **Fish farm:** All land-based ponds used from the fry stage to adult production.
- **Gutting and any downstream processes:** All excluded
- **National feed production:** Included by using generic data available in environmental databases.
- **Hatchery** (Excluded)
- **Transportation of:** feed, chemicals and other feedstock for the breeding process from retail distributor or international seaport (Included).
- **LCA Background:** National electrical mix.
- **Avoided functions:** Use of national electricity mix in scenario 2 by solar cells implementation.
- **CO2 capture** (Included)

3.2 Life Cicle Inventory (LCI)

- Initial fingerlings intensity: 90 - 110 fish / m3
- Final fingerlings intensity: 67 -75 fish / m3
- OPR operation: 8 m3, 30 cm depth, 85% capacity, 4 – 15 RPM in the paddlewheel, 5-12 % replacement water / week.
- Feed ratio in the fingerlings stage:
  0.2 g of commercial fishmeal/g fish.day
- Feed ratio in the aduts stage:
  5 to 6 g of commercial fishmeal/kg fish.dy
- Spriulina Yield in lab: 300 to 500 mg SST/L after 25 to 25 days.
- Water process source: underground aquifer of the swamp
- Wastewater from fingerlings stage (occasionally released)
- Wastewater from adult's stage: (10 - 25 m3 /cycle of adult fish harvesting).
- Replacement of commercial fishmeal by Spirulina biomass: 5 to 12% in the fingerlings stage.

4. CONCLUSIONS & PERSPECTIVES

- LCA of aquaculture activities (e.g. fish farming) is a topic with renewed scientific topic by the high possibility to implement circular bioeconomy strategies by means the coupling of microalgae cultivation benefiting of its nutrient-rich effluents as a growing medium
- The activities of experimental support and physicochemical characterization of the effluents fish farming process (Scenario 1) confirm the range of nutrients established previously for similar tilapia farming practices, It means: 0.5 to 1.5 kg P/100 kg of fish, with a ratio N/P of 4 to 6. The concentration of N in water from the fingerlings ponds seems to be barely upper to the expected.
- The methodological choices for the LCA application have been completed and currently the LCI data are being consolidated. The next stage correspond to the assessment of the mid-point indicators **EP, GWP, AP** and Cumulative Energy Demand.

Acknowledgement

*To the Ministry of Science, Technology and Innovation of Colombia **(MinCiencias)**, and the Federal Ministry of Education and Research of Germany **(BMBF)** for the funds awarded to the project **"CiBELESα: Circular Bio-Economy to Lead an Enhanced Strategy for Sustainable Aquaculture"** through the call: **"2020 International Bioeconomy"**. To **Yohana Castro H.** and **Emanuel Botia D.**, for supporting graphic design tasks.*

Selected References

1. *FAO, WHO et al. The State of Food Security and Nutrition in the World 2019.*
2. *Ferreira de Oliveira, A.P. and Bragotto, A.P.A. (2022). Future Foods 6, 100157.*
3. *Wilfart, A. et al. (2013). J. Environ. Management, 121, 96-109.*
4. *Taelman, S.E. et al (2013). Biores, Technol. 150, 513-522.*
5. *Tham, P.E. et al. (2023). Algal Research 74, 103186.*
6. *Cheirsilp, B. et al. (2023). Biores. Technol. 387, 129620.*

International Conference on
Algal Biomass, Biofuels & Bioproducts
10-12 June 2024| Hilton Clearwater Beach, Florida

unab

ε-BiO Centro de Investigación en Bioeconomía Circular