Sistema Multitrófico de Produção Aquícola: Eficiência e Sustentabilidade

Multitrophic Aquaculture Production System: Efficiency and Sustainability

XVII Simpósio Internacional de Aquicultura

XVII International Aquaculture Symposium

Natal, Rio Grande Del Norte, Brasil

November 21 (Thurdsday), 2024 11:00 AM -11:30 AM.

Francisco Javier Magallón Barajas

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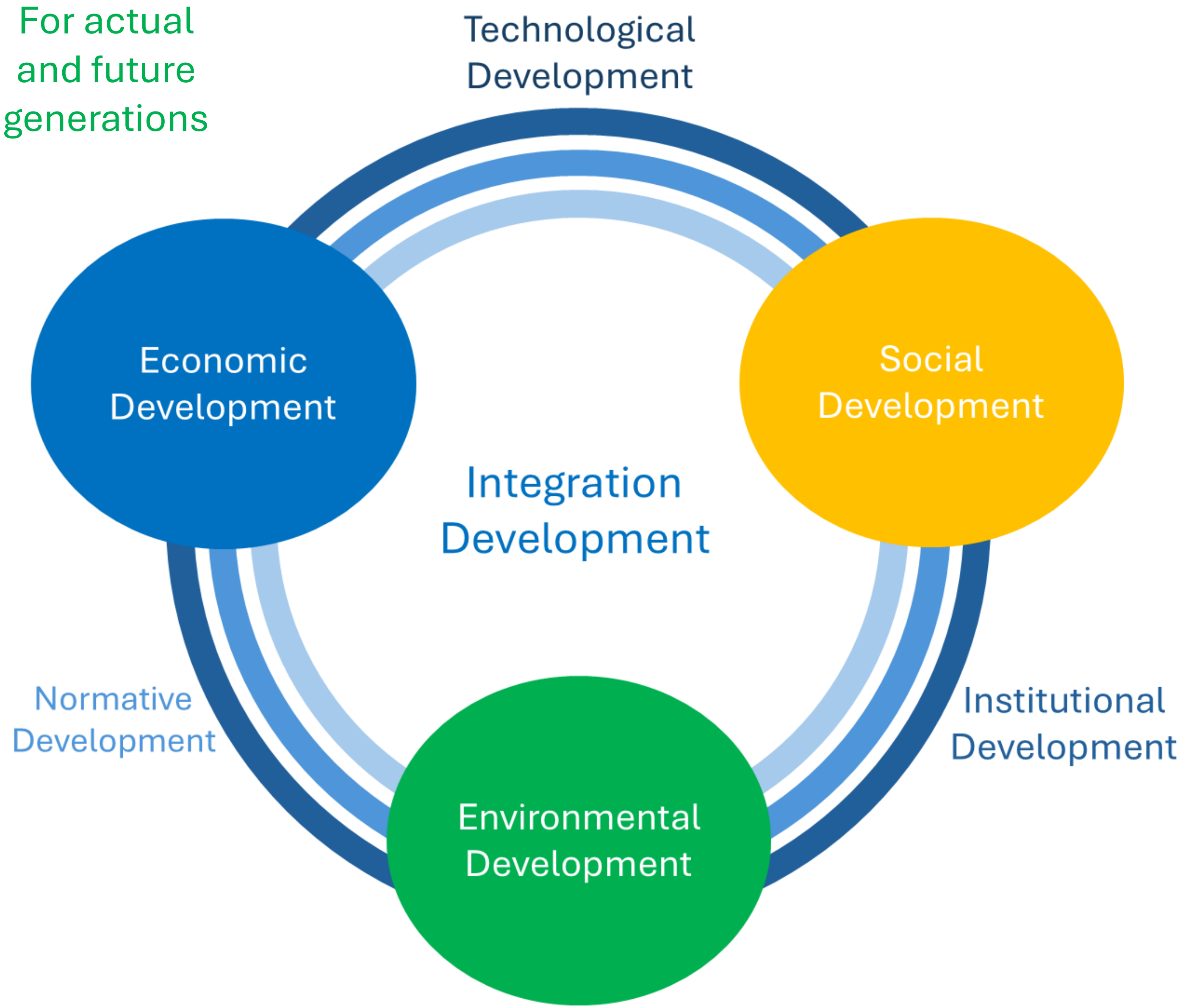
CENTRO DE INVESTIGACIONES BIOLOGICAS DEL NOROESTE, S.C.

Sustainable development harmony



(SDG: Sustainable Development Goals)

Food and Agriculture Organization of the United Nations

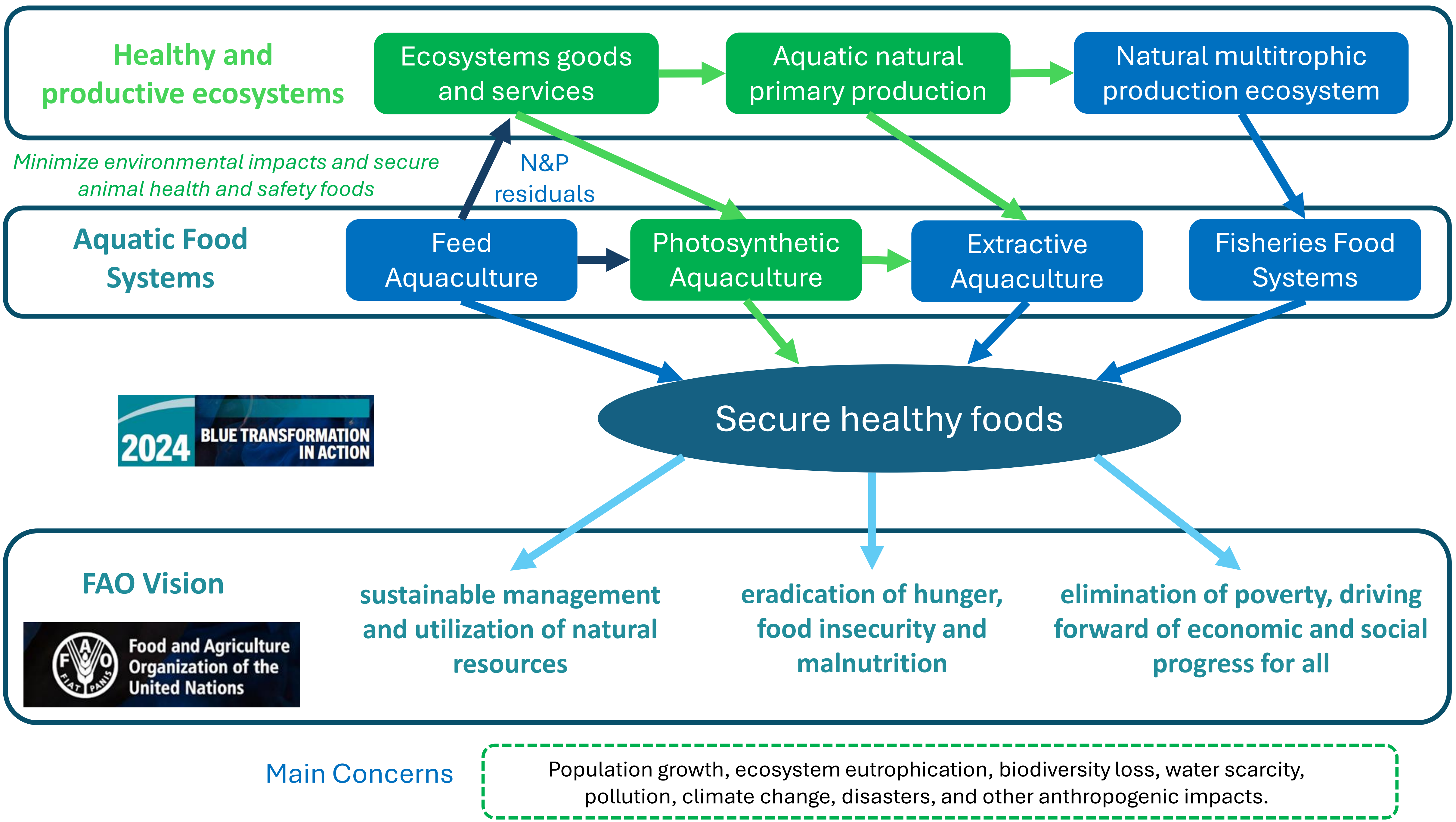
Sustainable aquaculture goals (SDG)

"at the midpoint of the 2030 Agenda, the progress on most of the SDGs is either moving much too slowly or has regressed below the 2015 baseline" (FAO 2024).

Blue transformation roadmap

"There is an urgent call to accelerate the transformational change required to address the many challenges of the 2030 Agenda (UN, 2020)" (FAO 2024).

2024 BLUE TRANSFORMATION IN ACTION



Healthy and productive ecosystems
Ecosystems goods and services
Aquatic natural primary production
Natural multitrophic production ecosystem
Minimize environmental impacts and secure animal health and safety foods
N&P residuals
Aquatic Food Systems
Feed Aquaculture
Photosynthetic Aquaculture
Extractive Aquaculture
Fisheries Food Systems
2024 BLUE TRANSFORMATION IN ACTION
Secure healthy foods
FAO Vision
Food and Agriculture Organization of the United Nations
sustainable management and utilization of natural resources
eradication of hunger, food insecurity and malnutrition
elimination of poverty, driving forward of economic and social progress for all
Main Concerns
Population growth, ecosystem eutrophication, biodiversity loss, water scarcity, pollution, climate change, disasters, and other anthropogenic impacts.

Transformation of nutrient residuals

Food and Agriculture Organization of the United Nations

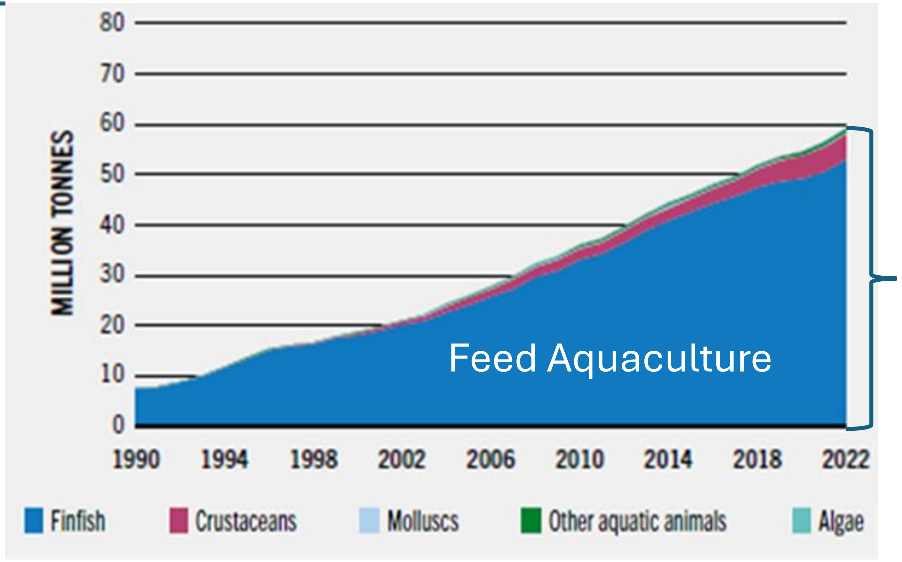
BLUE TRANSFORMATION

World Inland Fisheries	World Inland Aquaculture
11.32	59.07

91.12 Total 130.93

79.7	71.74
World Marine and Coastal Fisheries	World Marine and Coastal Aquaculture

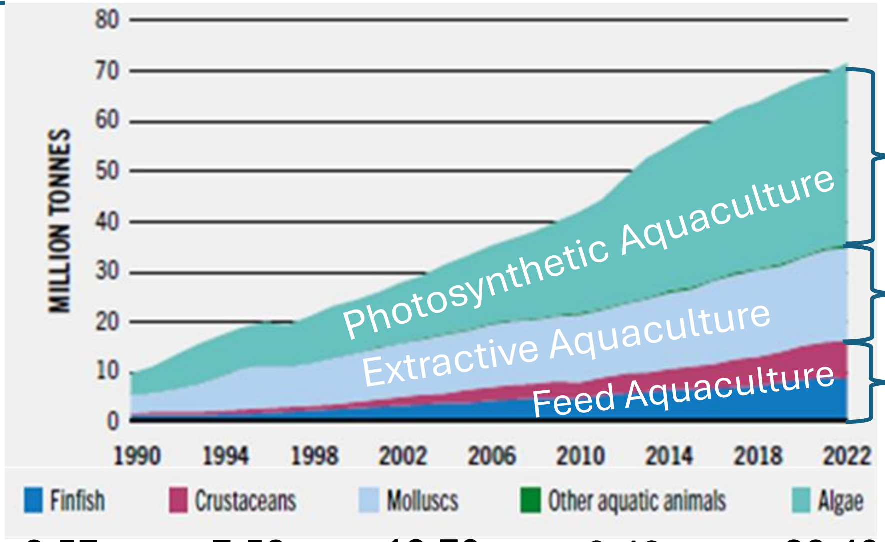
(Total (Million Tonnes)



52.99 5.16 0.20 0.70 0.10

Nutrient Residuals
N =3.570
Agriculture
P =0.687
(Million Tonnes)

Integrated Aquaculture with Agriculture



8.57 7.59 18.70 0.46 36.40

Primary Production

N =0.992
P =0.191
(Million Tonnes)

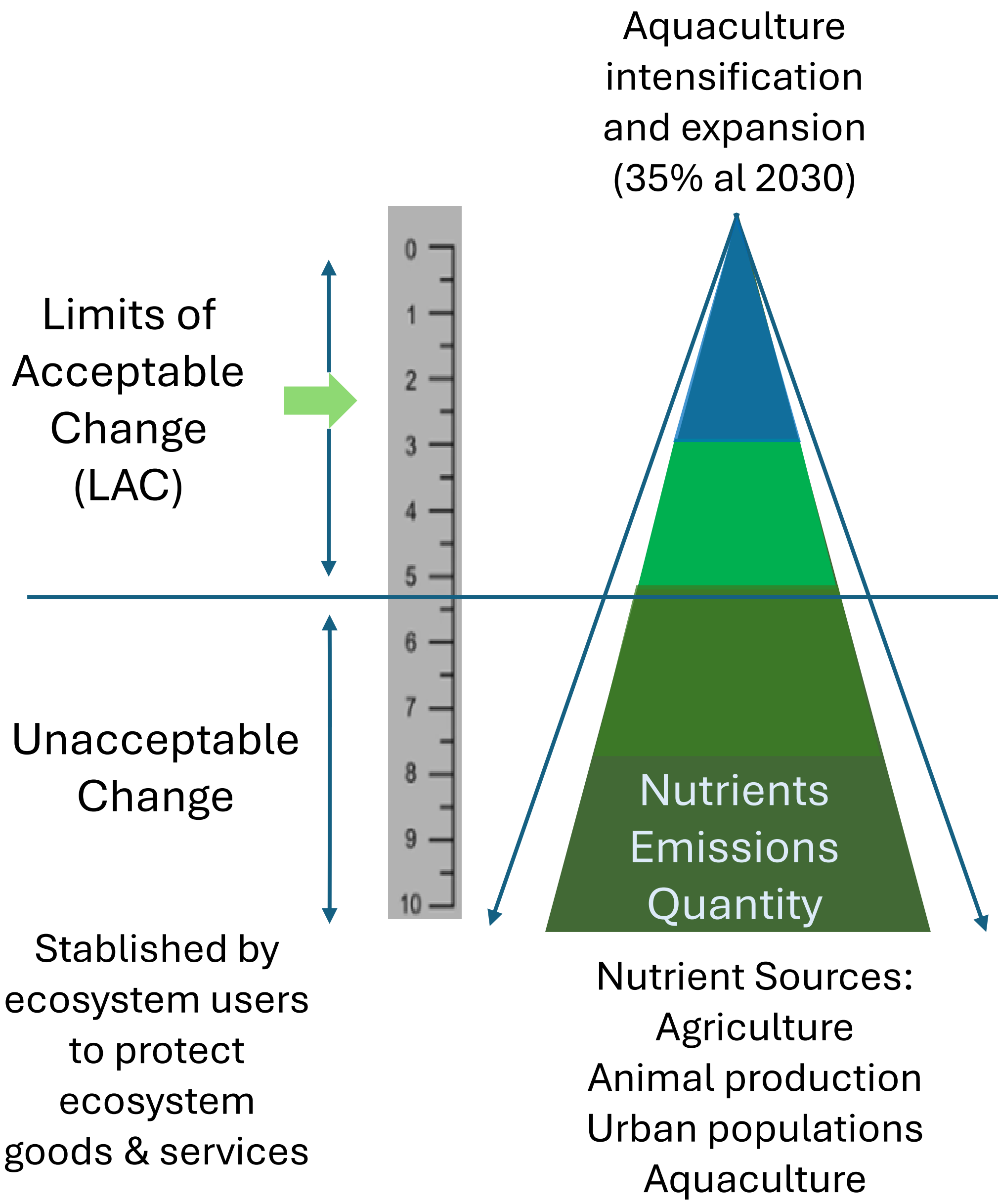
Nutrient Residuals

Integrated Multitrophic Aquaculture

2024 BLUE TRANSFORMATION IN ACTION

FAO. 2024. *The State of World Fisheries and Aquaculture 2024. Blue Transformation in action*. Rome. https://doi.org/10.4060/cd0683en

Multitrophic communities in ecosystems



- Oligotrophic ecosystems (Social and economic uses diving, touristic)
- Low level eutrophic ecosystems (Fisheries, photosynthetic aquaculture and extractive aquaculture)
- Medium level eutrophic ecosystems (Harmful algae events, biotoxins)
- Hypereutrophic ecosystems (Anaerobic process, oxygen drops, bottom soil deterioration, benthos mortality, fish migrations)

Multitrophic Aquaculture and Sustainable Development

The development of Multitrophic Aquaculture Production Systems is one of the best visions to achieve sustainability, ecoefficiency and blue transformation at same time.

Blue Transformation

The integration of feed aquaculture with the environment through the adjacent ecosystems like final depositary of aquaculture nutrient residuals can naturally follow fourth steps;

Ecoefficiency
Environmental Capacity
Carry Capacity
Multitrophic Aquaculture

1. Integration of aquaculture with adjacent ecosystem through Environmental Capacity and Carry Capacity models.
2. Integration of aquaculture with adjacent ecosystem through innovation in aquaculture systems oriented to process nutrient residuals to reduce emissions.
3. Integrated multitrophic aquaculture at ecosystem level through Environmental Capacity development.
4. Development of compartmentalized Integrated Multitrophic aquaculture through land based experimental models to achieve ecoefficiency and sustainability.

1. Integration of aquaculture with adjacent ecosystem through environmental capacity and carry capacity models.

Nutrient quantity residuals control
To
to avoid unacceptable effects on
aquatic environment trophic status
like hyper eutrophication

Healthy Fisheries Food Systems

Harmony between aquaculture development and the natural multitrophic process in adjacent ecosystems:

a) Adjusting the production levels according with Carry Capacity (CC)
b) Evaluate CC according with Environmental Capacity (EC)
c) Define EC according to Limits of Acceptable Change (LAC)
d) Define LAC to avoid unacceptable effects on aquatic environment trophic status
e) Establish trophic status by social and economic usuaries in the adjacent ecosystem
f) Stablish the inclusive institutions responsible to evaluate the trophic status, aquatic food systems and social perception from other usuaries.
g) Promote Ecoefficiency programs to reduce nutrient emissions in Aquaculture
h) Realize negotiations with other activities to reduce their nutrient emissions.

Carry Capacity is an attribute assigned to Human Activities

Environmental Capacity is an Ecosystem attribute to assimilate nutrients without unacceptable impacts

Other nutrient sources

Quote assigned to Shrimp Aquaculture for nitrogen emissions (Nitrogen tons)

Environmental Capacity to process Nitrogen (N tons)

Quotes assigned to Agriculture, Industrial and Urban Activities for Nitrogen emissions (N tons)

Carry Capacity Shrimp Aquaculture (Biomass Tons)

$$CC_{FAA} = \frac{Q_{AA}}{NE/CCU_{AA}} = \frac{EC_{Env} - Q_{AgriA} - Q_{AInd} - Q_{Aurb}}{NE/CCU_{AA}}$$

Nitrogen emissions / Carry Capacity Unit from Shrimp Aquaculture (Nitrogen Tons/ Biomass Tons)

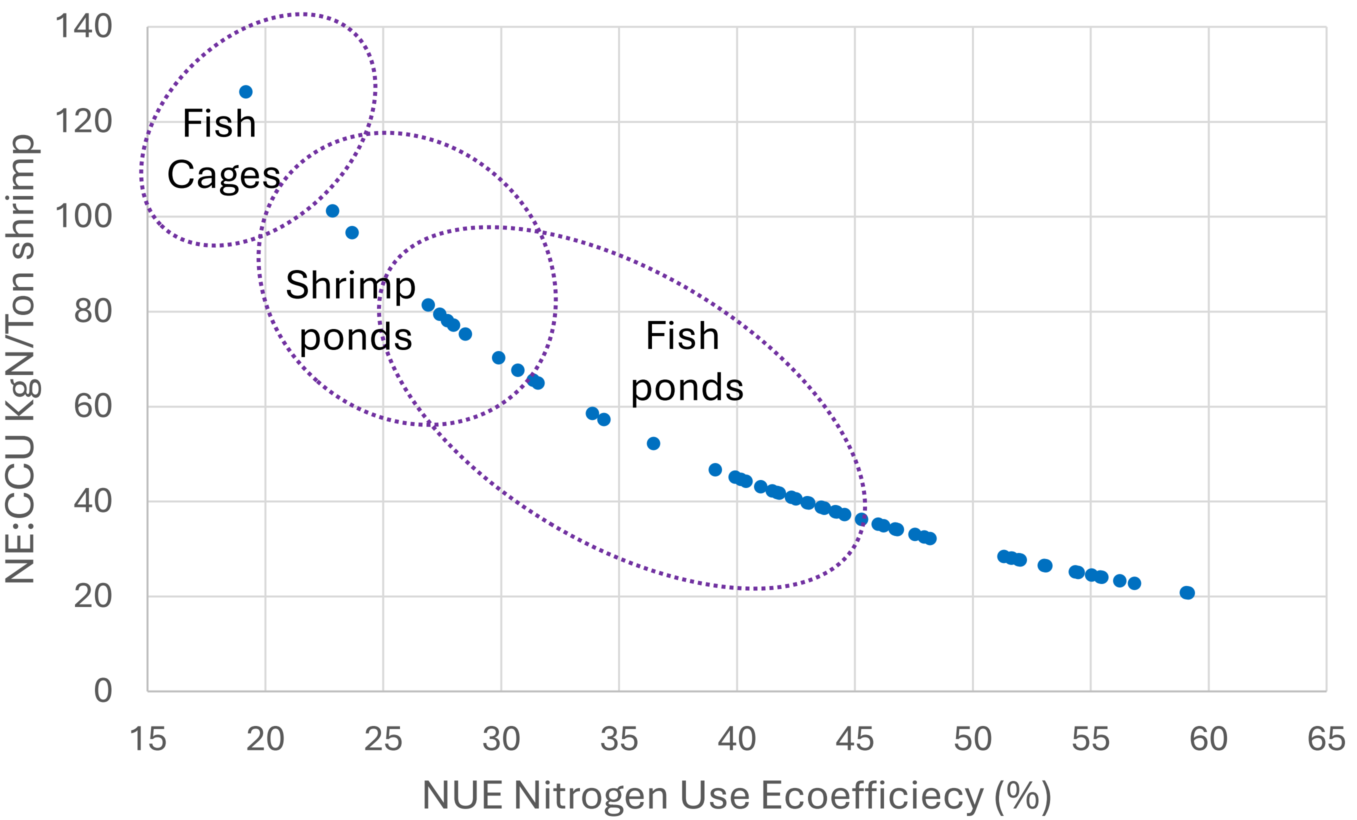
Ecoefficiency

Ecoefficiency programs to reduce nutrient emissions

Challenge

Increase the Nitrogen Use Efficiency
20-30% to > 50%

Diminish Nitrogen emissions from
65-115 to < 25 kgN/ton shrimp



Nitrogen and Phosphorous input and output in feed aquaculture residual waters

Nutrient use efficiency (NUE)

Shrimp ponds aquaculture

Retention 20-31% N, 11%P

Release 69-80% N, 89%P

(Muthuwan, 1991; Briggs and Fvnge-Smith, 1994; Jackson et al., 2003; Thakur and Lin, 2003 Casillas-Hernandez et al., 2006; Magallon 2006; Zhang et al 2015, Chen et al 2018)

Fish ponds aquaculture

Retention 25-46%N, 21.2% P

Release 73.1% N, 78.8% P

(Wang et al., 2007; Ai et al., 2007; Peres and Oliva-Teles, 2006; Zhang et al 2015; Chen et al., 2018)

Fish cages aquaculture

Retention 13.5% N, 8.7%P

Release 86.5% N, 93.3%P

Zhang et al 2015

Negotiations with other activities to reduce their nutrient emissions

	Aquaculture	Agriculture	Industry	Urban communities
China study case (TgN.year^{-1}) Lou *et al*., 2018	1.22 Nitrogen	10.92 Nitrogen	2.34 Nitrogen	1.84 Nitrogen
México study case %) (Several ecosystems) (Páez-Osuna *et al*., 1999)	1.7% Nitrogen 3.1% Phosphorous	54.9% Nitrogen 57.7% Phosphorous		3.6% Nitrogen 4.1% Phosphorous
México study case % (Northwest) (Magallón, 2006)	2-22% Nitrogen 2-7% Phosphorous	78-98% Nitrogen 93-98% Phosphorous		
	Ecoefficiency Integrated Multitrophic Systems	Integrated Nutrient Management Pesticides control	Contaminants control	Upgrade Urban Residual Waters plans

2. Integration of aquaculture with adjacent ecosystem through innovation in aquaculture systems oriented to reduce emissions and increase nutrient quality residuals.

Nutrient quantity residuals control
and improve nutrient quality
to
Avoid Hyper eutrophication
by innovations in intensive
aquaculture

Healthy Fisheries Food Systems

Process nutrient residuals, control of solids, oxidation of nitrogen compounds and solubilization of phosphates like Aquaculture Recirculation Systems models to release friendly residuals to adjacent ecosystems.

Nutrients Emissions Quality

- Organic nitrogen residuals (ON) → Inorganic residuals (NID),
- Reduced Nitrogen residuals (NH_4^+) → Oxidizing Nitrogen Residuals residuals (NO_3)
- Precipitated phosphates residuals → Soluble phosphates residuals (PO_4)
- Carbon compounds residuals; Organic Carbon → Inorganic carbon (CO_2)

Residual nutrient quality in feed aquaculture residual waters

Shrimp Feed aquaculture

	Nutrient use efficiency NUE	Organic Nitrogen (ON): Particulate PON	Organic Nitrogen (ON): Dissolved DON	Dissolved Inorganic Nitrogen (DIN): NH_4^+	Dissolved Inorganic Nitrogen (DIN): NO_2^-	Dissolved Inorganic Nitrogen (DIN): NO_3^-
Water Exchange System	23.58%	25.3%	5.21%	21.32%	15.30%	2.91%
Recirculated Aquaculture System	19.10%	39.46%	4.16%	3.85%	4.33%	25.97%

(Chen *et al*., 2018)

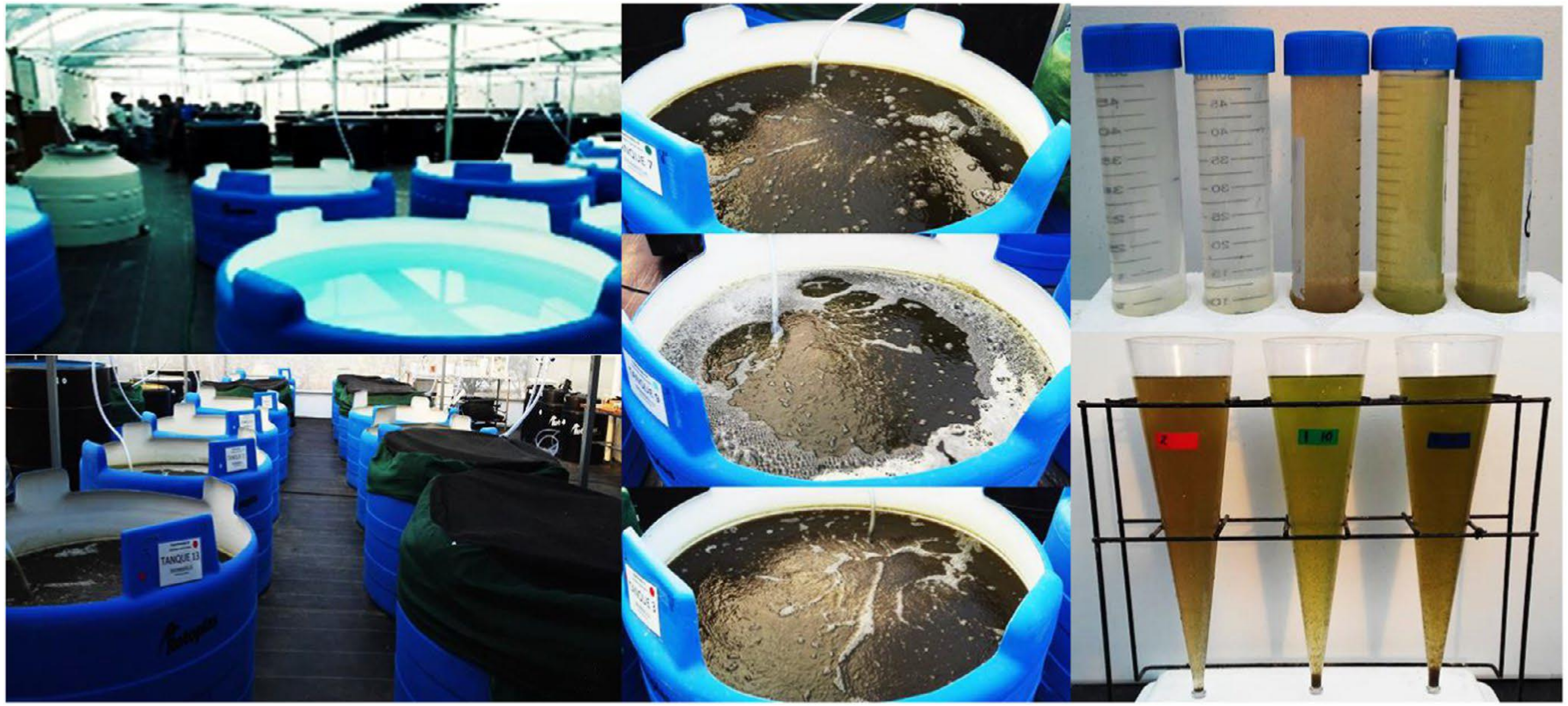
Extractive Aquaculture (PON)
Filter mollusks
Herbivorous Mollusks
Benthonic Omnivorous

Bio toxigenic agents (DON)
Dinoflagellates
Cyanobacteria
Vibrio

Photosynthetic Aquaculture (DIN)
Microalgae
Macroalgae

Biofloc Technology

Transformation of ammonia and Organic Nitrogen to Nitrates (NO_3^-)



Yield 19-23 kg/m^3, Average size 445-520 g, 5 months

(Fimbres Acedo *et al.*, 2020)

Final organic nutrient residuals

100 mL/L biofloc (Imhoff cone)
Biofloc content

25-42% Protein
31-42% NFE
17.8-25.2% Ash
2-12.5% Crude fiber
1-1.1% Lipids

Most micronutrients were incorporated to biofloc biomass

Final soluble nutrients concentration

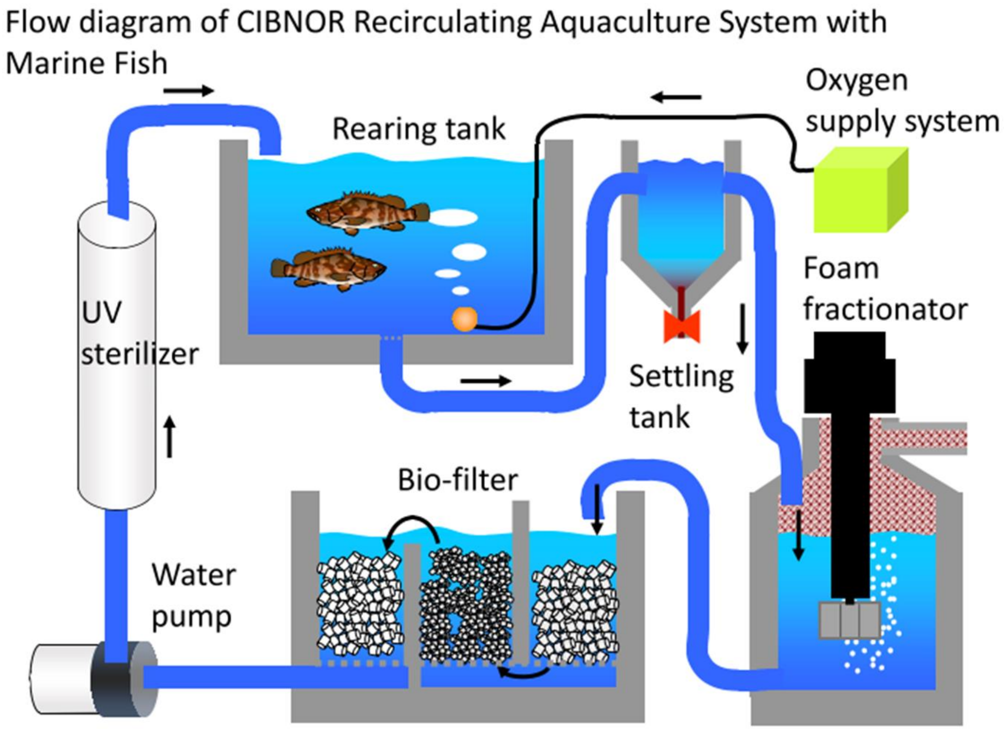
150 mg/L NO_3^-, 20 mg/L PO_4, <2 mg/L NO_2^-, 100 mg/L NH_3^+

Very low content of micronutrients in residual water

Recirculated Aquaculture Systems (RAS)

Retention of particulate organic nutrients in settling tanks

Transformation of ammonia and nitrites to Nitrates (NO_3^-) in Biofilters



Final residual nutrients concentration

125 mg/L NO_3^-, 20 mg/L PO_4, <1 mg/L NO_2^-, 20 mg/L NH_3^+

Yield 56-74 kg/m^3, Average size 627-829 g, 5 months

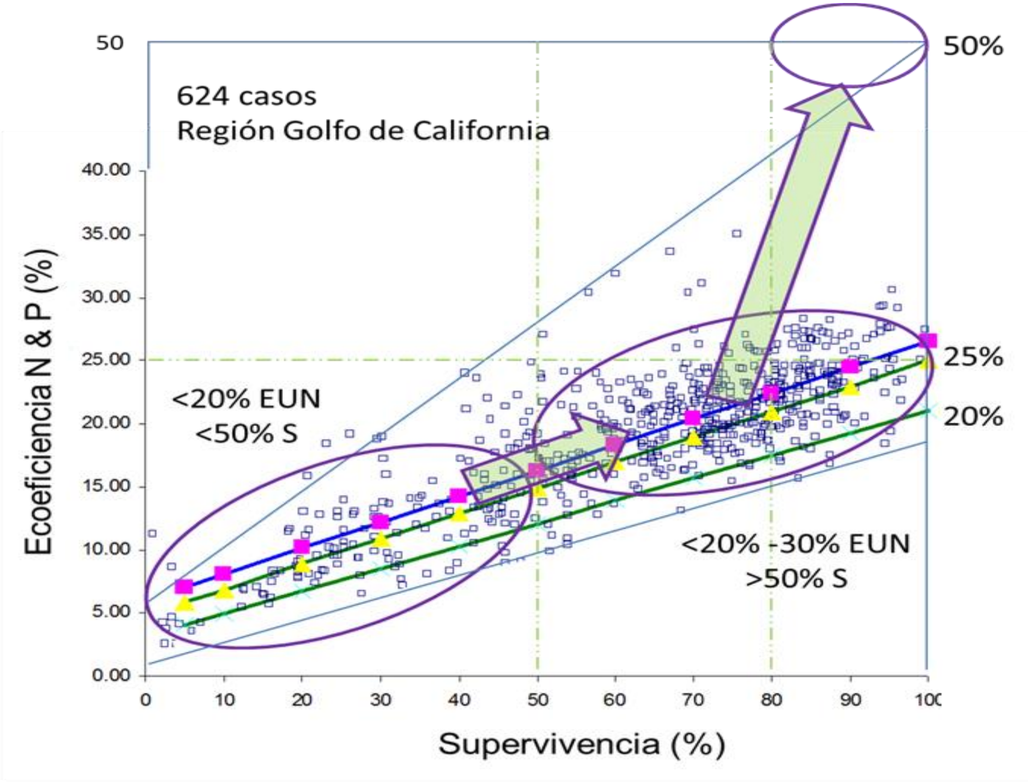
Oreochromis niloticus gift

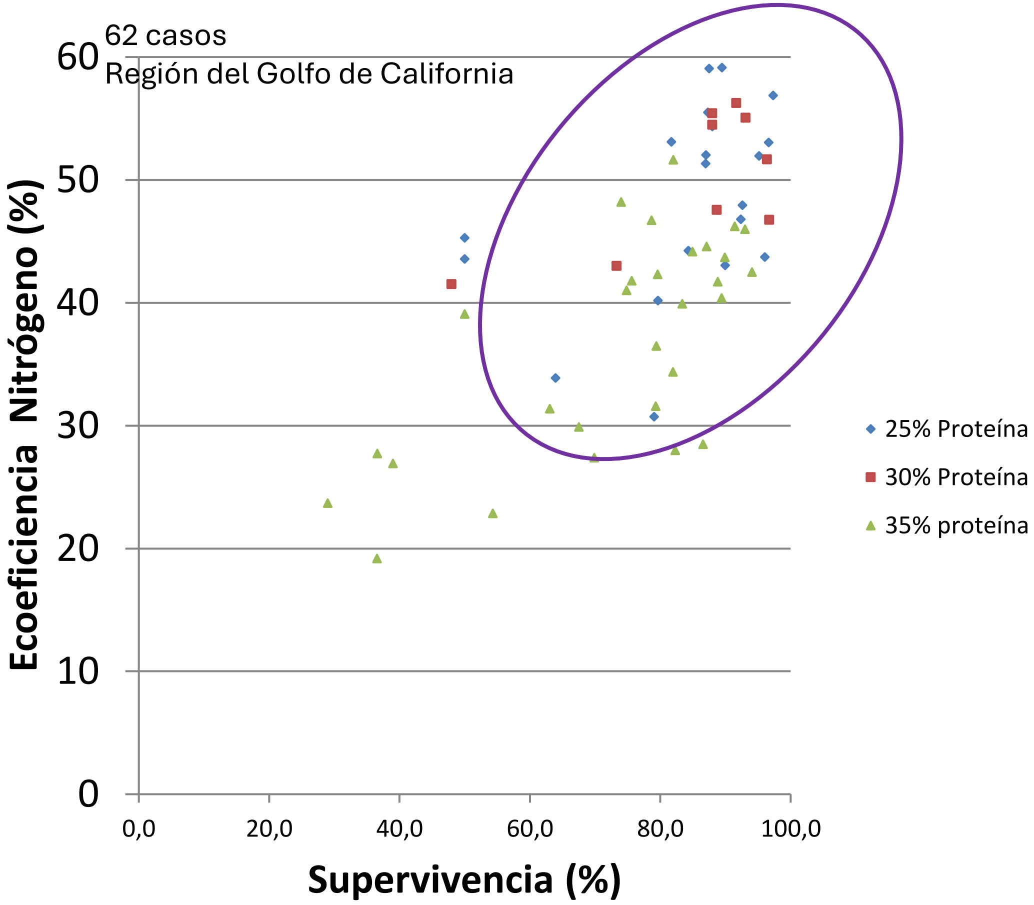
Shrimp hyper intensive system

31 Tons/ha
15g
90 days

Organic carbon and nutrient residual transformation in biofloc biomass, nitrates and phosphates

Shrimp hyper intensive systems improve ecoefficiency





Semi intensive Shrimp Aquaculture

Hyper Intensive Shrimp Aquaculture

Average Yields 0.08Kg/m2 = 0.8 Ton/ha

Average Yields 3.1 Kg/m2 = 31 Ton/ha

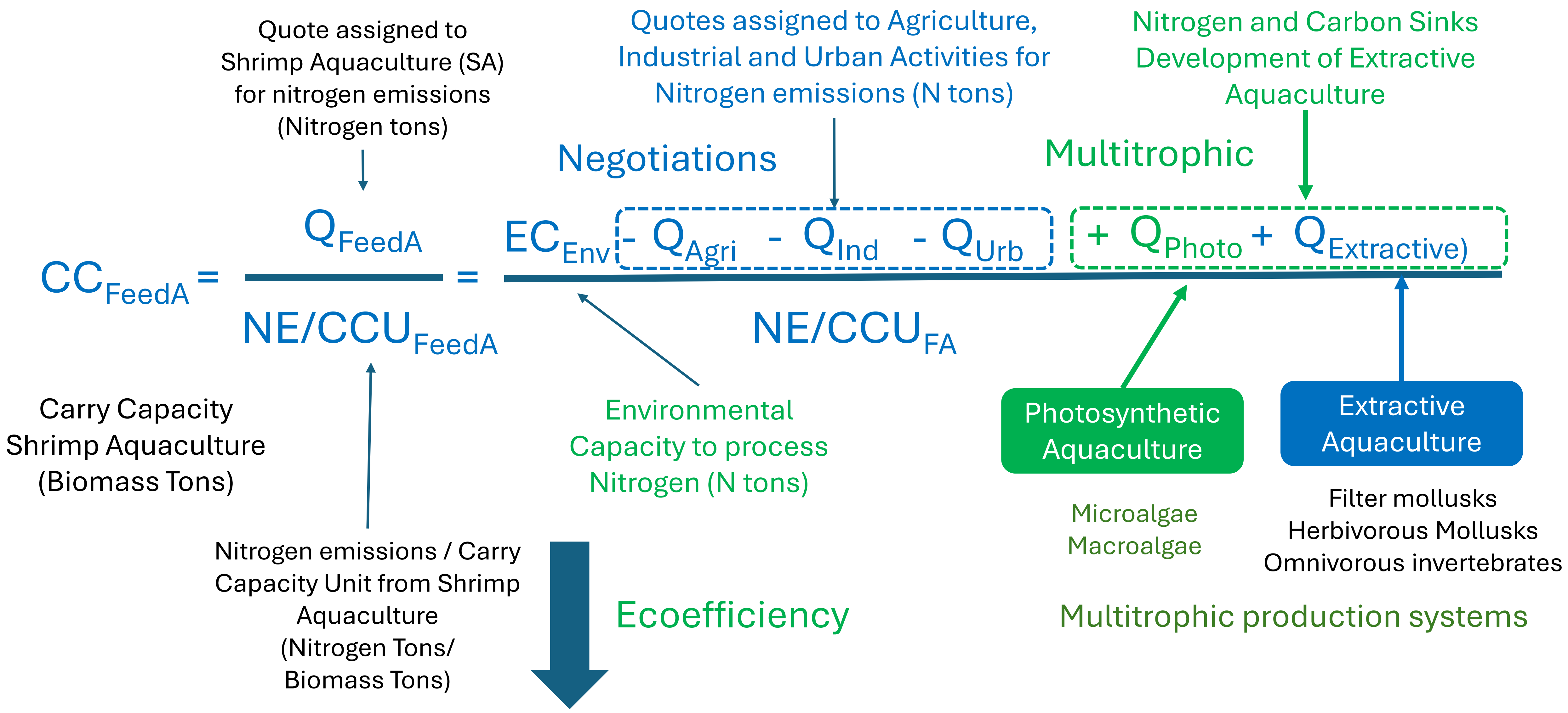
3. Integrated multitrophic aquaculture at ecosystem level through environmental capacity development.

Photosynthetic Aquaculture and Extractive Aquaculture development in ecosystems

Integrated multitrophic aquaculture (IMTA) involves farming two or more aquatic species from different trophic levels together to improve efficiency, to reduce wastes and to provide ecosystem services, such as bioremediation.

Herbivorous and omnivorous which extract organic matter by filter feeding	Extractive Aquaculture	Bivalve Mollusks
Photosynthetic species, which extract inorganic nutrients	Photosynthetic Aquaculture	Microalgae Macroalgae
Seabed-dwelling detritivores which extract organic matter	Extractive Aquaculture	Cucumbers Sea urchins Sea worms

Development of Environmental Capacity by Photosynthetic and Extractive Aquaculture at Ecosystem level



The development of Integrated Multitrophic Systems in China is mainly located on ecosystems in inshore coastal regions along the entire coastline of China.

The bioremediation capacity of Integrated Multitrophic Systems in China contribute to reduce the impacts of land-based nutrient runoff into coastal waters.

Large-scale Photosynthetic Aquaculture based on seaweeds, reduced nitrogen levels, controlled phytoplankton blooms and limited the frequency of toxic algal blooms (Xiao *et al.*, 2017).

The development of Extractive Aquaculture is needed to mitigate coastal eutrophication (Wilberg *et al.*, 2011)

It is estimated that 7 kg to 13 kg of seaweed would be needed to remove the wastes for each 1 kg of salmon produced, which would require large-scale seaweed production and refining (Schuitemaker, 2017).

3. Integrated multitrophic aquaculture at ecosystem level through environmental capacity development.

FAO. 2022. *Integrated multitrophic aquaculture: lessons from China.* Bangkok.

Photosynthetic Aquaculture

Nitrogen
Phosphorous
Carbon
Recovery

Farmers produce 1 500 tons of seaweed per square kilometer which remove an estimated:
40 tons of nitrogen,
5 tons of phosphorus and
500 ton of carbon
respectively from the coastal ecosystem (Fang et al., 2015).

Different IMTA systems practiced in China

1. Kelp, abalone, (*Gracilaria* spp), sea cucumbers
2. Kelp, abalone, (*Gracilaria* spp), sea cucumbers and clams
3. Kelp, abalone (*Haliotis* spp.), sea cucumber (*Holothuria* spp.)
4. Kelp, abalone and sea cucumber in lantern nets alongside the kelp longlines.
5. Kelp and oysters in a polyculture approach

(Dong *et al*. (2013)

Sea cucumbers clean sediment and benthic matter reducing the environmental impact of aquaculture(Fletcher, 2021).

6. Seaweeds and fish cages

Farming of kelp (*Saccharina japonica*), *Gracilaria lemaneiformis* fish cages (*Lateolabrax japonicus*), *Gracilaria* spp. on longlines and Pacific oysters in lantern nets.

Multitrophic Aquaculture systems must be combined with the control of nutrient emissions from other sources like; agriculture, industrial and urban areas.

4. Development of compartmentalized integrated multitrophic aquaculture through experimental models to achieve ecoefficiency and sustainability.

Land based of Integrated Multitrophic Aquaculture Systems and Integrated Aquaculture and Agriculture Systems

Land based of Integrated Multitrophic Aquaculture Systems and Integrated Aquaculture and Agriculture Systems

Feed Aquaculture

Fishes
Shrimps

Photosynthetic Aquaculture

Microalgae
Macroalgae

Extractive Aquaculture

Filter mollusks
Herbivorous Mollusks
Omnivorous

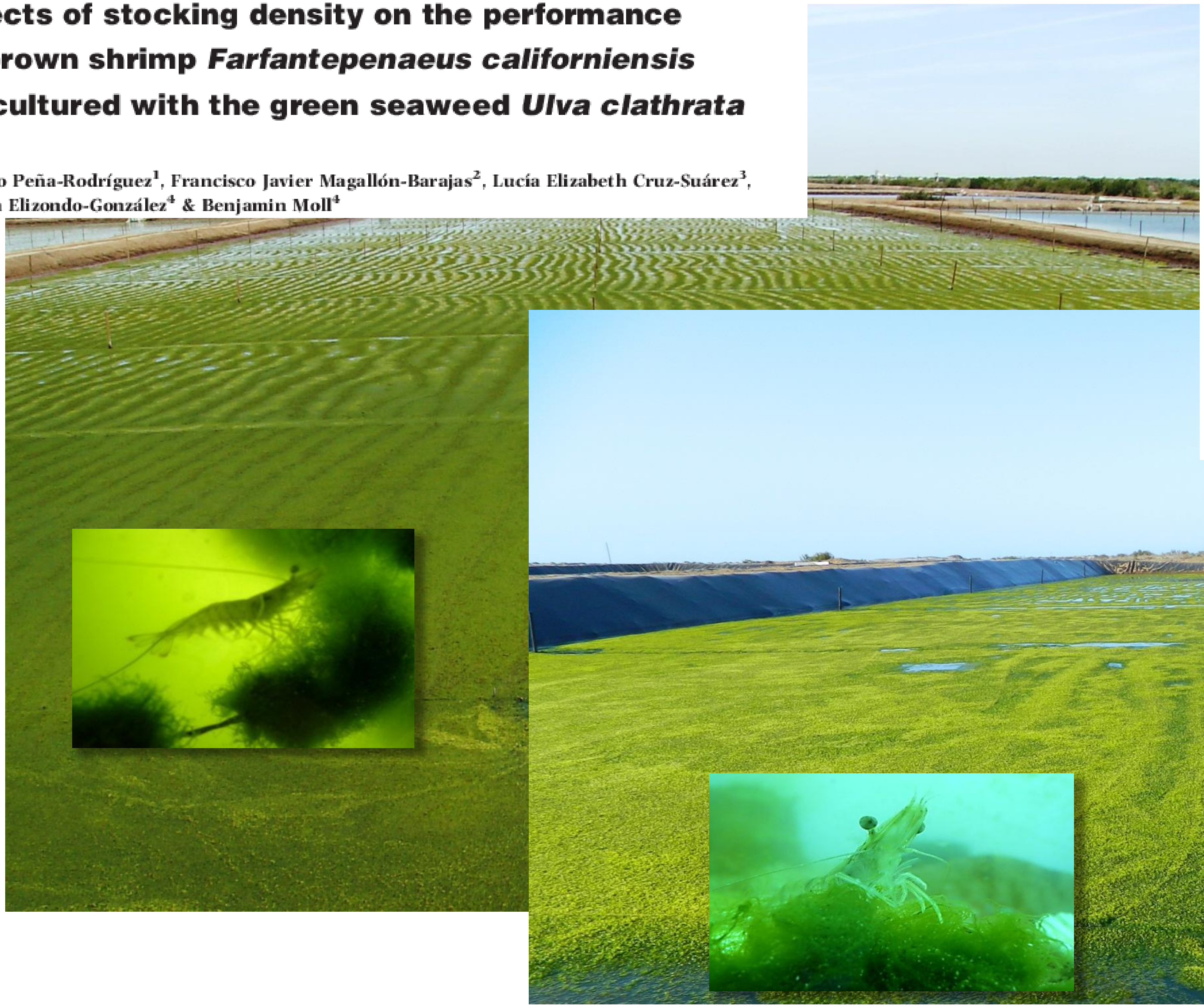
Aquaculture Research

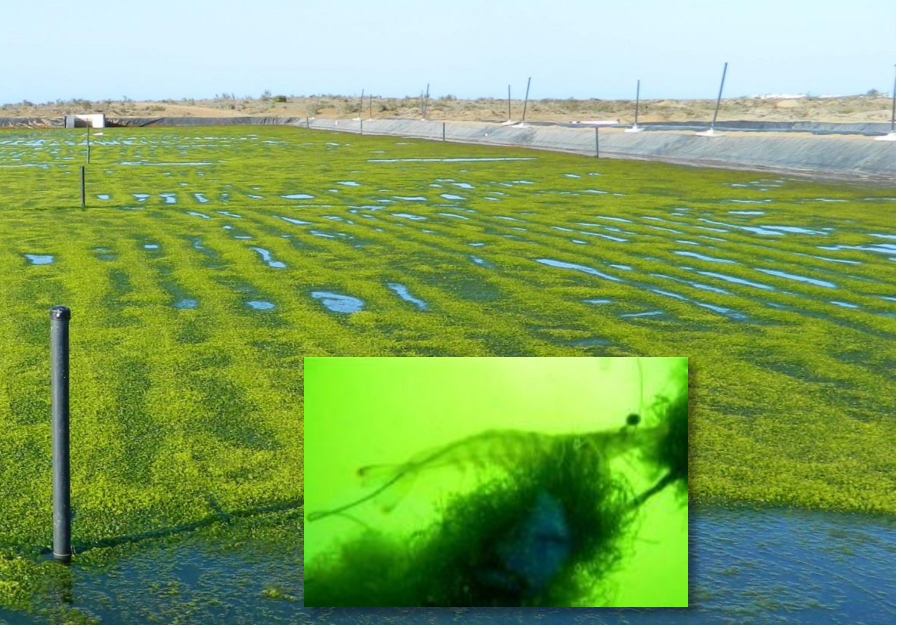
Aquaculture Research, 2017, 48, 2803–2811 doi: 10.1111/are.13114

Effects of stocking density on the performance of brown shrimp *Farfantepenaeus californiensis* co-cultured with the green seaweed *Ulva clathrata*

Alberto Peña-Rodríguez[1], Francisco Javier Magallón-Barajas[2], Lucía Elizabeth Cruz-Suárez[3], Regina Elizondo-González[4] & Benjamin Moll[4]

Photosynthetic Aquaculture





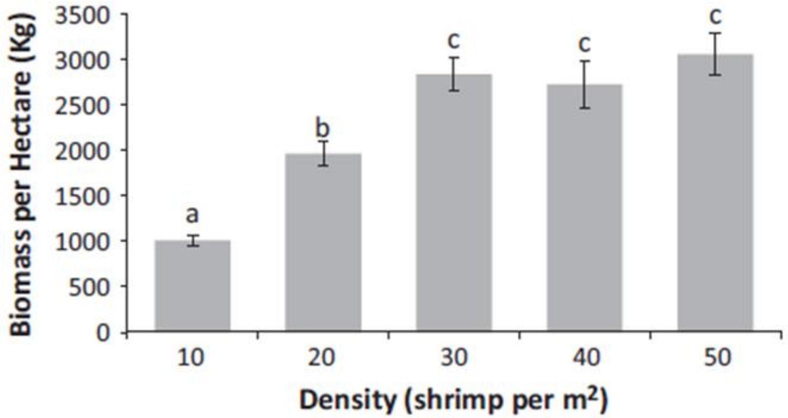


Figure 1 Estimated biomass production (kg ha^{-1}) of brown shrimp *Farfantepenaeus californiensis* co-cultured at different stocking densities with seaweed *Ulva clathrata* during 18 weeks of experimental trial.

Gobierno del Estado de Baja California Sur

Asociación de productores Acuícolas de Municipio de Comondú, Baja California Sur A. C.

SADER
SECRETARÍA DE AGRICULTURA Y DESARROLLO RURAL

Programa Social
Sembrando Vida en el Mar

Proyecto piloto

Extractive Aquaculture

UABCS

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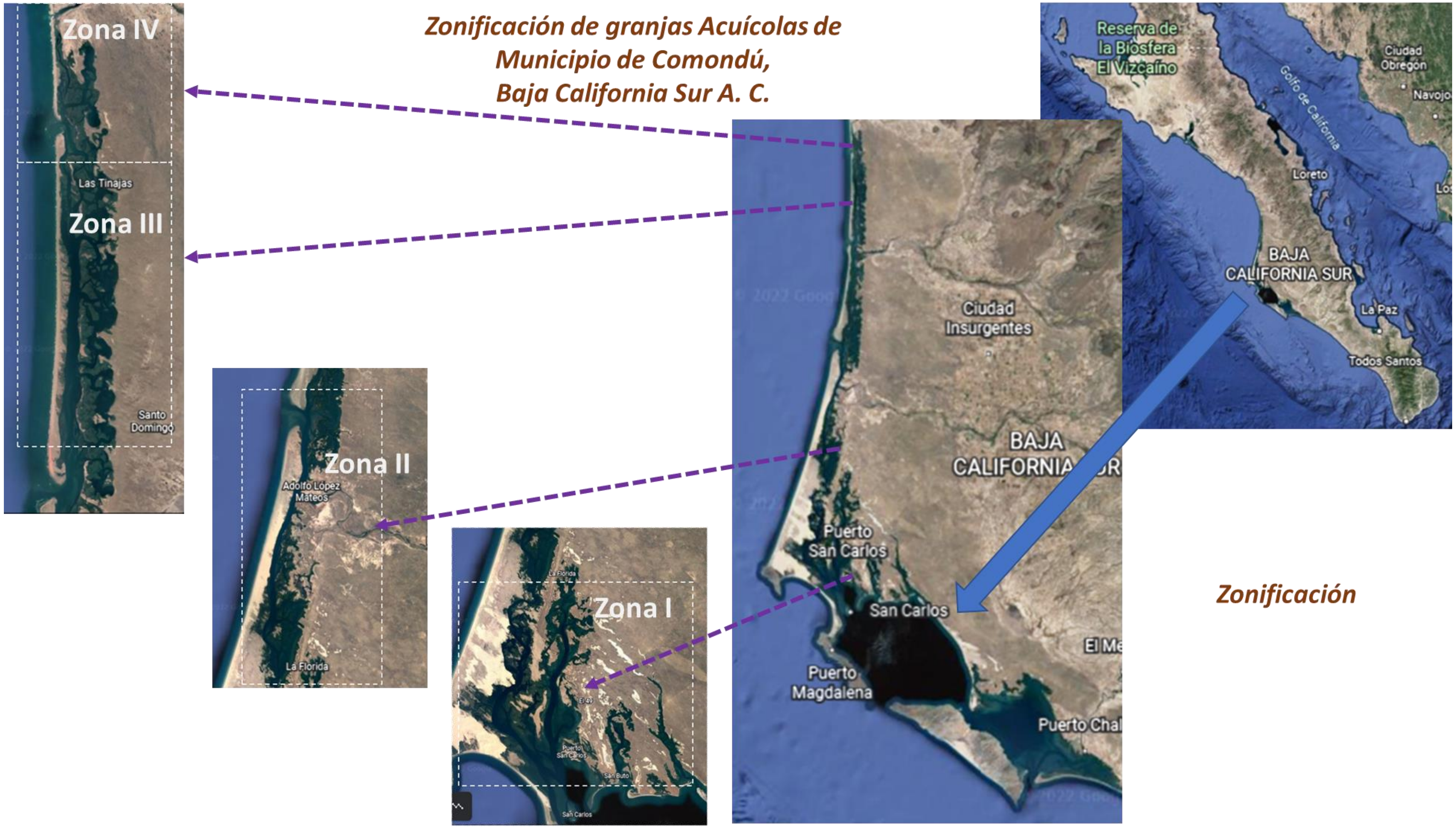
Zonificación de granjas Acuícolas de Municipio de Comondú, Baja California Sur A. C.



Zonificación

Objetivos

1) Transformar el modelo de monocultivo al modelo de granjas familiares de policultivos de moluscos bivalvos.

2) Transformar el modelo actual de producción de semillas de moluscos bivalvos para desarrollar la capacidad de abastecer las granjas familiares.

3) Ofrecer a la sociedad alimentos de alta calidad para mejorar la nutrición humana.

4) Cosechar productividad primaria para mitigar la eutrofización cultural de la zona costera.

5) Desarrollar sumideros de carbón con retención a largo plazo en las conchas de los moluscos.

Land based Integrated Aquaculture and Agriculture Systems

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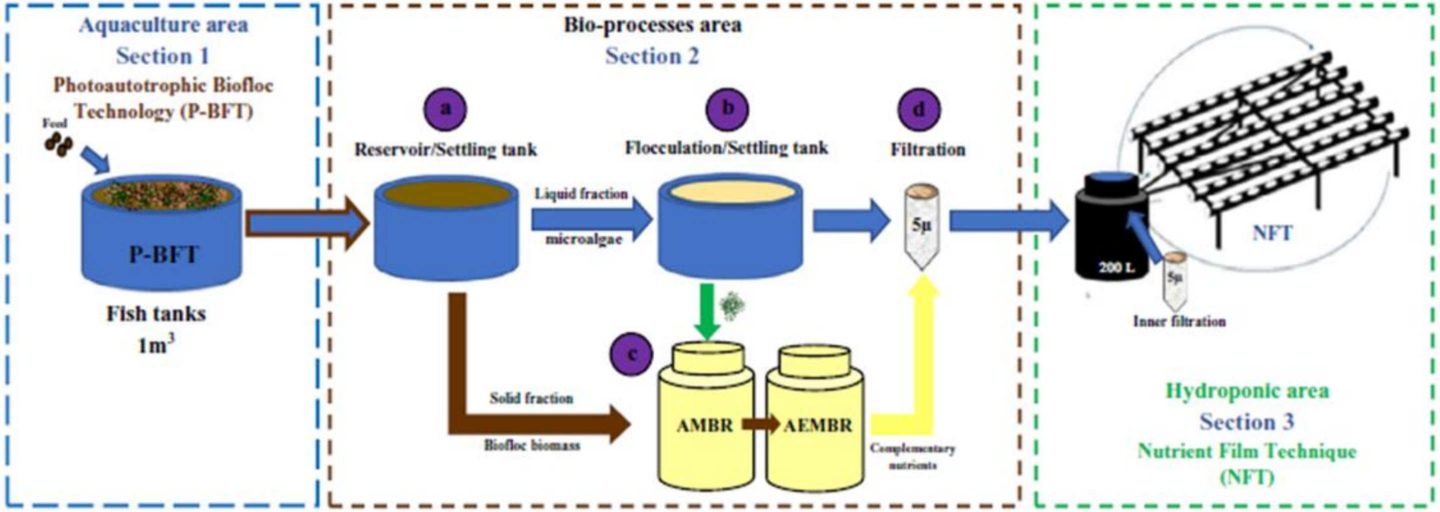
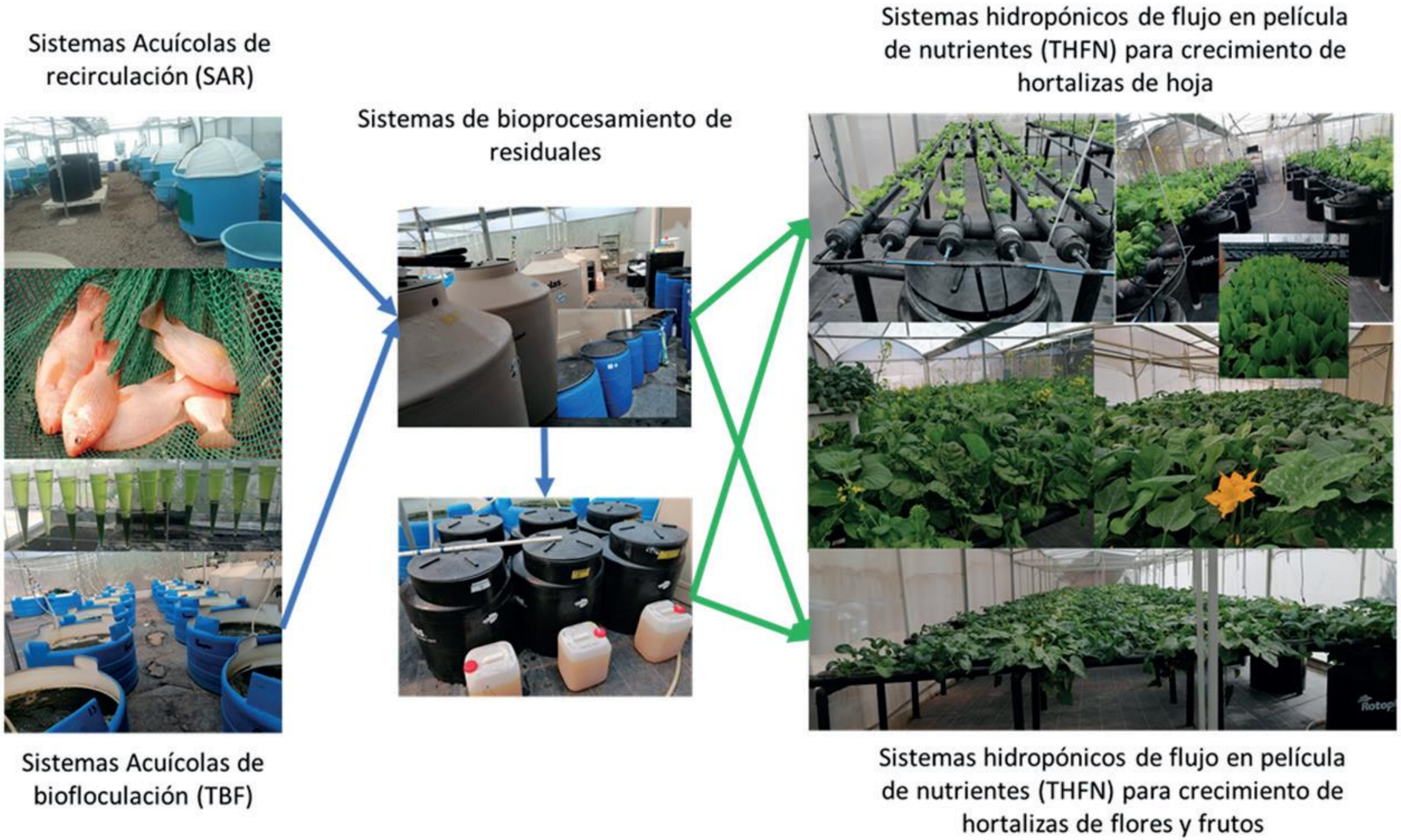
Aquaculture Research WILEY

ORIGINAL ARTICLE

Hydroponic horticulture using residual waters from *Oreochromis niloticus* aquaculture with biofloc technology in photoautotrophic conditions with *Chlorella* microalgae

Yenitze E. Fimbres-Acedo[1] | Rosalía Servín-Villegas[1] | Rodolfo Garza-Torres[2] | Masato Endo[3] | Kevin M. Fitzsimmons[4] | Maurício G.C. Emerenciano[5,6] | Paola Magallón-Servín[1,7] | Melissa López-Vela[1,7] | Francisco J. Magallón-Barajas[1]




Sistemas Acuícolas de recirculación (SAR)
Sistemas de bioprocesamiento de residuales
Sistemas hidropónicos de flujo en película de nutrientes (THFN) para crecimiento de hortalizas de hoja
Sistemas Acuícolas de biofloculación (TBF)
Sistemas hidropónicos de flujo en película de nutrientes (THFN) para crecimiento de hortalizas de flores y frutos

Collaborative relationship between aquaculture sector and academy, at national and international levels to develop Integrated Multitrophic Aquaculture

Scientific research

Relevant species for Photosynthetic Aquaculture

Native
Macroalgae
Microalgae

Nutrition value

Bioactive compounds

Technological development

Feed RAS & Biofloc Aquaculture

Photosynthetic Aquaculture Technology

Extractive Aquaculture Technology

Product extraction and process Technology

Innovation

RAS & Biofloc improvement

New differentiated foods

Silages

Biochemicals

Biomedicines

Energy products

Building materials

Profitability

Environment development

Economic development

Social development

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Muito Obrigado Gracias

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