Nutrient removal in a recirculating aquaculture (RAS) for white shrimp intensive culture using a biological filter wetland-type

International seminar DAAD

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Dr. Otoniel Carranza Díaz

Co-authors: **Marco Antonio Medina Astorga, Ricardo Arturo Quiñonez López, Carmen Alondra Torres Mendoza, Óscar Gárate González, Alejandra Medina Jasso, Pablo Piña Valdez, Mario Nieves Soto**

The Autonomous University of Sinaloa

Academic offers:

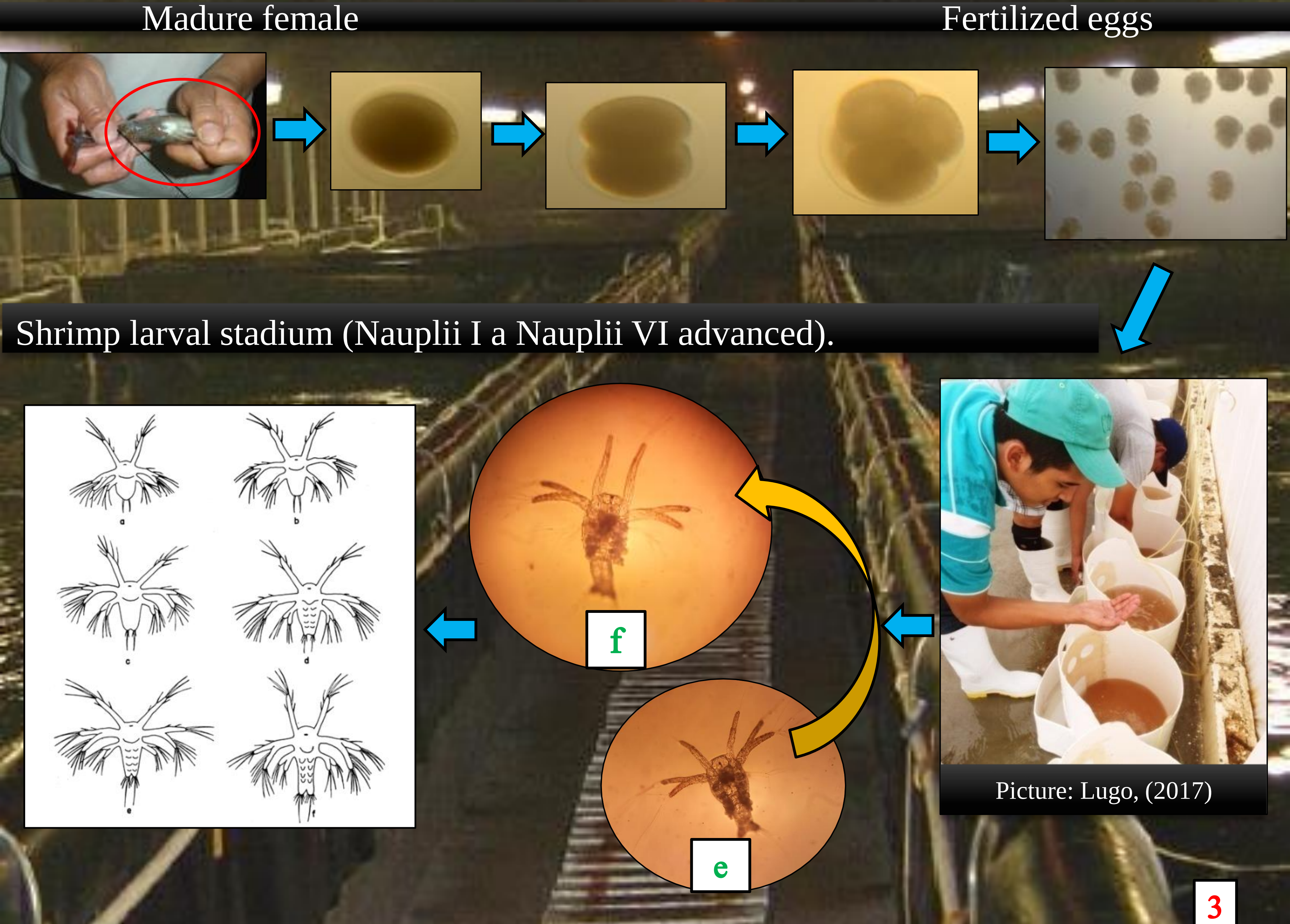
- **Fisheries biology, aquaculture biology, coastal zone management**
- **Postgraduate program (M.Sc. PhD) in aquatic resources (PNPC-CONACYT)**

White shrimp production in Mexico 2016

CESASIN, 2012; CONAPESCA, 2016; SAGARPA, 2017.

White shrimp reproduction facility

Picture taken by Osuna, (2017)



a. Nauplii I, b. Nauplii II, c. Nauplii III, d. Nauplii IV, e. Nauplii V, f. Nauplii VI (advanced)

Nauplii (6 stages)

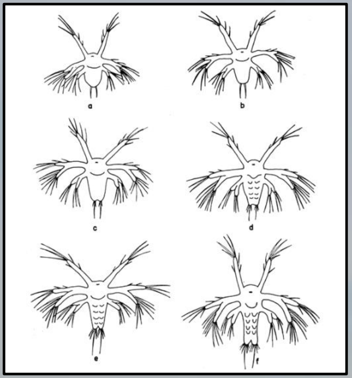
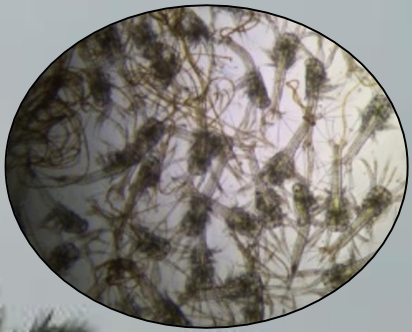


Foto: Lugo, (2017)

Zoea

27-29°C

Thalassiosira sp.* y *Chaetoceros sp.
29-30°C



Mysis 1-3
30-31°C
Artemia nauplii and micropellets.

Postlarvae 1-16
31-33.5°C

Fotos: Lugo, (2017) y Medina, (2017)

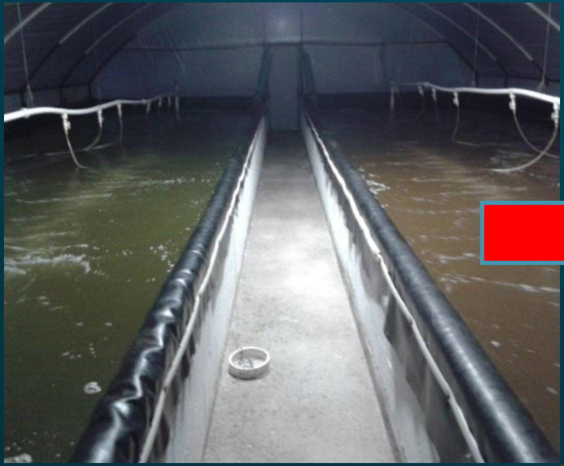
Nurseries, green house cultures and transport to fattening units

Pre-grown facilities

Water quality

Intensive cultures → 500 orgs/m^3

Nurseries (environmental control)



Pictures: Lugo, (2017) & Medina, (2017)

Aerial view of a white shrimp fattening production unit

What happened when wastewater is discharge to the environment ?
Is there a risk for groundwater contamination?

Environmental problems

Reproduction facilities, Nurseries, green house cultures

Demand energy
Discharge high concentration of solids, nutrients (N, P, K), organic matter and chemical substances

✓ **Aquaculture industry needs a lot of water**

Fattening

Deforestation
Lost of natural habitat
Discharge nutrients and chemical substances
Modify the natural drainage regime

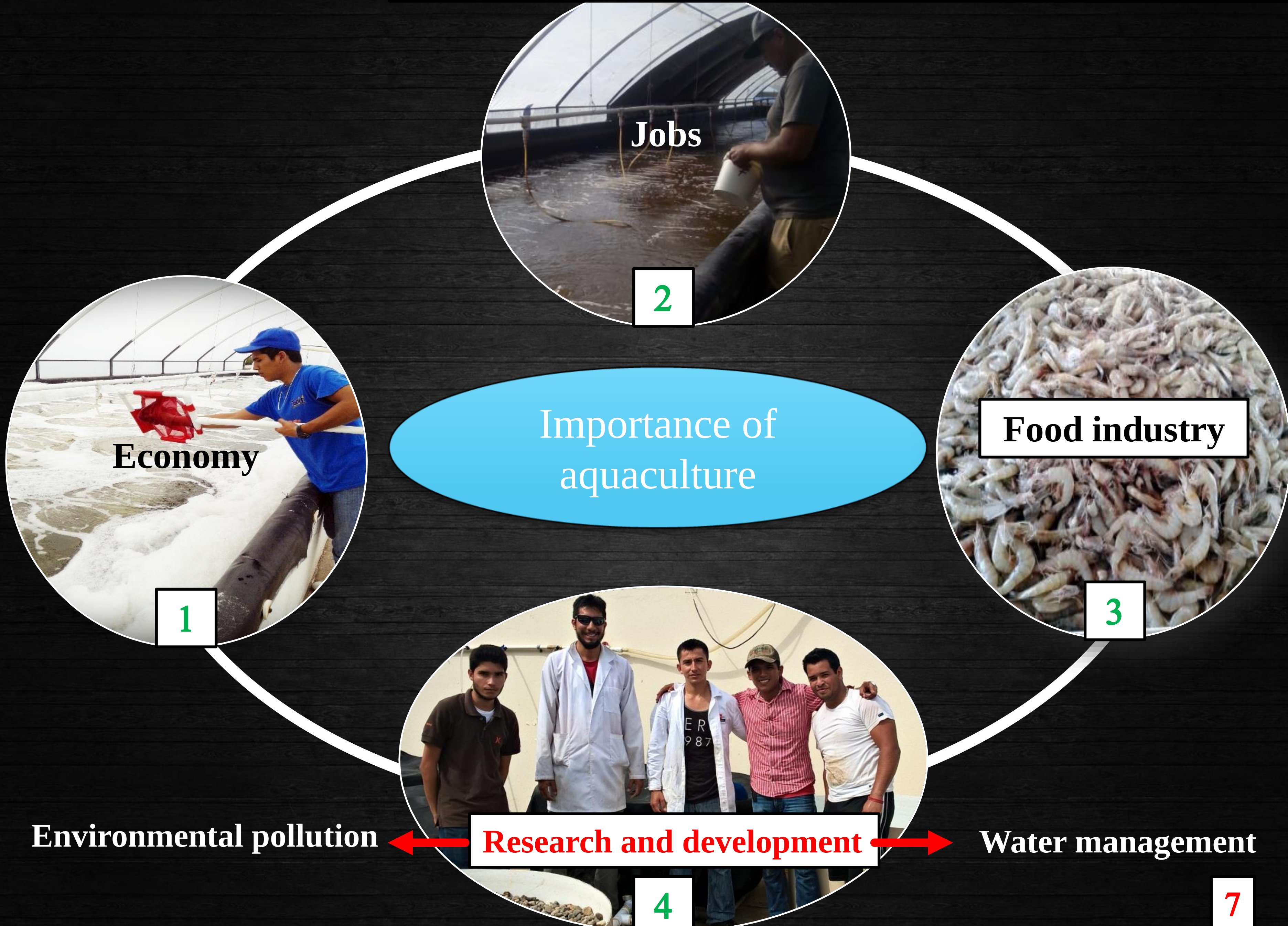
Páez-Osuna, 2001

The effluents of shrimp farms deteriorate the environment (Páez-Osuna, 2001). Sustainable aquaculture. There is a need to improve water management and contaminant mitigation strategies.

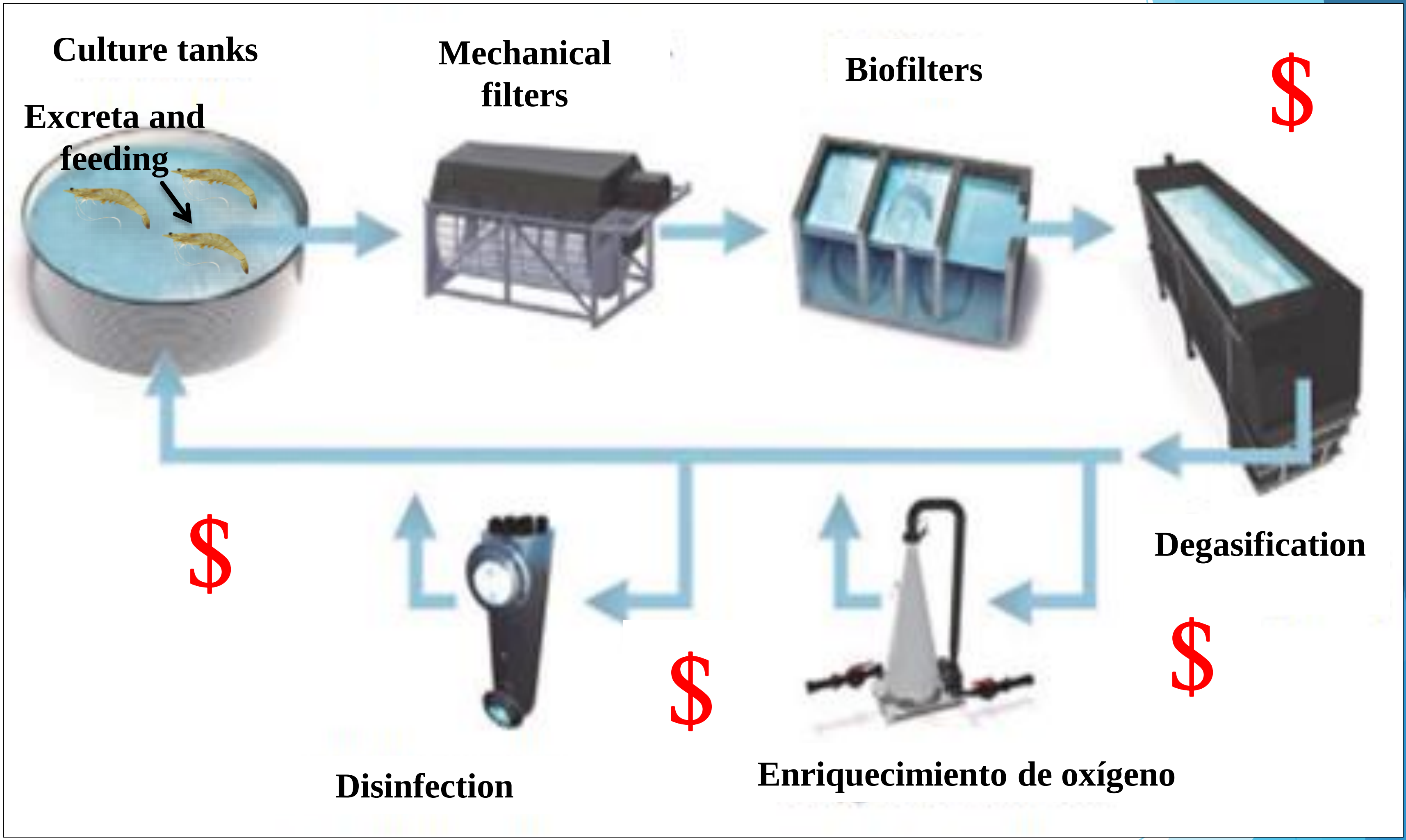
Environmental problems

Picture: Quiñonez-López, (2018)

Pictures: Medina-Astorga M.& Torres-Mendoza A. (2017)



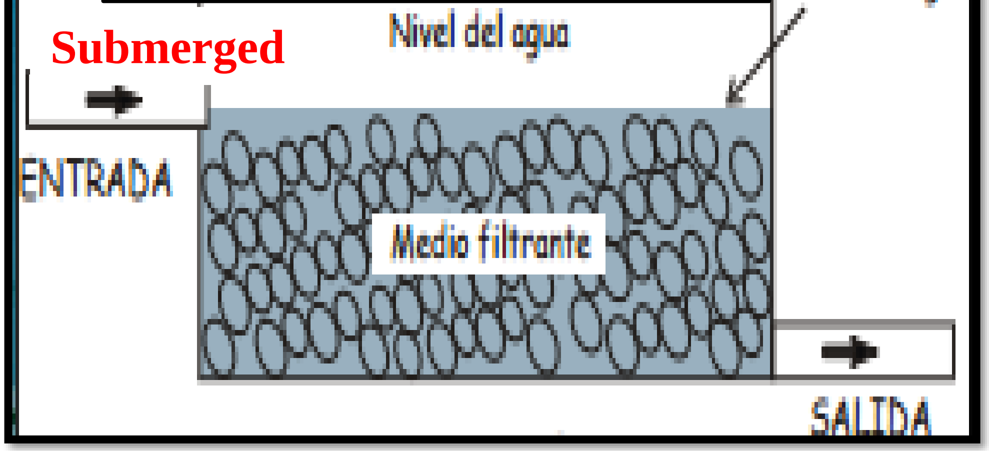
Recirculating aquaculture system (RAS)

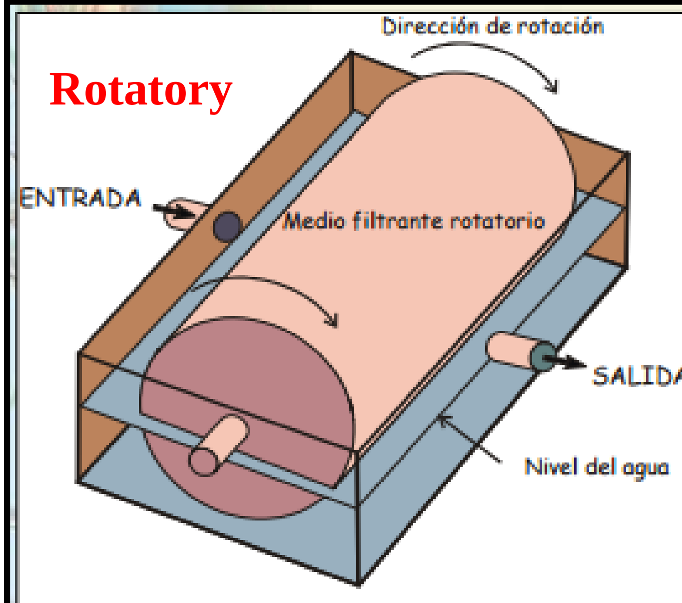


The wastewater treatment consist of mechanical filtration, biological treatment and disinfection.

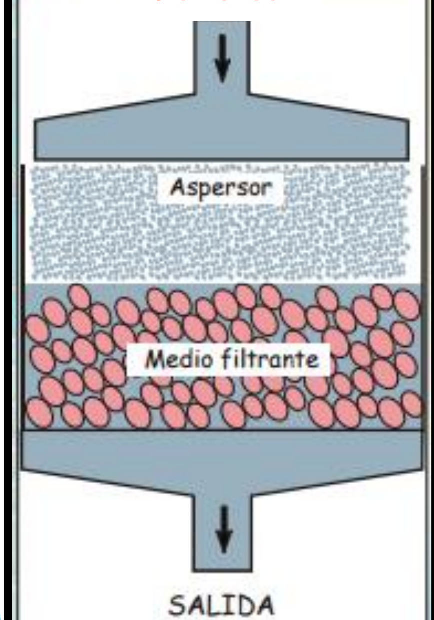
Martínez Córdova *et al*., 2009; Recirculation Aquaculture, FAO, 2015.

Typical units





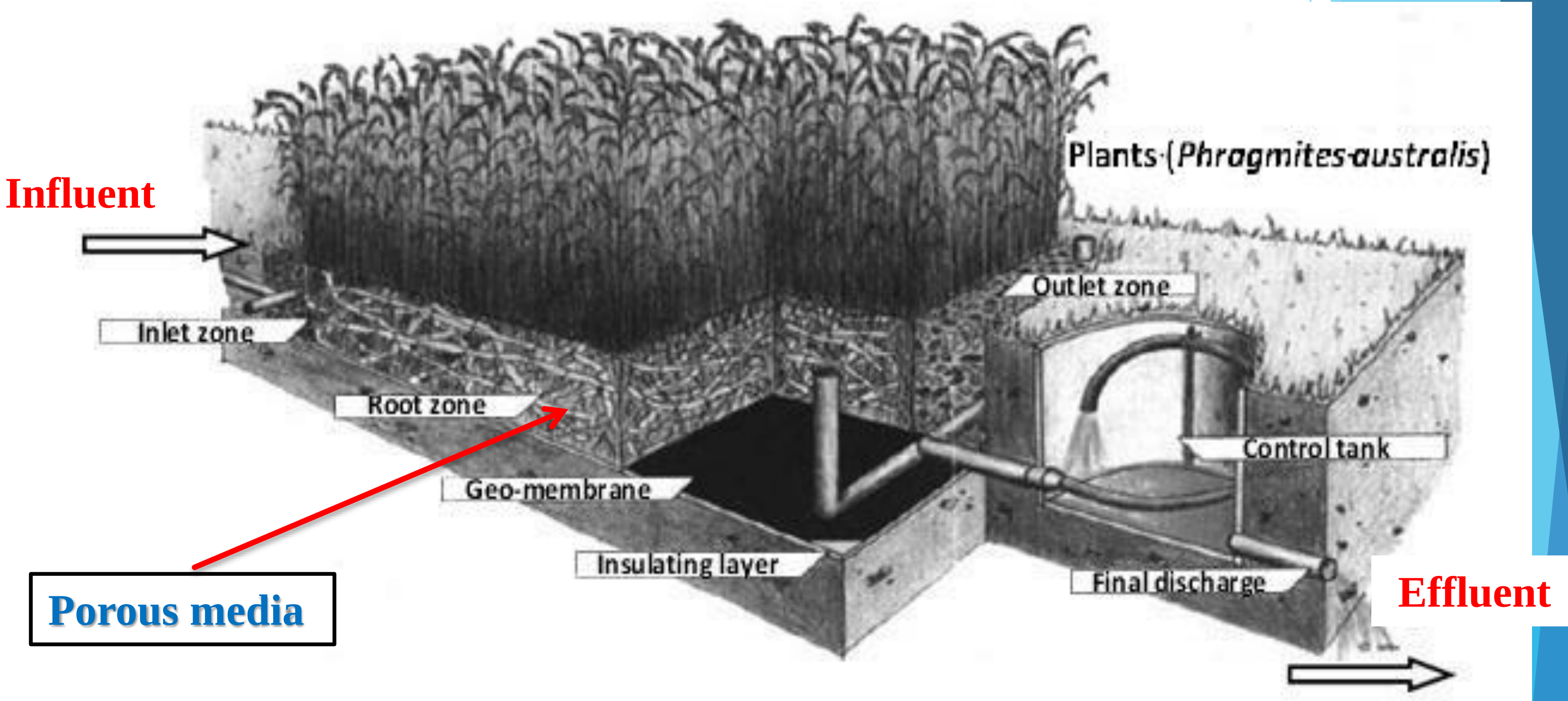
(Tilley *et al*., 2002)



Timmons y Ebelinf, 2007.

Constructed wetlands

Picture: Medina-Astorga, 2017.



Mexico: CW for treatment of aquaculture effluents (Ramírez-Carrillo *et al*., 2009)
Asia: CW in white shrimp RAS (Lin *et al*., 2005; Zachritz *et al*., 2008)

Pastor *et al*, 2003.

Constructed wetlands types (CW)

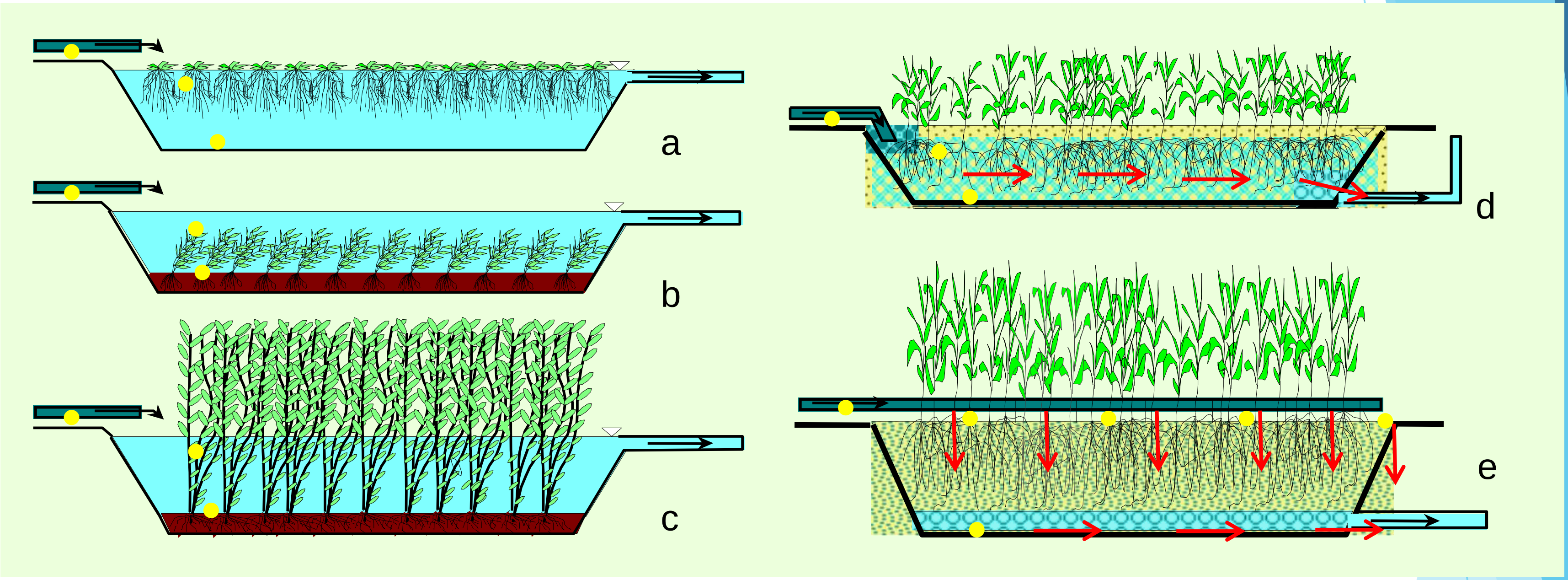


Figure Courtesy of Chen, (2012)

a: Surface Flow, floating aquatic plants

b: Surface flow, sumerged aquatic plants

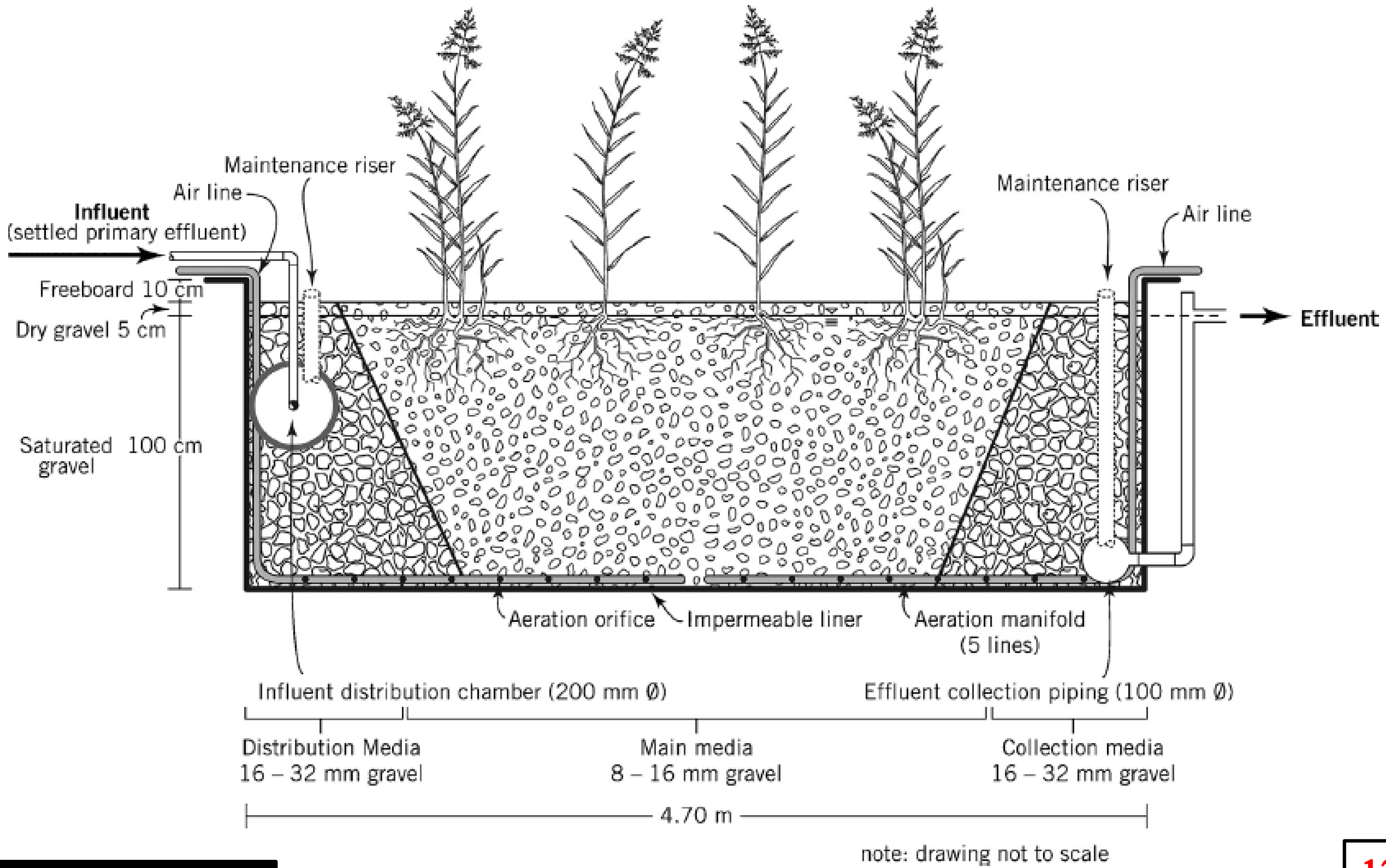
c: Surface flow, emergent aquatic plants

d: CW, horizontal sus-surface flow

e: CW, vertical flow

Intensified constructed wetlands

Total nitrogen removal was 22 % higher than not intensified unit



Nivala *et al*., 2013.

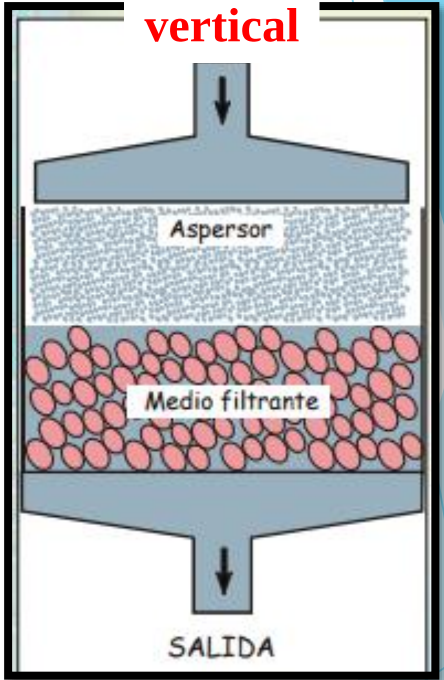
Biofilters in RAS

Constructed wetlands

Picture: Medina-Astorga, 2017.

Nutrient removal, solids, BOD (plant uptake, biodegradation)
Required area and oxygen can be limited

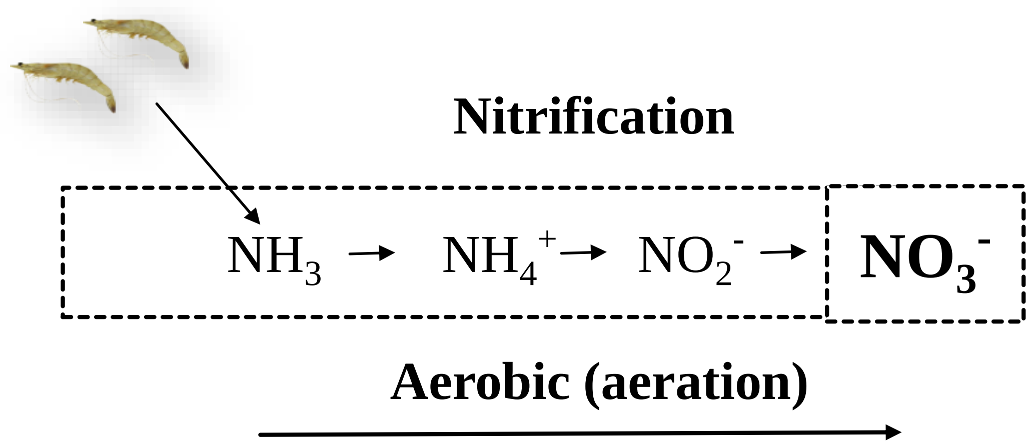
Other biofilters



Nitrification is achieved,
However nitrate accumulation

Zhan Y. G., 2002; Carranza-Díaz, 2015.

The bacteria *Nitrosomonas* and *Nitrobacter* enable nitrification under aerobic conditions however increasing nitrate concentrations in shrimp cultures



- Concentration of 200 mg NO_3^- L^{-1} → susceptibility to diseases and survival (Lee y Wickins, 1997, Frías-Espiricueta *et al*., 1999; Vinatea y Carvalho, 2007).
- The recommended value of NO_3^- by Van-Wyk y Scarpa, (1999) for shrimp culture is 60 mg L^{-1}.

Kadlec R. y Wallace S., 2009; Vymazal, 2011; CreveTec, 2012; Hargreaves, 2013; Mietto *et al*., 2015; Fitzgerald *et al*., 2015; Kim *et al*., 2016.

Nitrate removal process

In denitrification the organic matter can be can be used by heterotrophic bacteria as carbon source to reduce nitrate to N_2 under anoxic conditions.

Constructed wetlands ?

Nitrification | **Denitrification**

$NH_3 \rightarrow NH_4^+ \rightarrow NO_2^- \rightarrow$ $\mathbf{NO_3^-}$ $\rightarrow NO_2^- \rightarrow NO \rightarrow N_2O \rightarrow N_2$

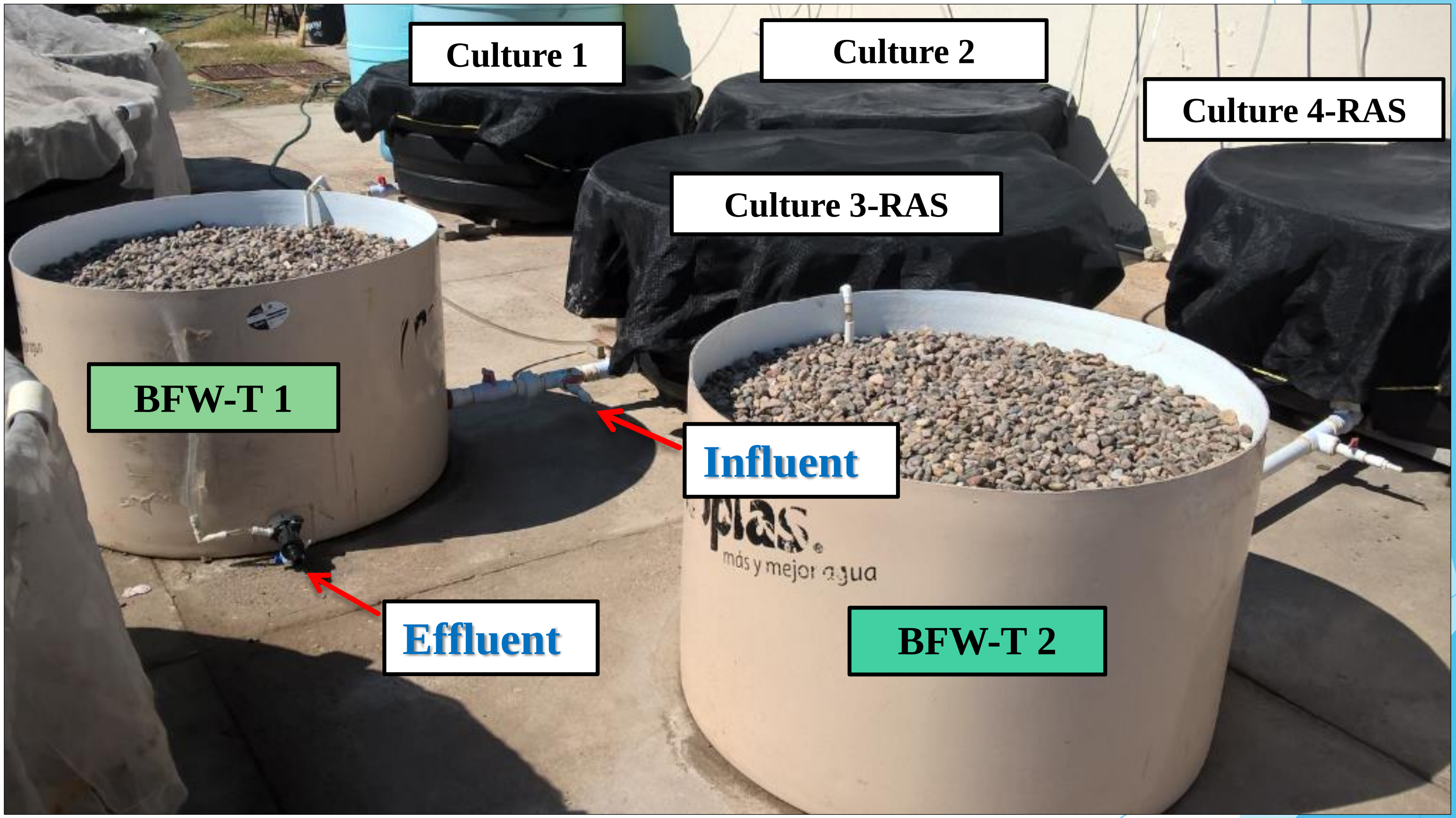
Aerobic (aeration) →

Anoxic (absence de O_2) →

Kadlec R. y Wallace S., 2009; Vymazal, 2011; CreveTec, 2012; Hargreaves, 2013; Mietto *et al*., 2015; Fitzgerald *et al*., 2015; Kim *et al*., 2016.

Development of RAS in Mazatlan Mexico

Experiences at the Autonomous University of Sinaloa

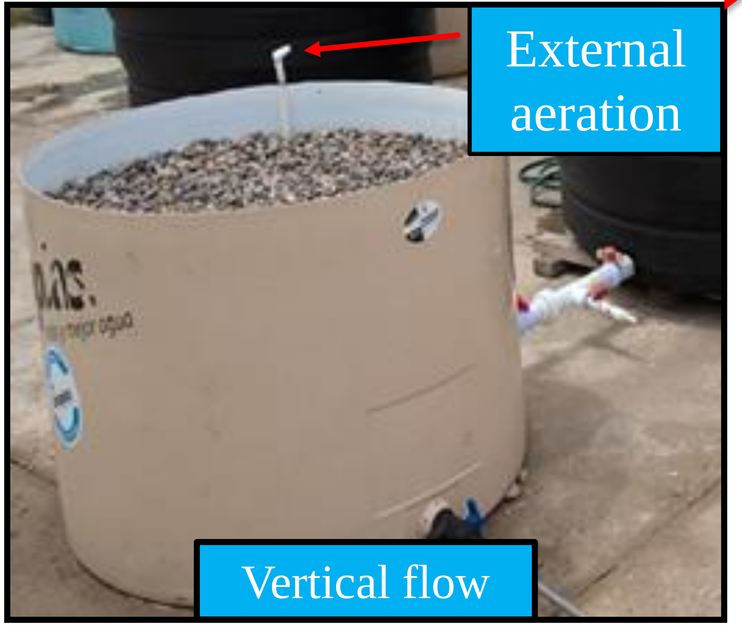


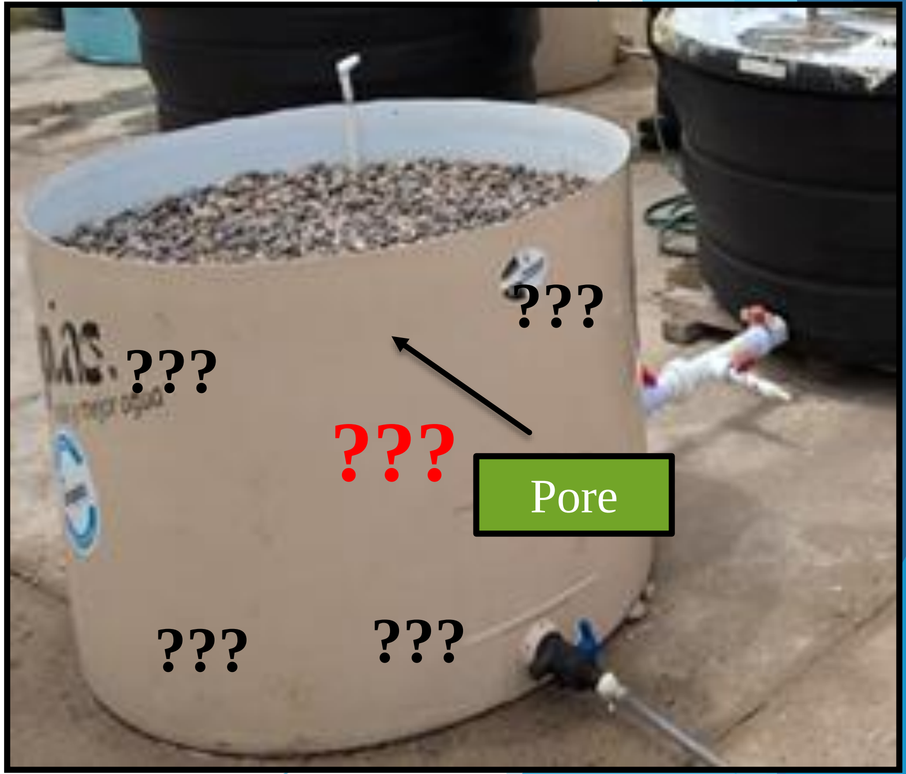
FACIMAR, 2016.

The prototype works as an external wastewater treatment module incorporated in a RAS. It has an external aeration (on, off, intermittent).

Implemented to enhance recirculating rate

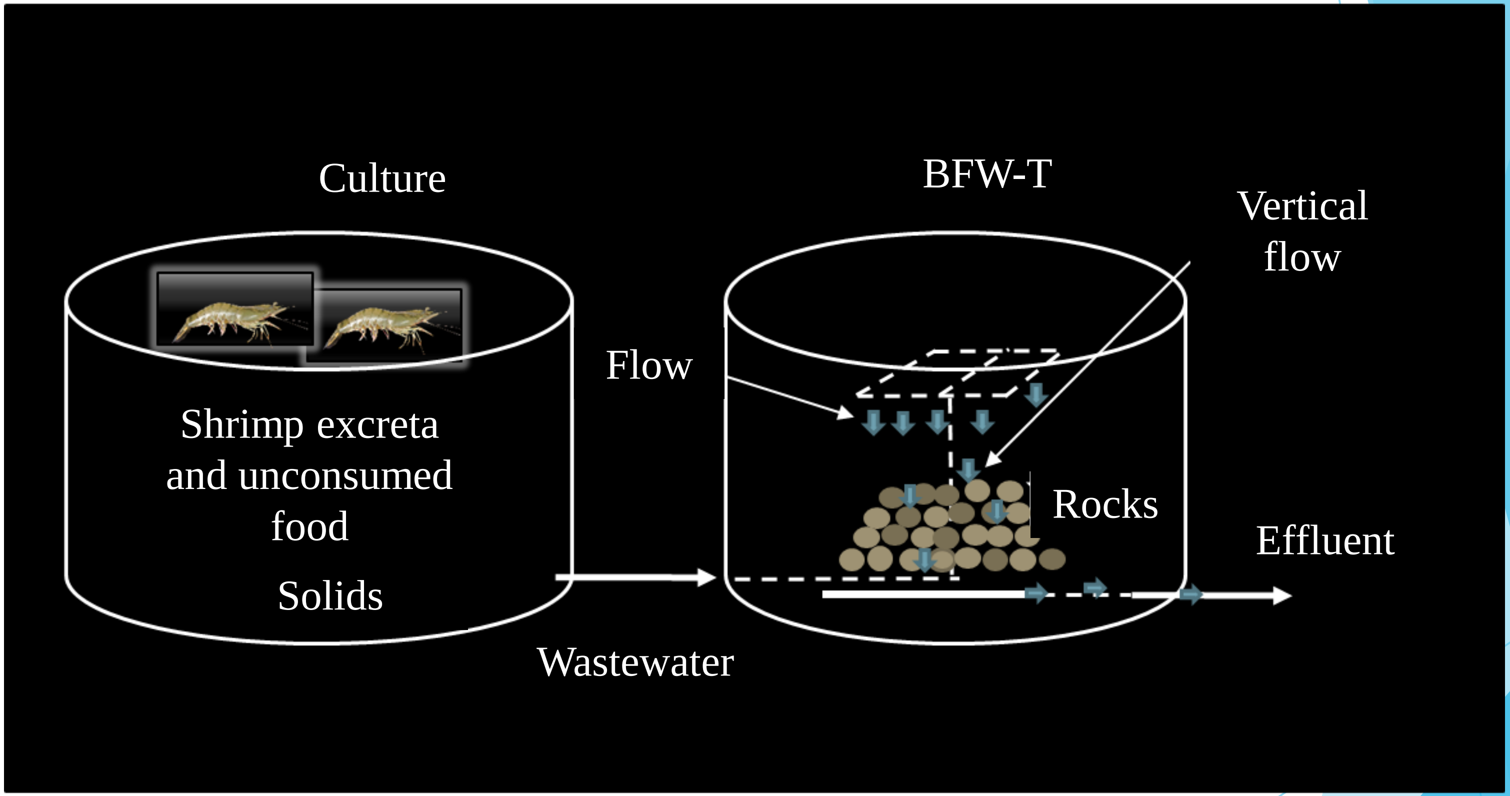
Experimental prototype





Wu *et al*., 2013; Ávila *et al*., 2014; Uggetti *et al*., 2016; Pratiksha *et al*., 2017.

Description of the RAS coupled with BFW-T



Quiñones-López, (2018)

Research questions

1. ¿Is the performance of the RAS culture (+ BFW-T) of *L. vannamei* comparable to a similar intensive culture using seawater exchange?.
2. ¿Does the BFW-T remove settleable solids?.
3. ¿Can selected nutrients be removed in the BFW-T when works i) with external aeration and ii) without external aeration?.

Objetives

General

Investigating selected nutrient removal in RAS cultures of *L. vannamei* post larvae (nursery) using a Biological Filter Wetland Type.

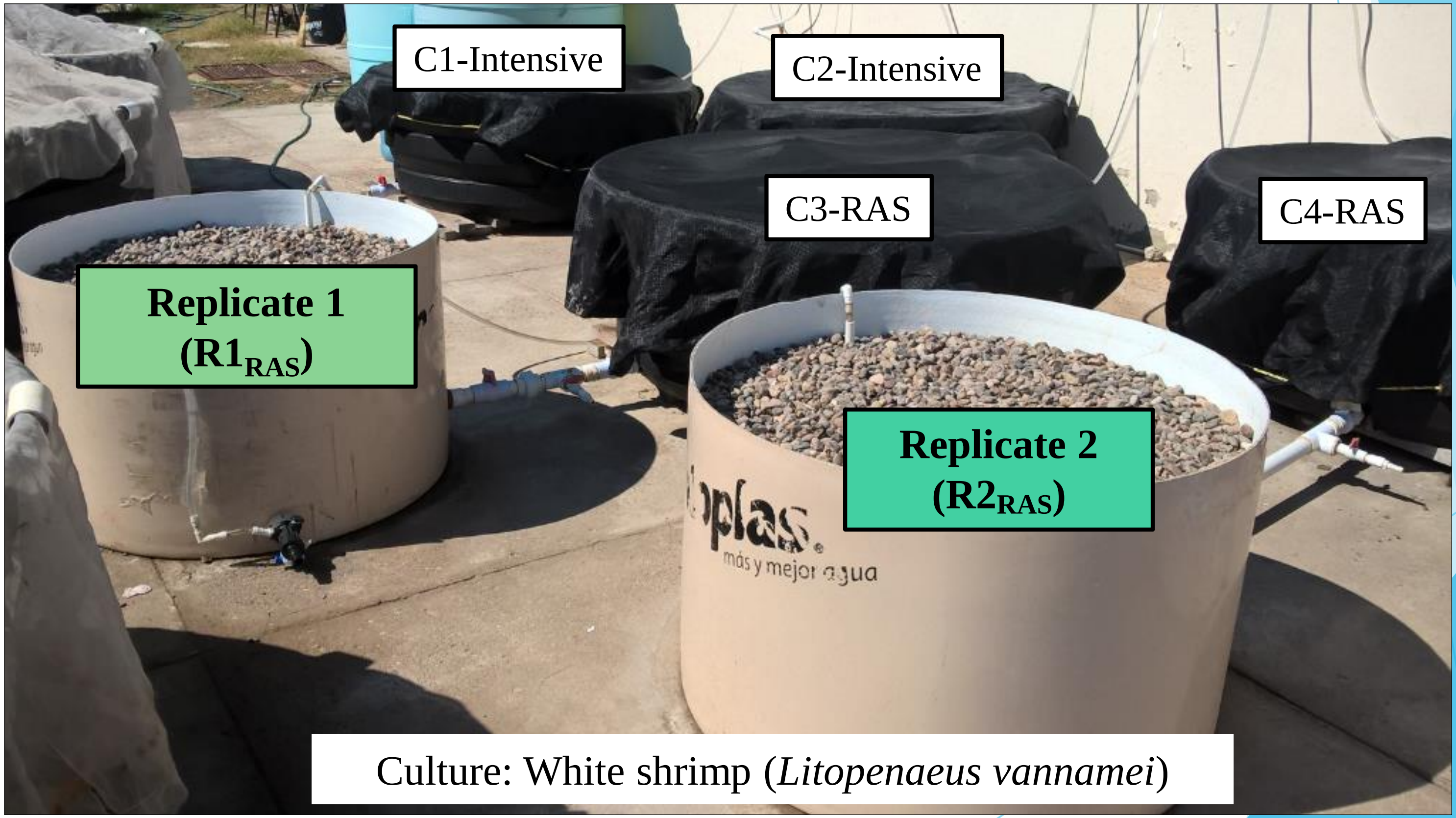
Particular

1. Determine the performance of the RAS culture and compare it with an intensive culture.
2. Determine the settleable solids removal using the BFW-T.
3. Evaluate selected nutrient removal (NH_3, NO_2^-, NO_3^-) (influent vs effluent of the BFW-T) in the RAS culture operating with external aeration.
4. Evaluate the response of nitrate (NO_3^-) in the pore when the BFW-T works without external aeration.

MATERIALS AND METHODS

Selected culture conditions

Density: 1000 organisms/m^3. Initial W (mean): 0.008 g (PL_{16}). Food: 2 times/day. Culture time: 86 days. Two culture technologies (Intensive *vs* RAS). Two replicates each one (Culture: 1-intensive, 2-intensive, 3-RAS y 4-RAS). The BFW-T were operated in Batch after WQ parameters were detected.



Picture: Carranza-Díaz, (2016).

Recirculating rate and seawater exchange

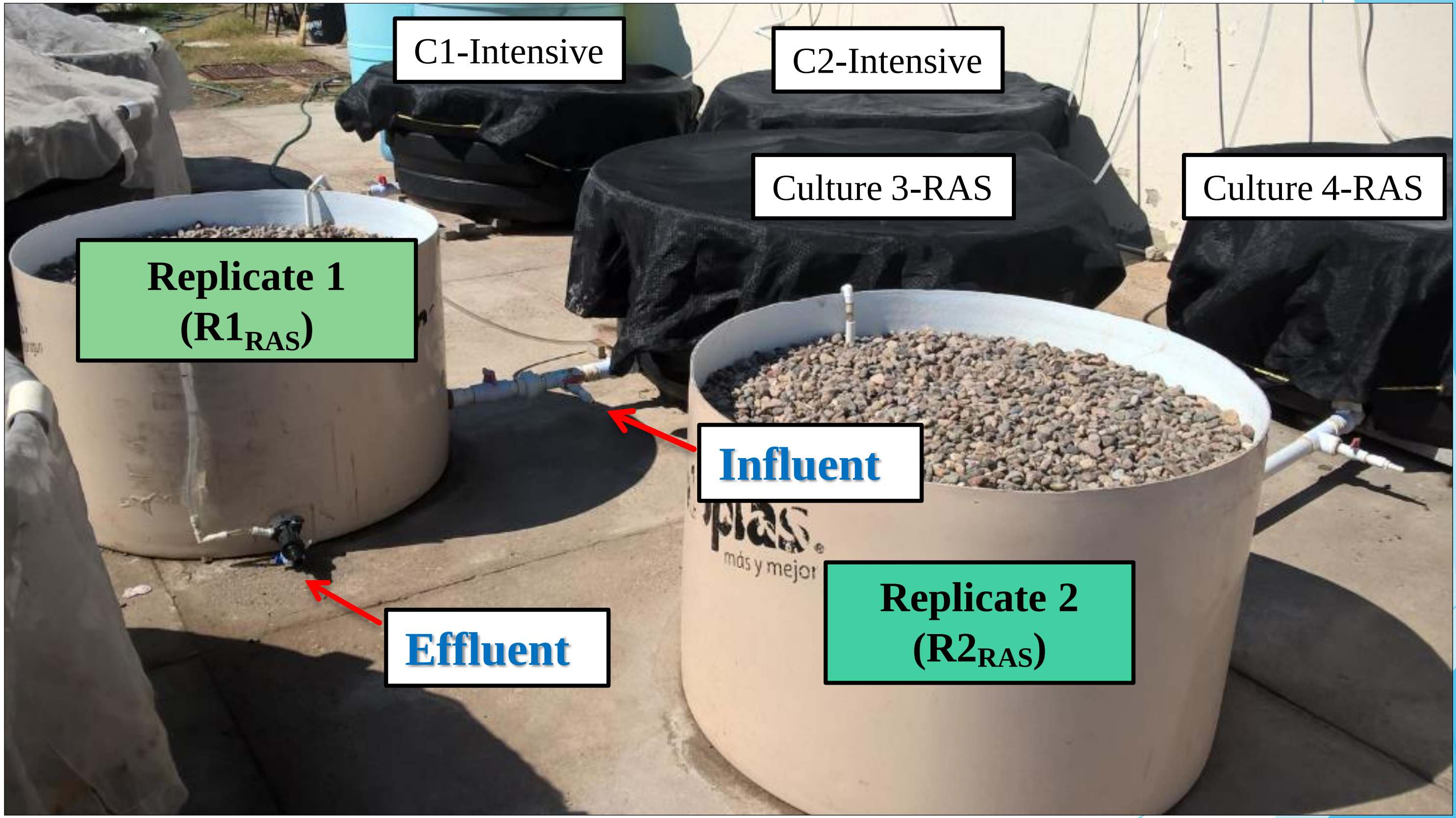
Intensive cultures: 2 seawater exchange/week (seawater + evaporation loss).

Water exchange: = 150 L (300 L/week).

RAS-Cultures: 2 recirculating events/week (BFW-T + evaporation loss).

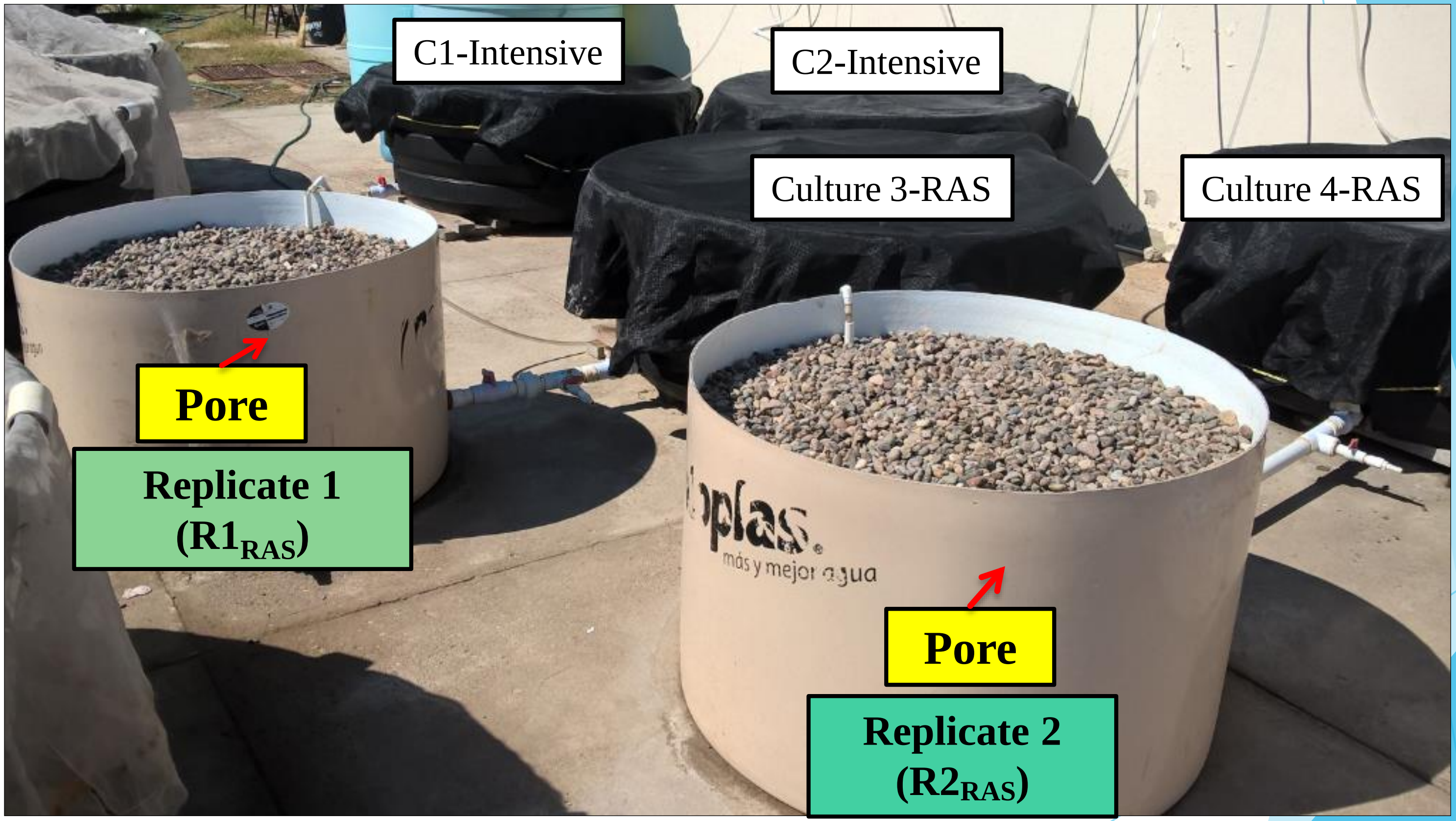
Recirculating rate = 150 L (300 L/week).

- 21 sampling events **influent, effluent** from 27.09.2016 to 13.12.2016



Picture: Carranza-Díaz, (2016).

- 18 sampling events **in the pore** from 07.11.2016 to 21.12.2016



Picture: Carranza-Díaz, (2016).

Pore water sampling

Dissolved oxygen and nitrate (NO_3^-) were measured

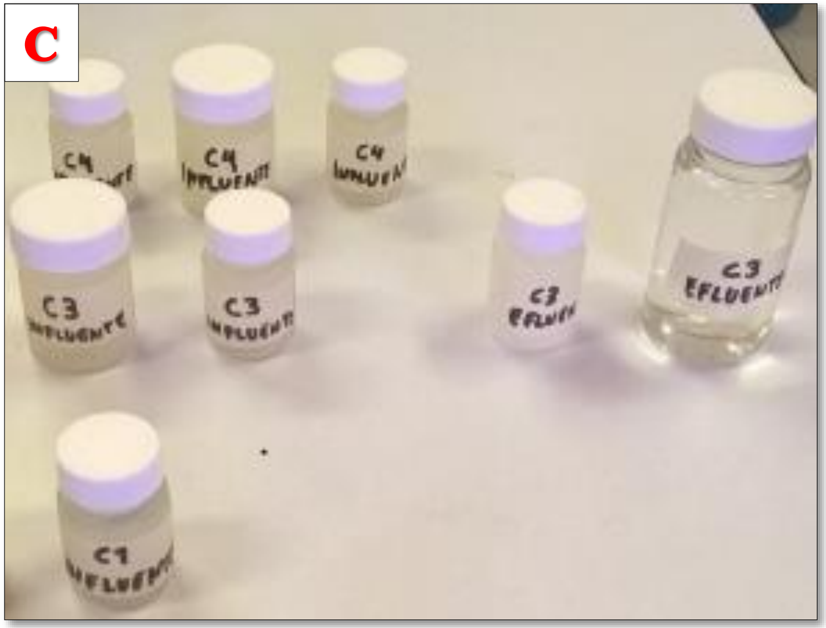
Without external aeration. 2 campaigns: Campaign 1 → 14/12/16 to 17/12/16 y

Campaign 2 → 19/12/16 to 21/12/16.

Plastic lance (25 cm), Vacuum pump, Erlenmeyer flask, Syringe

Dissolved Oxygen (DO) analysis in the Laboratory at FACIMAR, UAS

C



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D

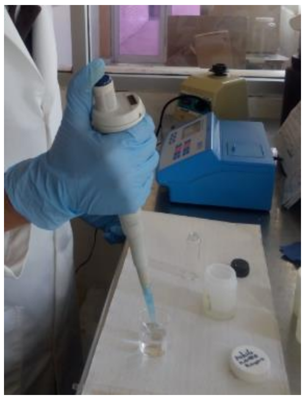
DO analysis: PreSens® (Limit of detection 1 µg/L)

Nutrient analysis: ammonia nitrogen, nitrite and nitrate

Nutrients (NH_3, NO_2^-, NO_3^-) were analyzed using a photometer Hanna HI 82203.

Laboratory at FACIMAR, UAS

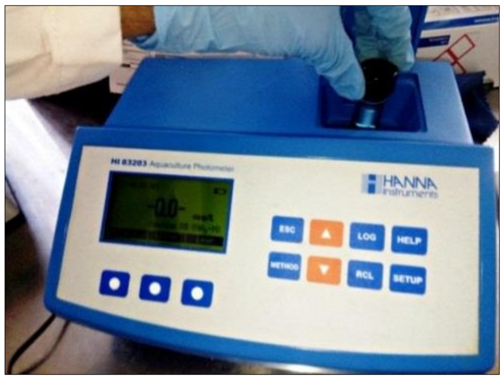
1



Water sample, dilution if needed

→

2



Sample without reactant (reference)

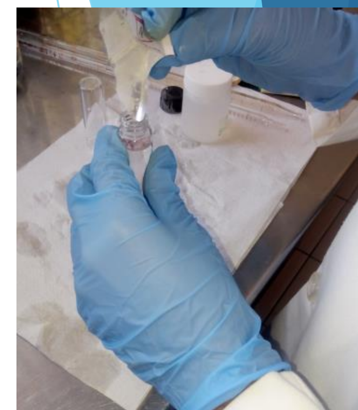
→

3

Reactant

→

4



Sample preparison

5

←

6

Analysis using photometer Hanna HI 82203

Measurements of settleable solids

AWWA, (1992)

Removal calculation

$$\text{Removal}(\%) = \frac{\text{Influent concentration} - \text{Effluent concentration}}{\text{Influent concentration}} \times 100$$

Concentration (mg/L) → nutrients
Volume (ml/L) → settleable solids

Zachritz *et al*., (2008)

Biomass (g) was registered once per week. The water consumption along the whole culture was registered.

Biometry/week

Harvest: Final (g) and survival (%)

Statistical analysis

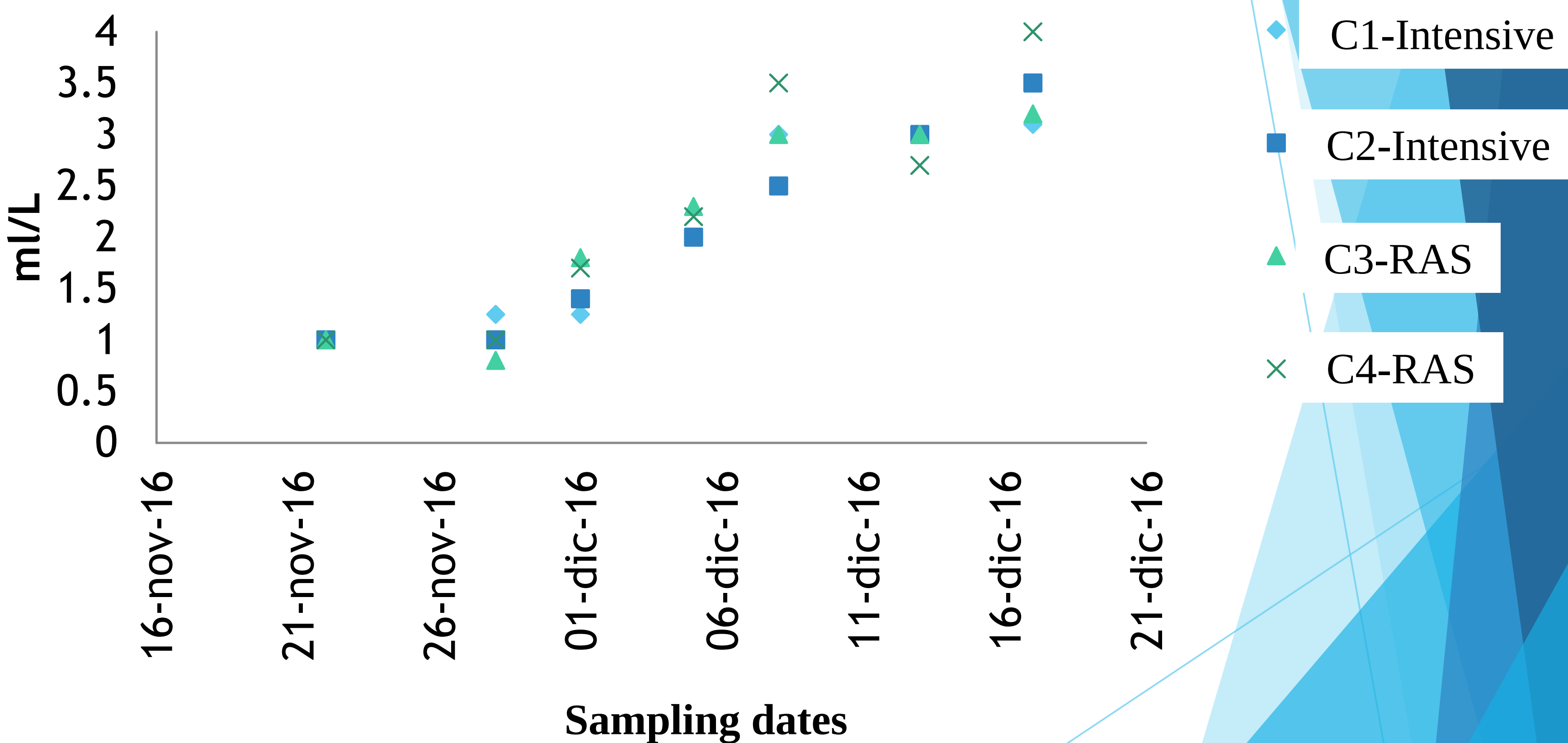
Mean comparison → Kruskal Wallis test

1. Dissolved oxygen concentrations between the four cultures.
2. Dissolved oxygen concentrations in the pore of BFW-T (aeration vs without aeration).
3. Volume of settleable solids influent and effluent of the BFW-T.

Significant differences were considered when $p<0.05$.

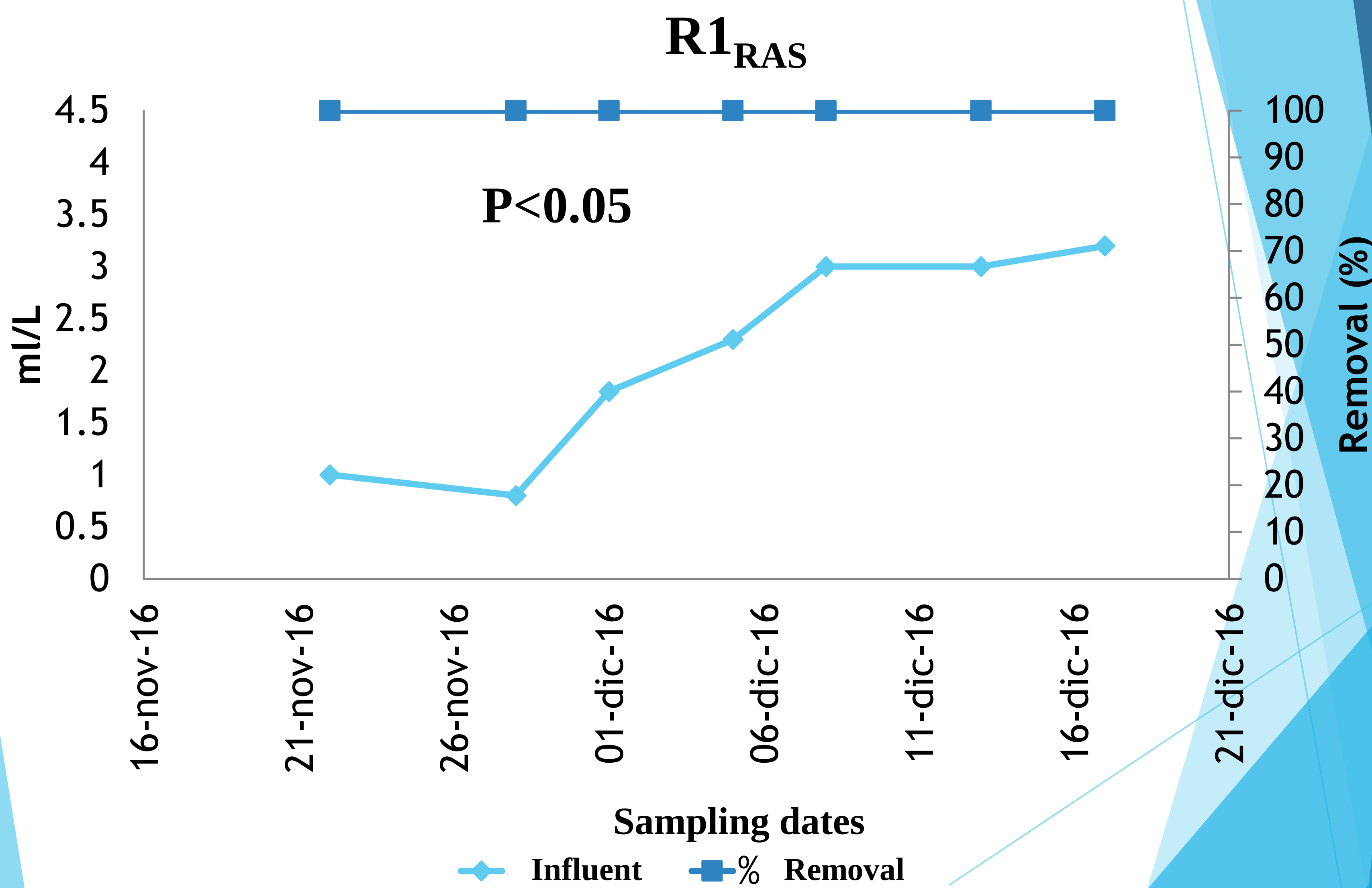
RESULTS

Settleable solids in the four cultures

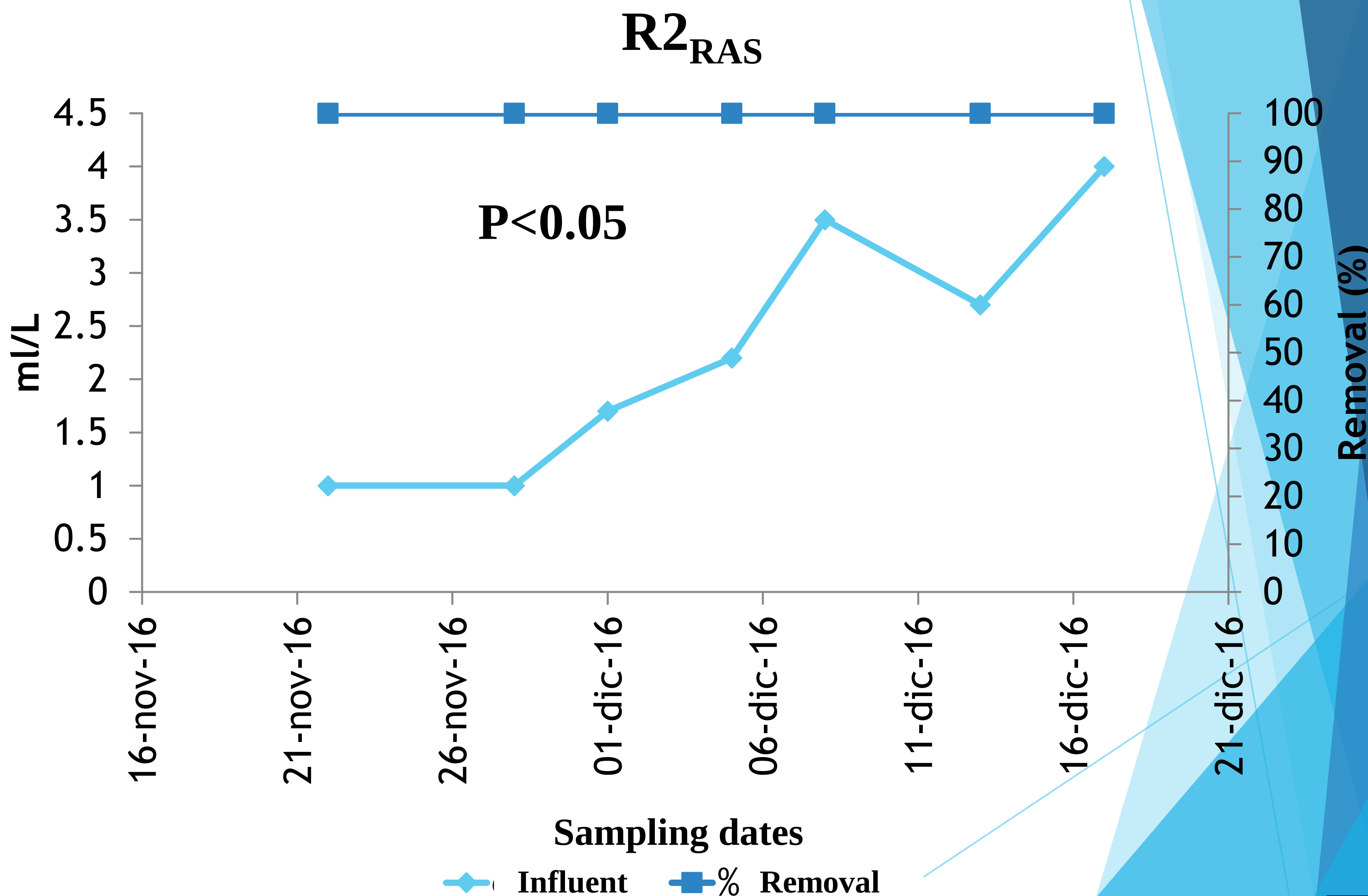


Biofloc cultures → 13 ml/L (Brito *et al.*, 2014)

Quiñonez-López, (2018)

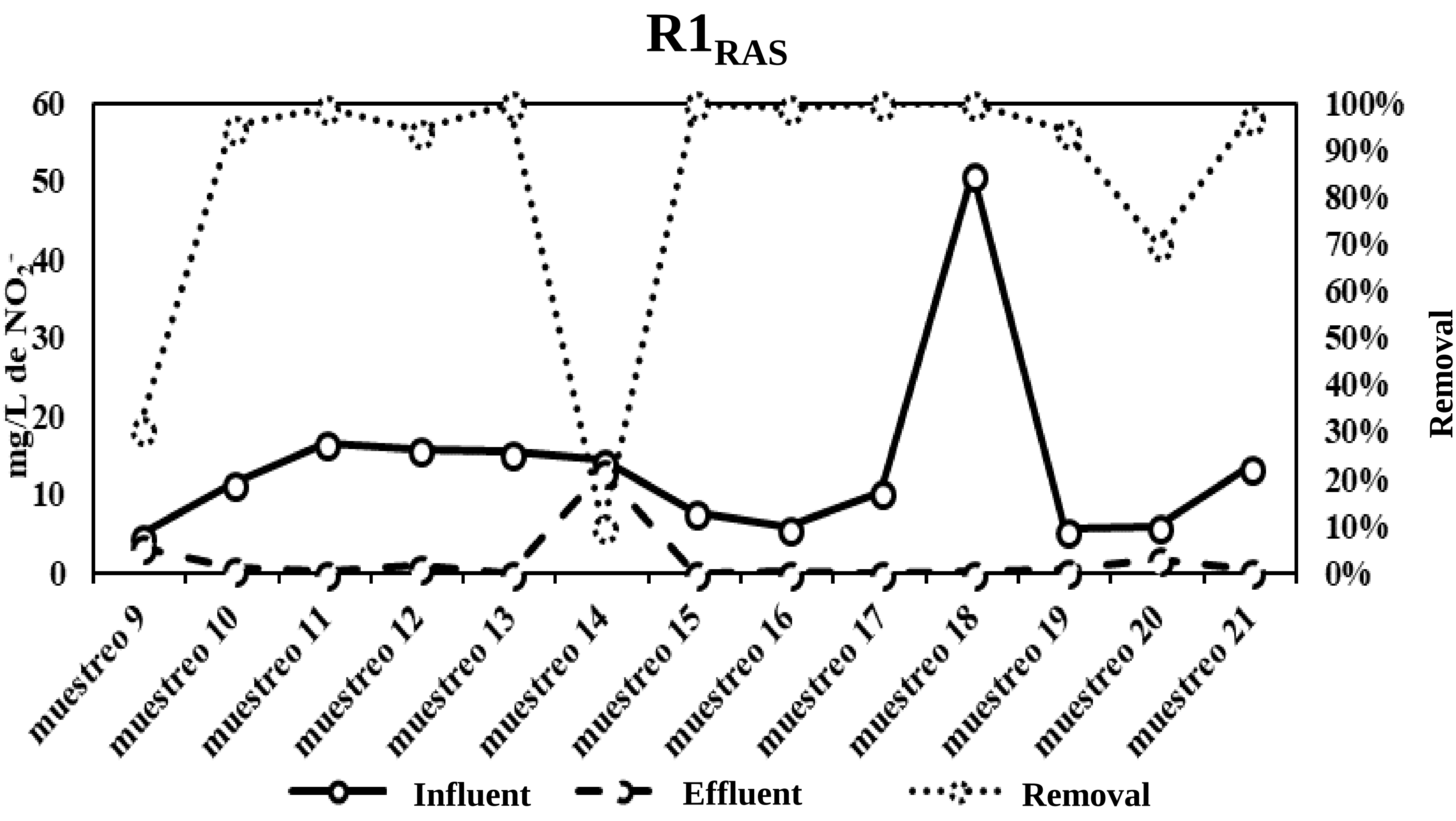


Quiñonez-López, (2018)

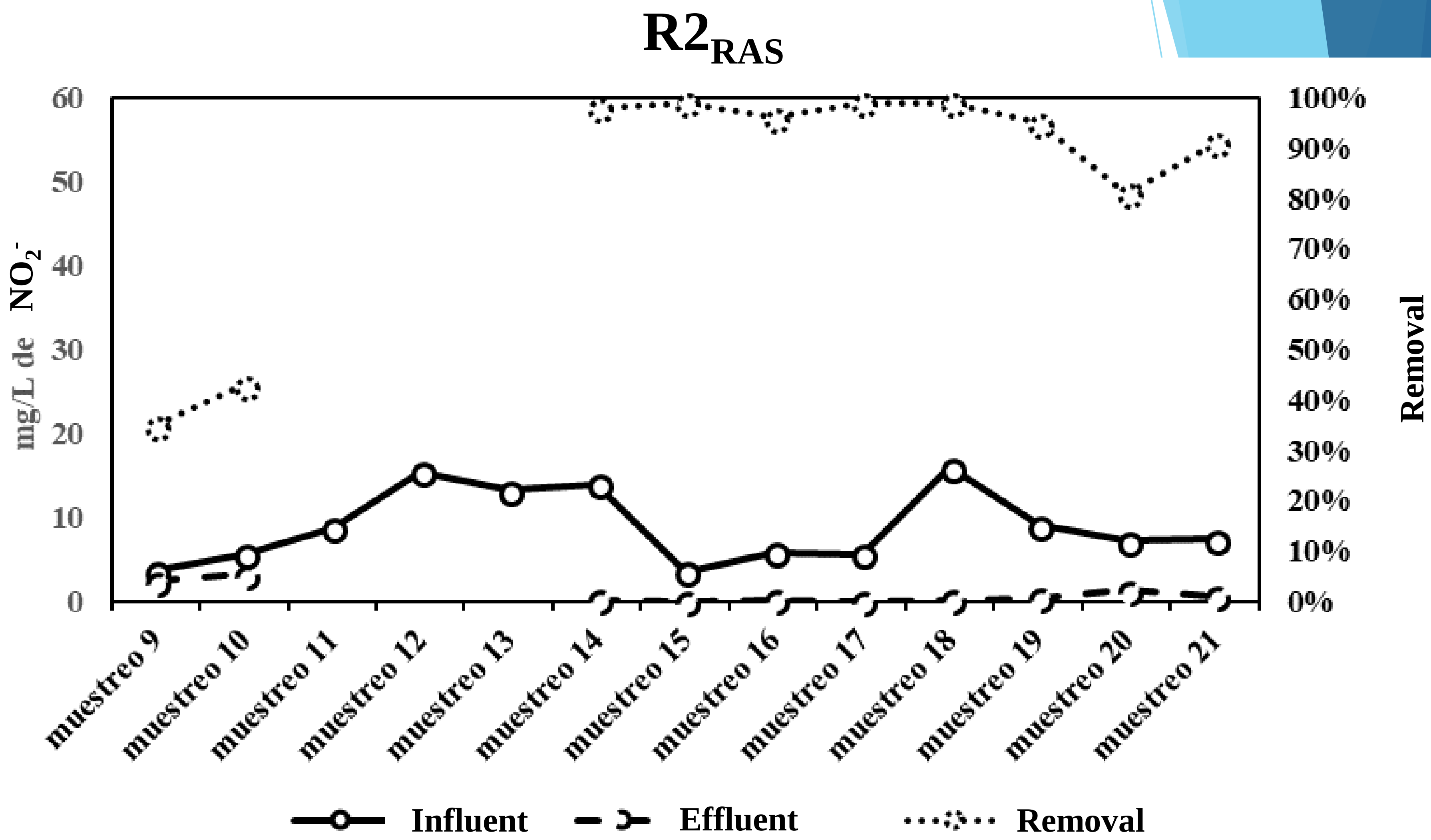


Quiñonez-López, (2018)

Influent and effluent nitrite (NO_2^-) concentration and removal in the BFW-T: **with external aeration**

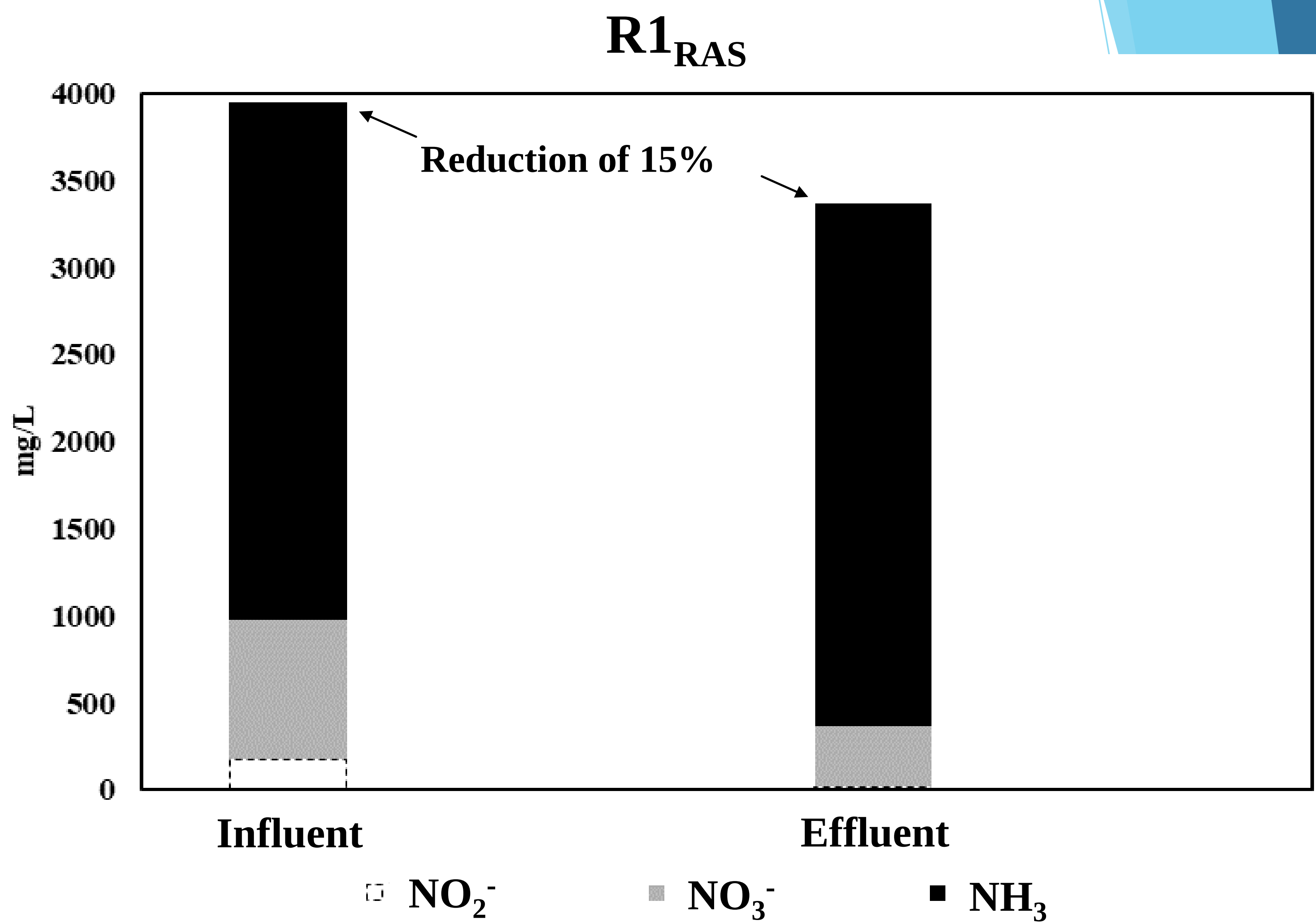


Torrez-Mendoza y Garate-González, (2018)



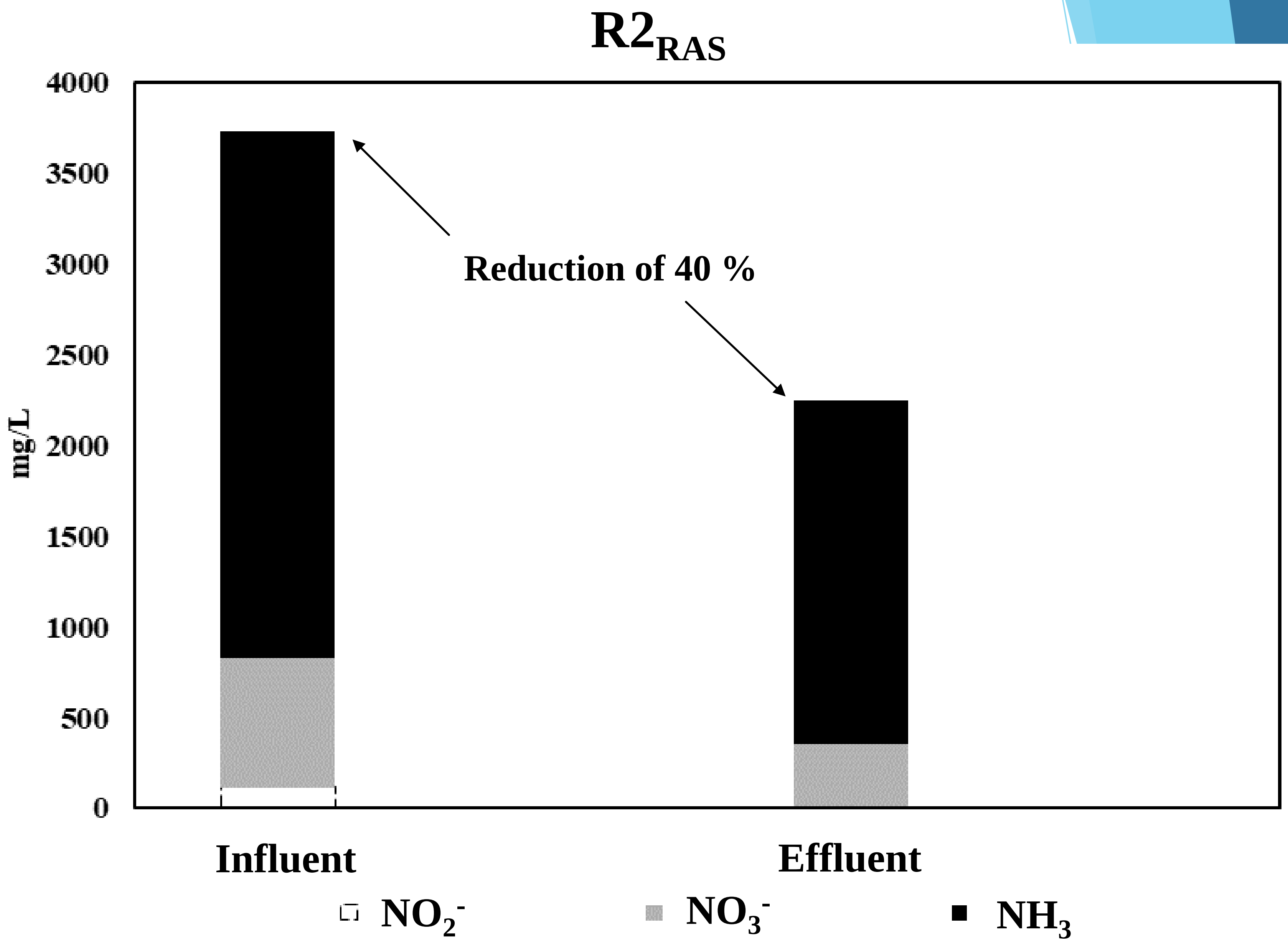
Torrez-Mendoza y Garate-González, (2018)

Cumulative influent and effluent nutrient concentrations in the BFW-T: with external aeration



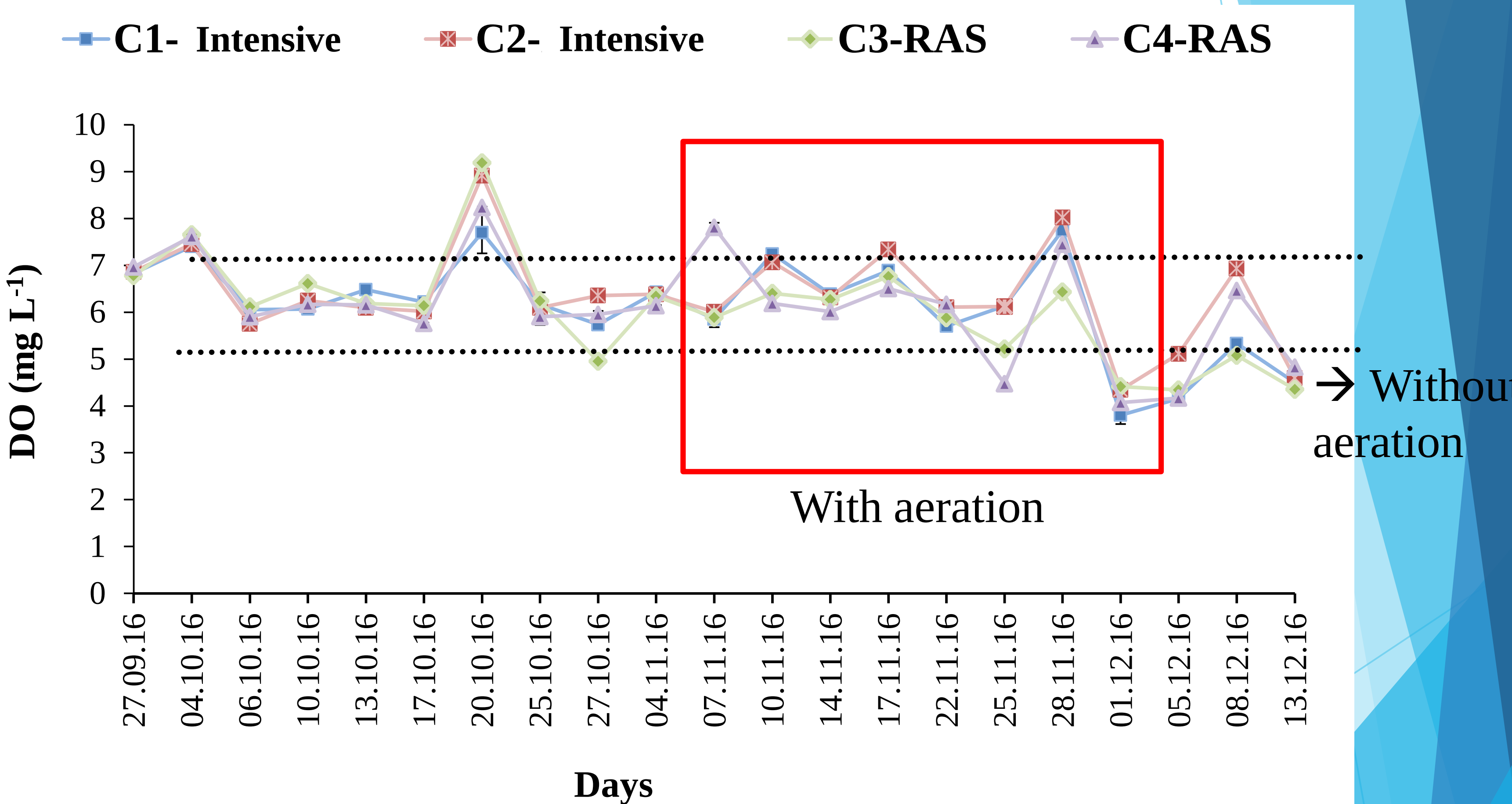
Torrez-Mendoza y Garate-González, (2018)

Cumulative influent and effluent nutrient concentrations in the BFW-T: with external aeration



Torrez-Mendoza y Garate-González, (2018)

DO concentrations in the four cultures of white shrimp: intensive *vs* RAS

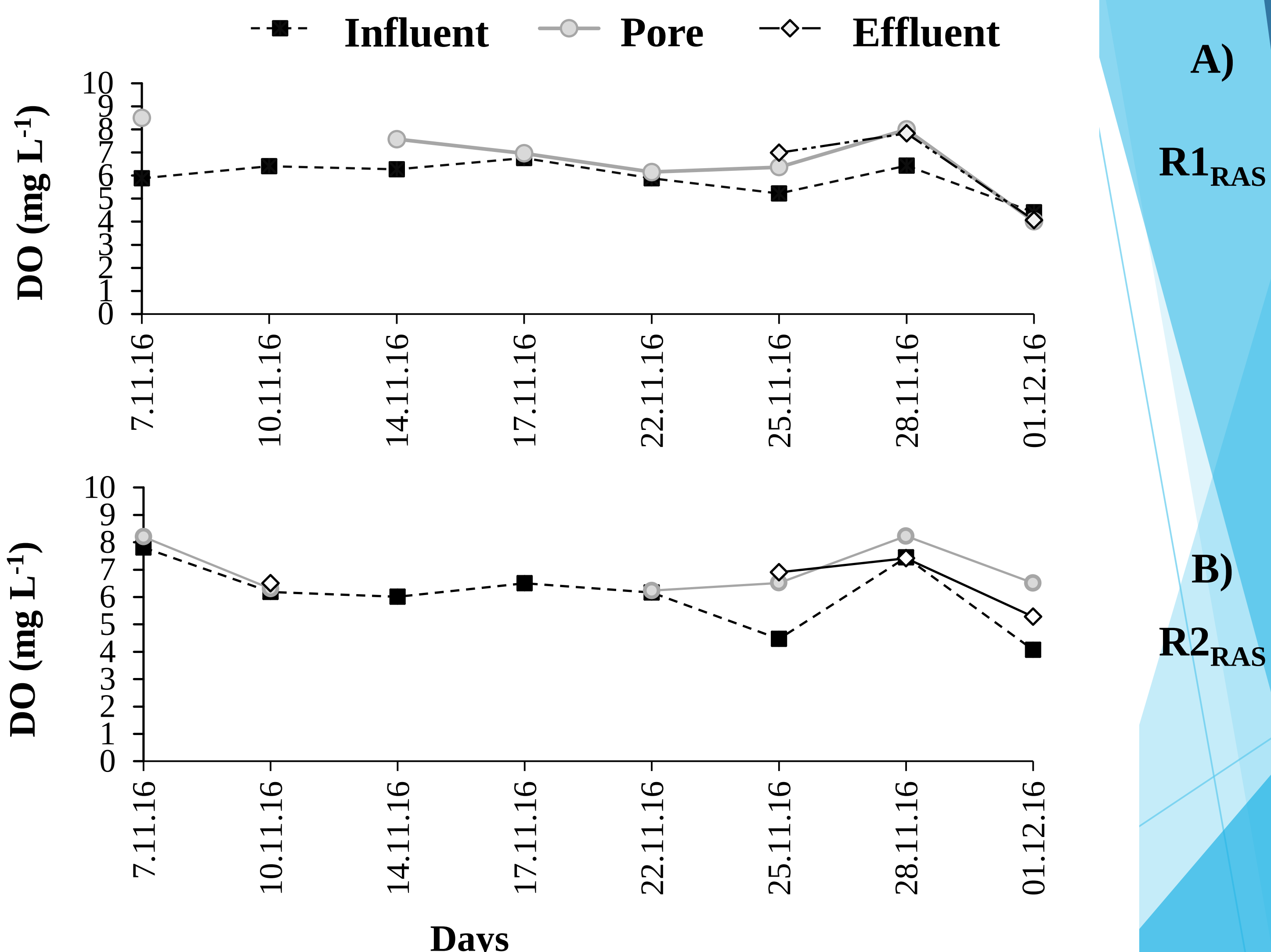


DO concentrations (mean, standard deviation). The dotted lines indicate the optimum DO interval of 5 a 7 mg L^{-1} for white shrimp culture (Martínez-Córdova, 1999).

- DO: **1 mg/L** → mortality (Díaz y Rosenberg, 1995).

Medina-Astorga, (2018)

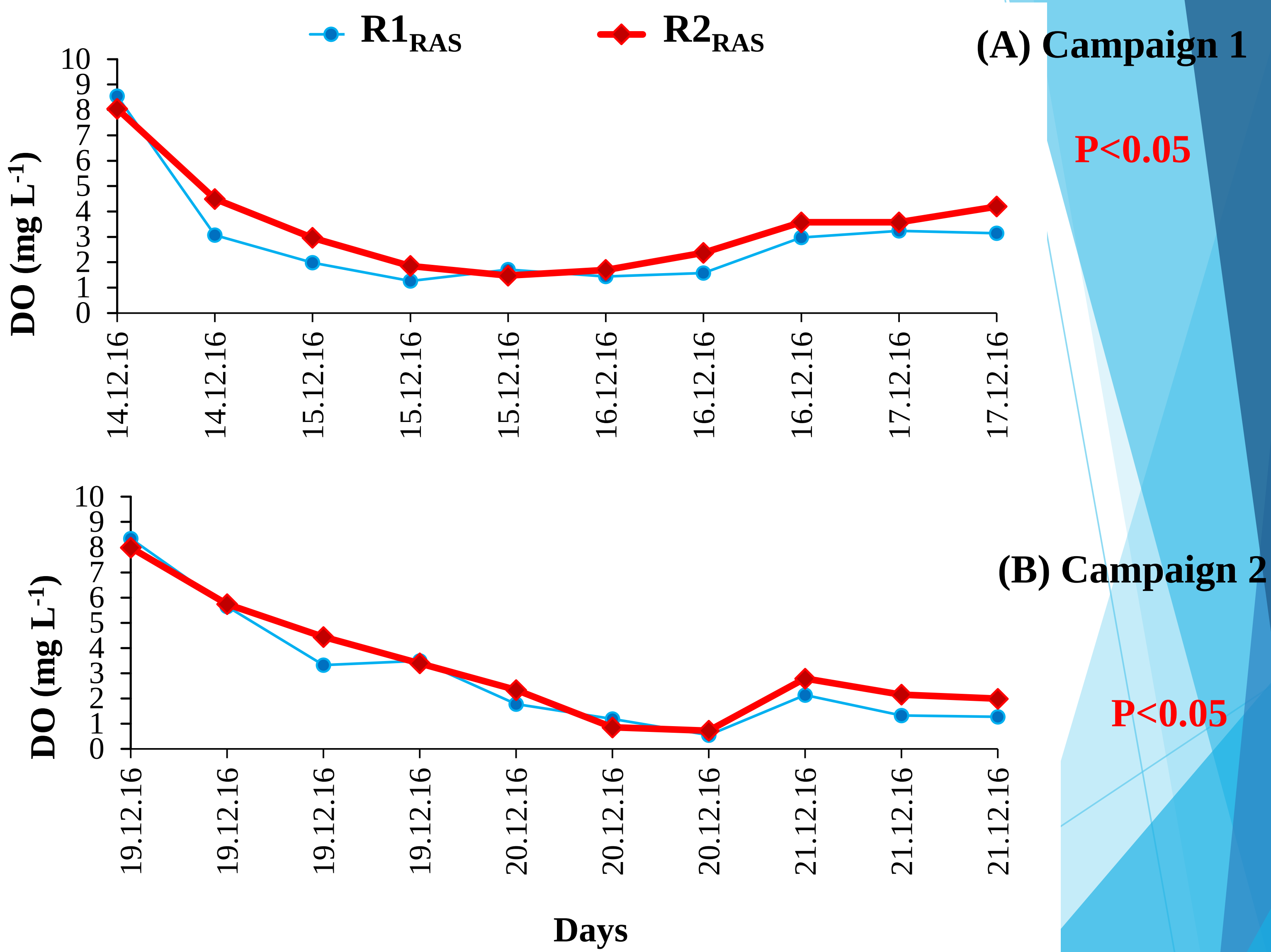
DO in the BFW-T ($R1_{RAS}$ y $R2_{RAS}$): with external aeration



DO concentrations (mean) in the $R1_{RAS}$ (A) and $R2_{RAS}$ (B): with external aeration

Medina-Astorga, (2018)

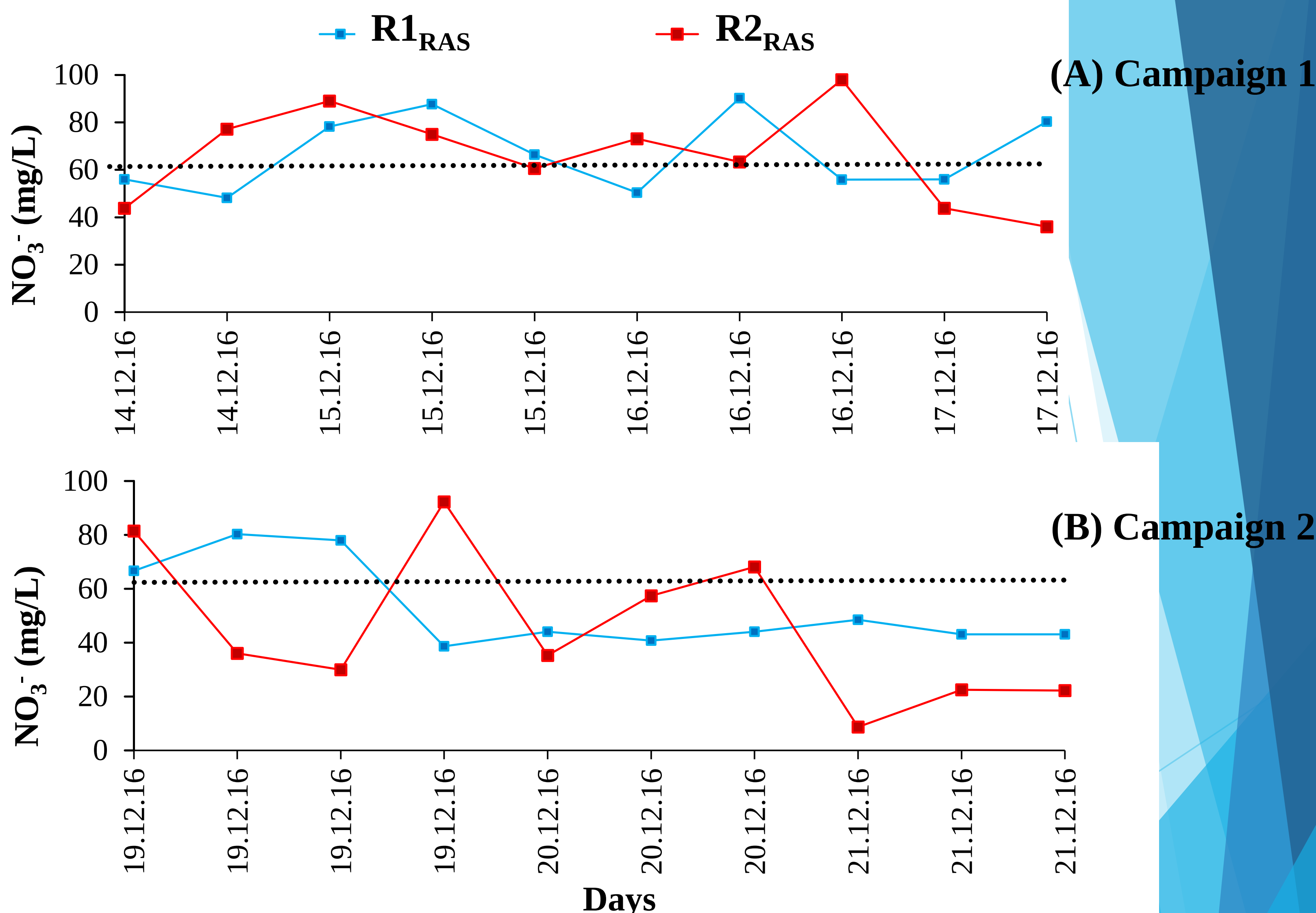
DO in the pore of both BFW-T ($R1_{RAS}$ y $R2_{RAS}$): without external aeration



DO concentrations (mean) in $R1_{RAS}$ y $R2_{RAS}$ during campaigns 1 (A) y 2 (B).

Medina-Astorga, (2018)

Nitrate in the pore of both BFW-T ($R1_{RAS}$ y $R2_{RAS}$): without external aeration



NO_3^- concentrations in $R1_{RAS}$ and $R2_{RAS}$ in both sampling campaigns: 1 (A) y 2 (B). The black dots indicate the maximum value of NO_3^- for the culture of *L. vannamei*: 60 mg L^{-1} (Van-Wyk & Scarpa, 1999).

Medina-Astorga, (2018)

Productivity (mean): Intensive *vs* RAS

Culture	**Inicial W (g)**	**Final W (g)**	**Survival (%)**	**Biomass (g)**	**Final density (org/m^3)**
Intensive	0.008	1.881	68.45	1,288	685
RAS	0.008	1.434	82.30	1,180	823

The relationship between survival-biomass has been documented in literature (Wasielesky *et al*. , 2013; Esparza-Leal *et al*., 2015; Ray y Lotz, 2017).

Medina-Astorga, (2018)

	C1-Intensive	**C2-Intensive**	**C3-RAS**	**C4-RAS**
Seawater (L)	4600	4600	1000 + 150	1000 +150

Evaporation losses were compensated with sea water in all systems

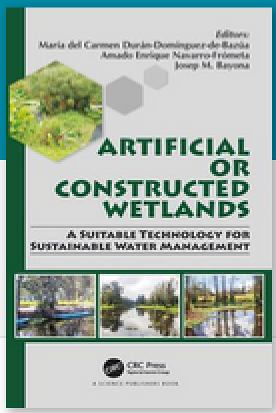
Water saving of 78 % in RAS

50

Conclusions

- The BFW-T were efficient for the removal of settleable solids (Removal>99%).
- The BFW-T were efficient for the removal of nutrients (NH_3 + NO_2^- + NO_3^-) between 15 y 40 %.
- The Dissolved Oxygen concentration in the pore of the BFW-T significantly reduced without external aeration. Thus, nitrate concentrations in the pore were reduce as well.
- The *L. vannamei* survival was better in the RAS cultures than the intensive cultures. In contrast, the biomass (g) was higher in intensive cultures tan in the RAS.
- The water demand in the RAS culture of *L. vannamei* was 78% les than in the intensive cultures.

Book chapter



Artificial or Constructed Wetlands

A Suitable Technology for Sustainable Water Management

Edited By María del Carmen Durán-Domínguez-de-Bazúa, Amado Enrique Navarro-Frómeta, Josep M. Bayona

Chapter 12

Bioremediation of Shrimp Aquaculture Effluents: The Convenience of Artificial Wetlands

By Otoniel Carranza-Díaz, José Guillermo Galindo-Reyes

Pages 16

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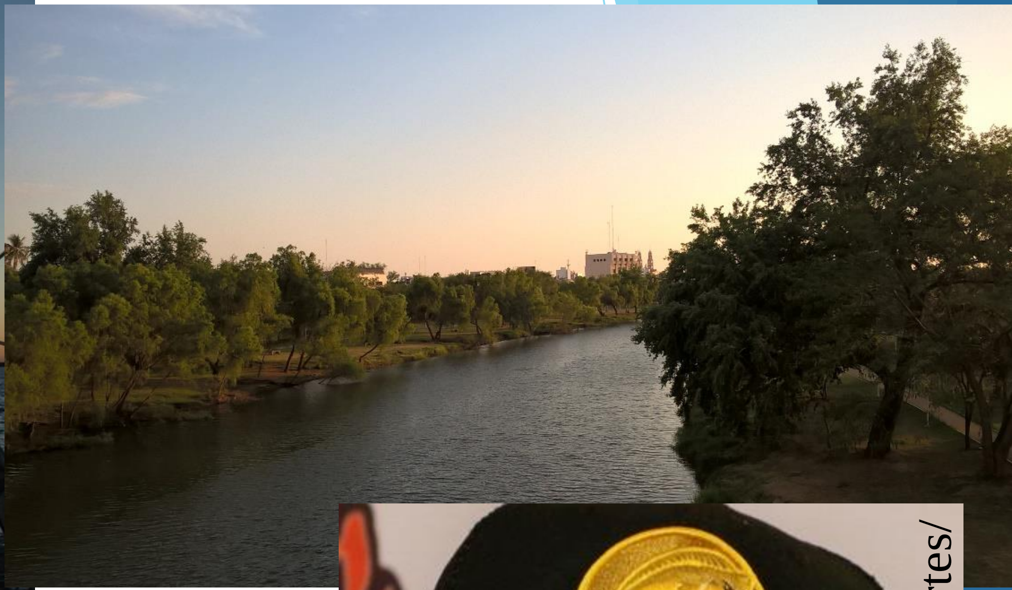

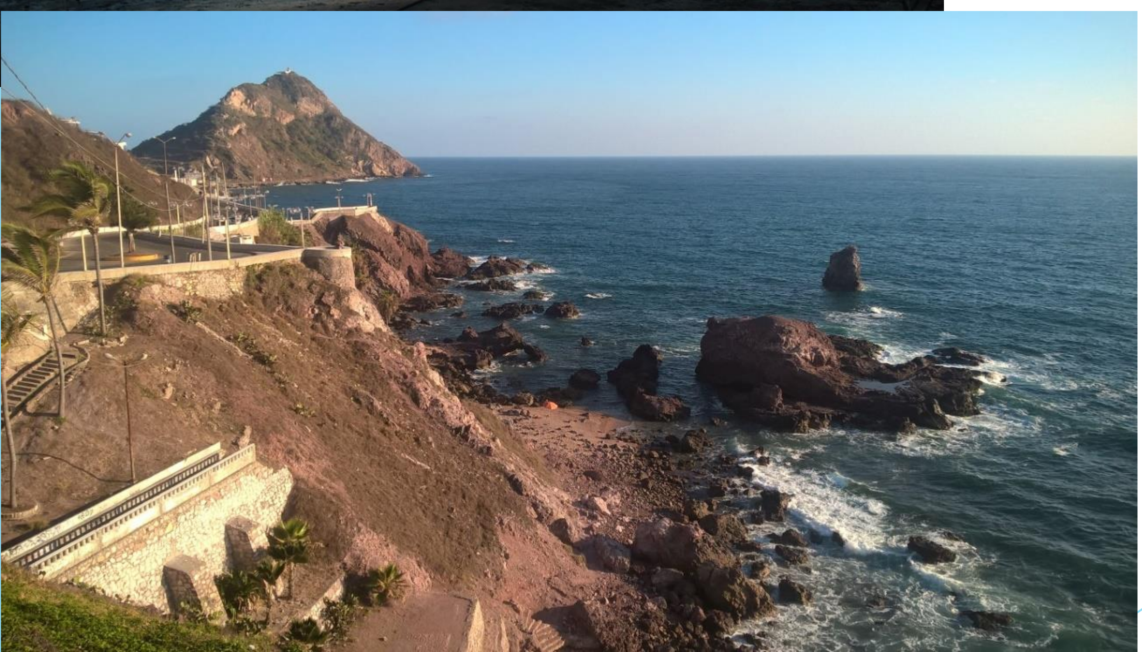

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¡¡Thank you very much!!

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- Proyect PROFAPI UAS 2015/060
- Proyect PROFAPI UAS 2015/172
- Proovedora de larvas FITMAR (donation of organisms)
- Laboratorio de ecofisiología de organismos acuáticos y cultivos de apoyo para la acuicultura (UAS)
- Laboratorio de toxicología y contaminación (UAS)