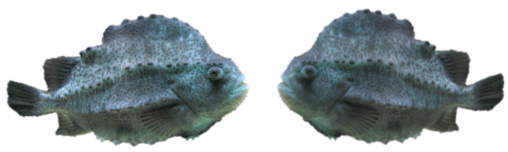
# INTEGRATE FACTSHEET 3
## Managing a pilot-scale recirculating IMTA system

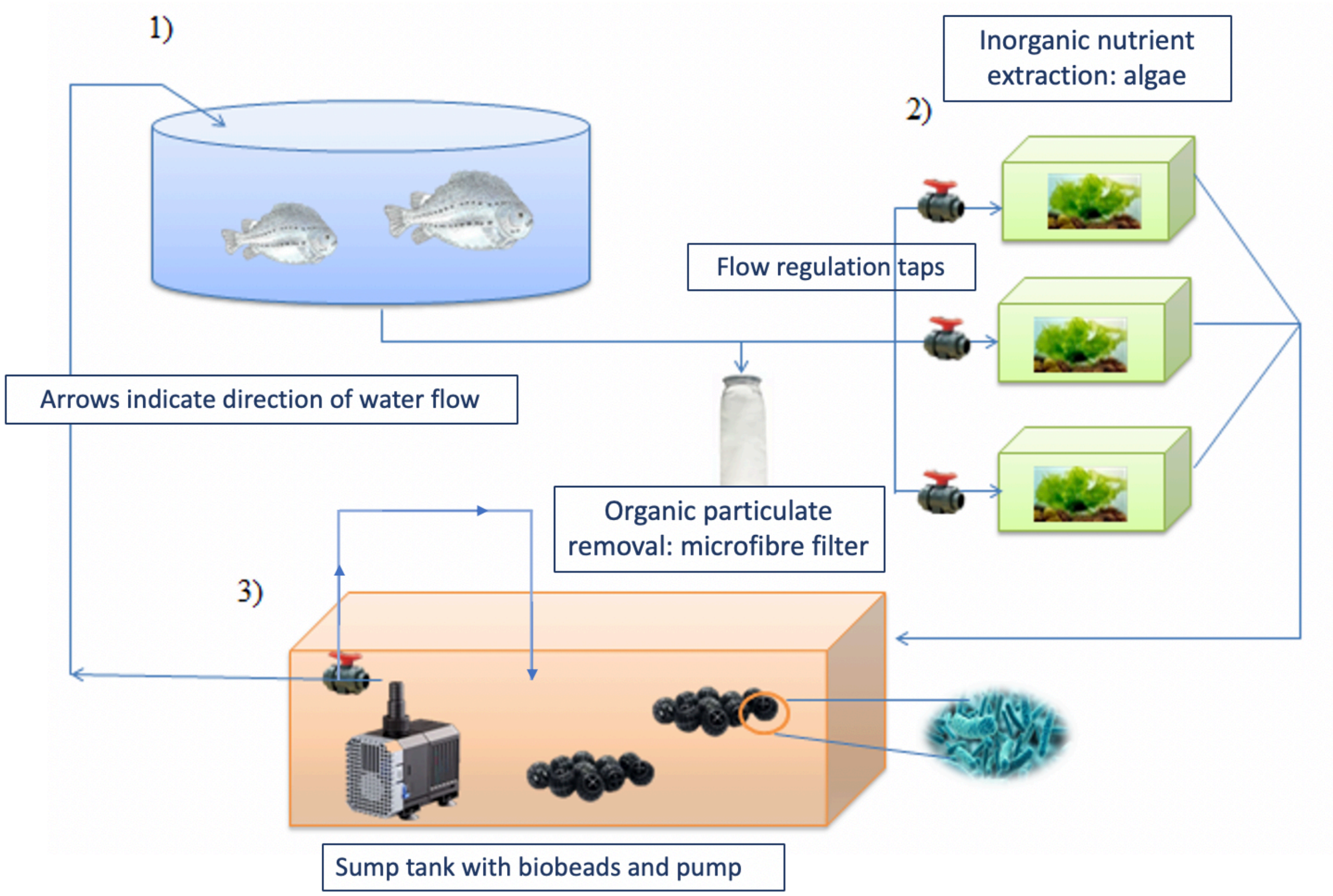
Irish Seaweed Research Group & Aquaculture Nutrition and Aquafeed Research Unit
The Ryan Institute, National University of Ireland, Galway



### INTRODUCTION

This factsheet will provide a brief overview of some aspects of the management of a simple, 2-trophic level **recirculating aquaculture system (RAS)** for research purposes**.** It follows on from factsheet numbers 1 and 2 in this series and, like the previous ones, this is not a step-by-step guide, but rather an overview of some things that are important to consider when your RAS is up and running. It is best read in conjunction with Factsheet 2 as many aspects discussed here are also important in the design and planning phase, and *vice versa*. A selected bibliography is included at the end for those who want greater detail of some of the topics mentioned.

Based on: **Our model – A fish (lumpsucker; *Cyclopterus lumpus*) and seaweed (sea lettuce; *Ulva* spp.) marine partial RAS** (schematised diagram below with explanatory text on the following page).



**Overview of the system:** Treated water is pumped from the sump into the fish tank (1) where it enters via a pipe *above* the water surface. This maximises oxygenation of the water as it enters the tank, and the position of the inflow pipe is such that the water is directed to circulate around the tank. The water flows out of the fish tank via a central standpipe that is covered with mesh to prevent fish/food escaping. It is filtered through a fine mesh filter to capture fine particulate matter before the flow is split 3-ways, providing equal flow to each seaweed tank (2). The seaweed tank outflow pipes are positioned at the water surface and mesh covered to prevent seaweed flowing to the sump. Each tank drains directly into the sump (3), which holds biobeads containing the bacterial biofilter at one end, and the pump that drives the system at the other, returning water to the fish tank. At the inflow to each of the seaweed tanks, and the outflow of the sump are flow regulation taps so that the flow into each compartment is effectively independent and can be easily adjusted according to need.

## THINGS TO CONSIDER

1. **What to cultivate**
2. **Stocking densities & relative volumes;** ratio of one species to another to fulfil *x* % bioremediation or *x* volume of production
3. **Maintenance of water quality**
   - **Biofilter**
   - **Flushing and makeup water**
   - **Daily monitoring**
4. **Optimisation of the system**
   - **Nutrient dynamics**
   - **Factors**
   - **Research questions and assessment**

## 1. Choice of Species


- **Local/locally adapted:** take care to consider that your species is appropriate to local conditions and the other species in your system. It is also of critical importance to risk assess and mitigate the potential for releasing non-local species into the surrounding environment. Biosecurity protocols are well established for aquaculture systems and these should always be adhered to but the safest approach is to only use species that are native to the area.
- **Market AND/OR non-market value:** This refers to the fundamental question of saleability, but also whether your chosen species may have a functional role in the system (i.e. waste remediation) even if it is not produced for profit. It may increase the efficiency of the system and therefore overall profitability while not being saleable itself.
- **Availability:** Can they be procured locally? Either from wild sources (is this legal/ appropriate?) or is there a hatchery nearby?
- **Husbandry knowledge:** Is the species already cultivated with well established techniques?
- **Compatibility:** Consider intra-specific trophic compatibility i.e. filter feeder that selects waste of the size that is produced / seaweed that preferentially uses ammonia.
- **Regulatory considerations:** Check with your aquaculture regulator.

**Our species:** *Ulva* spp. and *Cyclopterus lumpus* (sea lettuce and lumpsucker). These are both **local,** with established **market values,** were **available** in a local hatchery (lumpsucker) or in the wild (sea lettuce). **Knowledge** is widely available for cultivation of *Ulva* and we had extensive local knowledge of lumpsucker husbandry. Our motivation was to further knowledge of the **compatibility** of these species in an IMTA RAS.

## 2. Stocking Density & Relative Volumes

Stocking densities will be set according to known good husbandry practices of all species. For intensive systems this will mean the maximum (practical) stocking density of the fed species and for the extractive species this will often be a trade-off between factors i.e. ideal growth rate vs percentage bioremediation required.

Relative volumes refers to the proportion of one species to another, largely in terms of the remediation capacity of the extractive species. This will likely be a balance between space available and percentage remediation required

## 3. Maintenance of Water Quality

### Seeding and Managing the Biofilter

Biobeads may be seeded simply by running the system with a very low, and slowly increasing, input of ammonia until the bacterial populations build up sufficient numbers to be capable of transforming waste of animals at full stocking density. The ammonia may be supplied by adding ammonia to the system directly, without the introduction of any animals, or by the introduction of a low stocking density of the organism to be cultivated. The speed at which bacterial populations build will be dependent on the temperature, the supply of ammonia, and the initial supply of bacterial seed and so the ability of the system to deal with waste should be tracked continuously throughout this time. This is achieved by taking measurements of ammonia, nitrite and nitrate which will allow you to understand what is happening in your system and how you need to adjust the quantity of animals / ammonia / biobeads / inorganic extractive organisms to achieve a balanced system. Bacteria may be seeded naturally or by introducing appropriate species using a biofilter seeding product.

**Flushing and Makeup Water:**

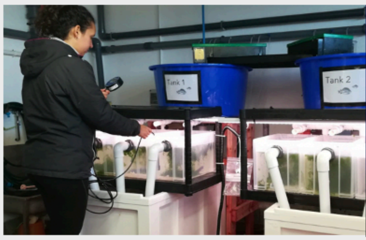
Water quality is paramount in most aquaculture systems and will affect not only growth rates and quality of the stock/crop, but declines in water quality may result in partial or full loss of the stock/crop. As outlined in Factsheet 2 water quality is maintained using a combination of particulate and dissolved waste removal, either using organisms (IMTA) or various mechanical and biological filtration systems. These processes maintain optimal water quality parameters under normal operating conditions, however, on occasions partial or complete water exchanges may be required. This may be by design, for example to fallow tanks or ponds between crops to manage pests or pathogens before re-filling, or it may be a measure introduced in an emergency if water quality fails and the organisms are in danger. Some systems use a partial flush and refill as routine, or to provide 'make-up' water, to compensate for what is lost to evaporation.

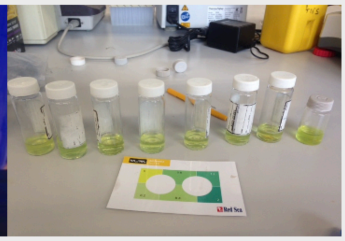
**Performing a partial flush of the system**

**Daily record keeping and monitoring:**

Because of the closed (or partially closed) nature of RAS, and the speed at which systems can fail if water quality declines, monitoring water quality must be carried out regularly. Daily logs must be maintained that include both physical and chemical parameters:

- temperature
- dissolved oxygen
- salinity (in marine systems)
- pH
- ammonia
- nitrite
- nitrate



Many commercial RAS are very high-tech and have fully automated systems that monitor water quality parameters in real time and will create an alert if certain thresholds are crossed. For small or non-commercial systems it is sufficient to carry out several daily checks and log the results. There are many single or multi-parameter probes that are sufficient for these purposes, and many home aquaria testing kits for approximate testing of water chemistry.

## 4. Monitoring and optimising the capacity of the extractive species

A useful initial question to ask is whether the focus for the inorganic extractive species is to be on maximising its productivity or maximising its remediation potential, as these will probably necessitate differing management strategies. For example, a focus on productivity may require a shorter water retention time in the algal tanks as algal nitrogen uptake rates are generally higher at higher concentrations (but this itself may depend on the internal N concentration of the algae). Both productivity and/or remediation will be affected by a range of physical, chemical and biological factors, and the interactions between these.

**Understanding the nutrient dynamics of the system:**

It is important to have an idea of how the nutrient dynamics of your system are likely to function before you design it so that you make appropriate decisions about relative tank volumes and flow rates – even if these are likely to be optimised further later. Necessary initial calculations are the nitrogen – N (and/or phosphorus - P) that will be input to the system, and what concentrations and forms of nitrogen is required by the algae in order to sustain growth in an optimal range.

### Estimating N input (fed species):

**Stocking density:** according to known husbandry practices
**Feed rate:** according to known husbandry practices
**Protein content of feed:** given on all feed packaging
**Protein to nitrogen conversion factor:** There is a fixed nitrogen to protein conversion factor of 6.25 that has been used by convention and can be used in the absence of specific information. It would be preferable if the nitrogen content of the feed is known or can be estimated directly as each foodstuff will in fact have a slightly different conversion value.
**Of N ingested, what is excreted as dissolved inorganic nitrogen (DIN)?** This may not be known depending on the state of research for the species in question but in some cases estimates exist in the literature. If not, a very rough guess can be made using the estimates for a different (but trophically similar) species.

**Worked Example:**

| | |
|---|---|
| **ESTIMATING N INPUT** | |
| | **Stocking density = 20 kg m$^{-3}$** |
| | **Feed rate = 1% of average fish bodyweight** |
| | **Protein content of feed = 62%** |
| | **Protein to nitrogen conversion factor = 6.25** |
| | **Excretion rate as DIN = 39% (of total N input)** |
| **Calculation:** | |
| | 20 kg = 20 000 g |
| **Feed input per day** | 20 000 g @ 1% = 200 g feed day$^{-1}$ |
| **Protein input per day** | 200 g @ 62% protein = 124 g protein |
| **Nitrogen input per day** | 124 g protein * 6.25 = 19.84 g N day$^{-1}$ |
| **DIN fraction excreted** | 19.84 g * 0.39 = **7.73g** DIN m$^{-3}$ day$^{-1}$ |

### Estimating N uptake (algal):

- **Stocking density**
- **Expected growth rate**
- **Internal N concentration**
- **Wet weight : Dry weight**

All this data will ideally come from pilot studies with similar cultivation conditions, but otherwise from cultivated or wild estimates in literature if they exist.

**ESTIMATING N UPTAKE**

**Initial wet weight stocking density per 1m$^2$ tank = 2kg**
**Expected growth rate = 15% day$^{-1}$**
**Internal N concentration = 3% (dry weight)**
**WW:DW = 10:1.5 (15% moisture)**

| Day | WW (g) | DW (g) | Internal N (g) | N required (g) |
|---|---|---|---|---|
| 1 | 2000.00 | 300.00 | 9.00 | |
| 2 | 2300.00 | 345.00 | 10.35 | 1.35 |
| 3 | 2645.00 | 396.75 | 11.90 | 1.55 |
| 4 | 3041.75 | 456.26 | 13.69 | 1.79 |
| 5 | 3498.01 | 524.70 | 15.74 | 2.05 |
| 6 | 4022.71 | 603.41 | 18.10 | 2.36 |
| 7 | 4626.12 | 693.92 | 20.82 | 2.72 |
| 8 | 5320.04 | 798.01 | 23.94 | 3.12 |
| 9 | 6118.05 | 917.71 | 27.53 | 3.59 |
| 10 | 7035.75 | 1055.36 | 31.66 | 4.13 |

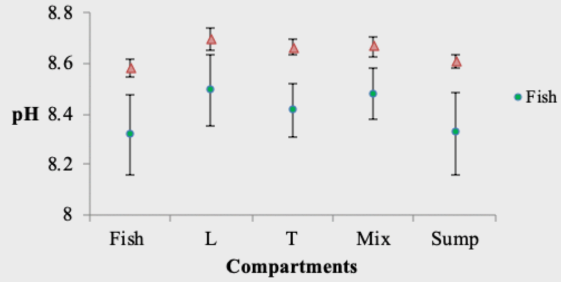
### Balancing input and uptake & harvest

An estimate of how much algae the DIN entering the system will be able to sustain can now be made. Of course, this is a very gross estimate subject to many sources of error, but should serve as a starting point from which to design and understand a system, and to guide initial expectations.

It can be seen that the nitrogen released by the fish (7.73 g m$^{-3}$ day$^{-1}$) in this hypothetical example should be sufficient to sustain the needs of the algae (max 4.13 g m$^{-3}$ day$^{-1}$). However, consider that it is very unlikely that the algae will be so efficient as to remove all of it, and secondly that as the algae grow their requirement increases but they may also be subject to density dependent effects that may alter the rate of uptake. Regular removal of biomass (harvest) will ensure that the stock remain at a density that optimises growth / uptake / remediation rate… see below.

## Factors affecting productivity and remediation rates:

- Stocking density
- Water flow rates and/or nutrient pulse dynamics
- Between species interactions: pests (e.g. epiphytic algae, nuisance algae), pathogens (pathogenic bacteria), antagonisms / synergisms between cultivated species
- Other nutrients/trace elements/contaminants etc.
- Temperature
- DO/salinity/pH
- Light: quality (spectral composition) and quantity (photon flux over time)



**Tracking the response of pH to the introduction of fish in each compartment of the RAS**

These factors are similar to those listed as necessary for daily monitoring. Broadly speaking, there will be a range within which the water quality parameters must be maintained to ensure the health of all the organisms cultivated within the system. Within this range there is scope for adjusting each factor to find its optimum range. Interactions between factors mean that there may be several optimal combinations, which might produce slightly different outcomes in terms of bioremediation or productivity, and therefore suit different situations. Finding these optima will be part of the research, development and commercialisation process.

## Research questions and assessment:

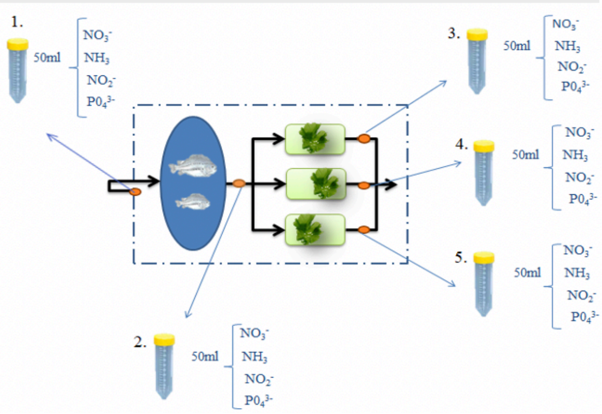
Optimising the system will be a long process of successive trials looking at the effects of the above factors on growth, productivity and remediation rates. Of course, specific questions will depend on the state-of-the-art of knowledge pertaining to those species and their interactions, or what it is feasible to modify within the bounds of the system. In our case, we chose to look at between species interactions within the macroalgal biofilter and effects of temperature and photoperiod/light intensity on macroalgal growth. We measured both growth and productivity of the algae, and took regular water samples to relate the nutrient concentrations in the system to algal growth and productivity. The diagram in the section below shows the points in the system where water samples were taken (fish inflow; fish outflow; individual seaweed tank outflows).

**Productivity:** total biomass generated through time

**Growth Rate:** expressed as relative growth rate to take the initial size of the organisms into account

**Remediation:**

- Effluent – tracking the concentrations of the nutrients at certain times will give a snapshot of what is happening **at that time**. Because nutrient concentrations vary widely depending on parameters such as feeding times and dark/light cycles this does not provide a comprehensive view of the system unless a very intensive sampling regime is undertaken, which is both time consuming and costly. (N.B. Aquarium test kits are not sensitive enough to measure effluent for research purposes.)
- Biomass – amount of extractive organism biomass generated over time x internal N concentration will give a mass-balance quantity that provides an integrated picture of uptake over the course of *n* days/weeks etc. This is less able to elucidate detailed nutrient dynamics in the system but gives a reliable estimate of remediation potential of your species.
- Combination – a combination of mass-balance type estimates (biomass based) may be used in conjunction with an effluent monitoring protocol to gain an overall understanding of the system and how it is responding. There are many possibilities for design and it is recommended to search the literature to get a good picture of what is possible. The diagram below shows the points in our system at which effluent was monitored, firstly on an intensive basis several times over 24h, and then on a weekly basis to corroborate the mass-balance estimates.




**Summary schema:**

1. Decide focus and main questions of interest
2. If the system is new, estimate N input to system, and N required by algae in order to start the system at a sensible point
3. Assess effects of factors by monitoring effluent/productivity and internal N concentrations of algae
4. Repeat, adjusting according to the new information and/or assessing new factors

### Useful Literature


**Pattillo, D.A. (2015).** Water quality management for recirculating aquaculture. Iowa State University Extension and Outreach. FA 0003A.

**DeLong, D.P. and Losordo, T.M. (2012).** How to start a biofilter. Southern Regional Aquaculture Center (SRAC) No. 4502.

Example of trial systems: **Meng, L. Callier, M.D., Blancheton, J-P., Galès, A., Nahon, S., Triplet, S., Geoffroy, T., Menniti, C., Fouilland, F., Roque d'orbcastel, E. (2019).** Bioremediation of fishpond effluent and production of microalgae for an oyster farm in an innovative recirculating integrated multi-trophic aquaculture system. Aquaculture 504, 314-325.


## Takeaway points from factsheets 1 – 3 in this series:

- RAS & IMTA are both tools that can be used to improve certain metrics relating to aquaculture sustainability
- RAS improves water use efficiency, effluent quantity/quality and land footprint; IMTA improves nutrient use efficiency and can (but not necessarily) improve productivity per unit area
- Building a recirculating IMTA requires design of a closed (> 90%) system that has an internalised water 'cleaning' processes, at least some of which are biological in nature ***and*** result in production of additional species for harvest
- Various different scales, complexity, species combinations and levels of commercialisation are possible
- Trophic connectedness and species compatibility are fundamental concepts for these systems
- Recirculating IMTA systems are in the early stages of development and commercialisation
- R-IMTA (or M-RAS – multi-trophic RAS) can generally be regarded as an example of sustainable intensification but care must be taken as neither system is inherently 'sustainable', but dependent upon context (location, site, species, system) and trade-offs between different sustainability metrics are inevitable.