A DEVICE FOR INCREASING FISHERY PRODUCTIVITY IN POOR COASTAL COMMUNITIES.

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INTRODUCTION

In many third world countries yields from coastal fisheries have decreased due to poor fishing practices such as overfishing or destructive fishing measures, e.g. the use of explosives or poisons, like cyanide. (FAO 2005-13). In the poorer areas with inadequate road access and little cash, the sea nearby is the major source of protein, but the available fishing equipment remains relatively simple. Artificial reefs have been used in many locations (Pickering and Whitmarsh, 1997) to increase fish catches, but these may just increase fish yields in the vicinity of the reef without an overall increase in numbers of fish, in which case they would easily lead to more over-fishing. The proposal being examined is for an artificial reef, which could enclose an amount of added nutrient (e.g. urea or a locally available fertiliser), held for sufficient time to grow phytoplankton within it to form the base of a local food chain, so as to increase overall productivity. This would provide a source of increased protein for a local community. The proposal is for this to be made, as far as possible, from locally available resources, using local skills and labour.

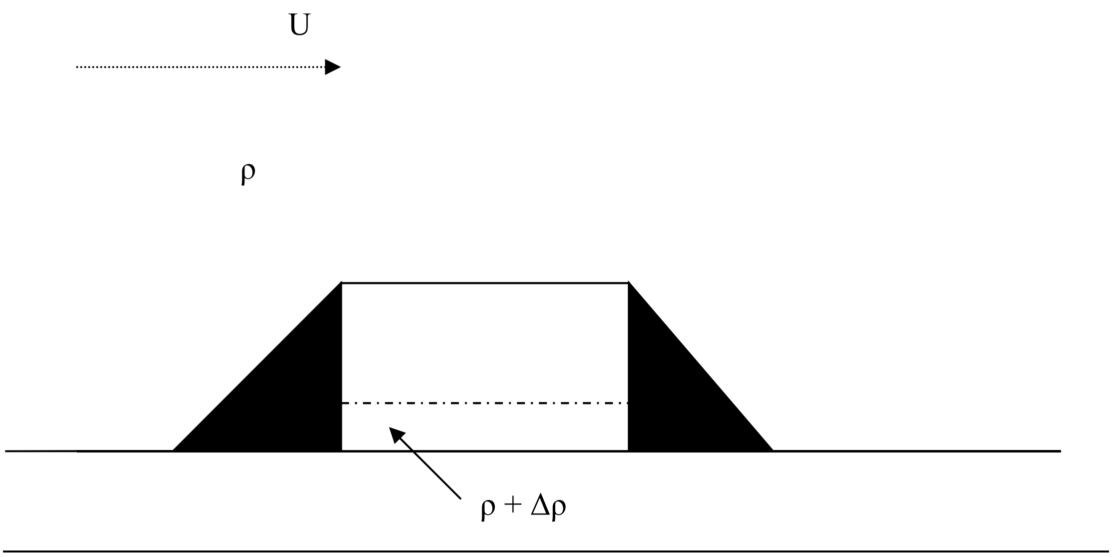
The aim is to construct an artificial reef in the photic zone of the coastal ocean that acts as a bioreactor able to produce organic carbon for consumption by organisms higher in the food train. A potential site being investigated for such a reef is in the Beqa Lagoon, near Yanuca Island, Fiji (Calamia et al., 2010 and website of Pacific Blue Bequa Lagoon Marine Reserve Project.) The rate of growth of phytoplankton concentration depends, amongst other things, on the assemblage of phytoplankton species, the photosynthetically available radiation (PAR) the available nutrients and the dilution rate. Growth is achieved by cells dividing and so the greater the concentration of cells, other things being the same, the more organic carbon is produced from a given volume of sea water. If this volume of sea water in the bio-reactor is continuously being exchanged with surrounding water of low phytoplankton concentration, the amount of phytoplankton produced in the bioreactor is reduced. The aim of a nutrient retaining artificial reef is to have a dilution rate that carries away the phytoplankton produced at a rate that maintains a high concentration of phytoplankton in the reef and consequently high production rates of organic carbon.

As well as limiting the dilution rate, the artificial reef needs to capture enough PAR to provide the energy needed to support photosynthesis. If we imagine cavities of simple shape admitting PAR from above, the relationship between upper open area and the volume of the cavity becomes an important consideration. It may be that to sufficiently restrict dilution in the cavity while maintaining high PAR within it, it will be necessary to use an upper surface for the cavity that is light transparent. This second line of investigation is left for a further study if a simple cavity does not appear to achieve sufficient PAR while trapping a volume of water.

Laboratory experiments have been carried out to examine the design features necessary for an artificial reef to retain an amount of nutrient, in our case urea, for sufficient time for phytoplankton to grow. The report first looks at the physical parameters which need to be considered in order to correctly scale up from laboratory models to full scale structures. This involves the use of non-dimensional groups of relevant parameters because retention times found at laboratory scale need to be adjusted to scale up to full scale. Retention times found in the laboratory have to be scaled up correctly to give valid results for full-scale structures. The report presents the laboratory equipment and measurement methods used. The experimental results are then presented. These results are then discussed.

SCALING FROM LABORATORY TO FULL SCALE

To scale up laboratory results to a full-scale case dimensional analysis must be used to obtain useful results.



The parameters governing the behaviour of the flow are:

Mean current velocity U;

Fractional density difference due to dissolved urea $\Delta\rho/\rho$, or even better buoyancy difference, $g\Delta\rho/\rho$;

where ρ = water density;

Some geometrical scale of the reef H, taken as cube root of included volume;

Kinematic viscosity ν (= μ/ρ.), where μ = viscosity;

Time for urea or dye to be removed by the flow T;

Molecular diffusivity of urea k;

Geometrical factors for different shapes.

That is 6 parameters, ignoring geometrical differences for the moment, and as there are 2 dimensions, length and time. Using $\Delta\rho/\rho$ and μ/ρ avoids using mass as a dimension, as is normal fluid mechanics practice. From the Pi Theorem only four non-dimensional groups are required.

These would be Richardson Number, Ri, Reynolds Number, Re, Schmidt Number, $Sc = \nu/k$, and a non-dimensional time TU/H. Sc will be the same in both the laboratory and at full scale.

$Ri = g(\Delta\rho/\rho)H/U^2$, $Re = UH/\nu$.

Ri is the ratio of buoyancy forces, which suppress mixing, and inertial forces which tend to enhance mixing. Re is the ratio of inertial forces to viscous forces.

It is impossible to have both Ri and Re matching in both laboratory models and in full-scale field tests. Normal practice is to at least have turbulent flow in both and attempt to match Richardson Numbers. If the flow is fully turbulent in both then inertial forces and mixing from the turbulence should totally dominate over viscous and molecular diffusivity effects. Results from the laboratory can then be presented using the non-dimensional variables Ri and TU/H, and these can then be converted to the full-scale. Once the full-scale dimensions are decided, times, T, at full scale can be estimated. However flow velocities within the reef structure will be much lower than outside it, and fluid viscosity and molecular diffusivity will be more important in the laboratory than in the field. However the laboratory experiments should still give a good indication of what will happen at full scale.

EXPERIMENTAL EQUIPMENT AND METHODS

Experiments were conducted in a flume, shown in Figure 1, which was 312 mm wide by 300 mm deep, with water depth of approximately 240 mm. The flow was driven by a 2hp Onga™ pool pump (model 800644). There was a conical diffuser, shown in Figure 2, at the start of the flume with diameter going from approximately 50 to 250 mm. This was followed by a channel section into which a deflecting vane was inserted to help better distribute the flow. This was then followed again by a flow straightener consisting of a bank of 23 mm diameter plastic tubes, 310 mm long, which filled the channel cross-section (See Figure3). From the downstream end of the flow straightener to the end of the flume there was a working length of 3.17 m.

For lower velocity cases (5 cm/s) a splitter plate was placed near the centre of the channel and the flow on one side was slowed by inserting a second bank of 23 mm diameter plastic tubes with Styrofoam pushed into them. Much of the flow was thus diverted to the unrestricted part of the flume. The low speed section was 117 cm long and 19 cm wide.

Water flow velocity within the flume was monitored with a Marsh –McBirney Flomate™ Model 2000 portable electromagnetic flow meter. The accuracy of the meter was determined using two flow meters, and the low-tech method of tracking and timing the movement of particles in the flow. The digital flow meter had a resolution of 0.1 m/s and a stated accuracy ±2%, but this is improved by increasing the period over which the device calculates the average flow. Averaging for ten second was used. Flow speeds in various experiments varied from 5 to 12 cm/second and were uniform over the flume throughout any one experiment with the exception of the end of the channel, where the water sped up to enter the return-pipe.

Conductivity was measured with a WTW LF330 conductivity meter.

To examine the retention times of a few simple containers - a laboratory beaker and two different laboratory flasks were used. The water within a container had red coloured food dye added to it, to make it clearly visible and had varying amounts of urea dissolved in it to provide various density differences. Some cases were run with no dissolved urea. The containers were spaced well apart, three at a time so as to shorten the overall time required for the tests, with either differences in the amount of urea used, or using different shaped containers. The separation between flasks was sufficient for wake effects on mean velocity to be too small to measure. Retention times were obtained by measuring the amount of time required for all of the dyed liquid to be removed from the container by the flow. Initially a lid was placed over a vessel's mouth and the pump turned on. Once the flow had stabilised the lid was removed and timing commenced. Observations with the conductivity probe indicated that the interface observed between the dyed and clear liquid corresponded to that between the urea solution and the ambient water. It was quickly found that retention times in the straight sided beaker were low, for all urea concentrations tested, so results from it are not included. (However later tests with a cover on the beaker, but without urea, were carried out and are discussed below)The geometry of the flasks, see Figure 4, helped restrict entrainment of liquid out of the containers. Two flasks were used: a nominally 250 ml flask, with a volume of 330 ml when full to its rim; and a nominally 500 ml flask, with a 630 ml volume when filled to its rim. Both had a 4 cm diameter opening.

Experiments without dissolved urea.

To examine the effects of varying the relation between container volume and opening size, without the densification effects of added urea, three other series of tests were performed using:

(1) 630 ml flask whose internal volume was varied by partly filling it with sand;
(2) 640 ml straight-sided beakers which had plastic lids in which different size openings were cut;
(3) a straight sided beaker with a fine gauze covering its mouth.

RESULTS

Experiments on flasks with dissolved urea.

Results are first presented in non-dimensional form in terms of TU/H versus Ri, as described above. To calculate the ratio $\Delta\rho/\rho$ in the Richardson Number, Ri, the mass of urea used was divided by the mass of water within a flask. This is an approximation, but because of the properties of urea it should not be a bad one. Results are shown in Figure 5, where the length scale H is taken to be the cube root of a flask's volume. These results are from experiments using the 630 ml and 330 ml flasks with flow speeds between 5 and 12 cm/s, and a range of urea concentrations. It can be seen that, for lower values of TU/H the Ri values for the 630 ml flask are lower than those or the 330 ml flask, but for higher values of TU/H results for both are very similar. This is strange as one would expect that the effects of different geometries would persist throughout the TU/H range.

Because the water within a flask was dyed it could be observed that, for cases with urea dissolved in this water, it was flushed out fairly quickly initially and then more slowly and that a sharp interface formed between the dyed, denser water and that above.

The conductivity measurements confirmed this, showing that for most of the upper volume inside of the flasks, the conductivity dropped dramatically almost immediately upon exposure to a external flow. No matter the initial concentration of salts, the decline in conductivity when measured near the bottom of the neck section was sharp and immediate, plummeting down to just above ambient conductivity shortly after removing the lid.

Experiments without urea added

To examine further the effects of geometrical changes two further series of experiments were performed..

(1) The volume inside the 630 ml flask was reduced by adding variable quantities of sand, so that the fluid volume inside the flask varied from 630 to 140 ml. The results are shown in Figure 6, where it can be seen that the retention time decreased with fluid volume, as one would expect, as there would be less fluid to remove through the same area opening.

(2) Secondly a series of experiments were carried out on 640 ml beakers whose mouths were covered with plastic film, in which different size single holes had been cut. As expected retention time increased as hole size decreased, as shown in Figure 6. (The volume stated here is that for a totally full beaker, not its nominal volume).

(3) Thirdly an experiment was carried out using a 640ml beaker with a fine gauze covering its mouth. Gauze. Retention time was 75 minutes, which was much longer than for any of the other beaker experiments, and gives a TU/H of 5232.

Reynolds Number effects.

As noted previously, because flow velocities within the flask would have been considerably lower than those outside, the fluid viscosity and molecular diffusivity would be more important in the laboratory experiments than in a full scale situation. This would modify the results but the broad conclusions should still be a good indication of what will happen in the field.

Laboratory Reynolds Numbers, based on flask diameters (neck to base) were in the range 2,000 to 10,300. The Reynolds Numbers within the flasks are likely to be a tenth of these values.

DISCUSSION

Flask experiments, with urea.

It can be seen from Figure 5 that with a large enough Richardson Number values of TU/H up to at least 270,000 can be obtained. For large TU/H a straight line through the data gives:

$$TU/H \approx 393,000\ Ri = 393,000\ g\ (\Delta\rho/\rho)H/U^2,\ Ri >> 0,$$

or $$T \approx 393,000 g(\Delta\rho/\rho)H^2/U^3.$$

So if a full scale artificial reef is ten times bigger, say, than a laboratory scale one, retention times at full scale will be one hundred times bigger, for the same $\Delta\rho/\rho$ and current.

As an example for TU/H = 135,000, with full-scale H equal to 1 m and an ocean current of 0.1 m/s, this is equivalent to a time of 12 days, which would be more than enough for plankton to grow. The Ri for this case would be 0.34, which for the above H and ocean current would require a $\Delta\rho/\rho$ of 1/2800, which seems quite feasible.

However the urea rich layer retained for that long would be in the bottom of a conical vessel, in which the light levels might not be sufficient for phytoplankton to grow fast enough. Some studies need to be carried out to determine if light levels would be sufficient in the locations where our artificial reef would be installed. Also a vessel with sides sloping inwards would not be easy to construct for a subsistence community, so more easily constructed shapes, which would retain the urea, or other fertiliser, need to be considered.

Experiments without urea.
For the experiments on 630 ml flasks with varying internal volume TU/H values up to approximately 3000 were obtained, while those for the plastic covered beakers were up to approximately 2000. At full scale with U of 0.1 m/s and H of 1 m, these correspond to retention times of 30,000 and 20,000 secs, respectively, or 8.3 and 5.6 hours which is quite inadequate. The experiment with a gauzed covered beaker yielded a non-dimensional retention time, TU/H, of 5232, which translates to a retention time of 14.5 hours, which is still inadequate.

CONCLUSIONS AND RECOMMENDATIONS

These laboratory experiments have demonstrated that it is possible to retain urea in a structure for sufficiently long for phytoplankton to grow, provided that the structure is suitably designed. It needs to have a volume within it sufficiently enclosed so as to retain the denser urea solution. A sharpish interface will form, within the structure, between the denser solution and the less dense water above it.

It will be necessary to design a structure which is easy to build and much larger than the laboratory model and which will not only retain the urea solution, but which will allow in sufficient light for the phytoplankton to grow.

ACKNOWLEDGEMENTS

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FIGURES

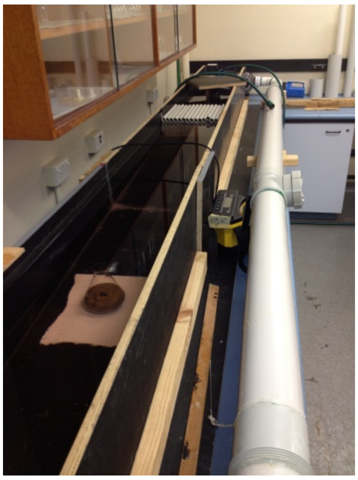
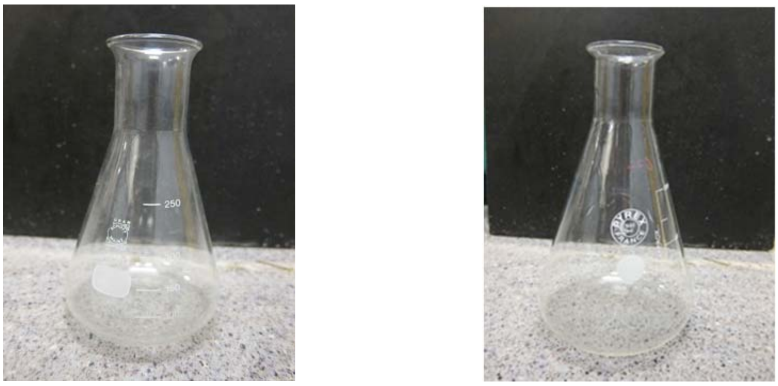


Figure 1. Flume

Figure 2. Diffuser

Figure 3. Flow Straightener



a b

Figure 4. Flasks used for measurements of retention times: (a) 330 ml flask with 4 cm diameter mouth; (b) 630 ml flask with 4 cm diameter.

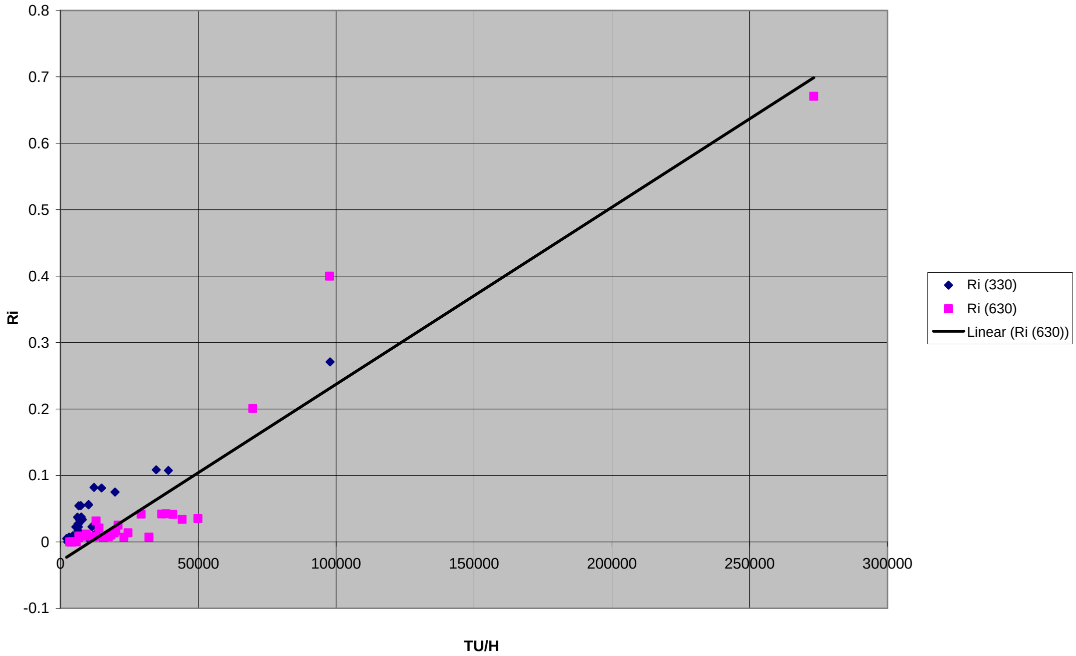


Figure 5. Richardson Numbers for 630 ml flask, Ri (630), and for 330 ml flask, Ri (330) versus non-dimensional time, TU/H.

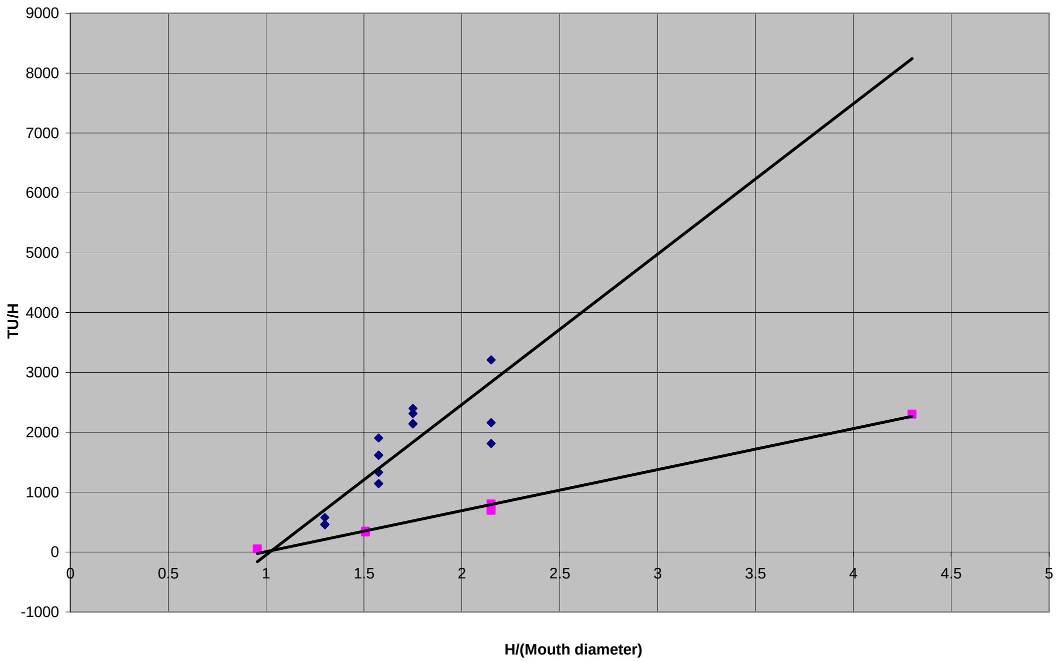


Figure 6. Non-dimensional time, TU/H, for cases without dissolved urea (zero Richardson Number) versus H/(Opening diameter)
Blue diamonds are for 630 ml flasks with varying internal volumes; Cyan squares are for covered 640 ml beakers with varying openings).