Final report for Mini-project MS0506:

Village Scale Sponge Aquaculture in the Solomon Islands

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Summary

This report describes progress in this ACIAR Mini-project funded through the larger ACIAR Project "Sustainable aquaculture development in the Pacific Islands region and northern Australia" designed to address technical issues regarding village culture of bath sponges is Solomon Islands.

To date we have shown that;

- The pacific bath sponge, *Coscinoderma mathewsi* is abundant in the Western Province of Solomon Islands.
- The sponge grows from 5 to at least 30 m depth, with most sponges being below 10 m. Large sponges tend to be more frequent at greater depths, though can be found throughout the depth range. Sponges are sufficiently plentiful to support small farming enterprises based on use of wild stock for provision of cuttings.
- Wild stock grow in the preferred shape for taking edge cuttings, and once cuttings are suspended from grow-out structures, the shape tends towards that of the desired commercial product.
- Two grow-out structures that result in the desirable rounded shape have been identified, horizontal lines and frames. Growth of sponges close to the reef slope or at depths of approximately 20 m has been shown to result in low epiphyte growth. Most rapid growth of cuttings measured to date, however, has been on horizontal lines at 10 m, on the reef slope. Evidence of an apparent depth-effect on growth rate on the reef slope is contradicted by other observations in open water and requires further clarification.
- Growth rates of wild sponges, cuttings and re-growth rate of donor sponges used to provide cuttings have been measured. Wild sponges grow at exponential areal growth rates of up to 0.4 y^{-1}. Re-growth rates of donor sponges of 0.4 to 1.0 y^{-1} (by area) have been measured.
- Cuttings approximating 40 mm cubes heal and grow quickly. Exponential volumetric growth rates of such cuttings are of the order of 0.3-1.0 y^{-1}. Smaller cuttings can be made, though these heal much more slowly and suffer substantial tissue loss. Small cuttings can be made more effectively if strips of sponge are cut first and allowed to heal before further cuts are made to create small cuttings (to 20 mm cubes).
- There is considerable variation between the growth rate of cuttings from different donor sponges and the option of selecting broodstock appears top be a good one. The fastest growing cuttings will grow from 40 mm to a market size of 120 mm within less than one year, while slower growing cuttings may take up to 2 years.

1. Introduction

Sponge mariculture is an industry that has simmered in the Western Pacific for many years. Initially developed by the Japanese over 60 years ago, only at Pohnpei in the Federated States of Micronesia has it been developed as a serious industry (Croft, 1990; MacMillan, 1996). There it flourished for some years, but appears to have declined in importance once technical support from donor agencies was withdrawn (Lee and Awaya, 2002). A small scale sponge farming initiative has been set up in Fiji, again with technical support to initiate the activity, where sponges are intended to be marketed to local tourists.

Despite the apparent lack of success, sponge farming remains an attractive proposition for those attempting to bring new rural industries to developing communities in the Western Pacific. This is because sponges suitable for farming are widespread and often abundant, the activity uses truly simple techniques, requiring very little specialist equipment and the intermediate product is light in weight and non perishable. Because of these factors sponges are an ideal industry for remote villages in less developed countries. Offsetting these favourable factors are the rather low wholesale price that can be obtained for small, easily grown sponges, and the long grow-out time required to produce the large sponges that are the most financially lucrative. In addition, wholesale markets require large numbers of sponges on a regular basis, which unsophisticated village producers can struggle to supply (Lee and Awaya, 2002).

Overcoming the barrier of a small financial return for farmed sponges has prompted attempts to identify a niche market outlet for sponges which should make village farming more profitable (e.g. Kelly-Borges 1995; 1996). Shifting emphasis from bulk production to specialist markets requires new research to determine how best to satisfy this demanding niche. It is research underpinning the marketing of sponges as sustainably cultured, clean, green, Solomon Island village products that is the basis of this research programme, funded as a miniproject within the ACIAR "Sustainable Aquaculture Development in the Pacific Islands Region and Northern Australia" Project. In particular we have tried to identify techniques to ensure environmental sustainability and to produce sponges with appropriate size and shape for niche markets. In addition we have attempted to determine the acceptability of sponge farming to Solomon Island communities and to begin selection of fast-growing strains.

While this report will coincide with the termination of this funding for this project, many of the experiments that have been set up will not finish until well after this, due to the long grow-out cycle of sponges. WorldFish Center staff in Solomon Islands are committed to continuing to service these experiments for at least another year, and we are confident that information collected will be communicated to those interested in this activity.

2. Objectives

The objectives, as set out in the application for this project are as follows;

1. Determine the distribution of sponge species suitable for aquaculture and the sponge trade within the Western Province, Solomon Islands
2. Initiate experiments to maximise healing and growth rates of cuttings to reduce the production cycle length.
3. Develop a suspension mechanism to improve sponge shape.
4. Identify an overseas buyer, determine the optimum sponge characteristics (size, shape etc) and the minimum volume and timing of shipments likely to be needed for a sustainable industry.
5. Determine the likely returns to farmers and their attitudes to the techniques to be used and the time and space constraints.

This report covers these objectives, though not all have been fully addressed at the moment. While the funding for this project runs out in December 2006, activities will continue using the in kind support provided by WorldFish Center in Solomon Islands. The incompatibility of the grow-out cycle of sponges and the duration of this project means that many experiments must continue for one or more years before definitive answers are available.

What has become clear during our work is that wholesale marketing of sponges into the bulk sponge trade is unlikely to realise enough return to make villagers invest significant amounts of time and effort in sponge farming. Instead we are attempting, in collaboration with other sustainable sponge farmers, to target niche markets for environmentally friendly/fair trade products in order to obtain a premium price for growers. Key research for this market is to attain a definitively sustainable approach to culture, and to develop systems for growing large numbers of large, rounded sponges in as short a time as possible. This interim report therefore focuses on the dynamics of natural populations and the best methods for establishing a genuinely sustainable farming approach (Objective 1), on testing various suspension methods for quality of sponge shape and ease of operation (Objectives 2 and 3), and preliminary results of sponge marketing to overseas buyers and to potential growers (Objective 4 and 5).

3. Activities

3.1 Environmental sustainability

A typical reef in Solomon Islands, as with all coral areas, supports a plethora of species of sponge, with a wide range of morphologies. As part of this project we surveyed the reef at Nusa Tupe, the island near Gizo in Western Province where the WorldFish Center is located and, with the assistance of Michelle Kelly from NIWA, New Zealand, produced an annotated list of the larger, foliose, epilithic sponges (Appendix 1). Of the sponges found only one, *Coscinoderma mathewsi* is recognised as being of commercial value. This is the sponge that has been traditionally used as a bath sponge by some Melanesian communities and the one that has previously been cultured at the Pohpei farm (MacMillan, 1996). *C. mathewsi* comes in three major morphs, which can tend to grade into each other, at Nusa Tupe; bracket, vase and spheroid (Figure 1). Vase and bracket shapes tend to merge and, as in the example below, we have termed an incomplete vase/near circular bracket a "broken vase".

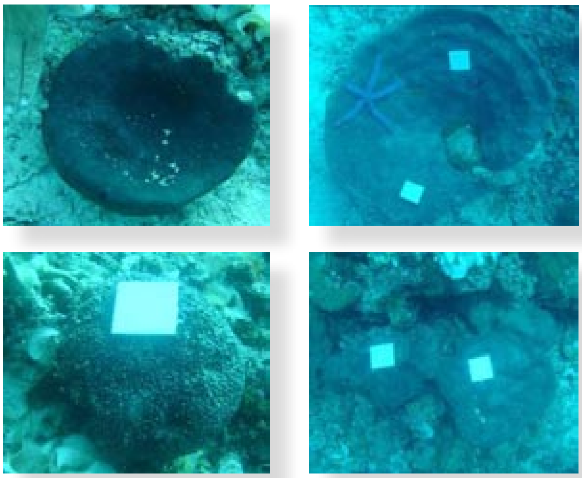

Figure 1. The major morphs of Coscinoderma mathewsi at Nusa Tupe. Where visible, the white scale object is a 61 x 61 mm bathroom tile. Top left- vase, Top right - "broken vase", bottom left - spheroid, bottom right - bracket.

3.1.1 Dynamics in natural populations

Methods

To determine the distribution of *Coscinoderma mathewsi* on Western Province reefs we undertook a systematic census of sponges in a 300 m length of reef at Nusa Tupe. Within this range the reef crest was 2-3 m below low water, the reef slope descended steeply to 20 m where it began to level off. Reef gradually gave way to sand over at 25 m depth. The section of reef haphazardly selected for the survey was divided into two sections each of 150 m, and transects along the main axis of the reef were swum in each section in turn by scuba divers centred on 22, 17, 12 and 7 m depth. On each sweep, divers scanned a 2.5 m depth band either side of them and noted all individuals of *Coscinoderma mathewsi*. For each sponge, a note was taken of the depth of growth. A digital photograph was then taken perpendicular to the flattest plane of the sponge, from approximately 1 m away, after one or two (depending on the size of the sponge) 61 mm square white tiles were placed on the sponge as scale targets.

On return to the laboratory, the images were downloaded onto a laptop computer and analysed using the freeware image analysis package Image-J. Image-J is a relatively simple tool that allows a scale to be set from a reference target, then this scale can be used to measure user-defined lengths and areas. The image analysis protocol was as follows. Firstly the contrast of the image was adjusted to provide the clearest resolution of the edges of the sponge and the target. A scale for the image was derived using (one of) the white targets; the edge of the target closest to the dominant plane of the sponge was used for setting the scale. If two targets were used on a large sponge, the second was then measured using the "measure length" option in Image-J. If the measured length was found to be more than 2 mm in error, parallax effects were inferred, and the image was divided into two parts by drawing a line equidistant between the two targets and each part was analysed separately. Analysis comprised measuring of the length (longest axis), breadth (longest perpendicular to length), area and perimeter of each sponge.

This survey was used to provide a snapshot of the structure of the *Coscinoderma mathewsi* population at Nusa Tupe. In order to determine growth and mortality rate, all of the sponges in the first half of the 300 m survey area were marked with numbered plastic tags attached to rocks adjacent to the sponge. Only sponges that were firmly attached to coral rock were included in the tagging programme. After 4, 8 and 16 month intervals, these sponges were relocated and measured again (Note that the 16 month measurements have yet to be made). Where sponges were no longer at the site where they were tagged they were recorded as lost from the population (even though they may have detached and still survived). After 16 months, a second comprehensive survey will be made and all sponges in the 300 m reach will be re-measured. We anticipate that after the 16 month survey (October 2006), an annual re-visit will be made for at least three more years.

Since the majority of wild sponges at Nusa Tupe are relatively flat vase or bracket shapes, growth rates of tagged sponges were calculated over two dimensions, i.e. based on area. We have used a simple exponential growth model:

$$A_{(t)} = A_{(0)} exp(t \cdot \mu_a) \quad \text{.......................Equation 1}$$

where $A_{(t)}$ is area at time t, $A_{(0)}$ is area at time zero and μ_a is areal growth rate over time interval t.

Results

1. Depth distribution of sponges

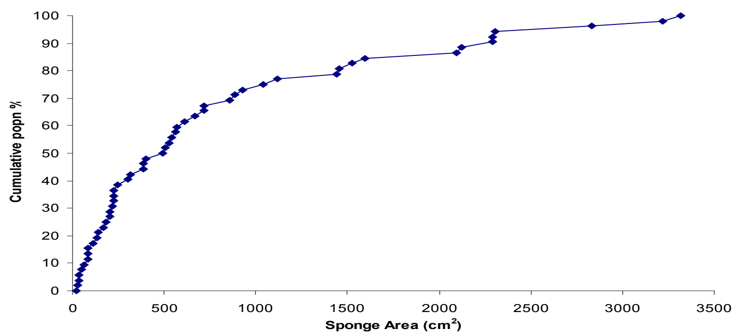

Figure 2. Cumulative frequency curve for sponge size (as area seen from above).

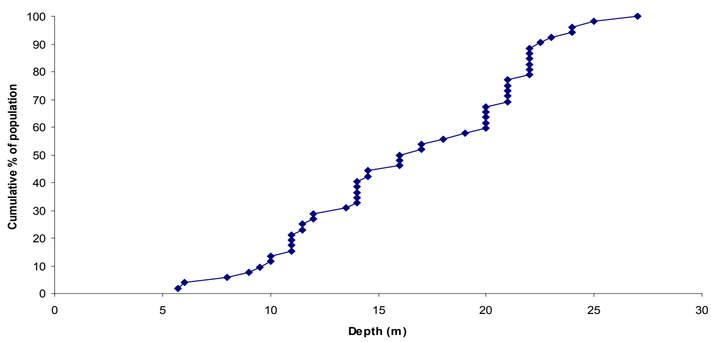

Figure 3. Cumulative frequency curve for sponges by depth (to nearest 0.5 m of recorded depth, not normalised to chart datum).

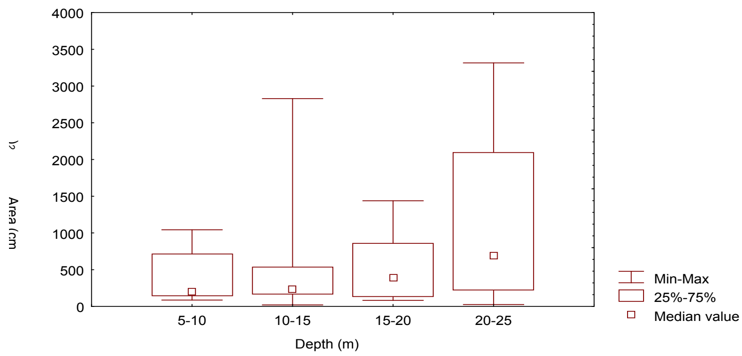

Figure 4. Sponge area, our measure of size, within four, 5 m wide depth bands. Symbols are medians, boxes are 25 and 75 percentiles, bars are ranges.

In total 53 sponges are were found on the survey dives. The population shows an exponential size structure, with many small sponges, a median size of 500 cm^2 and the largest sponge 3316 cm^2 (Figure 2). The largest sponge was also the longest, at 75.9 cm and was found at 22 m depth. The distribution of sponges by depth (Figure 3) shows that none were found above 5 m depth, and that most occurred below 10 m. Below 10 m the number of sponges appears to be largely independent of depth, though with a small peak in abundance at 20-22 m, followed by a drop at >25m. We note that the 20-22 m increase occurs at a depth where the slope of the reef decreases; the apparent increase in frequency may simply reflect greater useable substrate area per unit depth than at shallower depths. The drop in sponge frequency at 22-25 m corresponds to the change from rock to sand as dominant substrate.

When grouped into 5 m depth bands, there was an apparent tendency for sponges to be larger with depth (Figure 4). However, when analysed using a Kruskall-Wallace non-parametric ANOVA by rank (the area data are non-normal) this was found not to be significant (p = 0.29, n = 52).

2. "Mortality"

Using the working definition of mortality as a sponge that had fallen off of its perch, over 12 months of observation we recorded 6% mortality (three sponges). Two of these sponges were large bracket sponges and appeared to have torn off at the attachment point. While we can be confident that this indicates a low turnover, the numbers are too low to confidently use these to give a mortality rate. Our suspicion at this stage is that mortality is primarily due to sponges growing too large, and thus attracting too much drag in the presence of water motion, for the attachment point to withstand. This would also explain the tendency for the frequency of larger sponges to increase at greater depths, where water movement can be expected to be less than in shallow water. Several of the sponges showed evidence of damage to their margins, which we suspect is due to predation by the turtles commonly seen in the area, and it is possible that predation is a significant source of loss for smaller sponges.

3. Growth rates

Preliminary analyses of 2-dimensional exponential growth rate (μ_a), based on the first three measurements, give an overall average for μ_a of 0.23 y^{-1}. There is an intriguing indication that there may be two groups of sponges, one with a high growth rate (0.4 y^{-1}) and a second group showing little or no growth. There are no obvious other differences between the groups, as both contain all growth forms and are from a full range of depths. As the changes in size measured over these first periods are rather small, we would prefer to wait for the final measurements before considering growth rates in detail. In the meantime, we consider that using value of μ_a of 0.2 y^{-1} in further calculations in this report will be an appropriately conservative approach.

4. Photosynthesis

Many sponges contain symbiotic phototrophs, often cyanobacteria, and the predominantly lamellate growth form of *Coscinoderma mathewsi* is one that would appear to suit this mode of feeding. To determine if *Coscinoderma mathewsi* is photosynthetic, and if so, what are the optimal irradiances for photosynthesis (and hence the optimal depths for growth) we used a Walz Diving-PAM (a Pulse Amplitude Modulated fluorometer). This is a submersible, diver-operated instrument that can measure the fluorescence of chlorophyll-a and, by measuring the fluorescent yield in response to single flash of high intensity light, indirectly estimate the activity of photosystem II. Photosytem-II activity is an indicator of the rate of photosynthesis. However, despite the appearance of the sponge, we found that their chlorophyll-a fluorescence was extremely low, indicative of minimal phototrophic activity. In contrast almost every other sponge that we assayed was highly fluorescent, indicating the presence of phototrophic symbionts.

3.1.2 Sustainable broodstock management

The term sustainable has at least two meanings in sponge husbandry. Sustainable harvest is used by some to describe wild harvest where a small basal section of the sponge is left attached to the substrate, in the understanding that the sponge will eventually grow back from this fragment. This meets the sustainability criterion of not denying options to future generations, since the sponges have not been eliminated, though the consequences to sponge populations of individuals constantly remaining in recovery mode has yet to be considered. Our goal was to identify a mechanism for sustainably managing wild broodstock such that cuttings can be taken while retaining a near-natural sponge biomass.

Why use wild broodstock? Wild sponges tend to grow increasingly lamellate with size. This form is not suitable for niche marketing, since ovate bath sponges are preferred over flat ones. However, the lamellate form is ideal for taking cuttings, since cuttings recover most quickly and effectively if cut surfaces are kept to a minimum. Thus the edges of flat sponges can be used for making many cuttings, all with at least three of six sides undamaged. What is more, once a small segment of a lamellate sponge is taken into culture and suspended from a line, it tends to round up and form a sponge of the required shape. Finally, use of a range of wild broodstock animals rather than continuously cloning a few sponges will avoid two undesirable effects - the dominance of the local gene pool by a single genotype (we do not know the size at which these sponges reproduce) and vulnerability to disease that could come with low genetic variability. Thus there is a good argument to be made for managing large wild sponges as broodstock. We argue that if large wild sponges are husbanded such that edge material taken can be allowed to re-grow before another cutting is taken, then this would be a truly sustainable harvest. We used our estimate of 2-dimensional exponential growth to determine how large a sponge would need to be to re-grow a 50 mm strip around the edge within one year. 50 mm had been found previously to be a size that would almost guarantee that the cutting would survive and grow (smaller cuttings suffer increasing mortality).

For a circular sponge, the minimum radius (R) for a broodstock that will grow back to it original size within Y years at an areal growth rate of 0.2 y^{-1}, if 50 mm is removed will be given by

$$R = \sqrt{((R-50)^2 \cdot \exp^{(Y \cdot 0.2)})} \qquad \text{Equation 2}$$

This was solved in an iterative manner for periods of 1 to 3 years. The calculated predictions of necessary start radius for a given time between cutting are;

Table 1. Estimated time for a donor sponge of various start radii to recover the tissue lost from removal of a 50 mm wide strip of edge tissue.

Grow-out time (years)	*1*	*1.5*	*2*	*3*
Start radius (mm)	500	280	200	150

These calculations are based on the preliminary areal growth rate of 0.2 y^{-1} and on the assumption that growth of a cut sponge surface is at the same rate as extension of an uncut surface. Since few sponges have radii of 500 mm, and only large ones have radii of 280 mm, this analysis suggests that managing most potential broodstock sponges would mean taking cuttings at 2 year intervals.

In order to test this scenario, four sponges were selected, photographed and measured and the outer 50 mm was removed. The resulting strip of sponge was cut into approximately 50 mm squares and these were grown out on vertical long lines at 1 m intervals from 20 m depth upwards. Growth of the cuttings and re-growth of the donor sponges will be measured over the next two years. An example of the data to date, from one sponge, are shown below.

The sponge in Figure 5, of initial radius 200-260 mm might, on the basis of our measurements of growth rate of intact sponges, be expected to recover a removal of 50 mm of margin after 1.5 to 2 years (Table 1). The increase in dimensions over the 7 month period corresponds to exponential areal growth rates of from 0.45 y^{-1}. Overall, of the 20 linear measurements obtained, over a 7 month regrowth period we measured extension corresponding to an average exponential areal growth rate of 0.48 y^{-1} (standard deviation 0.29 y^{-1}), suggesting that the areal growth rate of of 0.2 y^{-1} obtianed from intact sponges underestimates the recovery rate of cut sponges. This apparent rapid re-growth of excised tissue is in agreement with other experimental findings where recovery from wounding was more rapid than "normal" growth (Duckworth and Battershill, 2003). The final results of this experiment will not be available until after the project has finished. Should the re-growth rate be as high as 0.5, then a large donor sponge (600 mm diameter) could be expected to recover lost tissue within nine months.

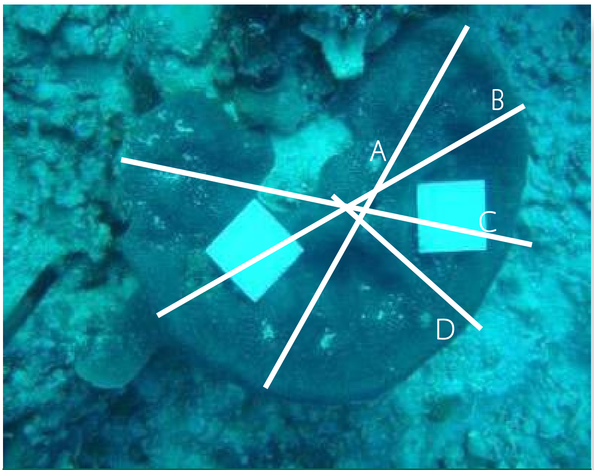

Figure 5. Sponge A. Tag 21, from 16.5 m depth of water. Dimensions A, B, C and D are shown in Table 2.

Table 2. An example of the initial recovery of a donor sponge (Figure 5) following removal of a 50 mm wide strip of edge tissue. All dimensions are in mm, and were measured on 13th April before and after cutting, then again on 18th July after 3 months recovery time.

Dimension	*13/4/06*	*After cutting*	*18/7/06*	*14/11/06*
A	390	290	340	350
B	400	320	340	360
C	390	280	320	350
D	260	210	220	210

3.2. Management of cuttings

Acceptance of sponge culture within villages seems to be strongly affected by how the amount of time that needs to be invested compares with the reward that can be realised. Since the reward from sponge aquaculture is likely to be rather small, at least initially, then if husbandry activity can be kept to a minimum outside the set-up and harvest periods, then we believe that there is more likelihood of success. The villagers that we have worked with so far have shown that they have no concerns over the farm structures, which we deliberately set well below the surface, but there is concern over who will purchase the sponges, which have no obvious value to villagers, and for how much.

3.2.1 Suspension systems for cuttings

Several experiments have been set up to identify a simple, low cost and low management input system for growing sponge cuttings, and to determine which produced the best shapes. Three basic suspension structures have been used, vertical lines, horizontal lines and frames (Figure 6). For horizontal and vertical lines, cuttings are attached using a loop of 15 lb fishing line threaded through the sponge. For frames, the 100 lb line that forms the grid of the frame is threaded directly through a hole made in the sponge. In early experiments, rice bag string (lengths of the raffia that is woven to form rice bags - plentiful and free) was used for threading through the sponge, but this was found to degrade after six months or more in the water.

Horizontal lines have been deployed at two locations, Nusa Tupe and Diamond Narrows (close to Noro, in Western Province). At Nusa Tupe two types of horizontal lines have deployed, reef lines and open-water lines. Reef lines were deployed at 5, 10, 15 and 22 m, with small floats weighted down by bags of coral rock used to hold lines 1 m above the bottom on the reef slope from which the sponges were collected. Open-water horizontal lines were anchored in 30 m of water over a sandy bottom well clear of the reef. These lines were tied between two vertical lines at 10 m depth.

Vertical lines were deployed at Nusa Tupe only, and these were away from the reef. Vertical lines comprised a subsurface float (at 5 m) from which a line weighted by a bag of coral rock was lowered to the bottom. Sponge cuttings were attached at 1 m intervals to these lines.

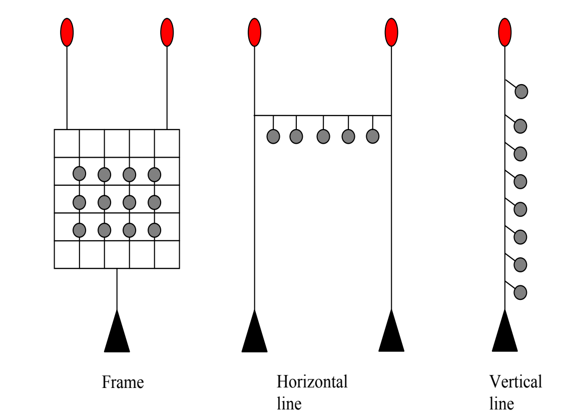

Figure 6. Basic arrangements used for culturing cuttings. Red ovals indicate buoys, black triangles, anchors (bags of coral rock) and grey circles, sponge cuttings. The illustrations are all for open water systems, and in all cases the buoys floated 5 m below the surface. Horizontal lines deployed on reef slopes were as above (centre) but with much shorter vertical lines.

At Diamond Narrows horizontal lines only were deployed and all were close to the reef, at 10 m depth. The Diamond Narrows trial was set up with collaboration of the local people and has been designed to test a system with minimum husbandry input. Essentially the villagers observed the techniques of making the cuttings and threading them on to line and the cuttings have been checked only once before the harvesting, which is planned for October 2006 (one year). At Diamond Narrows location we used either 6 mm, 3-strand rope or 120 lb test fishing line as supporting lines from which sponges were hung to determine whether different types of line suffered different degrees of fouling, and whether this made a difference to sponge growth.

3.2.1.1 Initial results comparing different types of sponge deployment

Reef slope deployment

Deployment of sponge lines in 5 m of water on the reef edge was not a success. Within one month a storm had removed all of the cuttings from the line and none could be relocated. We attribute this to wave action, since a line in shallower water inside the reef crest did not suffer the same fate At 10 m depth, only one cutting was lost, while at 15 and 22 m none were. Examination of healing showed that at all depths, healing, in terms of re-

Figure 7. Two sponge cuttings growing on a horizontal line at 10 m on the Nusa Tupe reef slope. Note the lack of epiphytes, despite the abundance of algal growth on neighbouring rocks.

growth of pinacoderm (the black external "skin" of the sponge), was complete within 1 week. It was evident, but not quantified, that the intensity of pigmentation was greatest in shallowest water. We hypothesise that the dark pigment has a UV screening role. Initial growth rates have been measured for this experiment are and presented in section 3.2.3 below. Fouling was found not to be an issue with reef slope deployments (Figure 7), with only minor coverage with films of cyanobacteria at times.

Sponges on horizontal lines at Diamond Narrows have yet to be harvested for measurement of growth.

Open water deployments

Open water horizontal lines and frames have been in the water only since July 2006.

Open water long lines were set up in April 2006 and are beginning to show interesting results. Healing of the sponges was good, with no obvious differences with depth. Fouling has, however, become an issue after three months, much more so than on horizontal lines on the reef slope. Figure 8 (compare also to Figure 7) shows how this is much more of a problem in shallower water, as might be expected. What is not clear yet is whether using three-strand rope for vertical lines has promoted fouling, since these lines tend to foul much more than fishing line. The important comparisons between fishing line and rope at Diamond Narrows and the performance of open water horizontal lines at Nusa Tupe compared to horizontal reef slope lines still needs to be assessed over a long enough period.

Figure 8. Sponges deployed on a vertical line in open water at Nusa Tupe. The left hand cutting was incubated for three months at 7 m depth, the right hand one at 17 m depth. It is clear that fouling is greater on the shallower sponge.

Frames have also proven to be effective. The frames that we used were made from PVC pipe (Figure 9), though inexpensive local materials such as bamboo should be equally effective. The advantages of a frame is that a large number of sponges can be grown in a small space without hindering water flow, that orientation is fixed and that they can easily be moved between sites and depths. Frames can, for example, be deployed at 10 or 15 m depth by lowering on a rope from a canoe, and retrieved easily for cleaning without any need for SCUBA diving. Frames are also easier to load with sponges, and have the advantage of a single thread rather than a loop running through the sponge (loops can lead to slightly misshapen sponges if it becomes too tight as the sponge grows and begins to constrict. The next phase with frames will be to assess the extent to which they suffer fouling in long deployments, and whether they are effective when deployed on the reef slope.

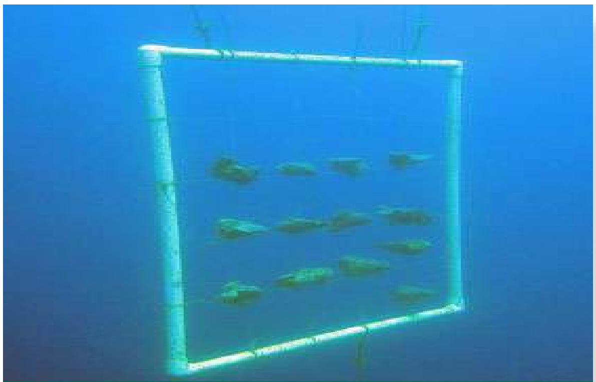

Figure 9. A frame of sponge cuttings after 1 month at 10 m depth at Nusa Tupe.

3.2.2. Fouling

Fouling of sponges and sponge lines has also been reported as a problem at Pohnpei, and movement of lines closer to the reef edge, and the grazing fish associated with the reef, was suggested as a solution (MacMillan, 1996). Michelle Kelly (NIWA, NZ, sponge expert; pers comm.) advised that fouling is a symptom of an "unhappy sponge" rather than incorrect line positioning. In her opinion sponges that develop heavy fouling are those that have been badly handled, such as being cut with a dull knife, squeezed or taken out of water. It is notable that wild sponges have very few fouling organisms, other than an occasional patch of cyanobateria or clusters of bryozoans. Comparison of fouling of cuttings on our reef slope and open water lines suggests that there is considerable advantage to either deploying sponge cuttings close to the reef or at sufficient depth to be away from most fouling.

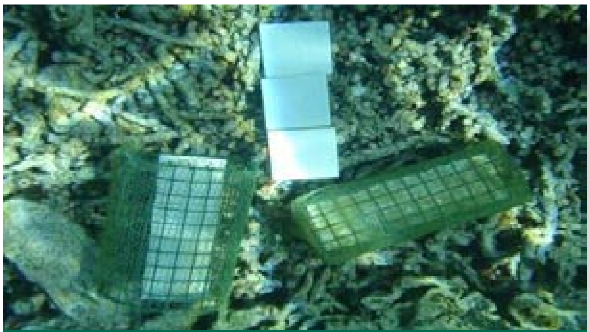

Figure 10. Set up of grazing experiment. Tiles are used here as an inert substrate. Three treatments are shown, tiles with no protection from grazing (top), tiles completely enclosed in 5 mm netting to prevent access by macrograzers (right) and control tiles in an open-ended tube of this netting (left), such that grazers have access but the tiles receive the same amount of shading and shelter from water movement.

In order to determine whether proximity to reef edge fish offered any potential for prevention of fouling, we also set up an experiment to test the efficacy of grazers at different distances from the reef edge. The design needed to be simple since, in the absence of any instruments to measure fouling, it had to be visually assessed.

A preliminary experiment was set up as in Figure 10. Each of three replicates included three treatments. Treatments were closed net, open ended net and no net, and each treatment contained three ceramic tiles as settlement substrates. The closed net is designed to prevent macrograzer access, while the open net and no net were designed to allow grazer access, but with the former replicating the shading and water restriction effects that were associated with the closed net. The replicates were positioned on the reef edge and left to colonise with grazers for three months. Results of this preliminary experiment were that no difference was seen between the no net and the open net treatment. Both accumulated little fouling, but what was there was primarily encrusting. After one month, the closed net treatments were fouled with filamentous algae and diatoms, and also had substantial deposits of loose sediment. After three months, the closed net treatments were full of macroalgae, in all cases species of the brown algal genus *Padina*. We considered that this preliminary experiment allowed us to establish the effect of grazers/no grazers. Differences between the open net and no net treatments were indistinguishable, suggesting that, within the limits of our resolving power, grazer access to the open-net treatment was good.

We subsequently deployed seven paired sets of closed net and open net, with two tiles in each, at 20 m intervals on a transect towards the shore from the reef crest at Nusa Tupe, across the mainly sandy floor of the back-reef lagoon. The intent was to increase distance from the reef edge and, by implication, from the highest densities of grazing fish. All deployments were at 2-3 m depth at low tide. After one month, the tiles were recovered and visually assessed for extent of fouling. Assessment visually determined which of the two treatments was most fouled at each transect site (scored as much more, a little more or the same), which we took as a measure of whether grazing was an important determinant of fouling biomass at each site, and ranked the open net replicates by degree of fouling for each set of nets (i.e. those exposed to grazing) by the degree of fouling. We assumed that the fouling rank for open net treatments reflected the degree of grazer control at the different distances from the reef crest.

Results from this experiment suggested that in all but one case the exclusion of grazers increased the degree of fouling. At four sites this was judged to be "much more fouled", at two sites (20 and 120 m) it was "slightly more fouled". At no sites was more fouling seen on the open net replicates, but at one site (at 40 m) the tiles were judged to be equally fouled. The ranking of degree of fouling did not show the hypothesised relationship with distance from reef crest (Figure 11). Indeed, there was an apparent trend for the reverse to be true. Reasons for this unexpected result are not clear, though a preliminary conclusion can be drawn that proximity to the reef crest, as least from the landward side, does not necessarily reduce the propensity for fouling.

This experiment has shown that grazers can make a difference to the extent of fouling on inert substrates, but that proximity to the reef crest does not have a clear and consistent effect on the extent of grazing - at least to landward of the crest. Sponges grown within back-reef lagoons are therefore unlikely to have major fouling problems.

Indeed, the sponge photographed on the cover of this report was grown in such the lagoon behind the Nusa Tupe reef crest, and did not suffer from fouling after it had healed. However, growth in shallow lagoons is slower than growth at 10-15 m. Experience with sponge cuttings suggests that to seaward from the reef, in open water, then there may be an increase in fouling over that seen in the back-reef habitat. This area is currently the subject of ongoing research, but initial findings suggest that good quality sponges with low epiphyte cover can best be grown from horizontal lines, or perhaps on frames, at 10-15 m depth, close to the reef face.

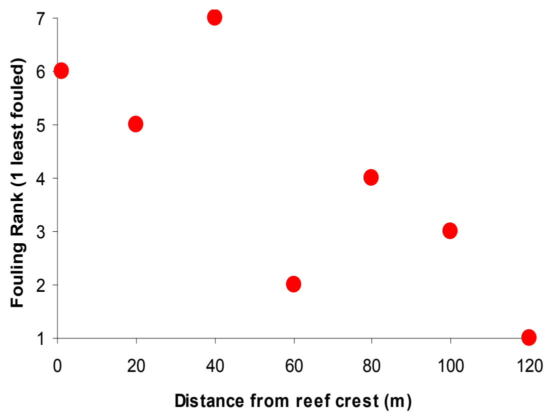

Figure 11. The ranking of degree of fouling on tiles to which macrograzers had access after one month exposure at different distances inshore from the reef crest at Nusa Tupe.

3.2.3 Growth rate of cuttings

The best data that we have for growth rate of cuttings comes from the horizontal lines deployed on the reef slope.

Methods

As described above, sponges were deployed from lines set to float 0.5 to 1.0 m above the reef surface, at 10, 15 and 22 m depth (Figure 12). Five replicates were deployed at each depth, and of these one was lost at each of 15 and 22 m. At the time of deployment, photographs were taken of each cutting and measurements made with calipers of each primary dimension, that is length, width and height. Once the cuttings had been taken, it was clear that growth ceased to be two dimensional, but rather there was a tendency for them to "round off" and grow in three dimensions (Figure 12). For this reason the two-dimensional analysis of growth rate used for assessing growth of wild sponges was not appropriate. Instead, we calculated volumetric and linear growth rates. For volumetric growth we assumed the sponge cuttings to be ellipsoids and used the product of the three dimensions, multiplied by ($4/3\varpi$), as an approximation of volume. This value, termed V, was then used to estimate the volumetric growth rate (μ_v), as;

$\mu_v = \ln(V_{(t)}/V_{(0)})/t$……………………………………Equation 3

For linear growth rate estimates (μ_L) we used a similar expression, substituting $L_{(t)}$ and $L_{(0)}$ for the $V_{(t)}$ and $V_{(0)}$.

Figure 12. A diver measuring a sponge cutting growing on a horizontal line at 10 m on the Nusa Tupe reef slope. Note the lack of epiphytes and rounded shape.

Results

There was an apparent trend of decreasing growth with increasing depth, with maximum growth rate at 10 m (Figure 13). We carried out an ANOVA by depth for these growth rates, and found that while 15 m did not differ significantly from either 10 or 22 m, these last two were significantly different to each other. Note that these volumetric growth rates are not comparable directly to the areal growth rates measured for the wild sponges.

Since sponges are typically sold by the length of their longest axis, we also examined the rate of change of individual measurements of length, breadth and depth of the 10 m depth sponges, over the experimental growth period of 11 months. We first compared the rate of growth of each dimension for the five sponges at 10 m using ANOVA, and found no significant differences. We then calculated an overall value for the rate of linear growth at 10 m depth, as 0.37 ± 0.11 y^{-1}. This can be translated as the time necessary for a cutting of a given size to grow to market dimensions. Table 3 shows the time taken for a cutting of 50 mm maximum length to reach various marketable sizes.

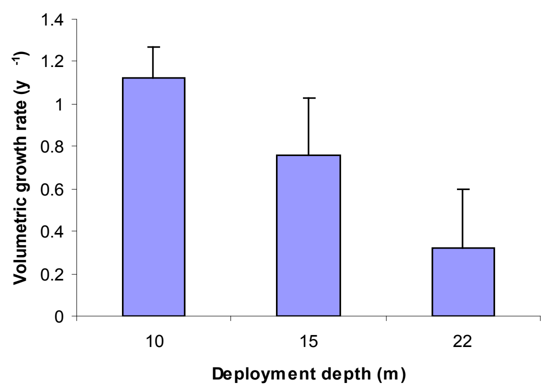

Figure 13. Volumetric growth rates of sponges at three depths at Nusa Tupe. Bars show mean, whisker shows standard deviation. ANOVA showed that growth was significantly faster at 10 than at 22 m, while 15 m growth rate was not significantly different (p>0.10).

Table 4. Estimated time taken for a sponge cutting of 50 mm, deployed at 10 m depth, to reach various marketable sizes.

Desired size (mm)	75	100	150	200
Grow-out time (years)	1.1	1.9	3.0	3.7

The range of growth rates and corresponding grow-out times that we report are similar to those reported by MacMillan (1996) and the growth rates are much higher than seen in temperate sponges (e.g. Handley et al., 2003). What is not clear at this stage is what factors give rise to the difference in rate of growth with depth, and whether even faster rates can be achieved at shallower depths. Given the absence of any evidence of photosynthesis, the increase in growth rate with decreasing depth is unlikely to be related to irradiance. To determine whether there are depth-related differences in water movement and temperature we deployed plaster of paris "water movement monitors", together with TinyTag temperature loggers. The plaster of paris was formed into cyclinders with a string passing through the center to allow them to be tied to the sponge lines. Each cylinder was soaked in seawater for 30 minutes, then blotted dry and weighed (to 2 decimals) before being deployed on a line. The TinyTags were deployed at the same time, and set to record at 15 minute intervals. The deployments were made for four days, after which they were retrieved, the plaster of paris cylinders were re-weighed and the TinyTags were downloaded.

The temperature loggers recorded no differences between the three depths, while the plaster of paris showed a weight loss of 29, 27 and 42% respectively at 10, 15 and 22 m depth. The apparently greater water movement at 22 m was suprising, and neither temperature nor water movement adequately explains the greater growth at 10 m than at 22 m. In order to further investigate whether depth is a factor affecting growth, we conmpared the growth rates of cuttings taken from each of four sponges used for the donor sponge experiment (section 3.1.2), which were deployed on open water longlines at a range of depths from 7 to 25 m. This experiment also allowed us to examine for differences in growth rates of cuttings between sponges (Figure 14). Of the four sponges in this experiment (sponges A-D), cuttings from sponge C failed to grow, while the average rates of growth of A and B were not significantly different (ANOVA), with exponential volumetric growth rates of 0.31 and 0.36 y^{-1}. Sponge D had a significantly higher rate of growth than either A or B, at 0.91 y^{-1}. We note that these rates of growth are comparable to those observed for reef deployments (Figure 13). Overall, this experiment showed no relationship between deployment depth and cutting growth rate (Figure 15).

Our tentative conclusions from these observations are that;

- Different donor sponges yield cuttings with different inherent rates of growth;
- Evidence of a relationship between depth and rate of growth is weak, and is likely to be masked by differences in inherent rates of growth of the sponge cuttings;
- Selection of broodstock for fast growing cuttings seems a viable option.

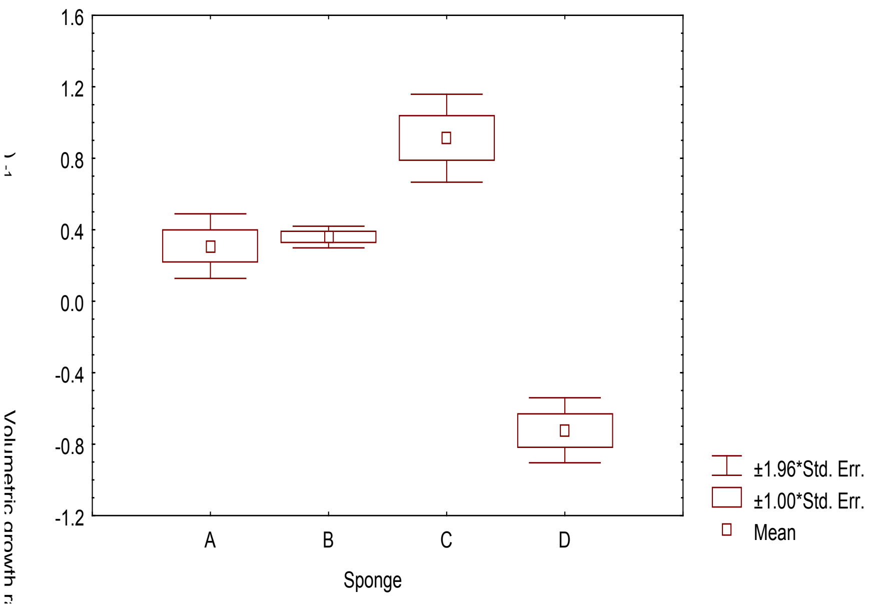

Figure 14. Exponential volumetric growth rates (mean and standard error) of cuttings taken from each of four sponges and incubated at a range of depths.

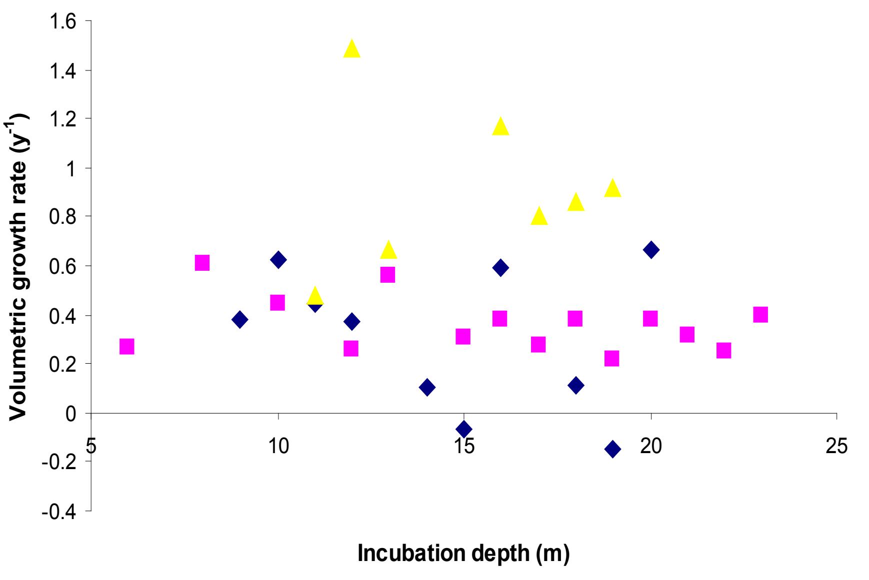

Figure 15. Exponential volumetric growth rates of cuttings from three sponges grown at a range of depths.

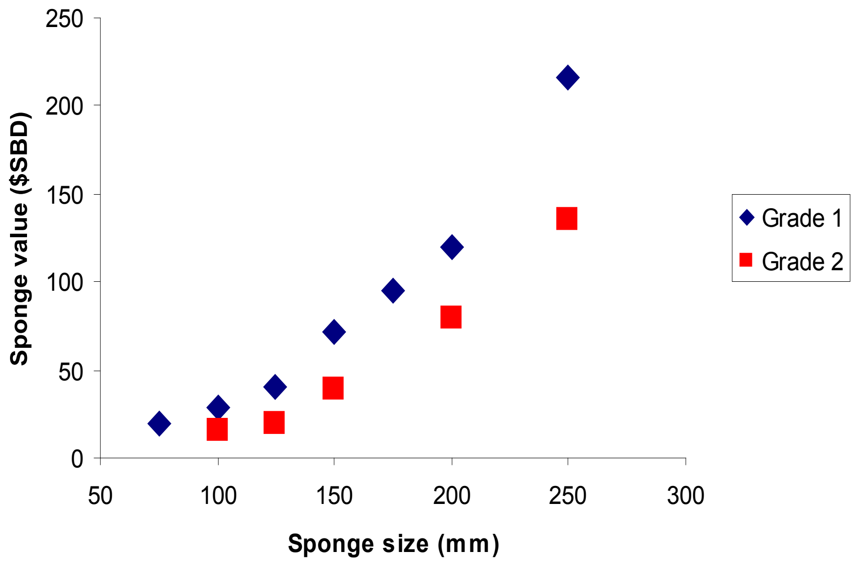

Figure 16. Prices of two grades of natural (wild harvest) sponges from Florida Sponge Company, USA. Prices have been translated to SBD from $US.

Economic viability of sponge aquaculture depends on a variety of factors, primarily the cost of production, the number produced and the sale price. Wholesale price increases rapidly with the size of a sponge (e.g. Figure 16).

Knowing now that these sponges that we grow are indeed *C. mathewsi*, previous work on their saleability becomes relevant. Kelly-Borges (2002) reported that this sponge is a high quality bath sponge, proba bly similar to grade 2 sponges in Figure 10. If we assume that Solomon Island sponges are of similar value to grade 2 sponges above, and that village growers can expect 10% of retail price, a 250 mm sponge, which would take over three years to grow from a small cutting, would only raise $6 (SBD) for the village farmer. To achieve an income of $10,000 per year, a farmer would need to raise over 1700 sponges a year or, with a 3.5-year turnaround of sponges, or would need to have 6000 sponges in culture at any one time.

Using frames of 20 sponges, and cuttings of 50 mm, this would mean 300 frames deployed at any one time. Obtaining 1700 sponge cuttings per year would require at least 100 donor sponges, which is likely to require access to at least 1 km of reef. These numbers are summarised in Table 5.

While we know that a marketable sponge of 100 mm can be produced from a good sized cutting within less than one year from our trials at Nusa Tupe, Table 5 does not paint a picture of a highly desirable industry if sponges are grown in quantity from smaller cuttings. By targeting smaller sized sponges, a similar number of stock units are required to be kept to achieve the target income, and rewards will come sooner. However, growing small sponges would require a very large number of cuttings per year, which may be beyond the capacity of a local reef to supply.

Table 5 (below). Reality check on what would be required to make an annual income of $10,000 for a Solomon Island sponge farmer selling into the retail trade.

Target sponge size	Value of sponge(SBD)	50 mm cuttings per year	Grow-out time (y)	Total Stock	Number of frames
200 mm	6	1700	3.5	6000	300
100 mm	3	3300	2	6600	330
75 mm	2	5000	1	5000	250

Our discussions with villagers, and experience form other projects, suggests that the poor financial return for a large investment in materials (300 frames, requiring anchor stones, bamboo, fishing line and floats), together with a long wait for that return, is a significant barrier to take-up and maintenance of sponge farming by potential village farmers. Villagers would be more willing to do this work for a regular wage, but as an investment of their own it does not meet the need of relatively quick cash in return for time invested.

What would make the industry more viable and attractive is a greater return for the product as it leaves the farm. This can be achieved by increasing cutting size, thus reducing grow-out time for a more valuable sponge, or by targeting niche markets where a better return can be maintained. For example, the sponges sold by The Florida Sponge Company used in the example prices above are dredged from the Atlantic waters off of Tarpon Springs. Dredging is one of the least environmentally friendly forms of marine harvesting and, while we know of no analyses of the impact of sponge harvesting there, a case could be made quite easily that these sponges are less environmentally friendly than farmed sponges. This could make sustainable sponges a market edge and increase prices. Any multiplier of farm gate prices could immediately translate to reduced numbers of cuttings needed to be grown, which could translate to larger cuttings, less work for the farmers, a shorter grow-out period and a viable village industry.

At present we have contacts in Australia sourcing environmentally friendly sponge sellers. We have indications from such a company in the UK who would be willing to pay $14 (SBD) for a small sponge, approximately five times the value we have used in Table 5. Samples have also been sent to "eco-friendly" marketers in New Zealand though as yet no response has been recieved. We have ongoing contact with the University of Waikato Business School who are suggesting use of New Zealand as a trial market, using a "story based" selling approach. This market research is ongoing. We believe that only by getting a premium price for sustainably farmed sponges can the industry develop. The barrier to this is not technological, but simply having an opportunity to grow enough sponges to make a serious foray into the market.

4. Reporting by objective

This report has gone a long way towards addressing the initial objectives of this miniproject.

Determine the distribution of sponge species suitable for aquaculture and the sponge trade within the Western Province, Solomon Islands.

The Pacific Bath Sponge (*Coscinoderma mathewsi*) is common in Western Province and has been found at every location examined to date, except for very steep ocean drop-offs in Western Kolombangra. The sponge is primarily distributed below 5 m depth and to at least 27 m.

Initiate experiments to maximise healing and growth rates of cuttings to reduce the production cycle length.

Optimal healing and growth is obtained using cuttings of approximately 40 mm side length and incubated at 10 m or more depth. Staged cutting (ie cutting a strip first and then cutting this into squares once the initial cut has healed) is also effective. There appears to be scope for selection of donor sponges tat provide fast-growing cuttings.

Develop a suspension mechanism to improve sponge shape.

Excellent shope was obtained from cuttings suspended from horizontal lines arranged close to the reef slope.

Identify an overseas buyer, determine the optimum sponge characteristics (size, shape etc) and the minimum volume and timing of shipments likely to be needed for a sustainable industry.

Oval sponges of 4-6 inches (100-150 mm) are specified by buyers. Samples have been provided to sponge marketers in New Zealand, who have been very positive about the shape and texture of Solomon Island sponges. To date no firm orders or indicative prices have been received.

Determine the likely returns to farmers and their attitudes to the techniques to be used and the time and space constraints.

Likely returns were calculated, an a profit can be realistically made, though identification of niche markets providing a better price will be required to sustain an industry.

5. Future developments

The techniques for culturing sponges within Solomon Islands are now locally adapted and proven to be effective. A strategy for ensuring genuine and defensible sustainability has been developed. What remains is to determine the availability of suitable niche markets where a better return can be expected. To achieve this we need to grow sufficient sponges to be able to market these as a commercial product. Once they are marketed, we will be in a position to attract more villagers into sponge aquaculture with guaranteed buyers, or to attract an investor to create wage-based sponge farming. Our goal for the next phase of this project will be to produce 2000 sponges to retail size within 2 years. To achieve this we will likely need to contract approximately 10 villagers to produce 300 sponges each – equivalent to 15 sponge frames on their reefs and needing approximately 20 donor sponges to provide cuttings.

At present we are negotiating with Tetepare Descendent Association (TDA) with respect to hosting an expanded trial. Collaboration with TDA has the advantage of a good story to go with the sponge marketing. For complex reasons, the original inhabitants and custom land owners of Tetepare – the largest unlogged island in Solomon Islands – no longer live on the island, and have agreed that it be set aside as protected area. The displaced descendents desperately need new livelihoods to replace income lost from lack of access to their custom lands and reefs, or the island will risk losing its protected status as TDA members are forced to exploit their remaining resources.

Once these sponges have been grown, they will be used in a marketing campaign using the story of the villages, the sustainable culture techniques and the purity of the Western Pacific environment as attractants.

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Appendix 1.

Common Sponges of Nusa Tupe.

Xestospongia testudinaria
Lamarck
Class Demospongiae of Order Haplosclerida Family Petrosiidae.
Large basket sponge, starts as vase. Purple/crimson colour. Common at 20 m plus at Nusa Tupe

X. exigua should also be present -enrcusting, 1 cm thick, with lobes and digits but no basket. Colour caramel exterior, patches cyanos, cream interior (sam as Xt). Very brittle.

Big spicules pointed at both ends (oxeas) 180 um long, arranged in a reticulation that forms circles of spicules. Circle structrure is character Red stuff is cyanobacteria.

Liosina paradoxa Thiele
Class Demospongiae
Order Halichondrida
Family Dictyonellidae.

"Mud sponge", orange on the inside, often with large oscules at the apex of each tube. Thje skin is polygonally patterned, waxy and slimy feel, shrinks out of water. Filled with broad tracts of sand, not connected by fibre in swirling swathes. Spicules are long styles (blunt one end, pointed on the other). Common, at a range of depths



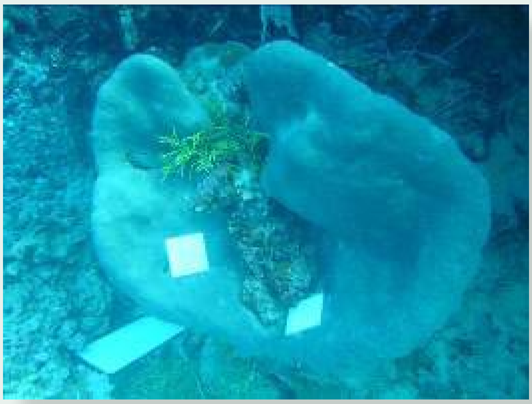

Coscinoderma matthewsi Lendenfeld,
Class Demospongiae
Order Dictyoceratidea
Family Spongiidae.

This is the traditional Pacific bath sponge, first discovered and used in Pohnpei (Micronesia) where women used skeletons for bathing children and sick people. Used as tributes to chiefs. Mothers would pass these hardwearing sponges on to their daughters.

Very thick wool tangle network of spongin fibres with short distinct connections rather that anastomosing (cf spongia). Primary fibres are a trellis containing sand and are not common, set apart by c. 5 mm, Very thick ectosome packed with collagen giving rubbery, flesh-liketexture. Bends readily, but does not tear. Colour ranges grey (esp at depth) to black in shallow water.

Most common at 10-25 m, when shallower likely to be in overhangs protected from sunlight. At NusaTupe thick-walled cups or plate-like vases predominate. In other places (eg Pohnpei) more spherical.

Common in Fiji, Pohnpei, Solomons, but not PNG.



Stylissa massa. ?Hentschel?

Orange lobed sponge with large apical oscules. Very common in shallow water

Stellettinopsis sarasinorum
Class Demospongiae
Order Astrophorida
Farm Copattidae

Tuberculate barrel, with deep cloaca into which the oscules open. Forms tube which exits at top or barrel. Often developes props ("legs"). Caramel brown, often with maroon cyanos on top. Thick skin.

Carteriospongia flabellifera
Oreder Dictyoserratida
Fam Thorectidae
SubFam Phyllosponginae

White knobbly surface cup.
Elastic, despite being packed with sand, due to tangled secondary fibres around the sand-filled primary fibres.
Very coomon on coral rubble in sand/reef shallows. Similar to Phyllspongia paparacea and Strepsichordaia in form, but distinguished by surface texture and colour.

Strepsichordia radiata Hyatt.
Oreder Dictyoserratida
Fam Thorectidae
SubFam Phyllospongininae

Green leaf with stars around holes.

Smooth, yellowy-green, foliose lobes noit froming cups, frequently lobes dissected and fused to form labyrinth/honeycomb. Soft and smooth, slightly granular like Phyllospongia, but distinguished by stars pattern on surface and colour. Frequent in shallow water

Phyllospongia paparacea
Oreder Dictyoserratida
Fam Thorectidae
SubFam Phyllosponginae

Thin, purple/lilac fans. Can be very expansive. Regularlly dispersed raised oscules on one side only. Sandy texture on both sides. Purple. Tends to be in deeper water than previous two. Common in water>10m.

Ianthella basta Lamarck.
Ordr Verongida
Fam Ianthellidae

Lilac (bit can be khaki, blue, lemon) fan with very regular, ladder-like skeleton, the fibres are deep magenta, appearing black on spnge surface. Spongiocytes are inside the fibres. Turns purple on exposure to air. Pigment in these sponges oxidise to various states giving different colours for the same pigment. Wholesponge turns royal blue/purple on exposre to air and on death. Character of Verongida.

Callyspongia aerizusa ?Lamarck?
Oreder Haplosclerideа
Fam Callyspongiidae

Blue conulose sponge - spiky surface, transluscent forms fans and tubes. Flexible with soft, quite long pinnacle-like spikes.

Hyrtios erecta Keller.
Class Demospongiae
Order Dictyoceratida
Fam Thorectida

Very black/brown, tan interior, brittle sponge (lots of sand in all fibres). Forms lobes and erect digits. Mosty common pacific sponge. Large oscules flush with surface. Granular and harsh to the touch, especially when out of water. Always seems o be covered in sediment. Can gro ata widerange of depths from 20 m + to 2m.

Hyrtios sp.
Class Demospongiae
Order Dictyoceratida
Fam Thorectidae

From Gizo entrance. Rounded, not lobate, surface very collagenous, smooth and fleshy relative to above, even after some time out of water. Not covered in sand, regularly conulose. Distinguished from erecta by shape and surface texture (smoother and fleshier). Distinguised from Coscinoderma by the harshness of the interior and easily snapped. IE lots of sand inside fibres.

Dysidea sp.

Icy blue tapering fingers. Skeleton like Hyrtios – irregular reticulation of sand grains that are connected by tiny bits if spongin. Fibres not dense, making it more elastic than Hyrtios. Icy colour comes from sand grains on the sponge surface. Quite delicate, with a surface tracery of sandgrains. :Lacy appearance.

Axinella carteri
Order Halichondrida
Fam Axinellidae

Fluorescent orange fans, can be elongated fans, with very irregular, conulose surface. Tough stipe/ stalk, but blade flexible. Fleshy texture felty surface caused by spicules projecting through surface. Tear easily as lack fibres, spicules plumose. White-ish sheen due to the spicules.

Ptilocaulis sp.

Orange club (palmate), very tough and not compressible. Deep orange, surface very regular and sharply conulose, sharp and rough to touch. Aquiferous canals on surface emerging towards oscules.

Paratetilla baca Selenka.
Order Spirophorida
Fam Tetillidae

Golfball sponge. Spicules sticking out like stubble. Orangey mustard, yellow colour, characteristic are sieve pores (inhalant current). Oscules small and inconspicuous. Very common in silty environments at bases of bommies.

?Pachypellina sp
Order Haplosclerida
Fam ?Phloeodictyidae?

Maroon ball. Undescribed spp common through pacific. Soft, Maroon surfaced. Buff or tan interior, like a crumbly cake. Big flush oscules. Feels like it is related Xestopongia.

?Pellina carbonaria
Order Haplosclerida
Fam ?Phloeodictyidae?

black inside and out. Featureless black blob. Emits black dye when touched. Parchment-like surface