

critters@lembeh

Lembeh House Reef Lava Rock Habitats
Volcano Alley



Lembeh Resort Environmental Volunteer Program
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Overview:

In 2003, Lembeh Resort (Lembah Island, North Sulawesi, Indonesia) initiated a house reef restoration project to rehabilitate damaged reefs in front of the resort and neighboring villages. A combination of environmental and anthropogenic factors, including sedimentation, destructive fishing practices, storms, pollution, and diver impact had conjoined to decrease the biomass and health of the reef ecosystem. In addition to establishing the house reef as a quasi-marine protected area (MPA), which limited fishing in the immediate vicinity, a number of artificial habitats known as Reef Balls were also placed at that time to provide habitat for marine species. In 2007, when the Lembeh Resort dive operations came under new management, *Critters@Lembeh*, a marine conservation volunteer program was implemented enabling individuals to develop and complete reef research and rehabilitation projects under the direction of the resident marine biologist and dive center staff. Subsequently, a variety of projects have led to new artificial habitats placed at various depths and locations throughout the House Reef. (See Table 1)

In 2010, one volunteer completed a research project examining population and biodiversity assessments of the different types of artificial reef habitats.¹ Based upon these analyses, and observations by the dive center's resident marine biologist², we (HMS & LWS) proposed a new habitat design to be constructed from locally found lava rocks. In comparison with concrete or metallic surfaces of other artificial habitats, it is surmised that the porous, rough surfaces of lava rocks will better facilitate colonization by coral larvae and other sessile species. A previous assessment of coral survival on concrete installations (Fish Houses) found transplanted mortality rates nearly 80%, supporting the observation that the substrate and surface of habitats may play an important role in coral colonization and health.³

In addition, the new habitat design incorporates structural or geometric complexity, thereby creating a wide variety of holes and small spaces that can serve as a protective environment for an array of vertebrate and invertebrate species. The present report outlines the rationale, design, construction and evaluation of a lava rock habitat project within the *Critters@Lembeh* Environmental Volunteer Program. Because of their shape and construction, these habitats have euphemistically become known as *Volcano Alley*.

¹ Dougherty, Lyndsay. Population, Species and Family Analysis of Artificial Reef Structures. An

² Catherine "Dimpy" Jacobs

³ Bondarenko, Olga. House Reef Report, Lembeh Resort, July-August 2008.

Background:

Since 2003, a variety of artificial reef habitats⁴ have been installed at various depths and locations throughout the house reef and on the reef in front of a neighboring village.⁵ (Table 1)

Table 1

Structure	Date of Installation	Primary Goal
Reef Balls	May 2003	Biodiversity habitat
Fish Houses	April-June 2003	Biodiversity habitat
Biorock	Dec 2007	Coral/Sponge re-colonization
Fish Houses	Jan 2006 – June 2007	Biodiversity habitat
Wreck	Dec 2007	Biodiversity habitat
Fish Net	Jul 2009	Biodiversity habitat
Concrete Blocks	Oct 2009	Biodiversity habitat
Drum Ladder	July 2010	Biodiversity habitat
Reef Builder Blocks	May-June 2011	Marine research habitat
Bottle City	July 2011	Cephalopod habitat

According to a recent report (Dougherty 2010) on population numbers and species biodiversity, every artificial structure on the house reef, although some more than others, managed to take on transplanted corals and experience levels of population, species, and family diversity that were previously absent in the area. While differences exist among habitat locations, the environmental factors impacting the entire reef (season, weather, sediment, pollution, tidal currents, nutrients, water quality) are likely to produce relatively similar conditions for growth throughout the immediate house reef vicinity. However, important features thought to explain the success of certain habitat designs included proximity to native reef, depth, internal volume, surface area, and structural surface area. It was determined that the Fish Houses and Biorock structures were the most successful habitats by volumetric comparison.⁶ An additional factor not evaluated in this previous report is the amount of water circulation through these structures. In comparison to solid volume habitat designs (Concrete blocks, Reef Builder blocks, Drum ladder) water is allowed to freely move through Fish Houses and Biorock structures. This movement of water can produce regular re-suspension of sediment and be vital to filter feeding organisms. The importance of these factors, as established by previous data collection and analyses, should not be ignored in considering the design of future habitats.

⁴ For additional detail on individual habitat structures, see www.lembehresort.com/house_reef_muck_scuba_diving_lembeh_strait_north_sulawesi_dives_h9b24.html

⁵ In 2011, several reef builder blocks were installed at the Pintu Colada dive site in front of the Pintu Kota Kecil village.

⁶ See Figures 4.1 and 4.4, Dougherty, Lyndsay. Population, Species and Family Analysis of Artificial Reef Structures. An Independent Research Paper, August, 2010

Habitat Design

Two important design considerations include a) structural complexity and b) the use of a naturally occurring substrate with rough, irregular surfaces. Artificial habitat studies have demonstrated that structural complexity provides protection to juveniles and smaller species from predation thereby increasing population diversity and abundance.⁷⁻⁸ Specifically, the “limited shelter hypothesis” maintains that the populations a reef can support are tightly correlated with the availability of refuge habitat. Thus structures with many holes and crevices provide shelter from piscivorous fish and can impact recruitment and population growth. Secondly, habitat construction is facilitated by the use of locally available, naturally occurring materials. But regardless of its origin, the habitat substrate should possess a rough and irregular surface, rendering it capable of natural colonization by sessile organisms such as corals, sponges, tunicates etc. Artificial reef builders have learned from prior experience that not all substrates support growth.⁹ A rough, irregular surface closely approximates a natural coral reef and allows coral larvae and other sessile organisms transported by water movements the opportunity to adhere and colonize the structure.

Other considerations for the habitat include:

1. Depth: Given the available light levels and sedimentation characteristics of the house reef, corals have been found to thrive optimally on other artificial habitats at depths in the 6-10 meter range.
2. Substrate Material: Lava rock¹⁰ (igneous rock of volcanic origin-basalt, mafic, fine grained) was selected for its rough irregular surfaces, availability, and potential for structural complexity and stability. Lava rock is also the origin of the black sand composition of many of the Lembeh Strait dive sites that support rich marine biodiversity.
3. Geometry: A pyramid shape was selected for practical considerations including ease of construction and structural stability. The pyramid shape optimizes both surface substrate area, for sessile organism growth, as well as complex internal volume, to create protective

⁷ Taylor, K. et al. The Influence of Substrate Composition and Habitat Complexity on Artificial Reef Communities. *Columbia Undergraduate Science Journal*, July 3, 2007.

⁸ Charbonnel, Eric et al. Effects of Increased habitat complexity on fish assemblages associated with large artificial reef units. *Journal of Marine Science*, January, 2002.

⁹ See Osborne Reef Waste Tire Removal Project, Broward County Florida http://www.underwatertimes.com/news.php?article_id=36210951740. A 40 million dollar collaborative clean up project was undertaken by the EPA, NOAA, and US Navy Salvage Divers to retrieve rubber tires that were used as to create the Osborne artificial reef after it was discovered that tires did not support coral growth.

¹⁰ Fichter, J.S. Introduction to Igneous Rocks, <http://csmres.jmu.edu/geollab/fichter/IgnRx/Introigrx.html>, 2000.

habitat for small and juvenile species. Structural complexity also allows water circulation which may re-suspend sediment and be healthier for filter-feeding organisms.

4. Experimental Design: While not intended as a formal scientific experiment, two of the five artificial habitats will be constructed using small-rock construction or large-rock construction. The purpose of testing different designs is to determine whether rock size influences habitat success or species recruitment.
5. Location: Relatively flat, barren areas of the house reef will be chosen as potential habitat locations. Habitats should not damage or interfere with nearby natural reef elements.
6. Stability: Artificial habitats should remain inherently stable, and unable to shift during strong currents or storm activity. This is not only to maintain the integrity of the artificial habitat but to prevent damage to surrounding natural reef elements. The intrinsic weight of the basalt lava rocks, in addition to their rough and irregular surfaces and shapes, produces a natural interlocking and stable structure.

Finally, a retaining wall to demarcate each habitat, and prevent structural changes was planned using cement paving blocks. These blocks will be acquired and deployed in the same fashion as the lava rocks and will serve to “frame” each pyramid structure. These paving blocks are made from coarse cement and will eventually support sessile species colonization as well.

Methods

Longitudinal observational data collection is the primary method of study for the lava rock habitat project. Once constructed, weekly observational (underwater slate documentation and photographic evidence) data collection will assess recruitment and colonization. Given that 5 habitats will be constructed, 10 minute observational periods allocated to each habitat will constitute a single assessment dive. Documentation of all forms of marine life found residing on, within, or remaining in the immediate vicinity will be included in the census. Since coral and sponge transplantation is not an intended part of the project, particular attention will be afforded to the natural recruitment and colonization of these organisms.

Construction

Construction of the lava rock habitats consisted of 3 phases: 1) site selection and marking, 2) delivery of substrate to sites, 3) habitat assembly. A breakdown of material costs for the entire habitat construction is also included in this section.

Site Selection & Marking

In accordance with factors predictive of habitat success defined above, several scouting dives were performed to assess possible locations for habitat placement. Sandy, barren areas of the house reef between 6 and 10 meters depth on relatively shallow sloped areas were identified as possibilities. Three separate weight and safety marker buoys were placed at three optimal locations. (See Figure 6, Map of House Reef, for final habitat locations) Lava rock and cement foundation blocks were ordered for delivery. On the day of delivery it was discovered that boat traffic in the area had cut the lines of two markers and these were replaced prior to substrate delivery. One site was relocated to a larger open area to prevent damage to the native reef during deployment of the lava rock and cement blocks.

Delivery of Substrate to Sites

Lava rocks of various sizes, and cement foundation blocks, were deployed from the surface and targeted the marker buoy at each site (See Figure 2). Despite a windy day and challenging navigation for the boat captain, substrate materials were concentrated around the buoy marker lines (Figure 3). An *Acropora sp.* coral and a barrel sponge were inadvertently damaged by lava rocks and these were subsequently transplanted successfully onto the Bio-rock structure.

Habitat Assembly

A total of five dives were needed to construct five separate habitats. First, the cement foundation blocks were organized into a square retaining wall. However, before lava rocks were piled within the frame, the need for a design modification was determined. One volunteer (LWS) observed that the intended flush-mounted cement retaining wall would actually prevent entry to and from the habitat structure for fish and bottom dwelling species. (See Figure 4) After brief experimentation, an overlapping block design was developed to improve access to the interior of the habitat and facilitate water circulation (See Figure 5). As lava rocks were placed in the habitat, they were often repositioned and “jiggled” to check for stability. Each habitat was built with roughly the same retaining wall dimensions, and sufficient lava rock existed to elevate the structures approximately 1 meter above the sea floor.

A consideration for any artificial reef project is the financial investment for labor and material costs. Lava rock was purchased from a local village and a modest price was negotiated for pickup, transportation and delivery of the substrate materials. A breakdown of all material costs is presented in Table 3. The overall financial investment for the assembly of five artificial reef habitats is relatively modest, at 2.2 million Rupiah (\$ 250.00 U.S.), or 440,000 Rupiah (\$50.00 U.S.) per structure.

Table 3: Material Costs

23.8.11	Bendrat 1/2 kg	Rp 7,500.00
23.8.11	Gunting	Rp 9,000.00
25.8.11	Pelampung 100 pcs @Rp 3500	Rp 350,000.00
25.8.11	Pelampung Besar 2pcs @Rp 20000	Rp 40,000.00
24.8.11	Sarung Tangan Tebal / Gloves	Rp 25,000.00
26.8.11	Pilox Yellow 6 pcs @Rp 20000	Rp 120,000.00
27.8.11	Rope / Tali 1 Gulung	Rp 50,000.00
20.8.11	Lava Rock	Rp 450,000.00
20.8.11	Transport For Lava Rock	Rp 500,000.00
20.8.11	Batako 300 pcs	Rp 360,000.00
20.8.11	Transport for Batako	Rp 300,000.00

Totals: Rp 2,211,500 (Approximately \$ 252.00 US)

Habitat Physical Parameters

The installation dates of the 5 habitats are as follows: **1** (8/22/11), **2**(8/21/11), **3** (8/21/11), **4** (8/23/11), and **5**(8/24/11). As evident, the structures have not been numbered sequentially according to construction date, but rather in a linear geographical fashion from right to left beginning with number 1 closest to the Bio-Rock structures. (See Figure 6, Map of House Reef) The numbering system is thus sequential as a diver would encounter the structures on the buoy marker trail system starting closest to the dive center.

Depth, base dimensions, height, and slope length of each habitat were measured and recorded. (See Table 2) Habitat surface area and internal volume were calculated using the formulas $SA=2bs + b^2$ and $V= 1/3 b^2h$. Surface area and internal volume are more appropriate and meaningful parameters for the assessment of livable habitat.

Table 2. Habitat Physical Parameters

Habitat	Depth (m)	Surface area (Sq. m)	Base Area (Sq. m)	Height (m)	Slope (m)	Volume (cubic m)
1	7.2	6.14	2.24	1.1	1.3	0.82
2 ^L	5.9	7.33	2.62	1	1.45	0.87
3 ^S	6.1	4.31	1.56	0.9	1.1	0.47
4	7.6	6.45	2.25	1.1	1.4	0.82
5	7.2	5.85	2.25	1	1.2	0.82

L= Large rock habitat, S= Small rock habitat

Recruitment Observations

Week 1

At the end of week 1, construction on habitats 1 through 5 had been completed and an observational dive was performed, allocating 10 minutes to each structure. Sediment in the water column, which had increased during the habitat assembly process, had cleared and it was possible to view the structures initially from a distance without disturbing marine life. Regardless of installation date, all lava habitats had damselfish (*Neoglyphidodon* sp.), and several species of surgeonfish (*Acanthurus* sp.) utilizing the structures as shelter, and then grazing on algae as it began to grow. Pygmy gobies (*Eviota sigillata*) were found ubiquitously on all habitats as were many small crustaceans (*Dardanus* sp.). Various other unique species identified on or in the habitat are listed in Table 3. No sessile organisms (corals, sponges, tunicates) were observed on the lava substrate in the first week.

Week 2

The second week witnessed an expansion in the diversity of organisms establishing residence in the habitats, as well as evidence of other feeding activities. On several of the habitat's flat retaining wall surfaces, small piles and pieces of crushed shells were observed, indicating nocturnal feeding locations. In addition to previously observed species, several crinoids (*Himerometra robustipinna* & *Cenometra* sp. - See Figure 7), sea cucumbers (*Pearsonothuria graeffei* & *Stichopus variegatus*), as well as new fish species such as *Cheilinus fasciatus*, *Canthigaster papua*, and *Oxycheilinus diagrammus* were routinely observed at the habitats. A final, yet important observation during week 2 pertains to habitat structural stability. Despite several days of strong currents on the house reef, none of the 5 habitats appears to have shifted or become unstable. Not a single lava rock had fallen to the seabed around any structure.

Week 3

The most important observations the third week involve colonization by a variety of sessile organisms across all habitats. Photo documentation indicates that corals, sponges, ascidians, bivalves, hydroids and various algae have been recruited and initiated growth on lava rock surfaces. (See Figures 9-13) In addition, sufficient fleshy algae growth on the structures has attracted herbivorous fish, which can be seen grazing on the lava rock. Species habitat diversification is evident with polyclad flatworms and grouper seen on structures 2 and 4, respectively. (See Figure 14) Juvenile bluestreak cleaner wrasse (*Labroides dimidiatus*) and other juvenile *Labroides* species are observed darting in and among the lava rock openings. (Figure 15) General observations include good structural stability and relatively uniform species populations and diversity across all habitats. No significant differences in recruitment were observed after three weeks between various habitats, or between small rock and large rock habitat designs.

Conclusions

For a variety of reasons, it may be justifiably concluded that lava rock habitats represent a successful design in artificial reef rehabilitation. These habitats are relatively inexpensive, simple to assemble, require no specialized equipment for construction or maintenance, and possess structural stability. More importantly, based upon preliminary observations, lava rock substrates have the potential to become colonized and utilized by a variety of marine organisms. The structural complexity is also consistent with previous artificial reef research demonstrating the importance of small nooks and crannies that offer protection to juvenile populations from predation.

The modification to the cement block retaining wall proved to be an important change to the habitat design. On numerous occasions, surgeonfish, tangs, and damsels were seen moving in and out of the habitat through the openings in the cement block wall. This seemed to occur particularly when these species sought refuge from approaching divers, and suggests that escape from piscivorous predators would be similarly possible not just between the lava rocks, but through the retaining wall itself (See Figure 8).

Monetary investment in artificial reef habitats can be highly variable. Installations such as Biorock requiring titanium mesh, rebar configurations, underwater cables, and a continuous energy supply can be extremely expensive. Reef balls, similarly, because of their significant mass, require cranes and other specialized equipment and techniques for transportation and placement. Moreover, Biorock and Reef balls may necessitate significant labor and specialized expertise for assembly. By contrast, lava rock habitats represent affordable structures that can be assembled by volunteers and dive staff without special assistance. In addition, acquiring lava rocks from local villages creates a revenue stream in the form of raw materials purchases and labor fees for transportation and delivery.

Future Recommendations

Periodic observations of colonization and recruitment are recommended to provide more definitive conclusions regarding the success of lava rock structures as artificial reef habitats. Data collection of sessile organism growth on habitats without prior transplantation will provide evidence that lava rock is a suitable substrate for coral reef rehabilitation. Habitats should also be evaluated for stability over time, given the possibility that storms or other strong current activity may shift or destabilize the structures. Particular attention should also be paid to structures 2 & 3, the large and small rock designs, to determine whether significant differences in species or population abundance become apparent, as this may influence subsequent habitat design.

Figure 1 Marking the habitat site on barren sandy area

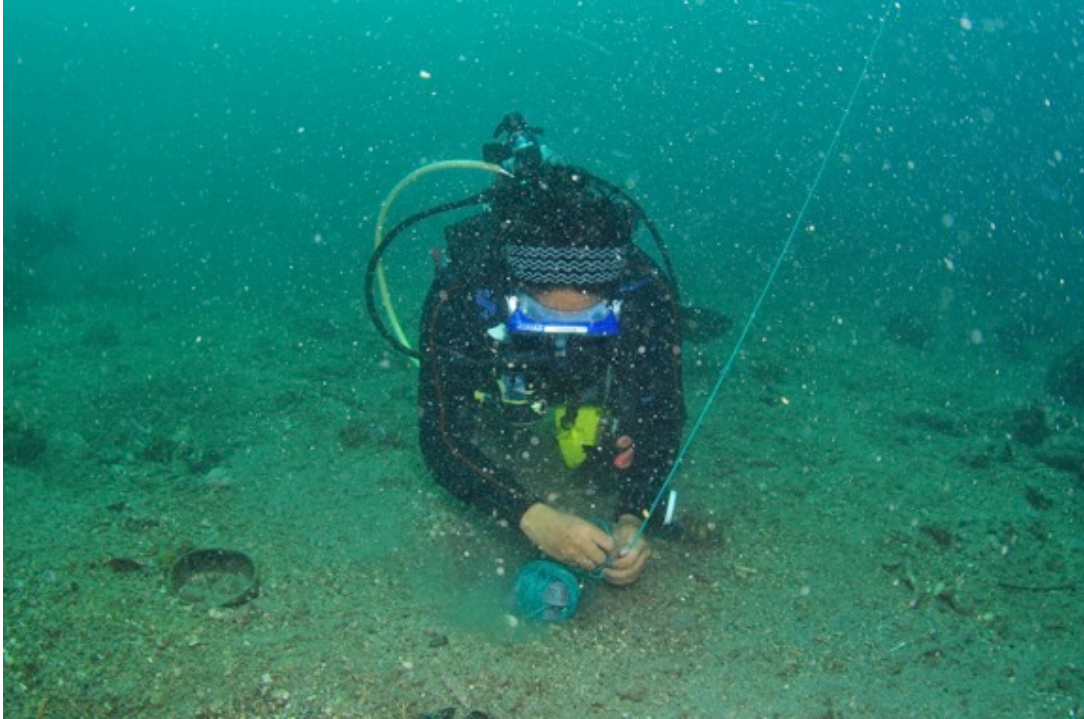


Figure 2 Deploying substrate materials at each marker buoy



Figure 3 Lava rock collection near marker buoy line

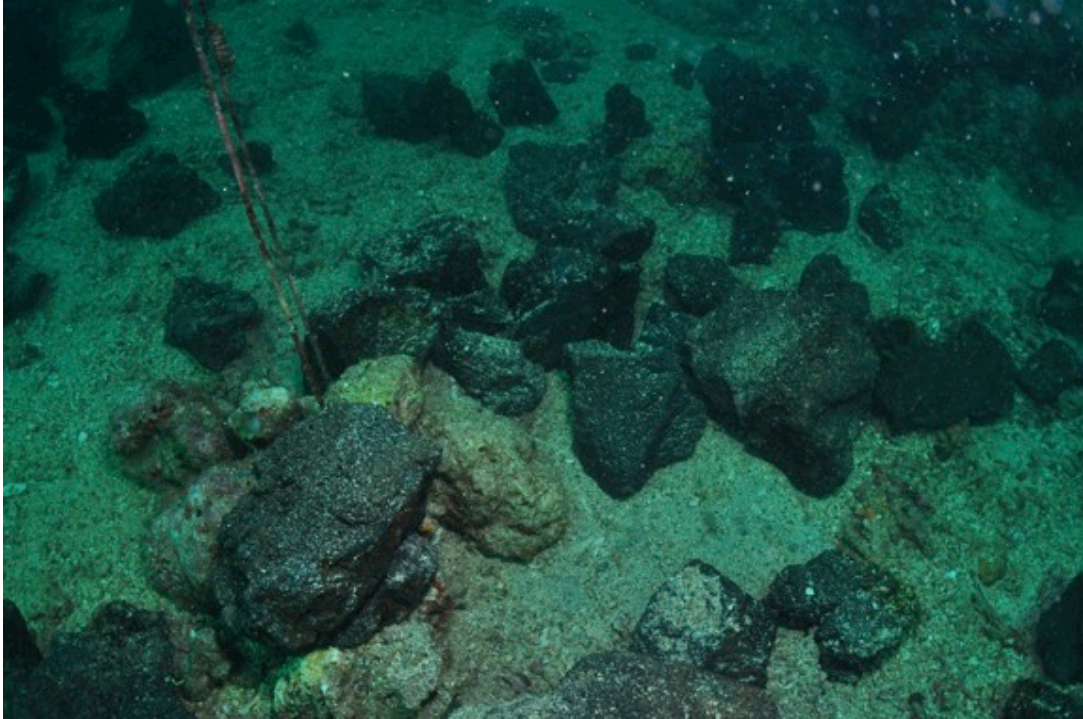


Figure 4 Initial habitat wall design



Figure 5 Modified Habitat Wall Design

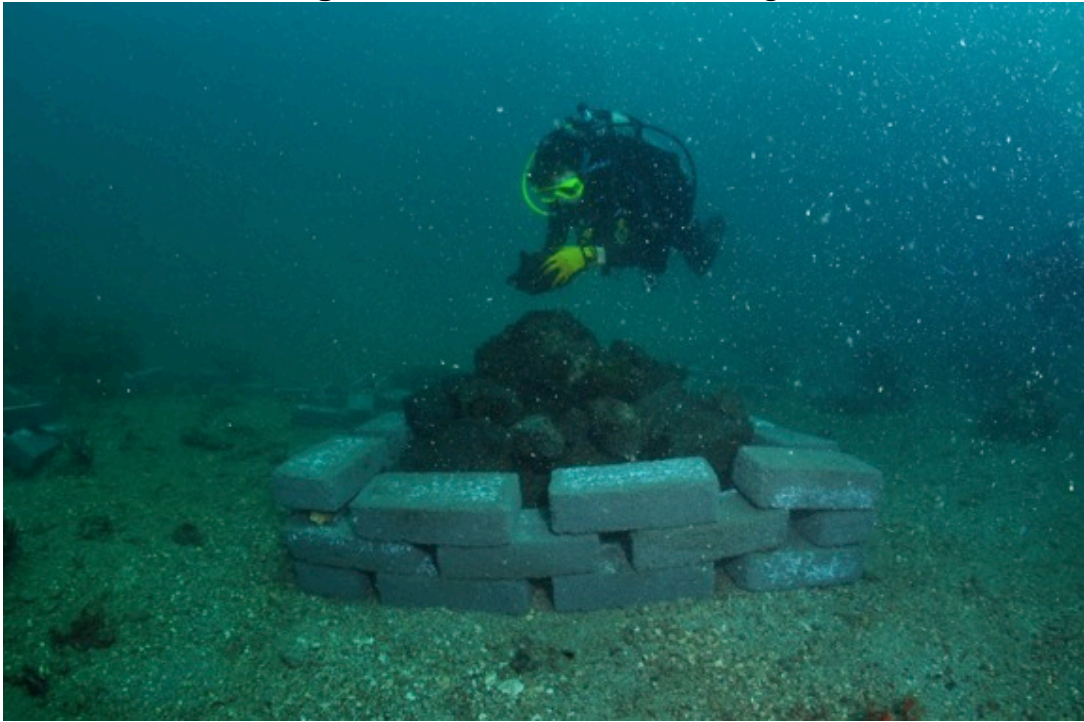


Figure 6 House Reef Map Mid-Section with Lava Habitats 1-5¹¹

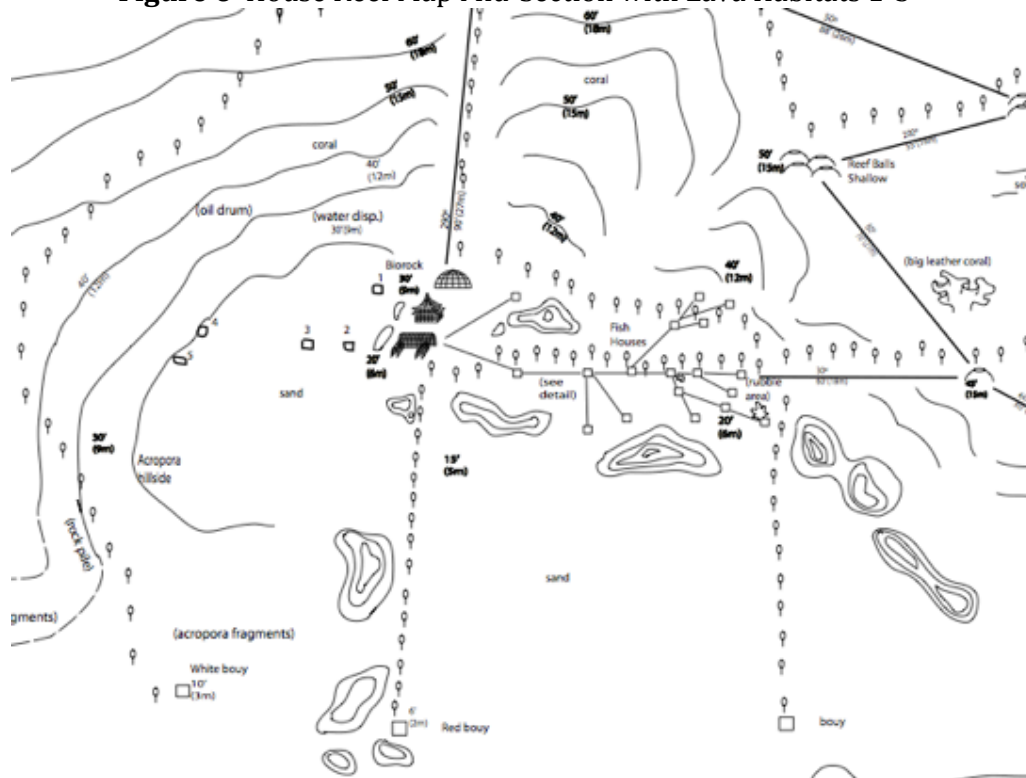


Table 3 Observational Data- Week 1

Observations	Observations	Observations	Observations	Observations	Observations
Installation Date	8/22/11	8/21/11	8/21/11	8/23/11	8/24/11
Species	<i>Oxycheilinus digrammus</i> <i>Choerodon anchorago</i>	<i>Canthigaster papua</i> <i>Acanthurus sp</i> <i>Eviota sigillata</i> <i>Neoglyphidodon crossi</i> <i>Neopomacentrus nemurus</i> <i>Dardanus sp</i>	<i>Canthigaster papua</i> <i>cheilinus fasciatus</i> <i>Neoglyphidodon crossi</i> <i>Halichoeres sp</i> <i>Eviota sigillata</i> <i>Dardanus sp</i>	<i>Cephalopholis microprion</i> <i>Eviota sigillata</i>	<i>Neoglyphidodon crossi</i> <i>Eviota sigillata</i> <i>Dardanus sp</i>

¹¹ Bromell, Madison. House Reef Report, Lembah Resort, October 2010.

Figure 7 Two crinoid species share a place at the top of Habitat 4



Figure 8 Damsel hiding in offset-block retaining wall



Figure 9 Coral Polyp



Figure 10 Sponge formation



Figure 11 Hydroid Species

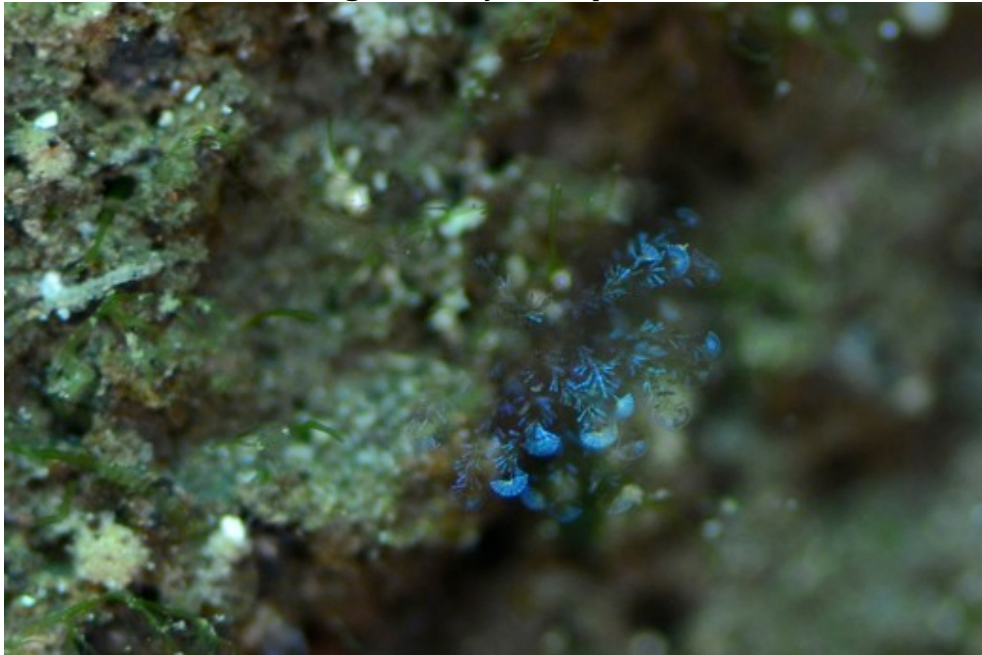


Figure 12 Juvenile Bivalve



Figure 13: Ascidian species



Figure 14: Grouper resting on retaining wall



Figure 15: Juvenile Wrasse hiding among lava rocks

