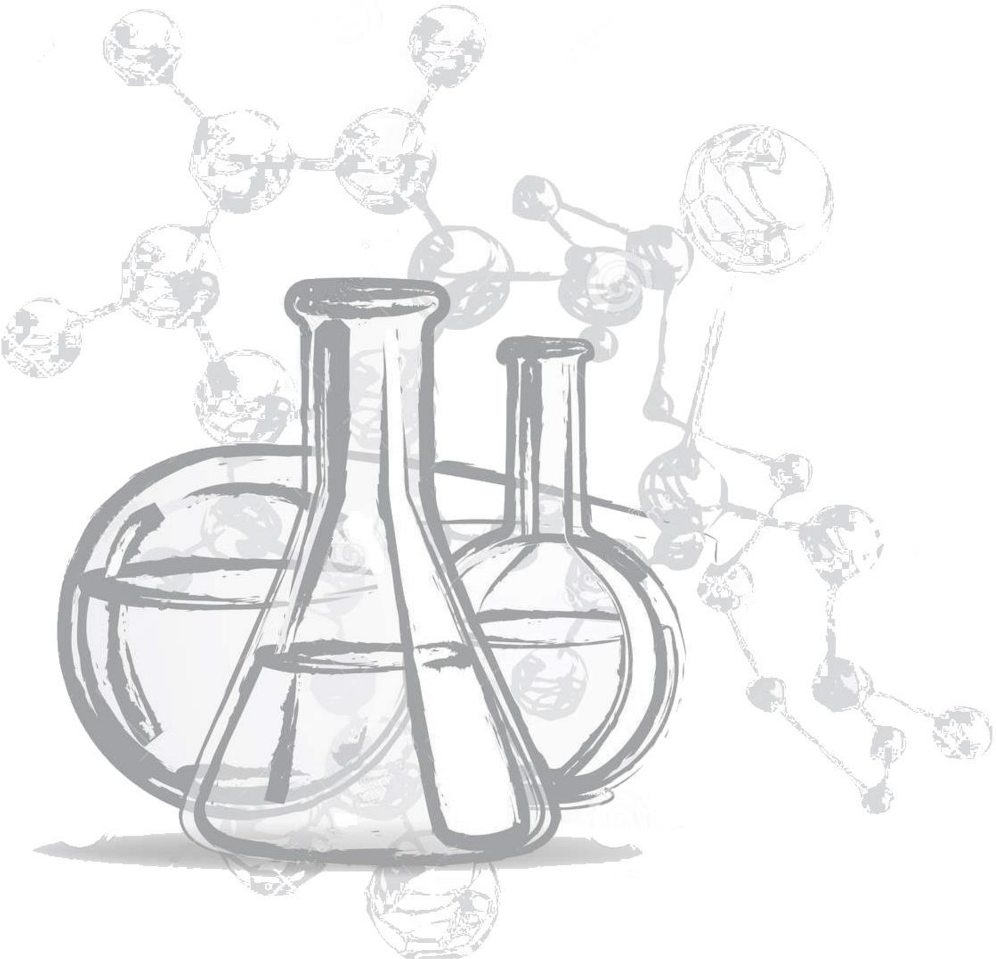
Anguilla Marine Water Sampling Pilot Study 2008



Department of Fisheries and Marine Resources

Part of the Anguilla Marine Monitoring Programme

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1. INTRODUCTION

Marine habitats and communities are intrinsically linked, if not defined, by the water chemistry that exists around them. For example, coral reefs have historically thrived in oligotrophic water, lacking nutrients that can allow algae to flourish and out-compete recruiting corals (Szmant, 2002). Similarly, the clarity of the water, a more physical characteristic often referred to as turbidity, affects light penetration that will influence photosynthesis in both coral zooxanthellae and seagrasses (AIMS, 2008). Furthermore, parameters such as temperature influence not just water chemistry, but also biological life directly: with the potential to initiate coral bleaching events or alter fish migratory patterns (Fitt *et al.,* 2001; Hannesson, 2007). In fact, changes to any variable will have a knock on effect to the present ecosystem balance in one way or another. Thus, monitoring such parameters is of utmost importance to help understand potential reasons for any observed ecological changes. Ocean chemistry is however complex, and many parameters require sophisticated technology to accurately measure them. With this being the case, the Department of Fisheries and Marine Resources (DFMR) set out to conduct a pilot study that would assess: The viability of collecting such data; the practicality and accuracy of measuring different parameters with the resources available; and potential site selection for long-term data collection.

2. METHODS

Although for this study the TSG Technologies (Anguilla) lab was used for the much of the analysis work, the ultimate aim is to utilise the Government of Anguilla’s Water Lab at the Department of Health Protection. This lab recently relocated and is as such still under construction. It is anticipated that continued annual sampling work to be designed based on the results of this pilot study will be able to make use of this lab.

Equipment used:

- Transportation – Boat and/or pickup depending on sample site location.
- Multiparameter research meter.
- Clipboard, paper and pens to record data in field.
- SCUBA equipment to collect deep samples and sediment.
- Sample bottles to collect samples.
- Coolers to store collected samples.
- Saltwater sampling kit.
- TSG laboratory and technician.

Methodology:

Sample sites were spread around the coast of Anguilla so to not leave any areas unrepresented. Some areas of specific interest had multiple sites to allow for mesoscale spatial variations (i.e. Road Bay). Ultimately seventy-five sites were selected to be part of this pilot study, details of which can be found in Appendix 1. Some of these sites had were sampled at different depths due to the presence of a thermocline, thus approximately eighty data points were collected during each replicate. Other sites were located around the offshore cays and reefs, with further sites a good distance away from land sampled to act as controls, (although it is recognised that they were not in fact true controls as contamination is always possible due to the dynamic nature of oceans). The multiparameter research meter must be able to measure a minimum of temperature, pH and dissolved oxygen as these tests must be performed as soon as possible. Other parameters (nitrates, dissolved solids etc) can be conducted within 48 hours of the sample being collected and could therefore be measured in the lab.

Sampling was finally ready to begin at the beginning of September 2008. Initially three replicates were aimed to be conducted at each sampling site, with at least two sediment replicates. However, because of logistical problems (DFMR vessel needing repairs), and because of interference by hurricane Omar, the number of replicates was somewhat reduced (most water samples were replicated twice, and most sediment samples replicated once). Hurricane Omar did however provide an interesting case study of how storm surges affect coastal water quality, and this will be discussed in section 4.

One member of staff was responsible for operation of the meter and data recording, while the other was responsible for collecting samples in sample bottles and labelling them correctly. The meter probes were submerged deeper than 30cm below the surface to avoid surface contamination, and not in areas where waves had churned up the sediment, so staff had to wade out into the water when collecting coastal samples. Water samples collected in bottles followed these rules also. Care was taken to avoid contamination from bathers when collecting coastal samples, or from the boat engine when collecting offshore samples. So, for example, samples were taken at least 30m away from bathers and off the bow of the boat to avoid engine contamination. In offshore areas deep enough to possess a thermocline, a deep-water sample close to the sea bed was also collected. When collecting this a secondary sample was also obtained for use with the probes once back on the surface. The purchase of a Niskin bottle was considered to collect these samples, but as only a small number of deep-water sites were incorporated into this study, and because none were below safe diving limits, the use of SCUBA equipment was adequate. Plastic sample jars were used while collecting these samples to allow for compression with depth, thus facilitating lid removal while at depth. If a glass jar were to be used the lid would be very difficult to remove and suck-back likely occur which might injure fingers.

Once water samples were collected and bottles/jars correctly labelled they were placed into coolers to restrict warming. Once sampling had been completed for the day (the number of samples taken per day was based on TSG's workload, but usually numbered 14 or 28 – only 14 samples at a time could be centrifuged) the coolers were taken to TSG's lab, and test results emailed the following day.

Most of the sites with suitable bottom composition also had a sediment sample taken. The purchase of a sediment scoop was considered to allow these samples to be collected from the surface, however because bottom composition was often that with scattered patches of sediment among predominantly hard substrate, the use of SCUBA equipment and a plastic jar was considered more appropriate. Once at the bottom the surface layer of sand/sediment was brushed aside (1-2cm) and the underneath layer collected in the container. Once back at the lab the sample was drained of liquid and this liquid was then tested in the same way as water samples. Consequently, the results for sediment samples are not a true description of the sediment itself, but do give an indication of its content. For example, although phosphorous may be in low quantities, this indicates there is quite a high level of it in the sediment. If phosphorous levels are however below detectable levels (BDL), then it can be concluded that negligible amounts are present in the sediment.

For detailed descriptions of the methodologies used by the TSG lab to run tests please contact fisheriesmr@gov.ai. All meters and other electronic equipment used in the lab were HACH. Parameters tested for were: Conductivity, total dissolved solids, ammonia, nitrates, phosphorous, chemical oxygen demand and turbidity. Other parameters were also tested by DFMR on a random selection of samples using the salt water testing kit. Parameters tested were: Hardness, nitrites, alkalinity and dissolved CO_2. For detailed descriptions of the methodologies used please contact fisheriesmr@gov.ai. The validity of these tests and their use will be covered in section 4. It should be noted that an error was noticed in the chemical oxygen demand test, and so all data relating to this variable collected prior to September 24th 2008 was discarded during analysis. This also contributed to the reduced replicate number mentioned at the beginning of this section.

Plates 1 to 3 – The pipe connecting Merrywing salt pond to Cove Bay; Collecting deep water samples in the St Martin Channel; Dark anoxic sediment in shallow water near Pelican Point (suggesting high organic content).

3. RESULTS

Water Samples

Table 1 – Mean primary results for the eighty water sample sites around Anguilla between 2nd September and 3rd December 2008. Note that these results do not include those for the week after hurricane Omar. (BDL = Below Detectable Limits).

Site	Temp C	DO (mg/L)	pH	Conduc -tivity (µs)	TDS (ppt)	Ammonia (as N mg/L)	Nitrate (as N mg/L)	Phos-phorous (mg/L)	COD (mg/L)	Turbid ity (NTU)
Road Bay Pond Channel	32.1	1.36	7.78	107.80	143.20	0.17	0.70	0.02	1490	4.05
Road Bay Floating Pier	29.8	7.49	8.24	51.30	53.60	0.03	0.16	0.12	940	1.92
Road Bay Yacht Club	29.6	7.91	8.29	51.25	53.55	0.01	0.16	0.02	880	1.31
Road Bay Wooden Pier	28.0	7.91	8.34	52.17	54.43	0.02	0.27	0.01	679	1.01
Road Bay Moorings	29.3	7.59	8.23	50.05	53.25	0.06	0.55	BDL	772	0.56
Road Bay Swing Low	29.1	7.95	8.34	52.15	50.55	0.04	0.40	BDL	1090	1.27
Road Bay Main Jetty	28.2	7.66	8.32	50.70	52.87	0.09	0.27	0.01	605	0.65
Road Bay Mariners	28.2	7.83	8.32	50.95	53.45	0.01	0.06	0.01	897	0.21
Road Bay Outer Seagrass	29.1	7.13	8.21	48.65	52.60	0.02	0.10	BDL	796	0.82
Katouche North Cliffs	27.3	7.89	8.39	50.75	51.05	0.02	0.15	BDL	906	0.43
Crocus Bay Beach	28.8	7.53	8.15	49.50	55.40	0.16	0.30	BDL	1002	0.90
Crocus Bay Desalination	30.9	10.54	7.29	77.65	107.15	0.17	BDL	BDL	1264	-
Crocus Bay Yacht Mooring	28.7	7.45	8.23	49.95	53.95	0.02	0.15	BDL	1231	0.34
Little Bay	28.2	7.50	8.32	50.50	53.17	0.04	0.27	0.01	1122	0.54
Limestone Bay	29.3	7.66	8.23	47.55	54.75	BDL	0.05	BDL	622	0.89
Shoal Bay East Fountain	28.3	8.62	8.39	50.80	52.10	0.01	0.10	BDL	776	0.75
Shoal Bay East Madeariman	28.1	8.08	8.34	50.95	53.55	0.01	0.05	BDL	875	0.49
Shoal Bay East Ernies	29.3	7.66	8.18	48.35	55.55	0.11	BDL	BDL	894	0.93
Shoal Bay East Gwens	29.4	8.25	8.28	50.30	53.05	BDL	0.15	BDL	870	1.03
Shoal Bay/Island Harbour	28.7	8.74	8.37	50.40	53.65	0.01	0.10	BDL	915	0.49
Island Harbour Kokos Reef	29.1	7.97	8.36	49.85	52.20	0.01	0.05	BDL	941	0.54
Island Harbour Scilly Cay	28.7	9.81	8.43	50.95	54.25	0.03	0.10	0.01	699	0.56
Island Harbour School	28.6	8.04	8.21	5BDL	54.23	0.11	0.23	0.03	950	1.25
Island Harbour Jetty	29.0	6.78	8.11	49.00	56.50	0.05	0.15	0.05	904	0.87
Island Ridge	28.1	7.45	8.29	50.50	54.00	BDL	0.05	BDL	752	0.69
Captains Bay	29.1	7.81	8.22	46.75	54.50	0.18	BDL	BDL	417	0.82
Scrub Island/Little Scrub	28.3	7.53	8.34	50.55	53.70	0.01	0.40	0.32	746	1.10
Scrub Island Scrub Bay	28.3	7.63	8.34	50.75	53.50	0.17	0.02	0.01	992	0.93
Windward Point Bay	27.8	8.46	8.39	49.35	52.50	0.01	0.05	BDL	818	0.76
Junks Hole Nats	28.7	8.60	8.26	47.55	54.55	0.01	0.05	BDL	671	0.70
Junks Hole Savannah Bay	28.5	6.80	8.24	50.90	53.50	BDL	0.05	BDL	360	0.26
SXM Channel (Shallow) East	28.8	7.50	8.28	50.40	53.35	0.05	0.05	BDL	260	0.49
SXM Channel (Deep) East	28.9	7.97	8.27	51.50	50.05	0.06	0.10	1.79	250	0.31
SXM Channel (Shallow) Central	28.0	7.78	8.41	51.90	50.35	0.12	0.05	BDL	685	0.89
SXM Channel (Deep) Central	28.0	8.42	8.41	52.35	50.75	BDL	0.15	BDL	1179	0.78
SXM Channel (Shallow) West	28.2	7.69	8.41	51.70	50.40	0.01	0.10	BDL	1106	0.61
SXM Channel (Deep) West	27.9	8.97	8.40	52.25	50.85	0.01	0.15	BDL	1045	0.86

Table 1 (continued…)

Site	Temp C	DO (mg/L)	pH	Conduc-tivity (µs)	TDS (ppt)	Ammonia (as N mg/L)	Nitrate (as N mg/L)	Phos-phorous (mg/L)	COD (mg/L)	Turbidity (NTU)
Sile Bay	29.0	8.75	8.29	51.35	52.40	0.01	0.20	BDL	195	0.26
Sea Feathers Bay	28.7	7.66	8.22	47.60	55.30	BDL	BDL	BDL	541	0.74
Conch Bay	28.8	7.17	8.28	50.75	53.45	BDL	0.10	BDL	380	0.16
Forest Bay Seagrass	29.2	7.78	8.26	50.45	53.50	0.01	0.10	BDL	730	0.69
Forest Bay Reef Channel	28.9	6.63	8.23	51.75	52.95	0.01	0.20	BDL	259	0.31
Corito Bay Buoys	29.1	7.38	8.26	51.10	54.40	BDL	0.23	BDL	419	0.21
Corito Bay Beach	28.3	8.47	8.36	48.70	55.90	0.04	0.50	0.02	723	0.72
Little Harbour Beach	29.9	9.76	8.34	49.40	52.05	BDL	0.35	BDL	1650	1.02
Little Harbour Middle Bay	29.0	7.47	8.27	51.80	52.90	0.01	0.20	BDL	464	0.94
Little Harbour Inlet	28.8	7.76	8.26	50.55	53.35	BDL	0.15	0.21	400	1.43
Blowing Point Fishing Boats	28.2	7.92	8.30	51.23	52.80	0.03	0.33	0.05	614	0.90
Blowing Point Ferryboat Inn	29.2	7.79	8.28	51.30	52.85	0.02	0.15	BDL	620	0.75
Blowing Point Sandy Point	28.1	7.66	8.33	51.13	52.70	0.03	0.23	BDL	941	0.62
Rendezvous Bay Great House	30.0	7.63	8.27	50.70	53.45	0.07	0.25	BDL	810	1.88
Rendezvous Bay Yacht Club	28.6	8.72	8.36	51.03	52.80	0.03	0.40	BDL	848	0.65
Rendezvous Bay Merrywing	29.0	7.67	8.28	50.90	53.85	0.05	0.25	BDL	790	3.36
Temenos Pond - Pipe	29.5	6.47	8.21	51.90	53.60	0.05	0.30	BDL	1760	4.10
Cove Bay Pond Pipe Outlet	28.6	6.50	8.31	50.10	52.75	0.06	0.20	0.01	1241	0.69
Cove Bay Smokeys	28.4	7.97	8.26	50.35	53.30	0.02	0.15	BDL	880	0.72
Cove Bay Pier	28.1	8.76	8.42	51.00	52.53	0.01	0.17	BDL	682	0.81
Cove Bay Cap Jaluca Access	28.6	8.22	8.31	50.20	53.30	BDL	0.10	BDL	740	1.59
Maundays Bay Pimms	28.0	7.68	8.36	50.40	53.60	0.02	0.05	BDL	992	0.23
Maundays Bay Villa 19	29.2	7.75	8.30	5BDL	52.90	BDL	0.05	BDL	800	1.74
Shoal Bay West Altamar	28.4	8.01	8.27	50.10	52.70	0.01	0.30	0.08	760	0.70
Shoal Bay West Cove Castles	28.6	7.60	8.28	50.40	53.45	0.01	0.15	BDL	790	0.87
Blowing Rock	28.3	7.78	8.35	50.55	54.35	0.06	0.10	BDL	672	0.74
Anguillita	28.5	7.95	8.36	50.65	54.00	BDL	0.05	BDL	863	0.67
West End Bay	27.7	8.08	8.36	51.50	49.80	0.02	0.30	BDL	890	0.89
Barnes Bay Mangoes	29.3	7.93	8.32	50.65	53.45	0.01	0.20	BDL	790	1.07
Barnes Bay Viceroy Beach	28.8	7.79	8.30	51.35	53.90	BDL	0.25	BDL	1350	1.27
Meads Bay Viceroy Point	28.1	7.73	8.35	51.05	53.65	0.02	0.10	BDL	832	0.85
Meads Bay Viceroy Beach	28.9	7.88	8.30	50.35	53.10	0.05	0.15	BDL	1000	0.64
Meads Bay Central Bay	28.2	7.74	8.34	50.50	52.70	0.11	0.05	BDL	438	0.96
Meads Bay Malliouhana	29.3	7.83	8.30	51.20	53.50	0.03	0.25	BDL	960	0.33
Long Bay Offshore Regis	29.0	7.56	8.24	49.60	54.25	0.01	BDL	BDL	742	0.55
Long Bay East Beach	28.7	8.26	8.31	50.95	53.60	0.03	0.10	BDL	670	0.72
Isaacs Cliffs	28.0	7.57	8.37	50.50	51.25	0.01	BDL	0.01	845	0.71
Sandy Island Moorings	28.8	7.23	8.23	49.30	54.10	0.01	0.10	BDL	819	0.67
Seal Island Channel (Shallow)	28.0	7.80	8.39	50.70	51.00	0.02	0.10	BDL	955	0.70
Seal Island Channel (Deep)	28.0	8.12	8.37	50.40	51.25	0.02	0.10	BDL	887	0.95
Dog Island	28.9	7.74	8.33	50.65	53.90	0.01	0.10	BDL	1121	1.10
Prickly Pear	29.0	8.24	8.34	50.20	53.05	0.06	0.15	0.93	918	0.77
Long Reef	28.7	8.16	8.33	49.80	53.65	0.03	0.05	BDL	931	0.31
Means	**28.7**	**7.80**	**8.28**	**51.53**	**54.97**	**0.03**	**0.16**	**0.05**	**826**	**0.90**

Selected parameters were also tested for at random sites in order to obtain baseline figures and/or assess the accuracy of the testing method (saltwater testing kit). These results are laid out in table 2 following. It should be noted that the results obtained for dissolved CO_2 were much higher than expected which called into question test accuracy. This will be discussed in section 4.

Table 2 – Secondary results for water samples obtained using the saltwater testing kit. It should be noted that only a random collection of sites were tested in order to obtain baseline figures and/or assess the accuracy of the testing method. (BDL = Below Detectable Limits).

Site	Date	Nitrites (mg/L)	Hardness (mg/L $CaCO_3$)	CO_2 (mg/L)	Alkalinity (mg/L $CaCO_3$)
Road Bay Pond Channel	Oct	BDL	6900	100	-
Road Bay Floating Pier	Oct	BDL	-	69	-
Road Bay Swing Low	Nov	-	-	-	124
Crocus Bay Beach	Oct	-	6330	47	-
Island Harbour School	Oct	-	6360	52	-
Island Ridge	Nov	-	-	-	121
Scrub Island/Little Scrub	Nov	-	-	-	120
Windward Point Bay	Oct	-	6290	43	-
Junks Hole Nats	Oct	-	6230	49	-
Channel (Deep) Central	Nov	-	-	-	123
Sea Feathers Bay	Oct	-	6420	50	-
Rendezvous Bay Great House	Oct/Nov	-	6250	50	126
Maundays Bay Pimms	Oct	BDL	6220	63	-
Maundays Bay Villa 19	Nov	-	-	-	125
West End Bay	Oct/Nov	-	6120	73	122
Barnes Bay Mangoes	Nov	-	-	-	129
Meads Bay Malliouhana	Oct	-	6200	56	-
Seal Island Channel (Deep)	Nov	-	-	-	124
Long Reef	Nov	-	-	-	119

The tests that were conducted the week after hurricane Omar hit the island (landfall 15th October) were separated from those listed above. Paired t-tests were performed on the data to look for any significant differences from the mean data collected during the rest of the pilot study: Unsurprisingly turbidity was significantly higher after the hurricane (t_{27} = 3.225, p = 0.003), as was clearly visible from land. Conductivity was also significantly higher, though marginally (t_{27} = -2.064, p = 0.049). Of more interest perhaps was the fact total dissolved solids (TDS) were significantly lower after the hurricane (t_{27} = -3.839, p = 0.001). No other results were significant.

Another noticeable effect of hurricane Omar was the water cooling that happened directly afterwards. Although the drop was not significant it did fall below the 29°C mark at most sites. The temperature variations over the whole study period are showing in figure 1, which will be discussed in more detail in section 4.

Other temporal relationships were analysed also, although because the study only took place over a three-month period, and possibly because a hurricane occurred during this, very few trends were noticed. Of most interest was that pH generally increased over the study period as illustrated in figure 2, although this may be related to the temperature trends, a fact that will be again be discussed in section 4, as illustrated in figure 3.

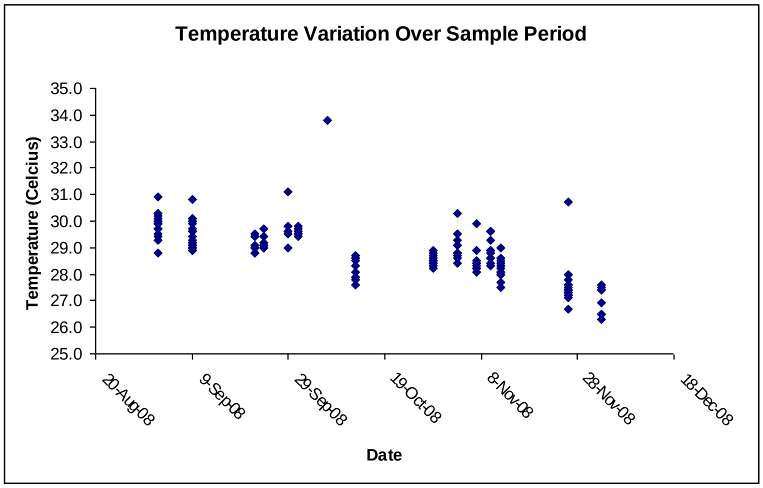

Figure 1 – Temperature trend through the study period. Note the interesting dip two days before hurricane Omar made landfall. Points noticeably above groups were from pond or inlet pipe samples. Graph does not include data collected the week directly after hurricane Omar.

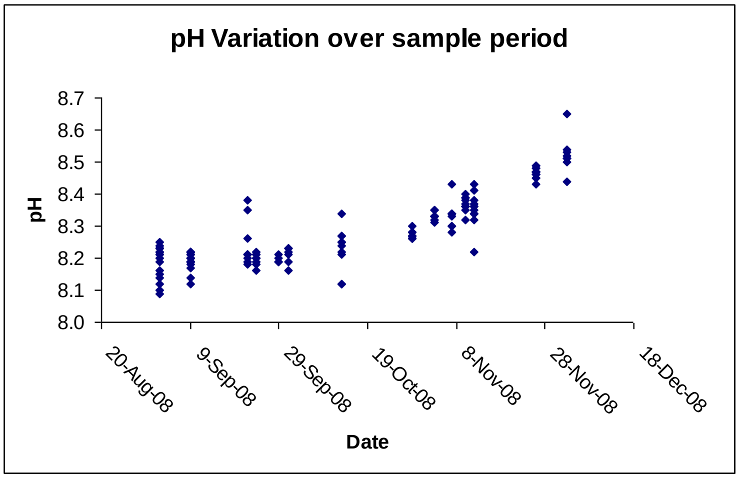

Figure 2 – Trend in pH through the study period. Note the inverse relationship that seems to be occurring with temperature (see figure 1), a relationship that is demonstrated further in figure 3. Graph does not include data collected the week directly after hurricane Omar.

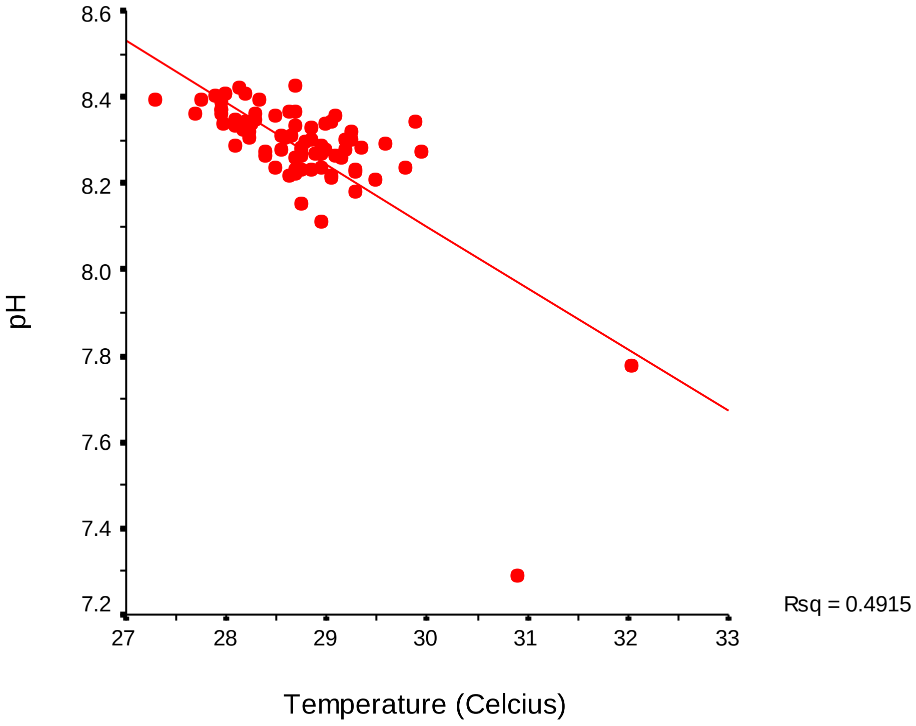

Figure 3 – Relationship between temperature and pH through the study period.

Table 3 - Mean results for the sediment samples collected at the water sampling sites around Anguilla between 2nd September and 3rd December 2008. (BDL = Below Detectable Limits).

Site	**Conductivity (µs)**	**TDS (ppt)**	**Ammonia (as N mg/L)**	**Nitrate (as N mg/L)**	**Phosphorous (mg/L)**	**COD (mg/L)**
Road Bay Pond Channel	-	-	2.45	-	-	-
Road Bay Floating Pier	-	-	0.36	2.85	1.16	1780
Road Bay Yacht Club	-	-	0.31	0.70	0.02	1210
Road Bay Wooden Pier	48.90	56.80	1.70	2.25	0.02	1435
Road Bay Moorings	55.40	56.10	0.21	0.40	BDL	1234
Road Bay Between Swing Low	-	-	0.20	0.30	0.06	910
Road Bay Main Jetty	50.10	53.40	0.12	0.20	BDL	2971
Road Bay Outer Seagrass	49.40	52.00	2.22	1.60	0.27	694
Katouche North Cliffs	49.80	51.70	0.49	0.60	0.11	2712
Crocus Bay Desalination	62.10	99.40	0.79	0.80	0.02	2731
Crocus Bay Yacht Mooring	48.10	51.80	5.50	2.20	0.79	1211
Little Bay	48.60	49.80	5.74	BDL	0.86	1131

Table 3 (Continued….)

Site	Conductivity (µs)	TDS (ppt)	Ammonia (as N mg/L)	Nitrate (as N mg/L)	Phosphorous (mg/L)	COD (mg/L)
Shoal Bay East Fountain	49.40	52.00	5.16	3.20	0.32	1074
Shoal Bay East Gwens	49.90	56.20	0.50	3.00	5.22	-
Shoal Bay/Island Harbour	48.90	57.20	0.21	BDL	0.02	407
Island Harbour Kokos Reef	49.00	55.40	0.33	0.40	0.03	302
Island Harbour Scilly Cay	48.70	55.10	0.21	0.10	0.02	732
Island Harbour School	48.80	55.30	BDL	0.02	BDL	-
Island Harbour Jetty	48.80	55.30	0.80	0.02	BDL	-
Island Ridge	52.10	50.90	0.11	0.20	BDL	971
Captains Bay	49.00	55.00	0.46	0.40	0.02	411
Scrub Island/Little Scrub	51.60	50.40	0.21	0.20	0.01	2730
Junks Hole Nats	-	-	0.02	0.10	0.09	211
Junks Hole Savannah Bay	-	-	BDL	0.20	BDL	340
Channel (Deep) East	49.80	54.00	0.61	0.35	0.01	419
Channel (Deep) Central	51.60	50.30	0.41	0.55	0.11	1242
Channel (Deep) West	51.70	50.40	0.39	0.65	0.09	1406
Sile Bay	48.90	53.70	0.02	BDL	BDL	1002
Forest Bay Seagrass	49.20	54.00	0.03	BDL	BDL	691
Forest Bay Reef Channel	49.30	54.00	0.02	BDL	BDL	738
Corito Bay Buoys	5BDL	54.30	0.04	BDL	BDL	1763
Little Harbour Beach	-	-	3.80	3.15	0.72	1110
Little Harbour Middle Bay	5BDL	54.30	0.37	0.20	0.01	1027
Little Harbour Inlet	48.50	54.20	2.90	3.00	5.50	-
Blowing Point Fishing Boats	49.10	56.60	1.40	BDL	0.63	333
Rendezvous Bay Yacht Club	-	-	0.02	0.20	BDL	930
Rendezvous Bay Merrywing Bay	52.70	50.90	0.19	0.20	BDL	2989
Temenos Pond - Pipe	-	-	0.21	2.70	1.40	-
Cove Bay Pond Pipe Outlet	49.60	56.70	0.90	BDL	0.86	-
Cove Bay Pier	52.40	51.00	0.21	0.30	BDL	1311
Maundays Bay Pimms	52.20	51.00	0.23	0.20	BDL	1432
Shoal Bay West Cove Castles	52.20	51.20	0.22	0.20	BDL	1094
Barnes Bay Viceroy Beach	48.20	52.10	0.28	BDL	0.04	549
Meads Bay Central Bay	52.00	51.00	0.24	0.20	BDL	1347
Long Bay Offshore Regis	48.70	51.70	1.12	BDL	0.41	931
Isaacs Cliffs	49.80	51.80	0.76	1.10	0.17	2654
Sandy Island Moorings	51.80	51.70	0.09	0.20	0.01	1218
Seal Island Channel (Deep)	49.70	52.10	0.31	0.40	0.21	3177
Dog Island	51.90	51.10	0.07	0.30	0.01	1114
Prickly Pear	52.70	51.10	0.21	0.20	BDL	1232
Long Reef	52.30	50.90	0.12	0.30	0.02	832
Means	**50.55**	**54.14**	**0.85**	**0.68**	**0.38**	**1267**

4. DISCUSSION

Sources of Error and Test Validity:

The first thing to appreciate in relation to the results presented is that water sampling with inexpensive equipment is inherently open to errors. This is not just the fault of the equipment (calibration errors) but also because holding probes in the water column allows considerable variation (depth, wave action etc). Furthermore, using such equipment in the field, it is not always possible to keep it in perfect condition (heat, rain, bumps etc), thus allowing for more potential variations. Finally, although all attempts to store the equipment in the correct manner were made, variations over time due to wear and tear cannot be ruled out, although periodic checks with control solutions hopefully minimised this. Samples were also regularly 'spiked' to check test accuracy.

In terms of laboratory tests other variations come to light. Firstly, human error measuring liquids is highly relevant (incorrect reading of graduation), or imprecision in taking such measurements with the rudimentary equipment available. Secondly, when reagent tests are conducted it is often necessary to 'choose' when an 'end point' has been reached, again leading to potential result variation. This was especially the case with the DFMR saltwater testing kit, but less relevant at the TSG lab where meters were often used to take measurements. Finally, methodology errors can sometimes inadvertently occur, as happened with the initial COD tests. Luckily this error was noticed and corrections made, although this did leave almost a months worth of COD data worthless. Perhaps a better approach would have been to continue with the old methodology while also testing the new methodology, then later introducing a conversion factor that could have been applied to the earlier data.

Whatever the case, this is one of the important uses of a pilot study, and it is hoped that the 2009 monitoring will be as free of such errors as possible, and through lessons learnt other variations mentioned above minimised. One essential means to do this is to standardise methodologies so that even if inaccuracies exist, changes to the variables themselves will still be visible, even if their recorded values are not entirely correct. Again, such standardisation is a vital output of such a pilot study.

As a final note, it is important to mention that during the 2009 sampling, the HACH meter DFMR used in 2008 will likely be replaced with the VWR sympHony meter that has recently been returned after the original unit malfunctioned. In order to introduce this meter into the programme, and in light of factors mentioned above, it will be necessary to use both meters side-by-side to begin with in order to check both are equally calibrated.

Results were usually only quoted to two decimal places, thus any results lower than 0.01 were considered below detectable limits (BDL). Very few standard wet chemistry tests can accurately reproduce standard values that are lower than this, which means any such values would always be questionable, and possibly be caused by unknown interferences in the analysis method and the ability of the method to accurately determine the correct values.

More questionable however are those tests carried out using the saltwater test kit. Because of the highly manual nature of these tests, and the subjective nature of the results – which is difficult to control for using standardised methods as what a researcher one day chooses to be a 'pink-green-grey', might be different from what they choose a week later, or indeed what another researcher chooses. Such reagent tests are however useful if looking for the presence or absence of compounds (i.e. nitrites), rather than an exact value for their abundance.

This came into question when testing for dissolved CO_2 as results obtained were much higher than expected. After contacting water chemistry specialists it was confirmed that the results were indeed very high, and after further discussions with them it was decided that attempting such tests was beyond the capabilities of this monitoring programme.

The hardness test has an obvious endpoint and so such discrepancies unlikely, although as this test uses up a lot of reagents it was decided to move to total alkalinity tests. This test also provides more information relating to ocean chemistry and is therefore of more potential use. However, after running this test a number of times it was again decided the end point was very hard to spot, although the results obtained were very close to that reported as expected for natural sea water (reported as 2.0-2.5 meq/l which is the equivalent of c. 125mg/L $CaCO_3$ – Tullock, 1996).

Although alkalinity, hardness and CO_2 differ from pH, any change in them will likely have a knock-on effect to it, and so it was concluded to just continue monitoring pH. If any concerning values are obtained in the future then the saltwater testing kit could be used to investigate further. In terms of current resources such tests are only really of use to look for extremes, rather than providing an accurate, precise figure.

Therefore in future the saltwater testing kit will only be used for:

- Presence or absence of compounds.
- Extremes of certain variables.

In light of this it may be prudent for DFMR to purchase test strips for heavy metals as this would fill a gap that exists in this current monitoring programme, and complement the conclusions drawn above.

Hurricane Omar

Although most variables were not significantly affected by hurricane Omar around Anguilla, some interesting insights can be drawn from the results. For example, the water in Maundays Bay directly after the hurricane smelt 'sulphurous' which was reportedly caused by a salt pond breach, although other sources reported that the waste water treatment plant had flooded, with untreated waste being flushed into the sea. Whichever is true is largely irrelevant as the salt pond is reportedly one of the most polluted on the island anyway. What is of relevance is that nitrate, and chemical oxygen demand were markedly raised directly after Omar, and dissolved oxygen much reduced. This implies that some kind of 'organic input' took place in the area and illustrates one potential hurricane effect if coastal defences or setbacks are not sufficient: nutrification. Nutrification is highly relevant at the moment in the Caribbean due to the 'phase-shift' that is occurring between nutrient-phobic corals, and nutrient-philic algae.

From a more positive perspective however, Omar can also be seen as a friend to Anguilla's coral reefs. Firstly, it was not powerful enough to have caused extensive structural damage, and secondly it caused a noticeable drop in sea temperatures. Before Omar the water temperatures were hovering between 29 and 30°C. If these temperatures are maintained they can lead to coral bleaching, which during an especially long hot season can cause significant mortality to corals. If Omar had not influenced Anguilla then it is quite possible that although not a record-breaking year in terms of temperature, it could have been sustained long enough to cause a moderate bleaching event. In actual fact only limited bleaching occurred before Omar hit, and none was observed subsequently.

One interesting anomaly in the data are lower than normal temperatures noted on the 13th October, two days before Omar made landfall. Here temperatures dropped by approximately 1.5°C from those recorded previously. This is a phenomenon not reported in the literature and could be an important aspect of a hurricanes impact on water masses immediately prior to passing.

Unsurprisingly turbidity significantly increased the week after hurricane Omar, which would have been caused by both sediments being stirred up, and runoff entering the sea from land. Interestingly however total dissolved solids (TDS) actually decreased immediately after Omar, which is opposite to what would be expected if more solids are suspended in solution and that solution is being shaken up. One possible explanation could be related to temperature. As temperature was lower, it is possible that fewer solids were able to dissolve. This would be an example of the complexities in ocean chemistry where different parameters are intricately related to one another, so changes in one might be due to changes in another and not other external factors. Such a relationship exists between temperature and pH for example, as demonstrated in figure 3. Here, the TDS might be related to the pH increase that occurs when temperatures drop. Possibly however, such a relationship does not exist and the drop in TDS is caused by another external factor. This is a subject that requires further investigation.

As a side note it is interesting to ponder this relationship between temperature and pH. If pH increases as temperature decreases, this means that acidity increases (lower pH) as temperature increases. In light of reported ocean acidification and reported increases in ocean temperature, one wonders if: Will increased temperatures mean that acidification will be more severe and add yet more stress to corals; or is the increase in temperature the reason that we are seeing a slight acidification of the ocean in the first place?

Nutrification:

Aside from ocean temperature and acidification, one of the greatest concerns relating to marine ecosystems is nutrification of coastal waters, otherwise known as eutrophication. Coral reefs are naturally oligotrophic (nutrient-poor water), hence they lack nutrients that would otherwise facilitate algal growth. If waters become eutrophic, algal growth on reef structures can out-compete recruiting corals, and algal blooms in the water column can block sunlight essential for coral zooxanthellae to photosynthesize.

Coral reef waters can be considered eutrophic when critical nutrient levels cause algae to dominate over corals, and thus such threshold definitions will be different to those applied to other aquatic systems. Goreau *&* Thacker (1994) concluded that levels of 0.003 mg/l Phosphorous (orthophosphate plus dissolved organic phosphorus) and 0.014 mg/l Nitrogen (nitrate plus ammonium plus nitrite) could be considered eutrophic in a coral reef ecosystem. These levels are so low that they would not be eutrophic in any other ecosystem, and also so low that they will fall into (or very close to) the BDL categories mentioned earlier. This means that any detectable nutrients represent a eutrophic situation. Furthermore, due to the low sensitivity of the tests used, even if a nutrient variable is recorded as BDL, it may still be high enough to be considered eutrophic. However, for the purpose of this report and the usefulness of results, we will tentatively use BDL as a limit of eutrophication. With this being the case, the only sample site that had no nutrients at detectable levels was Sea Feather Bay. However subsequent monitoring will be needed to confirm this site does not have pervasive eutrophic conditions.

It was also clear from the results that hurricanes can increase the input of nutrients into the marine environment via breaches, rain runoff, and also flooding of water treatment plants as reportedly happened at Maundays Bay. Similarly, septic tanks have been historically used in Anguilla and if in low lying coastal areas may also be inundated by storm surges. Although their current use at coastal developments is discouraged, no current legislation restricts their use, and older tanks may be prone to leeching all year round through cracks and other deterioration features. Furthermore: Agriculture is increasing on the island; fertilisers are used by many of the large coastal developments to aid decorative plant growth; salt ponds within tourist developments that act as natural nutrient sinks have been connected to the ocean via outfall pipes; beach flora is often removed by coastal developments and other land use patterns that would otherwise trap surface runoff and its associated sediments and solutes – all of which potentially increase nutrient input into the marine environment causing eutrophication.

So, the question remains: 'Where are these nutrients coming from?'. Deep-water upwellings are one potential natural source and are extremely likely given Anguilla's location. Indeed, certainly in terms of phosphorous, one of the offshore sites had the second highest value (Prickly Pear), and a deep sample taken from one of the St Martin Channel sites had a value almost twice this. Nitrates however differed, with coastal sites sometimes having the highest levels. This was especially the case with those near to salt ponds or other land-based sourced of pollution. Therefore, an upwelling source can only currently be suspected, and although natural, the amount of nutrients in such upwellings may be elevated through decades of nutrient input from many sources around the globe. This might explain the regional eutrophication that is being reported throughout the Caribbean that is suggested to be one of the main factors causing coral reef degradation on a regional level.

Such a regional source can lead to complacency from a local legislative standpoint, but it needs to be recognised that local sources of nutrients can't be ignored: they may prove to be the 'straw that broke the camel's back'. For example, chemical oxygen demand (COD) was elevated at a number of sites, which is a sign of poor water quality; Little Harbour; Barnes Bay (outside the Viceroy Development); Cove Bay (near Tenemos Golf Course); and Crocus Bay. All of these areas have potential 'pollution' sources: Little Harbour – Connected to a salt pond; Cove Bay – Pipe connects it to a salt pond; Crocus Bay – Near where mega yachts moor and probably illegally dump waste water. Without these sources it is possible these areas would be much lower in COD and even nutrients, even with regionally influential theoretical factors playing a role. On the other hand, in other locations, surprising results were obtained, with readings from the St Martin channel much higher than expected.

Although some nutrients might be brought in by ocean currents or deep water up-welling, and thus, like factors such as sea temperatures or ocean acidification, cannot be controlled at a local level, other sources can with the correct legislation. Such legislation or resources for surveillance and enforcement do not currently exist in Anguilla, and although the source of nutrification in our water needs further study, it would be advantageous to begin addressing this situation as soon as possible.

Possible steps that could be taken are:

- Decontaminate polluted salt ponds or minimise the risk of contamination via ocean breeches.
- Relocate landfill site away from coast and/or reduce risk of contamination through the use of subterranean barriers.
- Set water quality parameters and monitor the input of such into the marine environment by measuring outflow pipes (i.e. Desalination plant at Crocus Bay; Merrywing Pond outflow pipe).

- Legislate for septic tanks and organise alternative sewage treatment arrangements for residents in areas such as Sandy Ground.
- Establish a set back minimum for water treatment plants to avoid their flooding during storm surges.
- Surveillance and enforcement of legislation relating to the dumping of bilge or grey water in Anguillian waters by visiting or local vessels.
- General monitoring of other sources of pollution, for example: Oil leaks from vessels, petroleum leaks from storage areas; dumping of lead-acid batteries.

In general, although nutrient levels can be considered eutrophic, they are currently not at very high levels at many sites, and algae growth as a result would probably be controlled by grazers if: Over-fishing of grazers didn't occur; or if *Diadema antillarum* populations recover. These are aspects that need consideration, and as such are an important part of DFMR's other work priorities, which will be covered in subsequent reports.

Conversely however, and a potential concern, is that nutrient input may in fact be much higher than has been detected by this study because algae 'fixes' nutrients in the water through growth before it reaches detectable levels, thus algal presence (i.e. the blooms seen at Road Bay in 2008) are themselves an indicator of high nutrients. This is the same for the reefs around Shoal Bay – Island Harbour that are smothered in algae. Because the growing algae locks in nutrients and renders them 'undetectable' via water sampling, it was considered important to try to measure these nutrients once the algae died and began to release their nutrients once decomposing. Accordingly, sediment sampling was undertaken (see table 3), and although it is recognised that nutrients in the samples have many potential sources (as with water samples), the levels in them would at least be indicative of eutrophication levels.

From the sediment sample results it became clear that there were in fact more nutrients present than the water samples themselves revealed. Many of the samples smelt really bad (even in seemingly pristine areas), and a number of them had elevated levels of both nitrates and phosphates. Of the sites, the ones with the highest levels were: Road Bay; Crocus Bay; Shoal Bay East; and Little Harbour. These sites will be of special interest during continued monitoring as potential sources will be investigated further.

2009 Site choice:

Based on aspects discussed in this report the below list of sites were chosen for continued study in 2009, with the hope of them becoming long-term water quality monitoring sites. Priority was given to: Those sites that are currently part of the Anguillian Marine Monitoring Programme (AMMP); sites that may be included in AMMP if or when this project is expanded; sites with elevated levels of nutrients or associated parameters; sites close to future proposed development or current developments; and offshore sites that may serve as a control. Balanced against this were the logistics of conducting the sampling work combined with the testing labs work load capabilities as currently the TSG lab can only accept fourteen samples a day. Thus, sites proposed are (clockwise from Sandy Ground):

Road Bay – Fishing Pier
Road Bay – Wooden Pier
Road Bay – Main Jetty
Road Bay – Mid-moorings
Crocus Bay – Mega Yachts
Little Bay
Limestone Bay
Shoal Bay East – Fountain
Shoal Bay East – Ernies
Shoal Bay East – Gwens
Shoal Bay – Island Harbour
Island Harbour Jetty
Scrub – Little Scrub
Junks Hole
Sile Bay
Sandy Hill Bay
Conch Bay
Forest Bay - Seagrass
Forest Bay - Channel
Corito Bay
St Martin Channel (Shallow)
St Martin Channel (Deep)
Little Harbour - Beach
Little Harbour - Berm
Blowing Point – Ferry Terminal
Blowing Point – Sandy Point
Rendezvous Bay – Great House
Rendezvous Bay - Merrywing
Cove Bay – Fishing Pier
Cove Bay - Westend
Cap Jaluca - Pimms
Cap Jaluca – Villa 19
Shoal Bay West - Altamar
Anguillita
Barnes Bay – Viceroy
Meads Bay - Viceroy
Meads Bay – Mid Bay
Long Bay
Sandy Island
Prickly Pear
Dog Island
Long Reef

A total of 42 sites mean that sampling can be completed during a three-day period, and the sites chosen can be placed into three groups based on their locations to complement this (see figure 4). It is proposed that sampling be undertaken quarterly: January, April, July & October. Sediment samples will be collected if appropriate, depending on the testing labs capabilities at that given time.

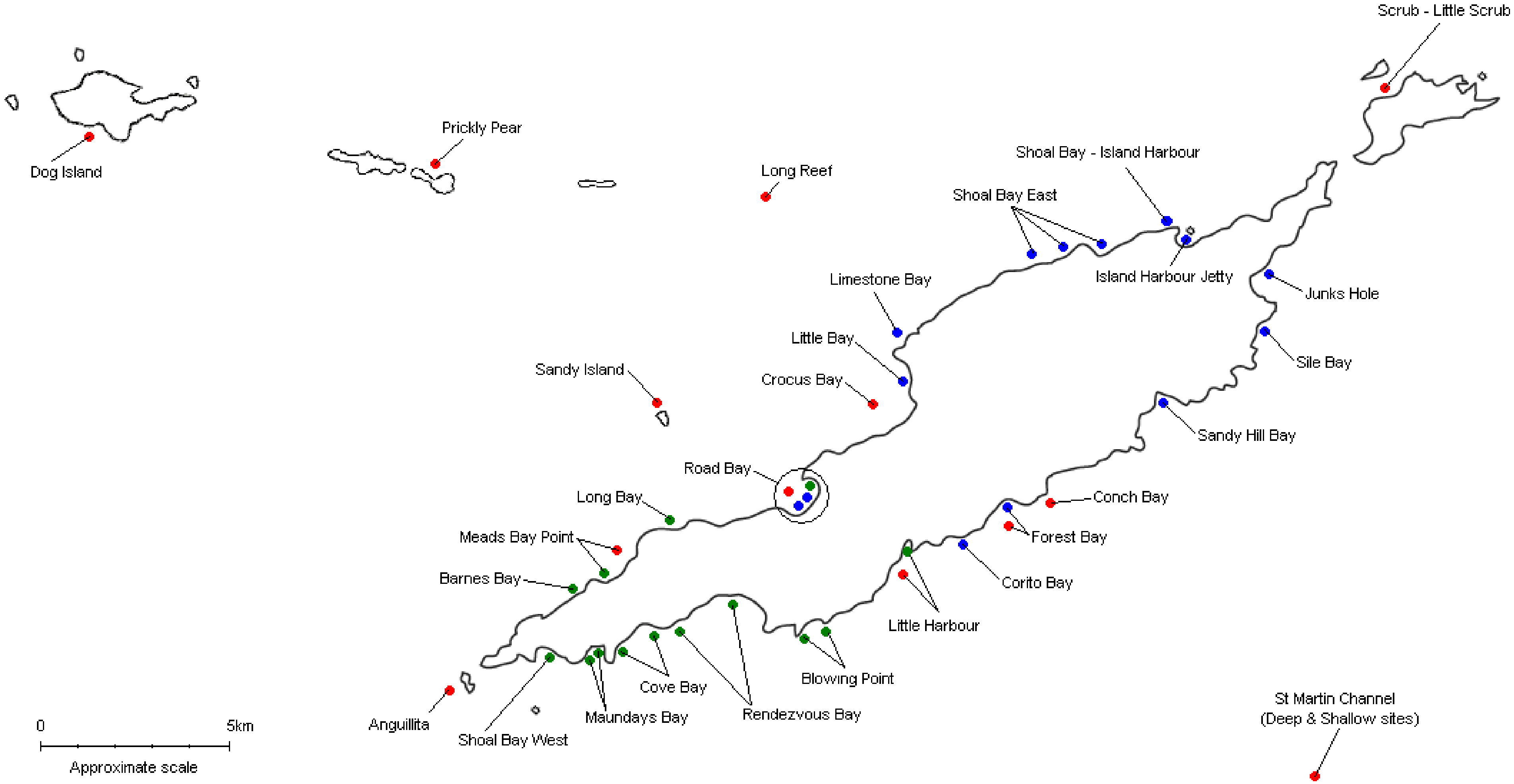

Figure 4 – Map illustrating the proposed study sites for the beginning of on-going monitoring in 2009. The sites have been divided into three groups to facilitate sampling efforts: Blue – Land based day 1 (East End); Green – Land based day 2 (West End); Red – Boat based day 3 (circular route). The exact locations of some of the pilot study sampling sites (see Appendix 1 following) have been modified slightly to allow this.

APPENDIX 1

Summary of Pilot Study Sites Sampled

Location	Description	Co-ordinates	Boat/Shore Access?	Notes
Anguillita	On western coast near AMMP site	N18 09.408 W063 10.650	Boat	No sediment collected
Barnes Bay	Outside Mangoes Restaurant	N18 10.533 W063 08.985	Either	Water Lab site
	A little offshore in front of Viceroy	N18 10.645 W063 08.882	Boat	Sediment collected
Blowing Point	Inside reef near fishing boats	N18 10.200 W063 05.479	Boat	Sediment collected
	Outside Ferry Boat Inn	N18 10.257 W063 05.691	Shore	No sediment collected
	Close to Sandy Point	N18 10.124 W063 05.851	Boat	No sediment collected
Blowing Rock	In between two parts of the island	N18 09.066 W063 09.643	Boat	No sediment collected
Captains Bay	In middle of Bay	N18 15.834 W062 58.911	Boat	Sediment collected
Conch Bay	Offshore a little	N18 12.156 W063 02.033	Boat	No sediment collected
Corito Bay	In among industrial buoys	N18 11.204 W063 03.392	Boat	Sediment collected
	On shore	N18 11.408 W063 03.368	Shore	No sediment collected
Cove Bay	In pond by pipes connecting it to the ocean	N18 10.257 W063 07.801	Shore	Sediment collected
	Next to fishing pier	N18 10.120 W063 07.729	Shore	Sediment collected
	Outside Smokeys	N18 10.211 W063 07.822	Either	No sediment collected
	In bay by pond outlet	N18 10.151 W063 07.812	Boat	Sediment collected
	West end, access via Cap Jaluca	N18 09.858 W063 08.438	Either	No sediment collected
Crocus Bay	In front of boat slipway	N18 13.236 W063 04.020	Either	Water Lab site. Sediment collected
	Desalination pipe outlet at c.10m	N18 13.567 W063 04.433	Boat	No surface collected. Sediment collected
	In Bay where yachts anchor	N18 09.858 W063 08.438	Boat	No sediment collected
Dog Island	Off Great Bay	N18 16.307 W063 15.141	Boat	Sediment collected
Forest Bay	Clear patch near seagrass AMMP site	N18 11.835 W063 02.782	Either	Sediment collected
	In reef channel near AMMP site	N18 11.583 W063 02.573	Boat	Sediment collected
Isaacs Cliffs	In between Road Bay and Long Bay	N18 11.660 W063 06.931	Boat	Sediment collected
Island Harbour	By the pier	N18 15.392 W063 00.069	Either	Sediment collected
	Near where Nature Boys mooring is	N18 15.507 W063 00.274	Shore	Water Lab site. Sediment collected
	Bay side of right next Scilly Cay	N18 15.564 W063 00.092	Boat	Sediment collected
	Outside reef near Kokos beach - AMMP site	N18 15.817 W063 00.375	Boat	Sediment collected
	Halfway along Island Ridge	N18 15.788 W062 59.521	Boat	Sediment collected
Junk's Hole	In front of Nats Place	N18 15.083 W062 59.106	Shore	Sediment collected
	Offshore in middle of Savannah Bay	N18 14.841 W062 58.868	Boat	Sediment collected
Limestone Bay	Between Limestone-Blackgarden - AMMP site	N18 14.129 W063 04.187	Boat	No sediment collected
Little Bay	Behind white moorings near AMMP site	N18 13.631 W063 04.237	Boat	Sediment collected
Little Harbour	Just off the beach	N18 11.341 W063 04.168	Shore	Water Lab site. Sediment collected
	In middle of bay	N18 11.228 W063 04.134	Boat	Sediment collected
	In channel inside berm entrance	N18 10.978 W063 04.237	Boat	Sediment collected

Location	Description	Co-ordinates	Boat/Shore Access?	Notes
Long Bay	Far eastern end of beach	N18 11.476 W063 07.526	Shore	No sediment collected
	Offshore - Outside St Regis resort	N18 11.535 W063 07.857	Boat	Sediment collected
Long Reef	In shallows north of MV Sarah - AMMP site	N18 16.209 W063 06.262	Boat	Sediment collected
Maunday's Bay	Next door to Pimms restaurant	N18 09.855 W063 08.520	Either	Sediment collected
	Off the beach from Villa 19	N18 09.815 W063 08.887	Shore	Water Lab site. No sediment collected
Mead's Bay	Off beach by Malliouhana Hotel resturant	N18 11.200 W063 08.084	Shore	Water Lab site. No sediment collected
	Offshore in middle of Bay	N18 10.969 W063 08.416	Boat	Sediment collected
	End of bay next to Viceroy	N18 10.772 W063 08.604	Shore	Water Lab site. No sediment collected
	Off rocks from point - Viceroy	N18 10.830 W063 08.777	Boat	No sediment collected
North Cliffs	Offshore from Katouche North Cliffs	N18 12.750 W063 05.028	Boat	Sediment collected
Prickly Pear	Inbetween Alans and Johnnos bar	N18 15.877 W063 10.406	Boat	Sediment collected
Rendezvous Bay	Next to Yacht Club pier	N18 10.171 W063 06.260	Shore	Sediment collected
	Outside Great House	N18 10.643 W063 06.681	Either	Water Lab site. No sediment collected
	In front of Merrywing Bay	N18 10.177 W063 07.345	Boat	Sediment collected
Road Bay	In the southern corner over at Mariners	N18 11.743 W063 05.585	Either	Water Lab site. No sediment collected
	Underneath main jetty	N18 11.873 W063 05.519	Boat	Sediment collected
	In amongst mooring area	N18 12.046 W063 05.561	Boat	Sediment collected
	Underneath wooden pier	N18 12.070 W063 05.457	Either	Sediment collected
	On beach near sailing club	N18 12.140 W063 05.451	Either	Close to Water Lab site. Sediment Collected
	Over in the northern corner by the floating wharf	N18 12.219 W063 05.527	Shore	Sediment collected
	In pond channel next to Fisheries Dept	N18 12.249 W063 05.519	Shore	Sediment collected
	In middle of bay near Seagrass AMMP	N18 12.249 W063 05.519	Shore	Sediment collected
	In middle of moorings	N18 12.001 W063 05.928	Boat	Sediment collected
Sandy Island	In middle of Seafeathers Bay	N18 12.695 W063 07.292	Boat	Sediment collected
Sandy Hill Bay	Inbetween Little Scrub and Big Scrub	N18 13.219 W063 00.326	Boat	No sediment collected
Scrub Island	In middle of Scrub Bay	N18 17.570 W062 57.251	Boat	Sediment collected
	Midway between Anguilla and Seal Island (18m)	N18 16.887 W062 57.441	Boat	No sediment collected
Seal Island Channel	Between Shoal Bay and Island Harbour	N18 13.841 W063 08.558	Boat	Surface, bottom & sediment collected
Shoal Bay East	Offshore near serinity and gwens reggae grill	N18 15.481 W063 00.994	Boat	Sediment collected
	Outside Uncle Ernies	N18 15.348 W063 01.406	Boat	Sediment collected
	Offshore a little west of Fountain - AMMP site	N18 15.287 W063 01.875	Shore	Water Lab site. No sediment collected
	Backside of Madeariman Reef	N18 15.161 W063 02.482	Boat	Sediment collected
	Offshore from Altamar development	N18 15.954 W063 02.010	Boat	No sediment collected
Shoal Bay West	On coast outside cove castles	N18 09.690 W063 09.254	Boat	No sediment collected
	In middle of Bay beyond boat mooring	N18 09.875 W063 09.543	Either	Sediment collected
Sile Bay	East end of channel (32m)	N18 14.240 W062 59.084	Boat	Sediment collected
St Martin Channel	Middle of channel (23m)	N18 12.777 W062 56.859	Boat	Surface, bottom & sediment collected
	West end of channel (18m)	N18 09.191 W063 02.307	Boat	Surface, bottom & sediment collected
	In front of access channel	N18 07.721 W063 07.644	Boat	Surface, bottom & sediment collected
West End Bay	In lagoon type area	N18 10.275 W063 09.521	Shore	No sediment collected
Windward Point	On western coast near AMMP site	N18 16.241 W062 58.115	Shore	No sediment collected

5. REFERENCES

AIMS 2008 – Published online at: http://www.aims.gov.au/pages/research/project-net/seagrass/apnet-seagrasses01.html (accessed 16th February 2009).

Fitt W.K., Brown B.E., Warner M.E., & Dunne R.P. (2001). 'Coral bleaching: interpretation of thermal tolerance limits and thermal thresholds in tropical corals'. *Coral Reefs 20*. p.51-65.

Goreau T.J. & Thacker K (1994). 'Coral Reefs, Sewage, and Water Quality Standards'. Report from the Caribbean Water and Wastewater Association Conference. Published online at: http://globalcoral.org/CORAL%20REEFS.%20SEWAGE,%20AND%20WATER%20QUALITY%20STANDARDS.htm (accessed 23rd February 2009).

Hannesson R. (2007). 'Global Warming and Fish Migrations'. *Natural Resource Modeling 20*. p.301.

Szmant A.M. (2002). 'Nutrient Enrichment on Coral Reefs: Is it a Major Cause of Coral Reef Decline?' *Estuaries 25*. p.743-766.

Tullock J.H. (1996). 'Water Chemistry – pH and alkalinity'. Published online at: http://www.amdareef.com/ho_chem1.htm (accessed 23rd February 2009).