Department of Environment and Conservation

Disturbance history of coral reef communities in Bill's Bay, Ningaloo Marine Park, 1975-2007

Data report MSP-2007-06
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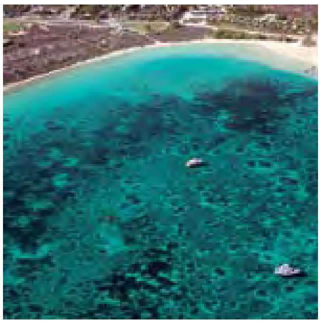


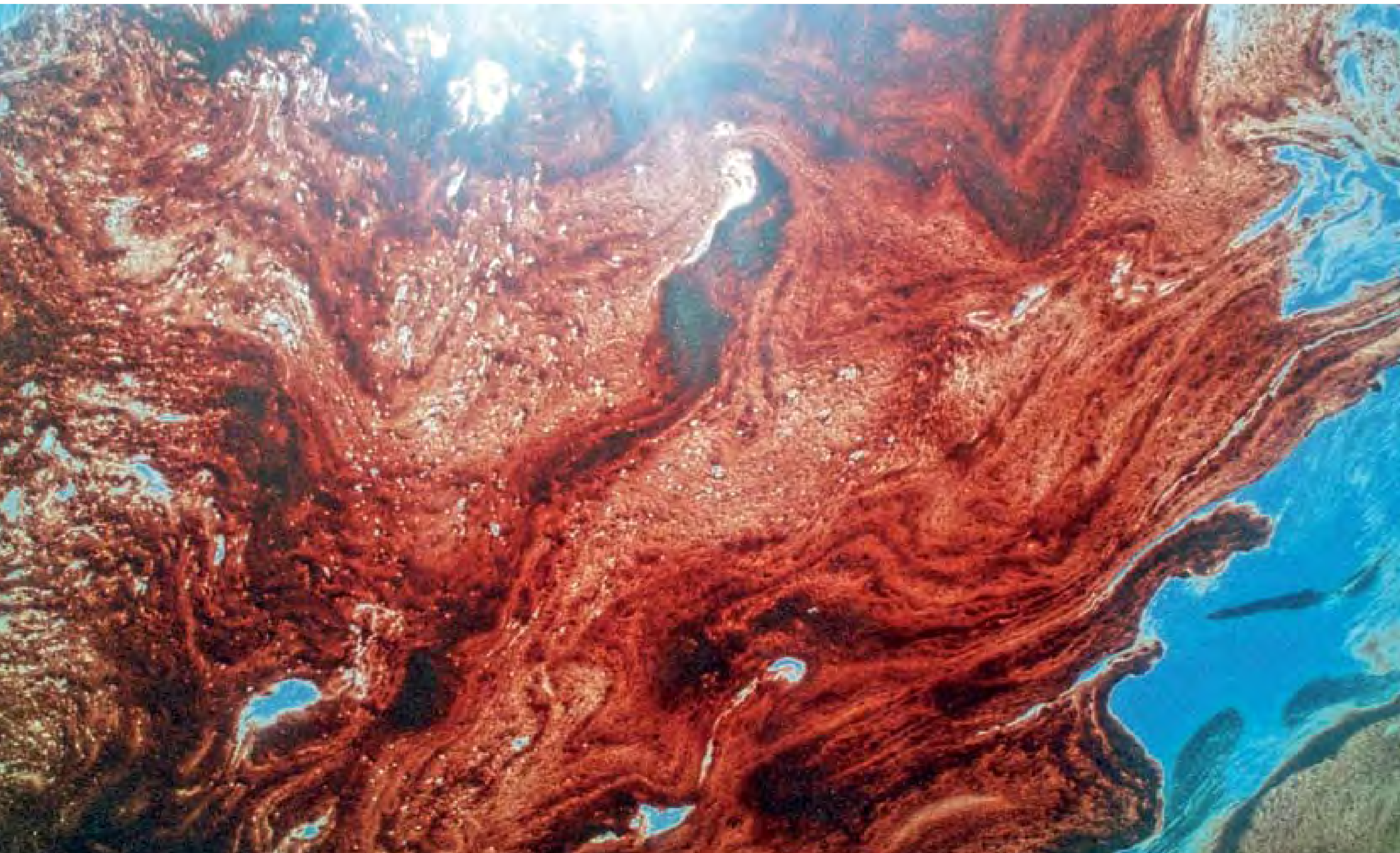

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Main photograph: Coral spawn slick in Bill's Bay in 1989 (subsurface view), during the mass mortality event that killed up to 100 per cent of fish, corals and other invertebrates.

Small photographs, left to right: Aerial view of Bill's Bay, April 2007.
Underwater landscape of disturbed coral reef, Bill's Bay, October 2006.
Blue staghorn coral (*Acropora* sp).
Aerial view of coral communities in Bill's Bay, April 2007.

Images — Department of Environment and Conservation

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Copies of this report may be obtained from:

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Acknowledgments

Direction

Program Leader, Marine Science Program – Dr Chris Simpson

Data Providers
The following people provided the information that has been compiled in this report:
Artist, Swainston Publishing – Roger Swainston
Curator of Marine Invertebrates, Western Australian Museum – Dr Jane Fromont
District Manager, Department of Environment and Conservation – Jennie Cary
Operator, Bayview Coral Bay - Dr Bill Brogan
PhD candidate, Murdoch University – Fiona Webster
Program Leader, Marine Science Program – Dr Chris Simpson
Secretary, North West Research Association – Laura Corbe

1. Summary

Successful management of coral reef ecosystems relies upon understanding the conditions affecting the resilience and recovery of corals from anthropogenic and natural disturbance. Fundamental to this is the need to understand the disturbance history of coral communities in terms of disturbance type, frequency, intensity and scale. Although there is currently a great deal of research into coral reef ecosystems occurring worldwide, there remains an underlying lack of long term and in-depth data within mainstream science to adequately inform management of the status and trends of coral reef ecosystems (Bellwood *et al.* 2006). This limits the ability of agencies to audit the effectiveness of management strategies or relate the snapshot status of coral communities to factors affecting the recovery and resilience of coral reef ecosystems. The knowledge gap can be addressed to a certain extent by using alternate information sources to increase our understanding of local disturbance histories.

Inclusion of a wide range of data sets facilitates more confident assessments of the observed responses of coral reef communities to disturbance. Such information can be found within local and indigenous communities (Berkes *et al.* 2000; Drew 2005). By harnessing such knowledge a more complete picture can be built of disturbance histories and ecosystem trends of coral reefs at local scales.

Gaps in our understanding of the unusual disturbance history of Bill's Bay (Coral Bay, Western Australia) are hampering interpretation of a long-term dataset describing changes in coral communities over time in this popular and heavily-visited area of Ningaloo Marine Park (Long 2007). This report seeks to address this deficit by bringing together a number of data sources describing disturbances in Bill's Bay, from the 1975 cyclone event through to the present time (2007). The majority of these data relate to the more recent disturbance events. Some of these data have been sourced from members of the public who have an interest in conserving coral reef ecosystems and an understanding of the importance of recording significant events that impact on the ecosystem; other data were collected on an opportunistic basis by department staff that happened to be on site at the time of the disturbance. The quality of the data varies, ranging from detailed measurements of species impacted by disturbance events through to general observations and geo-referenced images of the disturbance events and impacts on coral communities. This document contains a synthesis of the data sourced and information about where the data can be accessed.

Of particular value is the 1989 dataset supplied by Dr Chris Simpson, which includes quantitative and qualitative observations of mass mortalities of invertebrates, fish and corals, including baseline measures of size and abundance. This study gave rise to the 17 long-term monitoring sites now used by the Department of Environment and Conservation (DEC) to monitor reef recovery processes in Bill's Bay (see Long 2007). Data sourced from other individuals includes imagery, temperature log data, coral survey data and personal accounts of disturbance events and local conditions.

Where appropriate, the data have been presented overlaying an orthophoto of Bill's Bay, providing geographic reference points. A geo-referenced comparison of data for the disturbance events from 1989 to the present (2007) gives an approximate accumulative disturbance value for respective coral communities at the 17 long-term monitoring sites in Bill's Bay. While this approach is potentially valuable, it needs further refinement as it does not currently accurately reflect the observed condition of coral communities within Bill's Bay (see Long 2007).

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2. Introduction

The 17-year data set for Bill's Bay described in Long (2007) is rare for coral reef environments (Bellwood *et al.* 2006). Its interpretation would be enhanced by the compilation of a detailed disturbance history for the area. Such information often resides within local and indigenous communities (Berkes *et al.* 2000; Drew 2005). An information search and public survey were conducted to try to identify alternative sources of information regarding the disturbance history of Bill's Bay. This document contains a synthesis of the data sourced and a reference to where it can be accessed (if not presented in its entirety herein). Contacts and locations for additional data sets that could not be sourced before the completion of this report are also given.

The major disturbance events known to have occurred in Bill's Bay in the period 1975-2007 are listed in Table 1. This list is not comprehensive, and specific details on some events are limited. The information presented herein will prove valuable in establishing a better understanding of the processes that have influenced the development of the coral communities occurring in Bill's Bay today and in the future.

Table 1: Known disturbance history of Bill's Bay (after Long 2007, p. 55).

Date	Event
March 1975	Tropical Cyclone Beverley affected the North West Cape. Some localized damage to infrastructure in Bill's Bay. Impact on coral communities unknown.
1978	Coral spawn anoxic event with localized impact on Bill's Bay coral communities in the southern mid-lagoon area.
March 1987	Minor fish kill observed at Coral Bay, possibly associated with coral spawning.
Apr/May 1989	Coral spawn-associated natural anoxic event: death of almost all corals and fish in inner Bill's Bay.
Early 1990s	*Drupella* outbreak: large proportion of live acroporids and pocilloporids in Bill's Bay consumed by predatory snails.
4-7 April 2002	Coral spawn-associated natural anoxic event: death of up to 80% of acroporids in inner Bill's Bay
4-7 March 2005	Coral spawn-associated natural anoxic event: death of large numbers of fish, invertebrates, and some corals, mainly acroporids.
June 2006	Winter bleaching: non-lethal low temperature-induced bleaching, principally affecting shallow corymbose and tabular acroporids.

Natural and anthropogenic factors shape coral community structure. Anthropogenic-induced warmer seas, pollution, disease, eutrophication and overfishing are all major factors contributing to the current global decline of coral reefs (Hughes *et al.* 2003; Bellwood *et al.* 2006). Within Ningaloo Reef, considered healthy in the current global context (Department of Conservation and Land Management 2005), natural disturbances appear to be a major factor determining coral reef community structure. Within Bill's Bay, naturally-occurring coral spawn-induced anoxic events appear to be important influences on coral reef community structure (Simpson *et al.* 1993; Long 2007). Anecdotal reports of corals and other reef animals dying in the vicinity of coral spawn slicks on other reefs in Western Australia (such as Dugong Reef near Barrow Island, and the Abrolhos Islands) and the Cocos Keeling Islands suggest that this may be a relatively common phenomenon on shallow coral reefs where mass spawning occurs (Simpson *et al.* 1993). Simpson *et al.* (1993) went so far as to attribute the impoverished fish, coral and benthic invertebrate communities in the Cocos lagoon to regular coral spawn-related anoxic events. In the Abrolhos, oxygen depletion in relation to coral spawning occurs infrequently and at a very localised level, with a low incidence of fish and crustacean kills (Webster *et al.* 2002).

Successful management requires a better understanding of the contribution anoxic events play in determining the coral community structure in Bill's Bay, and how to best maintain community resilience to multiple stressors. This report synthesizes data from a variety of isolated and unpublished sources in order to better understand the geographical extent and ecological impact of these disturbances in Bill's Bay. The data includes imagery, temperature log data, coral survey data and personal accounts of disturbance events and local conditions.

3. Data Summaries

Data describing disturbances in Bill's Bay were sourced from seven individuals. Contact details, data time frames and data contents are listed in Table 2. The majority of data dates from a major coral spawning anoxic event in 1989, through to the present (2007). Information prior to 1989 is very limited. Hard copies of all relevant data received are reproduced within this report and/or included as appendices to this report. A CD attachment contains all the electronic data. Copies of visual data are either on file at the DEC Marine Science Program (MSP) or held by the relevant data provider.

Relevant parties should be informed of the use of data. All references to material contained within this report must cite the name of the person who collected and/or provided the data to DEC.

Pre 1989

Information supplied by Dr Bill Brogan indicated that reefs in the middle zone (defined in Simpson *et al.* 1993) of Bill's Bay appeared to be in a disturbed condition since at least the 1970s. In 1975, Cyclone Beverly affected Exmouth and the northwest coast of North West Cape, destroying a wooden jetty that Dr Brogan had constructed off the beach in inner Bill's Bay; however, the impact on coral communities was not quantified. In 1978, a coral spawn anoxic event is believed to have killed corals in the regions of sites 3, 4, 7 and 17 (Figure 1). Dr Brogan remarked that reefs in the outer zone of Bill's Bay appeared more or less unchanged over his ~40 year period of informal observation.

Dr Jane Fromont is currently investigating historical collections from Ningaloo stored at the Western Australian Museum. Surveys were undertaken around Coral Bay in 1978, 1981 and 1982; of relevance for this report may be two sites visited in 1978, the approximate locations of which are indicated in green in Figure 1 (WAM station 3: 23˚08'30"S, 113˚45'30"E and WAM station 6: 23˚08'20"S, 113˚46'10"E). The data records some species that were collected and identified. No coral coverage data was recorded. Publication of the data is pending.

Simpson *et al*. (1993) refers to a minor fish kill at Coral Bay in March 1987. The timing is suggestive of an association with coral spawning, but no further details are known.

March/April 1989 coral spawn

The following dataset was collected by Dr Chris Simpson in March/April 1989. Retention of coral spawn within Bill's Bay due to the earlier than usual spawning and low flushing conditions resulted in anoxic conditions and subsequent mass mortalities of corals, fish and associated invertebrates (Simpson *et al.* 1993). Some of the data collected at this time as well as the methods used are reported in Simpson *et al.* (1993). Data were collected at the 17 fixed monitoring sites (first established at this time) as well as at an additional seven quadrats (Figure 1). The sites are classified into either inner (sites 1, 5, 9 and 13), mid (sites 2-3, 6-7, 10-11 and 14-15), or outer (sites 4, 8, 12 and 16-17) zones. GPS coordinates for the 17 monitoring sites are listed in Table 5, Appendix 1.

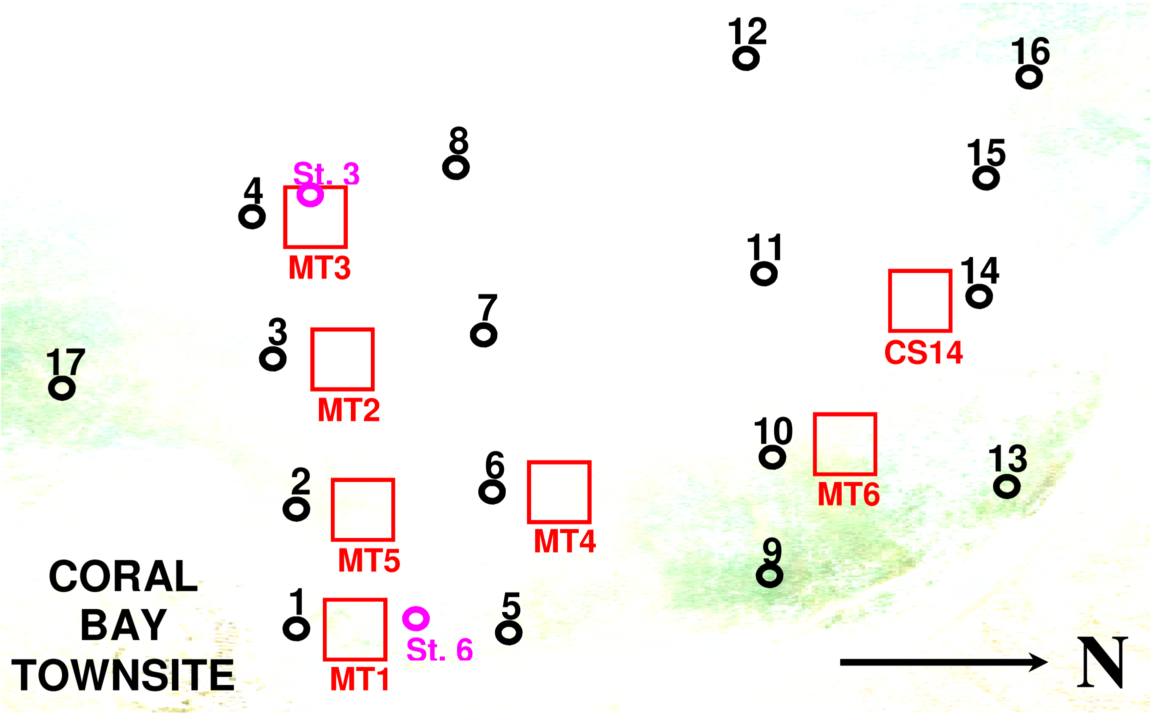

Figure 1: Bill's Bay, Ningaloo Marine Park, Western Australia. 17 long-term monitoring sites established by Simpson in 1989 (black); the approximate location of seven 50x50 m quadrats surveyed by Simpson in 1989 (red); sites identified from the Ningaloo Historical Collection at the WA Museum (pink).

The mean percentage of benthic cover for each of the 17 fixed monitoring sites was determined from two replicate 25 m transects. Live coral cover before the anoxic event was inferred by adding live and bleached coral cover recorded after the event. A qualitative survey was undertaken within the seven ~50x50 m quadrats for 10 minutes each to determine the extent of mortality of certain animal groups. (The positions of the seven quadrats shown in Figure 1 are approximate guides only).

The Simpson dataset includes:

- Qualitative observations of invertebrate and coral survivorship around the 17 long-term monitoring sites.
- Mean coral cover, substrate type and percentage coral mortality recorded around the 17 long-term monitoring sites.
- Inferred live coral cover by family group prior to the disturbance, number of colonies alive and number of colonies killed at each site around the 17 long-term monitoring sites.
- Length/weight data for killed specimens of the cowries *Cypraea eglantina*, *C. lynx*, *C. tigris*, and *C. vitalis*. Length data for killed giant clams *Tridacna squamosa* by quadrat.

Table 2: Sources and contact details for data relating to the disturbance history of Bill's Bay.

Data Source/Contact	Data Time Frame	Data Type	Data Quantity
Dr Bill Brogan, Operator of Bayview Coral Bay.	1970's	Qualitative observations.	Personal observations. Coral Bay resident since the 1970's.
Dr Jane Fromont, Curator of Marine Invertebrates, Western Australian Museum, Perth. Jane.Fromont@museum.wa.gov.au phone 9212 3745.	1978. Surveys ranged from the late 1960's to early 1980's.	Historical collections, qualitative, unlikely quantitative. Information pending.	Information pending.
Dr Chris Simpson, Program Leader, Marine Science Program, Science Division, Department of Environment and Conservation, Perth. Chris.simpson@dec.wa.gov.au phone 9334 0476.	March/April 1989 coral spawn.	Schematic map of live/dead/absent invertebrates. Size distribution of deceased invertebrates and fish. Some weight distributions of invertebrates. Substrate cover percentage and coral live cover before and after the spawning event. Fish and coral species list.	The data set is extensive covering invertebrates, fish and coral. 15 graphs, 4 figures and 12 tables have been presented in this report. A Microsoft Excel document on CD contains the raw data.
Roger Swainston, 'ANIMA', Hamilton Hill.	April 2002 coral spawn.	Written description of event. Colour transect photos of fish kill. Map of Monck Head to Point Maud coral kill area and approximate percentage.	1x A2 map. 2x A4 hand written notes. 21 colour photos reproduced on 6 A4 pages.
Jennie Cary District Manager, Department of Environment and Conservation, Exmouth. Jennie.cary@dec.wa.gov.au phone 9949 1676.	April 2002 coral spawn and March 2005 coral spawn.	Map of percentage mortality of live corals off Coral Bay. Maps of fish kill locations along Ningaloo. Descriptions of dead fish and spawn slick.	7x A4 B&W hand drawn maps. 2x A4 pages of notes.
Fiona Webster. Murdoch University, Perth. F.Webster@murdoch.edu.au	March 2005 coral spawn.	Written description with hand drawn map of coral mortality. Excel spreadsheet of temperature logs at 1.5 m depth at 3 hour intervals from 15th Dec 2004 to 5th May 2005.	1x A4 notes. 2x colour coral picture. 1x A4 hand drawn map with GPS points. A Microsoft Excel document on CD contains the raw temperature data.
Laura Corbe. North West Research Association, Coral Bay. lcorbe@another.com	March 2005 coral spawn.	Map of percentage kill from video transect and GPS points.	1x A4 colour map. 1x A4 email. 1x GPS locations table.

- Length data for four fish species: *Atrosalarias fuscus holomelas*, *Hemiglyphidodon plagiometopon*, *Leptoscarus vaigiensis* and *Pomacentrus coelestis*, from specimens washed up along the shore.
- List of species found dead at Coral Bay between March 28th and April 5th, 1989.
- Physical conditions at Coral Bay between March 26th and April 5th, 1989.

All raw data and some graphical representations of the data are available in Appendices 2-9. In summary, the appendices contain:

- Appendix 2: Each fixed monitoring site was assessed for the presence and absence of the following invertebrates: Cypraeidae, Tridacnidae, Trochidae, Asteroidea, Brachyura and Polychaeta. Their status was recorded as living, dead (decomposing), or absent. Raw data are displayed in Table 6 along with general observations of the status of corals surrounding each site. The data are graphically presented with geographical references in Figures 7 and 8. All invertebrates at inner and mid lagoon zones, except site 15, were recorded as dead or absent.
- Appendix 3: The substrate cover for each site was surveyed and recorded as reef, sand or coral cover. These data are listed in Table 7. Soft corals were treated separately but their presence was limited to two of the sites. Percentage coral mortality was determined from the inferred live coral cover before March 26th compared to live coral cover after the anoxic event. These data are graphically presented with geographical references in Figure 9.
- Appendix 4: Live coral cover was divided into dominant family groups: Acroporidae, Faviidae and Pocilloporidae dominated, with Mussidae and Oculinidae having a limited presence. The number of colonies for each family group per site is listed in Table 8 along with the percentage mortality of colony numbers. These data are graphically presented with geographical references in Figure 10.
- Appendix 5: Measurements of deceased *T. squamosa* and *C. tigris*, *C. eglantina*, *C. lynx* and *C. vitalis* were made at each quadrat site. The length and weight data for the cowries are in a grouped format, listed in Table 9. Figures 11-18 contain histograms of the length and weight distributions for the cowries. Length data for *T. squamosa* is divided by quadrat and listed in Table 10. Figures 19-21 detail average length measurements by quadrat, count by quadrat and a histogram of the size distribution across all quadrats for *T. squamosa*. Offshore quadrats contained greater numbers and larger individuals of *T. squamosa* than inshore quadrats.
- Appendix 6: The length data from the fish species *A. fuscus holomelas*, *H. plagiometopon*, *L. vaigiensis* and *P. coelestis* are listed in Table 11, with histograms of length distribution shown in Figures 22-25.
- Appendix 7: Tables 12-15 contain data summaries for the data listed above. The data covers the number of individuals, mean measurement, standard error, and minimum and maximum values for the corals, molluscs and fish.
- Appendix 8: Table 16 contains a species list of all deceased fish (73), corals (39) and molluscs (34) encountered (reproduced from Simpson *et al.* 1993).
- Appendix 9: A summary of the physical conditions including wind speed and direction, swell, lagoon flushing rate, water clarity and nocturnal low water mark are given in Table 17.

April 2002 coral spawn

The following qualitative observations of coral mortality associated with the 2002 coral spawning event were supplied by Jennie Cary. On 13th April 2002 a survey of 23 sites between Monck Head and Point Maud found that only branching and plate *Acropora* corals suffered mortality (Figure 2). Higher mortality rates occurred inshore and tended to be greater at the southern end of the survey area. No mortality was recorded for sites in the vicinity of the outer zone long-term monitoring sites. Around one million fish died during this event, washing onto the beach between Monck Head and Point Maud.

Roger Swainston conducted a photo survey of the fish kill wash line on 9th April, and a snorkel survey of *Acropora* mortality on 15th April 2002. Colour photos of the fish kill transect detail five northward facing views of the fish kill wash line and four groups of 1x1 m quadrats (one photo per 1x1 m quadrat) at 50 m intervals from the dune blowout to Point Maud. Four quadrat photos are available for most 50 m transect intervals. A wide diversity of biota is identifiable from the photos including angelfish, butterfly fish, crabs, eels, parrot fish and wrasse. Estimates of relative abundance could be made from the images. A geographically accurate hand drawn map of *Acropora* mortality roughly coincides with data supplied by Cary; a reproduction is not supplied in this report. Table 3 lists observations of coral spawning intensity and meteorological observations recorded during early April.

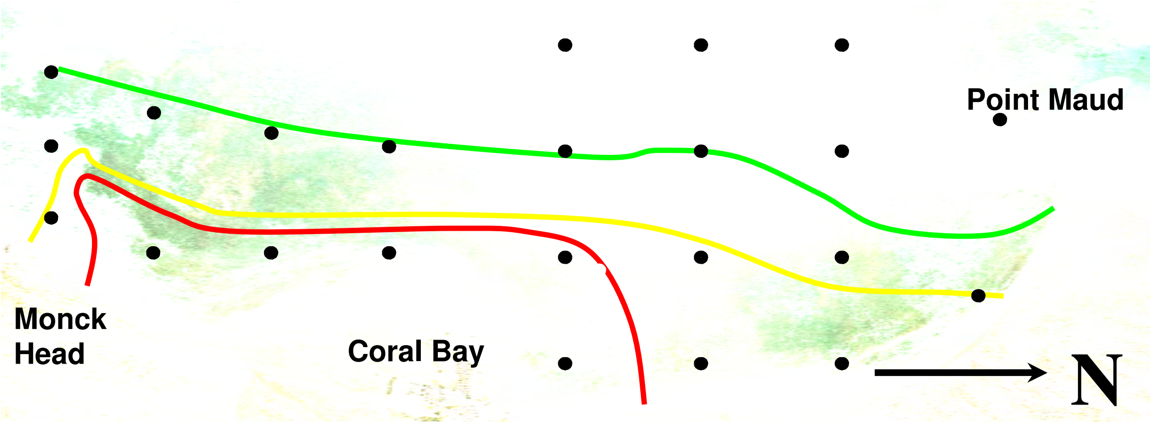

Figure 2: Reproduction of coral mortality data on April 13 2002, supplied by Cary. Areas inside the red contour line suffered about 80% mortality; inside the yellow line, about 30% mortality; and outside the green line 0% mortality. Black dots indicate survey points; white dot indicates approximate location of Site 2 referred to by Swainston in Table 3.

Table 3: Visual observations of coral spawn intensity, by Swainston, 3-9th April 2002.

Date	Observations
3rd April	Moderately heavy spawning.
4th April	Moderately heavy spawning, 3-4 species spawning.
5th April	Heavy spawning, most species; rapidly deteriorating visibility; huge numbers of tropical krill.
6th April	Very poor visibility; some fish apparent at the surface in the morning; cleaner water in a line about 30 m west of channel markers.
7th April	Fish kill on the beach south of Coral Bay; water opaque and reeking; visibility at North Reef moderate, water clear though full of large spawn particles.
8th April	Many more dead fish on the beach, Skeleton Beach heavily covered by dead fish.
9th April	Photo transects to Point Maud conducted; many dead fish on substrate and poor visibility at Site 2, a lot of mucus on corals, some algae already growing; surviving fish very sluggish and low in water column.

Swainston has also been conducting semi-annual fixed point photo mosaics of locations around Coral Bay. The photo mosaics have been performed annually except in 2005, with 2 sites beginning in 2002, and an additional site beginning in 2003, 2006 and 2007 respectively; this project will continue into the foreseeable future. Three of these sites fall within the study area, near the long term monitoring sites 3, 9 and 15. The photo mosaics are used to accurately reproduce the community structure at the time in paint at a scale and detail and with far more visual impact than conventional photography could attain. These images may be of interest for studies of changes in community structure over time, and the paintings will serve as a valuable medium to bridge the divide between science and the general public.

March 2005 coral spawn

Cary supplied field observations collected from a number of individuals related to coral spawns that were assumed to have occurred on the 4th, 5th and 6th of March of 2005. Steve Wall and Kristan Hall observed a fish kill numbering in the hundreds on 7th March. The fish kill slick was located offshore, north of the mooring control area in Maud Sanctuary Zone. Single species of wrasse and parrot fish in the 10-15 cm range were present. The coral spawn slick stretched from the snapper hole in the south to the northern edge of the reef within the Maud Sanctuary Zone. On the 8th March dead fish stretched along the entire Paradise Beach high tide mark. Fish kills were also observed north of Winderbandi Point and in Norwegian Bay on the 7th March. Around 2000 fish were observed north of Winderabandi Point, mainly Pomacentridae (40% pomacentrids, 20% gobies, 20% blennies). Lesser numbers of yellow box fish, leatherjackets, triggerfish, moray eels and one black angler fish were observed. Most fish were 10-15 cm in length. No details were put forward regarding the species composition along the Paradise Beach fish kill.

Figure 3 details the approximate daily movement of the coral spawn slick within Bill's Bay, reproduced from sketches supplied by Cary. Additional map sketches were supplied detailing fish kills/coral spawn slicks in Norwegian Bay and north of Winderabandi Point. Note that the timeframes of slick movement and slick size varies between sources. This information is complemented by two additional observations acquired separately by Laura Corbe and Fiona Webster.

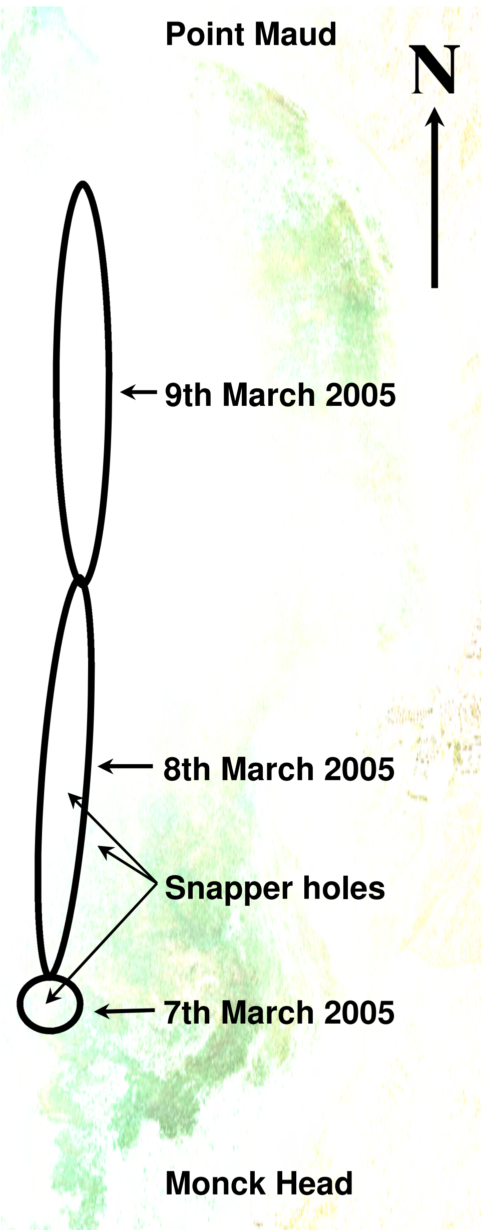

Figure 3: Movement of the coral spawn plume 7-9th March 2005, and sites of the snapper holes.

Corbe conducted a visual survey after the March coral spawning event using a glass bottom boat, a GPS unit and video recorder. A series of zigzags were performed while video recording and taking down GPS locations (coordinates given in Appendix 10) just west of the Coral Bay town site. The video data have audio references to the GPS locations labeled in Figure 4. Follow-up still photos were taken of ten sites in May 2006 and January 2007 by Vivian Matson-Larkin and Bill Brogan. A copy of this data is on file with the DEC Marine Science Program. Figure 4 details the coral mortality observed in association with the coral spawning event, predominantly *Acropora* species. The areas to the south were found to exhibit generally higher mortality rates. No recovery was observed of dead coral believed to derive from a much older mortality event, possibly 1989. Observations since 2005 have indicated recovery is variable between sites. The structure at the middle snapper hole indicated in Figure 3 was noted to have collapsed in 2006.

Figure 4: Coral mortality observed in March 2005 aboard a glass bottom boat; figure supplied by Corbe. Corals within the area marked by the blue line showed some level of mortality, mainly the *Acropora* spp.; the area outlined in green indicates 100% mortality of all coral species.

Webster supplied temperature log data and conducted a tow survey from Monck Head to the dune blow-out in Bill's Bay. Figure 5 shows the temperature profile recorded for the period 15th December 2004 to 5th May 2005. Temperatures were logged at three hour intervals. The logger was positioned at ~1.5 m depth in Bill's Bay (in the vicinity of the green dot in Figure 6). The maximum temperature recorded was 30.24˚C at 6 pm on the 8th March. Temperatures logged from 6 pm on the 7th March through to 3 am on the 9th March all exceeded 29˚C. Raw temperature logger data are given on the CD. Due to the temperature logger being about 1.5 m below the surface it is likely that surface temperatures were higher than those recorded. The entire temperature logger data set collected by Webster ranges from the end of 2004 to the start of 2007.

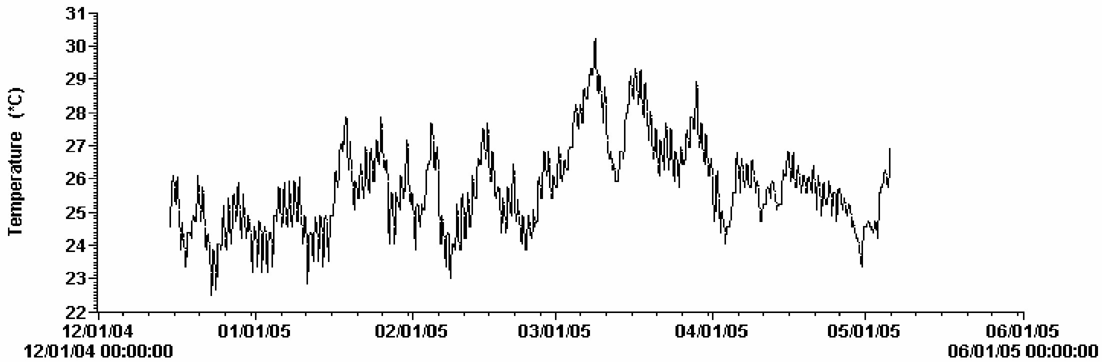

Figure 5: Data from the temperature logger in Coral Bay, 15th December 2004 through to 5th May 2005 (Fiona Webster, pers. comm. 2007); raw data available on CD.

A slick of dead fish was identified on the 7th March by local operators, and coral bleaching was later observed within the same area. From communications that Webster had with Frazer McGregor it is noted that coral larvae were recorded in March 7th samples, but not in samples prior to this date. Coral spawning was not observed in Coral Bay before coral spawn was detected within the bay. From this it was hypothesized that the spawn was externally sourced or from a small localized event. Additionally the fish and coral deaths are thought to have resulted from a combination of the high water temperatures and deoxygenation of the waters by decomposing coral larvae. Both factors would have contributed to the formation of anoxic conditions.

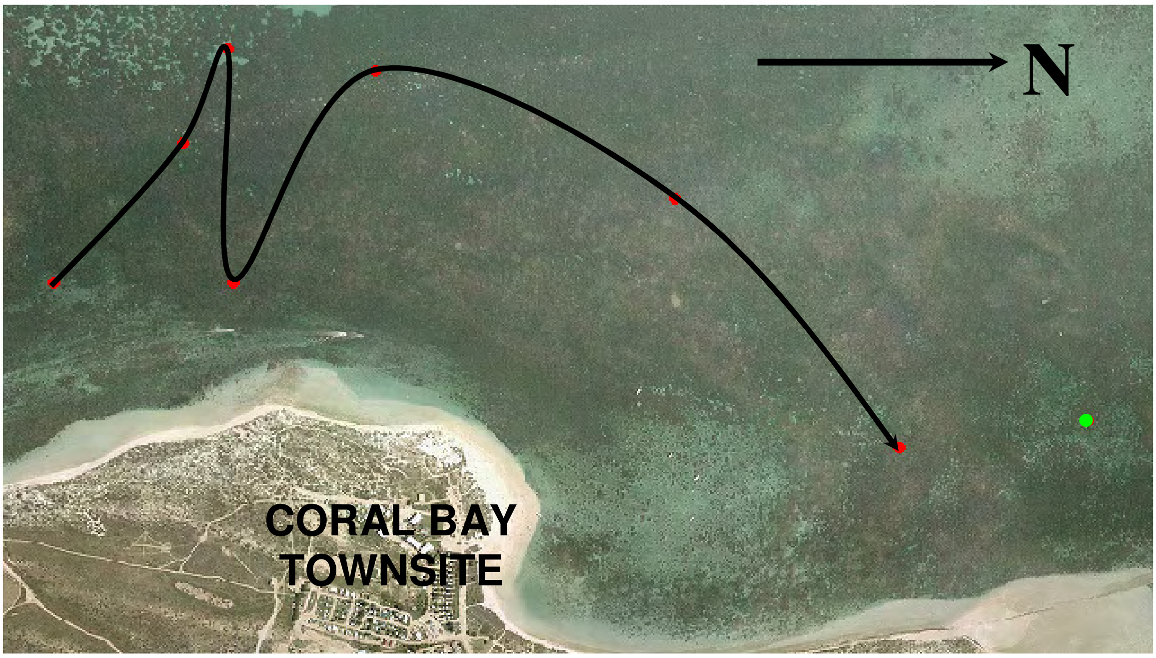

Figure 6: Indicative coral mortality survey path from GPS points (red) on 21st April 2005, supplied by Webster. Green point indicates the approximate position of the temperature logger.

On April 21st a tow survey was conducted approximately along the path indicated in Figure 6. Webster reported that bleached corals were identified via their white colour and a fine covering of *Enteromorpha* green algae. Observations indicated that about 30% of the corals in the identified area were bleached, with large branched *Acropora* spp. suffering the highest rates of bleaching. About 15% of *Montipora* spp. within the survey area suffered bleaching. These observations roughly coincide with those of Corbe and those supplied by Cary. Differences in the geographical extent of impacted area are likely attributable to the different methods used and differences in the timing of surveys. GPS locations for the temperature logger and registered tow paths are listed in Appendix 11. Tow path GPS locations were not all available for inclusion in this report, thus the actual tow path may differ from the indicative one given in Figure 6.

4. Brief Discussion

Disturbance events shape community structure. Events vary in type, frequency, intensity and geographic scale, and all interact differently with coral species exhibiting a variety of life history strategies. The data presented here show an apparent increase in the frequency of disturbance events in and around Bill's Bay, although the intensity of the 1989 event has apparently not been repeated. However, historical information from Brogan indicates this apparent increasing trend may be an artifact of increasing observation effort over time. The data of the Ningaloo Historical Collections at the WA Museum from the late 1970s may be able to shed more light on this. As much of the data presented herein is anecdotal, only subjective assessments of the impacts of different events can be made, with spatial and temporal variation in scale and intensity likely between different events. Even so the data presented in this report enables a more detailed interpretation of the Bill's Bay coral community disturbance history than would otherwise be possible.

The dataset supplied by Simpson is of great significance, providing detailed baselines on a number of species and the community structure before the 1989 anoxic event. Future studies of community structure and kills relating to anoxic events will find these data of great relevance and an essential gauge of subsequent rates of recovery and resilience of communities within Bill's Bay. The Simpson data set indicates that for the 1989 event inshore sites suffered higher mortality rates than sites further offshore. The higher abundance and presence of larger, presumably older, *T. squamosa* at sites further offshore may indicate that inshore sites are more susceptible to anoxic events of the nature that occurred in 1989. However, no definitive conclusions can be drawn from the limited analyses conducted here. Data collected regarding subsequent events in 2002 and 2005 reveal differing geographical extents and intensities of impact. Relative to 1989, the 2002 and 2005 events had smaller zones of impact, further offshore.

Taken together, the data supplied by Brogan, Cary, Corbe, Swainston and Webster provide information on events that would otherwise go unreported and/or unrecorded. Ongoing monitoring by members of the public, especially when conducted by people with scientific understanding, provides a valuable service to the community, and assimilation of these data helps DEC manage the local ecosystem. Bringing together a range of information sources can increase understanding of ecological dynamics and the application of management practices. In conjunction with long-term monitoring, a detailed disturbance history of Bill's Bay can potentially assist with elucidating the factors promoting or degrading reef resilience. Informed management strategies aimed at promoting reef resilience can then be implemented (Long 2007). Such findings and strategies would be of both local (Ningaloo, as well as elsewhere in WA) and global relevance.

The data presented in this report shed light on the range and extent to which some of the disturbance events have impacted upon the coral reef ecosystem. The known disturbance history at Bill's Bay (Table 1) is by no means complete; however this information can be used to indicate the relative level of disturbance suffered by different parts of the reef. Table 4 summarizes the level of impact for each of the 17 long-term monitoring sites, as indicated by the applicable data supplied from 1989 onwards. Geo-referenced data was layered to indicate the proximity of individual sites to disturbance events; '1' indicates the site suffered a major disturbance, '½' indicates the site is highly proximate to a major disturbance and '0' indicates no disturbance occurred during that event. As no assessment of the intensity of each disturbance event at each site was attempted, this index indicates frequency of disturbance only. The findings are indicative of the relative disturbance of different reef sections; for example, the outer zone appears to have suffered lower disturbance levels than mid and inner zones. While this has the potential to be a useful interpretative tool, further refinement is required, as there appears to be little correspondence between these disturbance indices and the coral community structure observed at these sites in Bill's Bay in 2006 (see Long *et al.* 2007).

Table 4: Accumulative disturbance value (disturbance per unit time) of the 17 long term monitoring sites in Bills Bay as implied by geographical data overlay of data from 1989 to the present (2007). 0 = no major disturbance, 3 = 3 major disturbances, ½ = site highly proximate to major disturbance. Note that this crude index involves only frequency of disturbance and takes no account of intensity, or the potential for increased stress caused by repeated disturbances within a relatively short interval.

Site	1989 Event	2002 Event	2005 Event	Cumulative Impact
1	1	1	0	2
2	1	1	0	2
3	1	½	½	2
4	0	0	1	1
5	1	1	0	2
6	1	1	0	2
7	1	½	0	1.5
8	0	0	½	0.5
9	1	1	0	2
10	1	½	0	1.5
11	1	0	½	1.5
12	0	0	0	0
13	1	½	0	1.5
14	1	0	0	1
15	½	0	0	0.5
16	0	0	0	0
17	0	1	0	1

Data associated with two other major known disturbances in Bill's Bay - the 1990s *Drupella* outbreak and 2006 winter bleaching – were not included in this report. The 2006 winter bleaching event is reported to have only affected plate and corymbose *Acropora* corals at the highest margins of the water column, thus predominantly affecting corals along the back-reef platforms (Armstrong *et al.* 2007; Roland Mau pers. comm.). Surveys of the 17 long-term monitoring sites in October 2006 detected little or no bleaching, although shallow coral communities may well have been sublethally disturbed (see Long 2007). *Drupella* surveys have not been specifically conducted around the 17 long-term monitoring sites and again the relative level of disturbance is unknown;

however, back-reef habitats are reported to have been most affected by *Drupella* with much lower levels of predation within lagoons (Turner 1994). The 2005/2006 survey data indicates *Drupella* were more abundant at outer reef locations and additionally where preferred prey species were more abundant (Armstrong 2007). Thus *Drupella* predation does not appear to have had a significant impact on coral community structure within Bill's Bay in recent years.

There are clearly a range of variables affecting the dynamics of shallow coral reef communities, both natural and anthropogenic. With continued observation and research into the past and present conditions of reef ecosystems, a better understanding of the roles of different disturbance events will aid management in successfully preserving the future of coral reefs.

5. Data management

Hard copies of this report containing the CD-ROM will be held at the following locations:

1) Marine Science Program, Science Division, Department of Environment and Conservation, 17 Dick Perry Avenue, Kensington, Western Australia, 6151. Ph: (08) 9334 0333. (CD also attached).

2) Woodvale Library, Science Division, Department of Environment and Conservation, Ocean Reef Road, Woodvale, Western Australia, 6026. Ph: (08) 9405 5100 Fax: (08) 9306 1641. (CD also attached).

3) Archives, Woodvale Library, Science Division, Department of Environment and Conservation, Ocean Reef Road, Woodvale, Western Australia, 6026. Ph: (08) 9405 5100 Fax: (08) 9306 1641. (CD also attached).

4) Serials Section, State Library of Western Australia. Alexander Library Building, Perth Cultural Centre, Perth, Western Australia, 6000. (CD also attached).

5) Exmouth District Office, Department of Environment and Conservation, 22 Nimitz Street, Exmouth, Western Australia, 6707. Ph: (08) 9947 8000 Fax: (08) 9949 1580. (CD also attached).

Copies will also be distributed to the data providers listed in the Acknowledgments section. Digital copies of this report and the electronic data will be held at the following:

The Science Division Server:
T:\529-CALMscience\Shared Data\Marine Science Program\MSP_reports\MSP-2007_06

The CD-ROM contains:

- A copy of this report.
- GPS locations for the 2005 survey supplied by Laura Corbe.
- Video footage by Laura Corbe and still images by Bill Brogan and Vivian Matson-Larkin
- GPS locations for the Ningaloo Historical Collections supplied by Jane Fromont.
- Raw data supplied by Chris Simpson.
- Water temperature data supplied by Fiona Webster.

Where provided, hard copy originals of the data are filed with the Marine Science Program in Kensington (*Bill's Bay Data – Disturbance History 1975-2007*).

6. References

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7. Appendix 1: GPS coordinates of the 17 long-term monitoring sites

Table 5: GPS coordinates in decimal degrees (WGS84) and in northings/eastings (AMG zone 49) for the seventeen long-term monitoring sites established at Bill's Bay, as specified by Grubba and Cary (2000).

Site No.	Longitude (º E) dec deg WGS84	Latitude (º S) dec deg WGS84	Easting (mE) AMG 49 WGS84	Northing (mN) AMG 49 WGS84
1	113.76963	-23.14141	783,616.84	7,438,121.61
2	113.76654	-23.1415	783,300.42	7,438,117.82
3	113.76262	-23.14209	782,898.08	7,438,059.91
4	113.75889	-23.14263	782,514.18	7,438,007.71
5	113.76964	-23.13652	783,628.48	7,438,663.79
6	113.76597	-23.13697	783,252.03	7,438,621.16
7	113.76185	-23.13721	782,829.18	7,438,601.97
8	113.75747	-23.1379	782,378.50	7,438,534.41
9	113.76797	-23.13049	783,470.12	7,439,334.93
10	113.76487	-23.13042	783,152.34	7,439,348.87
11	113.76017	-23.13074	782,670.33	7,439,322.39
12	113.75448	-23.13125	782,086.21	7,439,276.58
13	113.76554	-23.12498	783,232.99	7,439,949.78
14	113.76063	-23.12569	782,728.10	7,439,881.46
15	113.75747	-23.12565	782,404.48	7,439,891.74
16	113.75483	-23.12467	782,135.82	7,440,005.58
17	113.76347	-23.14696	782,974.04	7,437,519.33

8. Appendix 2: Coral and invertebrate observations in 1989

Table 6: Observations of mortality of corals and other animal groups in the general vicinity of the seventeen long-term monitoring sites after the mass mortality in 1989 (Key: Cy = Cypraeidae; Tri = Tridacnidae; Tro = Trochidae; As = Asteroidea; Br = Brachyura; Po = Polychaeta; L = observed alive; D = observed decomposing; - = not observed).

Site	Cy	Tri	Tro	As	Br	Po	COMMENTS
1	D	D	D	D	D	D	5.9 m *Hydnophora exesa* colony bleached; several 1 m diameter faviid colonies bleached; small *Cyphastrea microphthalma* colonies alive; some large faviids alive; numerous small molluscs dead on the sea bed.
2	D	L	-	D	D	-	Many *Acropora* colonies bleached; 10 m dia. *Acropora* colony bleached with dead crabs, starfish on outer surface, many dead cowries inside; 2.5 m diameter *Porites* colony alive; *Pocillopora* colonies alive.
3	D	D	D	D	D	D	Most *Acropora* colonies dead; most faviids alive.
4	L	L	L	L	L	-	No signs of recent mortality.
5	D	D	D	D	D	D	*Acropora* colonies bleached; most faviids bleached; encrusting *C. microphthalma* alive; numerous small molluscs dead on seabed.
6	D	D	D	D	D	D	*Porites* colony 4 m high x 9.5 m in dia. covered in mucus, subsequently recovered; *Acropora* colonies on top all bleached; *Montipora* colonies <2 m high bleached and collapsed.
7	D	D	D	D	D	D	Most corals bleached. Some small faviids alive.
8	L	L	L	L	L	L	No signs of recent mortality.
9	-	-	-	-	D	D	11 *Porites* up to 3 m dia. covered in mucus, nine subsequently recovered; many dead faviids; many dead crabs and chitons; numerous small molluscs dead on seabed.
10	D	D	D	D	D	D	Cowries and clams dead; no live coral observed.
11	D	D	D	-	-	-	*Acropora* colonies bleached; some faviids alive.
12	-	L	L	L	L	-	Very diverse reef; only tabular, arborescent *Acropora* and *Pocillopora* colonies bleached.
13	-	-	-	-	-	-	Many large *Montipora*, *Acropora* and faviid colonies structurally intact but dead not bleached.
14	D	D	D	D	D	D	2 m dia. *Porites* colony alive, 1.7 m *Porites* colony covered in mucus subsequently recovered; *Monitpora* and *Acropora* and faviid colonies bleached; some faviids alive; *Galatea* colonies alive; soft coral dead and decomposing.
15	L	D	D	-	-	-	4 m dia and 1.2 m dia *Porites* colonies alive; most *Monitpora* colonies alive; most *Acropora* colonies bleached; most faviids alive.
16	-	L	L	L	L	-	No signs of recent mortality.
17	-	L	L	L	L	-	No signs of recent mortality.

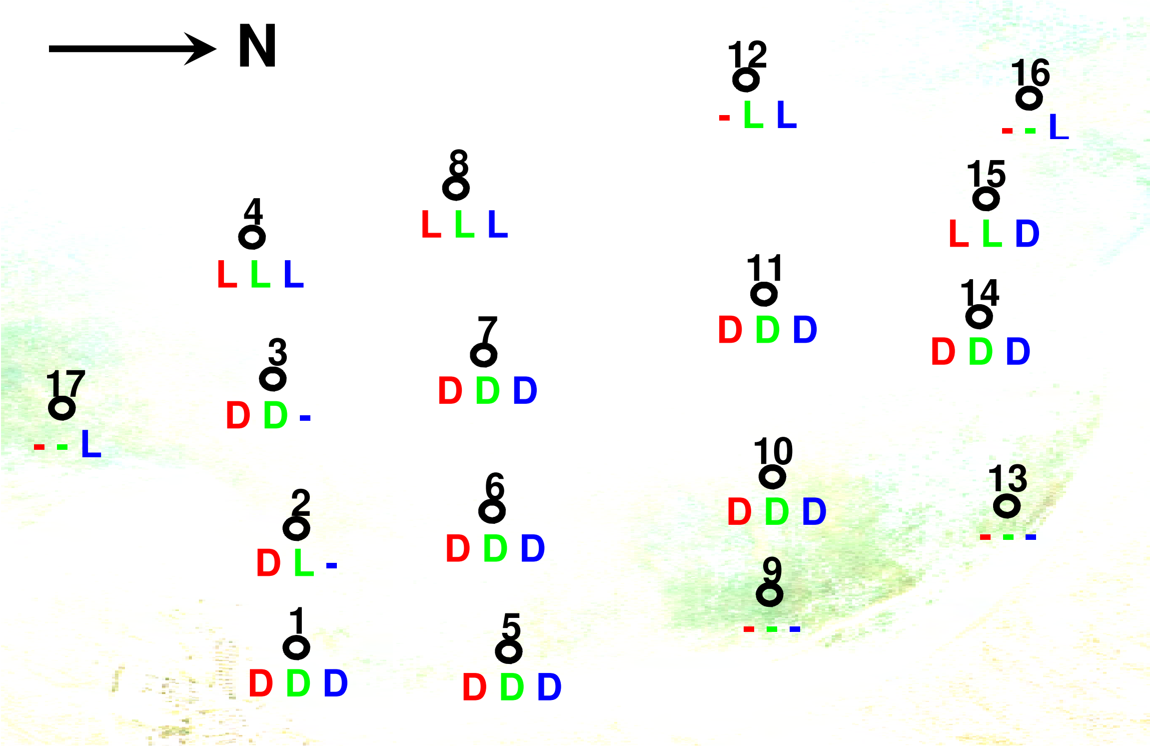


Figure 7: Observations of mollusc mortalities within the general vicinity of the long term monitoring sites; Cypraeidae = red; Tridacnidae = green; Trochidae = blue; D = observed decomposing; L = observed alive; - = not observed.

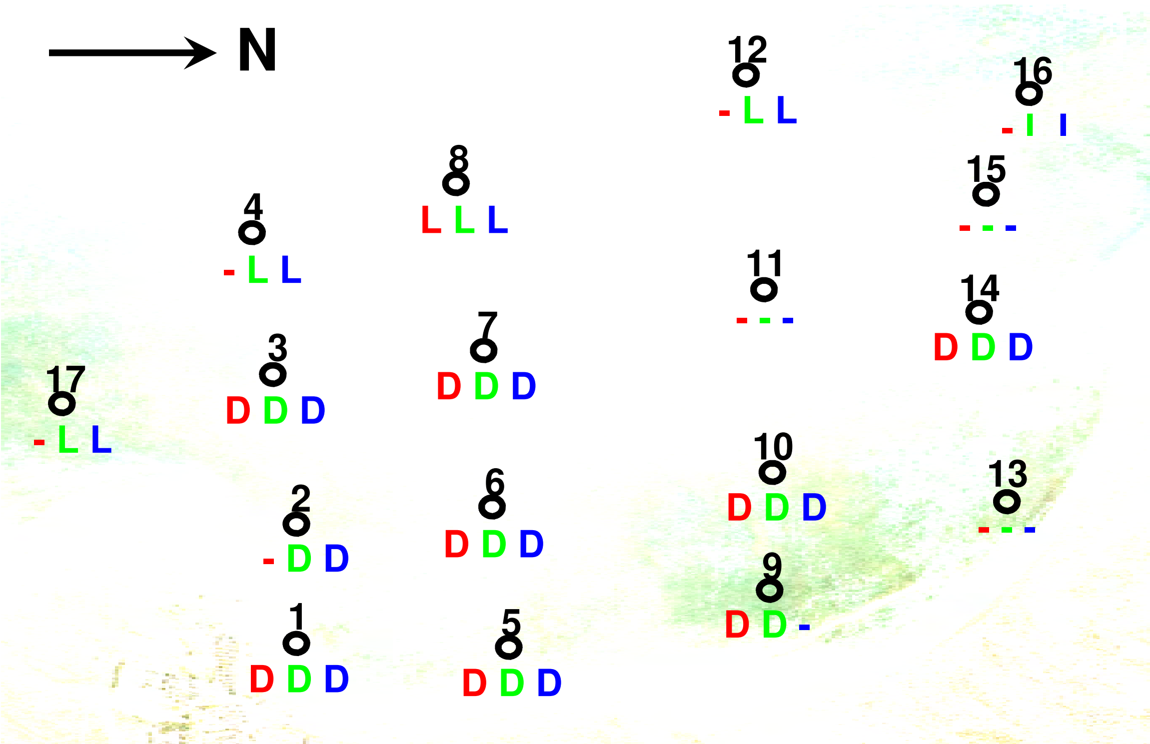


Figure 8: Observations of invertebrate mortalities within the general vicinity of the long term monitoring sites; Polychaeta = red; Brachyura = green; Asteroidea = blue; D = observed decomposing; L = observed alive; - = not observed.

9. Appendix 3: Substrate cover and coral mortality in 1989

Table 7: Mean cover (standard error, n = 2) of substratum type (m/100 m or %) and percentage coral mortality recorded at Bill's Bay between 26th March and 5th April, 1989; L = live, D = dead.

SITE	LIVE CORAL		RECENTLY KILLED CORAL		REEF		SAND		SOFT CORAL	CORAL ALIVE BEFORE 26th MARCH		CORAL MORTALITY (%)
	Mean cover	se	Mean cover	se	Mean cover	se	Mean cover	se		Mean cover	se	
1	0		38.8	4	50	5.6	11.2	1.6		38.8	4	100
2	23.5	1.7	29.2	5.6	7.4	0.6	39.9	7.9		52.7	7.3	55
3	7.2	7.2	35.8	4.6	57	11.8	0			43	11.8	87
4	65.8	7	0		26.6	14.6	0		7.6L	65.8	7	0
5	0		38.2	6.6	45.2	4	16.6	2.6		38.2	6.6	100
6	3.2	3.2	66.2	13.8	30.6	10.6	0			69.4	10.6	94
7	10.7	3.5	40.8	2.2	48.3	1.5	0.2	0.2		51.5	1.3	80
8	52	2	0		16.2	1.8	31.8	3.8		52	2	0
9	0		0		76.8	2.8	23.2	2.8		0		-
10	0		29	14.2	68.4	16.8	0		2.6D	29	14.2	100
11	5.2	2.4	34	2.8	45.8	14.6	15	15		39.2	0.6	87
12	39.2	2.8	4.4	4.4	56.4	1.6	0			43.6	1.6	10
13	0		0		100		0			0		-
14	1.2	1.2	17.9	15.5	47.9	15.5	33	29.8		19.1	14.3	75
15	13.5	6.3	34.2	3.4	52.1	3.1	0.2	0.2		47.7	2.9	72
16	33.3	8.3	0		45.9	12.5	20.8	20.8		33.3	8.3	0
17	55.2	1.6	0		44.8	1.6	0			55.2	1.6	0

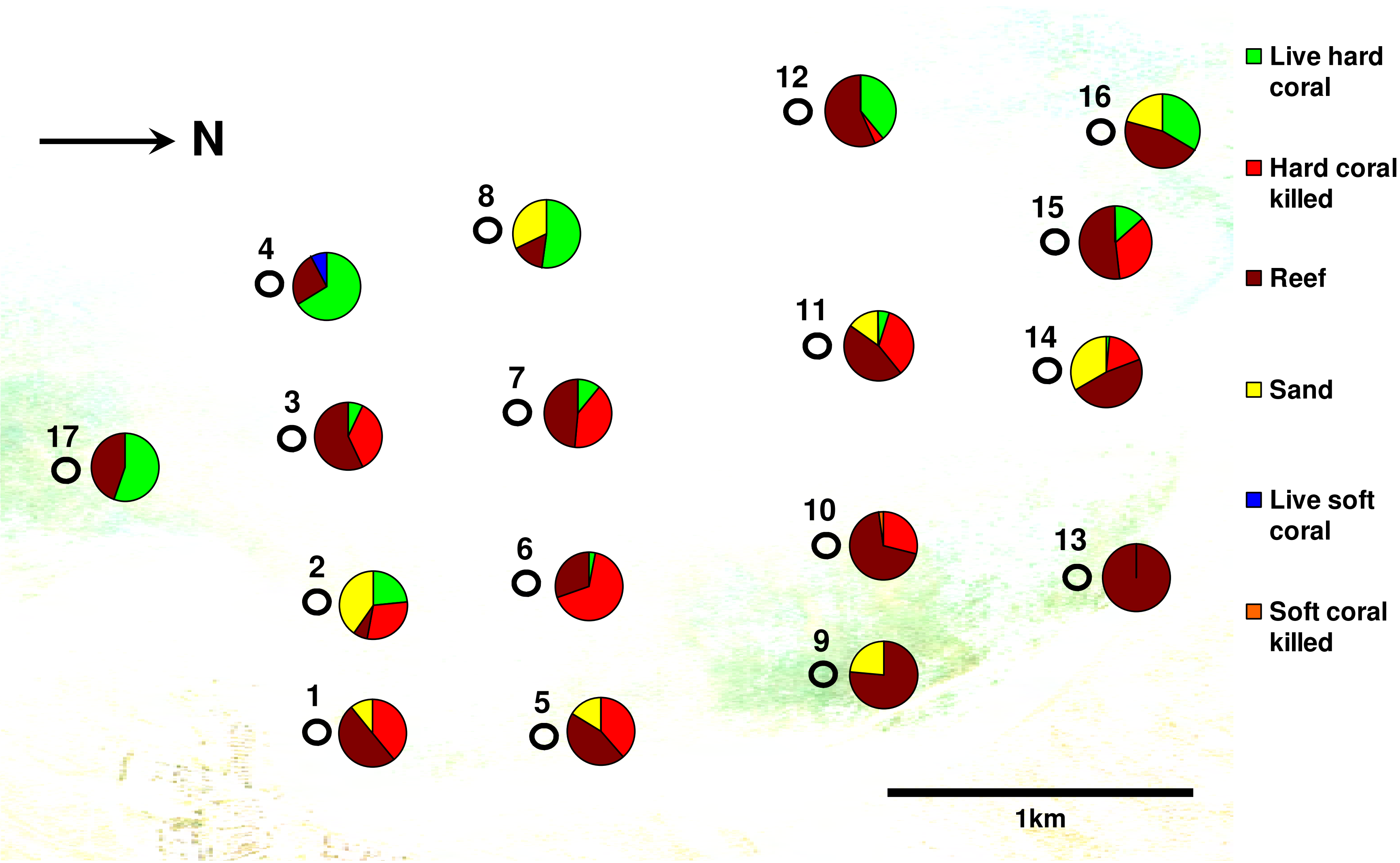


Figure 9: Mean cover of substratum type and percentage coral mortality recorded at the 17 long-term monitoring sites in Bill's Bay, April 3-5, 1989.

10. Appendix 4: Coral family colony counts and mortality in 1989

Table 8: Inferred live coral cover (m/50 m) after 5th April, number of colonies alive before 26th March 1989 and percentage of those colonies killed between 26th March and 5th April at each of the seventeen long-term monitoring sites in Bill's Bay.

SITE	ACROPORIDAE			FAVIIDAE			POCILLOPORIDAE			MUSSIDAE			OCULINIDAE		
	Coral cover	Colonies alive before March 26th	% killed	Coral cover	Colonies alive before March 26th	% killed	Coral cover	Colonies alive before March 26th	% killed	Coral cover	Colonies alive before March 26th	% killed	Coral cover	Colonies alive before March 26th	% killed
1	14	12	100.00	5.4	3	100.00	0			0			0		
2	24.3	29	41.38	0			2.05	5	0	0			0		
3	17.3	11	100.00	4.2	5	20.00	0			0			0		
4	23.2	20	0.00	8.6	16	0.00	1	4	0	0.1	1	0	0		
5	17.5	11	100.00	1.6	2	0.00	0			0			0		
6	34.5	16	81.25	0.1	1	0.00	0			0.1	1	0	0		
7	15.6	25	100.00	8.45	23	21.74	1.7	4	75	0			0		
8	17.8	17	0.00	6.8	13	0.00	1.4	6	0	0			0		
9	0			0			0			0			0		
10	4.7	7	100.00	9.8	13	100.00	0			0			0		
11	8.1	12	100.00	10.9	16	81.25	0.6	4	100	0			0		
12	16.9	21	4.76	3.8	6	0.00	1.1	5	0	0			0		
13	0			0			0			0			0		
14	7.75	19	100.00	1.7	6	83.33	0.1	1	100	0			0		
15	21.8	36	69.44	0.85	6	0.00	0.9	5	100	0			0.3	1	0
16	14.1	28	0.00	2	10	0.00	0.55	3	0	0			0		
17	26.8	26	0.00	0.25	2	0.00	0.5	3	0	0.1	1	0	0		

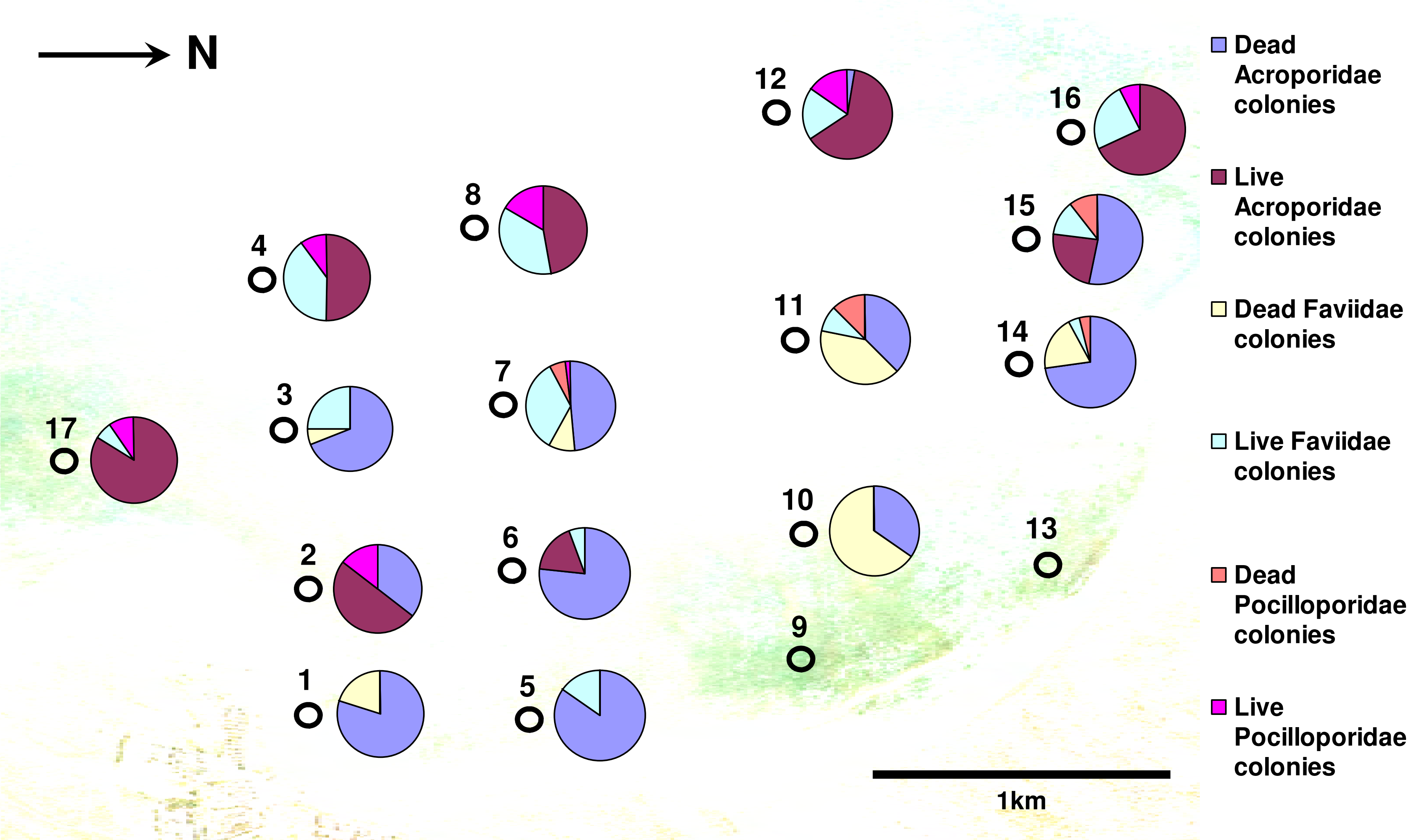


Figure 10: Coral cover after 5th April 1989; the number of live and dead colonies alive; sites 9 and 13 had no live coral cover before the event.

11. Appendix 5: Grouped mollusc data 1989

Table 9: Raw length and weight measurements of cowries found in the seven quadrats in 1989.

C. tigris		*C. eglantina*		*C. lynx*		*C. vitalis*	
Length (mm)	Weight (g)	Length (mm)	Weight (g)	Length (mm)	Weight (g)	Length (mm)	Weight (g)
93	113	60	21	63	32	54	18
102	169	51	16	47	14	58	35
105	176	65	24	45	12	51	25
103	170	59	22	43	13	58	47
109	156	62	25	46	12	64	58
90	111	58	25	39	9	52	29
97	150	60	23	49	16	56	46
104	160	52	15	53	26	55	29
107	180	59	21	50	16	46	22
101	149	53	13	44	14	56	33
95	120	63	27	45	13	54	33
90	137	58	24	47	15	53	27
110	202	63	24	44	16	57	39
105	170	63	26	39	9	58	34
104	177	58	19	48	15	57	35
93	144	60	23	52	19	63	47
89	121	57	20	46	13		
103	142	52	18	58	25		
105	142	63	23	49	17		
105	189	58	17	55	19		
104	150	58	19	59	28		
93	127	54	15	48	12		
94	147	62	23	33	6		
94	130	55	16	37	8		
99	153	58	20	46	16		
102	152	53	16	47	15		
97	140	57	23	48	15		
104	127	51	13	53	19		
101	178	49	13				
95	121	64	24				
107	167	65	24				
106	184	52	14				
106	176	61	24				
106	158	55	20				
102	150	54	17				
99	150	62	25				
91	138	60	24				
99	148	56	17				
104	166	66	32				
99	134	55	17				
102	144	54	16				
102	125	54	14				
86	125	62	22				

102	180	53	16
103	158	56	15
98	165	60	20
97	137	56	19
96	144	58	18
108	185	65	31
104	175	58	22
90		59	22
95		66	26
99		59	33
103		63	37
98		68	46
94		54	16
98		61	26
100		67	37
94		58	27
97		60	28
100		64	36
105		65	37
91		64	39
104		62	24
105		66	33
99		52	14
102		59	26
111		53	21
99		57	26
91		61	32
		66	29
		62	31
		63	39
		63	32
		52	18
		66	35
		54	21
		60	26
		61	30
		59	18
		59	28
		57	22
		61	32
		61	20
		54	18
		64	46
		66	31
		66	40
		61	35
		64	35
		56	25
		61	27
		67	38

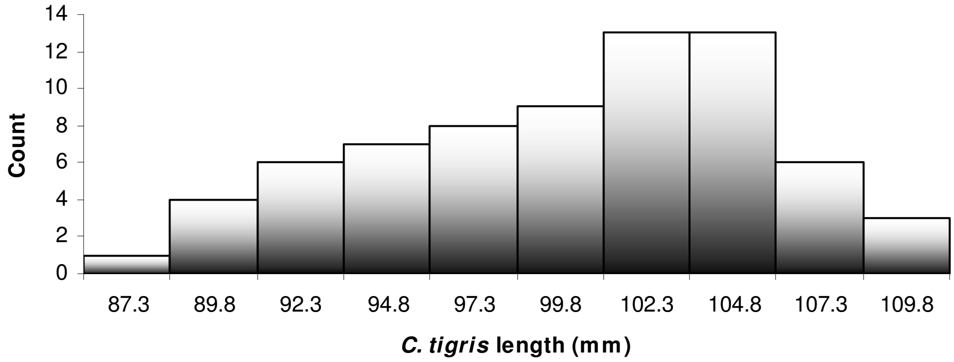


Figure 11: Histogram of *C. tigris* length from all seven quadrats sampled in 1989, average length per grouping labeled.

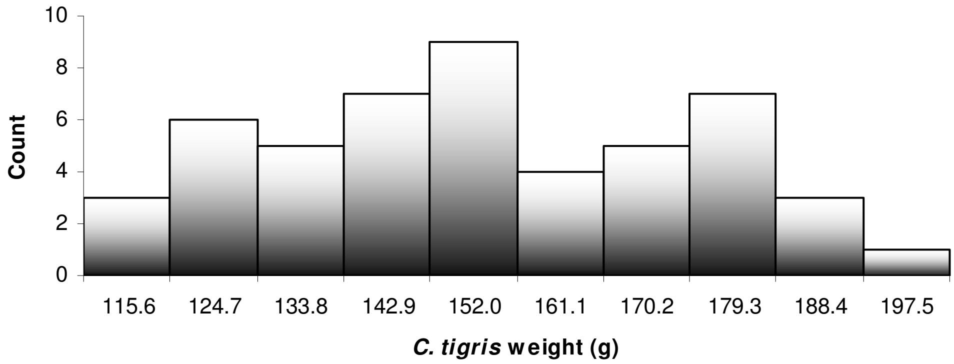


Figure 12: Histogram of *C. tigris* weight from all seven quadrats sampled in 1989, average weight per grouping labeled.

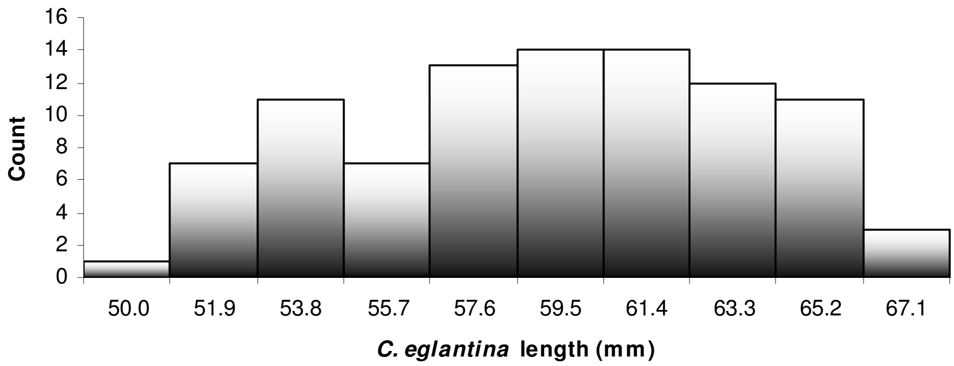


Figure 13: Histogram of *C. eglantina* length from all seven quadrats sampled in 1989, average length per grouping labeled.

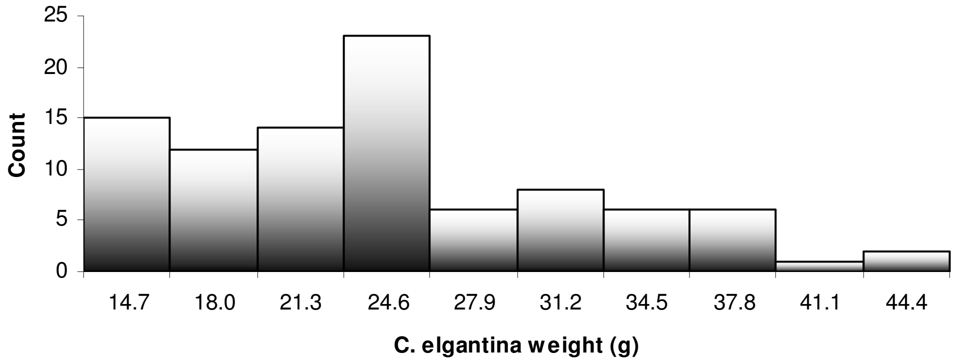


Figure 14: Histogram of *C. eglantina* weight from all seven quadrats sampled in 1989, average weight per grouping labeled.

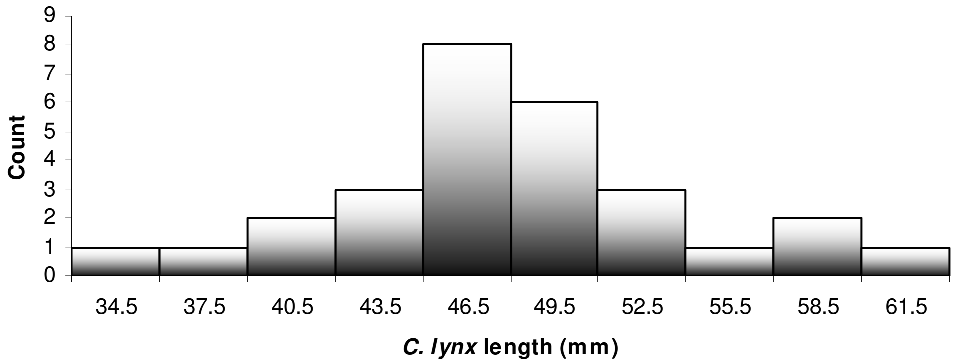


Figure 15: Histogram of *C. lynx* length from all seven quadrats sampled in 1989, average length per grouping labeled.

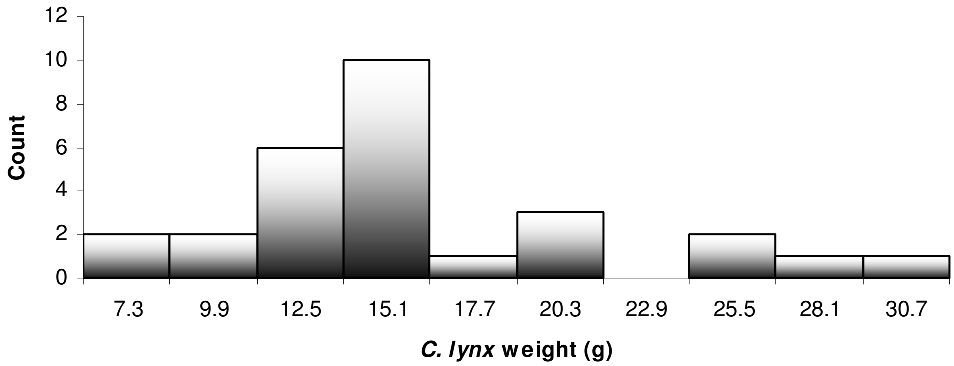


Figure 16: Histogram of *C. lynx* weight from all seven quadrats sampled in 1989, average weight per grouping labeled.

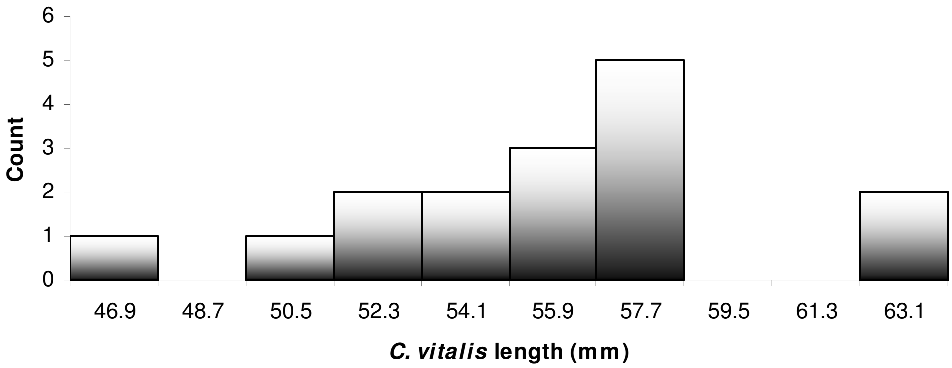


Figure 17: Histogram of *C. vitalis* length from all seven quadrats sampled in 1989, average length per grouping labeled.

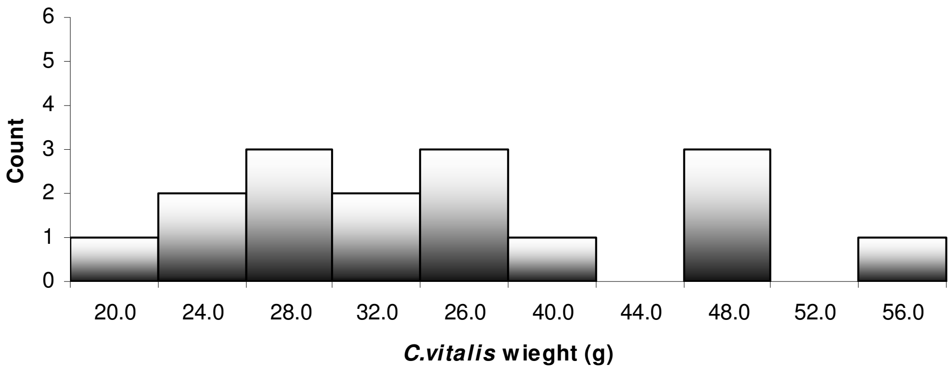


Figure 18: Histogram of *C. vitalis* weight from all seven quadrats sampled in 1989, average weight per grouping labeled.

Table 10: Raw length measurements (mm) of *T. squamosa* by quadrat, 1989.

MT1	MT2	MT3	MT4	MT5	MT6	CS14
160	300	450	260	180	260	360
240	270	480	280	180	130	310
290	300	340	320	260	280	390
360	230	470	290	260	220	410
190	220	150	270	200	130	370
200	200	210	200	220	150	390
200	290	210	220		280	270
220	350	220	220		150	210
230		530			240	210
180		250			230	310
220		150			520	310
160		270			220	310
250		190			330	360
240		530			280	410
310		200			230	310
220		520			300	290
180		300			290	290
		560			170	210
		200			320	310
		170			220	320
		190			330	300
		230			320	330
		310			260	510
		270			250	290
		220			160	210
		460			280	260
		350			280	200
		220			340	150
		280			280	130
		390			160	220
		410			150	220
					180	250
					160	250
					250	250

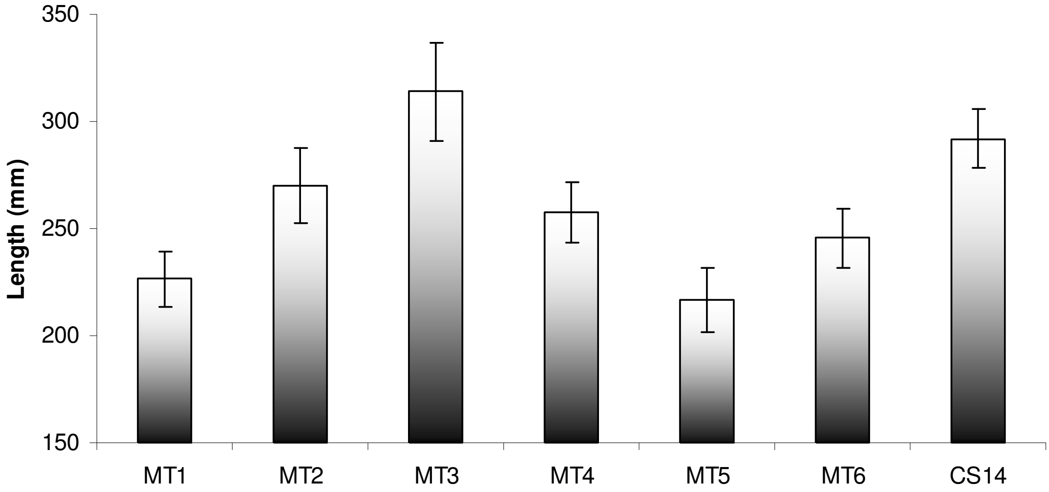


Figure 19: *T. squamosa* average length measurements within the seven monitoring quadrats in 1989, with standard error of length.

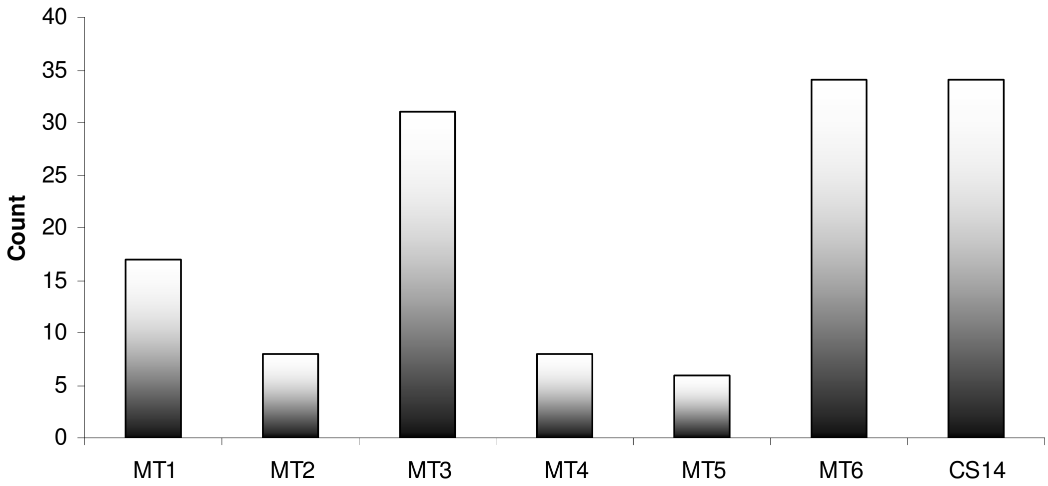


Figure 20: *T. squamosa* counts within the seven monitoring quadrats in 1989.

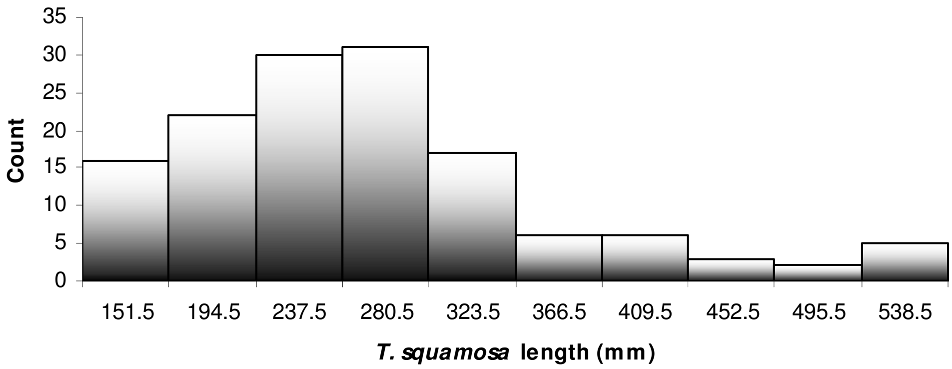


Figure 21: Histogram of *T. squamosa* length (all quadrats combined) in 1989, average length per grouping labeled.

12. Appendix 6: Fish data 1989

Table 11: Raw length measurements (mm) for dead fish measured at Bill's Bay in 1989.

L. vaigiensis		*P. coelestis*		*A. fuscus holomelas*		*H. plagiometopon*	
245	248	70	81	102	95	161	148
132	215	71	71	107	115	155	158
182	201	85	78	105	119	115	157
182	123	81	76	103	98	109	169
122	194	80	88	110	105	170	118
228	121	80	88	121	102	166	179
242	97	81	78	105	99	151	180
275	217	91	68	118	124	170	113
196	220	86	80	113	102	165	176
134	220	81	82	122	118	122	179
119	112	73	90	102	111	119	110
275	109	69	90	122	114	115	110
132	217	61	75	125	125	113	116
222	109	74	94	111	102	165	176
223	136	88	95	132	127	167	165
172	109	73	90	110	101	113	175
221	104	61	88	132	100	115	168
232	109	93	78	117	102	130	167
189	110	68	75	119	93	181	178
85	120	81	71	97	102	175	135
235	290	80	81	125	100	185	108
350	232	94	62	106	112	174	170
128	242	88	90	114	100	161	182
122	245	59	81	112	105	165	163
188	112	70	78	102	95	118	175
270	231	75	75	98	100	117	173
247	251	93	72	106	110	135	115
115	91	83	70	106	101	120	168
101	131	76	81	110	107	112	170
124	121	70	76	100	101	170	116
122	88	69	71	105	91	152	179
116	102	83	72	110	107	177	177
131	156	76	70	122	119	122	166
111	141	88	56	105	95	185	162
126	131	73	88	102	100	115	177
99	111	75	84	112	110	176	190
111	102	89	75	121	112	180	184
107	281	76	90	120	100	158	176
164	172	80	88	141	97	174	177
158	112	76	85	116	100	170	167
108	215	81	82	125	109	155	116
112	142	76	78	108	109	145	182
255	141	78	80	116	113	183	172

118	182	79	73	95	108	162	145
118	109	78	62	107	114	113	168
102	117	78	85	102	103	168	158
109	109	76	83	89	106	178	178
110	122	75	92	125	77	148	159
116	109	72	73	102	76	172	155
107	108	76	82	102	97	176	152
122	113	78	72	120	107	175	175
118	105	91	99	96	130	166	168
112	120	82	86	82	101	178	172
102	130	82	96	121	116	152	170
118	262	73	75	97	132	158	171
95	255	78	80	120	120	166	152
120	210	88	95	101	100	174	168
161	225	66	97	99	122	153	110
241	99	69	71	94	108	119	174
228	114	83	76	111	123	184	114
204	106	80	78	98	122	140	164
110	109	75	87	131	122	119	168
110	240	93	91	122	131	114	164
92	268	90	78	113	115	165	185
127	120	78	91	99	115	174	160
142	170	78	75	124	101	162	165
218	102	101	75	118	97	183	102
215	106	80	61	94	102	172	162
255	114	93	92	125	102	177	133
103	66	88	89	108	102	142	145
252	285	78	81	108	127	175	176
125	122	82	92	106	128	180	165
227	152	75	77	96	117	179	116
122	118	88	91	111	115	180	180
167	57	73	83	106	92	175	154
112	122	78		112	106	170	
231	264	90		122	109	182	
91	125	68		118	102	179	
163	113	81		130	114	175	
100	91	68		129	104	122	
153		71		105	107	108	
205		92		105	115	112	

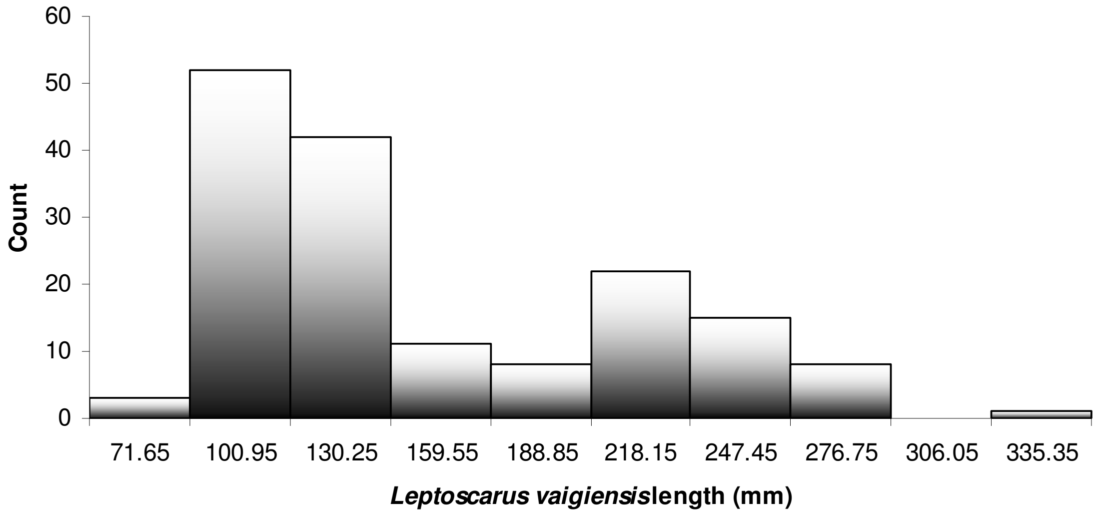


Figure 22: Histogram of killed *L. vaigiensis* length data from 1989, average length per grouping labeled.

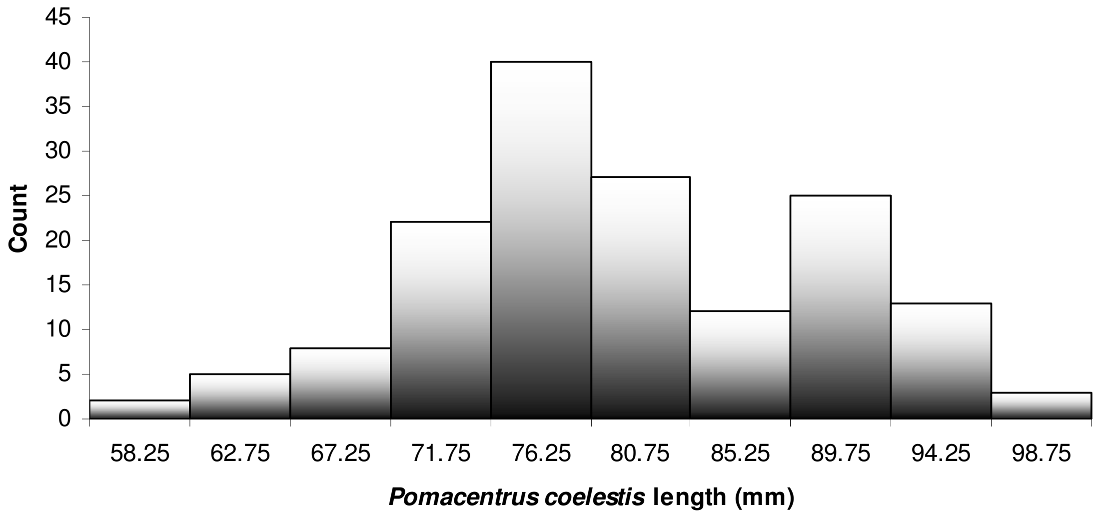


Figure 23: Histogram of killed *P. coelestis* length data in 1989, average length per grouping labeled.

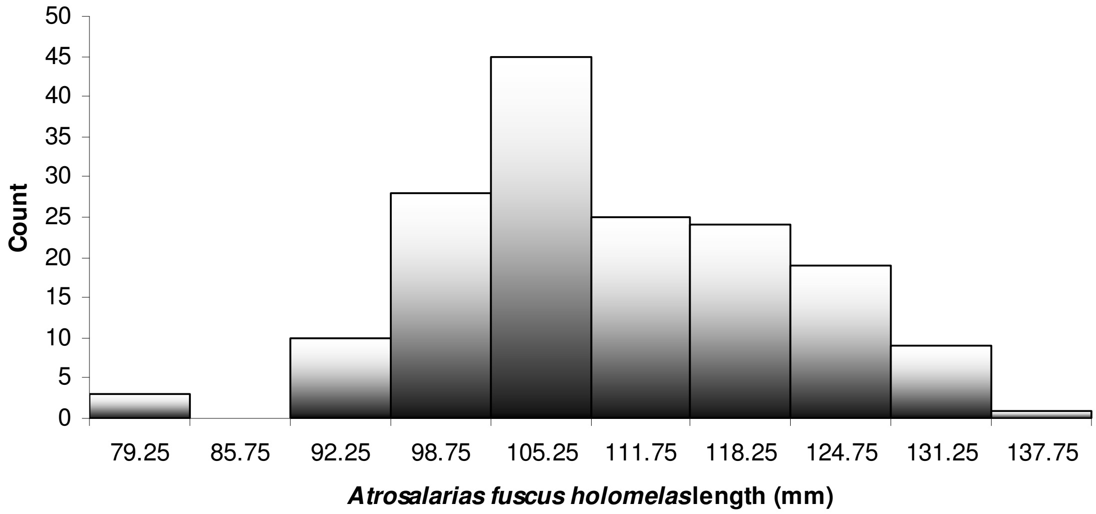


Figure 24: Histogram of killed *A. fuscus holomelas* length data in 1989, average length per grouping labeled.

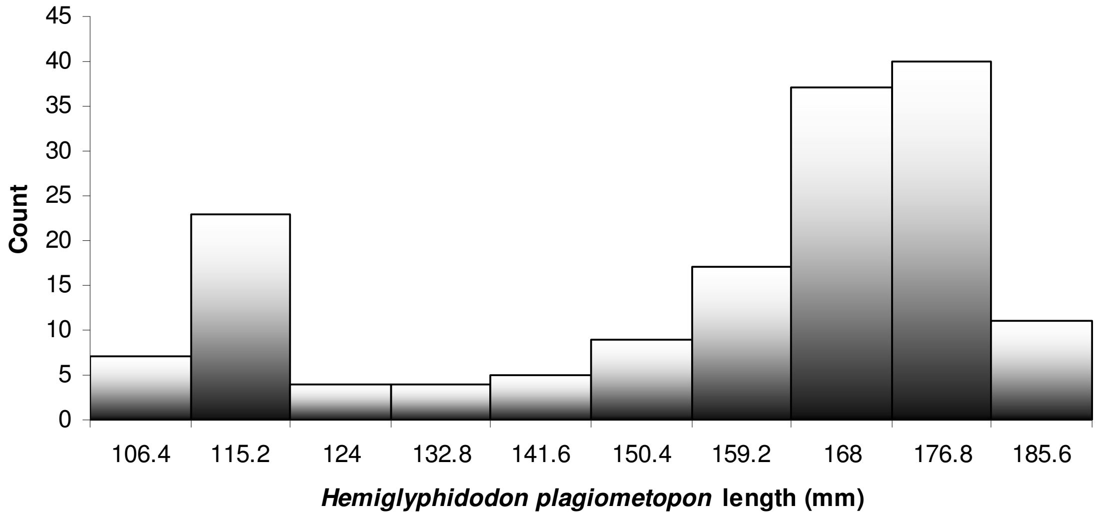


Figure 25: Histogram of killed *H. plagiomeopon* length data in 1989, average length per grouping labeled.

13. Appendix 7: Data summaries 1989

Table 12: Population parameters for killed corals surveyed at Bill's Bay in 1989.

	Acroporidae	Faviidae	Pocilloporidae	Mussidae	Oculinidae
Number of colonies	290	122	40	3	1
Mean	910	530	250	100	300
Standard error	90	60	30	0	0
Maximum size (mm)	14800	4700	900	100	300
Minimum (mm)	100	100	100	100	300

Table 13: Population length parameters for killed molluscs surveyed at Bill's Bay in 1989.

	T. squamosa	*C. eglantina*	*C. lynx*	*C. tigris*	*C. vitellus*
Number of individuals	138	70	93	28	16
Mean	270.8	99.8	59.3	47.6	55.8
Standard error	0.8	0.7	0.5	1.2	1.1
Maximum (mm)	560	111	68	63	64
Minimum (mm)	130	86	49	33	46

Table 14: Population weight parameters for killed cowries surveyed at Bill's Bay in 1989.

	C. eglantina	*C. lynx*	*C. tigris*	*C. vitellus*
Number of individuals	70	93	28	16
Mean	152.2	24.5	15.9	34.8
Standard error	3.1	0.8	1.1	2.6
Maximum (g)	202	46	32	58
Minimum (g)	111	13	6	18

Table 15: Population length parameters for killed fish surveyed at Bill's Bay in 1989.

	L. vaigiensis	*A. fuscus holomelas*	*H. plagiometopon*	*P. coelestis*
Number of individuals	162	164	157	157
Mean	157	109	156	80
Standard error	4.7	0.9	2	0.7
Maximum (mm)	350	141	190	101
Minimum (mm)	57	76	102	56

14. Appendix 8: List of species suffering mortality in 1989

Table 16: List of species found dead at Coral Bay between March 28 and April 5, 1989 (Simpson et al. 1993, p. 189).

Asterozoa: Scleractinia	Mollusca	Osteichthyes	
Acroporidae	**Bivalvia: Pinnidae**	**Acanthuridae (surgeonfish)**	*Epibulus insidiator*
Acropora aspera	*Pinna muricata*	*Acanthurus grammoptilus*	*Halichoeres melanochir*
A. florida	**Tridacnidae**	*A. nigrofuscus*	*Hemigymnus melapterus*
A. formosa	*Tridacna maxima*	*Ctenochaetes strigosus*	*Labrichthys unilineatus*
A. grandis	*T. squamosa*	**Apogonidae (cardinalfish)**	*Thalassoma lunare*
A. hyacinthus	**Cephalopoda: Octopodidae**	*Apogon savayenis*	**Monocanthidae (leatherjacket)**
A. latistella	*Octopus* sp.	*A. coccineus*	*Oxymonacanthus longirostris*
A. millipora	**Gastropoda: Cerithiidae**	*A. cyanosoma*	*Pervagor janthinosoma*
A. nobilis	*Rhinoclavis fasciatus*	*Apogon* sp.1	**Mugilidae (mullet)**
A. pulchra	**Cypraeidae**	*Cheilodipterus quinquelineatus*	*Liza sp.*
A. valenciennesi	*Cypraea arabica*	*Fowleria variegatus*	**Mullidae (goatfish)**
A. yongei	*C. caputserpentis*	**Atherinidae (hardyheads)**	*Parupeneus signatus*
Montipora aequituberculata	*C. carneola*	*Hypoatherina temminckii*	**Muraenidae (moray eels)**
M. capricornis	*C. caurica*	*Pranesus ogilbyi*	*Gymnothorax undulatus*
M. digitata	*C. clandestina*	**Balisitidae (triggerfish)**	*G. javanicus*
M. grisea	*C. contaminata*	*Balistapus undulatus*	*Gymnothorax* sp. 1
M. hoffmeisteri	*C. cribraria*	*Rinecanthus aculeatus*	**Nemipterridae (monocle bream)**
M. mollis	*C. eglantina*	**Blennidae (blennies)**	*Scolopsis bilineatus*
M. peltiformis	*C. erosa*	*Atrosalarias fuscus holomelas*	**Ophichthidae (snake eels)**
M. spumosa	*C. helvola*	*Meiacanthus grammistes*	*Callechelys catostomus*
M. verrucosa	*C. histrio*	**Bothidae (flounder)**	*Ichthyapus vulturis*
Faviidae	*C. isabella*	*Bothus pantherinus*	**Ostraciidae (boxfish)**
Cyphastrea chalcidicum	*C. leviathan*	**Carangidae (jacks)**	*Ostracion cubicus*
Echinopora lammellosa	*C. lynx*	*Gnathanodon speciosus*	*O. meleagris*
Favites abdita	*C. moneta*	**Centropomidae (snooks)**	*Rhynchostracion nasus*
F. chinensis	*C. pallidula*	*Silago analis*	**Platycephalidae (flatheads)**
Goniastrea retiformis	*C. talpa*	**Chaetontidae (butterfly fish)**	*Platycephalus cruentatus*
H. rigida	*C. tigris*	*Chaetodon aureofasciatus*	**Plotosidae (catfish)**

Hydnophors exesa
Merulina ampliata
Platygyra daelalea
P. sinensis
Fungiidae
Fungia fungites
F. scutaria
Mussidae
Acanthastrea echinata
Lobophyllia corymbos
L. hemiprichii
Oculinidae
Galaxea astreata
G. fascicularis
Pocilloporidae
Pocillopora damicornis
Poritidae
Porites sp.

C. vitellus
Haliotidae
Haliotis asinnia
Nassariidae
Nassarius dorsatus
Thaididae
Drupella cornus
Tonnidae
Tonna perdix
T. variegata
Trochidae
Tectus fenestratus
T. pyramis
Volutidae
Melo amphora
Polyplacophora: Chitonidae
Acanthopleura gemmata
Scaphopoda: Dentaliidae
Dentalium sp.

C. plebeius
Congridae (conger eels)
Conger cinereus
Dasyatididae (stingrays)
Taeniura lymma
Diodontidae (porcupinefish)
Diodon holacanthus
D. liturosus
Gobiidae (gobies)
Amblygobius phalaena
Amblygobius sp.1
Asterroptryx semipunctatus
Fusigobius neophytes
Gobiodon citrinus
G. histrio
Istigobius decoratus
Pipidonia bravoi
Valenciennea longipinnis
Grammistidae (soapfish)
Calloplesiops altivelis
Hemirhamphidae (garfish)
Hyporhamphus affinis
Hemiscyllidae (sharks)
Hemiscyllium ocellatum
Holocentridae (squirrelfish)
Sargocentron rubrum
Labridae (wrasse)
Cheilinus chlorurus
C. trilobatus

Paraplotosus sp.
Plotosus lieatus
Pomacanthidae (angelfish)
Pomacanthus imperator
P. navarchus
Pomacentridae (damselfish)
Amphiprion rubrocinctus
Cheiloprion labiatus
Chromis atripectoralis
Dascyllus aruanus
Hemiglyphidodon plagiometopon
Pomacentrus coelestis
P. moluccensis
Stegastes lividus
Priacanthidae (bigeyes)
Priacanthus cruentatus
Scaridae (parrotfish)
Leptoscarus vaigiensis
Scarus ghobban
S. schlegeli
S. sordidus
Scorpaenidae (scorpionfish)
Dendrochirus zebra
Parascorpaena picta
Siganidae (rabbitfish)
Siganus fuscescens
Tetradontidae (pufferfish)
Arothron hispidus
A. manillensis

15. Appendix 9: Environmental conditions in 1989

Table 17: Environmental conditions at Coral Bay, March 26-April 5, 1989.

Date		Wind Speed (m/s)	Wind Dir (º)	Water Temp. {ºC}	Swell	Lagoon Flushing	Water Clarity	Nocturnal Low Water (hrs)
26-Mar	Day	<1.5	315	28.6	low	poor	high	1855
	Night	CALM						
27-Mar	Day	<1.5	315	29.2	low	poor	medium	1935
	Night	CALM						
28-Mar	Day	<1.5	315	27.9	low	poor	low	2015
	Night	CALM						
29-Mar	Day	<1.5	315	29	low	poor	low	2055
	Night	CALM						
30-Mar	Day	<1.5	315	29.4	low	poor	low	2210
	Night	CALM						
31-Mar	Day	<1.5	315	29.2	low	poor	low	2355
	Night	CALM						
1-Apr	Day	~3.0	225	28.5	low	moderate	medium	0100
	Night	CALM						
2-Apr	Day	~4.0	225	28.2	low	moderate	medium	0155
	Night	~2.0	225					
3-Apr	Day	~5.0	225	27.8	low	good	medium	0255
	Night	~5.0	225					
4-Apr	Day	~5.0	225	27.5	low	good	medium	0345
	Night	~3.0	225					
5-Apr	Day	~2.0	315	27.1	low	poor	medium	0415
	Night	CALM						

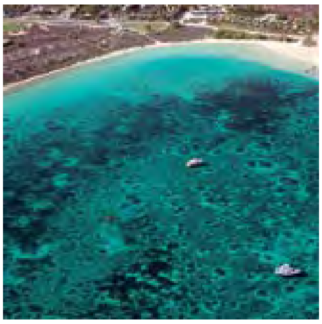
16. Appendix 10: GPS data from Laura Corbe (2005)

Waypoints	Date - time	(WGS84) Latitude	(WGS84) Longitude
336	15-JUN-05 15:00	S 23°08.744'	E113°45.641'
337	15-JUN-05 15:01	S 23°08.764'	E113°45.620'
339	15-JUN-05 15:04	S 23°08.824'	E113°45.536'
340	15-JUN-05 15:07	S 23°08.839'	E113°45.543'
341	15-JUN-05 15:08	S 23°08.841'	E113°45.581'
342	15-JUN-05 15:09	S 23°08.841'	E113°45.590'
345	15-JUN-05 15:15	S 23°08.869'	E113°45.687'
346	15-JUN-05 15:16	S 23°08.869'	E113°45.710'
347	15-JUN-05 15:18	S 23°08.876'	E113°45.692'
348	15-JUN-05 15:24	S 23°08.899'	E113°45.538'
349	15-JUN-05 15:26	S 23°08.914'	E113°45.504'
350	15-JUN-05 15:28	S 23°08.920'	E113°45.544'
351	15-JUN-05 15:30	S 23°08.921'	E113°45.576'
352	15-JUN-05 15:32	S 23°08.922'	E113°45.622'
353	15-JUN-05 15:36	S 23°08.943'	E113°45.724'
354	15-JUN-05 15:38	S 23°08.951'	E113°45.715'
355	15-JUN-05 15:44	S 23°08.997'	E113°45.565'
356	15-JUN-05 15:45	S 23°09.009'	E113°45.544'
357	15-JUN-05 15:47	S 23°09.016'	E113°45.553'
358	15-JUN-05 15:53	S 23°09.044'	E113°45.678'
359	15-JUN-05 15:55	S 23°09.041'	E113°45.736'
360	15-JUN-05 15:56	S 23°09.025'	E113°45.764'
361	15-JUN-05 15:59	S 23°09.010'	E113°45.792'
362	15-JUN-05 16:02	S 23°09.053'	E113°45.695'
363	15-JUN-05 16:04	S 23°09.079'	E113°45.668'
364	15-JUN-05 16:06	S 23°09.093'	E113°45.613'
365	15-JUN-05 16:07	S 23°09.097'	E113°45.584'
366	15-JUN-05 16:10	S 23°09.094'	E113°45.535'
367	15-JUN-05 16:12	S 23°09.012'	E113°45.545'
368	15-JUN-05 16:14	S 23°08.911'	E113°45.542'
369	15-JUN-05 16:15	S 23°08.856'	E113°45.528'
370	15-JUN-05 16:17	S 23°08.815'	E113°45.479'
371	15-JUN-05 16:19	S 23°08.800'	E113°45.545'
373	15-JUN-05 16:20	S 23°08.793'	E113°45.573'
374	15-JUN-05 16:22	S 23°08.780'	E113°45.614'
375	15-JUN-05 16:27	S 23°08.739'	E113°45.714'
378	18-JUN-05 16:10	S 23°08.565'	E113°45.939'
379	18-JUN-05 16:12	S 23°08.557'	E113°45.810'
381	18-JUN-05 16:15	S 23°08.605'	E113°45.636'
382	18-JUN-05 16:15	S 23°08.604'	E113°45.635'
383	18-JUN-05 16:19	S 23°08.644'	E113°45.545'
386	18-JUN-05 16:23	S 23°08.711'	E113°45.509'
387	18-JUN-05 16:27	S 23°08.671'	E113°45.443'
388	18-JUN-05 16:28	S 23°08.654'	E113°45.433'
390	18-JUN-05 16:31	S 23°08.625'	E113°45.496'
391	18-JUN-05 16:33	S 23°08.610'	E113°45.550'
392	18-JUN-05 16:35	S 23°08.594'	E113°45.596'
393	18-JUN-05 16:37	S 23°08.584'	E113°45.644'
394	18-JUN-05 16:41	S 23°08.568'	E113°45.739'
395	18-JUN-05 16:41	S 23°08.564'	E113°45.751'

396	18-JUN-05 16:42	S 23°08.560'	E113°45.765'
397	18-JUN-05 16:43	S 23°08.553'	E113°45.743'
398	18-JUN-05 16:44	S 23°08.544'	E113°45.717'
400	18-JUN-05 16:45	S 23°08.529'	E113°45.691'
401	18-JUN-05 16:47	S 23°08.496'	E113°45.652'
402	18-JUN-05 16:51	S 23°08.484'	E113°45.558'
403	18-JUN-05 16:52	S 23°08.468'	E113°45.518'
404	18-JUN-05 16:53	S 23°08.453'	E113°45.500'
405	18-JUN-05 16:55	S 23°08.441'	E113°45.520'
406	18-JUN-05 16:55	S 23°08.437'	E113°45.529'
407	18-JUN-05 16:56	S 23°08.430'	E113°45.569'
408	18-JUN-05 17:03	S 23°08.481'	E113°45.754'
409	18-JUN-05 17:06	S 23°08.503'	E113°45.908'
410	18-JUN-05 17:06	S 23°08.503'	E113°45.923'

17. Appendix 11: GPS data from Fiona Webster (2005)

Location	Date	Latitude	Longitude
Temperature Logger	15th Dec. 2004 - 5th May 2005	23´07.915	113´45.997
Tow point	21st April 2007	23´08.999	113´45.854
Tow point	21st April 2007	23´08.860	113´45.679
Tow point	21st April 2007	23´08.827	113´45.565
Tow point	21st April 2007	23´08.811	113´45.845
Tow point	21st April 2007	23´08.668	113´45.587
Tow point	21st April 2007	23´08.354	113´45.736
Tow point	21st April 2007	23´08.122	113´45.433



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