Does lagoon water eflux affect coral health?

An investigation of physical properties of lagoon circulation on coral health at Christmas Island and Palmyra Atoll

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Abstract:

At Christmas Island and Palmyra Atoll, two coral atolls in the Northern Line Group, we surveyed coral communities and gathered data on physical properties and flow patterns of the lagoon water to assess the effects of lagoon water efflux on their health and genus richness. Physical data and flow pattern information was gathered by using HOBO loggers to record light intensity and water temperature over time (May 22-24 and 28-30, 2007, at Christmas and Palmyra, respectively), using a towable CTD and doing transects near the channel openings at each island using the Acoustic Doppler Current Profiler. At Christmas Island, we hypothesized that effects of lagoon water would be indiscernible due to other anthropogenic forcings such as overfishing and sediment runoff; however, we found that areas of low live cover and genus richness seemed to be correlated to areas of higher lagoon water efflux, and that areas with the highest live cover seemed to be protected from the efflux of warm lagoon water. At Palmyra Atoll, we hypothesized that the lagoon water was flowing westward across the atoll and out the channel opening. Furthermore, that this warmer, more turbid water mass was negatively impacting the corals near the channel opening. Our findings support this hypothesis: we found evidence both for the westward flow of the lagoon water and lower live cover near the channel opening on the west side, which correlated to higher maximum temperatures at these sites.

Introduction:

Worldwide, coral reefs are in a state of decline (Hughes *et al.*, 2003). It is estimated that 30% are already severely damaged, and close to 60% may be lost by 2030 (Wilkinson, 2002). The direct and indirect effects of overfishing and land development have been one of the major drivers of massive decreases in the abundance of coral (Hughes *et al.*, 2003). In addition, climate change has been linked to mass bleaching events that have increased greatly in frequency and magnitude over the past 30 years (Hughes, 2003). Regional bleaching events have been strongly associated with elevated ocean temperatures that occur during El Niño Southern Oscillation (ENSO) events (Glynn, 1993). The Line Islands are a particularly fascinating place to study coral reef ecology because they offer the ability to examine coral health along a gradient of overfishing and land development. Furthermore, the Line Islands lie in the path of the Western Warm Pool as it moves across the Pacific during ENSO events. This causes the Line Islands to be highly impacted by sea temperature fluctuations. Christmas Island reefs show effects of overfishing, nutrient runoff, habitat alteration, and ENSO. In contrast, Palmyra Atoll is largely considered to be one of the most pristine coral reef ecosystems in the world, despite alterations from its use as a military base during World War II. Unfortunately, there are no truly pristine reefs left in the world (Jackson et al., 2001), meaning that Palmyra provides one of the closest baselines for understanding human induced reef changes and the global effort to recover coral reef ecosystems. During the military occupation in WWII, the most biologically and physically significant changes to both Christmas Island and Palmyra Atoll were the alterations made in order to create roadways and channels. The military dredged a 200-foot wide channel on the western side of the Palmyra lagoon and constructed causeways to connect the northern and southern islands and also North-South across the atoll, virtually eliminating the flow of water between the east and west lagoon (see Figure 1). The changes in the atoll structure made the inner lagoon virtually uninhabitable by coral reefs (Dawson, 1959). Since then, no apparent recovery of the original reef habitat has been made

(Chiu, 2003). Furthermore, the reduced flushing and modification of the lagoons' circulation pattern have been proposed to have completely altered the thermal regime of the lagoon (Kaly *et al.,* 1993). At Christmas Island, the exchange of the lagoon water with the outer ocean has seen a reduction of 95-97% because of the causeway construction, but the effects of this reduction on total lagoon flushing, water quality, and reef production are still unknown (Forbes *et al.,* 1995). Previous Stanford at SEA projects in 2003 and 2005 by Alice Chiu and Jina Hyun, respectively, have focused specifically on understanding the physical properties of the Palmyra and Christmas lagoons. Both projects were able to produce a snapshot of temperature, salinity, florescence, and oxygen profile for the lagoons, but neither project was able to examine the water circulation within the lagoon or changes over one or many tidal cycles.

The question has been posed by several scientists whether the changes in the lagoon circulation have had a destructive impact on the reefs outside the lagoon. Several lines of evidence exist that support the hypothesis of lagoon water in Palmyra as responsible for the destruction of coral habitat to the west of the lagoon near the dredged channel. Records indicate that a mass bleaching event of the broad western reef terrace at Palmyra, supporting thriving *Acropora* 'staghorn' coral thickets in 1987, caused death and degeneration into rubble deposits by November 1998 (Brainard *et al.,* 2005). Furthermore, verbal accounts of massively bleached table top corals near Penguin Spit (also called Tiger Shark Point) during the 2002 El Niño, and overall decreased live cover in the same place when sampled in 2003 by Stanford at Sea's Lynda Browning, suggest that this area is particularly vulnerable during periods of increased ocean temperatures. One hypothesis for why this area near the channel is particularly vulnerable is that water is moving primarily from east to west across the lagoon (in the same direction as the North Equatorial Current and the prevailing trades), causing the water that flows out of the west channel towards Penguin Spit to be warmer due to time it spent in the shallow lagoon. This may cause the corals outside the lagoon to cross the bleaching threshold during strong El Niño events. Both Hyun and Chiu's sea surface temperature data for Palmyra show a warm area of water near the mouth of the channel which supports this hypothesis.

At Christmas Island, the effects on the lagoon reef health from the physical changes that have occurred from human disturbance are more poorly understood. The greatest challenge in understanding only the effects of the lagoon circulation on coral health is that overfishing, nutrient runoff, and sediment runoff from unprecedented construction and human habitation have most likely altered the reef ecosystem. Total fish biomass at Palmyra is 428% greater than that of Christmas (Stevenson *et al* 2007), suggesting that overfishing has most likely had a large impact on the overall health of the ecosystem. Nonetheless, understanding circulation and its effects on coral health in the area would provide information for successful recovery. Again, Hyun's temperature, salinity, florescence, and oxygen profile data provided a baseline for understanding the general composition of the water in the lagoon at Christmas, but failed to provide a picture for how the water flows in and out of the lagoon throughout the tidal cycle.

The purpose of this study was to learn about the water movement into and out of the lagoon by gathering temperature and light data every ten seconds at various sites over at least one full tidal cycle, as well as current, wind, and salinity data, and then to see whether areas impacted by lagoonal flow had lower live cover. Another purpose of this study was to examine differences in genera composition and diversity at the sites that were affected by lagoonal flow. All of the collected data was aimed at creating a clearer picture about whether it is a reasonable hypothesis that lagoon water flow negatively impacts the health of corals outside the lagoon. The study of coral genera composition and richness was significant for increasing the understanding of the overall health of the reef and the physical conditions that it might experience. It had also been shown that different corals have different tolerances to bleaching (McClanahan et al., 2005), and a correlation was seen between more heavily lagoon impacted sites and increased proportion of bleaching-tolerant coral genera.

The main hypothesis in this study was that the flow of lagoon water out to the fore reef negatively impacts reef health outside the lagoon, and increased maximum and average temperatures due to lagoon water outflow correlate with decreased live cover and genera diversity. At Christmas Island, the expected differences between the reef health inside and outside the lagoon were minimal due to high mixing between the lagoon and the open ocean as a result of the large channel area. Other factors such as overfishing were also expected to have deteriorated the reefs around Christmas Island to such an extent that environmental impacts caused by increased temperature from lagoon water would be hard to distinguish. The expectation for Palmyra was to see that the lagoon water shows evidence for a general westward flow, and that this water warms as it crosses the lagoon, having a direct and evident impact on the corals near the channel opening. Overall, the study expected to see a difference in genera composition and number of genera at different sites depending on site favorability.

Methods:

At Christmas Island, eight Onset Company HOBO Pendant temperature and light loggers and two Onset Water Temp Pro HOBO temperature loggers were deployed at ten sites on the western side of the island from May 22-24, 2007 (Figure 2). Loggers were configured to record data every 30 seconds and placed on the bottom attached to lead weights. Seven of the Pendant temperature/light loggers and one of the Water Temp Pro temperature loggers were successfully retrieved. Positions, deployment times, and depths of the loggers are summarized in Table 1. At five of our HOBO sites, the study also conducted snorkeling surveys of the coral communities using 1-meter square quadrats with a 20-cm string grid, recording cover under each of the corners, at each intersection of grid lines with the frame and at each intersection of the grid with itself, for a total of 36 sample points per quadrat. To determine quadrat placement, we pre-generated a list of random compass headings and numbers of fin kicks (from 8 to 15) to advance from one quadrat to the next during surveys. At all sites percent live coral cover, algal cover, bare rock or sand, and live corals (identifications to genus and/or species level were recorded). Only percent live coral cover and genera data is reported in this paper for analysis.

At Palmyra, nine Pendant temperature/light loggers and two Water Temp Pro temperature loggers were deployed from May 28-30, 2007, all of which were successfully retrieved (see Table 2). Again, loggers were initialized to record every 30 seconds. We placed six loggers on the western side of the island, three in the lagoons, and two on the eastern side (Figure 3). We conducted coral surveys at four of the sites on the western side of the atoll.

In addition, at both Christmas Island and Palmyra Atoll we used the Acoustic Doppler Current Profiler (RDI Instruments) aboard the Robert C. Seamans set at 2 meter bins to record a snapshot of current direction and magnitude along a transect in front of the channel openings (see Figures 9 and 12 for track info). We also towed the Branker Towable Conductivity Temperature Depth Profiler (CTD) at 1m depth from a small motorized boat around the lagoon at both atolls (see Figures 8 and 11 for track info). The towable CTD recorded both temperature and salinity with time. We used the handheld GPS to record the track followed during the CTD tow.

The coral survey data collected for our study at both Christmas Island and Palmyra Atoll did not conform to the assumptions of an ANOVA; therefore, non-parametric tests were used for statistical analysis of all coral data. At Christmas Island, our study ran a Kruskal-Wallis test for differences between all sites. For analysis of survey data from Palmyra, a Kruskal-Wallis One-Way ANOVA was ran for all sites with 3 degrees of freedom. A Kruskal-Wallis test was also ran between the two sites closer to the channel opening (Inner Penguin Spit and North of Channel) versus the two sites further away from the channel opening (Outer Penguin Spit and Far North of Channel). For both Christmas Island and Palmyra data, correlation analysis was used to analyze covariance between mean live cover and maximum, minimum and average temperatures from the HOBO data.

Results:

At Christmas Island, water temperatures recorded by the HOBO loggers ranged from 26.88° C, recorded at Cook Island, to 31.06° C, at the North Lagoon site (see Figure 5). Site mean temperatures ranged from 28.83° at Cook Island to 27.19° at the Far South Shore. Cook Island and the Far South Shore also showed the widest and narrowest temperature ranges, at 3.98° and 0.88° respectively. Maximum, minimum, and mean temperatures are displayed in Figure 5. Light intensities varied from zero at night up to maximum intensities of 74,367 lum m^{-2} at the North Shore site and 198,391 lum m^{-2} at the South Shore site.

All sites had clear light and temperature structure through time, dominated by the diurnal solar cycle and coincident solar heating and radiative cooling of the water. Throughout the daylight hours, light intensities fluctuated through an order of magnitude on a scale of minutes and showed average peaks and troughs on a scale of tens of minutes to hours. Water temperature at the two channel and lagoon sites showed a periodic fluctuation with approximately the same period as the M2 lunar tide. These upward and downward swings in temperature were most distinct at night, and were not in phase with each other from site to site (see Figure 4). Both nights of the deployment, each channel and lagoon site saw a similar temperature increase of about 1 degree Celsius. These increases occurred at the lagoon sites before the channel sites, and at the southern sites before the northern sites.

The profile generated from the ADCP transit at Christmas Island showed northward flow of water offshore of London, and more variable flow further south (see Figure 9). The temperature and salinity data from the towable CTD showed that water became saltier and warmer with distance inside the lagoon (see Figure 8).

The five sites where coral surveys were conducted at Christmas Island had significantly different live coral cover (Kruskal-Wallis p=0.001), ranging from 0.4% to 44.6% mean live cover (see Figure 6). Furthermore, the two sites north of London (North Shore and Far North Shore sites) had lower live cover than the three other sites. Cook Island had highest live cover; and the South Shore site appeared to have slightly lower live cover than the Far South Shore site. A linear negative correlation of live cover with the minimum temperature recorded from the HOBOs showed a R value of 0.8709. Genus richness showed an exponential positive correlation to mean live cover with a R value of 0.9725. At the three sites with higher live coral cover, massive forms of *Pavona* and *Porites* dominated (see Figure 7). At the two sites with low cover on the North Shore, recruits of *Pocillopora* were predominant.

At Palmyra, maximum temperatures recorded with the HOBO loggers ranged from 31.27° at Sand Island to 28.39° at Barren Island. Site means ranged from 28.13° at Outer Penguin Spit to 28.67° at the North of Channel site. The widest temperature range, 4.39°, was at Sand Island, and the narrowest, 0.54° was at Outer Penguin Spit. Maximum, minimum, and mean temperatures at Palmyra are displayed in Figure 10.

Similar patterns in light and water temperature to those observed at Christmas were found at Palmyra. Light intensity, again, showed wide-range, short period variability within the diurnal cycle, and temperature again tracked average light intensity with tidally-associated perturbations, most visible at night. Sand Island, both North of Channel sites, East Lagoon, and Barren Island all saw clear drops in temperature with periods matching the M2 tide. These perturbations were closer in phase both to the predicted ocean tide and to each other than were the tidally-influenced sites at Christmas Island. At all but one of these sites, the time of high tide coincided with a dip in temperature, the exception being Barren Island, where similar drops in temperature were observed, but coincided almost perfectly with the low tide. Records from the Sand Island, Far North of Channel, and Barren Island sites are displayed in Figure 11.

The ADCP transect showed a variable current profile across the opening of the channel at Palmyra (see Figure 13). The towable CTD data showed primarily warmer, fresher water in the West lagoon compared to the East lagoon (see Figure 12).

The coral surveys at Palmyra showed significant differences between sites (Kruskal-Wallace p=0.002). The two sites closer to the channel opening, the Inner Penguin Spit and North of Channel site, appeared to have lower live cover than the two sites which were further away from the channel opening (see Figure 14). The data also showed a negative linear correlation between maximum temperature recorded by the HOBO loggers and proportion live cover. The genera data showed a greater species richness at the two Penguin Spit sites than the two sites north of the Channel (see Figure 15). It also showed a greater proportion of *Acropora* at the two Penguin Spit sites than was seen at any other sites surveyed by this study. *Pocillopora* was dominant at the two sites north of the channel.

Discussion:

At Christmas Island, this study did not expect to find differences in coral health attributable to lagoonal flow because of the large channel opening and other factors such as overfishing, sedimentation, and anthropogenic impacts. The findings, however, contradicted this initial hypothesis, suggesting that the lagoon water could have a negative impact on corals outside the lagoon, especially north of the north channel opening. The unexpected variability in live coral cover and genera richness at different sites can be attributed to the varying influence of lagoon water around the channel openings. The study found augmented negative affects north of the channel, where ADCP data indicated northern lagoonal flow, while the south showed variable flow directions and more diverse reefs and increased live cover. The coral data of this study accurately elaborated on the physical conditions present in the Christmas Island lagoon, adding to the Hyun and Chiu projects that reported similar findings of warmer and more saline water in the lagoon.

The data gathered on the physical properties, and probable flow patterns of the lagoon water, as well as the data collected in the coral surveys strongly supports a hypothesis that water from the lagoon has a negative impact on the corals to the north of the channel opening by the township of London.

Although only a snapshot in time, the fact that the ADCP transect showed that water was flowing northward in this region supports the hypothesis that this may be a general pattern of movement of water outside of the lagoon. Furthermore, the observed turbidity in this area, and demonstrated warmer water temperature from the CTD tow and HOBO loggers support this assertion, since this warmer, more turbid water is most likely being generated in the lagoon and transported outward. These factors seem to cause drastically decreased live cover and genera diversity. In other words, our data supports the hypothesis that the coral surveys showed low live cover at the North Shore and Far North Shore sites is from the flow of the lagoonal water.

The results from the other sites at Christmas suggested a more complex system than is explained merely by the movement of water outward and northward from the lagoon channel openings. The fact that Cook Island had the highest live cover of any sites surveyed by this study at both Christmas Island and Palmyra, despite its location directly north of the southern lagoon opening, provoked further hypotheses about the potential system surrounding this site. The ADCP transect data showed variable flow around Cook Island, indicating the possibility of eddy formation or westward flow from the ocean that transports a cool ocean water to the site on a consistent basis. The fact that the Cook Island site had the lowest minimum temperature of all the sites at Christmas Island supports this hypothesis. Although the reef at the Cook Island site is not directly dependent on the minimum temperature, it may indicate that this site remains cooler than other sites during abnormally warm conditions, such as an ENSO event, perhaps preventing bleaching or allowing earlier recovery than surrounding reefs. The fact that all of the sites showed a significant negative correlation with live cover versus minimum temperature further supports the hypothesis that access to cool ocean water may be protecting coral mortality from thermal stress. Further study of the current patterns over the long term, coupled with a detailed study of turbidity at each site would yield a clearer understanding about what is generating the relatively high live cover at the Cook Island site.

At Palmyra, the results of this study strongly supported the hypothesis that the lagoon water was negatively impacting the coral health directly outside of the channel opening. The comparison of coral live cover near the channel versus far away from the channel supported this conclusion (see Figure 14). However, the difference between the near and far sites was not significant, most likely due to low sample numbers. The data gathered on the possible movement of water across the lagoon also supported this finding. The fact that the water was warmer and less saline in the west lagoon compared to the east lagoon supported the hypothesis that the water moves from east to west across the lagoon; if it were indeed flowing this way, the temperature would increase due to containment in the shallow lagoon and having to pass through the shallow channels. Unlike Christmas Island, which receives relatively little to no rain, the water at Palmyra would become less saline by extended periods of time in the lagoon due to the large quantities of rain that it receives consistently throughout the year due to its location near the Inter-tropical Convergence Zone (ITCZ). The data gathered from the loggers also supported a general westward flow of water across the lagoon. The fact that the Barren Island site had a very narrow range of temperatures suggests that it does not receive any warmed lagoon water. The ADCP transect data did not provide clear support for the hypothesis that the water is flowing out of the lagoon, but since it only represented a snapshot in time, it showed that the water movement is variable around the area. The fact that during the two passes to the north of the channel opening the direction of the currents almost completely reversed shows that the direction of water movement is not consistent in the area. Long term data collection is necessary to shed additional light on this complicated physical system of water movement.

At Palmyra, the hypothesis that the increased temperature from the lagoon could be partially responsible for the coral mortality outside of the lagoon was further validated by the positive correlation between percent live cover and the maximum temperature that was recorded by the loggers. This positive correlation supports the hypothesis that these sites would experience higher temperatures during ENSO events, perhaps crossing the threshold for bleaching and mortality sooner than the sites that are not subjected to temperatures as high. Furthermore, more frequent crosses of this threshold during less mild events than strong ENSO events generated by climate variability, would explain why even five years after the reported die off of the corals around Penguin Spit, the inner site appears to have recovered less than the outer site.

In order to fully understand whether temperature or turbidity, or a combination of both, is the property of the lagoon water which is having a more severe impact on the live coral cover and genus composition at each of the sites at Palmyra Atoll, a longer term data set of temperature and a study of turbidity over time would be desirable. More coral surveys, especially after an ENSO or period of increased ocean temperature, would also shed light on which sites might be more vulnerable to climatic variations.

At both Christmas Island and Palmyra, the genus *Pocillopora* dominated the live coral cover in areas of high lagoonal impact. Christmas Island featured increased incidence of massive corals such as *Porites* and *Pavona*, comprising thirty to fifty percent of the coral live cover at each of the three southern sites. In contrast, the Palmyra sites exhibited greater live cover of *Acropora* and proportionally less of the massive corals, most notably *Pavona*. The latter massive corals are more resistant to bleaching and thermal stress (McClanahan, 2005). This suggests that the reefs at Christmas Island are more disturbed than those at Palmyra, and the lagoonal flow may be exerting a larger impact on Christmas. It could also be that other factors such as the presence of human disturbance and sedimentation are causing the alteration of the coral community composition. The data also suggests that *Pocillopora* is resistant to stresses from the lagoonal flows as well, perhaps more so than *Porites* and *Pavona,* since the sites with low live coral cover at both Christmas Island and Palmyra featured almost exclusively *Pocillopora* recruits less than 30cm in diameter. These data sets and qualitative observations may depict how areas affected by the stresses of lagoonal flow or other reef disturbances can re-colonize, offering exciting possibilities for future research on the effects of lagoonal flow on coral-based ecosystems.

Conclusion:

This study supported the hypothesis that lagoonal efflux has a significant negative impact on coral health and genus richness at both Christmas Island and Palmyra Atoll. At Christmas Island, low coral cover and genus richness are most likely caused by lagoon water flowing northward out of the channel adjacent to London. The appearance of slightly lower coral cover close to the lagoon on the south shore also suggests that the lagoon water is decreasing the live cover close to the channel openings. The presence of high live cover and genus richness and low minimum recorded temperature at the Cook Island site, however, indicate that despite its proximity to the channel, it is weakly influenced by lagoon water.

At Palmyra, the hypothesis that the lagoon water is flowing westward and negatively impacting the corals outside of the lagoon was validated by the fact that the sites on the far eastern side of the atoll showed minimal range in temperatures throughout the three days of deployment, as well by the towable CTD data. The sites close the channel opening showed a trend of lower live cover than the sites further away; however, more surveys are needed to determine if the trend is significant. The fact that the sites with lower percent live cover correlated with higher maximum temperatures closer to the channel opening further supported the hypothesis that these sites are indeed receiving warmer lagoon water and are therefore more susceptible to crossing the mortality threshold during periods of thermal stress such as ENSO events. In general, knowledge of lagoon characteristics and physical processes is important in understanding and predicting the physical stresses to coral community health both between islands and between sites at single islands.

Figures:

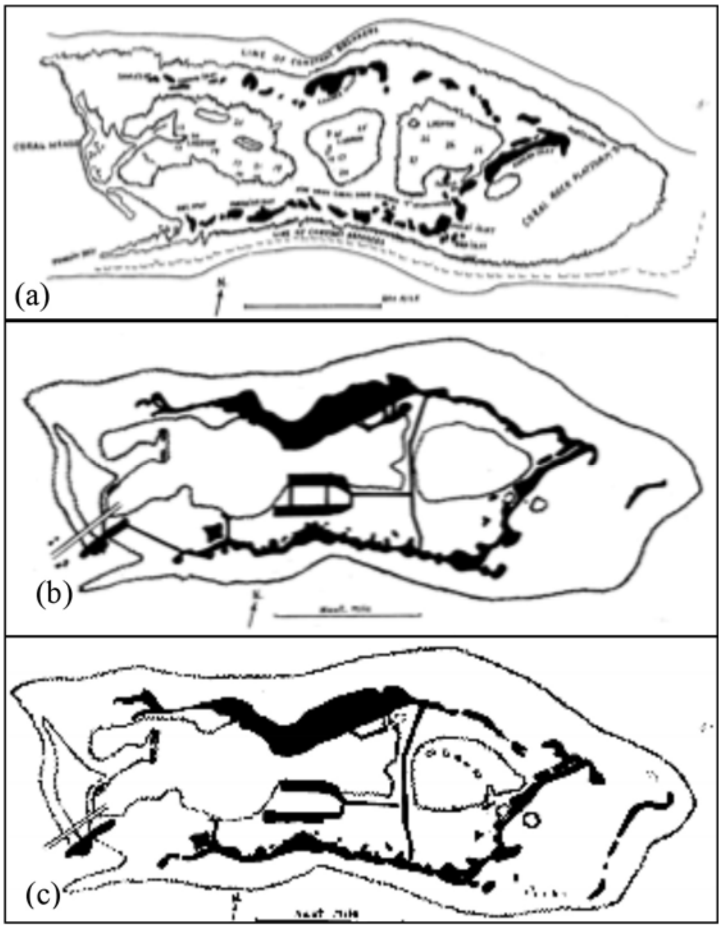

Figure 1: Changes at Palmyra over time: (a) the atoll in 1913, with open lagoon and many hoa, (b) in 1944, after the Navy's construction, including a road connecting the motu and causeway bisecting the lagoon, and (c) in 1958 after a decade of erosion. (Dawson, 1958)

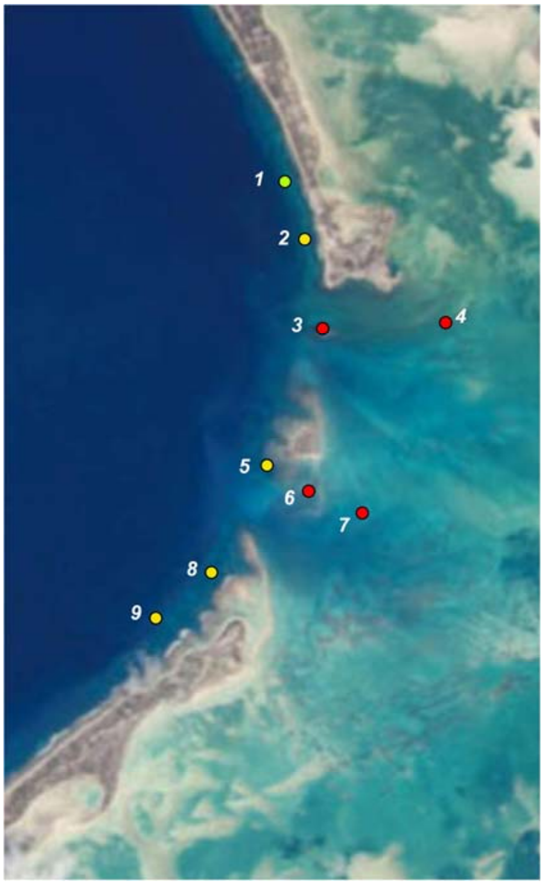

Figure 2: Satellite image of Christmas Island with sites marked. Site names: 1-Far North Shore, 2-North Shore, 3-North Channel, 4- North Lagoon, 5- Cook Island, 6- South Channel, 7- South Lagoon, 8- South Shore, 9-Far South Shore. Red denotes sites where loggers were deployed but coral surveys were not done. Yellow is where loggers and surveys were conducted. Green is where coral survey was done but logger was not retrieved.

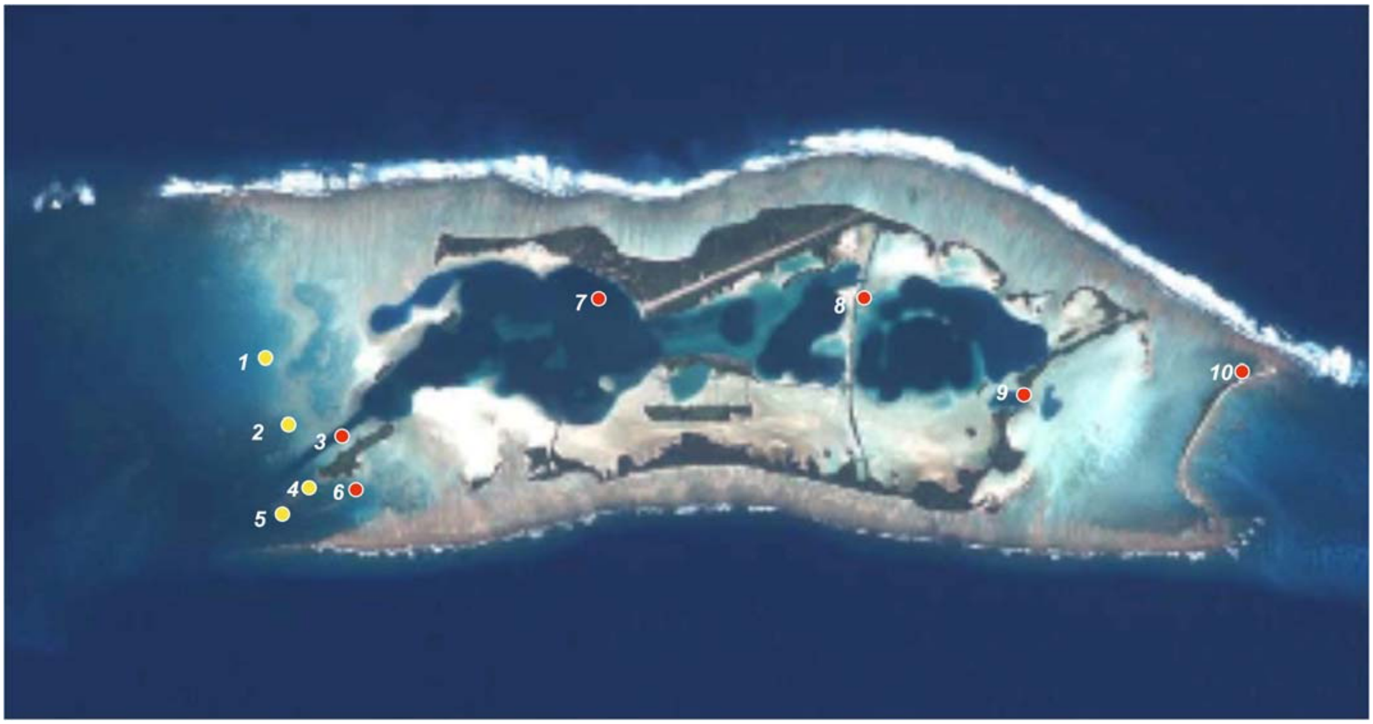

Figure 3: Satellite image of Palmyra Atoll with sites marked by dots. Site names: 1-Far North of Channel, 2-North of Channel, 3-Channel, 4-Inner Penguin Spit, 5-Outer Penguin Spit, 6-Sand Island, 7-West Lagoon, 8-Causeway, 9-East Lagoon, 10-Barren Island. Red denotes sites with loggers but no coral surveys. Yellow denotes sites where loggers and coral surveys were conducted.

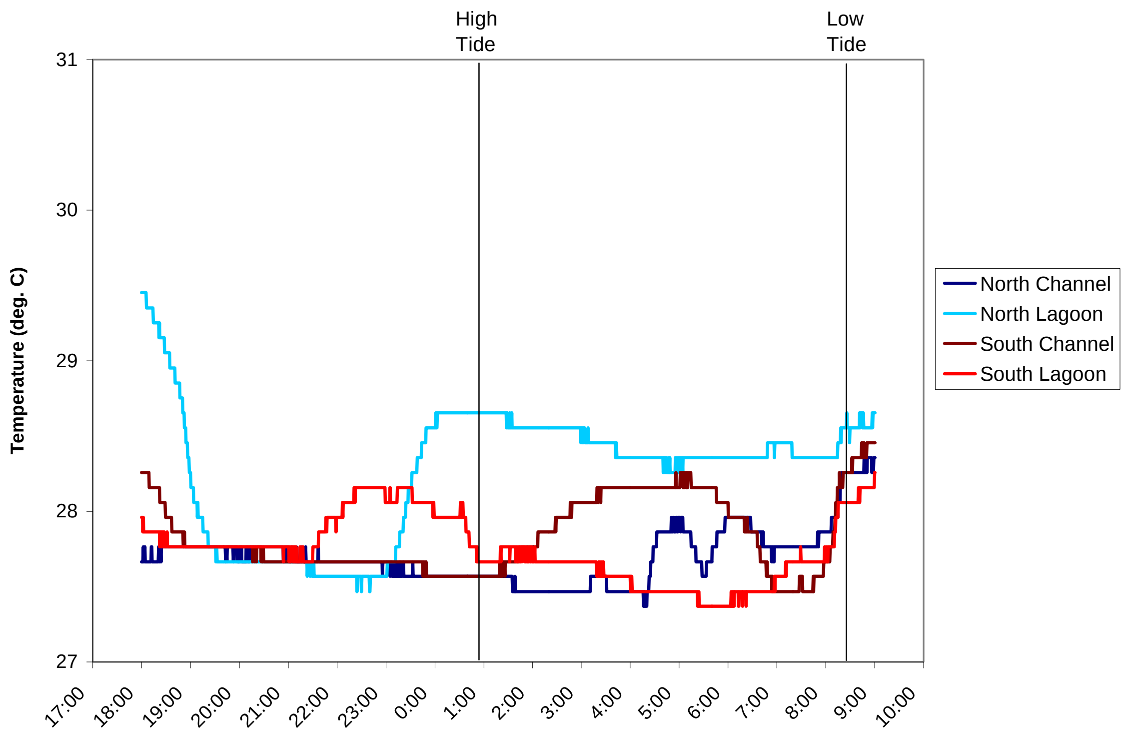

Figure 4: Temperature data from channel and lagoon sites at Christmas Island overnight May 22-23.

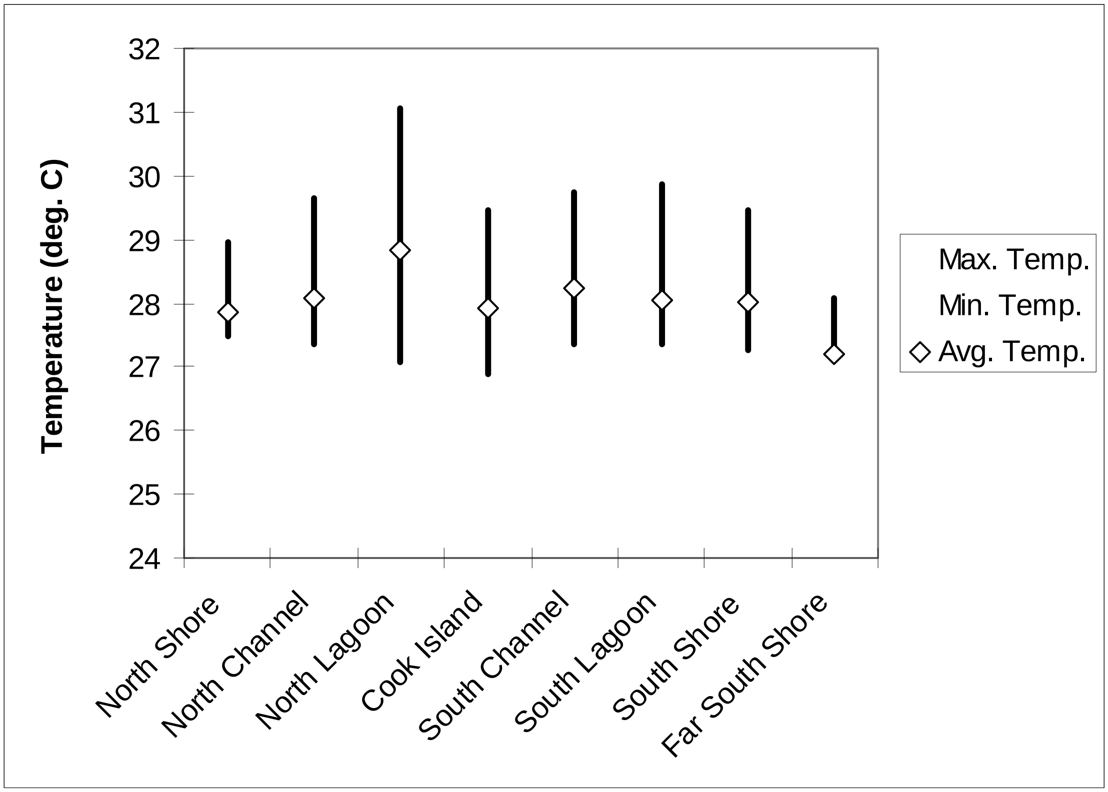

Figure 5: Maximum, minimum and mean temperatures recorded at each site at Christmas Island from May 22-24.

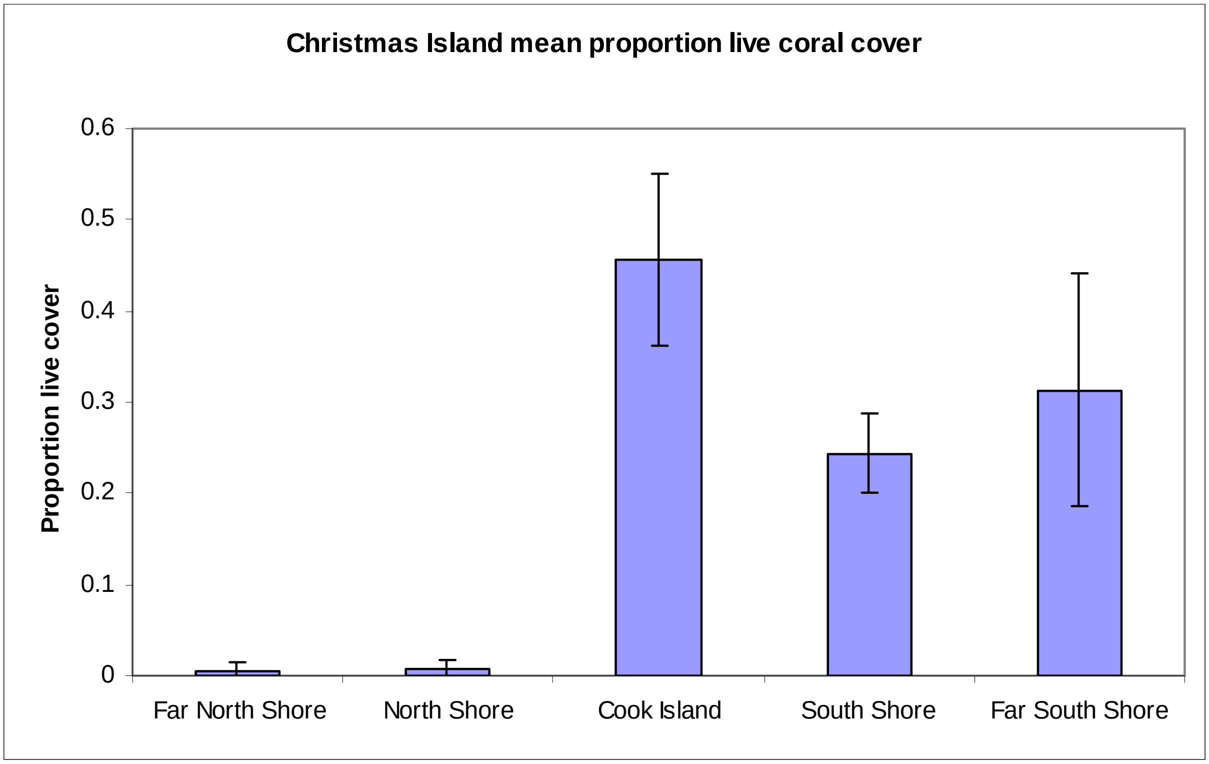

Figure 6: Mean proportion live coral cover at each survey site at Christmas Island with 95% confidence intervals.

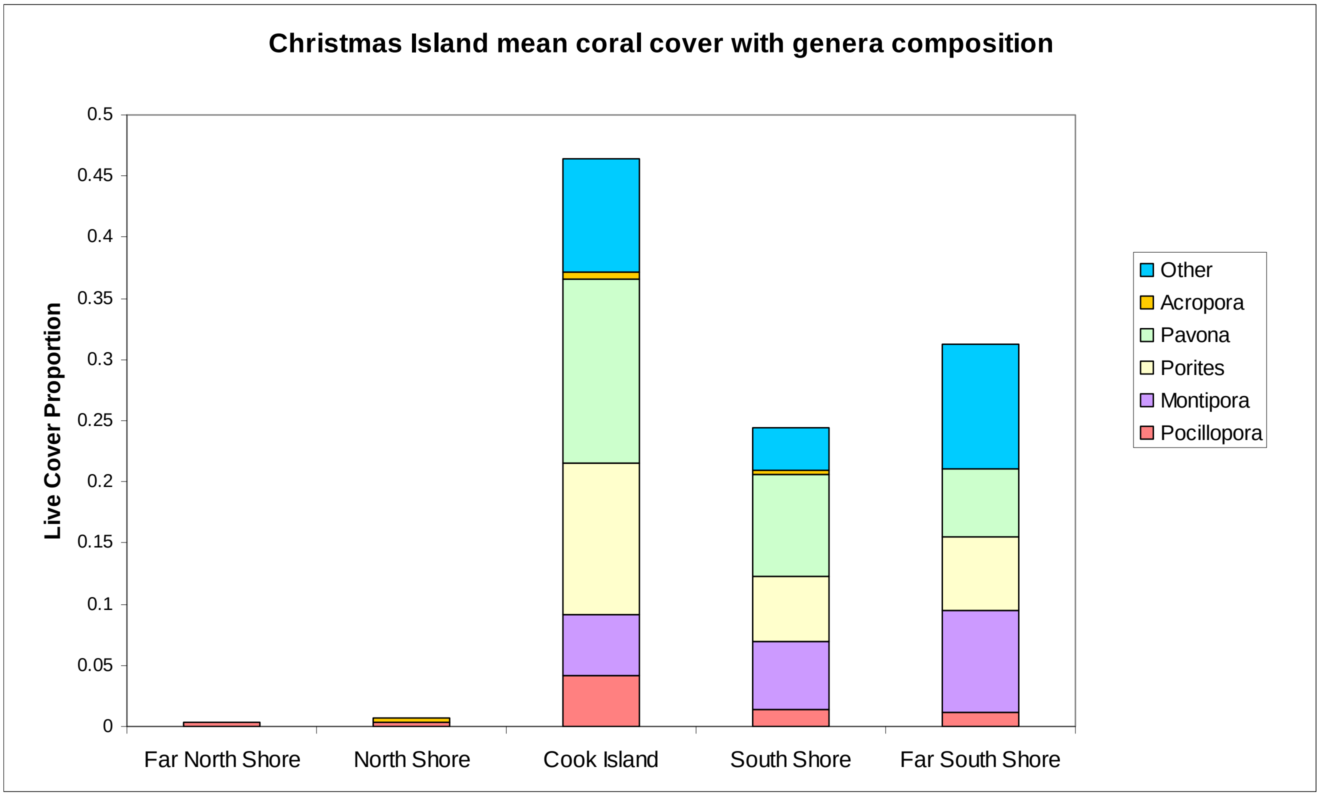

Figure 7: Mean proportion live cover with genera composition at Christmas Island.

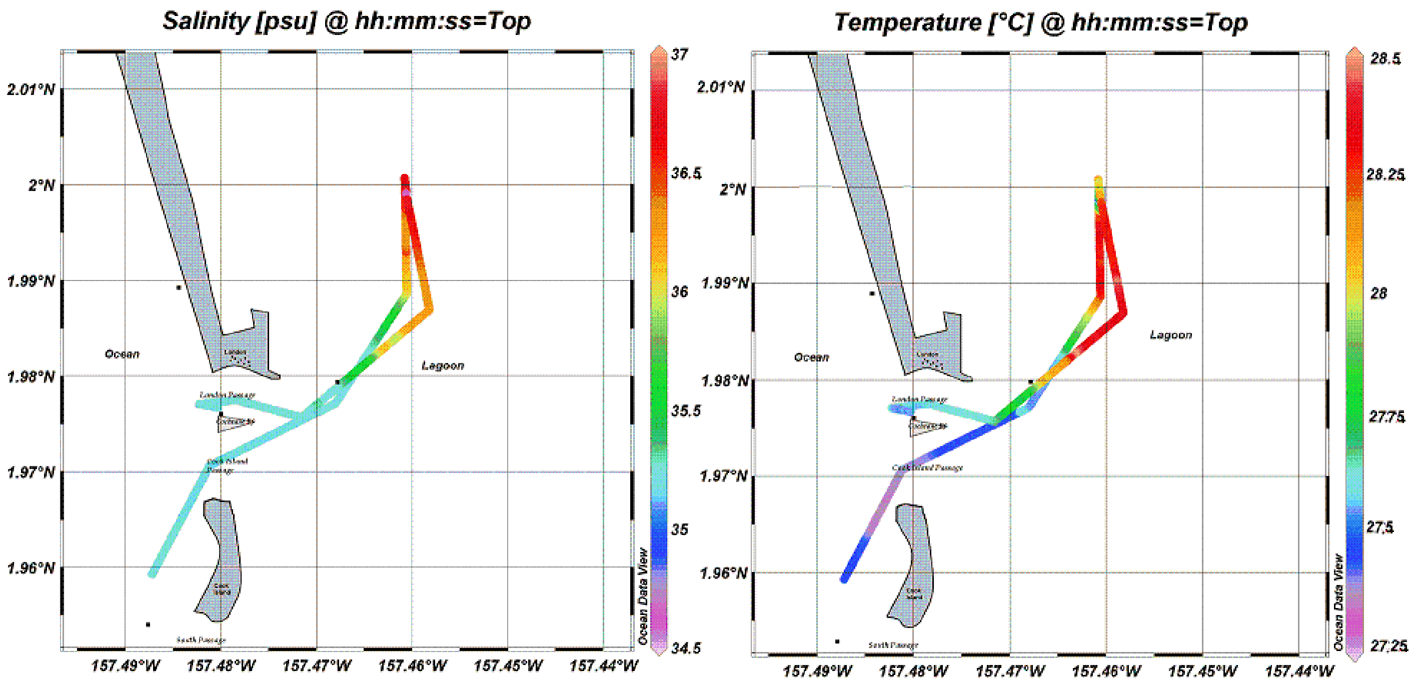

Figure 8: Salinity and temperature profile from CTD tow at Christmas Island. Recorded May 23, 2007.

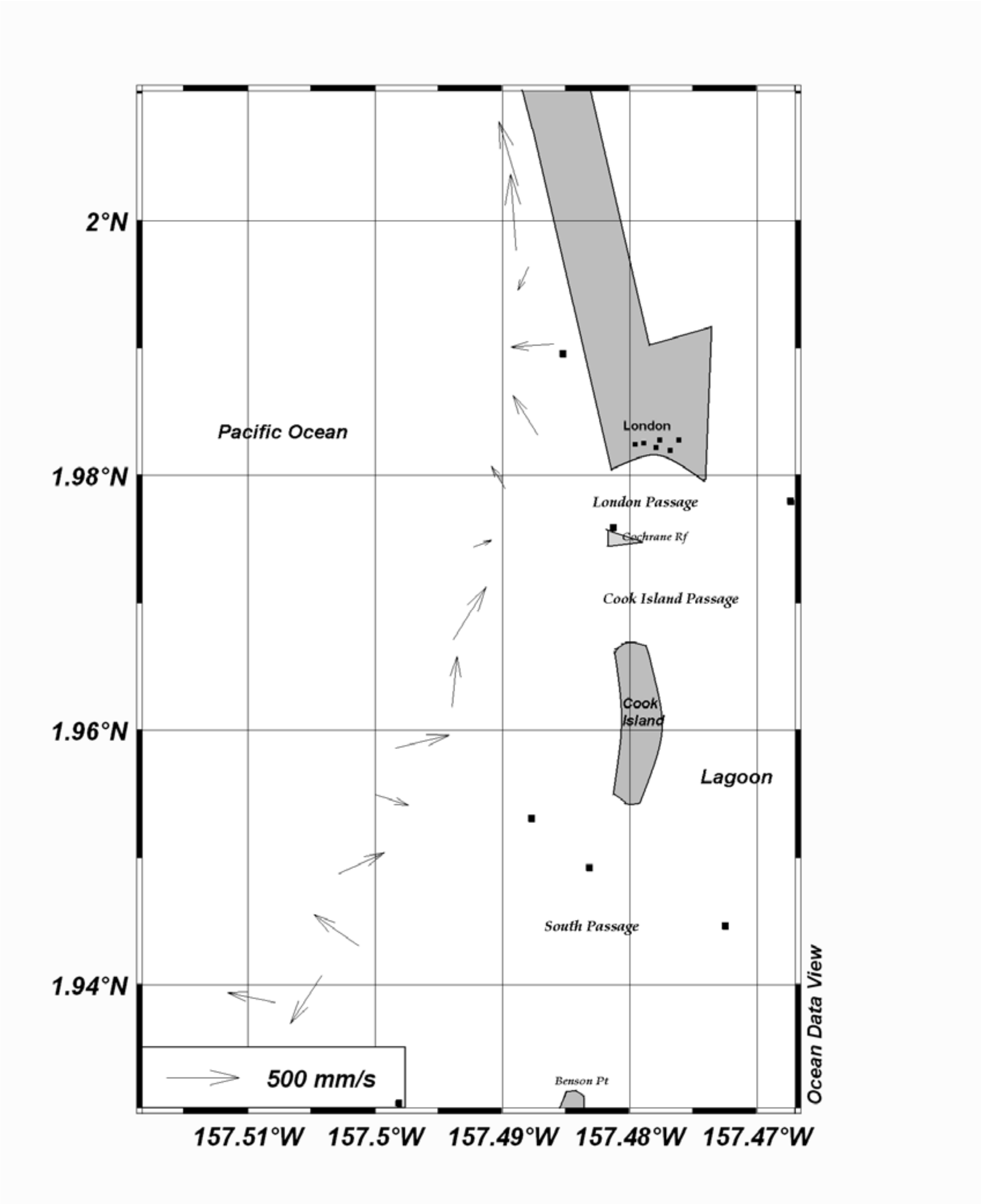

Figure 9: Surface current profile (up to 14m) at Christmas Island from Acoustic Doppler Current Profile. Recorded on May 24, 2007.

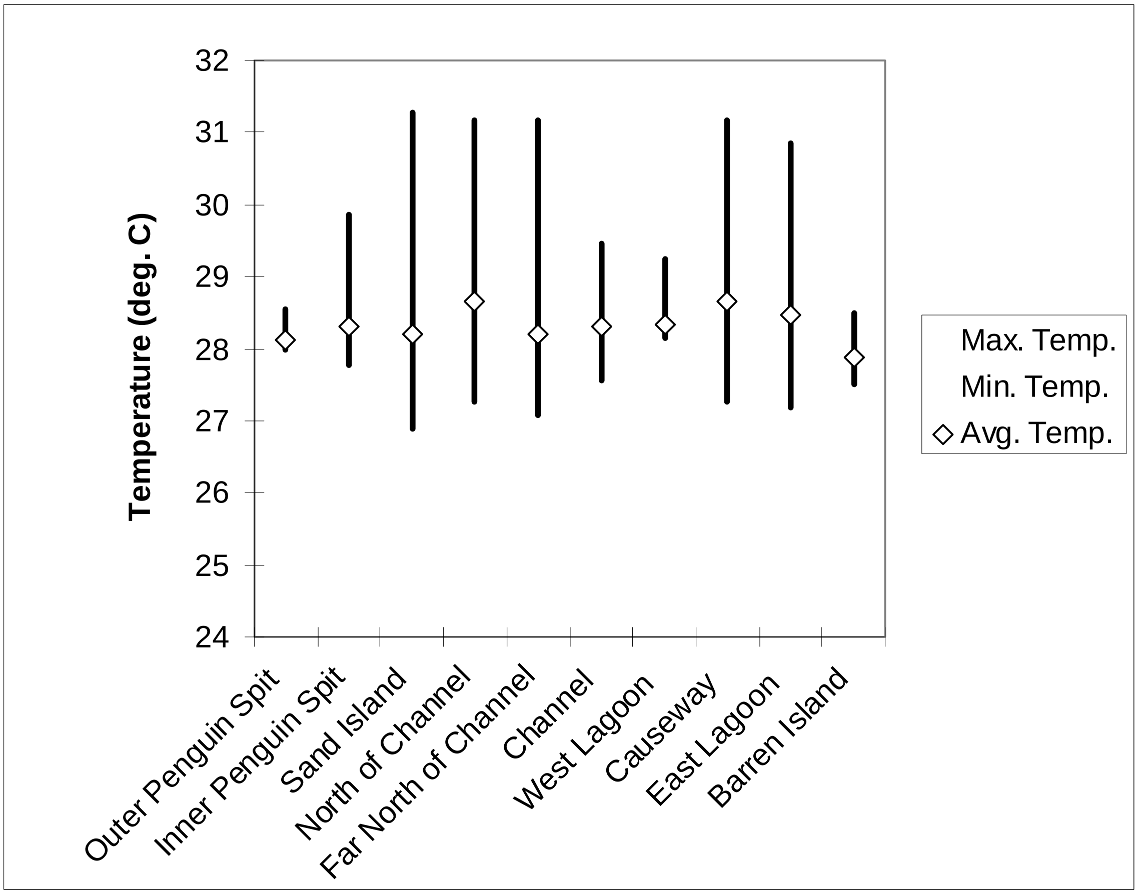

Figure 10: Maximum, minimum and mean temperatures recorded at each site at Palmyra Atoll from May 28-30.

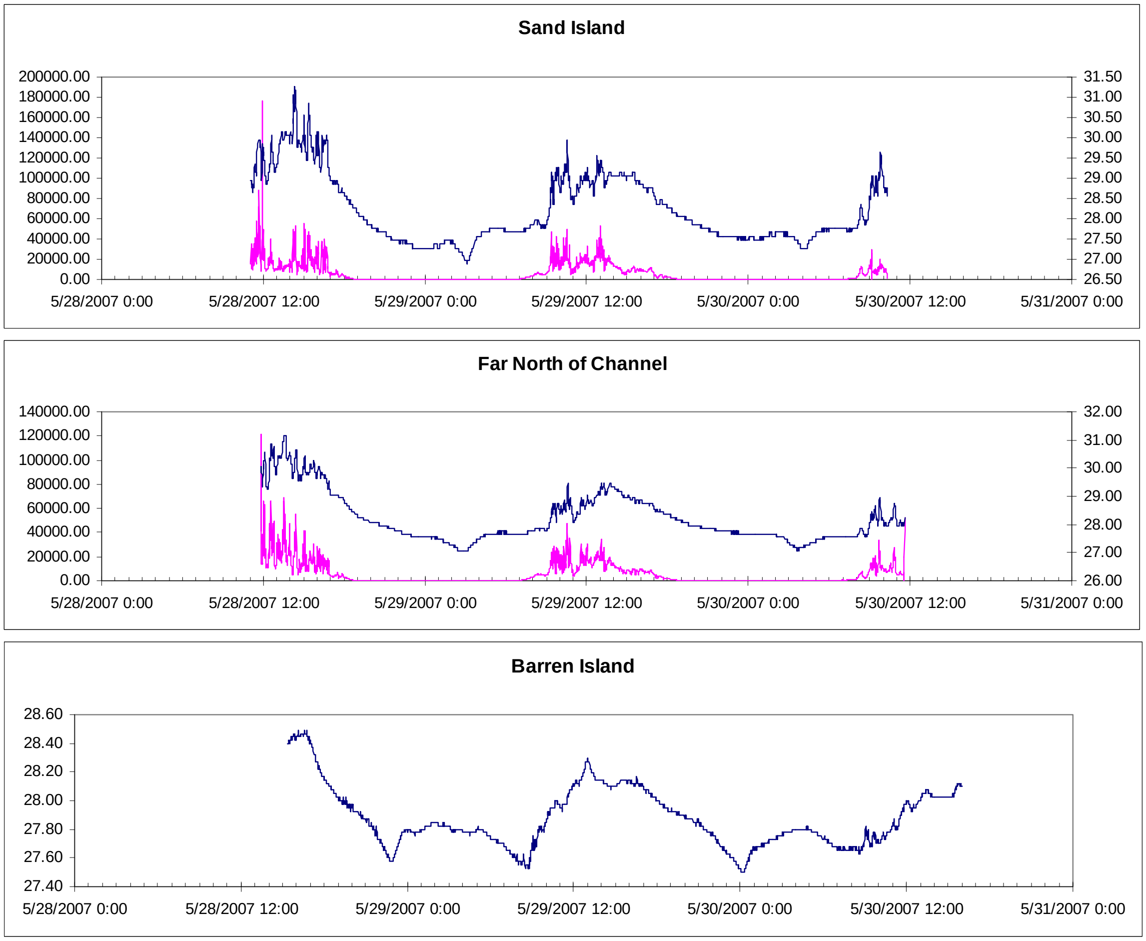

Figure 11: Temperature and light records from selected sites at Palmyra Atoll. Temperature (deg. C) is dark blue line. Light intensity (lumens/m^2) is pink line.

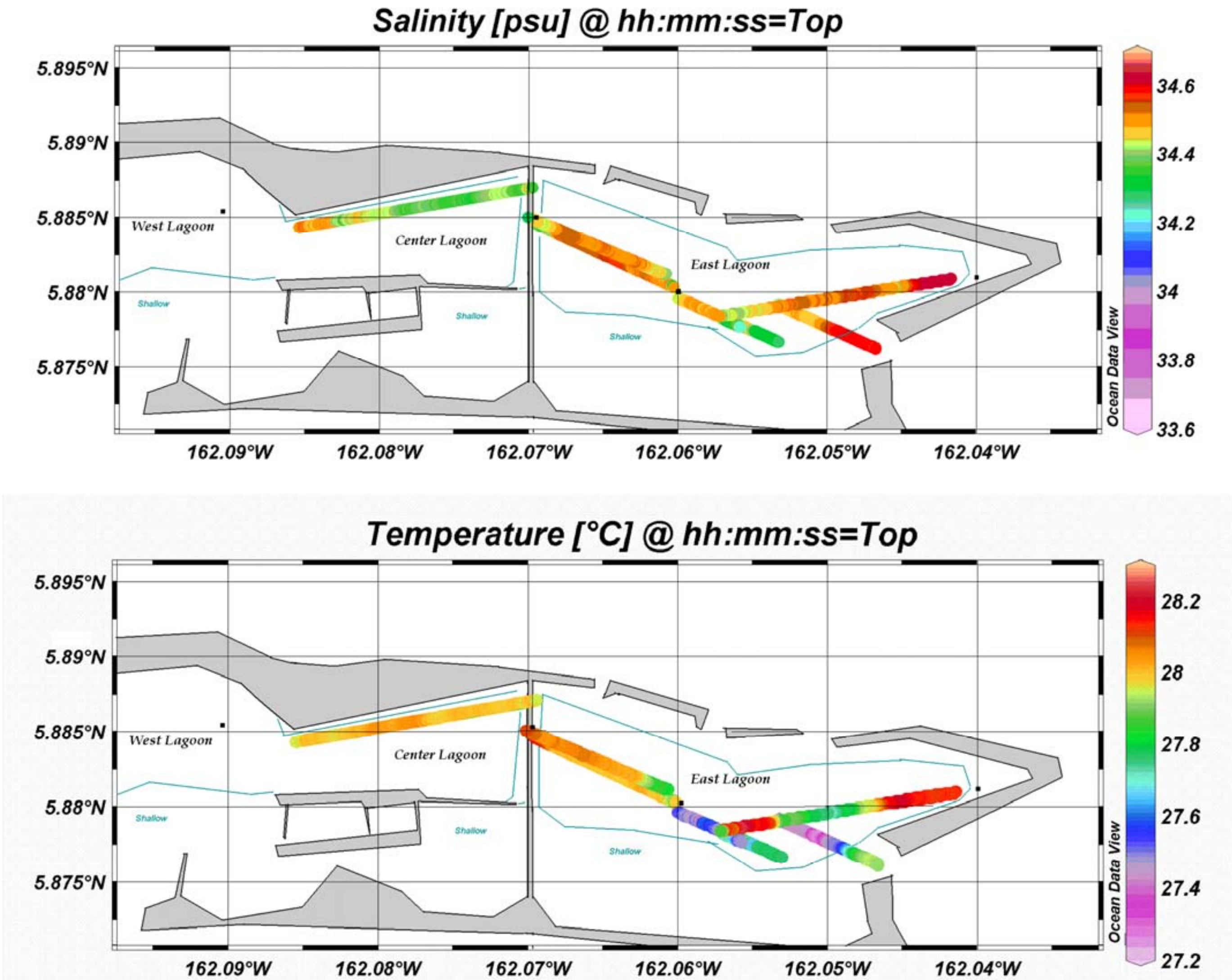

Figure 12: Salinity and temperature data from CTD tow at Palmyra Atoll. Recorded May 30, 2007.

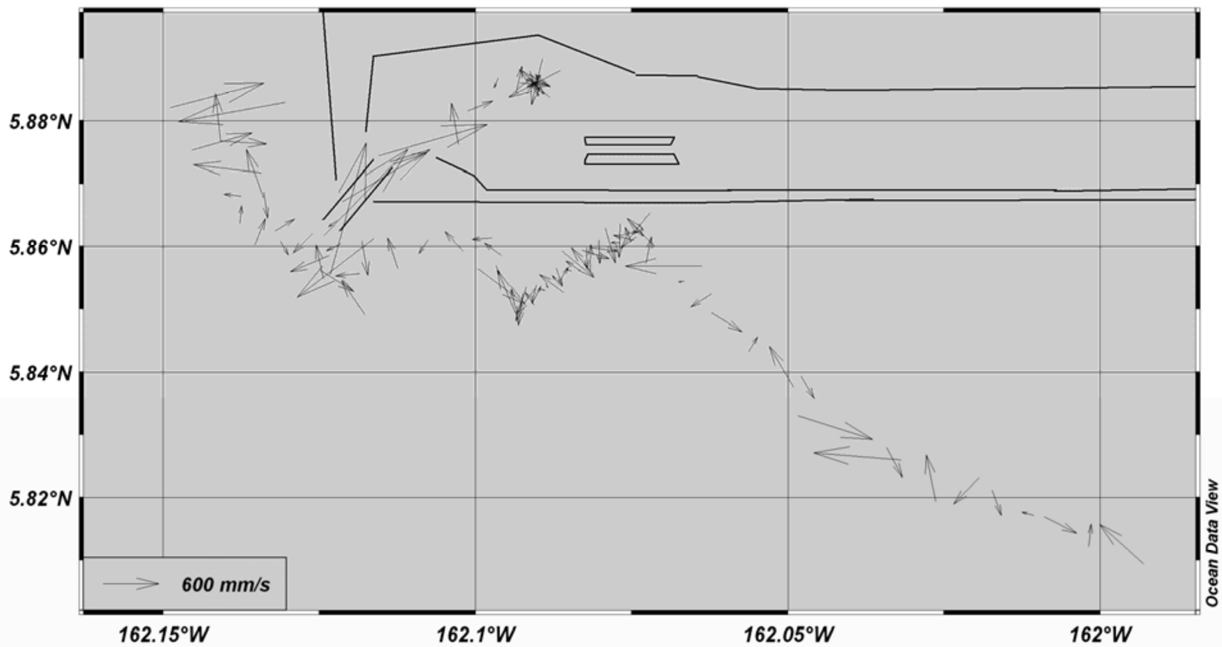

Figure 13: Surface current profile from Acoustic Doppler Current Profiler at Palmyra Atoll (with rough sketch of Palmyra for scale). Recorded May 27, 2007.

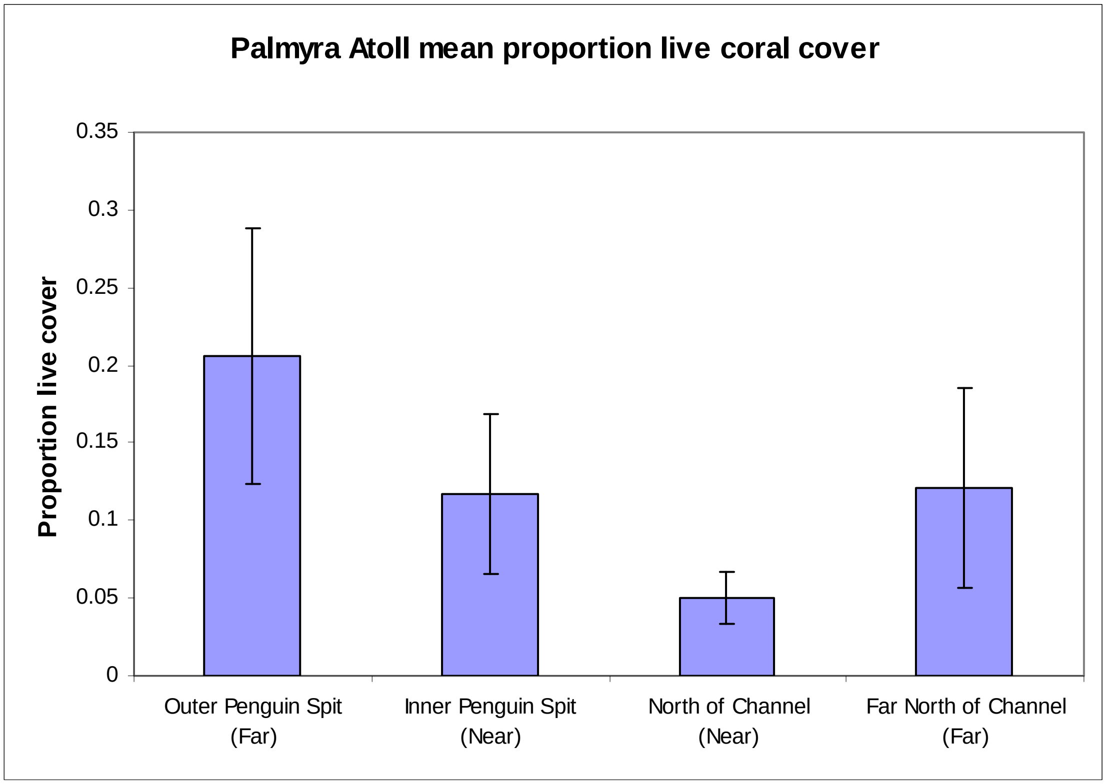

Figure 14: Mean proportion live coral cover at each survey site at Palmyra Atoll with 95% confidence intervals.

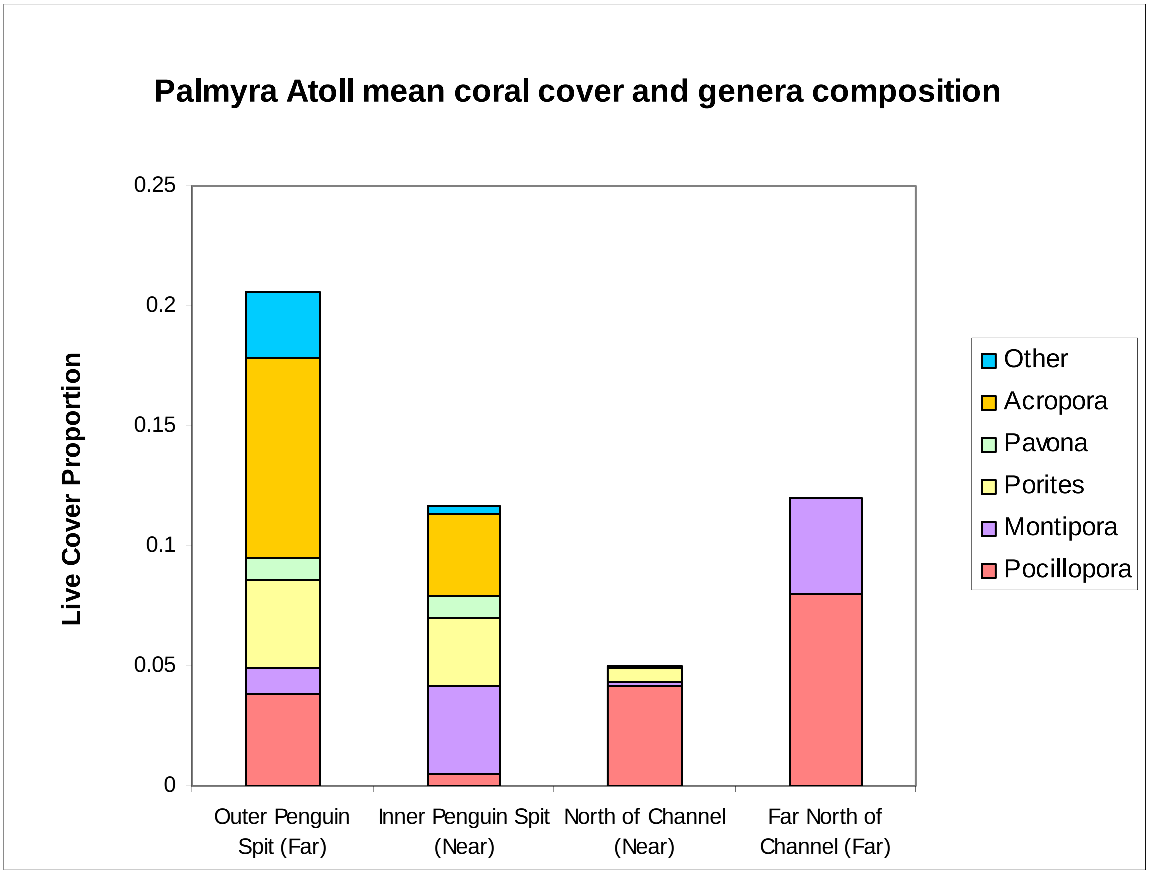

Figure 15: Mean coral cover at Palmyra Atoll with genera composition.

Tables:

Site	Time Deployed (22 May)	Time Retrieved (24 May)	Depth (m)	Logger Type
North Shore	1348	0849	2.0	HOBO Pendant Light/Temp
North Channel	1412	0857	2.3	HOBO Pendant Light/Temp
North Lagoon	1453	0931	1.2	HOBO Pendant Light/Temp
Cook Island	1515	0948	2.3	HOBO Pendant Light/Temp
South Channel	1543	0950	2.1	HOBO Pendant Light/Temp
South Lagoon	1559	1058	1.6	HOBO Pendant Light/Temp
South Shore	1620	1028	2.1	HOBO Pendant Light/Temp

Table 1. Christmas Island sites with HOBO type, depths, and times of deployment.

Site	Time Deployed (28 May)	Time Retrieved (30 May)	Depth (m)	Logger Type
Outer Penguin Spit	0905	0930	3.99	HOBO Water Temp Pro
Inner Penguin Spit	1005	0945	3.7	HOBO Pendant Light/Temp
Sand Island	1042	1017	0.9	HOBO Pendant Light/Temp
North of Channel	1109	1057	0.7	HOBO Pendant Light/Temp
Far North of Channel	1124	1137	2.5	HOBO Pendant Light/Temp
Channel	1150	1203	5.1	HOBO Pendant Light/Temp
West Lagoon	1305	1730	4.1	HOBO Pendant Light/Temp
Causeway	1355	1405	0.48	HOBO Pendant Light/Temp
East Lagoon	1648	1437	0.25	HOBO Pendant Light/Temp
Barren Island	1500	1601	n/a	HOBO Water Temp Pro

Table 2. Palmyra Atoll sites with HOBO type, depths, and times of deployment.

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