4.3 Results

4.3.1 $\delta^{13}C$ and $\delta^{18}O$ isotope records from the unshaded (control) colony, *Porites australiensis*

The $\delta^{18}O$ isotope trace obtained from the unshaded colony of *P. australiensis* (Figure 4.3) contains 7 complete and 2 incomplete seasonal cycles. The cyclicity of the oxygen trace appears to agree well with the instrumental record of temperature for Pioneer Bay (Figure 4.4) in the years for which temperature data are available. Mean $\delta^{18}O$ for the period of the trace is -4.77‰ ± 0.046 relative to VPDB. The isotope ratios vary between -3.89‰ ± 0.103 and -5.25‰ ± 0.020.

The broad range of the $\delta^{18}O$ minima is in large part due to a pronounced enrichment of heavier isotopes ($\delta^{18}O$ = -3.40‰) in the period corresponding to early 1998 (the GBR mass bleaching event). This coincides with a noticeable truncation in the trace – which would normally be interpreted as a cessation of linear growth. Remarkable, also is an anomaly corresponding to an enrichment of lighter isotopes ($\delta^{18}O$ = -4.26‰) in the period corresponding to 1996. This precedes a similar anomaly to the 1998 deviation, albeit not as pronounced. This colony (and several others in Pioneer Bay) experienced a profound tissue thickness diminution in late 1995 (Chapter 3). No extrinsic sign of environmental stress was evident at the time, nor were abnormal temperatures or rainfall evident from the instrumental records.

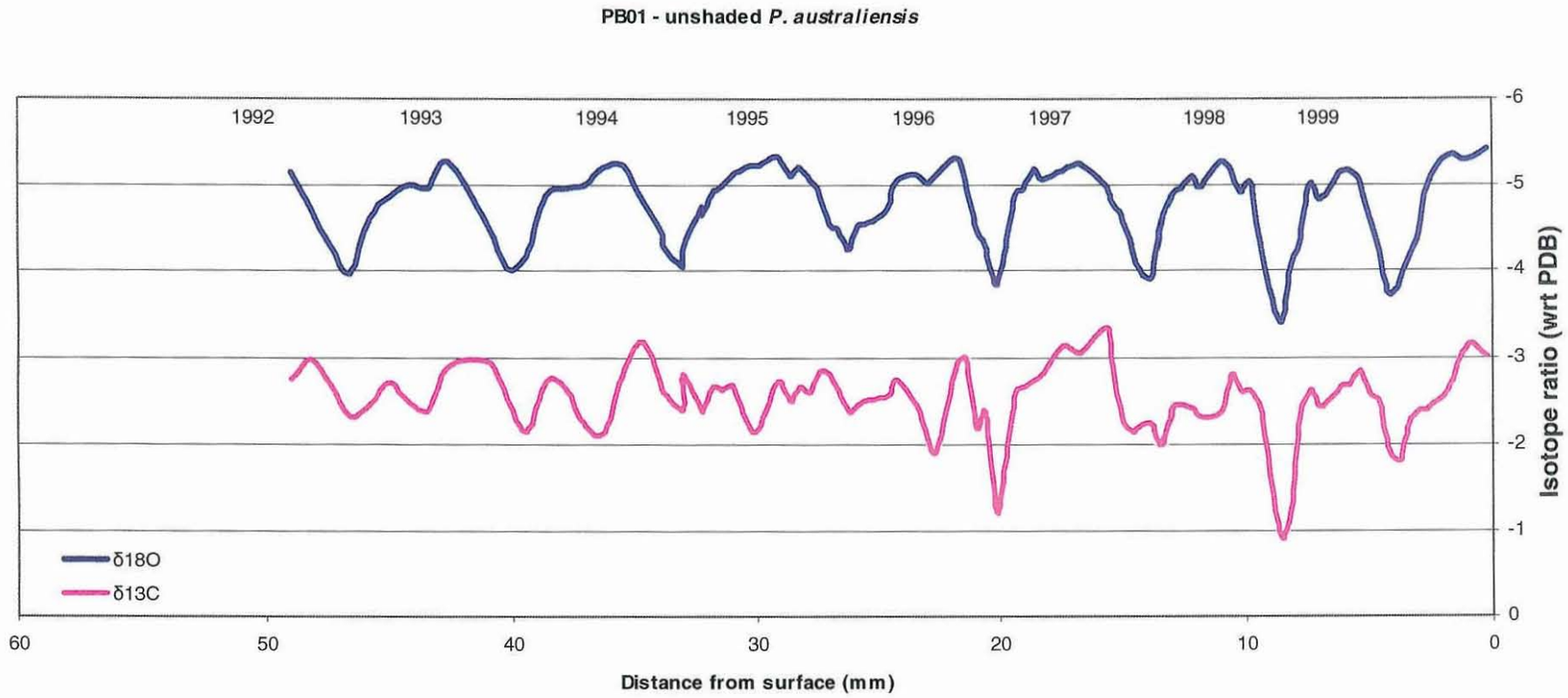

Figure 4.3 Isotope trace for unshaded coral PB01 (*P. australiensis*). Years at top of graph represent annual cycle commencing at the height (most negative) portion of the cycle corresponding to January (summer). Most recent (surface) samples are at right. Upper trace is $\delta^{18}O$, lower trace is $\delta^{13}C$.

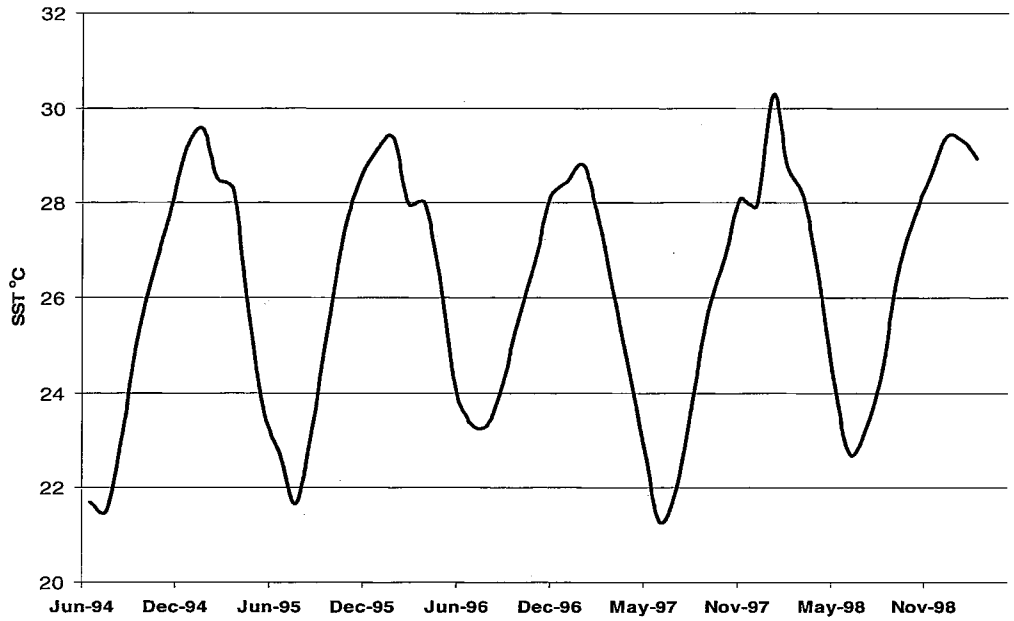

Figure 4.4 SST in Pioneer Bay during the period represented by the isotope trace in Figure 4.3, recorded by GBMPA data loggers in 3m of water approximately 20m away. The bleaching event of 1998 coincided with the small excursion above 30°, but was not exclusively attributed to it.

The $\delta^{13}C$ trace does not exhibit any pronounced seasonal cyclicity in the control colony. Mean $\delta^{13}C$ is -2.49‰ $\pm$ 0.0409. 90% of the variability of the $\delta^{13}C$ record lies between -1.90 and -3.05‰. A single negative enrichment episode (i.e. enrichment of lighter isotopes, causing the $\delta^{13}C$ ratio to become more negative), corresponding to 1996, immediately follows a marked positive enrichment anomaly and is the culmination of a prolonged negative trend for that year. The rapid shift back to median values is followed the next year by another positive enrichment anomaly in 1998. This anomaly coincides with the $\delta^{18}O$ artifact just described (coincident with the 1998 GBR bleaching event). This event is represents the highest level of heavy isotope enrichment in this record (-0.96‰). The magnitude of this and the previous positive excursion prompted questions about the fidelity of values returned by

the mass spectrometer; however, when duplicate samples were analysed, they returned similar values, indicating that the anomaly is real.

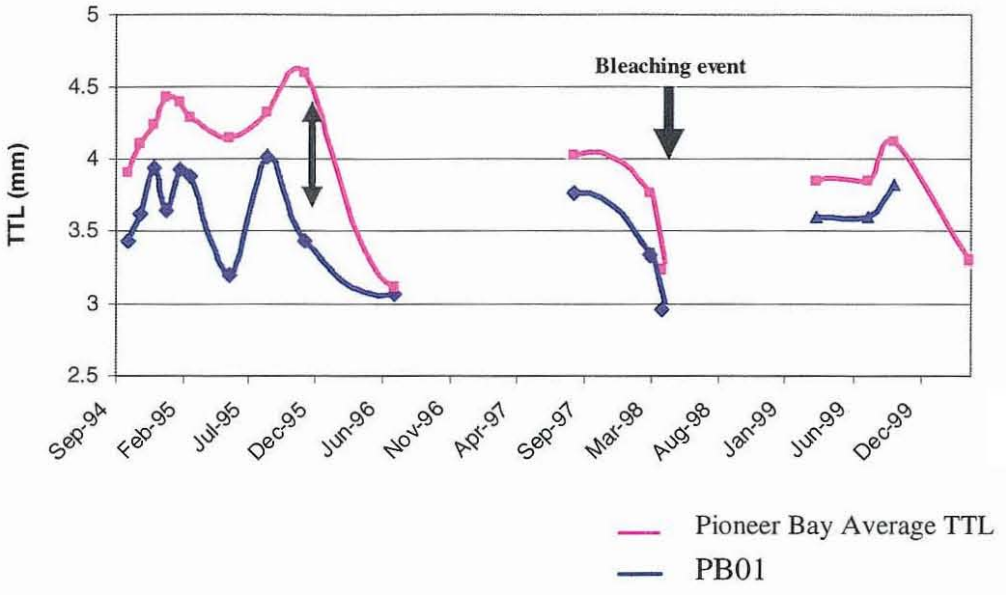

Figure 4.5 Record of tissue thickness variation for the unshaded coral PB01. This colony appears be quite sensitive to the quality of its environment. The double arrow at left corresponds to the a TTL anomaly coinciding with the first isotope anomaly described in the text (cf. Figure 4.3) – this colony apparently suffered some stress event at that time (1995-6) which did not affect many of the other study colonies; the arrow at right corresponds to the 1998 mass bleaching event. Inspection of a similar (albeit smaller) event in 1994-5 suggests that this colony may be prone to stress during the summer months.

The unshaded colony exhibited seasonal cycles in TTL in both years corresponding to the shading experiment (Figure 4.5). Tissue thickness varied between 3.4mm (Oct-94) to 3.9 (Dec-94) down to a winter value of 3.2mm (June-95) in the first year of the experiment. In the second year, the amplitude of TTL variation was greater; values ranged from 4.1mm (Sep-95) to 4.3mm (Dec-95) down to 3.1mm (Jul-96). For the period prior to shading, this coral grew at ~6.8mm per annum. During the shading experiment, it grew at ~6.4mm per annum; the first year apparently normal, the second year slightly truncated by the anomaly mentioned above.

4.3.2 $\delta^{13}C$ and $\delta^{18}O$ isotope records from the shaded coral, P. *australiensis*

During the years prior to the imposition of shading on this colony, the $\delta^{18}O$ traces for PBS04 (Figure 4.6) vary consistently, with average minimum values of -4.03‰ $\pm$ 0.02. There was a sharp peak in the $\delta^{18}O$ trace corresponding to the 1991 summer. Apart from this deviation, the mean value $\delta^{18}O$ trace appears to decrease slightly between 1988 and 1994, probably because of the trend for smaller-amplitude summer peaks. Subsequent to this period, two short cycles are seen in the $\delta^{18}O$ trace, with duration approximately half that of the mean cycle. The minima of the second of these and the two succeeding cycles are significantly less negative than the mean cycle minimum. The amplitude of the cycles, although less than average, is not significantly less. The two short cycles correspond to the period of the shading experiment. The cycles following the shading period are characterised by significantly more negative $\delta^{18}O$ minima in each cycle. The amplitude of the first and third cycles after the shading experiment have amplitude equivalent to the highest of the pre-shading cycles, whereas the second cycle has reduced amplitude. This cycle corresponds to the GBR bleaching event.

Linear extension of this coral up to the imposition of the shading stress was approximately 8mm per annum (Figure 4.6). For the two annual cycles subsequent to this point, linear extension of the shaded *P. australiensis* (measured as trough-trough distance) is halved. After removal of the shading, the distance between $\delta^{18}O$ peaks returns to the approximately the pre-shading value. The previously noted correspondence between temperature and $\delta^{18}O$

appears to have weakened as well. The minima and maxima of these two cycles are significantly less negative (i.e. they are more enriched with heavy isotopes) than the non-shading cycles, including the cycle corresponding to the GBR bleaching event.

The $\delta^{13}C$ trace for this coral displays a slightly more obvious annual cycle in the years preceding shading than the unshaded coral (Figure 4.6). A cycle of larger amplitude than any other coincides with the 1990-91 period. The annual cycles in the $\delta^{13}C$ trace roughly coincide with those in the $\delta^{18}O$ trace, albeit slightly lagged in most years. During most cycles, the $\delta^{13}C$ values lie within a band between -2 to -3‰. A notable exception to this rule is during the period of the shading experiment, during which time the annual $\delta^{13}C$ cycle seems to be absent. The $\delta^{13}C$ trace experiences a prolonged negative excursion during this period. A strong positive (=^{12}C depletion) excursion coincides with the end of the shading experiment, whereupon the annual cycle reasserts itself. The strong negative excursion seen around sample number 20 is spurious – this region was within the tissue layer and is likely to be a) incomplete skeleton, thus not averaging the same amount of temporal variation as other parts of the skeleton; b) contaminated by organic material from the tissue layer.

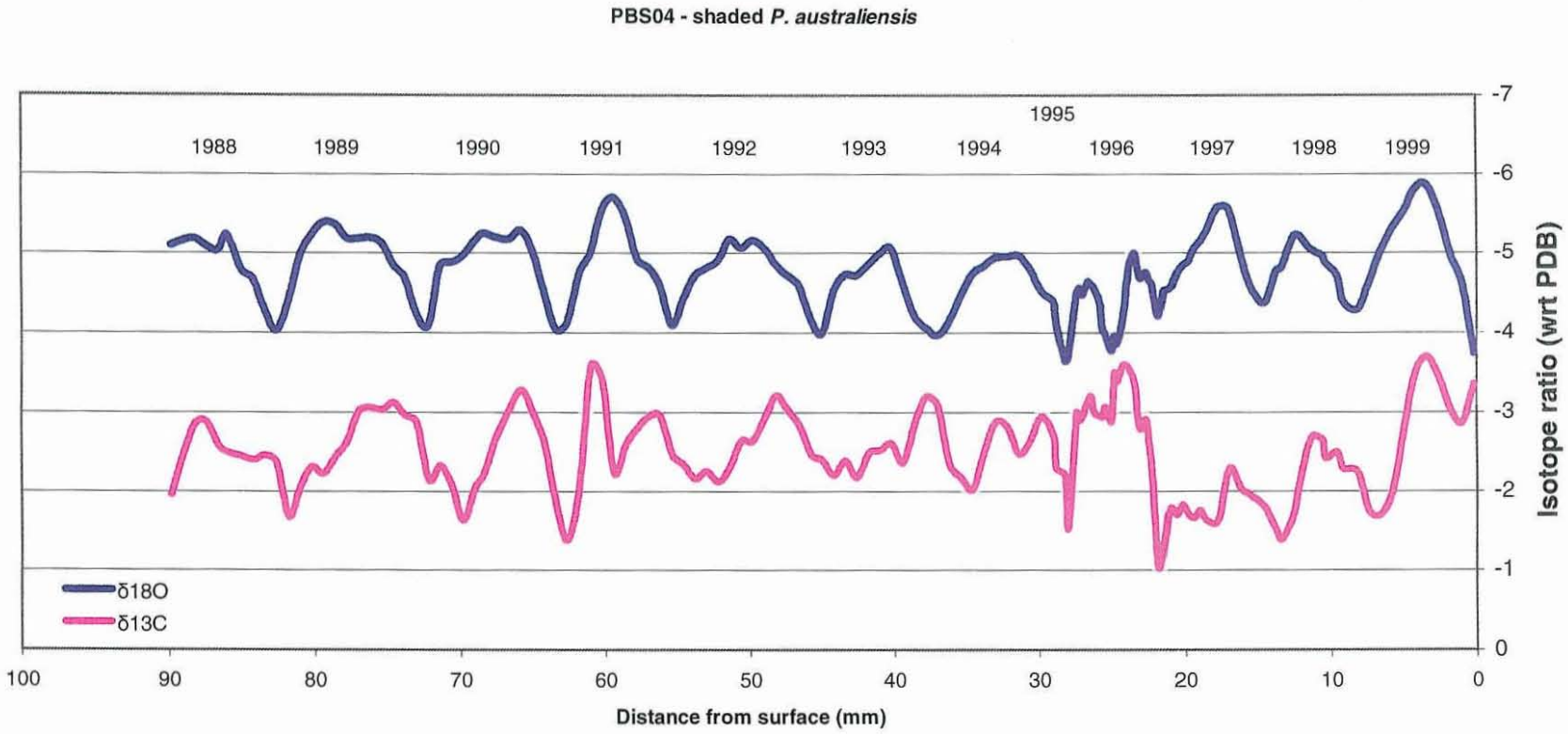

Figure 4.6 Isotope trace for shaded coral PBS04 (*P. australiensis*). Years at top of graph represent annual cycle commencing at the height (most negative) portion of the cycle corresponding to January (summer). Most recent (surface) samples are at right. Upper trace is $\delta^{18}O$, lower trace is $\delta^{13}C$.

Cycles in tissue thickness variation were subdued in this shaded colony (Figure 4.7). The thickness of the tissue layer of this shade colony declined from 3.1mm in October 1994 to 2.7mm in June 1995 and further to 2.1mm in July 1996 (the end of the shading period). A small (seasonal) increase in TTL during the first summer of shading was not seen in the second year (Chapter 3). For the period prior to shading, this coral grew at ~9.1mm per annum. During shading, it grew at ~3.2mm per annum; slightly over one third of its previous rate.

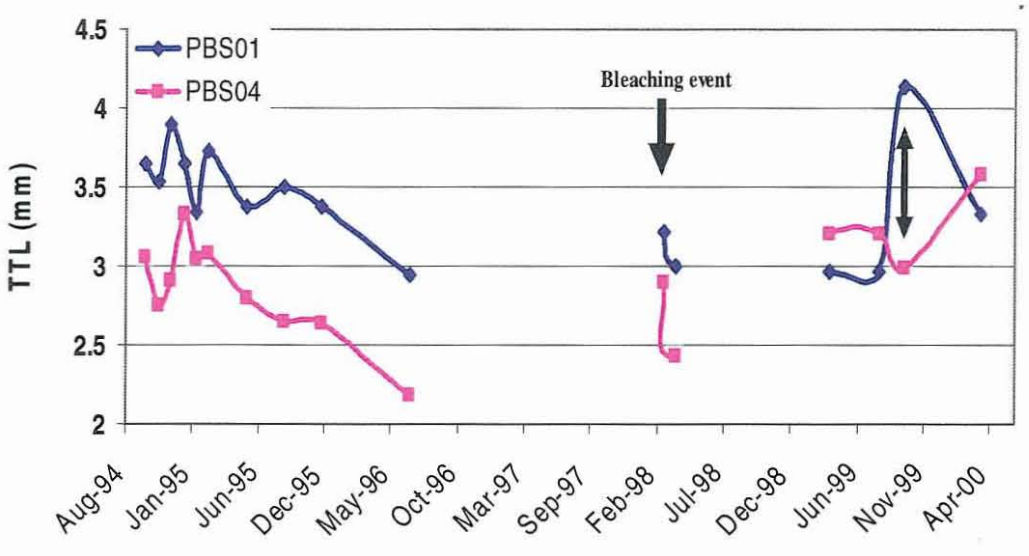

Figure 4.7 Tissue thickness records for the two shaded corals. The colony of *P. lobata* appears to have suffered much less from the stress events than the *P. australiensis* colonies. This seems to be reflected in the different amplitudes of variation in the isotope traces between the two cores. Arrow at right highlights the apparent difference in recovery rate of the two species.

4.3.3 $\delta^{13}C$ and $\delta^{18}O$ isotope records from the shaded coral, *P. lobata*

The $\delta^{18}O$ trace of the second shade coral (PBS01) appears similar to that of the other two corals in the pre-shading period (Figure 4.8). $\delta^{18}O$ maxima and minima are approximately the same as the *P. australiensis* colonies, however the mean amplitude of the $\delta^{18}O$ signal in this colony for the three years prior to shading is slightly less than in the first shaded coral (A_{PBS01} =1.06‰ ± 0.09; A_{PBS04} = 1.22‰ ± 0.11) and the unshaded control (A_{PB01} = 1.29‰ + 0.04).

The behaviour of this coral during the period of shading is markedly different to that of the shaded *P. australiensis*. While the suppression of linear extension appears to be consistent between shaded colonies, the isotope trace for this colony differs in several ways. The amplitude of the $\delta^{18}O$ signal during the shading experiment for this coral is significantly changed from the pre-shading period ($A_{1991\text{-}4}$ =1.06‰ ± 0.09; $_{1994\text{-}5}$=1.63‰, $A_{1995\text{-}6}$=1.48‰). The trace returns to the previous pattern in the same way as the other coral subsequent to removal of shading in 1996, albeit the $\delta^{18}O$ minima average slightly more negative than prior to shading (as for the other shade coral).

The $\delta^{13}C$ trace is also quite different in this colony to the other colonies. There is no seasonal cyclicity in the signal in the few years prior to shading. During the shading period, however, large annual variations in $\delta^{13}C$ are observed. The amplitude of seasonal variation in the $\delta^{13}C$ trace is markedly greater in this core than in the other shaded colony during the shading period, although the absolute magnitude of the excursion from mean values is the

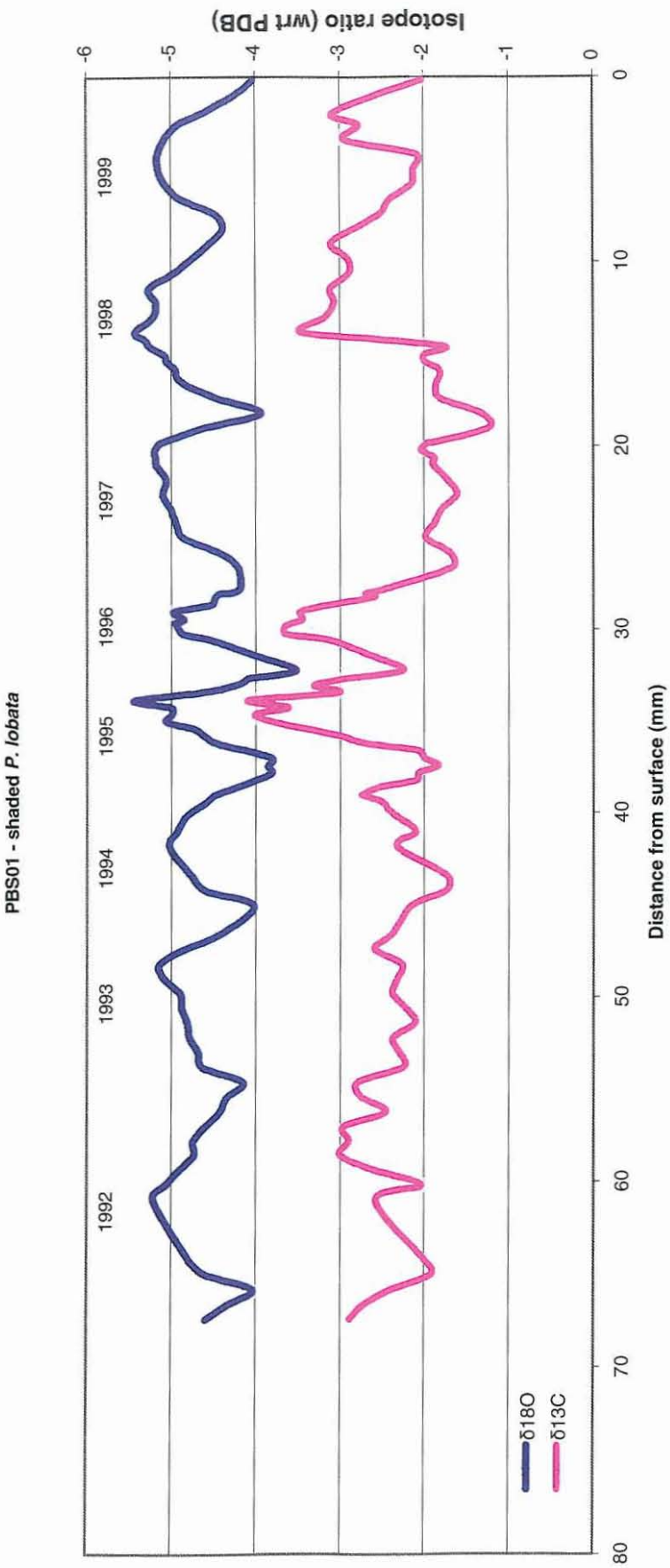

Figure 4.8 Isotope trace for shaded colony PBS01 (*P. lobata*). Years at top of graph represent annual cycle commencing at the height (most negative) portion of the cycle corresponding to January (summer). Most recent (surface) samples are at right. Upper trace is $\delta^{18}O$, lower trace is $\delta^{13}C$.

same (~2‰). Prior to the shading stress, the mean $\delta^{13}C$ value for this colony was -2.36‰ ± 0.052. Similarly to the other shaded coral, the $\delta^{13}C$ trace returned to slightly less negative values after the removal of the shade frames (-1.79‰ + 0.04). A marked negative excursion in 1998 precedes the GBR bleaching event, which does not seem to be recorded in the $\delta^{18}O$ trace.

For the period prior to shading, this coral grew at ~9.6mm per annum. During shading, it grew at ~4.6mm per annum; approximately one half of its previous rate.

4.4 Isotope records in a temporal context

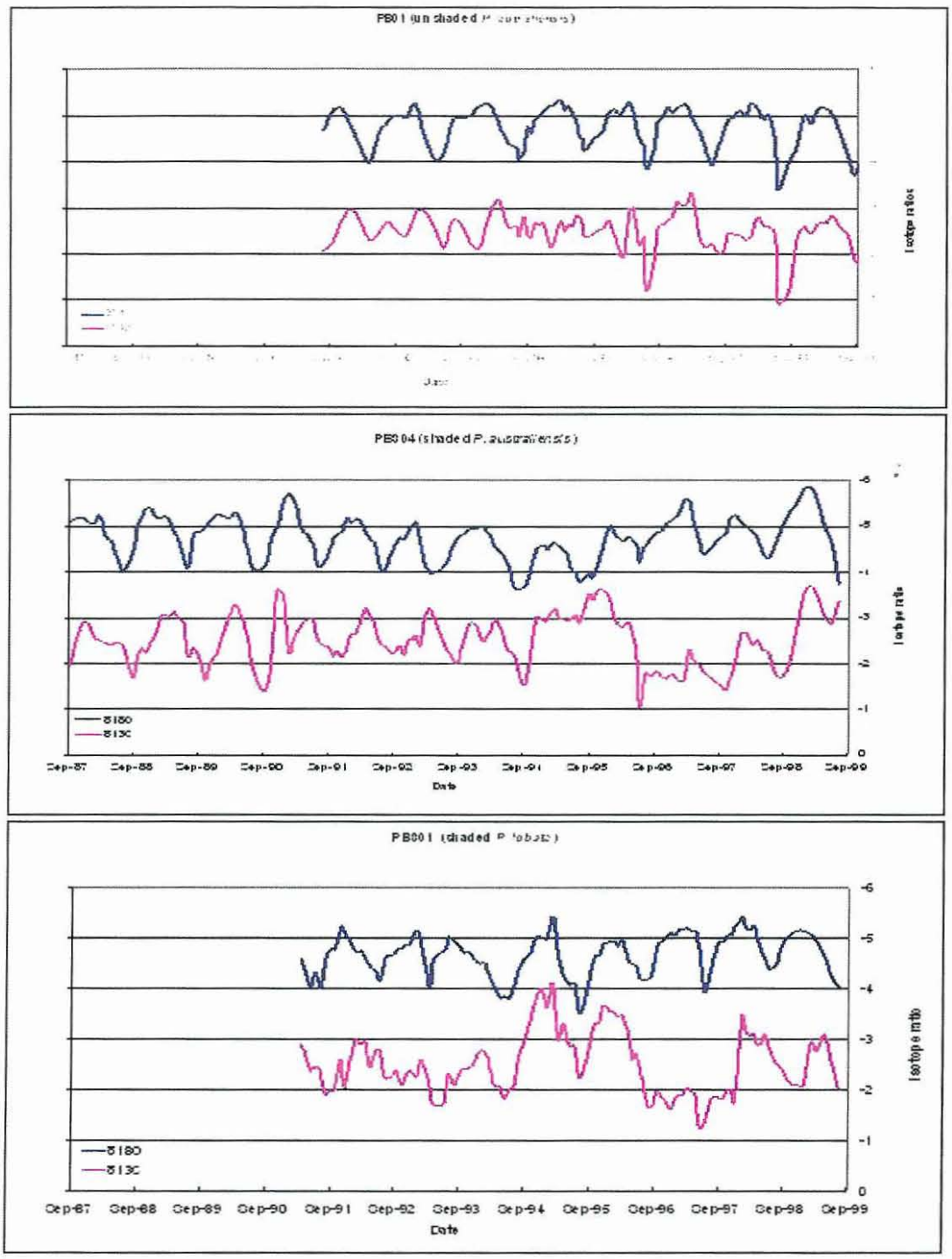

Figure 4.9 Isotope traces of the three cores translated into a time domain. The two shaded cores exhibit strong $\delta^{13}C$ anomalies during the shading period (late 1994-mid 1996), although the $\delta^{18}O$ traces display no consistency of response when linear growth is removed as a visible cue. Note also apparent differences in the traces corresponding to the GBR mass-bleaching event of early 1998.

By making some fairly strong assumptions about skeletal growth and the timing of $\delta^{18}O$ minima, one can translate the linear sampling scale into something approximating a temporal series (Fig. 4.9). In this technique, quite standard within the proxy record literature, $\delta^{18}O$ minima are mapped to recorded SST minima. One major effect of the technique is to remove the linear growth response variable from consideration, thus allowing the interpretation of temperature/salinity fidelity to be addressed directly.

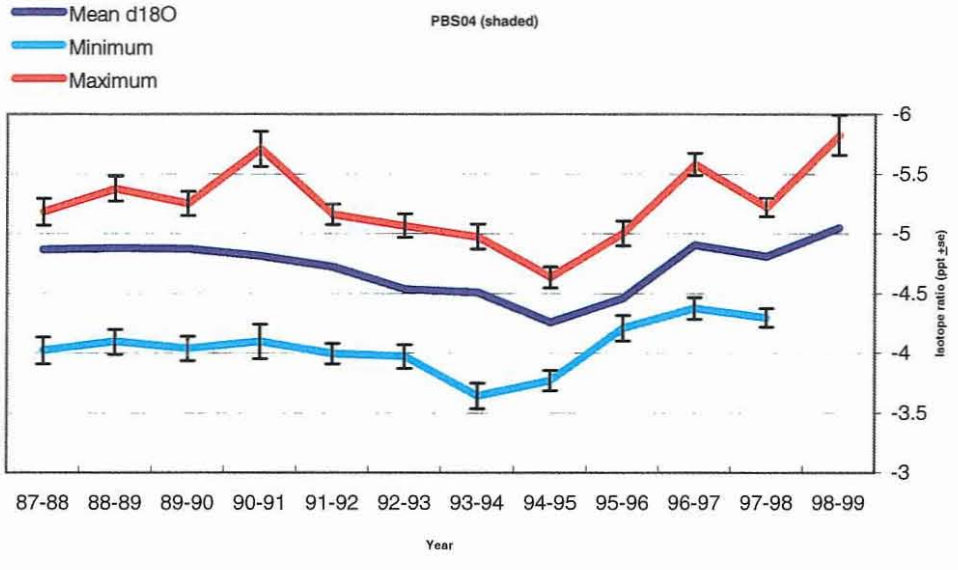

Figure 4.10 Mean $\delta^{18}O$ values for annual periods (winter-winter) for shaded coral PBS04. Minimum & maximum values were calculated using a 5-point average (hence error bars) corresponding to 1mm of skeleton (or, about 6 weeks average growth for this colony). Similar graphs for the other corals described in this Chapter may be found in Appendix 3.

Since $\delta^{18}O$ captures changes in both SST and surface salinity, the maximum values represent a combination of high summer SST and monsoon rainfall. High summer values for $\delta^{18}O$, from central GBR corals therefore can be interpreted either as excessively wet or warm, without discrimination. Winter figures are slightly more reconcilable to SST because of the seasonal dryness of the climate – ambient seawater $\delta^{18}O$ is thus more stable. Examination of

year-to-year variability in $\delta^{18}O$ can be used as an indication of environmental changes (its most common use), or a record of how the coral reacts to that changeability. It is this second use that shows most promise in the current study.

Examination of a record of $\delta^{18}O$ variation for the shaded colony PBS04 (Fig. 4.10) shows the high flux in skeletal $\delta^{18}O$ during the monsoon "wet season" (e.g. the 90-91 period corresponding to a record Burdekin River flood event). The $\delta^{18}O$ minimum values, on the other hand, are remarkably stable in the years prior to the shading experiment (shading commenced in 1994, however it is evident that the 1993-94 period is anomalous; at this time there was approximately 4mm of skeleton within the tissue layer – or 5 months growth - suggesting that the skeleton within the tissue layer during the initial shading period records environmental change while it remains exposed to the calicoblastic tissue). Subsequent to the shading experiment (1995-96 onwards), the $\delta^{18}O$ minima are substantially higher than prior to the bleaching experiment.

Examination of the SST records for Pioneer Bay (Fig. 4.4) indicates that, while the winter of 1996 was warmer than average, this period was not anomalously warm (certainly not enough to justify a statistically significant change in $\delta^{18}O$ minima). Such an increase in the "baseline" $\delta^{18}O$ values – having the additional effect of pushing up the annual mean value – has implications for the interpretation of long-term proxy records based on annual bulk sampling.

At face value, the record (Fig. 4.10) shows a slight dip and rise in the average $\delta^{18}O$ ratio during the period of this study, which cause a loss of fidelity to SST and rainfall records. That is, while the $\delta^{18}O$ ratio suggests that the summers of 1994-5 were cooler and drier than those before and after, the instrumental records show that SST and rainfall were normal for those years (see also Appendix 4). When looked at another way, these fine scale records are, in fact, reflecting the *response* of the colony to environmental change more than they are reflecting the actual change. The colony has physiologically adapted to the changed conditions in several ways: the thickness of the tissue layer has decreased (Chapter 3, Fig. 3.6, Fig. 4.7); within-tissue energy storage has decreased (Chapter 3, Figs. 3.9, 3.11), skeletal linear extension is reduced (Fig. 4.6). All of these adaptations indicate that, in the context of an energy crisis (such as prolonged shading or bleaching event), energy-saving measures are implemented by the coral animal. The skeletal isotope ratios of the skeleton formed during stress an event are therefore subject to *different* controlling factors than skeleton formed in normal times. Even the amount of secondary skeletal thickening varies during the stress event, since both linear extension rate (i.e. the rate at which new skeleton is added) and the thickness of the tissue layer (influencing the time the skeleton lies within the tissue layer) were reduced. Unless the calcification rate and the thickness of the tissue layer vary in synchrony, the averaging effect of secondary thickening on the environmental signal captured by the skeletal isotope ratios cannot be predicted (e.g. the models proposed by Taylor *et al.* 1993).

The $\delta^{18}O$ offset subsequent to the shading experiment (Fig. 4.10) encompasses another highly significant stress event (see below) and continued until the core samples were obtained, and so it is difficult to know whether the values will return to the pre-shading level or not. Certainly, this result raises an important question regarding sub-decadal environmental anomalies identified in coral proxy records in that the response to the stress event appears to persist for at least several years. Are corals "hiding" the frequency of environmental changes from us? A "hold-over effect" from particularly severe environmental perturbations may explain the apparent deviations of the proxy record from the instrumental record (e.g. Hendy *et al.* 2003). Researchers relying on skeletal isotope ratios to detect stress events in the life of a coral thus are likely to underestimate the frequency of such events.

4.4.1 Skeletal isotopic records of the 1998 natural bleaching event

The $\delta^{13}C$ traces of both shaded corals in the period 1996-7 (subsequent to removal of shading stress) exhibit prolonged positive excursions to previously unrecorded values (<-2‰). The following year, when both were observed to have bleached in the GBR mass-bleaching event, the $\delta^{13}C$ traces differ. The $\delta^{13}C$ trace of the shaded *P. lobata* changes from <-2‰ to >-3.5‰, in a rapid shift, which coincides with the onset of bleaching. The trace gradually returns to the level of variation seen prior to shading (-2<$\delta^{13}C$>-3‰). The $\delta^{13}C$ trace of the shaded *P. australiensis* becomes more negative (-1.5‰ to -2.5‰), the shift is no greater than seen many times in the pre-shading trace. The trace corresponding to the next year, however, shows a substantial excursion below

-3‰. This value was seen previously only in the second year of shading, however it is likely that this is an artefact produced by the samples' proximity to the tissue layer (as is the corresponding $\delta^{18}O$ negative anomaly).

The $\delta^{13}C$ trace of the unshaded coral does not appear to deviate negatively during the bleaching event; unlike those of the shaded corals it remains within the normal ($-2<\delta^{13}C>-3$‰) band. The unshaded coral's $\delta^{13}C$ trace in fact deviates markedly in the positive direction. While this colony, too, was observed to have bleached during the event, there is no similarity in its $\delta^{13}C$ response with those of the other corals.

Two of the three corals exhibit a slight truncation of the $\delta^{18}O$ trace for the 1998-99 period (Fig. 4.9). The $\delta^{18}O$ trace for one shaded coral (*P. australiensis*) is markedly truncated and the amplitude of signal variation for that year is smaller than any other year (min-max amplitude = 0.89‰). A truncation of the cycle and abrupt positive excursion in the $\delta^{18}O$ trace of the unshaded coral (*P. australiensis*) coincides with the previously described excursion in the $\delta^{13}C$ trace. The $\delta^{18}O$ of the second shaded coral (PBS01: *P. lobata*) does not appear different to any other (non-shaded) year. Neither shaded coral displays the marked positive anomalies in $\delta^{13}C$ and $\delta^{18}O$ shown by the unshaded *P. australiensis* colony.

Discussion

4.4.2 Variable tissue thickness and environmental records

During the years prior to the imposition of shading on this colony, the skeletal isotope traces for the shaded corals of both species (Figure 4.7, 4.8) vary consistently with those of the unshaded coral (Figure 4.3). There was a sharp peak in the $\delta^{18}O$ trace for PBS04 (shaded, *P. australiensis*) corresponding to 1991, which represents the trace during the period of the large Burdekin River flood of that year. This peak is detectable in proxy skeletal records from many other corals in the Palm Islands area near the study site (e.g. McCulloch *et al.* 2000). The flood lowered salinity considerably in the region, causing a spike in the $\delta^{18}O$ trace. That $\delta^{18}O$ in coral skeletons varies with both temperature and salinity is easily seen by comparing the isotope traces of both this colony and the other two colonies during the dry years 1993, 1994.

The $\delta^{18}O$ ratios of the study corals tracks increasing temperature very closely in the dry winter and spring, showing small sharp peaks corresponding to the onset of the rainy season late in the summer. The $\delta^{18}O$ minima of all three colonies are identical in this pre-shading period (-4.06 $\pm$ 0.025 ‰). Immediately after the onset of shading, the $\delta^{18}O$ minima of the shaded colonies were reduced by 0.25‰, whereas that of the control colony remained >-4‰. An explanation of this might be found in the immediate reduction in the thickness of the tissue layer of the shaded colonies. Models suggest that a reduction length of time the skeleton resides within the tissue layer would limit the "blurring" of an environmental signal (Taylor *et al.*, 1993).

The "Townsville Model" of growth in *Porites* (Taylor *et al.* 1993, Taylor *et al.*, 1995) has implications for isotope records stored in coral skeletons. In that model, the determinants of skeletal density were held to be linear extension rate, calcification rate and tissue layer thickness. Variations in any of these parameters will affect the amount of skeletal material laid down during a given period. This is equally true for all parameters in the model, since secondary thickening occurs throughout the depth of the tissue layer (Barnes & Lough, 1993); the length of time the skeleton remains within the tissue layer will influence the amount of secondary thickening. Secondary thickening of skeletal elements within the tissue layer causes blurring of the environmental signal captured when the skeletal elements are first formed.

Taylor *et al* (1993) introduced a term called "Effective Tissue Layer (ETTL)", defined as the proportion of annual linear extension that lies within the tissue layer, to incorporate tissue thickness variation in their series of models. These workers assumed variable linear extension and calcification, but varied the value of a constant ETTL factor for each model to emulate the natural range observed in massive *Porites* colonies. They found that by doing so, they could replicate patterns of density observed in the skeletons of various colonies. They found also that the greatest damping of the environmental signal occurred when the ETTL was equivalent to 50% of the annual growth increment, so that, for example, summer extension is "overwritten" by winter temperature signals.

What these workers did not know, however, was that the thickness of the tissue layer of a colony varies over time (Chapter 2) and under stress (Chapter 3). Therefore, unless the tissue layer varies in a way that is exactly proportional to skeletal extension rates, the ETTL will change continuously over time. During normal seasonal variation, TTL is greatest in spring/summer, when growth and calcification are also greatest. The winter low temperature signal is therefore subjected to a greater degree of blurring than any other - perhaps explaining why the $\delta^{18}O$ minima are so consistent across the board, despite some variation in winter SST's.

During the shading period, however, the winter $\delta^{18}O$ minima were significantly lower than prior to the experiment. Subsequent to the removal of shading, the $\delta^{18}O$ minima tended to be higher. In contrast, the unshaded colony records these seasonal minima as the same or lower. Although this was not entirely consistent (possibly because the winter SST in 1997 was cooler than the years either side of it), it suggests that something might have changed in the way the shade corals record temperature.

While stable isotope ratios tend to fluctuate at the same time as the thickness of the tissue layer, this corresponds to an over-riding seasonal pattern. During the shading experiment described in Chapter 3, the thickness of the tissue layer of the shaded corals showed some of its incipient seasonal pattern over the first summer and then diminished rapidly to a minimum value and subsequently varied little during the remainder of the experiment. In both the cores from shaded corals examined in this study, it was seen that the annual

cycle of $\delta^{18}O$ variation remained pronounced. The amplitude of variation in the $\delta^{18}O$ trace of PBS01 (*P. lobata*) was actually greater during the experiment than prior to shading, despite linear extension being reduced to half its previous rate.

The Townsville model suggests that the amplitude of an environmental signal will be greatest when ETTL exactly corresponds to the annual linear extension and least when it corresponds to 6 months growth (Taylor *et al.*, 1993). The shaded *P. australiensis* colony started the experiment with TTL=3.1mm. This measurement increased slightly to 3.3mm over the summer and declined to nm in the first winter; the decline was uninterrupted until reaching its lowest value the next winter (2.1mm). For the period prior to shading, this coral grew at ~9mm per annum. During shading, it grew at ~3.2mm per annum; slightly over 1/3 of its previous rate. The amplitude of the seasonal $\delta^{18}O$ cycle in the first year of shading is the same as during the second year, albeit the mean $\delta^{18}O$ value is slightly more negative in the second year. ETTL at the start of the experiment was equivalent to 4 months growth. By the winter of the first year, it was equivalent to 10 months growth. At the end of the experiment, ETTL was back to about 8 month's growth.

The Townsville model suggests that the amplitude of the environmental signal should have been the same for the first and last ETTL figures, since both are 2 months out of phase with the minimum signal ETTL of 6 months. By the same token, the amplitude of the signal at the end of the first year should have been maximal, since this ETTL was most out of phase with the formation of

skeleton. The mean amplitude for non-shading years prior to the experiment (excluding the 1990-91 flood event, which was an unrepeated 1.64‰) was 1.20‰ ± 0.04. The mean amplitude of the shading years was 0.97‰ ± 0.04, but the difference between the first winter and second summer was 1.23‰.

This study did not offer the opportunity to explore the changing rate of linear extension. Nor can it offer insights into why the $\delta^{18}O$ minima subsequent to the shading experiment are further out of equilibrium than prior to it; nor how (apart from changes in the rate of linear extension) the environmental signal might have been modified by the shading stress. It does suggest, though, that ETTL, while an extremely useful convenience for creating the models (themselves very useful) described by Taylor *et al.* (1993, 1995), does not satisfactorily describe the role of tissue thickness in skeletal formation. The combination of variable tissue thickness and variable linear extension and calcification on skeletal density and the fidelity of proxy records to environmental variation will require the serious application of differential calculus and a great deal more fundamental *biological* research to properly model. In the meantime, it behooves the scientists relying on skeletal proxy records to interpret their data with some degree of skepticism, since corals seem to be not at all the black box recorders first hoped of them.

4.4.3 Fidelity of isotope records to environmental stress events

The $\delta^{18}O$ anomaly displayed by the control colony in this study (Fig. 4.3) duplicates some aspects of "signature" stress anomalies reported to be characteristic of bleaching events (see Suzuki *et al.* 2003). These workers reported a characteristic sharp decline in $\delta^{18}O$ negativity, as if the coral had stopped growing during the summer and recommenced skeletogenesis in a cooler time. In isolation, the isotope record presented here would appear to support Suzuki *et al.*'s (2003) hypothesis; certainly their hypothesis is supported by the physiological reaction of the colony to the bleaching conditions (Chapter 3). An identical $\delta^{18}O$ anomaly is evident two years prior to the 1998 bleaching event, however, accompanied by a similar sharp deviation in the $\delta^{13}C$ trace (see below). The lack of corroboration for this behaviour from the previously-shaded colonies is, likewise, problematic. The isotope records of neither shaded coral appeared to be affected in the same way as the control colony by the 1998 GBR bleaching event.

Both the hyposalinity event (Figure 4.9: Dec-1997; corresponding to extremely heavy rains, the runoff from which caused a considerable lens of fresh water to overlie the study site in Pioneer Bay) and the excursion of SST over 30°C in the 1997-98 summer (Figure 4.4) appear to be recorded by the unshaded coral as small peaks in the $\delta^{18}O$ record prior to the isotope anomaly. These apparent anomalies are not sufficiently prominent, however, to be certainly attributed the bleaching event (whether, in fact, they did or not). The prior anomaly (1996: Figure 4.3) is similar in structure to the 1998 anomaly. While it does appear to reflect an unidentified stress event of some sort

(Chapter 3: unfortunately, the pathology was not obvious at the time of tissue sampling and not every colony in the study area suffered tissue loss; neither did the stress event appear to affect the shaded colonies, further confusing the issue), it could certainly be mistaken for another bleaching event if one were relying on the patterns described by Suzuki *et al.* (2003).

Between September and December 1995, the control colony lost an average 0.6mm of tissue; the previous year, it gained a similar amount during the same period. The colony did not bleach during the 1995-6 stress episode, suggesting that the anomaly records stress resulting in the loss of tissue rather than a bleaching event *per se*. Researchers looking for ways to identify causative factors in historical bleaching events identified by Suzuki's isotope signatures will find no joy in the proxy record.

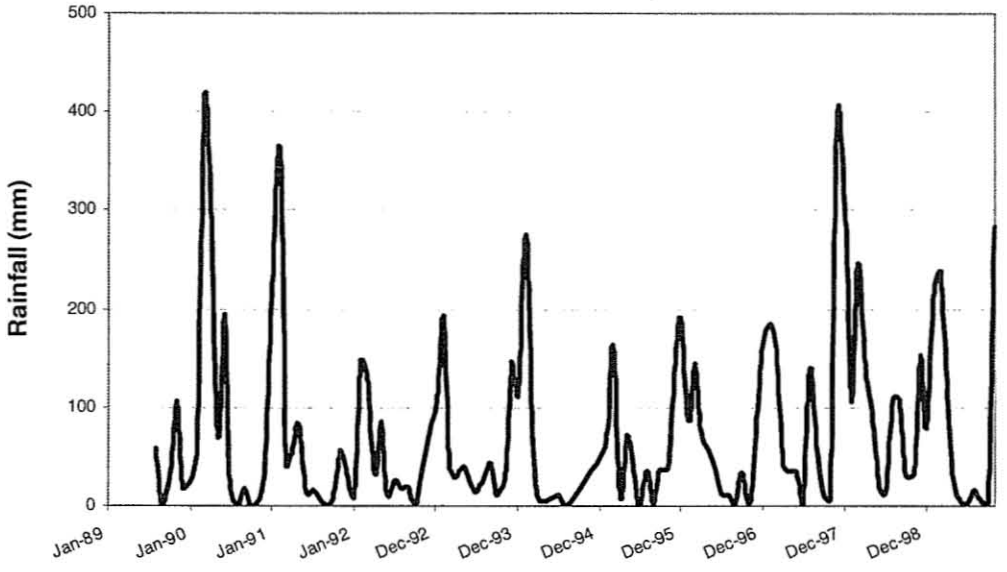

Figure 4.11 Monthly rainfall figures from Lucinda Jetty, approximately 8km west of the study site at Orpheus Island. The bleaching event of early 1998 coincided with the large rainfall peak after December 1997. Extreme rainfall, coupled with river runoff, caused a severe drop in salinity in the shallow waters around the Palm Islands.

Paradoxically, the bleaching event did not seem to trouble the shade corals as much as the control colony. The shaded *P. lobata* (Figure 4.6), apart from a minor negative excursion in the $\delta^{13}C$ record, does not record the event at all – even the salinity and temperature events are unrecognisable. This is despite the colony bleaching during the event. The shaded *P. australiensis*, on the other hand (Figure 4.8), records the event in a similar way to the shading stress, albeit without the prolonged period of low linear extension. The entire annual $\delta^{18}O$ cycle in this coral is truncated and of lower than normal amplitude during the year of the bleaching event. Likewise, the $\delta^{13}C$ trace of this colony appears to record nothing of the bleaching event.

The biological analysis of the GBR bleaching event in Chapter 3 suggested that the previous stress from the shading experiment may have influenced the behaviour of the erstwhile shaded colonies. The shaded group lost proportionately more tissue during the bleaching event than the control group. It is not obvious how this disparity might be translated into the isotope records presented here. Given the differences between colonies and between species that are hinted at by these results, it would be sensible to repeat the isotope analyses on more of the experimental colonies to determine whether these patterns are consistent.