Centuries-long records of coral growth on the Great Barrier Reef

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Abstract

Detailed observations and measurements of coral reefs began only about 20 years ago. Centuries-long records of annual growth contained in massive coral skeletons provide a means to objectively identify background variability in coral growth allowing recent growth trends to be assessed against a historical perspective.

Skeletons of massive corals include annual density banding because the corals deposit skeleton of varying density during the year. Annual growth rate, annual average density and annual calcification were measured in cores removed from 35 very large colonies of the reef-building coral, *Porites*. The longest record started in AD 1479. The 10 largest colonies provided data covering the common period, 1746 to 1982. Average calcification for these 10 colonies is significantly related to sea-surface temperature (SST) variations on the Great Barrier Reef (GBR) during the 20th century. The long coral record can, therefore, be viewed in two ways: 1) a proxy for SST variations on the GBR and 2) a measure of the performance of a major-reef building coral. In both cases, the 237-year long record dramatically lengthens our perspective on long-term variability. Features of the 237-year record of calcification in these 10 colonies, which cover the length of the GBR, include high calcification (= high SSTs) in the late 18th century and low coral calcification (= low SSTs) in the early 19th century. This low growth period is not matched in any of the subsequent record. There is no indication of recent, unusual declines in the annual calcification that might be attributed to human activities. Indeed, the 20th century witnessed the second highest 50-year period (1927-1976) and the third highest 10-year period (1964-1973) of calcification across the full record. A decline of average calcification since this peak may simply represent a return to long-term average conditions. Calcification and, possibly reef performance, appear to be highly variable at time scales much longer than decades.

Introduction

Concern about the impact of global environmental change on coral reef ecosystems such as the Great Barrier Reef (GBR) has highlighted our lack of knowledge of the natural range of variability expressed by constituent organisms. Detailed observations and measurements of coral reefs began only about 20 years ago. Trends or variations in reef communities and reef performance observed in recent decades may be responses to abnormal environmental change or natural variations in the system. Separation of unnatural change from natural variability requires long records. Centuries-long records of annual growth in massive coral skeletons provide a means to objectively identify background variability, allowing recent growth trends to be assessed against a historical perspective.

Annual density banding in massive corals was discovered nearly 25 years ago (Knutson et al. 1972). These authors suggested two potential applications: (i) development of long-term coral growth histories and, recognising the similarities with tree rings, (ii) reconstruction of paleoclimatic records. In this report we use the first application as a tool to retrospectively monitor the GBR. The growth characteristics of *Porites* provide insights into the spatial and

temporal variability of a major reef-building coral of the GBR. The report summarises the results of several studies (e.g. Lough and Barnes 1992; Lough and Barnes, submitted).

Materials and methods

The Australian Institute of Marine Science (AIMS) has collected cores from very large colonies of *Porites* since the early 1980s. Growth characteristics are examined for 35 of these cores from sites covering the length and breadth of the GBR (Fig. 1). These records range in length from 49 to 507 years (see Lough and Barnes, submitted) and provide a perspective on the temporal variability of *Porites* growth on the GBR. AIMS has also collected over 300 whole *Porites* colonies from known environmental gradients of the GBR. These colonies provide records 15-50 years in length and provide a perspective on the spatial variability of *Porites* growth on the GBR. Growth characteristics are presented for an inshore to offshore transect of the central GBR (Lough and Barnes 1992) and for an inshore to offshore transect of the northern GBR (Lough and Barnes, in prep.).

Slices, 6-7 mm thick, were removed from the coral cores or colonies. The slices were X-radiographed to reveal the annual density banding pattern characteristic of massive corals from the world's reefal areas (Fig. 2). Skeletal density was measured along a central track on each slice using a gamma densitometer (Chalker and Barnes 1990). The high density band portion of annual density bands in *Porites* from the GBR appears usually to form during the Southern Hemisphere summer. Peaks in the density profile were successively counted backwards from the last (outermost or youngest) peak. Density was assumed to peak in January and the most recent peak was dated from the date of collection of the coral sample. Dates were then assigned to all peaks in the series. Time series of the following skeletal density parameters were then obtained for each coral sample:

- average annual density (g $CaCO_3$ cm^{-3})
- annual linear extension measured between high density peaks (cm yr^{-1})
- annual calcification (g $CaCO_3$ cm^{-2} yr^{-1}): the product of annual average density and annual linear extension

Any record in a coral skeleton is biased and distorted by coral growth processes and the 3-dimensional architecture of the coral skeleton (e.g. Barnes and Lough 1990, 1993). Representative measures of coral characteristics can be obtained, using existing techniques by appropriate averaging over space or time. The spatial growth characteristics presented here are averages over common time periods for several colonies from a particular location. Temporal characteristics presented here are based on 5-year gaussian filtered series.

Results

Spatial variations of *Porites* growth characteristics on the Great Barrier Reef

The coral density banding literature includes considerable evidence that coral growth (density, extension and calcification) varies across environmental gradients, over time and that it changes in response to changes in the marine environment (see Lough and Barnes, submitted, for recent review). A considerable amount of work is needed, however, before we can begin to understand and, hopefully, predict which growth characteristics of which species is likely to respond to a given environmental change in a particular location.

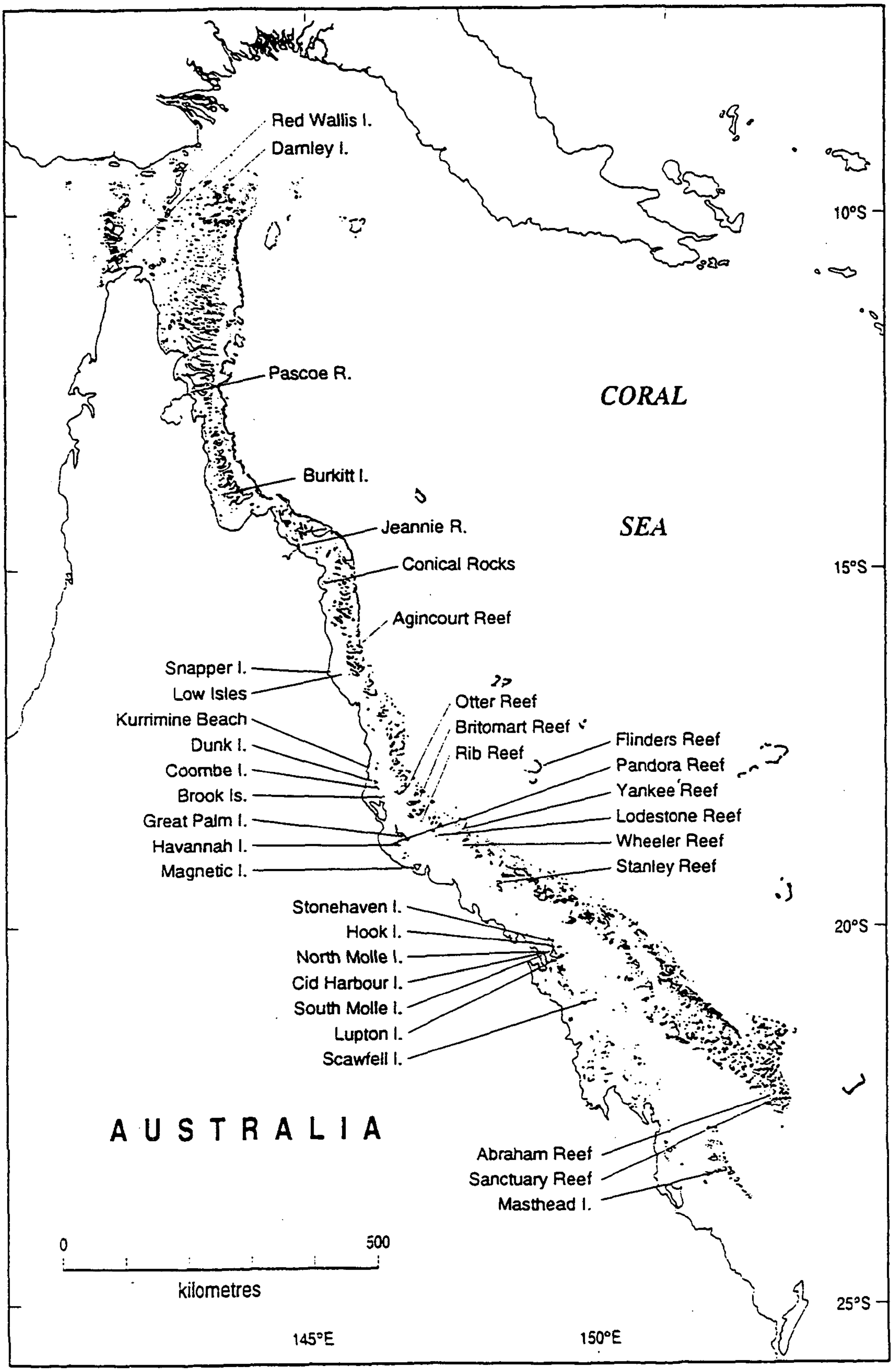

Figure 1. Location of 35 reef sites on the Great Barrier Reef at which large *Porites* were cored

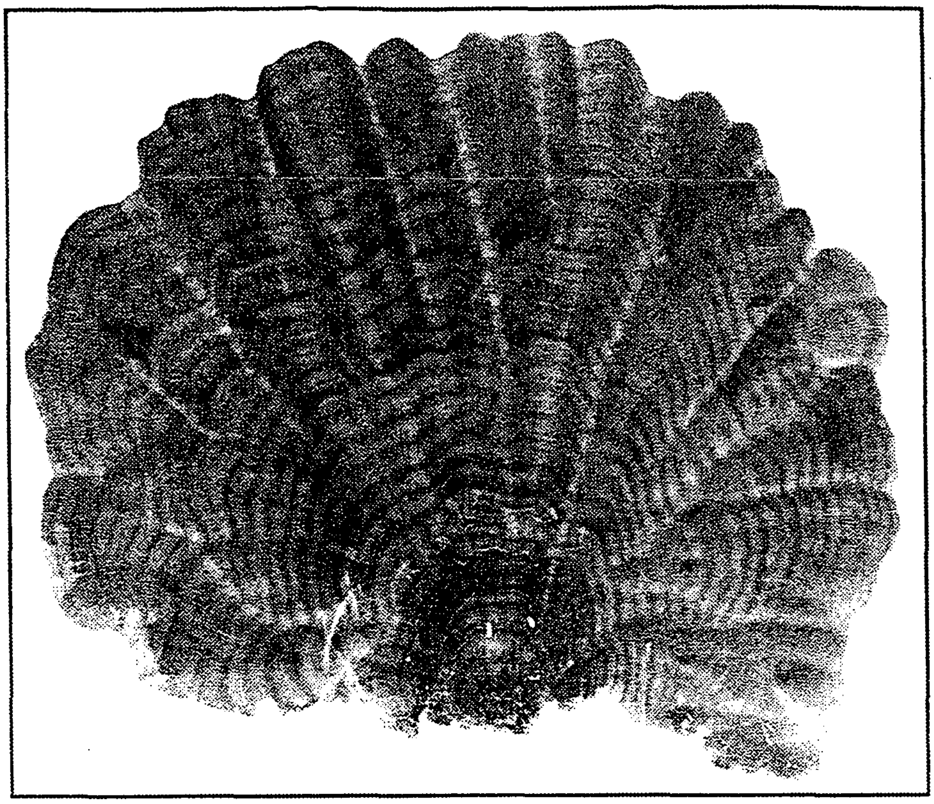

Figure 2. X-ray positive of a 7 mm slice cut from a colony of *Porites lobata* from 13-055 Reef, a mid-shelf reef in the northern Great Barrier Reef. Alternating dark and light bands represent dense and less dense skeleton, respectively. Consecutive dark and light bands represent growth over a year.

In response to this need to establish 'baseline' data we have been measuring average growth of similar-sized colonies of *Porites* from various environmental gradients on the GBR. Figure 3 summarises average density, extension and calcification for colonies collected along inshore - offshore transects across the central and northern GBR. All colonies were collected in shallow water (>5 m) towards the rear of the windward reef flat.

Across both transects, density significantly increased from inshore to offshore (Fig. 3a). Density in colonies from the central transect was significantly higher than in colonies from the northern transect. Linear extension was lowest at offshore sites in both transects. Changes in extension rate across the transects were significant only for the central region (Fig. 3b). Average extension was significantly higher in colonies from the northern transect (cf., Isdale 1981). Calcification was significantly lower at the offshore site in the central GBR whereas it did not change significantly across the northern transect (Fig. 3c). Calcification was significantly higher in colonies from the northern transect.

Temporal variations of *Porites* growth characteristics on the Great Barrier Reef

Density, extension and calcification were measured in massive *Porites* colonies from the 35 sites shown in Fig. 1. The longest record began in 1479 and came from a 7.5 m high colony at Abraham Reef in the southern GBR. The shortest record began in 1934 and came from a 3 m high colony at Snapper Island in the northern GBR. Average growth characteristics for the period common to all 35 cores, 1934-1982, are summarised in Table 1.

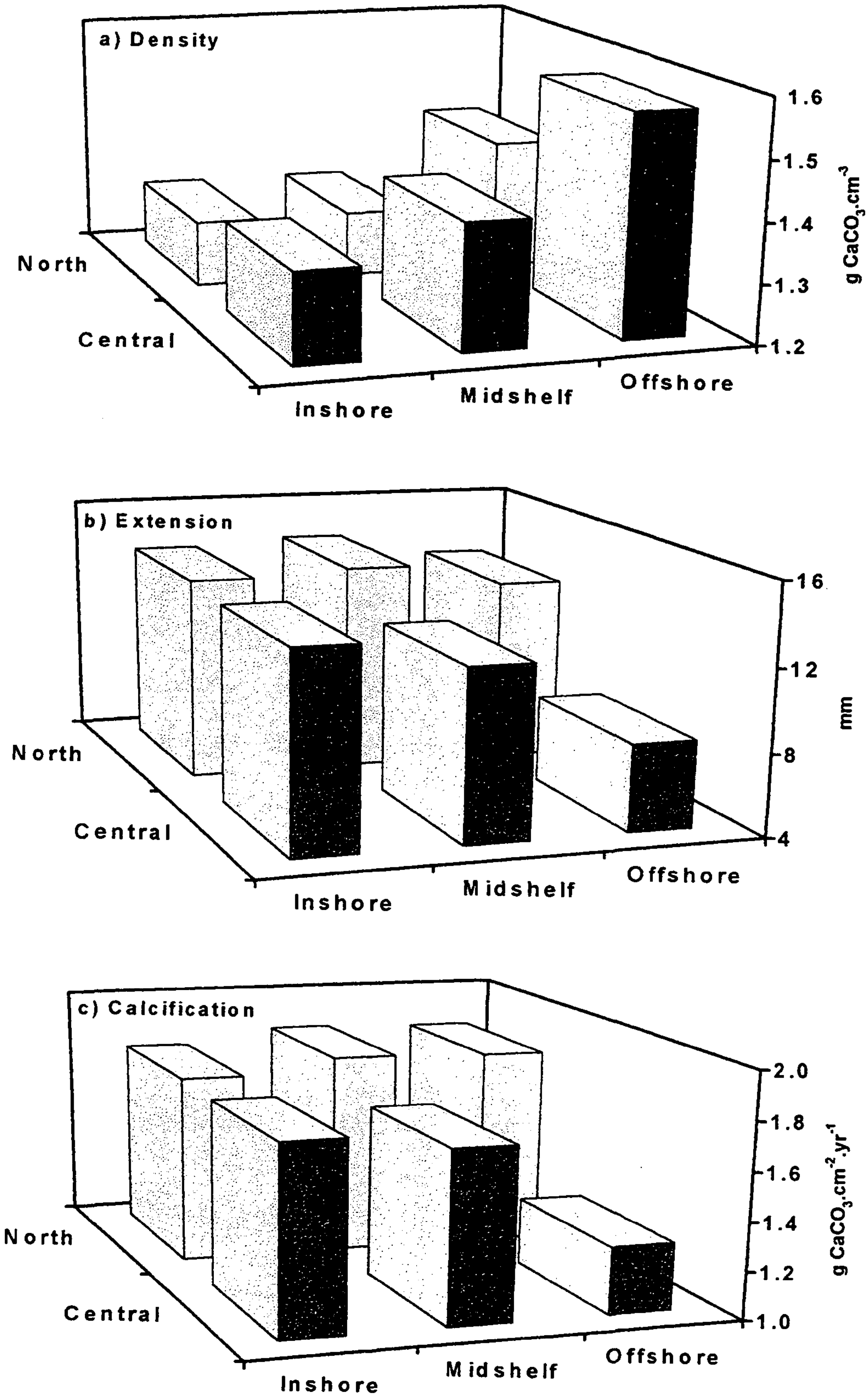

Figure 3. Average growth characteristics for 25 colonies of *Porites* in inshore, mid-shelf and offshore locations of the central Great Barrier Reef (18-19°S) and 69 colonies of *Porites* in inshore, mid-shelf and offshore locations of the northern Great Barrier Reef (12-13°S) for a) average annual density, b) annual linear extension and c) average annual calcification.

Table 1. Mean and s.d., over the period 1934-1982, of coral growth variables for cores extracted from coral colonies at 35 reefs

Core	Density $g.cm^{-3}$	Extension $cm.yr^{-1}$	Calcification $g.cm^{-2}.yr^{-1}$
Darnley Is.	1.39±0.06	1.32±0.39	1.83±0.51
Red Wallis Is.	1.14±0.06	1.73±0.45	1.96±0.51
Pascoe River	1.12±0.06	1.30±0.39	1.45±0.44
Burkitt Is.	1.17±0.07	1.94±0.63	2.26±0.68
Jeannie River	0.99±0.03	1.16±0.39	1.15±0.38
Conical Rocks	1.17±0.07	1.87±0.65	2.17±0.71
Agincourt Reef	1.06±0.07	1.91±0.59	2.02±0.62
Snapper Is.	1.16±0.11	2.17±0.67	2.49±0.76
Low Isles	1.20±0.08	1.99±0.44	2.36±0.49
Flinders Reef	1.24±0.06	1.14±0.30	1.40±0.36
Kurrimine Bch	1.21±0.04	1.09±0.39	1.32±0.46
Dunk Is.	1.21±0.05	1.76±0.60	2.13±0.74
Coombe Is.	1.34±0.07	1.15±0.39	1.53±0.47
Otter Reef	1.12±0.06	1.76±0.45	1.96±0.51
Brook Is.	1.26±0.07	1.36±0.30	1.70±0.35
Britomart Reef	1.21±0.04	1.31±0.35	1.58±0.41
Rib Reef	1.22±0.04	1.41±0.48	1.72±0.59
Yankee Reef	1.07±0.08	1.52±0.22	1.62±0.25
Great Palm Is.	1.02±0.05	1.89±0.39	1.94±0.39
Lodestone Reef	1.17±0.06	1.46±0.38	1.70±0.44
Wheeler Reef	1.25±0.09	1.52±0.50	1.90±0.60
Pandora Reef	1.20±0.05	1.53±0.26	1.85±0.30
Havannah Is.	1.22±0.04	1.21±0.33	1.47±0.40
Magnetic Is.	1.01±0.11	1.45±0.36	1.45±0.34
Stanley Reef	1.21±0.08	1.74±0.53	2.10±0.66
Hook Is.	1.25±0.09	1.43±0.35	1.77±0.43
Stonehaven Is.	1.30±0.09	1.61±0.43	2.09±0.58
N. Molle Is.	0.99±0.07	1.63±0.55	1.61±0.56
S. Molle Is.	1.03±0.07	1.23±0.44	1.27±0.46
Cid Harbour	1.17±0.05	0.98±0.33	1.16±0.39
Lupton Is.	0.98±0.05	1.58±0.33	1.55±0.34
Scawfell Is.	1.12±0.08	1.62±0.26	1.82±0.26
Sanctuary Reef	1.26±0.06	0.94±0.35	1.18±0.44
Abraham Reef	1.10±0.06	1.30±0.40	1.42±0.45
Masthead Is.	1.30±0.05	0.88±0.29	1.14±0.37
Mean	1.17	1.48	1.72
s.d.	0.10	0.32	0.36
Maximum	1.39	2.17	2.49
Minimum	0.98	0.88	1.14

The 10 longest coral records cover the 237-year period, 1746-1982. These 10 corals had twice as much variance in common as would be expected by chance. This is a strong indication that some large-scale environmental factor, such as climate, is influencing Porites growth on the GBR. The 10 coral records were averaged together to form a single record of calcification in Porites for the GBR (Fig. 4). This series is significantly positively correlated with the instrumental record of sea surface temperature (SST) on the GBR over the period 1906-1982

(30% variance in common). Thus, longer-term variations in Porites calcification reflect variations in SST with higher calcification occurring at higher temperatures.

The record presented in Fig. 4 can be interpreted in two ways: (i) as a proxy record of SST on the GBR for the past 237 years, and (ii) a history of growth in a major reef-building coral on the GBR. There is considerable concern about the degradation of reefs in various places around the world. Management of the GBR must involve an ability to monitor the system and recognise unnatural change. The history of *Porites* growth presented here shows features which are especially relevant to monitoring for change on the GBR.

The 237-year record shows that calcification in *Porites* is highly variable on a range of time scales. The data suggest that it would be unwise to compare growth characteristics for individual years and rash to compare individual years in different decades without considering the long-term trends. Long-term trends in calcification also show considerable variability. *Porites* calcification was high on the GBR in the late 18th century and low in the early 19th century. Low growth in the early 19th century is not matched in any of the subsequent record. Calcification in *Porites* shows no indication of a recent, unusual decline which might be attributed to human activities. In fact, the 20th century has witnessed the 2nd highest 50-year period (1927-1976) and the 3rd highest 10-year period (1964-1973) of calcification across the full record. The data indicate that recent reports of a decline in coral performance on the GBR may simply reflect a return to 'average' conditions rather than the effects of human activities.

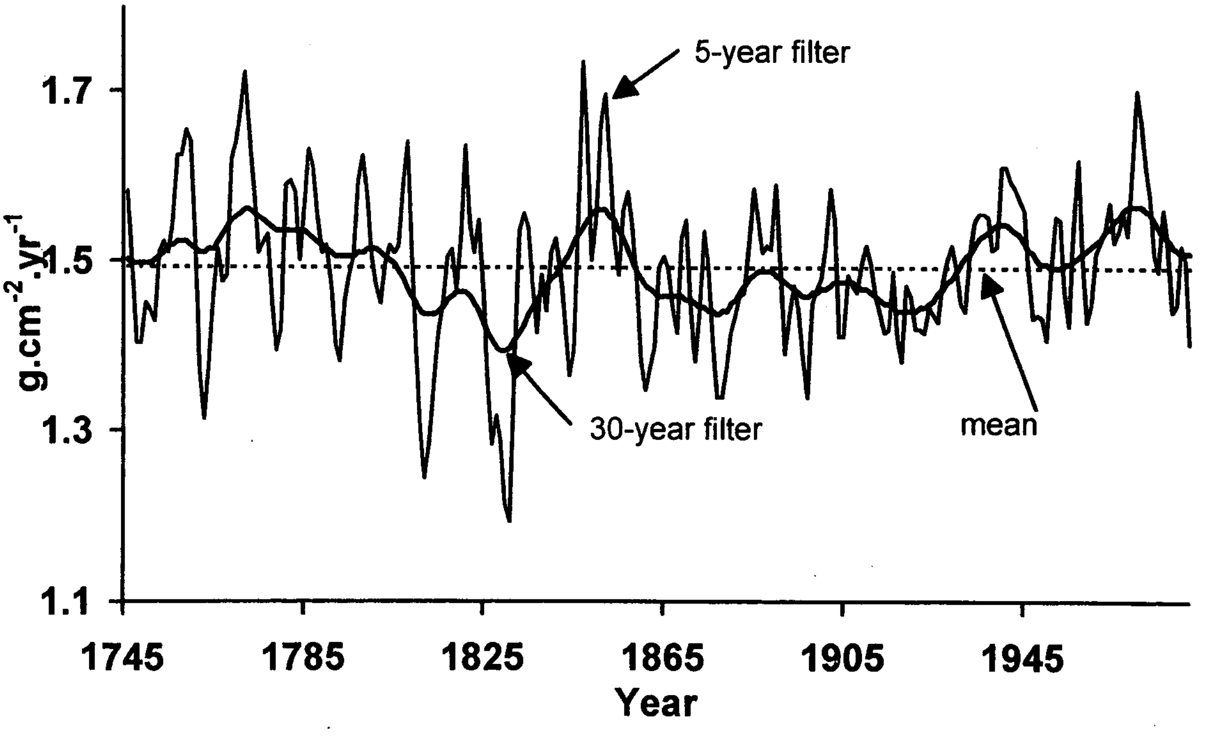

Figure 4: Average annual calcification for 10 *Porites* colonies on the Great Barrier Reef, 1746-1982.

These data also have implications for long-term monitoring of coral reefs because they indicate the temporal scale of variability in performance of a major reef-building coral. The data indicate it might take 30-50 years of monitoring to establish average conditions. This is comparable to the length of time required to establish average climatic conditions. Given

current concern about change in, and rapid degradation of, reefs, long-term monitoring may not be able to establish a useful, baseline against which to assess reports of change.

Summary

Massive corals characterised by annual density bands, such as *Porites*, contain a history of themselves and their environment. Information about coral growth obtained from density bands (density, extension and calcification) provides a tool for retrospectively monitoring reef environments over the past several centuries.

Growth characteristics obtained for whole, 15-50 year-old, colonies of *Porites* from the Great Barrier Reef (GBR) provide baseline information about average growth rates and their variation from inshore to offshore reefs and with latitude. The three coral growth variables (density, extension and calcification) do not necessarily respond in the same way to gradients and changes in environmental conditions (see Dodge and Brass 1984). Average coral growth characteristics presented here (Fig. 3) represent an early stage in our attempt to provide a picture of spatial variations in *Porites* growth on the GBR. Such baseline data about coral growth characteristics is necessary to fully develop their application to retrospective monitoring of coral reef environments. Comparisons are also needed between measures of coral performance obtained from skeletal growth histories and other measures of reef health.

Growth characteristics obtained for large colonies of the GBR provide a temporal perspective on the natural variability exhibited by a major reef-building organism. Again, such data provides new information about the average status of the major reef-building coral *Porites* on the GBR. Average calcification in *Porites* is highly variable, from year-to-year and over longer timescales. The 20th century has witnessed the 2nd highest 50-year period of *Porites* growth during the past 237 years. Evidence of a recent decline in coral calcification is tempered by the occurrence of similar declines and recoveries over the past few centuries. The present decline may well represent a return to 'average' conditions.

Acknowledgments

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