

Chapter 9

Coral husbandry and long-term coral survival in the Coral Reef Exhibit at Reef HQ Aquarium, Townsville, Australia

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ABSTRACT

Reef HQ Aquarium, previously called the Great Barrier Reef Aquarium, houses the world's largest living coral reef aquarium system, called the Coral Reef Exhibit (CRE). Evolving coral collection and husbandry techniques, combined with improvements in water quality and filtration systems over more than two decades of operation, have led to much longer survival rates for both soft and hard corals. However, coral disease in the form of tissue sloughing is still a significant source of mortality, especially for Acroporids. True *in-situ* spawning was first observed in 2002, and continues to occur yearly at the same time as nearby natural reefs, although at this time very little settlement has resulted. This chapter presents long-term observations of coral husbandry and survival in the CRE, reviews improvements seen in CRE ecosystem health over the years, and discusses these improvements in relation to the major operational changes and shifts in water quality described in Chapter 26.

INTRODUCTION

The Coral Reef Exhibit (CRE) at Reef HQ Aquarium in Townsville, Australia, is a 2.8 million liter (35 by 17 meters and 4.5 meters deep) living coral reef mesocosm designed to replicate an inshore reef on land (Eager and Peterson, 1988). Built in 1987, and located in the coastal tropics in Townsville near the middle of the Great Barrier Reef (Figure 1), Reef HQ had several natural advantages to accomplish this, including a tropical climate, open access to sunlight, and ready coral availability. Nevertheless, building the largest living coral reef aquarium in the world included numerous technical challenges at the time, and, although advances in coral husbandry have been made around the world in terms of coral husbandry in the last two or three decades, challenges still remain 20 years later.

For a detailed review of technical operations

and water quality in the CRE, please refer to Chapter 26.

Ongoing improvements in water quality and filtration methods have led to significant changes in long-term survival rates for most coral species. However, the keeping of Acroporids and Pocilloporids still remains difficult, as the majority of colonies are lost to tissue sloughing (sometimes referred to as Rapid Tissue Necrosis).

This chapter focuses on the biological information regarding corals in the CRE, particularly the improvement in survival rates over the years, as well as spawning and recruitment information, and an overview of disease issues occurring in the CRE. The discussion reviews some key factors (as a result of operational changes) that have made a significant improvement to CRE coral husbandry, and gives direction for the future.

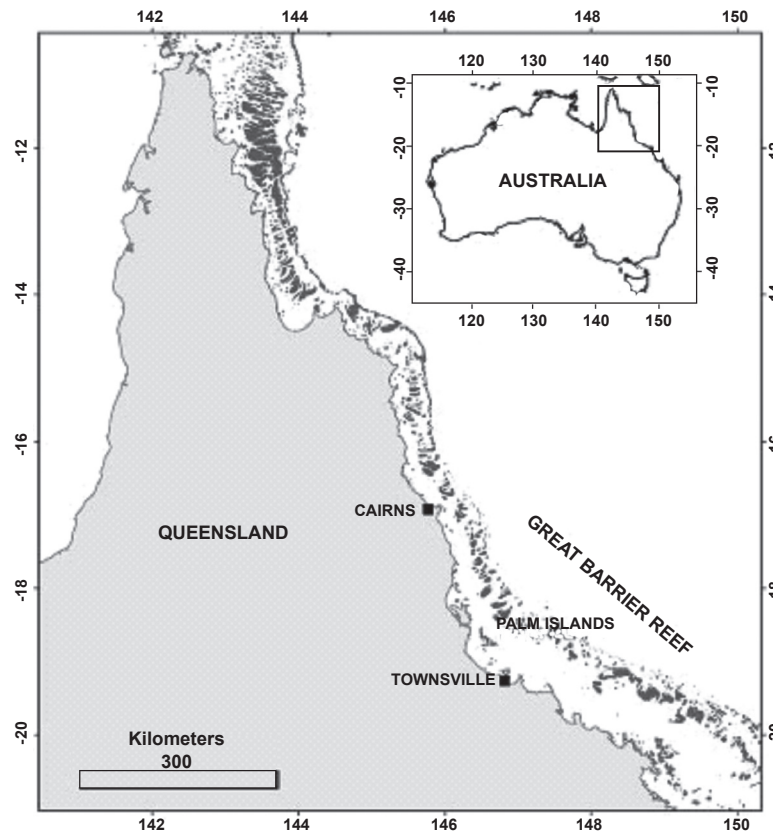


Figure 1: Map of the Great Barrier Reef and location of the Reef HQ Aquarium in Townsville in relation to the coast of Australia.

CORAL HUSBANDRY IN THE CRE

Coral collection and monitoring

For the first 10 years of operation of the CRE, several large-scale collection trips were required throughout each year to keep enough living corals available for visitor viewing. Although no records were kept, anecdotal information indicates that survival times were generally very short across all genera, generally less than 6 months for the majority of colonies (Suosaari, pers. com.). For Acroporids, the survival time was even less, usually between 30-90 days maximum (Harriot, unpub. data). In 1996, a tagging program was initiated to keep track of the number and type of coral colonies collected per year, and also to follow coral survival over time. Numbered tags were made using a labeling gun and labeling tape. Years were differentiated by tag color, and numbered between 1 and 999. A small hole was made at the end of each tag into which a cable tie was inserted and wrapped around a small section of live rock attached to the coral. After a coral was tagged, the following information was recorded:

- Date of collection
- Coral species (when possible, or at least to genus)

- Tag number and colour
- Collection site
- Date transferred into the CRE

The coral was then placed into the general reef structure, in areas where it would have the highest visitor impact, usually close to the viewing windows.

Once a coral died (whole-colony mortality) or was very close to death (loss of most tissue), it was immediately removed from viewing window areas and left in the CRE as live rock. The colony number and date of removal (i.e. approximate date of death) was recorded in the Coral Log, giving an estimated number of days survival in the CRE.

This record was maintained up to 2004, and then began to break down due to the changes in CRE operations, as described in the previous chapter. Coral colony removal was relatively easy prior to the water quality changes occurring throughout 2002, as colonies had little or no accretion, and could easily be lifted to check tags and/or be moved from one place to another. However, since the Estuarine Water period started in 2002, most corals have completely accreted and grown into the reef structure, making it very difficult to remove them and check tag numbers without

doing significant damage to surrounding living corals and substrate. Although this can be viewed as a positive advancement, we are no longer able to accurately record which corals have been lost, based on the written record alone. New tagging and mapping methods are now being investigated to solve this problem, and underwater photographic monitoring is currently used to keep track of overall survival, growth, and disease occurrence.

Coral survival: 1996-2006

Coral survival was relatively difficult to portray statistically, as colonies were collected at several different times (up to six large-scale collection trips) during each year and had highly variable survival times between collection groups and coral families. For those reasons, as well as the sheer quantity of colonies logged, the data presented here are in the form of averages and yearly trends,

rather than by individual collection date and species.

Prior to 2001/2002, average survival rates for all corals collected was very low, between ~20-30 % (Figure 2b). Survival rates rose to 47 % and 60 % for the 2001 and 2002 total collections respectively, corresponding to changes in technical operations during 2002. The increased survival in 2001 is explained by the fact that the colonies collected in large groups during late 2001 lasted long enough into 2002 and even 2003 to be positively affected by improving conditions. The sharpest increase occurred for the 2003 group (85%), but dropped slightly in 2004 (74 %). This is due to several factors, including:

- i) the cessation of large collection trips after 2003 due to increased survival;
- ii) the significantly fewer colonies collected (Figure 2a), and;
- iii) the targeting of Acroporids and Pocilloporids in 2004, groups that had (and

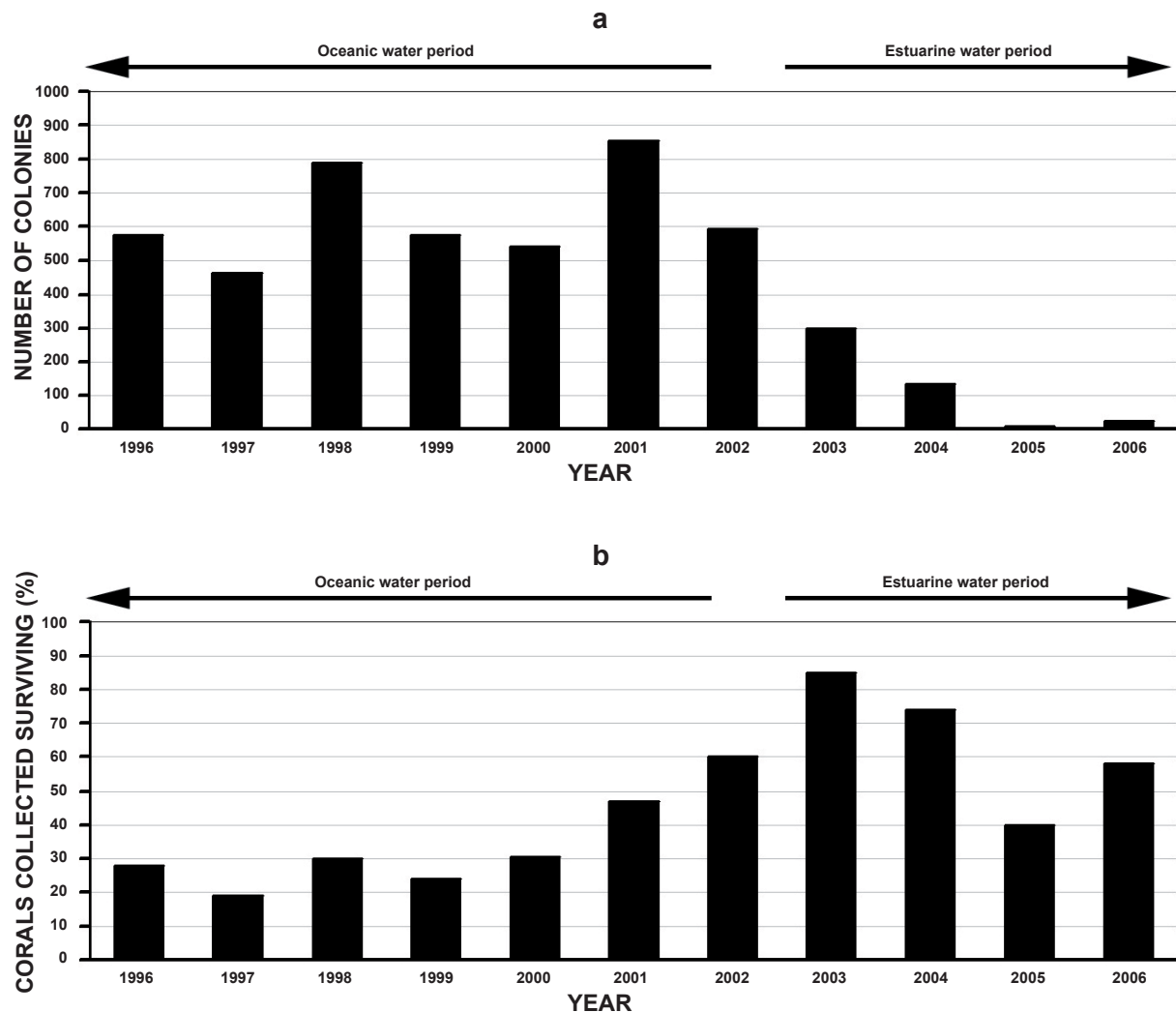


Figure 2: a) Total number of colonies collected per year for the period 1996-2006; b) Percentage of coral survival over time for all species collected during each yearly collection period. Results are skewed downward after June 2004 due to the much lower number of colonies collected and the low-survival time species targeted (see text for details).

continue to have) the lowest survival rates (Figure 3).

Causes of mortality in the Coral Reef Exhibit

Although the actual causes of death were not officially recorded in the Coral Log, anecdotal evidence, photographic evidence, and continuous daily observations by the authors and other staff members over the last 10 years (Anthony, unpubl. data) all indicate that the main causes of death for hard corals can be divided into two general but distinct categories: i) gradual reduction of colony size due to reabsorption or slow retraction of tissues (Figure 4a), and; ii) tissue sloughing (TS) also referred to collectively as 'White Syndrome' (Willis *et al.*, 2004) (Figure 4b). The latter process has previously been referred to as Rapid Tissue Necrosis (RTN) within the aquarium industry; however, this is a misnomer as the tissue loss is not always rapid, nor has necrosis been proven histologically. For these reasons, tissue loss in the Coral Reef Exhibit will be referred to hereafter as White Syndrome (WS).

Slow recession is generally observed in the following coral families: Agariciidae, Carophylliidae, Dendrophylliidae, Faviidae, Merulinidae, Mussidae, Pectinidae, Poritidae, Siderastreidae, as well as octocorals. It is usually accompanied by gradual macroalgal invasion and encroachment, spatial competition and eventual overgrowth, and can take several years for total colony loss to occur. White Syndrome (defined below for the CRE) is a much more rapid process, leading to colony death within weeks or months, and is observed primarily in the Acroporidae and Pocilloporidae families, with few exceptions.

Minor sources of partial colony mortality can include occasional feeding injuries from parrotfish, angelfish, and butterfly fishes, sediment and fish waste accumulation on plating corals located in 'dead zones', injury due to careless diving and/or handling practices, and snail predation. However, colonies are regularly inspected for signs of predatory snails, and if any are found, they are immediately removed. At this time, very few incidents of snail predation have been observed.

Coral disease

The most significant cause of coral mortality for the Coral Reef Exhibit by far is White Syndrome (WS), defined here as relatively rapid disintegration of coral tissues and characterized

by a distinct line of intact, healthy-appearing tissue next to a margin of bare skeleton (Willis *et al.*, 2004). This is a common sign associated with many coral diseases, including white band, white plague, shut-down reaction, stress-related necrosis, and rapid tissue necrosis (reviewed in Borneman, 2002; Sutherland *et al.*, 2004). WS mainly affects Acroporid and Pocilloporid corals in the CRE, although other species also demonstrate tissue sloughing without loss of the entire colony (Anthony, unpubl. data). The rate of progression is highly variable between colonies and even within the same colony, occurring over days, weeks, or months. The mode of tissue loss in WS is easily distinguishable from feeding scars; in addition, no ciliates or other invasive organisms are observed in association with the tissue/skeletal interface, even under microscopic examination.

As previously mentioned, causes of death were not recorded in a written format in the Coral Log; however, long-term staff observations and continuous photographic records show that all acroporids in the CRE die from WS, making statistical analysis of this group the most meaningful. Almost 98 % of collected and/or propagated Acroporids continue to die from WS in the Coral Reef Exhibit, still resulting in a much shorter survival period and drastically skewing total coral survival data (Anthony, unpubl. data).

At this time, there is no established protocol for treating the progression of WS on colonies in the CRE, although a few methods have been tried, such as removal from the system into a smaller tank or a different part of the reef structure. Relocation met with poor results and the stress of detaching a solidly accreted colony was eventually determined to be too detrimental. Treatment with antibiotics in such a large system (regardless of side effects on other organisms) was not viable, and has not conclusively been proven to be effective (Borneman, 2002). Anecdotal observations showed that outbreaks appeared to occur following the breakdown of nearby circulators, indicating that sufficient flow was a key factor in prevention. Related experimental work on the infectiousness of WS in this system (Anthony, unpubl. data), and in nature (Ainsworth *et al.*, 2007), do not indicate that a bacterial pathogen is necessarily the cause; samples of these experimental corals as well as sloughing CRE colonies are currently being processed for histopathological analysis (Anthony, unpubl. data).

Other disease types observed in the CRE in

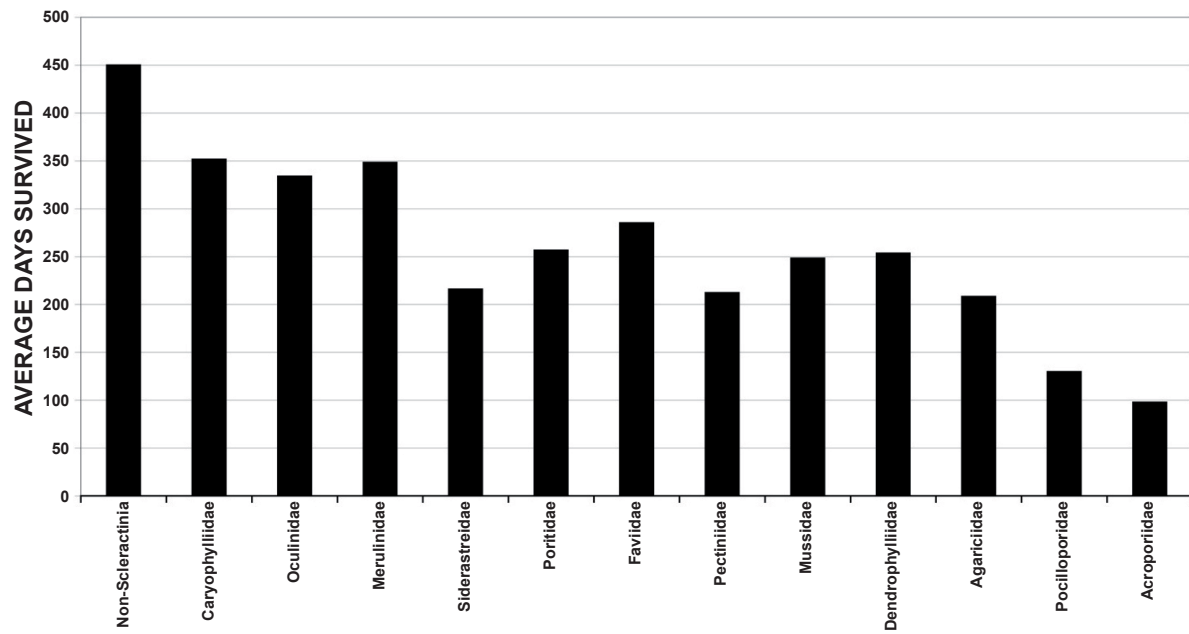


Figure 3: Example of coral survival between families. Although survival times increased following the changes made in 2002, comparative survival time trends remain similar.

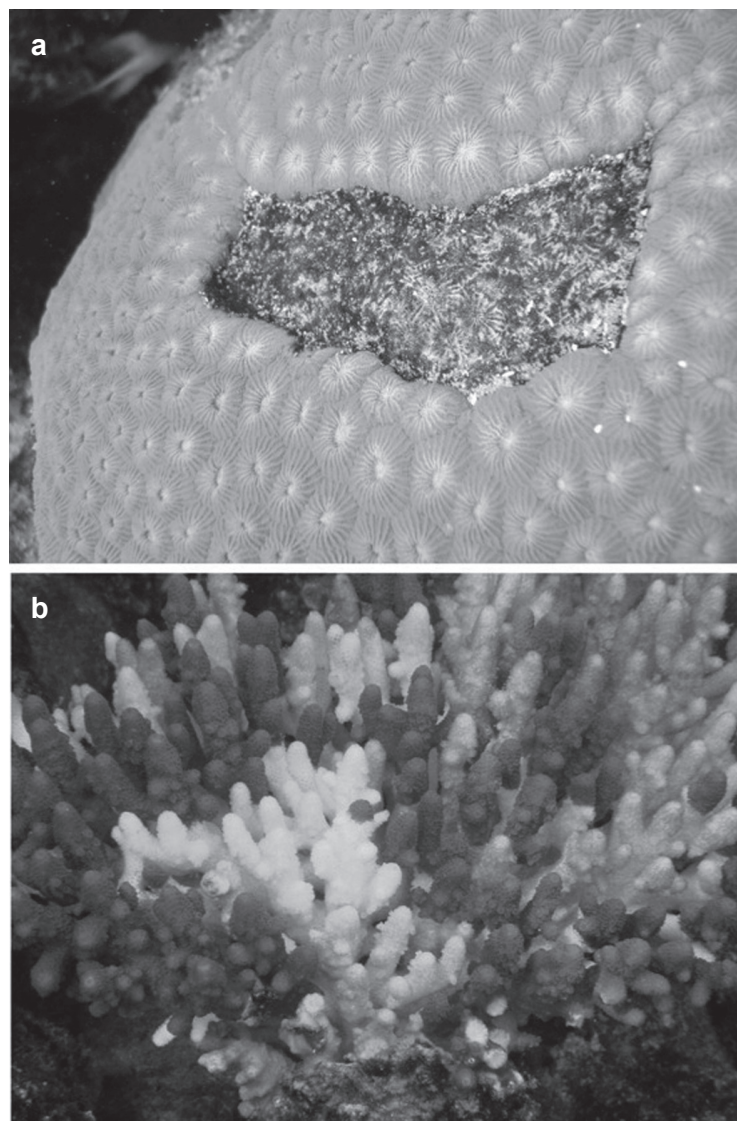


Figure 4: a) a massive coral showing the slower recession of tissue that allows establishment of macroalgae on exposed skeleton; b) an acroporid showing the stark white skeleton left by recent and relatively rapid WS progression, as well as older sections where algae is growing.

the past include: black-band disease, brown-band, skeletal eroding band, atramentous necrosis, and pink-spot syndrome (Anthony, unpubl. data; see Willis *et al.* (2004) for review of Indo-Pacific disease types). However, these occurrences are very rare and are not an important source of coral mortality; therefore, they will not be discussed further in this paper. Coral bleaching as a result of both warmer and colder water temperature extremes may also occur seasonally in the CRE, and does in a few 'indicator' colonies on a yearly basis. Although this may compromise long-term coral health, no systematic correlation between water temperature and disease outbreaks has been found thus far, and it is not regarded as an important cause of colony loss at this time.

Coral accretion and growth

Coral accretion was observed for the first time approximately one month following the first

creek water intakes in mid-2002, and growth could then be monitored photographically over subsequent years (Figure 5). Coral growth was recorded approximately fortnightly on some target colonies up until October 2007 using time series photographs. The establishment and spread of coralline algae, as well as calcareous macroalgal species (e.g. *Halimeda* spp.) also occurred for the first time, probably as a result of the dramatically increased calcium levels (up from 250 mg Ca²⁺.L⁻¹ to ~ 410 mg.L⁻¹), as discussed in Chapter 26.

Coral reproduction

Both sexual reproduction (brooding/broadcast spawning) and asexual (budding, polyp bail-out) reproduction have been observed in the CRE. Spawning of many established colonies (i.e. not collected within the last six months and solidly accreted) has occurred for the last six years during the months of October/November

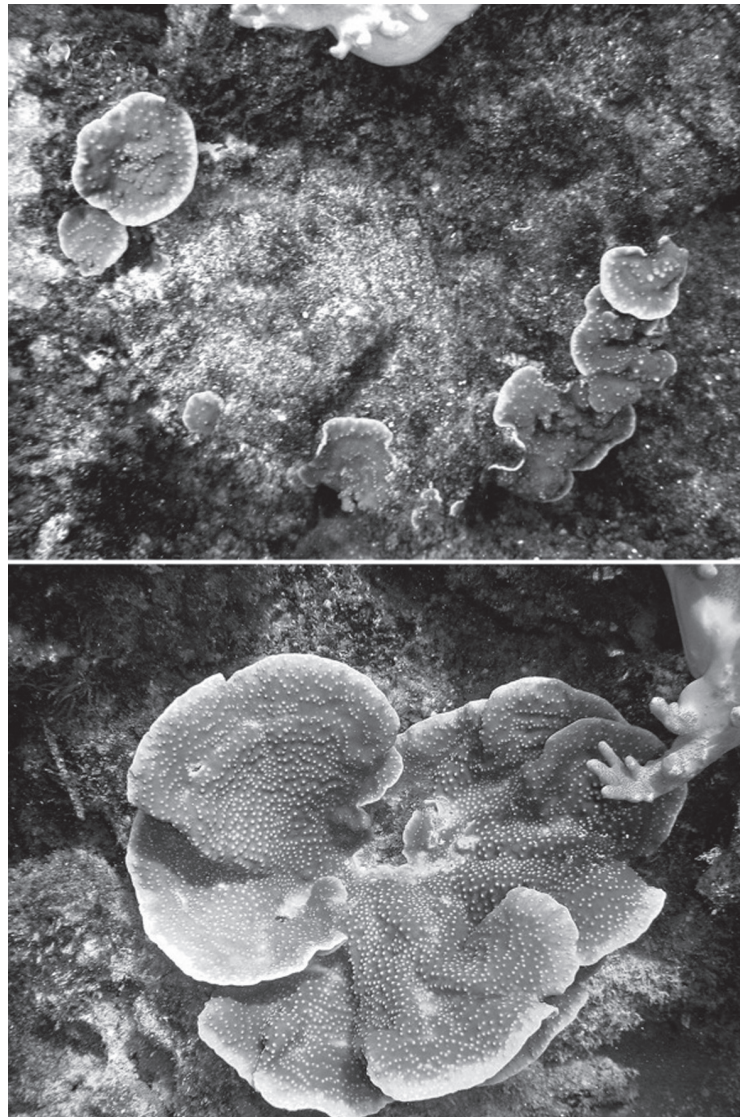


Figure 5: Time-series photographs of a *Turbinaria reniformis* colony's growth in the CRE.

(depending on the year). The spawning day and time is predictable for the 4th day following the full moon and just after sunset (~ 20:00 hours); this synchronizes closely to nearby inshore reefs (3-6 d after the full moon). Differences are attributed to the CRE temperatures running at 1-2 °C higher than those in the bay area.

The majority of spawning colonies are soft coral species, but over successive years (2004, 2005, 2006) the types and number of spawning scleractinian corals has continued to increase (species observed to spawn in 2006 are listed in Table 1.) All filtration and circulation systems are taken off-line several hours before predicted spawning times and left off overnight to increase chances of fertilization, development, and settlement. However, this is probably not enough to prevent most of the planulae from being filtered out or preyed upon during the following days. At this time, there are only three known small *Lobophytum compactum* colonies resulting from *in-situ* spawning and settlement (Michalek-Wagner, pers. com.).

Asexual planulation and larval brooding are successful reproduction strategies for *Pocillopora damicornis* colonies in the CRE. New juveniles appear regularly on the walls or other hard substrate areas and establish healthy colonies; however, it cannot be determined whether these processes occur seasonally or year-round, due to lack of regular observations on settlement and/or growth.

DISCUSSION

Coral husbandry has advanced considerably in the CRE since its opening in 1987. Overall survival across all coral groups increased steadily for the 2001/2002 collection years, following the beginning of creek water intakes and subsequent normalization of calcium concentrations (described in the previous

chapter). Increases in survival were even more apparent after the 2003 collection year, correlating strongly with increased flow conditions from installation of the circulator pumps. The authors strongly believe that these changes were the most critical in the process of improving CRE long-term coral survival, together with the progressive elimination of mechanical filtration (reviewed in Chapter 26). Creek water intakes and large water exchanges also provided an external source of plankton; this, combined with the greatly reduced filtration of internal plankton populations, potentially increased food availability in the system, benefiting corals as well as filter feeding organisms. Comparative plankton counts throughout the time periods of operational changes found an increased number and diversity of plankton species, as well as the newer presence of larval organisms and larval fish stages (Anthony, unpubl. data). These results indicate that the reduced filtration allows greater time for potential larval development and settlement. Other improvements include the first-time growth of coralline algae and calcareous algal communities, the successful establishment and maintenance of filter feeding species (e.g. crinoids, sponges, and tunicates), and the new appearance of many other reef organisms, including juvenile sea stars and beneficial snail species (Anthony, unpubl. data).

Changes in collection strategy are also thought to have made a difference in the successful maintenance of a more diverse coral community. Based on diving logs and collection records beginning in 1996, large-scale collection trips were carried out 4-6 times per year, usually to nearby (within ~100 km) mid-shelf reefs with heavy coral cover, abundant light, and clear waters. Each trip harvested between 100 and 300 healthy colonies (plus attached live rock where possible) from relatively shallow depths

Table 1: Species of coral observed spawning in November 2006.

Scleractinia	Alcyonacea	Gorgonacea
<i>Favia</i> sp.	<i>Lobophytum compactum</i>	NONE
<i>Goniastraea</i> sp.	<i>Sarcophyton elegans</i>	
<i>Hydnophora</i> sp.	<i>Sarcophyton</i> sp.	
<i>Pavona</i> sp.	<i>Sinularia</i> sp.	
<i>Acropora florida</i>		
<i>Acropora humilis</i>		
<i>Acropora</i> sp.		

(< 5 m); the large majority of these were at least 30 cm in diameter, depending on the species. Many colonies were even larger, up to 50 cm in diameter or more, to provide maximum impact for viewing from the outside of the CRE windows. From this size-class data (not shown), it can be assumed that collected corals were mature and well-established in their natural reef environment.

This collection strategy continued until early 2003, when a new approach was tried. During this final year of large-scale collection trips, coral harvesting was conducted at depths of at least 10 m, i.e., in light conditions considered comparable to the CRE. Large-scale trips were then ceased altogether after March 2004 due to increased coral survival trends (and resulting lack of need to replace dying colonies), and a second shift in collection strategies.

Coral collections are now very rare and target either those species with known high survival times and success rates (e.g. *Turbinaria* spp., massive and brain corals), and/or smaller and potentially younger and more 'adaptable' colonies (diameter 5-15 cm) for less successful species (i.e. *Acropora* spp.). Although these small colonies have less immediate impact on visitors' experience, it is hoped that they will adapt better to aquarium conditions, and eventually grow into healthier large colonies with better long-term survival prospects. In addition, collections focus on nearby inshore reefs with lighting, water quality, and other environmental conditions comparable to those in the CRE. As an indication of the success of these changes in strategy, the total number of colonies collected between 2004 and 2007 is less than the number of colonies collected for any single trip prior to 2004 (Figure 2), as very little replacement of colonies has been necessary since the Estuarine Water period began (described in the previous chapter).

Unfortunately, the ongoing challenge presented by White Syndrome still prevents successful long-term husbandry of Acroporids. However, progress has been made in the last five years with much better survival times. Propagation of those few remaining resistant colonies in the CRE is now being tried, but results over the long term will not be available for some time. Although several studies of the various causes of WS in the CRE have been completed (Anthony, unpubl. data), much research still remains to be done in this area of coral husbandry.

Increased restrictions and limits on coral harvesting allowances from government

permitting agencies within the last few years, as well as the need to promote tangible reef conservation efforts to the general public, are quickly reducing the viability of continued coral collection from natural reefs. For these reasons, and for others already discussed, it is clear that perfecting coral propagation techniques remains the most viable way that coral husbandry can be maintained in the CRE. However, past efforts in coral propagation have not shown convincing results.

Although coral fragments grow well in attached shallow, high flow propagation tanks, transplantation into the open CRE tank generally results in subsequent bleaching with eventual algal overgrowth for most species. Smaller branching fragments are also very attractive to the larger parrotfish in the CRE, and most only survive for a few weeks or months before being crunched down to nubbins. Recent *in-situ* fragmentation and transplantation of pieces of established *Echinopora* sp. and *Turbinaria* spp. colonies have been successful in accreting to most transplant sites and are growing well (Anthony, unpubl. data). An extensive review and improvement of propagation practices for the CRE is much overdue, and should be the primary focus of future coral husbandry efforts.

CONCLUSIONS

Based on over 20 years of data from CRE operations history, practical experience, records of coral survival, and long-term observations of all organisms and the CRE system as a whole the authors conclude the following:

1. Average coral survival has increased from 20-30 % during the Oceanic Water period to 70-80 % during the Estuarine Water period across all species. However, the survival times for Acroporids remains very low.
2. Coral mortality is mostly due to White Syndrome in Acroporids, but the cause for the White Syndrome in the CRE is not known to date.
3. Large short-term variations in some water quality parameters, such as salinity and temperature (reviewed in Chapter 26), are not necessarily detrimental to coral survival, but overall stability within

acceptable ranges is still most important in the longer term.

4. Reduced artificial filtration in large-scale systems such as the CRE can actually improve overall tank health by avoiding 'overstripping' the water column of particulates and encouraging plankton production, greater food availability, and larval settlement, especially during spawning periods.

5. In-house CRE coral propagation through fragmentation is important to reducing collection of corals from natural reefs, and to provide a continuous source of coral already adapted to aquarium conditions.

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PERSONAL COMMUNICATIONS

Suosaari, G. 1996-current, Reef HQ, GBRMPA, Townsville, Australia.
 Michalek-Wagner, K. 2001-2007, Reef HQ, GBRMPA, Townsville, Australia.

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APPENDIX: Coral reef exhibit fish list

Genus	Species	#	Genus	Species	#
<i>Paracanthus</i>	<i>hepatus</i>	10	<i>Chelmon</i>	<i>rostratus</i>	2
<i>Acanthurus</i>	<i>olivaceus</i>	10	<i>Chaetodon</i>	<i>flavissimus</i>	2
<i>Zebrasoma</i>	<i>scopus</i>	10	<i>Forcipiger</i>	<i>longirostris</i>	2
<i>Zebrasoma</i>	<i>veliferum</i>	10	<i>Heniochus</i>	<i>varius</i>	2
<i>Acanthurus</i>	<i>nigricans</i>	10	<i>Heniochus</i>	<i>chrysostomus</i>	2
<i>Acanthurus</i>	<i>pyroferus</i>	10	<i>Heniochus</i>	<i>diphreutes</i>	2
<i>Naso</i>	<i>lituratus</i>	10	<i>Chaetodon</i>	<i>kleinii</i>	2
<i>Naso</i>	<i>unicornis</i>	10	<i>Chaetodon</i>	<i>lunula</i>	2
<i>Naso</i>	<i>vlamingii</i>	10	<i>Valencienna</i>	<i>strigata</i>	6
<i>Naso</i>	<i>brevirostris</i>	10	<i>Amblyeleotris</i>	<i>guttata</i>	4
<i>Acanthurus</i>	<i>lineatus</i>	10	<i>Bodianus</i>	<i>axillaris</i>	5
<i>Balistapus</i>	<i>undulatus</i>	3	<i>Cirrhilabrus</i>	<i>lineatus</i>	5
<i>Balistapus</i>	<i>conspicillum</i>	1	<i>Epibulus</i>	<i>insidiator</i>	2
<i>Odonus</i>	<i>niger</i>	20	<i>Gomphosus</i>	<i>varius</i>	5
<i>Melichthys</i>	<i>vidua</i>	6	<i>Hemigymnus</i>	<i>fasciatus</i>	2
<i>Rhinecanthus</i>	<i>aculeatus</i>	2	<i>Hemigymnus</i>	<i>melapterus</i>	2
<i>Rhinecanthus</i>	<i>verrucosus</i>	3	<i>Labroides</i>	<i>dimidiatus</i>	10
<i>Sufflamen</i>	<i>chrysopterus</i>	2	<i>Novaculichthys</i>	<i>taeniurus</i>	5
<i>Ecsenius</i>	<i>midas</i>	4	<i>Thalossoma</i>	<i>lunare</i>	3
<i>Ecsenius</i>	<i>bicolor</i>	4	<i>Thalossoma</i>	<i>janseni</i>	2
<i>Caesio</i>	<i>cuning</i>	20	<i>Thalossoma</i>	<i>lutescens</i>	2
<i>Ptercaesio</i>	<i>marri</i>	15	<i>Cirrhilabrus</i>	<i>scottorum</i>	2
<i>Chaetodon</i>	<i>ulietensis</i>	2	<i>Monotaxis</i>	<i>grandoculis</i>	20
<i>Chaetodon</i>	<i>auriga</i>	2	<i>Parupeneus</i>	<i>multifasciatus</i>	4
<i>Chaetodon</i>	<i>plebius</i>	2	<i>Parupeneus</i>	<i>signatus</i>	2
<i>Chaetodon</i>	<i>favirostris</i>	2	<i>Parupeneus</i>	<i>cyclostomus</i>	2
<i>Chaetodon</i>	<i>ephippium</i>	2	<i>Pentapodus</i>	<i>paradiseus</i>	3
<i>Chaetodon</i>	<i>mertensii</i>	2	<i>Scolopsis</i>	<i>bilineatus</i>	3
<i>Chaetodon</i>	<i>melannotus</i>	2	<i>Scolopsis</i>	<i>margaritifer</i>	4
<i>Chaetodon</i>	<i>rafflesi</i>	2	<i>Plotosus</i>	<i>lineatus</i>	30
<i>Chaetodon</i>	<i>rainfordi</i>	2			