

Zoology of *Porites cylindrica*: potential for use in reef-rehabilitation transplantation efforts

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Abstract- The life history strategies of a branching, arborescent coral, *Porites cylindrica*, were observed at Orpheus Island on the Great Barrier Reef, Australia, to investigate its potential for use for transplantation programs in reef rehabilitation efforts. My research suggests that *Porites cylindrica* is a tolerant, long-lived, fast-growing coral which relies heavily on asexual fragmentation as a mode of reproduction and dispersal. *P. cylindrica* demonstrated weak competitive strategies but was able to avoid most confrontations by using the fugitive strategy (Jackson 1979) to acquire living space in a direction away from a potential competitor. The data also suggest that *P. cylindrica* has taken deleterious incidents like breakage and turned them into advantageous events by reproducing asexually via fragmentation, possibly increasing its fitness. No differences in percent mortality were found due to colony size. The qualities of fast growth, ability to out-compete other coral species for living space, tolerance to environmental extremes, and resistance to bleaching allow *P. cylindrica* to be a major reef-building coral as well as a prime species for transplantation efforts.

Keywords- *Porites cylindrica*, scleractinian coral, fragmentation, branching, bleaching, rehabilitation, transplantation, Great Barrier Reef, Orpheus Island, Australia.

Introduction

Scleractinian corals are sessile, colonial organisms which create the main component of the coral reefs which serve as the refuge for much of the biodiversity in the shallow waters of the tropical oceans. The widespread degradation of coral reefs in the Indo-Pacific due to bleaching events and anthropogenic causes has increased the interest in the transplantation of corals as a means of rehabilitating degraded reef areas. The success of a coral as a transplant species depends mainly on its set of life history traits. Differences among scleractinian coral species with respect to growth form, population distribution, mode of reproduction, and tolerance to environmental extremes (wide ranges of salinity, turbidity, sedimentation, water temperature, solar radiation, wave action, etc), cause particular coral species to be better candidates for transplant rehabilitation endeavors over others. Many studies have examined one life history aspect for many species, but few have been conducted with the purpose of examining the life history traits for a single species, or even a single genus. This study was done to investigate the potential success of using *P. cylindrica* in reef-rehabilitating transplanta-

tion efforts by examining the coral's life history strategies considering the evolutionary trade-offs which have molded its status as a major reef-building coral of the Indo-Pacific, including the Great Barrier Reef. Jackson (1979) discussed the implications of the different coral growth forms and related a coral's morphology to the way it is able to protect itself from potentially deleterious interactions with its environment or competitors. Branching corals tended to be faster growing organisms, and had the ability to locate more favorable microenvironments, while corals with a more massive growth form (mounds, plates, sheets) had a greater commitment to their point of attachment and thus were not able to alter their location to avoid environmental stress, predation, or injury.

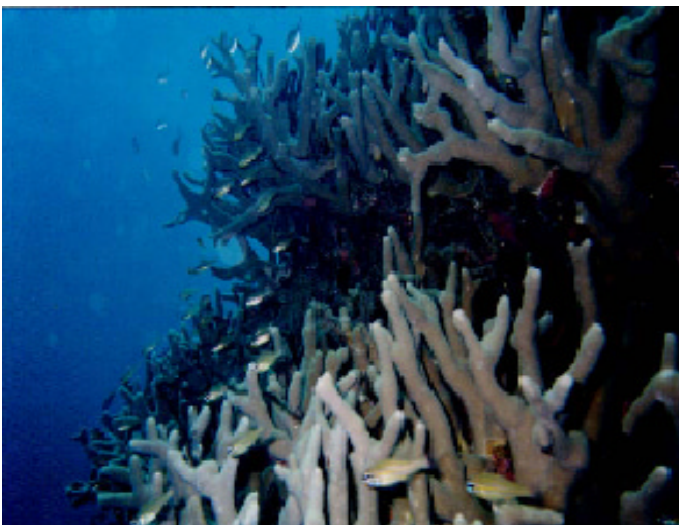
A coral's morphology not only influences its likelihood of being stressed or injured, but also affects the mechanisms by which a coral is able to protect itself against the other corals that compete for its resources: Lang et al. (1990) discussed a trend between morphology and mechanisms of competition in reef corals. It was noted that slowly growing, massive or encrusting coral species tended to have well-developed structures that assisted the coral in

aggressively defending their location of attachment (Lang et al. 1990). These corals typically relied on mesenterial filaments or sweeper tentacles (structures having specialized nematocystic cells that sting, kill, and begin to digest living tissue) to seek out and destroy neighboring colonies that were invading their space. Their mechanism of defense was primarily digestive, and were thus labeled “digestively dominant” corals (Lang and Chornesky 1990).

Other research has shown a correlation between coral morphology and the repair and regeneration of sustained injuries. Hall (1996) discovered that regenerative ability could be ranked according to morphological attributes (arborescent>bushy>tubular>massive). The recovery rates for each growth form did not significantly differ among species which suggested that growth form was a strong factor influencing regeneration. Hall also determined that regenerative response was based on the type of injury sustained. Skeletal repair (in an event like scraping) was much faster than the repair of an injury which damaged tissue, and the repair of a broken branch was the slowest-healing injury.

The branching coral *Porites cylindrica* is a dominant coral in many inshore reefs and midshelf reefs (Dauget 1991). The species is a branching coral and its stubby projections classify it as having a bushy morphology (Figure 1). Because its branching form

Figure 1- *Porites cylindrica* on Pioneer Bay Reef of Orpheus Island. Note the coral’s stubby digitate morphology which classifies it as having a bushy growth form as defined by Jackson (1979). Photo by J. Seebauer



allows growth in many directions, *P. cylindrica* is likely to follow Jackson’s model for morphology and be a fugitive strategist. The species has very small polyps, as well as short tentacles. It also lacks well-developed defense structures like mesenterial filaments or sweeper tentacles, and is often the loser in competitive interactions with other coral species in a laboratory setting (Willis, pers. comm.). Like any branching coral, *P. cylindrica* is subject to breakage, a costly injury (Hall 1996). And yet, amidst qualities which would seem to detract from the fitness of a coral species, *P. cylindrica* is able to successfully dominate much of a reef without being threatened by environmental changes or by other coral colonies looking to advance. I was interested in researching what life history trait advantages *P. cylindrica* has gained while compromising the ability to actively defend itself from aggressive corals.

Methods

Field Studies

The study was conducted at Orpheus Island Research Station, located 15 km off the North Queensland coast, Australia (18°35’S, 146°20’E). Thirty 8m x 4m transects were laid out parallel to shore with underwater transecting tape at three different depths (10 transects each at 2m, 4m, and 6.5m), and all colonies of *Porites cylindrica* along the transects were mapped and length and width were measured (two diameters at right angles were recorded for each colony). Underwater observations provided information on the demographics of *P. cylindrica* as well as its life history strategies including parameters such as habitat (ie abundance at different depths), growth form (ie possible growth form changes as a function of habitat), colony size structure and abundance, distribution (ie dispersed, aggregated, or random), tolerance to environmental extremes, recruitment (ie evidence of new colony recruits), competition (ie observing the interface between neighboring colonies), and mortality (ie visually estimating colony percent death).

Data analysis

The average percent mortality for the colonies on each transect was calculated, and regression analysis was preformed to investigate a possible relation-

Table 1- Analysis of variance demonstrating no significant variation among the abundance at different depths.

ANOVA

PER DEAD					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	801.199	2	400.600	1.018	.368
Within Groups	22822.571	58	393.493		
Total	23623.770	60			

ship between colony size and percent mortality. A one-way ANOVA was performed to investigate the relationship between abundance of colonies and water depth. A one-way ANOVA was also performed to investigate the relationship between percent mortality and water depth. Also, the nearest-neighbor distance was used to determine the distribution of colonies.

Results

Habitat, growth form, population size structure and distribution

There was no significant variation among the abundance at different depths (Table 1). I observed the growth form of the colonies to be branching and arborescent, and there was little to no variation in this growth form at the different depths. I mainly observed several large colonies surrounded by many smaller colonies on each transect. I also noted solitary large and small colonies, some with a large distance from

the next nearest colony. Colonies ranged in size from 100-15,000 cm², a distribution which is log-normal (Figure 2). There was no relationship between colony size and percent mortality ($R^2=0.0062$) (Figure 3). By completing a distribution analysis, I found that the colonies along each transect were aggregated (nearest neighbor histogram was skewed to the right).

Tolerance to environmental extremes and Competitive ability

There was no significant difference in percent mortality of colonies among the three transects (Table 2). The transects examined were dominated by *Porites cylindrica*, with mostly bare ground in between colonies-there were only rare instances of another coral species found within our transects. When direct inter-specific competition did occur, it usually involved a soft coral rather than another Scleractinian coral. The exception to this was several instances of over-growth by a foliaceous coral (a Faviidae spp. which

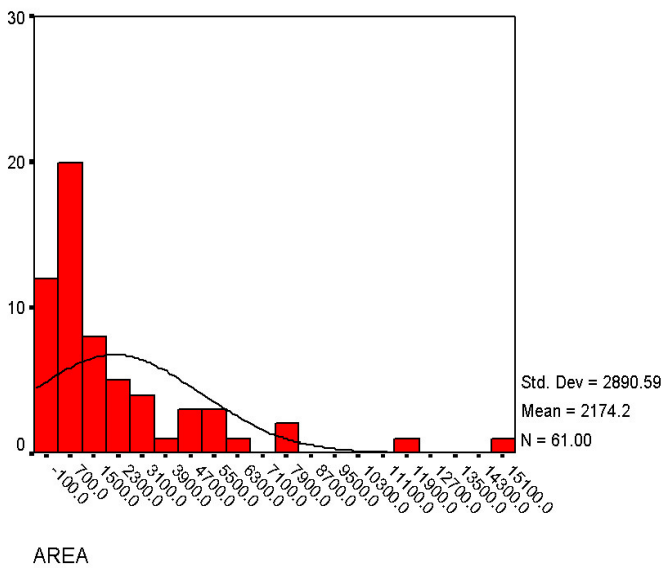


Figure 2- Size distribution frequency of *Porites cylindrica* colonies on all transects. Colonies ranged in size from 100 - 15,000 cm².

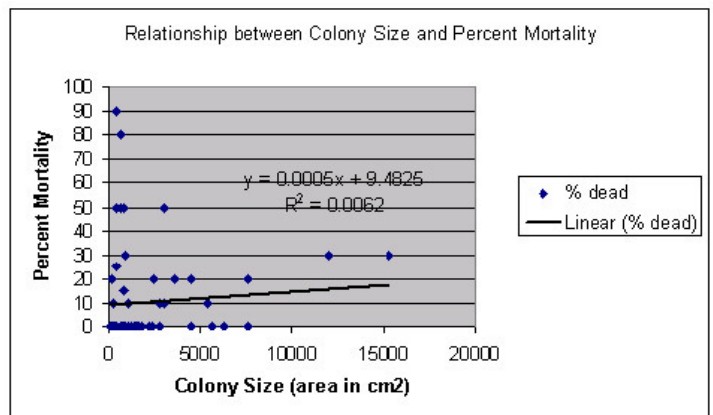


Figure 3- Regression analysis demonstrating no relationship between colony size and percent mortality of the colony ($R^2=0.0062$). This is important because it indicates that smaller fragments of *Porites cylindrica* do not have a higher mortality, a consideration which is important when considering the size of transplantation fragments.

had established in the center of a *P. cylindrica* colony and competed for available solar radiation). In these instances, the *P. cylindrica* had formed a white layer at the point of contact with the foliaceous coral, but overall the colony did not seem to suffer (there was little to no mortality on these colonies, suggesting that large sections of the coral did not seem to be adversely affected by the competitor). The same pattern was noticed for direct competition between hydrocorals: *P. cylindrica* turned white at the point of contact, but did not suffer extreme damage as a result.

Interestingly, sections of *P. cylindrica* colonies seemed to die randomly without an apparent cause. Many of the *P. cylindrica* colonies showed a high percentage of mortality (~30%) as estimated by eye by the presence of fouling organisms such as algae or the presence of obviously dead tissue. Most of the mortality was indicated by algal overgrowth. The colonization of algae on the *P. cylindrica* occurred in single clumps on the coral colonies (ie. The algal overgrowth was confined to one section of the colony, not on branches scattered over the colony).

Discussion

Based on my study on Orpheus Island and previous research, *P. cylindrica*'s lack of competitive aggression is more than compensated for by its ability to avoid competition, tolerate extremes, acquire living space, and reproduce to dominate a reef. These same abilities deem *P. cylindrica* an excellent species with which to rehabilitate degraded coral reefs through transplantation efforts. Its resistance to environmental extremes indicates that it will not only thrive in many different habitats but also withstand the stress of transplantation, and its ability to successfully disperse via fragmentation indicates it will quickly generate

in the site of transplantation. The finding that smaller fragments were no more susceptible to mortality is highly important because it suggests that transplantation efforts can be successful using transplant colonies of all sizes. This means that established colonies which are manually fragmented in order to produce transplant colonies may not have to lose a significant portion of their size to produce successful transplant colonies, thus, conservation of the healthy reefs used to aid rehabilitation is possible.

For a coral to be successful as a candidate for use in transplantation efforts it must reproduce asexually, be tolerant to a range of environmental stresses, have a long lifespan, and either be a strong competitor or be able to grow in a direction away from potential competition. *Porites cylindrica* has all of these qualities.

Habitat and tolerance to environmental extremes

My data show that *Porites cylindrica* is able to reproduce asexually via fragmentation, as well as tolerate a range of environmental conditions. The fact that the colonies were present in similar densities at all depths and demonstrated no significant difference in percent mortality at different depths suggests that this species is tolerant to factors that have been determined to change as a function of water depth (such as solar radiation and water temperature) (Jokiel and Coles 1974, Rex et al. 1995, Anthony 1998). This is supported by previous research which has stated that *P. cylindrica* is able to tolerate extreme gradients in salinity (Jokiel and Coles 1974), ambient temperature (Jokiel and Coles 1974), solar radiation (Jokiel and Coles 1974), and wave action (Rex et al. 1995). *P. cylindrica* is also very tolerant to turbidity (Anthony 1998); it almost seems to thrive on increasing levels of suspended particulate matter (SPM) until a threshold

Table 2- Analysis of variance demonstrating no significant difference in percent mortality of colonies at different depths.

ANOVA

AREA1					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	3951889	2	1975934.270	.230	.795
Within Groups	4.97E+08	58	8575484.319		
Total	5.01E+08	60			

level is reached which causes the small polyps to become clogged and unable to be cleared by the coral's flushing mechanisms (Anthony 1998). My observations show that *Porites cylindrica* maintains the same growth form in all habitats, further evidence of its tolerance to environmental extremes; there is no environmental gradient which causes it to compromise its primary growth form by exhibiting phenotypic plasticity. This is fairly unique among coral species since the growth form of most corals is a function of a combination of environmental factors; for instance, a branching *Tubinaria* species will grow to form a plate structure in deep or turbid water to maximize solar radiation in order to increase photosynthesis (Jackson et al 1979).

Competitive ability, Investment in repair and maintenance

The overtopping foliaceous coral I observed on one of the colonies is utilizing the solar energy that would otherwise be a resource for the *Porites cylindrica*. This means that the *P. cylindrica* is essentially the loser in these types of competitive interactions. However, although the overtopper is diverting a potential energy source, the *P. cylindrica* did not seem to be adversely affected by the foliaceous coral. The skeleton at the point of contact had turned white (a sign of damage), but overall the colony seemed to be thriving—there were no obvious signs that the affected colony was not as sound as the other colonies on the transect.

All the mortality observed on my transects was a result of algal overgrowth. There was no apparent reason for the weakening of the coral colonies that would allow algae to colonize. It is possible that the corals may still be in the process of recovery from the severe bleaching event of 1998, a condition which may have allowed for the opportunistic colonization of the algae (Willis, pers. comm.). However, it is also possible that my estimates of mortality based on the presence of algae are severely overestimated: *P. cylindrica* has been observed to secrete a layer of mucus to protect itself against such fouling organisms until it can properly heal from injuries such as bleaching (Kato, 1987). The *P. cylindrica* sheds these mucus sheets either when healed, or to secrete another sheet of mucus, thus, it is possible that the area of the

colonies I classified as being dead are actually still alive under the algal film. *P. cylindrica* has very poor structures and strategies to protect it against injuries from aggressive corals (its mucus coat may protect it from smaller organisms such as algae, but without mesentery filaments or sweeper tentacles it cannot protect against other corals), but it is able to prevent the injuries incurred from causing the death of the colony because, being a bushy coral, it has one of the highest recovery rates among corals of different growth forms (Hall 1996). This suggests that *P. cylindrica* can survive when up against competitors because it tends to spend most of its energy on maintenance, repair, and growth rather than on aggressive or protective techniques. This idea is supported by considering another morphologically-based life history aspect for *P. cylindrica*: it has a greater energy investment into tissue growth relative to skeletal growth due to its digitate structure (visual examination of a decalcified branch reveals that *P. cylindrica* is a fleshy coral; rather than tissue being restricted to the surface of the colony as it is in a massive *Porites* species, *P. cylindrica*'s tissue has a penetrating morphology and is webbed through out the skeleton) (Anthony, pers. comm.). Tissue is more energetically expensive because it must be maintained, whereas skeletal matter, once secreted, is a static structure. Corals with massive morphologies (which have more skeleton relative to tissue) tend to be digestively dominant (Lang et al. 1990) and rely heavily on aggressive competitive mechanisms because they are slow growing (Lang et al. 1990), have a greater commitment to their point of attachment (Jackson 1979), and take a long time to heal after being injured (Hall 1996). As *P. cylindrica* has the opposite of these qualities, it is acceptable to assert that this coral can sustain injuries because they do not become deleterious the way they would in a massive coral. Ruesink (1997) stated that the persistence of coral colonies depends on growth and recovery exceeding damage; because *P. cylindrica* is fast-growing, fast-healing, and has a low commitment to its point of attachment, the damage it incurs from other corals is not a major catastrophe because its growth and recovery will exceed most damages.

Reproduction: Mode, Recruitment, Abundance, Distribution, and Population Size Structure

The stronghold of *Porites cylindrica* is the manner in which it reproduces. Highsmith (1982) asserted that the corals which reproduce primarily asexually by fragmentation are the species which are classified as the major reef-building corals (ie. Families Acroporidae and Portidae in the Indo-West Pacific). These major reef-building corals are the species which are best employed in transplantation efforts, specifically because they reproduce asexually. The arrangement of colonies on my transects is suggestive of asexual reproduction via fragmentation (Highsmith 1982); the distribution of *P. cylindrica* colonies along my transects was confirmed as having an aggregated population structure by a nearest neighbor distance histogram. *Porites cylindrica*, like most of the corals in the Portidae family, is a brooder (Fadlallah 1983). It does not participate in the mass spawning event, but rather experiences internal fertilization (Willis et al. 1985), and though its gametes are relatively large compared to a spawning coral, they are also fewer in number (Willis et al. 1985). I did not observe any evidence of recent episodes of sexual recruitment, but did observe genets and large, extensive colonies which may actually be several colonies that have grown intertwined together and appear as a single colony though they actually may have started as separate colonies. The possibility of clones creating a large colony as opposed to the growth of a single colony to a great size is deserving of more research. It is possible I did not observe any episodes of recruitment because *P. cylindrica* relies more heavily on fragmentation as a method of asexual reproduction and consequently allocates more energy into the maintenance of preexisting tissues than into fecundity. Brooders tend to be found in unstable habitats (Fadlallah 1983) because the mechanism of internal fertilization and subsequent larger larval size give the colony an advantage in unpredictable situations (Highsmith 1982): the larvae are deposited near the adult colony which results in recruitment in a favorable environment (as demonstrated by the parent colony's existence). This life history strategy of brooding is utilized by the *Porites* species, which all tend to be found in unstable habitats, but *P. cylindrica* has the added advantage of being a branching brooder which means its dispersal and domination of a reef is not slowed by the high mortality rates of larvae

and juveniles (Highsmith 1982) because it can achieve space via fragmentation, an important mode of local distribution among major reef-building corals (Highsmith 1982). This can be understood when examining a coral like a massive *Porites* species: it lives in an unstable environment and is a brooder (Fadlallah 1983), but it is not a major reef-building coral and is rarely seen to cover vast stretches of the ocean floor (Highsmith 1982). *Porites cylindrica* is more successful with respect to the acquisition of space compared to a massive species because it has the advantage of using fragmentation to create new colonies which are large in size compared to an establishing larvae or juvenile, already at an adult stage, have an optimum genotype predictable from the parent colony, have a low mortality rate, develop close to the parent, and are produced continually rather than being seasonally limited by spawning cycles (Highsmith 1982).

Because it has a branching morphology, *P. cylindrica* is fairly susceptible to breakage. Hall (1996) stated that the loss of a branch was the most severe and slowest recovering injury a coral could sustain, but *P. cylindrica* seems to turn this unfortunate damage into a prosperous event by taking the opportunity to reproduce asexually. This is supported by Highsmith (1982) who suggested the mechanism of reproduction via fragmentation was selected for as a part of a corals' life history strategy to maximize the fitness of the species. Highsmith (1982) asserted that high growth rates often result in large colonies which are susceptible to breakage due to instability arising from weight or large surface areas presented to currents and waves, and that, if breakage was not somehow industrious to the coral, then growth forms which minimized this type of damage would have been selected for over the process of evolution. However, species which are most susceptible to breakage are those which are the major reef-building corals of the Great Barrier Reef and Indo-Pacific. Because the production of genets and clones are advantageous, corals such as *P. cylindrica* have incorporated this mechanism into the life history strategy: mortality rates for clones are lower than those for single colonies because the probability of mortality is independent for each fragment (Highsmith 1982), so there is a higher probability that the genotype will survive. Nevertheless, despite the benefits of fragmentation, a glar-

ing disadvantage of the lack of genetic recombination and diversity that accompanies asexual reproduction is that it is easier for the colonies to be abolished if a stochastic event or infectious agent selects against the genotype. However, these types of disturbances occur so infrequently and pose such a small threat to the fragmenting coral that this type of reproduction is still highly advantageous.

Conclusions

Since *P. cylindrica* is a hardy, persistent, and tolerant coral, asexual reproduction has few drawbacks for this species because it is able to avoid and/or survive these potentially disastrous events. *P. cylindrica* has taken deleterious incidents like breakage and turned them into advantageous events by reproducing asexually via fragmentation, thus increasing its fitness. Species-specific life history studies such as this are of great importance to the development of transplantation rehabilitation and should be expanded to further developed to monitor a coral's responses throughout the transplantation process.

Acknowledgements

The author wishes to thank Dalma Sobek for valuable assistance in the field, as well as Bette Willis, Ken Anthony, James True, and Morgan Pratchett of James Cook University for their wisdom and guidance. Thanks also goes to Dr. Isidro Bosch and Dr. Gregg Hartvigsen of SUNY Geneseo for their assistance in manuscript review. This study was conducted at the Orpheus Island Research Station and was funded through the marine sciences division of James Cook University, Townsville, QLD.

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