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A Practical Guide to the Construction and Management of Artificial Reefs in Northwestern Australia

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1

Background

This manual addresses artificial reefs only in the context of coral reef habitats, and only as regards their biological function. Of course, artificial reefs may have valuable uses in cold water habitats, and may provide physical functions such as shoreline protection, but these topics are outside the scope of this manual. In the context of this manual, the function of an artificial reef is to provide an ecological offset to the loss of biodiversity caused through anthropogenic degradation of a coral habitat.

The manual has been developed to share the experiences of Rio Tinto and MScience in planning, designing, permitting, constructing and monitoring an artificial reef within an active harbour area of the Port of Dampier, Western Australia. The purpose of the guide is not to promote the construction of artificial reefs per se, but to inform companies or entities who may be considering constructing an artificial reef. Although most specific examples in this document relate to the Dampier artificial reef, the implications should be relevant throughout northwestern Australia.

In the sense of restoring a loss of biodiversity in coral habitats, artificial reefs are viewed as a 'direct offset' under the Western Australian Environmental Protection Authority's offsets policy (WAEPA Position Statement 9). This means they should have a net environmental benefit and should be considered only after all other reasonable attempts to mitigate the impact have been evaluated. To undertake these evaluations, it is necessary to first understand what has led to the current degraded state of the local habitat. Temporary impacts, such as poor water quality during dredging or construction, are likely to be reversible, and are best managed by allowing natural regeneration following the return of acceptable water quality. Longer term water quality impacts might preclude an artificial reef solution unless the poor environmental conditions are removed first.

As a general rule, all feasible alternatives for natural reef restoration should be explored before artificial reef construction is considered. Reviews of the value of artificial reefs conclude that removing the stress that has caused the loss of natural coral communities and allowing natural regeneration is a far more cost effective solution (Jokiel and Naughton 2001; Naughton and Jokiel 2001). However, where impacts cause permanent habitat loss, artificial reef construction may be the best practical method of directly offsetting that habitat loss.

In the case example considered here, reclamation of nearshore intertidal and subtidal habitat caused the physical loss of a coral community in an area (the inner

Dampier Port) where the history of development had already led to the reduction of coral cover. With an increasing ratio of non-coral:coral habitat, it was identified that placing artificial substrate suitable for coral development in an area of soft bottom with little existing coral was an appropriate response. This manual describes the design, construction and management of the artificial reef.

Permits for Artificial Reefs

The construction of artificial reefs is regulated under the Australian Government's *Environment Protection (Sea Dumping) Act* 1981. Permit requirements are strict and the reef proponent will need to demonstrate that the construction of an artificial reef in a specific location is a necessary action. Permit applications must assess, among other things, social, economic, environmental and biological considerations, and must provide details on the proposed location, configuration, materials and construction.

It cannot be assumed automatically that the construction and presence of an artificial reef will provide a net benefit to an area. The artificial reef construction and long term role in the immediate ecosystem should be evaluated against both positive and negative potential.

The requirements for artificial reef permits, and the application forms, can be found at:

http://www.environment.gov.au/coasts/pollution/dumping/artificial-reefs.html

Before applying for a permit there should be a clear view on why an artificial reef is needed, what purpose it will serve and why it is the best option to meet that end. These conclusions will need to be well justified in the permit application.

- Permit applications must also demonstrate that groups seeking to establish an artificial reef have the resources (funds, committed personnel, expertise, equipment, insurance, and divers) to construct the reef, transport the materials to the site and to carry out longer term monitoring requirements.
- The suitability of a site for the construction of a reef. Factors such as water depth, currents, substrate type, wave action and biota can have a bearing on this.
- Suitable construction materials for the artificial reef.
- Reef layout and factors such as spatial arrangement, orientation to currents and vertical relief need to be taken into account as they can have a bearing on the success of the artificial reef.
- Long term monitoring requirements. Ongoing monitoring and management programs are usually expected to take place over the entire

> life span of an artificial reef. Monitoring requirements may include collecting comprehensive baseline data on the artificial reef site and adjacent areas prior to placement of the artificial reef. This is to ensure adequate monitoring of the impacts of the new reef on environmental factors such as ecosystem health, hydrology and the effect on populations on nearby natural reefs. Applicants may also be required to verify that there is no scouring or alteration to natural sediment transport and deposition patterns around the artificial reef.

Demonstrating structural integrity and stability of the proposed artificial reef is an important part of the permitting process. The proponent must demonstrate that the reef components will be stable under a variety of wave and current conditions likely to occur in the area. Good understanding of local oceanography will have to be incorporated into a well advanced reef design prior to applying for the permit.

Post-placement monitoring and management will be a condition of most permits. As the development of coral communities on bare substrates will usually take many years to show evidence of target outcomes, monitoring programs may need to continue for 5 to 10 years or more. Also it is essential to include in the monitoring and management program a provision for ongoing maintenance and possible minor design adjustments or further interventions as the artificial reef develops, so as to address unforseen factors that may inhibit coral development and the achievement of target outcomes.

In addition to the direct regulation of all artificial reef projects under the above legislation, there are other Commonwealth and State Acts that may be invoked, depending on the characteristics of the project. These include both legislation for the protection of the environment from detrimental impacts and acts governing marine navigation and installations.

It is also important to identify and consult the agency with vested responsibility for the seabed. In port areas, ports authorities will have their own administrative requirements. Consultation undertaken for the permit under the Sea Dumping Act will need to be extensive and, at a minimum, should address these issues of consultation with other agencies.

Chapter
2

Design and Construction

Siting

Siting the reef is probably the single most important decision to be made once the need for an artificial reef has been confirmed. The site must be suitable for establishment and long term persistence of a coral community. This must be assessed not only with respect to the environmental setting, but also to the current and expected future uses of the site. In areas such as operational ports, establishing a replacement reef close to the original site may provide a geographically sound offset, but also could put the new reef within the impact zone of future planned development.

The essential ecological requirements for coral establishment and growth include a stable hard substrate for coral attachment, adequate light for photosynthesis, good water quality and sufficient water movement to oxygenate the water and prevent sediment build-up.

While corals can adapt to a range of environmental conditions, it will be important to build the reef to deliver environments within the tolerance range of local corals. An understanding of the degree to which local corals can adapt will be essential when developing a reef design to allow successful natural establishment and long term viability of a coral community.

Factors to be considered in site selection are divided into three broad categories below: physico-chemical, biological and anthropological. Table 1 lists the factors, summarises the desirable characteristics and/or guideline ranges for each, suggests field-based methods of quantifying them, and gives examples drawn from the Parker Point artificial reef. Direct investigation of these factors should always be preceded by a literature search, as some of the necessary data may already be routinely collected by organisations such as local port authorities.

Physico-chemical

Depth

Depth of the artificial habitat should take into account the tidal range of the site, the light requirements of corals, the degree of exposure to wave action and, if applicable, the requirement for navigable depths over the constructed reef.

- Tidal range considerations – depth specifications must be established relative to the tidal range, likely to be 3 m to 10 m in northwestern Australia.
- Light attenuates rapidly in the turbid inshore waters of northwestern Australia, restricting corals to relatively shallow depths (e.g. 6-7m below LAT inshore Dampier). An artificial reef is unlikely to be successful if established at a greater depth.
- Wave action in shallow water can be extreme, especially during cyclones. Reef development in shallow exposed sites may be set back by physical damage to colonies.
- Navigable depth requirement may be determined by the Department of Transport (DOT) with respect to the type of boat traffic.

Wave exposure

Exposure of the site to metocean events under cyclonic and non-cyclonic conditions is an important consideration and will include such factors as seasonally prevailing wind strength and direction, cyclone wave exposure, and wave fetch, which determines wave strength and periodicity.

Water temperature

18 to 31°C is the generally accepted range of water temperature for coral reef development worldwide. In general, artificial reefs designed for coral colonisation should be situated in waters within the 18 to 31°C range if possible. Water temperatures on inshore Dampier reefs occasionally fall slightly below 18°C in winter and regularly exceed 31°C in summer (MScience, unpublished data). The high summer temperatures may be a significant stress to Dampier corals, judging by the prevalence of coral bleaching in summer.

Turbidity

Turbidity is usually highly variable in inshore northwestern Australia. Turbidity varies with respect to background tidal and seasonal patterns, with occasional spikes in turbidity associated with strong winds and/or rainfall. Coral communities generally have a good capacity to withstand short duration turbidity events but will gradually decline in environments where turbidity higher than normal background conditions becomes a long term chronic condition. In areas of shipping and port activity, the turbidity regime is likely to be critical in determining the type of coral community that develops on an artificial reef.

Light attenuation

Light attenuates rapidly with increasing depth in turbid water; the higher the turbidity the greater the light attenuation. Corals communities which have developed in clear waters may become light limited after an increase of only 3 NTU (Cooper and Fabricius 2007). (Cooper et al. 2008) suggest that long-term turbidity >3 NTU leads to sublethal stress to corals, whereas long-term turbidity >5 NTU corresponds to severe stress at shallow depths.

Salinity

Surface salinity of coastal waters in northwestern Australia may be greatly reduced during periods of heavy rainfall and runoff. Salinity stress during these events can cause widespread mortality in corals and other sessile benthic organisms on shallow reefs. The potential for periods of low salinity from land runoff should be considered during the site selection process. This factor can be addressed by identifying and avoiding sites where major drainage pathways from the hinterland enter the ocean.

Sedimentation

Other than the postulated effects of global warming, sedimentation is arguably the most common anthropogenic cause in the decline of coral communities (Erftemeijer et al. 2012; Fabricius 2005). As well as the lethal effects of smothering of corals, the continual requirement for corals to expend energy in clearing sediment (Stafford-Smith 1993) may weaken them and make them vulnerable to a variety of indirect sources of mortality. Few corals can survive in environments of constant high sedimentation.

Biological

Existing community

The characteristics and values of the existing reef community (or perhaps the historical reef community) are a primary driver in the decision to construct an artificial reef and the design of that reef. Decisions on whether the artificial reef should emulate the one that is going to be lost, or whether it could be designed in a way that the expected result will emulate a type of reef that has become rare or less common due to general coastal development pressures, are fundamental.

That initial determination will be important for both the physical design of the reef and its management (e.g. will selective species transplantations to the artificial reef be used to transplant rare or unusual corals).

The main focus should be towards the provision of a coral community that has well defined structural components and species composition. That is, success should not be only defined by just a percent cover metric, but by the mix of coral life forms in the reef community. This is despite the likelihood that most successful transplantations and natural regeneration processes will result in pioneer type corals dominating which are typically branching and encrusting growth forms.

Artificial coral habitats will usually be constructed over bare sediment. Artificial reefs should obviously not be placed over existing living benthic habitats, although it may be acceptable to cover small patches of existing habitat if they cannot be avoided, provided the loss of those patches is considered in assessing the net environmental benefit of the artificial reef. Potential effects of reef emplacement on nearby habitats should also be considered, both in terms of direct effects (e.g. physical damage) and indirect effects (e.g. shading, modification of water circulation).

Areas of bare hard substrate should be viewed with caution as potential artificial reef sites. Generally, any area of hard substrate that is suitable for coral colonisation will already be colonised by corals. If corals are absent there is likely to be an environmental reason for their absence, although it may not always be immediately obvious.

Competition

Like corals, many benthic invertebrates and macroalgae settle and grow on hard substrate. Invertebrates and macroalgae may compete with corals for space through rapid growth, shading, physical abrasion, and allelopathy (chemical toxicity). Competition may cause a reduction in suitable surface area for coral colonisation, and reduced vigour or increased mortality in affected coral colonies. Macroalgae appear to be significant coral competitors in nearshore Pilbara habitats, particularly *Dictyopteris australis, Asparagopsis taxiformis* and *Sargassum* spp. Most macroalgae show some seasonal variation in abundance. In Dampier, *Dictyopteris* appears to be most abundant in late winter to spring and *Sargassum* in late summer to autumn. When assessing potential artificial reef sites it should be noted that seasonal macroalgal abundance may be underestimated, depending on the season in which the assessment is undertaken.

Predation

Coral predators such as crown of thorns starfish and *Drupella* spp. gastropods have the potential to severely impact coral community development on artificial reefs. There is little point is locating an artificial reef in an area where the predation potential is predictably high. Field reconnaissance of potential sites should therefore include an assessment of the likelihood of predation by these organisms.

Larval availability

As most coastal waters in northwestern Australia are well mixed by tidal and wind-driven currents, planktonic coral larvae are likely to be widely distributed across most nearshore areas (see Kinlan and Gaines 2003 for instance) and there should be few areas where they are completely absent. A reliable larval supply would be expected if potential sources of coral larvae, i.e. natural coral reefs, are present within a few kilometres of the proposed site, particularly if the natural reefs are upstream with respect to the prevailing current directions during coral spawning periods. If time and resources permit in the planning stage, artificial reef site evaluations could benefit from studies examining the presence and density of coral larvae at alternative potential sites. It can also be beneficial to test for the presence of available larval settlement in monitoring established artificial reefs. If larval recruitment is consistently poor, coral transplantation may have to be considered. It should be noted however, that inter annual recruitment rates can vary substantially, so recruitment data from more than one reproductive season will be necessary to establish the natural background levels of coral larvae availability.

Anthropological

Commercial and recreational activities

Human activities have the potential to damage corals and retard coral reef development. Commercial activities include direct impacts such as land reclamation or jetty construction, and indirect impacts such as increased turbidity and sedimentation due to vessel traffic and dredging. Recreational activities include boating and fishing (particularly through anchor damage), and the provision of supporting infrastructure such as public boat ramps and marinas. In constructing an artificial reef as an offset for anthropogenic degradation of a coral reef habitat, it is obviously necessary to ensure that the replacement reef will not suffer the same fate as the degraded reef.

Regional development plans

Artificial reefs should be sited at an appropriate distance from areas planned for future development. The appropriate distance would have to be assessed on a case by case basis, bearing in mind the likely range of vessel traffic around the development footprint. Most port authorities in northwestern Australia provide their development guidelines and development plans on the internet, and these should be consulted early in the process of artificial reef siting.

Site Evaluation for Artificial Reef Placements

Factor	Desirable characteristics	Information required	Data methods/sources	Dampier Parker Point example
Spatial context: Characteristics of the impacted reef and other coral communities in the vicinity.	• Artificial reef should result in no net biodiversity loss • Community composition and structural features similar to adjacent naturally occurring reefs. • Focus on rare/vulnerable coral types.	• Mapping and characterisation of the closest naturally occurring reefs as a guide as to what are the most likely features to emulate • Characterisation of the reef needing to be offset due to development	• Scale of surveys to include representative reefs within the broad coastal type of the reef to be offset, e.g. within a bay • Visual assessment of relative percent presence of growth forms and dominant species present	Coral communities and hard substrate for 2-3 km around the impacted reef were mapped. The artificial reef was placed in an area of soft sediment mostly devoid of corals within 1 km of the area lost.
Depth	• Within the depth range of the maximum coral cover on nearby natural reefs • Minimum depth may be imposed for navigational safety	• Local coral depth distribution relative to LAT • Seafloor depth at potential artificial reef sites relative to LAT • Proposed topography of artificial reef	• Acoustic (sonar) surveys • Diving surveys to record depth range of live coral on naturally occurring reefs	The depth of the artificial reef was designed to be 1 to 3 m below LAT which was consistent with surrounding reefs and similar to, although slightly deeper than, the lost habitat.
Exposure	• Good water circulation and flushing rates but limited exposure to damaging waves (limited fetch)	• Hydrodynamic model • Wave climate*	• Hydrodynamic instruments, Simulation model using real data from the area • Comprehensive (seasonal) wave data available for ports	Hydrodynamic conditions were not optimal, but were considered adequate and less important than surrounds.
Water temperature	• Annual range within approximately 18-31°C	• Temporal (annual or longer) record of water temperature at potential artificial reef sites*	• Instrument records of long term diurnal measurements	Water temperatures were considered to be equivalent to those of surrounding reefs supporting a coral community.

Factor	Desirable characteristics	Information required	Data methods/sources	Dampier Parker Point example
Turbidity/Light attenuation	• Within the 80% percentile of light attenuation recorded at nearby reefs with coral communities	• Temporal record of turbidity as nephelometric turbidity units (NTU) or total suspended solids (TSS) and photosynthetically active radiation (PAR)*	• NTU and PAR logging sensors, or periodic site visits to measure NTU, TSS, PAR • Satellite imagery and aerial photographs may be useful in indicating general turbidity patterns	The target area was assessed as highly turbid due both to natural influences and port activity. However, it was felt the target coral community would be resilient to turbidity and location was more important.
Salinity	• Distance from sources of major freshwater runoff points	• Temporal record of salinity*	• Satellite/aerial records of flood water behaviour • In situ temporal salinity measurements	The target area has no major inputs of freshwater.
Sedimentation	• While sedimentation is a clear impact on corals, there is an enormous range in ability of different corals to withstand its effects. The best way to ensure development of a coral community is to ensure that the sedimentation regime is within bounds of areas containing similar communities.	• Temporal record of sedimentation rate* • Particle size distribution (PSD) and sediment organic content	• Sediment traps or logging sedimentation sensors • Direct surface sediment sampling for PSD and organics	See turbidity

Factor	Desirable characteristics	Information required	Data methods/sources	Dampier Parker Point example
Existing community	• Little sessile benthic habitat within the direct footprint • Nearby coral communities demonstrate the area's suitability and may provide connectivity with a broader genetic pool	• Habitat maps in and around potential artificial reef sites	• Diving surveys • Ground truthed satellite and aerial photos	Diving surveys confirmed there were few corals within the immediate footprint. Some minor coral development immediately north of the reef required protection during construction. Communities of corals within 1km of the reef suggested the area was suitable for coral survival.
Competition and predation	• Low density of potential competitors, especially macroalgae, and predators	• Quantitative or semi-quantitative estimates of macroalgal and invertebrate density at potential AR sites	• Diving surveys (seasonal)	No coral predators noted in unusual density in 2 years of monitoring near this site
Larval availability	• Ongoing natural supply of planktonic coral larvae		• Survey for corals on any hard substrate at potential artificial reef sites • Tile deployments around predicted coral spawning periods	Unknown at the time of design.
Anthropogenic activities	• Minimal anthropogenic disturbance	• Current commercial and recreational uses of potential artificial reef sites	• Port Operations department	Within the radius of water quality impacts from port operations, but location requirement to be near original loss and survival of nearby corals outweighed these concerns.
Development plans	• Appropriate buffer distance between artificial reef and future commercial developments	• Zoning of potential artificial reef sites	• Port Development Guidelines & Plans	Secure from future port expansions at the time of design.

*physico-chemical parameters should preferably be logged continuously for at least a year

Materials

Some early attempts at artificial reefs used inappropriate waste materials such as tyres and car bodies. The subsequent failure of these reefs and the costly remediation have engendered a precautionary approach in the permitting process—discriminating against 'materials of opportunity' in favour of modular, purpose-built artificial reef materials. A variety of purpose-built materials are available, constructed of concrete, steel, ceramic or polyvinyl chloride (PVC). The modules are generally configured with voids and spaces to increase surface area and provide shelter for mobile vertebrates and invertebrates. Depending on the manufacturer and the situation, modules can be either freighted to site or built onsite under licence. Multiple modules are deployed close together, or stacked, to create an artificial reef.

A disadvantage of purpose-built reef materials is their cost, both in monetary terms and in the consumption of raw materials and energy for production and transport. In comparison, locally sourced materials of opportunity are a lower cost, environmentally sound option, as long as the materials are appropriate for the intended purpose and their properties are thoroughly evaluated and understood. The Parker Point reef proves that materials which might otherwise be considered waste can meet relevant criteria for reef construction.

The Parker Point artificial reef was constructed from two locally sourced materials: rock boulders from a dismantled seawall and concrete sleepers recycled from conveyor foundations. These materials proved suitable in stability criteria (shape and weight) and in supporting coral recruitment and growth.

Local dredged material, other than that with a high friable sediment content, might be suitable for use as a substrate for artificial reef construction if it is composed of calcium carbonate. The choice of binding material or method of attachment to deliver a stable reef will have to be made on a case by case basis but will be influenced by the source material chosen for the artificial reef and the hydrodynamic setting.

In the Parker Point case a second reef was constructed using 24 Reef Balls® (www.reefball.org) constructed on site from commercially available moulds and set out in groups of 3 attached to concrete footings. The footings were used to guarantee the stability of the Reef Balls in this relatively shallow area. This component was included to allow this project to provide data for an evaluation of reef construction methods being undertaken by the Global Environment Fund at that time.

Figure 1. Recently constructed concrete ReefBalls at the RioTinto worksite in Dampier.

Figure 2. Concrete conveyor footings at the RioTinto worksite in Dampier.

Reef Configuration

Artificial reefs created as offsets will usually have a prescribed area, based on the area of degraded habitat they are offsetting. However, it will usually be up to the proponent to propose the spatial configuration of the reef. Defining the optimum configuration of artificial reefs is an evolving field, and there are currently few rules or guidelines available. Where attempts have been made to optimise reef configuration for a specific purpose, it is usually for fish habitat, e.g. by maximising the reef's perimeter length and/or providing fish migration corridors between adjacent reef modules. While such modifications may indirectly benefit corals by increasing the density of herbivorous grazers, more substantial direct benefits may be achieved by designing coral specific features into artificial reefs.

There will often be site constraints to configuration, so it will be necessary to map the surrounding area of a proposed site to determine the presence of other reef communities. Nearby habitat that should be avoided includes seagrass or other important soft sediment communities as well as hard substrate communities.

Considerations to optimise artificial reef configuration for corals are outlined below, including the reef's orientation with respect to wave and current directions, reef surface rugosity, and the proportion of horizontal to vertical substrate surface.

Reef orientation

Natural reefs are usually best developed at the reef front (the edge facing directly into the prevailing wave direction) because corals and coralline algae tend to grow best in clear and well oxygenated water. This pattern may also occur at a small scale on an artificial reef, and if so it could be exploited by orienting the reef to present the maximum surface area to the oncoming waves (i.e. long axis perpendicular to the direction of wave approach).

Coral colonisation on the Parker Point was greater on the seaward side than the landward side, consistent with the idea outlined above. However, local factors, such as the presence of natural reefs to seaward, could have contributed to this pattern. The concept of optimum orientation therefore remains hypothetical, but potentially beneficial.

Rugosity

In general, high rugosity means more surface area and microhabitat diversity, which should lead to higher coral cover and diversity. Newly settled coral require protective microhabitat from grazing animals, so high rugosity on the scale of a coral larvae requirements provides a good recruitment surface for attachment and early growth.

Horizontal vs. vertical substrate

Substrate orientation affects several physical variables that influence the distribution of benthic organisms, most importantly light availability and sedimentation. Both parameters will generally be greater on horizontal surfaces than vertical surfaces. As light is an essential requirement for scleractinian corals and sedimentation is a stressor, there is probably no universal coral preference for substrate orientation. Consequently, coral preference for substrate orientation could be expected to vary at different sites, and for different species as light and sediment tolerance levels vary between coral species.

On the Parker Point artificial reef, there was a clear preference of corals for horizontal substrates. Anecdotally this was attributed primarily to the distribution of invertebrate competitors. Invertebrates, primarily encrusting sponges, were far more abundant on the vertical surfaces. Being faster growing than corals, they rapidly occupied space on the vertical surfaces, and may have competitively excluded corals from settling there. Invertebrates were less abundant on the horizontal surfaces, possibly because they could not tolerate the higher sedimentation on horizontal surfaces.

Impacts to adjacent communities

Risks to adjacent biotic communities from the artificial reef can arise from physical impacts during construction (e.g. fugitive rocks during placement. suspended sediments) and from scouring caused by changes to the local hydrodynamics from the reef's physical presence. Impacts will be usually quite close to the reef edge and typically form a halo effect. Where the area of the artificial reef is relatively much larger than the potential halo of impact, this issue should not require consideration beyond an effort to minimise impacts by practical methods.

At the Parker Point artificial reef, concerns for the relatively sparse coral community on rocks surrounding the proposed reef were raised. As a result a component of the monitoring program followed individual corals in that area over time. This monitoring showed that over six years, mortality rates of these corals were no different to those of corals in a similar area, but far enough from the reef to be outside of any halo effect.

Construction

Artificial reef construction can be logistically challenging due to the mass of the materials and the difficulties in moving and deploying them in anything other than calm conditions. Therefore, the construction phase should be timed for the calmer months if possible. The most efficient method for bulky components will generally be the use of a crane and barge to load and deploy the material.

Prior to putting any materials into the water, efforts should be made to clear as much of the fine sediment from the material as possible. Simple screening with a loader bucket with holes in it has proven quite effective in this regard. Fine materials below 2 mm diameter will be particularly troublesome as they can be suspended by wave action and cause impacts at considerable distance from operations.

Deployment techniques range from simply pushing the material overboard without controlling placement on the seafloor, to precise placement of individual components guided by differential GPS positions into areas previously mapped by divers. The appropriate technique for a given situation will depend on the planned complexity of the reef configuration, the proximity of any nearby sensitive habitats, the susceptibility of the individual modules or components to physical damage during deployment, and whether it is necessary for the modules or materials to be placed in a particular orientation or format.

Figure 3. Rock boulders being cleaned in a digger bucket and then craned into place on the Parker Point artificial reef site, December 2006.

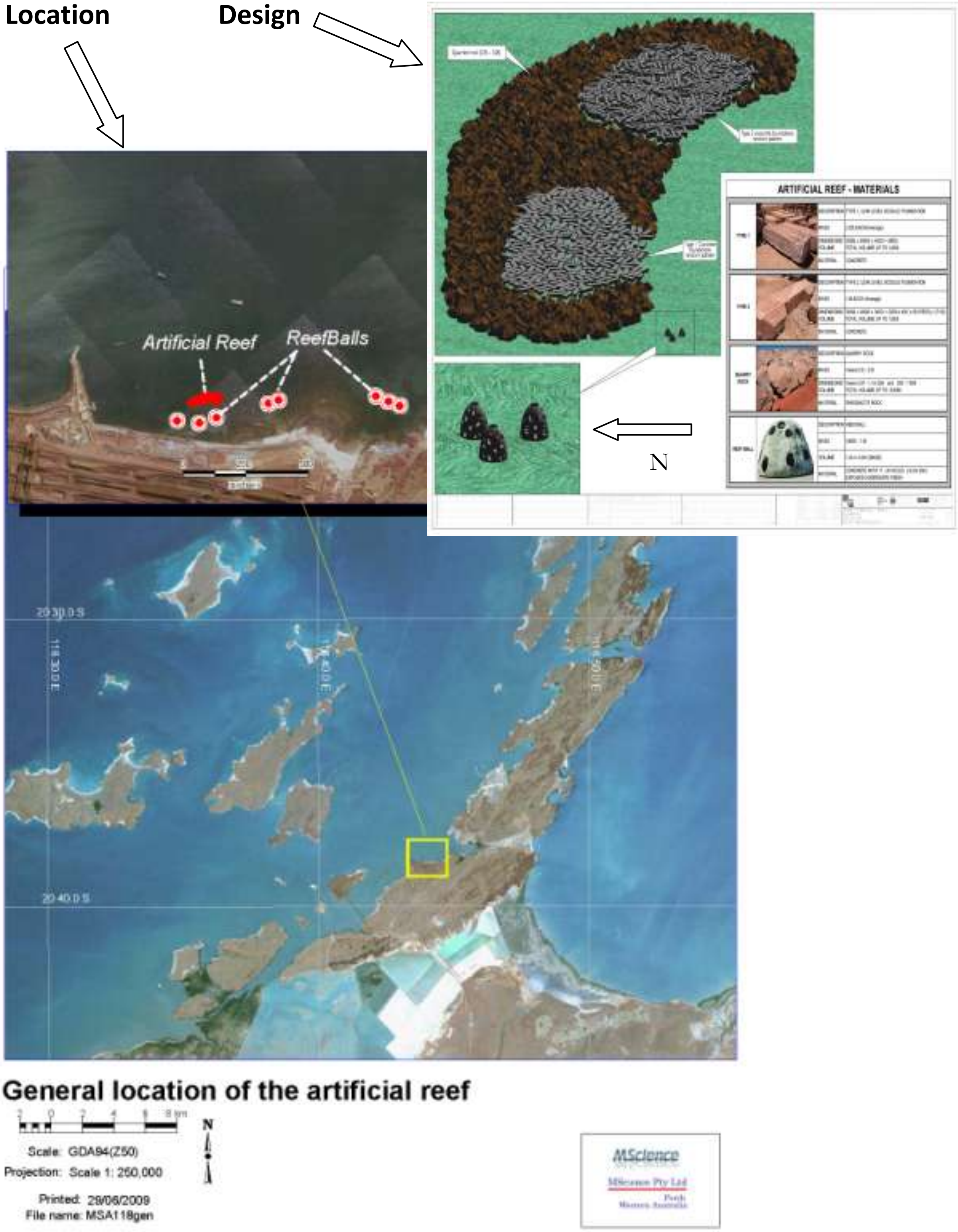

Figure 4 General location of the Artificial Reef within the Port of Dampier

Coral transplantation

If an artificial reef is situated in an area suitable for natural coral recruitment and growth, there should be no need to transplant coral colonies to the reef (Edwards and Clark 1999). Coral transplantation may be beneficial at sites where natural recruitment is low. However transplantation may only be a stop gap measure in these environments because a transplanted coral community may not persist in the long term without significant natural recruitment.

Where an artificial reef is created to offset coral habitat lost to environmental degradation or land reclamation, it is natural to consider transplanting coral colonies from the degraded area or the reclamation site to the artificial reef. However, coral transplantation is an extremely labour intensive and, from a cost-benefit perspective, inefficient process. This is especially so in northwestern Australia, where transplants will almost invariably have to be undertaken by commercial divers at great expense. In general, the resources required for transplantation would probably be better spent on upstream management to reduce anthropogenic pressure on existing reefs, or on research directed at optimising artificial reef design for natural colonisation and benthic community development. Transplantation is perhaps best reserved for situations where either:

- rare or valuable species are involved;
- accelerated coral community development is required, or
- competent volunteer divers are available to undertake the work.

The difficulties outlined above were underscored by the experience of the Parker Point artificial reef coral transplantation program, which consumed several hundred person-hours for only a moderately successful outcome (<50 % survival after 6 years). Learnings and recommendations from this program, and from other accounts of coral transplantation in the scientific literature, are summarised below with the intent of informing future coral transplantation projects in northwestern Australia, should they be considered necessary.

Species selection

Different types of coral have different environmental preferences. Survivorship of transplanted colonies will be improved by targeting species that are suited to the conditions at the transplant site. In nearshore northwestern Australia, this will generally mean selecting species that are tolerant to wave action, sedimentation or both. Species of the genus *Porites* are tolerant to both aspects, as are most of the massive (dome-shaped) faviids. *Turbinaria* are very tolerant to sedimentation but not as wave resistant as the massive genera.

In general, the species composition of the donor reef or other nearby natural reefs will be a useful guide to potential transplant species (Edwards 2010), bearing in mind that some species may not endure the transplant procedure as well as others—for example *Lobophyllia hemprichii*, an abundant species in Dampier Harbour, tends to break apart unless handled carefully.

(Edwards and Clark 1999) argue that there has been too much focus on transplanting fast-growing branching corals, which in general naturally recruit well but tend to survive transplantation and re-location relatively poorly, to create short-term increases in live coral cover, at the expense of slow-growing massive corals, which generally survive transplantation well but often recruit slowly. In cases where transplantation is justified, (Edwards and Clark 1999) recommend the early addition of slowly recruiting massive species to the recovering community. The aforementioned *Porites* and massive faviids will be appropriate corals in most of northwestern Australia.

Colony size

Large colonies have several advantages over small colonies for transplantation. Their major advantage is that, other things being equal, larger colonies have a better survival rate (Hughes 1984; Bowden-Kerby 1996). Their reproductive output will also be higher than small colonies, and they will provide more habitat and topographic relief at the transplant site. Although more small colonies can be transplanted per unit effort, our subjective impression from the Parker Point artificial reef transplants is that large colonies are more efficient in terms of biomass transplanted per unit effort.

The major disadvantage of large colonies is that, depending on size and weight, they may be difficult to bring onboard a small vessel, and may have to be towed below or behind the vessel. If the artificial reef is distant from the donor site, it will probably be more efficient to limit the maximum size to that which can be carried onboard. Of course, larger vessels with cranes and lifting equipment could be considered, if justified by a cost-benefit approach. The Parker Point experience was based on using small (4.6m) rigid inflatable vessels to transport colonies of up to approximately 100kg for a distance of less than 500m.

Transport

Heavy duty perforated plastic baskets ('prawn' baskets) are suitable for collecting and transporting small to medium-sized coral colonies. Most corals appear to comfortably tolerate transit on deck for at least an hour, although the aim should be to minimise the time exposed to air. Covering the baskets with wet towels is recommended, especially in hot or dry conditions. Some other invertebrates that may be attached to the coral rock, for example sponges, are less tolerant to exposure in air and would be best transported submerged.

Baskets, or individual colonies, that are too large to be brought aboard can be slung beneath the vessel, or beneath lift bags, and towed. As mentioned above, towing is slow and may not be feasible for distances more than a few hundred metres.

Attachment

Survivorship of unattached coral transplants is usually very poor in high wave energy environments. Almost all coastal environments in northwestern Australia would be classified as high wave energy, due to the prevalence of cyclones. Therefore, as a rule, cementing or glueing transplanted colonies to the substrate is recommended in northwestern Australia. A pilot study undertaken before the Parker Point transplant found that specialist underwater cement gave better results than either standard cement or two-part underwater epoxy. Nevertheless, the cementing undertaken in the transplant was only moderately successful, and many coral colonies were dislodged during storms and cyclones. Only a minority of dislodged colonies were found and the mortality rate among these was high. The usual cause of dislodgement was failure of the cement-to-substrate bond, not the coral-to-cement bond. This was probably due to the relatively smooth surface of the rock and concrete substrates; greater roughness would almost certainly have increased the cement bond strength.

Depending on the nature of the artificial reef materials, cable ties, embedded bars or other forms of physical attachment could conceivably be used to hold transplants in place until they can grow their own attachment base. But these too would have limitations due to the labour intensive nature of the process and the potential for the extra handling to reduce colony survivorship.

Regardless of the attachment technique, corals with a large flat base and a streamlined profile will have a greater likelihood of remaining in place. Again, *Porites* and faviids are suitable corals from this perspective.

Chapter

3

Management

In the context of this manual, the ultimate goal of an artificial reef is to develop a coral community that is similar in cover, composition and diversity to that of nearby natural reefs, and is sustained indefinitely[1]. This is a long term goal that could take decades to achieve, and is not always guaranteed to occur. It is therefore necessary to develop interim criteria and indicators that can be measured over shorter time scales to assess progress toward the desired goal. The criteria will change as the community develops, requiring different indicators and different methods to be adopted through time.

Monitoring

Monitoring natural coral community progression on an artificial reef (i.e. without coral transplants) will move from a small scale focus to relatively larger scale records over time. Monitoring will initially concentrate on early settlement and recruitment rates, then will include juvenile corals, and finally adult community dynamics as well. At the adult community stage, all three focal areas should be monitored to some degree.

The standard metric of reef condition is percent live coral cover, defined as the proportion of the substrate, in plan view, that is live coral. Coral cover is generally quantified by analysing photographic images of the reef surface. This method is not applicable in the early stages of colonisation, as newly-settled corals are too small to be detected in images. Instead, these early stages can be sampled by direct counts of individuals, presented as corals per m^2. Counts are undertaken visually underwater, within square quadrats of specific size, usually within the range 0.04 to $0.25m^2$. With intensive searching, corals down to approximately 1mm diameter can be identified with this method. Most corals of 1mm diameter are already at least 1 month old, so an accurate estimate of absolute coral recruitment rates will require other approaches such as the tile technique to obtain earlier stage colonisers (English et al. 1997). Programs using artificial settlement surfaces such as tiles can record most newly settled coral recruits even if they die soon after initial settlement.

An estimate of percent live coral cover can be obtained from the quadrat counts if coral diameters are recorded. The estimate is derived by calculating the combined

[1] A variety of other organisms would also be expected to colonise the artificial reef, but are not discussed here.

area of coral tissue (assuming circular colonies) and dividing by the total area of quadrats surveyed. The photographic percent cover method can probably replace the count method after approximately 5% live coral cover is achieved.

Juvenile coral taxonomy is useful in assessing whether the artificial reef community is approaching the natural reference site composition. Because most recruits less than one to two years old cannot be accurately identified beyond family level, initial comparisons between recruits and established coral communities will be general and non specific. However, genus and even species identifications should be possible within a few years and this will allow robust inter-community assessments. If genus level taxonomy is not possible, growth form community composition would be the next most accurate comparative approach.

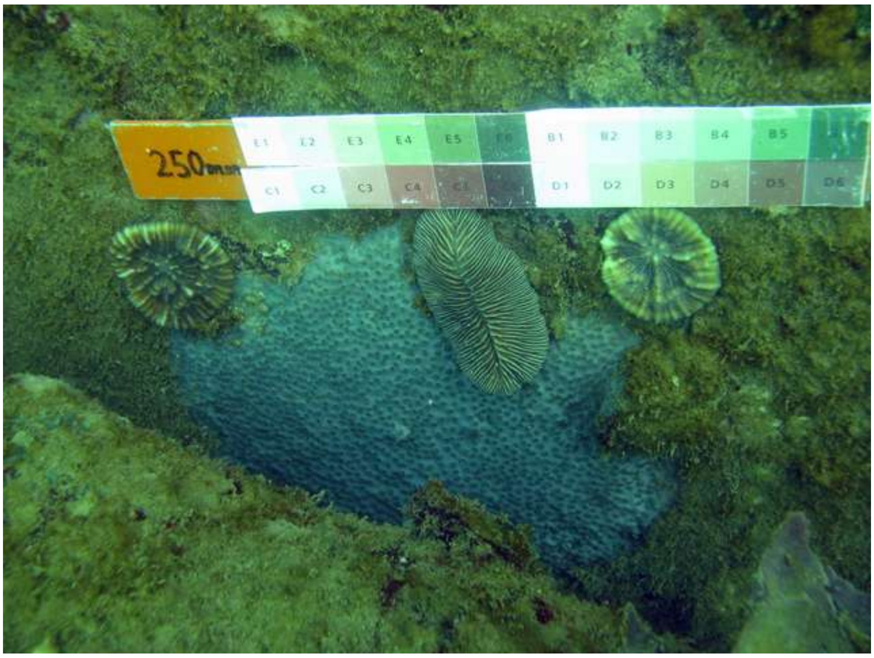

Figure 5. Juvenile corals growing on a vertical surface

It is important to note that even relatively long monitoring programs such as the six years at Parker Point is brief in the context of reef community development. Currently, the Parker Point artificial reef community composition is different to adjacent natural communities. For example there are fewer colonies of the larger longer-lived genera *Porites* and *Lobophyllia* on the artificial reef than in the natural reference community. The community composition of the artificial reef may eventually converge to that of the natural reefs but that is not certain at this stage. Intermittent events such as major cyclones or freshwater inundation could drastically alter survivorship and species composition on the artificial reef and/or the natural reefs. The community on the artificial reef might respond differently to perturbations compared to the natural reef community due to differences in the age structure of both communities and the likelihood of the reference community being relatively more resilient and adapted to the conditions at this site.

The recommended interim criteria to assess success of the artificial reef should be based around individual counts (predominantly of juveniles), taxonomy, and percent coral cover.

Fish and fishing were also regarded to be a significant aspect of the Dampier marine ecology of interest to many of the local population. In these nearshore areas, the physical topography of the local corals and the rocks they grow on provides an important component of the habitat as does their productivity. For that reason there was interest in what support the artificial reef might provide to fish. Biannual monitoring using underwater visual census was conducted to determine whether fish were using the reef and how they were using it.

Figure 6. Juvenile catfish within a ReefBall

Monitoring of most artificial reefs created within or near industrial operations will require monitoring teams with commercial diving qualifications. Elsewhere, involving the local diving community can be highly cost effective and produce a sense of ownership and empowerment for the reef's management. In either case, the monitoring program will need to be designed by someone with an appropriate marine science background.

Some results from the five years of monitoring since construction of the reef include:

FACTOR MONITORED	OUTCOME
Coral cover of the reef substrate	2.3%
Coral larval supply around the reef	100 –900 recruits per m^2 over a spawning season
Corals settling on the reef and surviving to visible size (>2 cm)	4.6 per m^2 per year
Coral distribution	Greater coral density on horizontal surfaces than vertical
Fish species	57 species recorded in 2008-2012 compared to 109 on nearby natural reef
Fish abundance	6.4 individuals per standard visual transect vs 7.0 per transect on nearby control reefs

Predictive models

To plan efficiently for establishing and monitoring an artificial reef, some simple predictive models of coral community development should be developed to set goals and interim criteria indicating progress of the project. The reason for incorporating a predictive model is that it can take a long time for a coral community to develop from an initial bare surface to a functioning coral reef. As a result of community succession processes, the monitoring focus is likely to change over time as the artificial reef community develops. While it is desirable to maintain continuity in general descriptors such as percent cover, a monitoring program may be strengthened by substituting other variables, such as individual counts or reproductive capacity, into or out of the program at appropriate times. A model can provide valuable guidance regarding monitoring or management emphasis.

Even the simplest models will need coral settlement, growth and mortality rates. More complex models include other classes of organisms, interaction and competition between adjacent organisms and predictions on the frequency, severity and spatial scale of disturbance events. These require considerable knowledge of local and regional processes as well as coral ecology.

In many instances, the group constructing the reef may not be the long term managers of the area, and may not have accountability for regulating or managing biodiversity conservation in the area. In these circumstances, there will come a stage at which the reef becomes part of the natural area and its management is divested. A predictive model of community development will be a very useful tool to indicate when the reef becomes 'self managing' and its management can be divested to public agencies.

For Rio's Parker Point reef, a predictive model built on the framework of the Compete® model was produced to examine coral community development on the Great Barrier Reef (Wakeford et al. 2008). It used coral recruitment, growth and survival parameters estimated from coral monitoring on the artificial reef and other programs in the area. The figure below shows coral cover predicted from 3 different versions of the model compared to the line of best fit describing actual cover recorded on the reef. In later years, the lowest estimate is probably the better predictor of cover as once corals become dense they start to compete for space with their neighbours. All versions of the model indicated that the target of 10% coral cover would be met within approximately eight to ten years after reef construction.

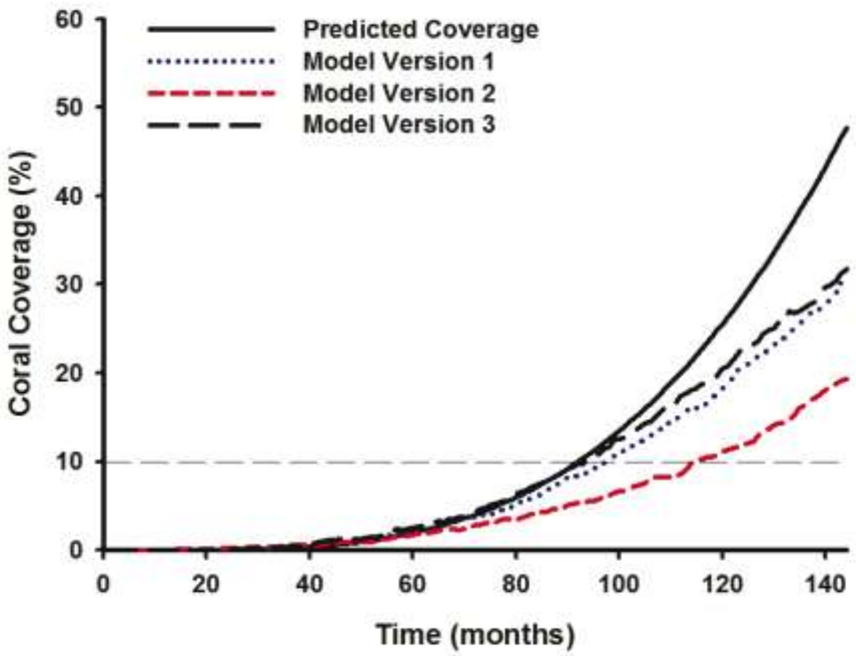

Figure 7. Model predictions of community growth on the Artificial Reef

Intervention

Decisions to intervene or not with an artificial reef will be guided to a large extent by the long term goals and will probably need expert opinion. Intervention may be beneficial if it appears that deficiencies in design or construction are preventing or significantly affecting the natural succession of a coral community on the artificial reef. In particular, unstable components of the artificial structure that are moving with the prevailing sea conditions will have to be stabilised or removed as they will damage adjacent coral colonies and/or colonies on the mobile components.

Intervention, in the form of removal, may be beneficial in the event of unseasonal or atypical colonisation of the artificial reef by highly competitive organisms such as macroalgae, or by outbreaks of predators such as crown of thorns starfish or *Drupella*. If left unchecked, such influxes of competitors or predators could feasibly reset the artificial reef community back to the initial establishment phase.

Intervention after natural phenomena such as cyclones could be deemed necessary, particularly if the artificial reef base material has been destabilised. Other types of perturbations that selectively remove components of the developing coral community (e.g. temperature anomalies, brief low salinity intrusions) should be looked on as part of the natural selective processes at the site. Species that are adapted to these occasional impacts will survive to be an important resilient component of the artificial reef's coral community.

No management intervention has been necessary for the Parker Point reef. Post construction surveys of the location of the rocks and concrete blocks have shown that these have behaved as predicted and have not moved out of the original footprint. With the current levels of coral settlement and survival, it appears that the targets for coral community development and other ecological values, such as supporting fish communities, will be met without the need for additional management.

Other useful guides

Artificial reefs have received considerable attention over the years and there is abundant scientific and grey literature discussing them. Many of the techniques used in creating and monitoring artificial reef are the same as those used in the rehabilitation of damaged natural reefs; therefore publications on reef rehabilitation are often directly applicable to artificial reefs. Some recent manuals and guidelines are listed below. Most of these documents contain extensive reference lists introducing the reader to earlier research.

Edwards, A.J. (ed.) (2010). *Reef Rehabilitation Manual*. Coral Reef Targeted Research & Capacity Building for Management Program: St Lucia, Australia. 166 pp.

Edwards, A.J., Gomez, E.D. (2007). *Reef Restoration Concepts and Guidelines: making sensible management choices in the face of uncertainty*. Coral Reef Targeted Research & Capacity Building for Management Programme: St Lucia, Australia. iv + 38 pp.

Lindberg, W.J. and W. Seaman (eds.) (2010). *Guidelines and Management Practices for Artificial Reef Siting, Usage, Construction and Anchoring in Southeast Florida*. Florida Department of Environmental Protection. Miami, FL. 3 pp.

Precht, W.F. (ed.) (2006) *Coral Reef Restoration Handbook*. CRC Press. Florida. 363pp.

Lukens R.R. and Selberg C. (2005) *Guidelines for Marine Artificial Reef Materials*.2nd Ed, Atlantic and Gulf States Marine Fisheries Commissions Publication 121, Ocean Springs MS. 205pp.

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Stafford-Smith MG (1993) Sediment rejection efficiency of 22 species of Australian scleractinian corals. Marine Biology 115: 229–243

Wakeford M, Done T, Johnson C (2008) Decadal trends in a coral community and evidence of changed disturbance regime. Coral Reefs 27: 1-13