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CORAL TRANSPLANTATION AS A REEF MANAGEMENT OPTION

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ABSTRACT

Transplantation of hard corals as a means of accelerating the regeneration of damaged coral reefs, or as a way of establishing reef areas where none exist naturally has been tested in many parts of the world. The transplantation is generally successful from a biological point of view, with survival rates in most cases ranging between 50% and 100%, when corals are transplanted into similar habitats to those from which they were collected. The different techniques used for coral transplantation are described here, and the costs and limitations of coral transplantation in coral reef management are discussed. The process has a potential role in the repair of reefs damaged by human activities, analogous to terrestrial re-forestation projects. However, coral transplantation is a very expensive process and generally would be considered as a valid option only in areas of high commercial, recreational or aesthetic value.

INTRODUCTION

The potential role of coral transplantation in coral reef management has been discussed by several authors. Maragos (1974) produced one of the earliest reports, investigating the transplantation of two coral species into areas of Kanehoe Bay, Hawaii affected by eutrophication (Banner, 1974). Coral transplantation was also considered to have potential for replacement of corals killed by heated effluent from a power station at Guam (Birkeland et al., 1979). The aim was to replace, the corals killed with more thermally tolerant species. Auberson (1982), Alcala et al., (1982) and Yap and Gomez (1984, 1985), discuss coral transplantation to reefs in the Philippines. Bouchon et al. (1981) successfully transplanted entire patch reefs in the Red Sea.

In reports on the Great Barrier Reef, Kojis and Quinn (1981) discuss the selection of corals for transplantation, while Harriott and Fisk (1988a) report on trials of coral transplantation at Green Island reef, which was affected by the crown of thorns starfish.

Here, we compare the published reports and outline the favoured techniques for coral transplantation. We look at some factors that might limit the rates of natural reef recovery, discuss the role coral transplantation can play in the management of damaged reefs, and assess the limitations of the methods.

DAMAGE TO CORAL REEFS

Damage to coral reefs has been extensively reported in the literature, and has been reviewed by Stoddart (1969), Endean (1976), Johannes (1975), and Pearson (1981). The damage can be grouped into three general categories: physical events such as storms; biological events such as predation by the crown of thorns starfish coral or bleaching; and those caused by man.

Physical damage is most commonly caused by storms and cyclones, which cause wave action, freshwater runoff and high sediment load. Earthquakes, volcanoes, red tide, and extreme low tide also cause widespread death (Loya, 1976a; Stoddart, 1969; Grigg and Maragos, 1974).

Damage caused by man's activities include acute disturbances such as dredging (Maragos, 1974), blasting (Auberson, 1982), ship groundings (Curtis, 1985); the effects of coral collection (Oliver, 1985a; Wells, 1982); and chronic events such as damage caused by runoff from agricultural land and pollution (Loya, 1976a; Banner, 1974).

Coral bleaching as a reaction to some physical stress has resulted in extensive coral mortality in reef areas throughout the world (Glynn, 1983, Fisk and Done (1985), plus reports in this proceedings). On the Great Barrier Reef and other areas of the western Pacific, predation by the crown of thorns starfish has caused great damage to coral communities (Moran, 1986). At some reefs on the Great Barrier Reef, over 80% of the hard coral cover was eaten by the starfish in each of the two outbreaks (Cameron and Endean, 1982; Moran, 1986; Fisk et al. 1988).

NATURAL RECOVERY OF DAMAGED REEFS

The rate of recovery of hard corals from reef damage will depend on the type and extent of damage, position on a reef where damage has occurred, the species affected, and on the recruitment rate of ner corals (Endean, 1976; Pearson, 1981). Recovery from damage caused by man's activities will additionally depend on whether the cause of the damage has ceased, and whether there are any long term effects, e.g. from pollution residue. Recovery of a reef flat from an extreme low tide was found to be slower on a reef affected by oil pollution than on a nearby unpolluted reef (Loya, 1976a), and recruitment of juveniles may be inhibited on surfaces covered by sediment (Johannes, 1975).

Estimates for time of recovery of coral reefs from serious impact vary from as little as 5 years to centuries (Pearson, 1981), and depend greatly on the definition of recovery. A survey of Green Island Reef over five years following extensive predation by the crown of thorns starfish showed a hard coral cover of less than 10% at 15 of the 20 sites surveyed, despite good juvenile coral recruitment (Harriott and Fisk, 1988b).

Growth rates of new hard coral recruits are generally slow (Wallace, 1983; Harriott, 1985; Babcock, 1985), so it is many years before new recruits contribute significantly to an increase in coral cover. The primary aim of coral transplantation is to bypass the early slow growth phase by adding established colonies with a higher probability of survival and rapid growth rate.

IS RECOVERY RECRUITMENT LIMITED?

A second function proposed for coral transplantation is to add adult corals to the population so that they produce larvae that recruit locally to accelerate the recruitment process. Kojis and Quinn (1981) provide an extensive summary of factors to consider to increase the probability of successful reproduction by transplanted corals.

Transplantation to increase local recruitment is only a factor where the rate of recovery of corals is limited by the availability of larval recruits (Maragos, 1974; Pearson, 1981), and when the larvae of transplanted corals are likely to recruit close to the adult corals e.g. for some planulating species and those with negatively bouyant eggs. However, Harriott and Fisk (1988c) report that coral recruitment onto settlement plates was significantly greater at Green Island with its depauperate adult coral community than at nearby undamaged reefs, and thus lack of larval recruits as unlikely to always slow reef recovery. There is accumulating evidence, at least for the Great Barrier Reef, that coral planulae with larval lives in the order of 3 to 10 days may potentially be dispersed 10's to 100's of kilometers from the parent reef (Williams et al., 1984; Babcock, 1985; Oliver and Willis, 1987). If wide dispersal of coral propagules is the rule in other geographical locations, the larvae of transplanted corals that are broadcast spawners may well be removed from the transplant reef.

APPLICATIONS FOR CORAL TRANSPLANTATION

Circumstances under which a reef user or manager might elect to transplant corals are:

1. To increase coral cover in areas of recreational significance, especially economically important areas,where the coral community has been damaged by a natural physical disturbance, or by the crown of thorns starfish, or even if the area is naturally depauperate (Bouchon et al. 1981).

2. The process of construction of tourist facilities on or near reefs may damage the coral community, and it may be desirable to accelerate reef recovery to reconstruct the reef.

3. Where reefs have been damaged by commercial activities e.g. by dynamiting, dredging, sewerage, power station effluents, boat groundings, and particularly where the damage was caused as the result of negligence, the responsible agent might take steps to return the community to a healthy state. One recent example is the grounding of the "Wellwood" in Florida (see reports in this symposium) which resulted in intensive efforts to accelerate the recovery of the damaged reef community.

4. Populations of rare species threatened by loss of specific habitat can be transplanted to comparable unthreatened sites (Plucer-Rosario and Randall, 1987). Similarly, corals in areas that will be subsequently destroyed by construction activities, such as the "capping" of coral patch reefs for a floating hotel at John Brewer Reef, Australia, can be transplanted away from the area before the damage is done (Fisk, personal observations).

5. Coral reef aquaria that maintain living corals require transplantation of corals to the aquaria, under similar conditions to transplanting in the field.

CORAL TRANSPLANTATION TECHNIQUES

Corals must be collected from a habitat similar to that into which they will be transplanted, especially with respect to the degree of water movement, depth and turbidity. Corals from shallow clear turbulent reef fronts will not do well in turbid sheltered bays (Maragos, 1974; Plucer-Rosario and Randall, 1987).

While there is considerable variation in coral survival between different species in published reports (Table 1), in most cases where corals were transplanted into comparable environments, survival rates of 50% to 100% were found several months following transplantation.

Harriott and Fisk (1988a) recommended branching staghorn *Acropora* species as transplants in the Pacific, because of their high survival rate, aesthetic appeal, fast growth rate, and ability to occupy large amounts of space for their weight. Species of similar structure and habitat in the Caribbean could also be used. Alcala et al. (1982) found the highest survival and fastest growth rate for transplanted *Acropora* fragments.

Several studies of coral transplantation have tested the option of seeding large areas of reef with small colony fragments (less than approx. 10cm length) (Table 1). Despite the fact that some corals are known to survive fragmentation (Highsmith, 1982), this technique has not proved feasible in transplantation experiments because of the extremely high mortality rates of small fragments, even for taxa that reportedly fragment naturally (Harriott and Fisk, 1988a; Oliver, 1985a; Birkeland et al. 1979; Plucer-Rosario and Randall, 1987).

Coral "nubbins" (3 - 6cm fragments glued to bricks or tiles) have also been transplanted, but with insufficient success to justify the time for their preparation other than for experimental purposes (Birkeland et al., 1979; Rosario and Randall, 1987).

Most experiments on corals transplantation have involved transportation of the colonies submerged in water, to reduce the potential stress on the transplant. This limits the number of corals that can be carried at a time because of the weight and space occupied by water containers. Harriott and Fisk (1988a) report no significant decrease in survival for coral colonies and fragments of three taxa transported shaded on the boat deck for up to one hour, compared to colonies transported in water. Even after longer exposures, coral survival of two taxa was approximately 50% and 90%

Table 1: Published results of experiments testing coral transplantation.

Author	Location	Method	Species/taxa	Time	Survival
Bouchon et al. (1981)	Red Sea	Patch reef	Various	1 yr	65%
Auberson (1982)	Philippines	Segments	Heliopora coerulea	1 yr	100%
			Montipora prolifera	1 yr	50%
			Acropora brueggemanni	1 yr	44%
			Acropora prominens	1 yr	52%
			Millepora platyphylla	1 yr	58%
			Millepora dichotoma	1 yr	68%
Birkeland et al. (1979)	Guam	Colonies or Segments	Various	-	95% of attached corals
		Fragments	Porites cylindrica	2 mo.	0%
		Nubbins	Two species	-	0%
		Colonies or Segments	Porites cylindrica	10 mo.	47%
Plucer-Rosario & Randall (1987)	Guam	Nubbins	Pavona cactus	-	14 - 100%
		Heads	Pavona cactus	-	20 - 90%
		Shards	Pavona cactus	-	3 - 33%
		Nubbins	Montipora pulcherrima	-	0 - 83%
		Heads	Montipora pulcherrima	-	10 - 73%
		Shards	Montipora pulcherrima	-	0 - 21%
		Nubbins	Leptoseris gardineri	-	0 - 99%
		Heads	Leptoseris gardineri	-	0 - 83%
		Shards	Leptoseris gardineri	-	0 - 11%
		Nubbins	Acropora echinata	-	0 - 81%
		Heads	Acropora echinata	-	7 - 93%
Harriott & Fisk (1988)	G.B.R.	Fragments	Porites cylindrica	5 mo.	75%
		Segments or Colonies	Pocilloporidae	5 mo.	89%
		Segments or Colonies	Faviids	5 mo.	96%
		Segments or Colonies	Acropora (plate)	5 mo.	96%
		Segments or Colonies	Acropora (staghorn)	5 mo.	57%
		Segments or Colonies	Acropora (staghorn)	7 mo.	60 - 100%
		Segments or Colonies	Pocillopora damicornis	7 mo.	50 - 100%
		Segments or Colonies	Faviids	7 mo.	92%
Maragos (1974)	Hawaii	Segments or Colonies	Montipora verrucosa	-	25 - 60%
		Segments or Colonies	Porites compressa	-	6 - 71%

for 2 hour exposure, and 40% and 70% for 3 hour exposures.

Yap and Gomez (1984) report higher mortality of corals transplanted during the hotter months. This correlates with the period when many coral species show depressed growth, and when minor bleaching events indicating physiological stress can occur (Oliver, 1985b). The additional stress of transplantation should be avoided at that time.

The shape of the coral colony or fragment is significant, with branched fragments able to survive better because part of the living tissue is raised above the substratum (Kojis and Quinn, 1981; Harriott and Fisk, 1988a). Yap and Gomez (1985) found higher survival of Acropora pulchra fragments placed upright in the natural growth orientation compared to those set prone in tyres. On the other hand, Harriott and Fisk (1988a) and Oliver (1985a) found no difference in survival of Acropora fragments and Pocillopora damicornis fragments respectively that were either carefully placed in the growth orientation or randomly scattered.

Maragos (1974), Plucer-Rosario and Randall (1987) and Harriott and Fisk (1988a) report that survival of transplanted corals was high in sheltered conditions even when corals were not attached to the substrate. At shallow sites or in rough conditions, unattached corals are likely to be rolled over, broken up or moved large distances. During Cyclone Winifred, a small cyclone in N.E. Australia, coral transplants that had survived for 9 months were totally destroyed (Harriott and

Fisk, 1988a). Similar sized fragment of Pocillopora damicornis had higher survival in one study when they were attached (Kay and Liddle, 1983) than in a similar study when they were not attached (Oliver, 1985a), although other factors such as location also varied between the two reports.

Various methods have been used to attach coral transplants, e.g., cement (Auberson, 1982; Alcala et al., 1982); plastic coated wire (Birkeland et al., 1979); metal bedframes (Maragos, 1974); or plastic electrical cable ties (Harriott and Fisk, 1988a). Bouchon et al. (1981) overcame such a difficulty in an area where no reefs had existed by transplanting small intact patch reefs (one containing 42 hard coral colonies) so that no attachment was necessary. The requirements for any attachment method used for repair of recreationally important reefs are that the process is rapid, aesthetically pleasing, and permanent. Cement or plastic cable ties meet these criteria, but cable ties are only effective when a dead coral framework is present.

EFFECT ON COLLECTION SITE

By definition, coral transplantation requires the removal of coral from one site in order to transplant to a second site. The relative impact on the collection site and the transplant site must be considered by reef managers is assessing the net benefit of transplantation.

Among the published reports, only Harriott and Fisk (1988a) have apparently investigated the impact of transplantation on the collection site. They indicate that only a small percentage of the corals at a particular site are likely to be suitable for transplantation by meeting the criteria of being a target species, the appropriate size with a small, dead, readily-breakable base. They recommend that collecting effort should be spread over a wide area to minimize the impact at any one site, and that part of a large branching colony be left in place at the site to allow rapid replacement of the removed coral (Loya, 1976b).

COSTS

The major cost of a coral transplantation programme is labour. Other costs are boat charter or operating expenses, diving equipment, and small amounts of equipment such as bins, hammers etc.

The costs of the project would vary depending on

1. the objectives of the exercise in terms of appearance and coral cover
2. the amount of pre-existing coral cover
3. the attachment method for transplants
4. the experience and skill of the collectors
5. the distance to a site with corals for collection
6. the area and density of corals at the collection site.

Coral transplantation is time-consuming and therefore expensive where labour costs are high. Birkeland et al. (1979) and Harriott and Fisk (1988a) give approximate time periods necessary for the transplant methods described, and cost estimates could be calculated from these.

CONCLUSIONS AND MANAGEMENT IMPLICATIONS

The applications of coral transplantation in reef management is more limited than might have been predicted theoretically. In regions where coral larvae disperse widely, coral transplantation is unlikely to play a major role in increasing the recruitment of coral juveniles. Transplantation of planulating species or those known to recruit loca. In addition, transplantation of many small fragments as a means of seeding large reef areas is unlikely to succeed, despite observations on the significance of fragmentation to the localised dispersal of many coral species.

However, transplantation of large fragments or whole colonies is biologically feasible, with survival rates of 50% to 100% reported in some studies when corals are transplanted between similar habitats. There is a real role for coral transplantation as a way of preserving corals before a premeditated impact, and in the repair of recreationally important reefs damaged either by natural events, or more particularly those damaged by negligence or construction activities.

Coral transplantation is expensive, especially in locations where labour costs are high. Where reefs remain valued recreational and commercial resources, legal requirements to ensure the repair of reefs damaged by commercial activities (such as shipping accidents or construction) in a similar manner to terrestrial reforestation projects would mean that coral transplantation will become increasingly important.

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