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Review: Current trends in coral transplantation – an approach to preserve biodiversity

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ABSTRACT

Ammar MSA,El-Gammal F, Nassar M, Belal A, Farag W, El-Mesiry G, El-Haddad K, Orabi A, Abdelreheem A, Shaaban A. 2013. Review: Current trends in coral transplantation – an approach to preserve biodiversity. Biodiversitas 14: 43-53. The increasing rates of coral mortality associated with the rise in stress factors and the lack of adequate recovery worldwide have urged recent calls for actions by the scientific, conservation, and reef management communities. This work reviews the current trends in coral transplantation. Transplantation of coral colonies or fragments, whether from aqua-, mariculture or harvesting from a healthy colony, has been the most frequently recommended action for increasing coral abundance on damaged or degraded reefs and for conserving listed or “at-risk” species. Phytoplanktons are important for providing transplanted corals with complex organic compounds through photosynthesis. Artificial surfaces like concrete blocks, wrecks or other purpose-designed structures can be introduced for larval settlement. New surfaces can also be created through electrolysis. Molecular biological tools can be used to select sites for rehabilitation by asexual recruits. Surface chemistry and possible inputs of toxic leachate from artificial substrates are considered as important factors affecting natural recruitment. Transplants should be carefully maintained , revisited and reattached at least weekly in the first month and at least fortnightly in the next three months. Studies on survivorship and the reproductive ability of transplanted coral fragments are important for coral reef restoration. A coral nursery may be considered as a pool for local species that supplies reef-managers with unlimited coral colonies for sustainable management. Transplanting corals for making artificial reefs can be useful for increasing biodiversity, providing tourist diving, fishing and surfing; creating new artisanal and commercial fishing opportunities, colonizing structures by fishes and invertebrates), saving large corals during the construction of a Liquified Natural Gas Plant.

Key words: Coral transplantation, biodiversity, aquaculture, mariculture, nursery, artificial reefs

INTRODUCTION

Coral reefs are underwater structures made from calcium carbonate secreted by corals. They are also colonies of tiny living animals found in marine waters that contain few nutrients. Most coral reefs are built from stony corals, which in turn consist of polyps that cluster in groups. Coral reefs are fragile ecosystems, partly because they are very sensitive to water temperature. They face numerous threats from climate change, oceanic acidification, blast fishing, cyanide fishing for aquarium fish, overuse of reef resources, and harmful land-use practices, including urban and agricultural runoff and water pollution, which can harm reefs by encouraging excess algal growth. The coral reef ecosystem is a diverse collection of species that interact with each other and the physical environment. The sun is the initial source of energy for this ecosystem. Through photosynthesis, phytoplankton, algae, and other plants convert light energy into chemical energy. As animals eat plants or other animals, a portion of this energy is passed on. The Importance of corals and coral reefs include: (i) Corals remove and recycle carbon dioxide. Excessive amounts of this gas contribute to global warming. (ii) Reefs shelter land from harsh ocean storms and floods. (iii) Reefs provide resources for fisheries. Food items include fishes, crustaceans, and molluscs. (iv) Coral reefs attract millions of tourists every year. (v) The coral reef is an intricate ecosystem and contains a diverse collection of organisms. Without the reef, these organisms would die. (vi) Some evidence suggests that the coral reef can potentially provide important medicines, including anti-cancer drugs and a compound that blocks ultraviolet rays. (vii) Coral skeletons are being used as bone substitutes in reconstructive bone surgery. The pores and channels in certain corals resemble those found in human bone. Bone tissue and blood vessels gradually spread into the coral graft. Eventually, bone replaces most of the coral implant. (viii) The coral reef provides a living laboratory. Both students and scientists can study the interrelationships of organisms and their environment.

Those very important coral reefs suffered sharp decline due to several reasons which are both natural and anthropogenic. So, urgent strategies are needed to save coral reefs, the most important of which is coral transplantation. The purpose of the present work is to provide a review for current trends in coral transplantation as a basis for preserving biodiversity.

NEED FOR CORAL CONSERVATION

The increasing rates of coral mortality associated with the rise in stress factors and the lack of adequate recovery worldwide have urged recent calls for actions by the scientific, conservation, and reef management communities (Rinkevich 2008, Teplitski and Ritchie 2009). In cases of acute physical damage to reefs, such as in ship groundings, sophisticated engineering methods have been developed to mitigate damage and to maximize recovery and are used in combination with substrate stabilization and colony transplantation (e.g., Jaap et al. 2006). Loss of live coral cover has been more related to abnormally high sea-surface temperatures and incidence of diseases, rather than direct human activities (e.g., Miller et al. 2009). De Vantier et al. (2006) studied the indicators of management effectiveness in Bunaken National Park. On a global scale, the value of total economic goods and services provided by coral reefs have been estimated to be US$375 billion per year with most of this coming from recreation, sea defence services and food production, that equates to an average value of around US$6,075 per hectare of coral reefs per year (Edwards and Gomez 2007). Degradation of reefs means the loss of these economic goods and services, and loss of food security to people living in coastal areas (Sutton and Bushnell 2007). Reef restoration may face economic, legal, social and political constraints which are very much critical to coral reef conservation policies like the ecological factors (Job et al. 2003).

Recently, restoration strategies have focused on the broader conservation effort, emphasizing the need to combine local management actions, such as establishment of no-harvest marine reserves and effective management of the coastal zone (both terrestrial and marine), with direct actions, such as transplantation (Mumby and Steneck 2008, Bruckner et al. 2009). Transplantation of coral colonies or fragments, whether from aqua-, mariculture or harvesting from a healthy colony, has been the most frequently recommended action for increasing coral abundance on damaged or degraded reefs and for conserving listed or “at-risk” species (Teplitski and Ritchie 2009, Williams and Miller 2010). It has been suggested that newly developed molecular tools be used to optimize selection of coral propagules for cultivation and transplantation, to deepen our understanding of transplant survival (Baums 2008), and to identify and maximize the genetic diversity of transplants (Ammar et al. 2000, Shearer et al. 2009), which is considered essential. Debate continues over the effectiveness of transplantation in conserving threatened coral species, increasing coral abundance, and accelerating reef restoration or enhancement at ecologically relevant temporal and spatial scales. This controversy is due in part to the small scale of transplant studies compared to the scale of reef damage (e.g., Edwards and Gomez 2007) and the relatively short duration of most studies. Roeroe et al. (2009) developed a coastal environmental assessment system using coral recruitment. No coral conservation strategy will be effective until underlying intrinsic and/or extrinsic factors driving high mortality rates are understood and mitigated or eliminated (Garrison and Ward 2012).

REHABILITATION VS. RESTORATION

Rehabilitation can be defined as ‘‘the act of partially or, more rarely, fully replacing structural or functional characteristics of an ecosystem that have been reduced or lost’’ (Precht 2006). It may also be the substitution of alternative qualities or characteristics than those originally present provided that they have more social, economic or ecological value than existed in the disturbed or degraded state (Elliott et al. 2007) Thus, the rehabilitated state is not expected to be the same as the original state or as healthy but merely an improvement on the degraded state (Bradshaw 2002). Ecosystem restoration has been defined by Baird (2005) as ‘activities designed to restore an ecosystem to an improved condition. However, this does not imply the highest quality of the final ecosystem but merely that it is better than the degraded situation. Because of this, a preferable definition of restoration is ‘the process of re-establishing, following degradation by human activities, a sustainable habitat or ecosystem with a natural (healthy) structure and functioning’ **(**Livingston 2006, Yeemin et al. 2006). Simenstad et al. (2006) and Van Cleve (2006) take this to be returning an ecosystem to its predisturbance condition and functioning.

TRANSPLANTATION OF STORM-GENERATED CORAL FRAGMENTS

Transplantation of coral colonies or fragments, whether from aqua-, mariculture or harvesting from a healthy colony, has been the most frequently recommended action for increasing coral abundance on damaged or degraded reefs and for conserving listed or “at-risk” species (Ammar et al. 2000, Rojas et al. 2008, Teplitski and Ritchie 2009, Shaish et al. 2010). Yet there is a deepening awareness that no habitat, once damaged or degraded, can be restored to its original condition and that the basic factors causing declines must be addressed if restoration of reefs and conservation of threatened reef species are to succeed over time (Bruno and Selig 2007). In response to dramatic losses of reef-building corals and ongoing lack of recovery, a small-scale coral transplant project was initiated in the Caribbean (U.S. Virgin Islands) in 1999 and was followed for 12 years (Garrison and Ward 2012). The primary objectives were to (i) identify a source of coral colonies for transplantation that would not result in damage to reefs, (ii) test the feasibility of transplanting storm-generated coral fragments, and (iii) develop a simple, inexpensive method for transplanting fragments that could be conducted by the local community. The ultimate goal was to enhance abundance of threatened reef-building species on local reefs. Storm-produced coral fragments of two threatened reef-building species [*Acropora palmata* and *A. cervicornis* (Acroporidae)] and another fast-growing species [*Porites porites* (Poritidae)] were collected from environments hostile to coral fragment survival and transplanted to degraded reefs. Inert nylon cable ties were used to attach transplanted coral fragments to dead coral substrate. Survival of 75 reference colonies and 60 transplants was assessed over 12 years. Only 9% of colonies were alive after 12 years: no *A. cervicornis*; 3% of *A. palmata* transplants and 18% of reference colonies; and 13% of *P. porites* transplants and 7% of reference colonies. Mortality rates for all species were high and were similar for transplant and reference colonies. Physical dislodgement resulted in the loss of 56% of colonies, whereas 35% died in place. Only *A. palmata* showed a difference between transplant and reference colony survival and that was in the first year only. Location was a factor in survival only for *A. palmata* reference colonies and after year 10. Even though the tested methods and concepts were proven effective in the field over the 12-year study, they do not present a solution. No coral conservation strategy will be effective until underlying intrinsic and/or extrinsic factors driving high mortality rates are understood and mitigated or eliminated.

SAVING LARGE CORALS DURING THE CONSTRUCTION OF A LIQUIFIED NATURAL GAS PLANT

As parts of a mitigation measure associated with the construction of a Liquefied Natural Gas plant, four large coral transplantations were carried out in Yemen between January and October 2007 (Seguin et al. 2008). Around 1,500 selected coral colonies were removed from areas to be impacted, transported and cemented in new sites. Transplanted colonies belong to 36 species and 25 genera. Among these, 140 large *Porites* spp. weighing from 200 kg up to 4 tonnes, were moved using new transplantation techniques. Growth, *in situ* mortality and health of the transplants were monitored over one year using photo quadrats, close-up pictures and linear growth measurements. Overall, survival of corals one year after transplantation was 91%. Most losses of transplants were apparently due to sedimentation of fine particles in the transplanted areas, fish predation, fisher activity and swell effects. Evidence of coral growth after transplantation was observed, especially in *Acropora* and *Porites* species, and on some faviids. The transplantation results demonstrate the capacity of corals to adapt to a new environment, in favorable conditions. They show that carefully designed coral reef rehabilitation strategies can be part of industrial development processes, whenever necessary.

TRANSPLANTATION OF JUVENILE CORALS

Clark and Edwards (1994) suggested that transplantation of mature coral colonies may help restore degraded reefs. However, such procedures cause damage to other reef areas and are labor intensive. Knowledge obtained on the reproductive patterns and settling preferences of the Red Sea corals (Benayahu et al. 1990) urged scientists to assess for the first time the potential use of their propagules for transplantation to an artificial reef. In addition, the unique autotomy process in *Dendronephthya hemprichi* (Dahan and Benayahu 1997) facilitated the use of its fragments for this purpose. The survivorship rates of transplanted species is related to the structural features of the modular experimental artificial reef (Ammar and Mahmoud 2005).

MASSIVE VS BRANCHING CORALS

Branching morphologies are usually used in experiments on coral regeneration for two main reasons: they have a life history with high asexual reproduction by fragmentation (Bruno, 1998), and have rapid growth and regeneration (Karlson and Hurd, 1993). They are also more fragile than other morphologies, often suffering the most damage from different stresses. The vertical arborescent structure of branching *Porites palmata* was expected to be snagged, dislodged or damaged by seine net fishing to a greater extent than the spherical or horizontal encrusting structure of *P. lutea. Porites palmata* is more susceptible to fish predation than the massive species. Massive corals are thus recommended for transplantation due to their low damage and mortality and may ultimately produce the habitat required for fish and other coral morphologies.

SEXUAL REPRODUCTION IN TRANSPLANTED CORAL FRAGMENTS

Studies on survivorship and the reproductive ability of transplanted coral fragments are important for coral reef restoration (Forsman et al. 2006). It is especially important to determine the ideal collection time and minimum fragment size that are necessary for successful propagation (Kai and Sakai 2008). This is because the maximum survival rate with the possibility of spawning needs to be established in order to develop successful restoration techniques. For example, aquariums try to establish coral breeding facilities and nurseries using sexually reproducing corals. Although several reports have stated that naturally or artificially occurring fragments reduce fecundity or stop gonad development, those studies were performed only once or just a few times after fragmentation (e.g., Zakai et al. 2000, Okubo et al. 2007). Survivorship and growth of transplanted fragments have been surveyed and discussed (e.g. Yap 2004), but the spawning of fragments had never previously been reported. Connell (1973) postulated that the occurrence of sexual reproduction in a colony is determined by the size of the colony or age of the polyps comprising the colony. Okubo et al. (2009) concluded that transplantation of larger fragments during the cooler season resulted in an increased survival rate and spawning ratio in the 1st year after transplantation in *A. nasuta*.

Figure 1. Use of asexual recruits and molecular biological tools for transplantation studies (Ammar et al. 2000).

Figure 2. Big transplanted branches of *Acropora* (Photo’s copyright: Czaldy Garrote)

TRANSPLANTATION OF CORALS USING SEXUAL REPRODUCTION AND CERAMIC CORAL SETTLEMENT DEVICE (CSD)

A new type of coral-restoration technology has been developed since 1999 (Peterson et al. 2005, Okamoto et al. 2005, 2008, 2010) to overcome bleaching and degradation caused by global warming (Carpenter et al. 2008, Okamoto et al. 2007, Sato 2008). A case study was done by Okamoto et al. (2012) who conducted a survey of the coral community structure and recruitment of *Acropora* in six sites around Manado, Indonesia, in 2007 and 2008. They found that the population of *Acropora* corals as well as recruitment of juvenile coral was extremely low. To examine the future of *Acropora* corals around Manado, they assessed the reproduction potential of *Acropora* at two sites of Bunaken Island. As a result, spawning was estimated to occur several times in 2007. Anyway, *Isopora* corals could not be separated from *Acropora* (hereafter referred to as Acroporidae). The number of Acroporidae that settled on Coral Settlement Devices (CSDs) and Marine Block (MB) plates was very low. The spawning peaks of *Acropora* were estimated to be between February and June, and around October. The spawning around October was lower than that observed between February and June. They attempted to apply a coral restoration method using sexual reproduction developed and successfully applied in Japan's largest coral reef, Sekisei Lagoon, to prevent the extinction of *Acropora*. For the experiments, they used CSDs to settle and raise corals *in situ* for transplantation and MB plates as artificial substratum on sandy bottom areas. The ceramic coral settlement device (CSD) contained within a polypropylene case is fixed to the sea bottom 1 week before mass spawning. Settled corals were raised *in situ* for approximately one and half year (corals grew to approximately 1.5 cm in diameter). These corals were transplanted to coral reefs or onto marine blocks (MBs) on a sandy bottom. CSDs have been improved by applying the results of *in situ* examination with regard to materials, shapes, and arrangement within a case. A small CSD case makes the following features easy: underwater handling, deployment at the settlement site, and transportation to the nursery and restoration site. The CSD case is readily transportable between the sea and the water tank onboard a ship in a small plastic bucket filled with seawater.

INCREASING SUBSTRATE FOR SETTLEMENT

On a damaged reef, the availability of suitable substrate for larval settlement can rapidly decrease due to algal or soft coral overgrowth, and sedimentation (Schlacher et al. 2007). Minimizing land based sources of nutrient enrichment and maintaining algae-eating fish populations will help reduce algae. Techniques for actively increasing suitable substrate are briefly described belowe.

Introducing artificial surfaces for larval settlement

Artificial reefs such as concrete blocks, wrecks or other purpose-designed structures may have an additional benefit for fisheries management but the cost may be prohibitive for large areas.

Encouraging natural surfaces

This can be done by stabilizing or removing loose substrate material (such as coral fragments) and removing algae and other organisms that might inhibit larval settlement or damage young recruits. Certain substrates, e.g. *Goniastrea skeletons*, appear to induce settlement and larval metamorphosis. This approach should only be taken if expert scientific advice is available.

Creating new surfaces through electrolysis

A unique technology developed by a German architect named Wolfe H. Hilbertz in 1977 involves precipitation of ionic calcium and magnesium in seawater to form a carbonate substrate under the presence of low direct current underwater (Hilbertz, 1992). This substrate may serve as a natural platform for the transplanted corals and subsequent colonization of marine larvae (Schillak et al. 2001, Ammar 2001). The three hypotheses concerning growth enhancement mechanisms suggested by Hilbertz and Goreau (1996) are not fully explored experimentally. The first hypothesis is that the electric field that enables accretion may cause the precipitated carbonates to attach directly to the skeletons of coral transplants. The second is that the method induces $CaCO_3$ enrichment of water in the immediate vicinity of the coral, thereby enhancing natural calcification. The third one is that excess production and release of electrons due to the electrochemical processes occurring within the vicinity of the coral might affect the electron-transport chain for ATP production where the excess energy can be used for growth enhancement. This requires considerable financial and human investment, and a source of permanent electrical current while the structure is being built. The long-term impact of the electrical current on marine life is not known.

Sabater and Yap (2002) investigated experimentally the effect of electrochemical deposition of $CaCO_3$ on linear and girth growth, survival and skeletal structure of *Porites cylindrica* Dana. Transplanted coral nubbins were subjected to up to 18 V and 4.16 A of direct current underwater to induce the precipitation of dissolved minerals. Naturally growing colonies showed a significant increase in percentage of longitudinal growth over the treated and untreated corals. Survival followed a similar trend as the growth rate. Lowest survival rates were found in the untreated nubbins. Phenotypic alterations were observed in the treated nubbins where the basal corallites decreased in size with a concomitant increase in their number per unit area. This was probably due to increased mineral concentration (such as Ca^{2+} , Na^-, Mg^{2+} , CO_3^{2-}, Cl^-, OH^-, and $HCO3^-$) at the basal region of the nubbins. These alterations were accompanied by a significant increase in girth growth rates of the treated nubbins at their basal regions. The abundance of mineral ions at the basal region thus appeared to be utilized by the numerous small polyps for a lateral increase in size of the nubbins instead of a longitudinal increase.

CHEMICAL SIGNALS AND SURFACE CHEMISTRY

The topics of surface chemistry (Spieler et al. 2001) and the possible inputs of toxic leachate from artificial substrates were discussed and considered as important factors for enhancing natural recruitment (Ammar 2009). At least one artificial reef manufacturer (Reef Ball) recommended the addition of microsilica to concrete to provide a neutral pH surface. In addition, the organic and microbial biofilm that is quickly formed on any clear substrate that is immersed in seawater may provide negative settling cues. It is also well documented that initial colonizing microbial algal and invertebrate assemblages may affect settlement of coral larvae; moreover the chemical glycosaminoglycan isolated from a coralline alga (*Hydrolithon boergesenii*) that signals *Agaricia agaricites humilis* larvae to settle, the synthesized material, called "coral flypa per", proved effective for attracting larvae (Rinkevich 2005).

THREATS TO CORAL TRANSPLANTATION

Coral algal transition in coral transplantation experiments

Yap et al. (2011) found that coral transplantation experiments can provide a useful platform by which to examine the overgrowth of coral by algae under different environmental conditions. Macroalgae are well known competitors of corals for space and light (Lirman 2001, Diaz-Pulido 2009). They can cause damage to coral tissue, or the demise of coral colonies. However, the debate continues as to whether the algae themselves are capable of outcompeting, and then overgrowing, healthy coral colonies. It is believed that algal spores or filaments generally do not settle directly on live corals (McCook 2001). However, when established algae come in direct contact with corals on the reef, this can cause shading, tissue abrasion, and/or overgrowth (Quan-Young and Espinoza-Avalos 2006). Abrasive contact or overgrowth can eventually result in partial or total coral mortality. Live corals are also capable of overgrowing algae (Diaz-Pulido et al. 2009) and inhibiting algal growth (Nugues et al. 2004). Once established, algal populations tend to persist, thus hindering reestablishment of coral populations via recruitment (Kuffner et al. 2006) or the regrowth of adult colonies.

Algal overgrowth is one major problem (Shaish et al. 2010). It can be a significant factor that hampers the success of coral restoration efforts because of reduced growth or mortality of the transplants. Under certain conditions, coral transplants appear unable to resist algal invasion, and eventually die, apparently because of smothering (Dizon and Yap 2006). In some cases, algae were observed to cause bleaching of the underlying coral tissue (Rojas et al. 2008). The bleached tissue subsequently deteriorated. Contact with algae can cause direct stress to coral tissue, after which the algae proceed to overgrow the coral (Quan-Young and Espinoza-Avalos 2006). In experiments where the performance of coral transplants in the presence of algae was compared with that of corals in cleared plots, transplants in the latter instances survived better (Soong and Chen 2003).

Invertebrate corallivores

Cros and McClanahan (2003) found the coral-eating snail *Drupella cornus* on one block of transplants preying on *Porites palmata* in the vicinity of a large patch of dead *Acropora*. There were three to four snails on each branching coral and they killed 60% of each colony/transplant, mostly at the base. This was similar to previous observations of *D. cornus* preying on the genus Acropora and the family *Pocilloporidae* on damaged reefs in Kenya and western Australia (Turner, 1994). In the past, damage by *Drupella* outbreaks has been compared to damage by crown-of-thorns (COTs) outbreaks (Cumming, 1999). Reports of mass mortality due to this snail have been recorded in Western Australia and Japan (Turner, 1994). Outbreaks have been in part attributed to over fishing and the removal of key predators of the snail (McClanahan, 1994).

ROLE OF AUTUTROPHS FOR TRANSPLANTED CORALS

Primary producers, or autotrophs, make up the base of all food chains, however, they are capable of synthesizing complex organic compounds such as glucose from a combination of simple inorganic molecules and light energy in a process known as photosynthesis (Baum et al. 2003). The same author further indicated that some common autotrophs in a coral reef ecosystem are phytoplankton, coralline algae, filamentous turf algae, the symbiotic zooxanthellae in corals, and many species of seaweed. Phytoplanktons are one of the most important primary producers in the world and include a wide variety of organisms. Those organisms include: 1-diatoms which are the most productive type of phytoplankton 2-dinoflagellates and silicoflagellates which move by way of flagella 3-coccolithophores which have peels made of calcium carbonate 4-cyanobacteria, and other extremely small phytoplankton species referred to as nanoplankton (2.0-20 mm) and 5-picoplankton (0.2-2.0 mm). In brief, the phytoplanktons are important for providing transplanted corals with complex organic compounds through photosynthesis.

REGENERATION AND GROWTH OF CORAL FRAGMENTS IN A NURSERY

Soong and Chen (2003) indicated that one of the effective and commonly used methods to restore coral communities is the transplantation of coral colonies or fragments. The same author, in this investigation, used fragments of *Acropora* in a semiprotected nursery in southern Taiwan between 1996 and 1998. The possible effects of different factors on the generation of new branches and the initial skeletal extension rates of transplants were tested. The variables under study were the origin and length of the fragments, their new orientation, presence of tissue injury, and position in the fragment. All these factors were found to make a difference in either one or both aspects of coral growth (i.e., branching frequency and skeletal extension rate). These two factors clearly determine the success rate of a small fragment developing into a large colony that has a much higher probability to survive and grow on its own. It was found the success of coral fragments in a semiprotected nursery depended on many factors. With all factors taken into consideration, a large amount of acroporid corals could be produced within a reasonable period. These materials can then be used either to restore natural populations directly or to satisfy the market demand for live corals, which would obviously reduce exploitation of natural populations.

Branching acroporids are known to translocate nutrients directionally, which leads to faster extension rates of axial polyps (Fang et al. 1989). Likewise, the ability of corals to regenerate was found to be dependent on the position of the injuries in the colonies. In *Acropora palmate* the regenerative capability decreases away from the growing edge (Meesters and Bak 1995). In a multispecies comparison, however, no position effect was found in the regenerative ability in six of seven species (Hall 1997). The results of orientation experiments on fragments without axial polyps, however, indicate that the distal or proximal ends in the original colony did not have any inherent advantage in generating new axial polyps. Instead, the local environment determined the end at which new axial polyps were produced. It is possible that all the branches we used in the experiment were distal branches of the colonies and that the two ends of the 6-cm fragments posed little difference in ontogenic gradients along the branches. Accordingly, whichever end pointed upward had a higher frequency of generating new axial polyps. It may be concluded that the resulting new branches are likely to be distributed in the upper portions of fragments. This characteristic is potentially adaptive in that branches in lower shaded regions of a colony tend to be overgrown and smothered by other organisms or sediments (Meesters et al. 1997).

Coral fragments are transplanted to a protected site and ‘grown out’ to a certain size before being used for rehabilitation and for creating new fragments. The source of fragments must be chosen with care, to avoid damage to other reefs. Coral farms potentially have an additional benefit as an attraction for snorkelers. Further investigation is required to reduce costs and increase success rates. The concept of nursery installed on the sea floor has already been applied to corals (Rinkevich 2005). One of the major *ex situ* restoration approaches is the collection, settlement, and maintenance of planula larvae and spats under optimal conditions (Epstein et al. 2003). The *in situ* nursery approach sustains the mariculture of nubbins, coral fragments, and small colonies. A coral nursery may also be considered as a pool for local species that supplies reef-managers with unlimited coral colonies for sustainable management (Epstein et al. 2003). Both *ex situ* and *in situ* approaches can also provide ample material for the coral trade, thus reducing collections of coral colonies from the wild (Heeger and Sotto 2007).

BIOGEOCHEMICAL PROCESSES AND NUTRIENT CYCLING WITHIN AN ARTIFICIAL REEF

Reef structures, by providing protection for marine species, can result in marine system biomass enhancement (Godoy et al. 2002). As a result of biomass enhancement, sediment becomes more active in the process of nutrient regeneration providing a nutritional source for other forms within the ecosystem, or being exported by water movements increasing the general productivity of neighbouring areas, furthermore, planktivorous fish species can induce nutrient production in the water column, excreting substantial amounts of ammonium, urea and depositing organic material, which is then incorporated into the reef food web (Falcao et al. 2006).

SUCCESSFUL CORAL TRANSPLANTATION

For a successful coral transplantation, selection of proper area to be used for transplantation is necessary (Okubo et al. 2005). It has been mentioned that the transplantation might not be suitable in an area where the coral recruitment has failed over the years. This is because the transplanted corals may not recruit. Also studies have shown significant effects of environmental factors (eg. light, temperature, sedimentation and water movement) on growth and / or survival of coral transplants. (Montebon and Yap 1995, Palomar et al. 2009). Choice of a particular habitat for coral transplantation is therefore a critical aspect of coral transplantation studies.

One more problem in coral transplantation is the selection of species to be transplanted. Studies have shown that different coral species show different growth and survival after transplantation due to the differences in their life history strategies (Yap et al. 1992). Till now only selected species have been used in the transplantation studies. But information on the suitability of a particular coral species for transplantation and their responses to relocation needs to be established by more research. Edwards and Clark (1998) have argued that there has been too much focus on transplanting fast growing branching corals over slow growing massive corals. They further mention that fast growing branching corals although recruit fast, are not able to survive the effect of transplantation and relocation. Another factor to be considered in the coral transplantation efforts is the size of coral colonies or fragments. In the previous studies, it has been shown that the size of the coral plays an important role in the survival of transplanted fragments (Bowden-Kerby 1996, 2009).

However, the relationship between colony size and growth was shown to be significant for some species, but not in others (Clark and Edwards 1995). Miyazaki et al. (2010). observed the survival and growth of transplanted fragments of the reef coral species *Acropora hyacinthus* and *Acropora muricata* over a period of 3 years from

Figure 3. Coral farming (Rinkevich 2005)

Figure 4. A new innovated and cheap model for building artificial reefs (Ammar and Mahmoud 2005). (A) New buds at the top of the branch. (B) A thick layer of the substrate built after 9 months of installing the unit. (C) Algae settling on the built substrate.

November 1999 to November 2002 in a high-latitude coral community in Shirigai National Marine Park, Otsuki, Kochi Prefecture, Japan. A total of 36 coral fragments (a total area of 4.4 m^2) (thirty one *A. hyacinthus* fragments and five *A. muricata* fragments) were transplanted into 3 separate blocks at 3-4 m depth with each block consisting of approximately equal number of coral fragments in each species. Out of 36 coral fragments transplanted, all *A. muricata* fragments died before the first survey (one year after the transplantation) and only 29 *A. hyacinthus* fragments survived the initial relocation. The results showed an increase in the coral cover to 48% of the total area form the initial 8.9% in case of *A. hyacinthus*. There was a horizontal increase in the coral size resulting in the accretion of the coral skeleton with the neighboring coral fragments. Transplanted fragments grew rapidly (6.9-15.8 cm) in the warmer (17-25ºC) months compared to the slower growth (0.9-4.8 cm) in the colder (below 17ºC) months.

CONCLUSION

Coral transplantation should be carried out by people with relevant experience. Prior to considering coral transplantation, ensure that the transplant site is not subject to ongoing impacting processes, such as strong waves, shallow water snorkel areas, crown-of-thorns (COTs) infestation, or shading by structures or vessels. Ensure donor areas have a sufficient healthy and diverse coral cover. Total coral collection impacts must be within the natural variability of the area and must not significantly reduce the donor area coral cover or species composition. For the transplant site, identify and record the proposed species, numbers, sizes and placement of the individual colonies to be transplanted. Document a methodology, addressing careful removal, fragmentation, handling and attachment of corals, and describing how impacts to live tissue will be minimized.Transplant all corals to the same depth, aspect, habitat, water flow, proximity to adjacent colonies and orientation as the site from which they were removed. Consider interactive impacts between adjacent colonies.Tag, photograph and otherwise easily and accurately identify each transplanted colony for the duration of the transplantation and at least 12 months following completion of the project.Carefully maintain the transplants. Revisit and reattach corals at least weekly in the first month and at least fortnightly in the next three months.A coral nursery may be considered as a pool for local species that supplies reef-managers with unlimited coral colonies for sustainable management.Recoverability depends on the stressor, the impacted species/community and the temporal and spatial intensities of the stressor. the larger the transplanted fragment, the greater the probability of survival (Garrison and Ward 2012). Transplanting corals for making artificial reefs can be useful in increasing biodiversity; providing tourist diving, fishing and surfing; creating new artisanal and commercial fishing opportunities; colonizing structures by fishes and invertebrates). Artificial reefs can have positive economic impacts which is significant and may reach several hundreds of million dollars per year. Coral transplantation will not be effective in conserving coral species or in assisting reef recovery over time until the underlying factors causing degradation of reefs and mortality of corals are understood, addressed, and eliminated or mitigated.

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