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Aspects écologiques et physiologiques de la restauration des récifs coralliens : Transplantation de coraux de culture sur un récif dégradé

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YAEL HOROSZOWSKI

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RÉSUMÉ

Les récifs coralliens, classés parmi les écosystèmes les plus productifs et bio-diversifiés au monde, protègent les zones côtières limitrophes contre l'érosion, jouent un rôle économique de premier plan pour les populations humaines et fournissent une source importante de protéines à des centaines de millions d'individus. Les activités anthropogènes ont réduit considérablement la capacité des récifs à faire face aux perturbations naturelles et ont mené à une dégradation substantielle de cet écosystème au cours des dernières décennies. L'échec des actions traditionnelles a montré que la restauration active est devenue maintenant inévitable afin d'entraver le déclin des récifs et d'assurer la persistance de cet habitat. Dans le but d'améliorer les pratiques de restauration active et de surmonter certains inconvénients des méthodes traditionnelles, un nouveau concept, le "Jardinage du Récif Corallien", a été proposé. Inspiré de la sylviculture, cette méthode se présente en deux étapes : 1) la génération et la culture de grandes quantités de minuscules fragments de coraux ou de larves dans une pouponnière à corail, 2) la transplantation de ces colonies, une fois adultes, sur des zones de récif dégradé. La réalisation de la première étape de cette méthode à Eilat (sur le bord de la Mer Rouge, en Israël), dans le but d'examiner si ce concept de Jardinage pouvait être mis en application, a été effectuée avec succès et a eu pour résultat la génération d'un nouveau stock de coraux disponibles pour la restauration. Ceci a permis de démarrer la seconde étape de cette méthode, à Eilat également. 554 colonies de *Stylophora pistillata* et de *Pocillopora damicornis* issues de la pouponnière ont été transplantées sur cinq massifs coralliens dénudés du récif d'Eilat, afin d'évaluer la faisabilité de l'utilisation de colonies coralliennes issues de pouponnière pour la

transplantation. La transplantation a été divisée en deux activités principales, la préparation des transplants en pouponnière, d'une part, et le transfert et la fixation des colonies sur le site étudié, d'autre part. La phase de préparation a été mise en œuvre avec l'aide de treize bénévoles et a duré une semaine. Le transfert des coraux de culture vers la zone à restaurer et leur fixation sur les massifs coralliens par cinq plongeurs a été terminée en deux semaines. Un suivi de 17 mois a révélé que les deux espèces ont la capacité de s'intégrer dans le nouveau milieu que constitue un récif dégradé. L'étape de pouponnière précédant la transplantation sur récif dégradé a permis de réduire le stress initial du à leur transfert ou à la transplantation elle-même. Les transplants de *P. damicornis* ont montré une forte capacité d'adaptation aux conditions rudes de l'habitat naturel. Leur taux de survie, de 77,8% ±2,9% après 17 mois, ne différait pas de façon déterminante de celui des colonies naturelles ; la proportion des colonies transplantées souffrant de mort tissulaire partielle, ainsi que l'ampleur de la perte de tissu par colonie, étaient comparables à celles des colonies locales. De plus, la prédation des poissons corallivores sur *P. damicornis* n'excédait pas celle sur les colonies naturelles témoins. Les transplants de *S. pistillata* se sont avérés moins performants que ceux de *P. damicornis* face à cet environnement difficile. Leur taux de survie, de 52,2% ±5,7% après 17 mois, était significativement plus faible que celui des colonies naturelles. La mort tissulaire partielle était courante chez les colonies de *S. pistillata* sur le site restauré. Néanmoins, parmi les colonies souffrant de ce syndrome, la proportion de transplantées surpassait celle de colonies naturelles. Il en allait de même de l'importance de la perte de tissu par colonie. Durant les premiers mois qui ont suivi la transplantation, les colonies de *S. pistillata* issues de pouponnière ont été

sévèrement attaquées par les poissons, attaques dont le nombre a diminué avec le temps pour atteindre une valeur comparable aux niveaux des colonies témoins au bout de 4 mois. Après avoir passé 16 mois sur le récif naturel, les colonies de *S. pistillata* transplantées montraient un nombre de zooxanthelles par unité d'aire plus faible que les colonies témoins en pouponnière. La concentration totale de chlorophylle par cellule de zooxanthelle ne présentait cependant aucune variation. Par contraste avec les colonies à croissance naturelle sur le site restauré, les transplants de *S. pistillata* ont contribué à la reproduction corallienne locale en libérant un nombre important de larves planula. Durant cette étude, nous avons enregistré un taux de détachement de colonies 3 et 10 fois plus important respectivement pour les transplants de *S. pistillata* et de *P. damicornis*, en comparaison avec les colonies témoins naturelles. Le taux de croissance des deux espèces transplantées n'a pas été influencé par la transplantation car il est resté identique au taux de croissance élevé des colonies conservées dans la pouponnière à corail. Les deux espèces ont créé de nouveaux espaces de vie sur le récif, de nouvelles niches écologiques, qui ont été utilisées par des invertébrés associés aux coraux. Le nombre de décapodes *Trapezia* et d'annélides *Spirobranchus* comptés dans les transplants, ainsi que le pourcentage de colonies transplantées où ces invertébrés élisaient domicile ont augmenté avec le temps. Néanmoins, davantage de colonies de transplants de *P. damicornis* que de colonies de *S. pistillata* ont été colonisées par les invertébrés associés aux coraux et les premières ont abrité un plus grand nombre de ces invertébrés. Des décapodes *Alpheus* ont également colonisés les transplants de *P. damicornis*. 5 mois après la transplantation, de nouveaux bivalves *Lithophaga* ont été remarqués sur les deux espèces de coraux. Ces deux espèces ont ainsi

stimulé la faune récifale par leurs capacités d'ingénieurs écologiques. Nous en concluons que cette nouvelle méthode peut offrir une alternative aux pratiques traditionnelles. Une pouponnière de corail présente l'avantage certain de produire, en peu de temps, un grand nombre de colonies en bonne santé capable de prospérer, de croître et de se reproduire dans des zones dégradées. Toutes les colonies transplantées survivantes ont constitué un accroissement net de la population du récif dégradé car, issues de pouponnière, aucune d'entre elles n'a été prélevée sur la nature. Nous proposons quelques directives pouvant permettre aux praticiens d'obtenir une restauration réussie. Nos résultats suggèrent que l'utilisation des espèces de coraux branchus a des avantages supplémentaires à une simple restauration de la communauté corallienne en zones dégradées. Les capacités d'ingénieurs écologiques de ces espèces sont un avantage important pour la restauration de l'ensemble de l'écosystème du récif corallien.

ABSTRACT

Coral reefs, one of the most productive and diverse ecosystems on earth, not only protect adjacent costal areas from erosion, but also serve as an economical assess for human populations, providing as well a major source of protein to hundreds of million of people. Anthropogenic activities have greatly reduced the reefs' ability to cope with natural disturbances and have led to a severe degradation of this ecosystem during the past few decades. The failure of traditional acts have clarified that active restoration measures are now crucial to impede the reefs' further decline and to ensure the persistence of this habitat. With the aim of improving active restoration practices and overcoming disadvantages of the traditional methods, a new concept, "Gardening Coral Reefs", has been proposed. Inspired from silviculture, this concept consists of two steps: 1) generating and culturing of large pool of minute coral fragments or coral larvae in a coral nursery, 2) transplanting these colonies, when grown up, in degraded reef sites. In order to test the applicability of the Gardening concept the first step of the method was applied successfully in Eilat (Red Sea, Israel) and has resulted in the generation of a new coral stock for the purposes of restoration. This has permitted to initiate the second step of the method in Eilat. By transplanting 554 nursery-grown *Stylophora pistillata* and *Pocillopora damicornis* colonies onto five denuded knolls in Eilat's reef, we evaluate the feasibility of using nursery-grown coral colonies for coral transplantation. The transplantation act was divided into two major activities, in-nursery preparation of the transplants and transfer and attachment of the colonies at the study site. The preparation phase was carried out with the help of 13 volunteers and lasted one week. The transfer of the farmed corals to the restoration site and

their attachment on the knolls by 5 SCUBA divers were completed within two weeks. Seventeen months of monitoring revealed that both species have the capacity to acclimate to the new environment in a degraded reef. The nursery phase prior to transplantation was successful in diminishing any initial stress to the transplants due to their transfer or to the transplantation act. *P. damicornis* transplants showed high adaptability to the harsh conditions at the natural habitat. Their survival, 77.8±2.9% after 17 months, did not differ significantly from naturally growing colonies. The proportion of colonies suffering from partial tissue death and the average magnitude of the tissue loss per colony were comparable with local colonies. The fish predation on *P. damicornis* transplants did not exceed that of the natural colonies. *S. pistillata* transplants showed lower performance than *P. damicornis* transplants once faced with the harsh conditions of the natural habitat. Their survival, 52.2±5.7% after 17 months, was significantly lower than that of the naturally-growing colonies. Partial tissue death was common for *S. pistillata* colonies at the restored site, though the average proportion of transplants suffering from this syndrome was higher than natural colonies as well as the magnitude of tissue loss per colony. During the first months after transplantation, the nursed *S. pistillata* colonies were heavily attacked by fish, attacks that decreased with time and became comparable to the control levels after 4 months. After 16 months at the natural reef, transplanted *S. pistillata* colonies had lower numbers of zooxanthellae per area unit than the nursery-control colonies. Total chlorophyll concentrations per zooxanthella cell, however, showed no change. In contrast to the naturally-growing colonies at the restored site, the *S. pistillata* transplants contributed to the local coral reproduction by liberating significant numbers of planula larvae. A 3 and 10 fold

higher detachment was recorded during this study for *S. pistillata* and *P. damicornis* transplants respectively, in comparison to the natural controls. The growth rates of both transplanted species were not impacted by the transplantation act as they remained identical to the high growth rates of colonies kept at the coral nursery. Both species created new living space at the reef, ecological niches that were used by coral associated invertebrates. The number of *Trapezia* decapods and *Spirobranchus* annelids counted in the transplants as well as the percentage of transplanted colonies recruited by those invertebrates increased with time. Nevertheless, more colonies of *P. damicornis* transplants were colonized by the coral-associated invertebrates than *S. pistillata* and they housed higher numbers of these invertebrates. *Alpheus* decapods were also observed settling in *P. damicornis* transplants. Five months after transplantation new recruits of *Lithophaga* bivalves were observed on both species. Thus, both *S. pistillata* and *P. damicornis* stimulated the reef-associated fauna by their ecological engineering capacity. It is concluded that this new methodology can offer an efficient alternative to traditional measures; a coral nursery has clear benefits of providing, in a short time, a large number of physiologically fit colonies capable of thriving, growing and reproducing in degraded areas. All of the surviving nursery-grown transplants at a degraded reef area are a net addition to the coral population since none of the new colonies is collected from the wild. We propose some guidelines that could help achieving successful restoration by practitioners. Our results suggest that the use of branching species has additional benefits to simply restoring the coral community in degraded areas. The engineering capacity of branching corals is an important advantage for the restoration of the entire coral reef ecosystem.

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1. INTRODUCTION

The shallow waters of coastal tropical waters are dominated by colorful formations impressive for their variety of motifs and forms—coral reefs. Stretching over a vast region of the tropics, coral reefs form the most biodiversed marine habitats, which represent 5% of all marine species (approximately 91 000 species) (Karlson 1999). They are also classified among the most productive ecosystems of the world, fixing approximately 700 billion kilograms of carbon annually. In addition, reefs protect adjacent coastal areas from erosion, have a significant economical importance for human populations living in proximity and provide a vital and important source of protein to hundreds of millions of people.

While other reef organisms may contribute to the reef's consolidation, hermatypic corals (phylum Cnidaria, class Anthozoa) are responsible for building the massive biogenic structures that span entire reefs, islands and barrier reefs over the past 200 millions years. Hermatypic corals are colonial animals that live in symbiosis relationships with dinoflagellate unicellular algae, the zooxanthellae, situated in their gastrodermic tissue. The coral structures and architectures form three dimensional niches—home to many species of marine invertebrates and fish.

Despite the long history and geological persistence of coral reefs, human activities and anthropogenic pressures have significantly altered their ability to cope with natural disturbances and to maintain themselves (Nyström *et al.* 2000, Pandolfi 2002). Natural

stresses, such as rising sea temperatures resulting in bleaching events (Douglas 2003, Obura 2005, Graham *et al.* 2007), outbreak of coral diseases (Richardson 1998), along with human stresses such as increased load of sediment and pollution (Aleem 1990, Guest *et al.* 2007), recreational activities, destructive fishing methods and over-fishing and collection of animals for the ornamental trade (Lovell and McLardy 2008), have pushed reefs beyond their adaptive capacity (Bell *et al.* 2006). Worldwide coral reefs are declining at an unprecedented rate (Lesser 2004) and the massive degradation over the past three decades has led in many cases to permanent shifts in reef communities, modifications of the abiotic environmental conditions and substantial loss of reef areas (Rinkevich 2005b, Aronson and Precht 2006, Hoegh-Guldberg 2006). Alarmingly, 20% of the world's coral reefs have been destroyed and show no immediate potentialities of recovery, 24% are under a severe risk of collapse due to human pressures and 26% face the same threat of collapse in the long run (Edwards and Gomez 2007). Wilkinson (2000) predicts a decline between 40 to 60% of the world's reefs during the next 50 years, unless proper steps are taken. Not only are the biological communities of coral reefs threatened, but also millions of people in over 100 countries who depend on this ecosystem for food and income.

In order to impede the reefs' further decline and to conserve this habitat, restoration measures must be taken. The objective of restoring an ecosystem is to preserve the original ecosystem, in addition to the replacement of lost habitat or destroyed populations (Rinkevich 2005b). Restoration of a coral reef can be of a passive form. Passive restoration is characterized by acts that do not directly interfere with reef organisms, but concentrates on imposing of traditional management efforts, such as no-use zone, imposing of

legislation, etc. By doing that, passive restoration creates the appropriate conditions for reef self-healing through natural processes. On the other hand, active reef restoration requires human intervention (i.e., coral transplantation, coral farming, etc.) and is appropriate anywhere when recovery needs to be accelerated in order to protect threatened biodiversity or when natural recovery needs assistance due to a profound change in ecological conditions and reef resilience (Kauffman *et al.* 1997, McIver and Starr 2001, DellaSala *et al.* 2003, Mansourian *et al.* 2005).

It is becoming more and more evident that degraded reefs rarely recover naturally from human induced changes without any intervention (Bowden-Kerby 2004, Rinkevich 2005b). In many cases the physical integrity of the reef is damaged, rendering the substrate inappropriate for new recruitment (Fox and Pet 2001). Marine Protected Areas and "no use zones" are successful in reducing recreational and fishing pressures but are insufficient in countering current-carried pollution and poor to no natural coral recruitment (example of Eilat's "no-use zone", Epstein *et al.* 1999, Epstein *et al.* 2005). The rate of coral recruitment is variable, can take up to several years and can be of limited dispersal range for some species, impacting damaged areas' diversity (Soong and Chen 2003, Rinkevich 2005a). The anthropogenic (usually chronic) damage acts in the short term, whereas the regeneration of the reef, characterized by a large post-settlement mortality and slow coral growth, is a long term procedure; these two scales need to be bridged (Sato 1985, Soong and Chen 2003). In addition, as was pointed out by Baums (2008), while corals have certain abilities to adapt to changing environmental conditions, their adaptation responses towards human disturbances (such as dynamite fishing) seem improbable, regardless of the time frame. In light of these

facts, it is becoming clear that, in addition to conservation and protection, active restoration is now crucial to preserving this highly diversified and productive ecosystem.

Although active reef restoration is still in its infancy (especially in comparison with forest restoration), various restoration methodologies were employed to address different causes of damage. In cases where the quality of hard substrate was damaged due to ship grounding or blast fishing, primary efforts usually concentrated on consolidating the bottom or adding new hard substrate for colonization (Clark and Edwards 1994, Fox *et al.* 2003, Schrimm *et al.* 2006). While this addresses the physical characteristics of the system, rehabilitating the substrate alone is not sufficient to ensure the reestablishment of the habitat's ecological functioning.

Artificial reefs have been widely used as a restoration tool, especially when fish populations were targeted and are usually involved in projects that help promote public awareness (Thailand: Yeemin *et al.* 2006, Japan: Akakura *et al.* 2006, French Polynesia: Schrimm *et al.* 2006. Atlantic Ocean: Koenig 2001, Seaman 2007, Florida: Fahy *et al.* 2006, and examples reviewed in Spieler *et al.* 2001). Although artificial reefs have the ability to shift some pressure away from the natural reef by creating new dive sites (Leeworthy *et al.* 2006) and can offer a punctual additional substrate for settlement, they are rarely considered as a promising restoration approach by coral reef restoration ecologists (Abelson 2006, Rinkevich 2005b). An artificial reef can mimic some of the characteristics of a natural reef, but nonetheless, it remains artificial and the community development on the artificial reefs can hardly be predicted or controlled. Even after a long

time, their communities rarely resemble the natural reef species' composition (Perkol-Finkel and Benayahu 2005, Perkol-Finkel *et al.* 2006). Artificial reefs can also reduce the larval supply to natural reefs (Abelson 2006) and cannot counter the problem of lack of seeders stock. Therefore, it could be more appropriate, in the context of coral reefs, to refer to them as "enhancers" rather than "restorers" (Svane and Petersen 2001).

Another common approach, one that is often used in cases of coastal development projects or at locations that have been damaged by ship grounding, is reattachment and translocation. Threatened or broken colonies are translocated to adjacent un-impacted reefs. When possible, at ship grounding localities or at sites damaged by storms and hurricanes, remaining corals are secured and fixed to hard substrate to prevent their dispersion by currents and water movement that will lead to tissue abrasion (reviewed in Rinkevich 2005b, Bruckner and Bruckner 2006).

By far, the most commonly used approach for active reef restoration has been the transplantation of corals on artificial or natural remaining hard substrates at denuded areas. The addition of live coral colonies aims to reinforce or to re-establish the poor local coral community and thus accelerates or enables recovery. Two main practices were used: the transplantation of whole coral colonies and the transplantation of coral fragments.

In the first approach, whole coral colonies are taken from healthy localities and transferred to degraded sites. Variable degrees of success were reported from such efforts. Bouchon *et al.* (1981) transplanted coral heads on an artificial reef in the northern Gulf of Aqaba (Red Sea, Jordan). After 1 year, 14% of the transplants were dead and 21% of the

colonies were decaying. Schrimm *et al.* (2006) transplanted colonies from nearby donor sites in French Polynesia and secured them onto concrete blocks or simply placed them in between the blocks. The survivorship after 2.3 years varied between genera from 100% to 73%. A month later, due to phytoplankton bloom, survivorship dropped dramatically to an average of 38%. In contrast, Clark and Edwards (1995) reported 51% survivorship of colonies transplanted on Armorflex mats in the Maldives after 2.3 years, with most of the mortality occurring during the first seven months of the experiment. They also suggested a trade-off between growth rates and survivorship of the transplants and concluded in a follow up publication that even when transplants are carefully handled they tend to have higher mortality rates than undisturbed colonies (Edwards and Clark 1998). In Japan, Akakura *et al.* (2006) transplanted colonies from a nearby harbor on concrete blocks next to a breakwater. They found varying survival rates between coral species, 80% to less than 20% after 1.5 years.

Beside the lack of uniformity in the method's success, all colonies used by this approach are scarified from the natural reef. Removing corals from healthy reef localities damages those areas and consequently, contributes to the overall damage. In addition, the number of colonies that can be sampled from the reef is very limited, restricting this methodology to localized small scale interventions. Facing today's wide reef decline, too many localities are threatened, leaving too few undamaged reefs capable of supplying whole colonies for transplantation.

The second approach, using fragments instead of whole colonies as source material for transplantation, attempts to overcome the disadvantages associated with the former approach. Excised branches, fragments and portions of corals have the ability to grow and regain the initial spatial complexity, allowing for a new colony to be established (Epstein and Rinkevich 2001, Shaish *et al.* 2006). Fragmentation indeed results in a much higher number of "units" to begin with but also has obvious downfalls.

First, the survival capacity of fragments directly transplanted onto a degraded reef is reduced. Yap *et al.* (1998) observed a survival rate after 1.3 years varying from zero to 40% in fragments of two *Porites* species transplanted onto different sites in the Philippines. Dizon *et al.* (2008) encountered after 5 months 43% mortality of fragments transplanted onto giant clam shells. Van Treeck and Schuhmacher (1997) combined the direct fragment transplantation of four coral species with substrate electrolysis inducing calcium carbonate accretion in the Red Sea (Jordan). While no exceptional mortality was documented soon after transplantation, a 1 year followed up observation revealed low survivorship (36% for *Pocillopora damicornis* (Linnaeus, 1758), 52% for *Stylophora pistillata* (Esper, 1797), 72% for *Acropora variabilis* (Klunzinger, 1879) and 68% for *Pavona varians* (Verrill, 1864)). Only a few studies, such as Guzmán (1991) have shown high survival of directly transplanted ramets, indicating that only a few sites are adequate for this methodology.

Most of the studies investigating the relationship between fragment size and survivorship have come to the conclusion that survival is size dependent: the larger the fragment is the better chances it has to survive (Smith and Hughes 1999, Lindahl 2003,

Soong and Chen 2003, Bruckner and Bruckner 2006, Latypov 2006, Garrison and Ward 2008). On the other hand, the bigger the fragment, the more stress is inflicted to the donor colony, compromising the mother colony's survival and reproduction (Ward 1995, Zakai *et al.* 2000, Epstein *et al.* 2001). Other studies have also shown that direct transfer of coral material resulted in stress associated with transplantation leading to high mortality (Yap *et al.* 1992). In addition, small fragments are more susceptible to threats encountered in natural reefs, such as predation. When a coralivorous fish or gastropod attacks a small fragment, the resulting damage in comparison to its surface area is much higher than in the case of a colony.

Fragmentation may also affect reproductive activities. Guest *et al.* (2007) have shown that, in the case of *Goniopora columna* (Dana 1846), when fragments are transplanted to more disturbed sites, their oocytes number, oocytes size and polyp size are significantly reduced, suggesting a diversion of energy from reproduction to other needs in response to stressors in the new environment. Zakai *et al.* (2000) has found that fragmentation of *P. damicornis* reduces the number of larvae produced by broken colonies and delays their onset of larval release. Small fragments (1-7 cm) studied in this experiment released very few planulae and died within a month. Rinkevich and Loya (1989) have documented a significant reduction in reproductive activity of fragmented *S. pistillata* colonies, noticing that the effect of breakage on reproduction could take place at least over two reproductive seasons.

In order to overcome the drawbacks of direct transplantation, a new approach, inspired from silviculture (forest restoration), has been devised by Rinkevich (1995). Reefs are often compared to forests since they share in common essential ecological and structural traits (Epstein *et al.* 2003). Forest restoration has been undertaken for over a century in many countries worldwide, allowing the development and refinement of wide array of protocols. Rinkevich proposed to benefit from the knowledge gained in this parallel ecosystem and suggested the "Gardening Coral Reefs" concept. This approach is based on a two steps methodology: 1) generating a huge number of minute coral fragments and their *in situ* nursery culturing until they form large colonies amenable for transplantation and 2) transplanting these colonies in degraded reef sites (Rinkevich 2006).

The use of a nursery phase allows for coral culture to be initiated from extremely small fragments as small as 1-10 polyps, each (few millimeters, commonly named "nubbins") or from sexual recruits, without compromising their survivorship rate due to the protected idyllic environment (Forsman *et al.* 2006, Shafir *et al.* 2006, Shaish *et al.* 2008). The employment of nubbins substantially reduces the stress inflicted to donor colonies (Shafir *et al.* 2001, Shafir *et al.* 2003). This permits a large scale random sampling of corals at a targeted locality that is capable of representing local species abundance and genetic variability without damaging a whole reef or compromising its health. Creating new colonies from nubbins and rearing them in a coral nursery allows for the rapid generation of an extremely large stock of corals that can then be used for restoration (Shafir *et al.* 2006).

The transplantation of whole colonies, rather than coral fragments, could potentially increase their ability to acclimate to the new environment. Adult colonies can also contribute to coral reproduction and enhance the local larval pool. Moreover, bypassing one of the reef restoration biggest bottlenecks, the availability of source colonies for rehabilitation, allows rapid, larger-scaled restoration acts.

The first step of the gardening concept has been tested in several reef localities in the world, including the Red Sea, Thailand, Singapore, Philippines, Tanzania and Jamaica, (Rinkevich 2008). Several nursery prototypes have been established: *in situ* nurseries such as mid-water floating nursery (Shafir *et al.* 2006) and leg-fixed nursery (Shaish *et al.* 2008, Soong and Chen 2003); and *ex situ* nurseries on land (Shafir *et al.* 2001, Forsman *et al.* 2006). Various aspects related to nursery rearing, such as divers nursery structures adapted to different environmental conditions, optimization of coral maintenance at the nursery and elimination of fouling organisms, the use of the nursery as planulae hub, are still being explored (Amar and Rinkevich 2007, Rinkevich 2008, Shafir *et al.* 2008). The first step of the Gardening methodology has shown promising results and has proven to be successful (Forsman *et al.* 2006, Shafir *et al.* 2006, Shaish *et al.* 2008). Whether nursery-grown coral colonies are suitable for transplantation in damaged reef areas is yet to be proven.

The aim of this study is to evaluate the applicability of the second step of the "Gardening Concept" and to develop guidelines for nursery-grown coral transplantation. We used new branching coral colonies of two species, *Stylophora pistillata* (Esper, 1797) and *Pocillopora damicornis* (Linnaeus, 1758), generated in a floating coral nursery in Eilat

for transplantation in a degraded zone of Eilat's reef (Red Sea, Israel). We followed the transplant's acclimation in their new environment and monitored their survival, growth and contribution to the local larval stock during 17 months after transplantation. We tested the hypothesis that the transfer of the farmed coral colonies to the natural reef will not influence their survival and, once transferred back to the oligotrophic waters of the reef, their growth will be reduced. We were also interested whether the spatial positioning on the knolls would impact their survival and detachment. We characterized tissue damage occurring due to partial tissue death or fish action. In addition, we examined the ecosystem engineering effects the branching nursed colonies might have in the restored site and followed their impact on model species inhabiting living hermatypic corals.

2. Materials and methods

2.1 Study sites

In order to examine the applicability of the Gardening concept and develop the methodology for farmed-colonies transplantation, a degraded zone of Eilat's reef (Gulf of Eilat, Red Sea: 29°30'N; 34°57'E) has been targeted. The reef of Eilat has been in decline for the past four decades as a result of anthropogenic activities, amongst the rapid development of Eilat city, recreational and tourist activities, urban affluences and pollution (Epstein *et al.* 1999, Rinkevich 2005a).

A floating *in situ* nursery was established in 2003 in the northern part of the Bay (Fig. 1A), away from the reef, coral predators and recreational activities. The nursery is situated at a depth of 8 m (12 m above the sea bottom) and resides in an enriched nutrient area due to its proximity to Ardag and Dag-Suf fish farms. The intensive mariculture of Gilthead seabream (*Sparus aurata*) resulted in elevated nutrient concentrations and particulate organic matter that accelerated coral growth (Bongiorni *et al.* 2003a, b).

The restoration site at the natural reef, the Dekel Beach, is located 2.7 Km south to the nursery between a navy base and the commercial port of Eilat and in front of a busy dive center (Fig. 1A). The first 18 meters depth of this reef are characterized by a moderate sandy slope with scattered knolls that contain varying amounts of hermatypic-dominance coral covers (from completely bare to well covered knolls, though the latter are very rare).

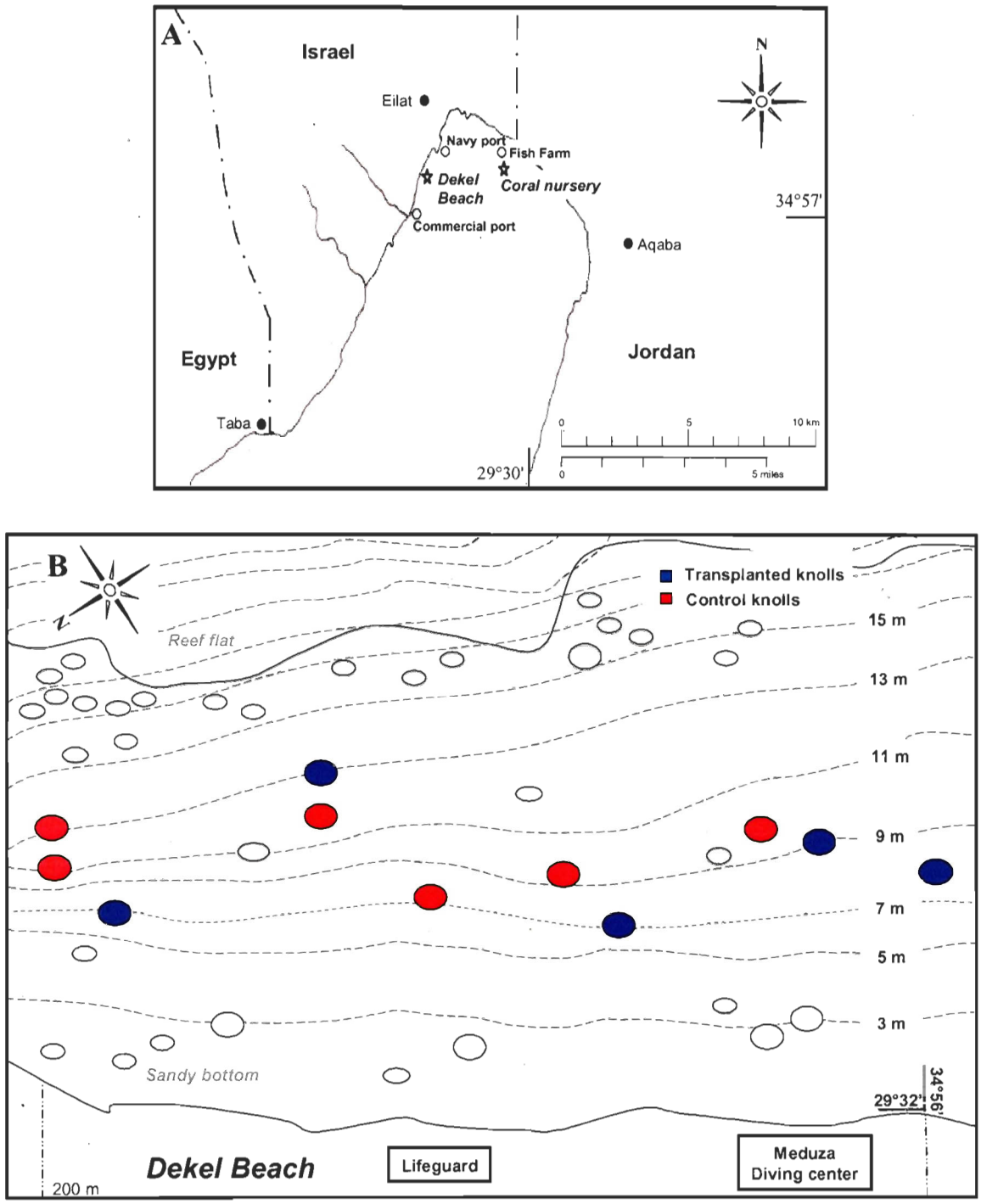

Figure 1: **Maps of the study sites. (A) A map of the northern part of the Gulf of Eilat (Red Sea), showing the coral nursery and the restoration site (Dekel Beach). (B) Location of the five transplanted knolls and six control knolls at the restoration site (Dekel Beach).**

The Israeli Nature and National Park Protection Authority permit restricted our experiment to 5 denuded knolls situated in shallow water (6-13m depth) and aligned from north to south on a 200 m stretch (Fig. 1B).

2.2 Coral rearing at the nursery

New coral colonies were generated at the nursery by re-pruning the initial nursery-grown coral stock of *Stylophora pistillata* and *Pocillopora damicornis* established in the nursery at 2003 (Shafir *et al.* 2006). The donor colonies, clones of three *S. pistillata* and four *P. damicornis* mother colonies collected at Eilat's navy port, were pruned by electrician's wire cutters providing fragments between 1 to 2 cm size. The fragments were glued to the flat surface of a plastic peg (Red Sea Corals LTD., Israel; 9 cm long, 0.3-0.6 cm wide leg with a 2 cm diameter "head", Shafir *et al.* 2006) and reared in the nursery on trays constructed from 50X30 cm PVC frames with stretched plastic nets (0.25 cm^2 mesh size) according to the protocol of Shafir *et al.* (2006). The number of colonies per tray was adjusted every three to four months to space between the new colonies to optimize growth conditions. The new farmed colonies were maintained for a period of eight to 14 months prior to transplantation and reached a diameter of 6 to 9 cm.

2.3 Preparation of nursery-grown coral colonies

During November 2005, 554 nursery-grown colonies of two abundant branching species in Eilat, *Stylophora pistillata* and *Pocillopora damicornis*, were prepared for

transplantation at the coral nursery. All colonies were prepared during a period of seven days with the help of a team of 13 untrained volunteers. The plastic pegs on which the corals grew were cleaned of settling algae and other sessile fouling organisms using forceps, dish-pads and various scratching dental tools (Fig. 2A). The colonies were examined for existence of coral predators, such *Drupella* snail, that were removed when found. An average of 10 to 15 farmed colonies per hour was prepared by one worker. The prepared colonies were then arranged on trays for transportation (Fig. 2B). Some of the colonies (n=100) were placed in aerated tanks and incubated for 12 hours (from sunrise to sunset) with 15 mg/L Alizarin Red S (Barnes 1970) in order to follow future coral's growth. The tanks were placed in plastic containers with a constant water flow generated by a water pump in order to maintain constant water temperature during Alizarin incubation (Fig. 2C). They were shed by plastic net of 0.25 cm^2 mesh size to avoid excessive radiation between 10 am to 14 pm.

2.4 Transplantation methodology

Once cleaned, the coral trays were placed in plastic containers filled with seawater and transferred by boat from the coral nursery to the restoration site. The colonies were transplanted onto the five denuded knolls by five SCUBA divers. Holes were drilled in the knolls' hard substrates in regular distances of 20 cm using an underwater pneumatic drilling powered by a SCUBA tank (Fig. 3A, B). A very small amount of epoxy glue (AquaMend) was placed at the bottom of each hole and the pegs were inserted in the holes, permitting a

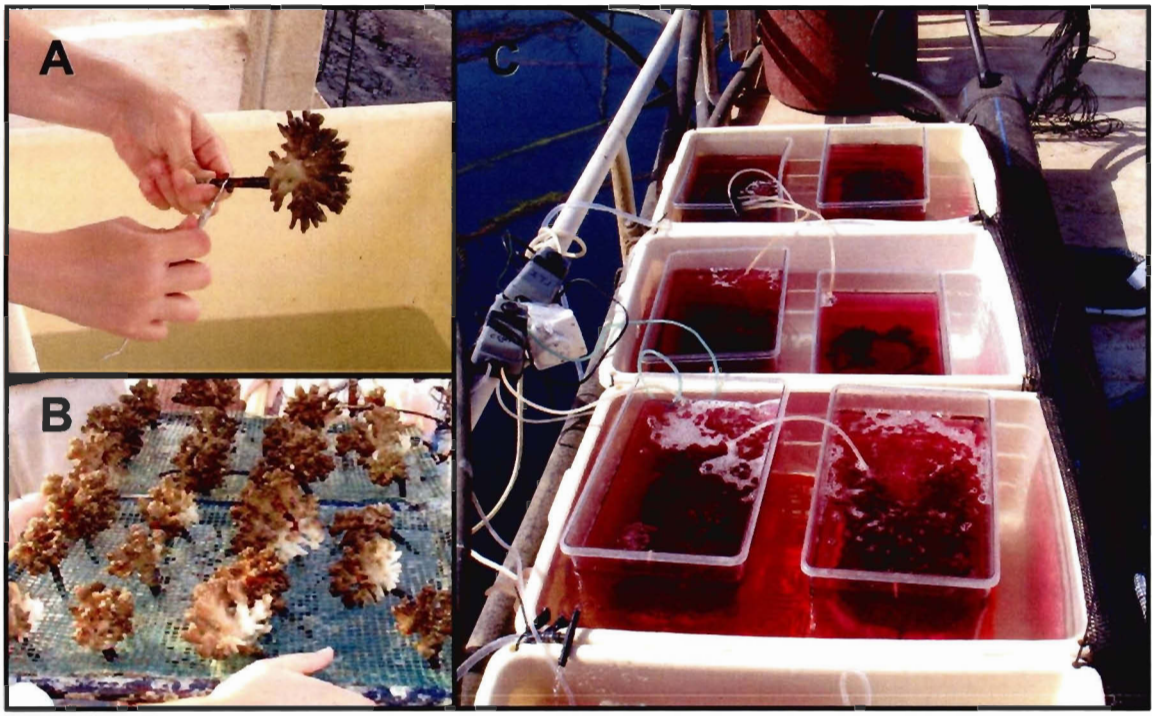

Figure 2: Preparation of nursery-grown coral colonies. (A) A plastic peg cleaned of settling algae and fouling organisms with the aide of a scratching dental tool; (B) Corals on trays at the nursery ready to be transferred; (C) Colonies selected for growth analysis incubated with Alizarin Red S.

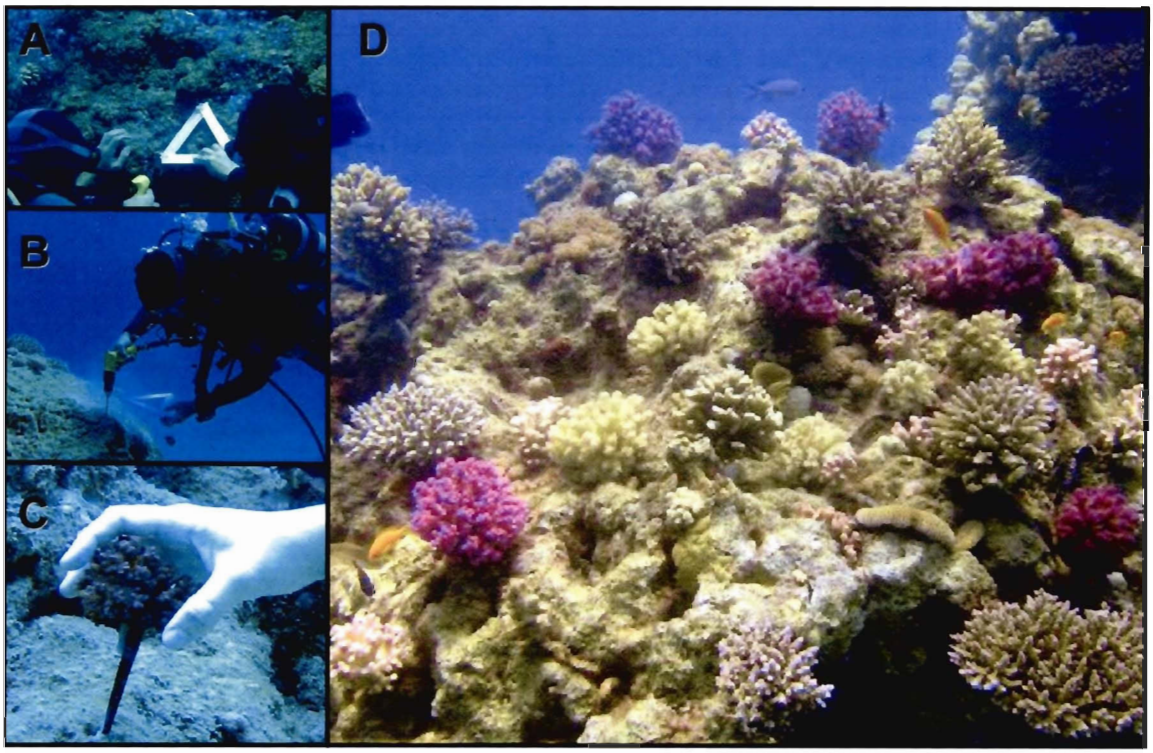

Figure 3: Transplantation procedures. (A, B) Drilling the substrate of a denuded knoll at the restoration site; (C) Transplantation of a *P. damicornis* colony; (D) A denuded knoll covered with nursery-grown colonies subsequent to transplantation.

good attachment of the corals to the substrata (Fig. 3C, D). Each colony was tagged with a numbered plastic stripe in order to follow each colony's acclimation and survival during the next months. The whole transplantation operation took approximately 2 minutes per colony transplanted. Two pneumatic drillers powered by SCUBA tanks were used. A 12 L aluminum SCUBA tank compressed to a pressure of 200 bars permitted the drilling of 25 to 30 holes in the hard calcareous substrate of the bare knolls. The most efficient way of transplanting the colonies was to drill and transplant simultaneously. When large substrate areas were drilled prior to the insertion of the colonies, problems of spotting the pre-drilled

holes occurred. The five untrained volunteer divers performed three dives per day (net 3 hours of underwater work per day). One untrained volunteer was capable of transplanting 30 colonies within one hour, including the activities of drilling, epoxy glue mixing, colony tagging and colony anchoring. Two weeks were required in order to complete the transplantation. One square meter of substrate was covered by an average of 15 colonies.

2.5 Monitoring

The transplantation was evaluated on a monthly-basis using SCUBA diving and underwater digital photos. Two control groups were established: a group of 76 naturally growing colonies at the experimental site, of the same species and approximate sizes and a group of 217 nursery-grown colonies prepared for transplantation that was left at the nursery. The two control groups were monitored in parallel to the transplants.

Data on detachment, survival, partial tissue mortality and fish bites was collected on a monthly basis. Partial tissue death and the magnitude of tissue loss per colony due to partial tissue mortality were estimated by eye. Partial tissue mortality is defined as a bare patch of skeleton on the surface of a coral colony due to the loss of part of the living tissue. The proportion of tissue mortality per affected colony was estimated at 10% intervals. Fish bites were counted individually. The bites inflicted lesions due to the removal of tissue, exposing the underlying skeleton. The size and shape of such injuries were not constant. The spatial orientation of each transplanted colony on the knoll (north, south, east, west, or up facet) was determined.

Starting one month after the transplantation, the number of *Trapezia* (Latreille, 1825) crabs (Fig. 4B) and *Alpheus* (Fabricius, 1798) shrimps appearing in each colony was counted at each monitoring. The count of settling *Spirobranchus* (Pallas 1766) worms (Fig. 4A) was added a month later. On April 2006, we witnessed numerous black spots on several S. *pistillata* and *P. damicornis* transplants, which appeared to be, after an examination under a stereomicroscope, metamorphosed bivalves, *Lithophaga* (Röding 1798) that settled on the corals (Fig. 4C-E). We followed the *Lithophaga* recruitment to the transplanted colonies thereafter. Adult *Lithophaga* are hard to spot since they are found in the coral skeleton with only the ends of their siphons appearing on the coral's surface. Therefore, only colonies that had new settlement which are easily recognized were considered in our survey.

2.6 Zooxanthellae abundance and chlorophyll concentrations

The densities of algal cells in coral tissues as well as the chlorophyll content per algae are variable parameters that are responsive to light and nutrient conditions. Witnessing a color change in the transplants a short time after transplantation, we decided to compare those two parameters with those of the control colonies left in the nursery. For this analysis, fragments of four *S. pistillata* colonies from each locality were sampled in duplicate after 16 months. The fragments were taken to the National Center for Mariculture at Eilat where they were incubated in calcium magnesium free artificial seawater with

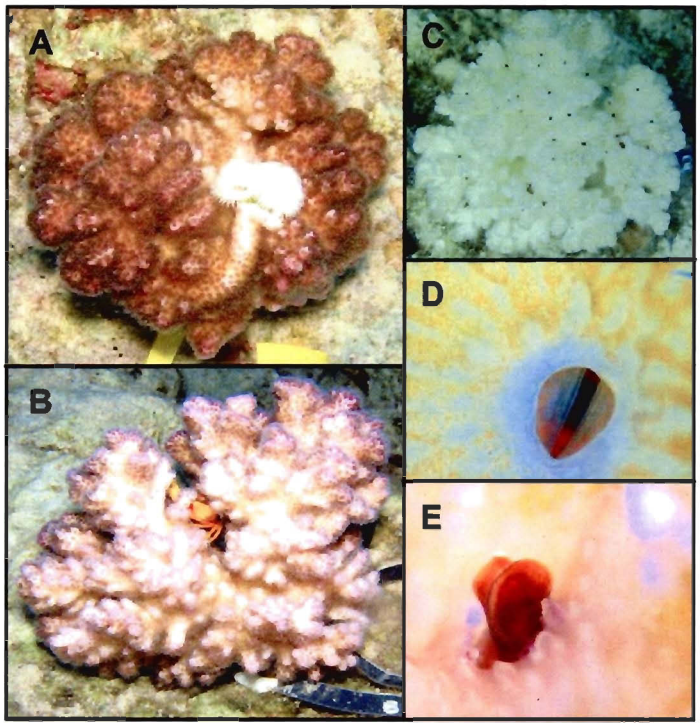

Figure 4: Recruitment of coral-associated invertebrates to the transplanted corals. (A) A *Spirobranchus* annelid settled *on P. damicornis*; (B) *Trapezia* decapod crab in a *P. damicornis* colony; (C) A colony of *P. damicornis* infested by new recruits of *Lithophaga* bivalves; (D) Shell of a newly settled *Lithophaga* in *S. pistillata* colony (x40); (E) Siphon of a newly settled *Lithophaga* in *S. pistillata* colony (x40).

ethylene diamine tetracetic acid (EDTA) in order to dissociate the living tissue (Rinkevich *et al.* 2005). Aliquots of 20µl from each sample were spread on a Hemocytometer and counted under a light microscope in order to determine the zooxanthellae cell number. For chlorophyll extraction acetone 100% was added to each sample. The samples were placed on ice in dark conditions and transferred to the laboratory at Haifa (National Institute of Oceanography) where they were kept at 4°C. They were analyzed with a spectrophotometer (630nm, 663nm) within 48h following shipment. The chlorophyll concentrations were calculated using Jeffrey and Humphrey's (1975) equations:

Chlorophyll a = 11.43 E_{663} – 0.64 E_{630} [1]

Chlorophyll c_2 = 27.09 E_{630} – 3.63 E_{663} [2]

The fragment's surface area was determined using a Desktop 3D laser scanner (NextEngine). Prior to scanning, all skeletal bare parts, resulting from the fragment's cuts, were colored in black in order to be omitted from the scan. The fragments were glued on plastic sticks using epoxy glue (Devcon 5 minute Epoxy) and colored in red using a mat spray-paint (Duplicolor, Germany). Two scans were made for each fragment—a 360 degrees scan (6 scans/360°) and a bracket scan—in order to cover the entire fragment's surface. The fragments were scanned together with a reference object, enabling an accurate alignment of the 2 scans. The surface area of each fragment was computed by the NextEngine ScanStudio Core software.

2.7 Growth analysis

Unfortunately, some of the Alizarin-stained colonies were detached during the course of the experiment, restricting and determining our choice of quantity for this analysis. Seven *S. pistillata* colonies (3 transplants and 4 nursery controls) along with ten *P. damicornis* colonies (5 transplants and 5 nursery controls) were sampled after 18 months for growth determination. The colonies were placed in a recipient containing freshwater followed by an overnight immersion in a 50:50 freshwater – bleach (sodium hypochlorite) solution in order to eliminate living tissue. The skeletons were washed from any tissue

remains under tap water and left to dry. They were weighted and measured using an electronic digital caliper to obtain the weight, width (w), length (l) and height (h). The new skeletal additions appearing after the Alizarin red marks were cut using electrician's wire cutter and the colonies were then weighted and measured again. Each colony's diameter and ecological volume were calculated for the initial and the grown structure using the equations (Rinkevich and Loya 1983):

Colony diameter $d = (l+w)/2$ [3]

Ecological volume $E = \pi r^2 h$ with $r = (l+w)/4$ [4]

The growth rate constants (k) per day for ecological volumes (E) were obtained using the formula:

$E_t = E_0 e^{kt}$ [5]

$k = (\ln E_t/E_o)/t$, t = time in days (0 at the beginning of the study). [6]

2.8 Larvae collection

In order to assess the transplants' contribution to local coral population's reproduction, 10 transplanted and 10 naturally growing *S. pistillata* colonies were selected. These colonies were chosen for their size (approximately 10cm in diameter) and for their state of health (without damaged tissue parts). *S. pistillata* is a brooding species (Shlesinger *et al.* 1998) that releases planulae larvae during a long reproduction period that stretches

from December to July in Eilat (Rinkevich and Loya 1979, 1987). Recently, a shift in the reproductive seasonality was documented by Amar *et al.* (2007), who reported an extension in the seasonality of planulae shedding, now occurring between January and August, with peak planulation between April and June. Two samplings have been carried out on June 19 and June 26, 2006. Planulae collection devices, consisting of a plankton net sleeve glued to a plastic cup (Amar *et al.* 2007), were placed over the selected colonies from sunset to sunrise. The plastic cups were drained from water and the planula assemblages over the lid were washed out to a wide petri dish. They were then counted under a stereomicroscope.

2.9 Statistical analysis

Data analyses were performed using SPSS software for Windows version 16.0. The results were examined for each species separately, using the knoll as the sampling unit of repetition. Normality was tested using Kolmogorov-Smirnov or Shapiro-Wilk statistical tests. When needed, the proportions observed were transformed using the arcsine square root transformation in order to approximate normality. Survival, detachment, partial tissue death and fish bites of nursery-grown transplants and control colonies were assessed using a repeated measures analysis of variance (ANOVA). When interactions between the parameters studied appeared, a monthly one way ANOVA was performed using a multiple-comparison Bonferroni correction to account for multiple testing, in order to maintain the 5% error rate (significant differences admitted when the probability is inferior to 0.003). When a significant effect was found, means were compared with a Bonferroni post hoc test (significant differences admitted when the probability is inferior to 0.05).

Zooxanthellae densities and chlorophyll content of transplants and nursery control colonies, as well as their growth were compared using a Student's *t* test for independent samples. The growth rate constant (k) was compared with a test for equality between two percentages.

Both the increase in the average percentage of transplants recruited by invertebrates over time and the increase in the average number of invertebrate specimens residing in each transplant over time were studied using correlation analysis. When a linear correlation was found, linear regression was carried out and statistically significant (ANOVA, $p<0.05$) equations of best fit were computed. Data are reported as mean ± standard error of the mean (SE).

3. RESULTS

3.1 Acclimation of the nursery-grown corals at the restoration site

3.1.1 Coloration

Two notable phenomena occurred one to six weeks after transplantation:

1. A change in the colonies' tissue color (Fig. 5 A, B). The colonies at the nursery were characterized by a darker tissue-pigmentation than reef grown colonies. Few weeks after their relocation tissue colors became pale, and colonies regained the natural appearing color.
2. Transparent tissue areas (appearing white) lacking zooxanthellae due to shading caused by their proximity to sibling colonies on the nursery trays regained their pigmentation (Fig. 5 C, D)

Those changes occurred in both species.

3.1.2 Survival

Survival rates of nursery-grown transplants, naturally-growing controls and nursery control colonies of *S. pistillata* and *P. damicornis* are shown in Fig. 6. One of the first concerns when carrying out a transplantation is whether the transfer of corals to a new location and the transplantation act are stressful to the transplants, which could result in an increased mortality during the first months after transplantation. The results of the first four months of monitoring revealed high survivorship (exceeding 95%) for both species'

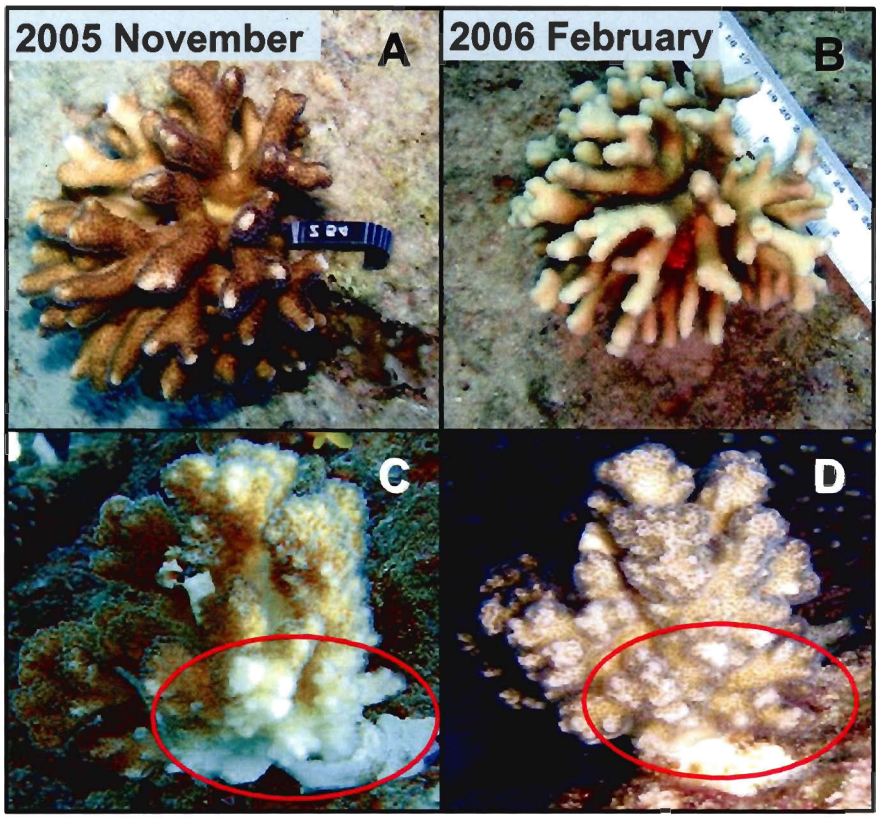

Figure 5: Qualitative changes observed after the transfer of the transplants to the natural reef. (A) *S. pistillata* colony subsequent to transplantation (November 2005) showing a dark tissue color pigmentation; (B) The same colony 3 months later, after regaining the typical tissue coloration; (C) White (bleached) zone on *P. damicornis* colony (November 2005, circled) soon after transplantation; (D) Same tissue area 3 months later, with normal appearing pigmentation.

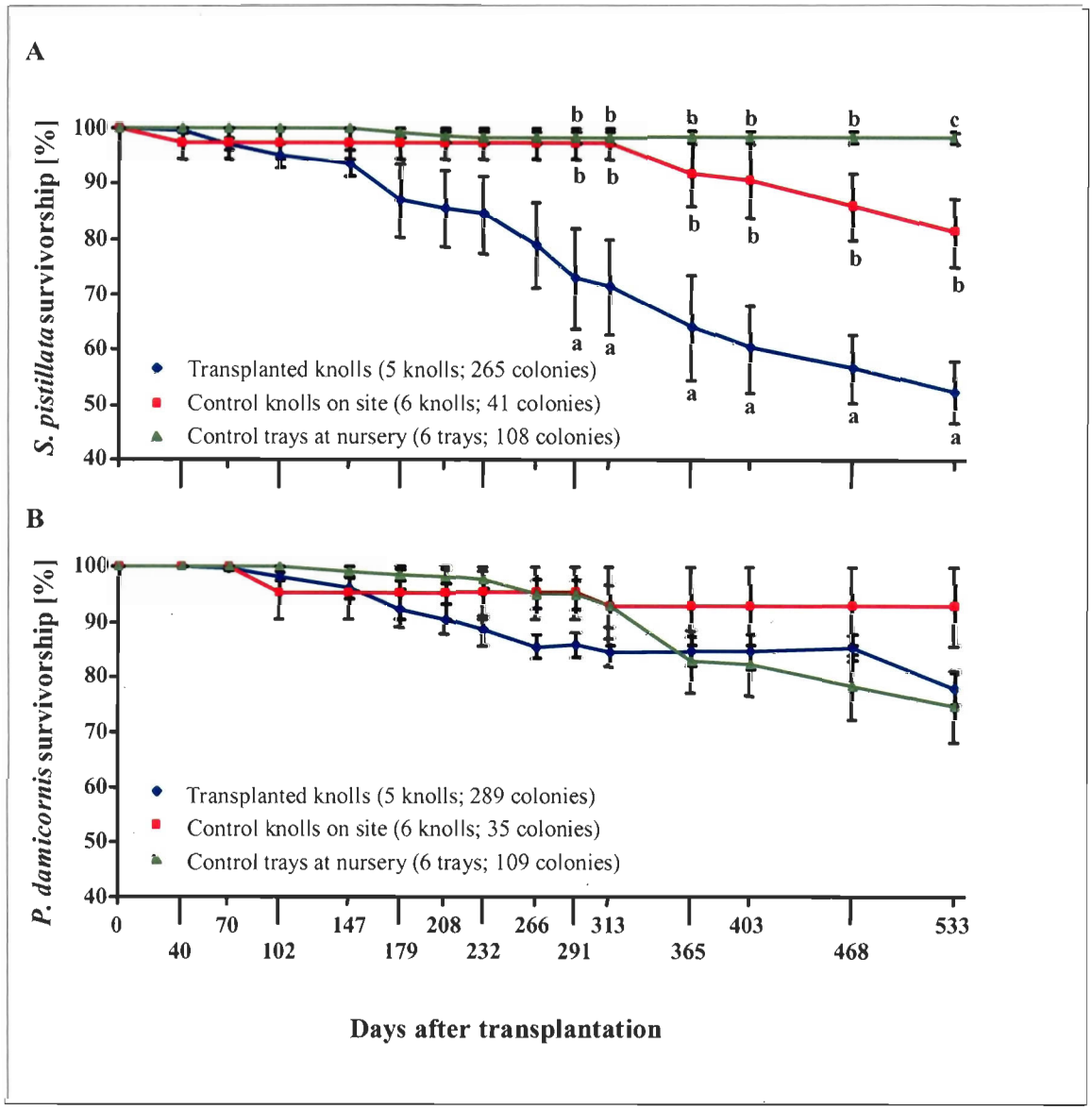

Figure 6: Survivorship (Nov. 05-Apr. 07) of nursery-grown colonies transplanted onto degraded knolls, naturally-growing control colonies on studied knolls and control colonies at the nursery. (A) *S. pistillata*; (B) *P. damicornis*. Data reported as mean ± SE. Letters denote statistically significant monthly-groups.

transplants, a survivorship very similar to that of the two control groups (Fig. 6). In fact, no statistically significant difference was observed between these three groups until 291 days after transplantation (9 months) for *S. pistillata* (one way ANOVA with Bonferroni correction[1], $p>0.003$ for days 40-266) and throughout the entire monitored period in the case of *P. damicornis* (one way ANOVA with Bonferroni correction, $p>0.003$ for all dates) (Fig. 6, Appendices Table 7.1.2).

Mortality over time was dependent on the experimental group (transplants, naturally-growing colonies and nursery-kept colonies) as indicated by a repeated measures ANOVA (*S. pistillata*: $F_{5.28,36.97}=7.033$; $p<0.001$; *P. damicornis*: $F_{5.37,37.59}= 4.213$; $p=0.003$; Appxs. Table 7.1.1) and differed significantly between the two species (Fig. 6). For *S. pistillata*, mortality was low and rather constant in the nursery as 98.3±1.1% of the colonies were still alive after 17 months. Survivorship was also quite constant for the naturally-growing *S. pistillata* at the restoration site until September 2006 (313 days after transplantation; 97.2±2.8%). Then, mortality increased revealing, after 533 days, significant higher values than the one recorded at the nursery (one way ANOVA with Bonferroni correction, $p<0.003$; post hoc Bonferroni multiple comparison, $p>0.05$ for days 291-486; $P<0.05$ for day 533; Appxs. Table 7.1.2). After 17 months, 81.3±6.1% of naturally-growing *S. pistillata* controls at the restoration site remained alive. The survivorship of transplanted

[1] The multiple-comparison Bonferroni correction was performed to account for multiple testing, as the same hypothesis was repeated 14 times (for each month). In order to maintain the 5% error rate, we divided 0.05 by the number of repetitions (14). Therefore, significant differences between groups are only admitted when $p<0.003$. When significant values were found ($p<0.003$), means were compared with post hoc tests, admitting statistically significant differences for $p<0.05$.

S. pistillata colonies was lower than that of the controls and decreased gradually. After 17 months only 52.2±5.7% of the transplanted *S. pistillata* remained alive (Fig. 6).

The survival of *P. damicornis* colonies at the coral nursery was lower than that of *S. pistillata* (Fig. 6). After 17 months, 74.6±6.4% of the *P. damicornis* control colonies continued thriving at the coral nursery. At the restoration site, the survivorship of naturally-growing colonies decreased at day 102 (Feb. 06; 95.2±4.8%) and day 313 (Sep. 06; 92.8±7.1%). Other than that the survivorship remained constant throughout the observation period (Fig. 6). After 17 month, 92.8±7.1% of naturally-growing *P. damicornis* were still alive. *P. damicornis* transplants exhibited lower mortality rate that increased gradually with time. The survivorship had stabilized after 266 days at the natural reef, remaining around 85% for the next 7 months. At the last observation, an increase in the average mortality of transplanted *P. damicornis* was observed (Fig. 6). Consequently, after 17 months following transplantation, 77.8±2.9% of *P. damicornis* transplants remained alive. This survivorship is quite identical to the survival of the *P. damicornis* colonies left at the coral nursery (74.6±6.4%; Fig. 6).

3.1.3 Detachment

Detachment patterns of coral transplants and control groups, the naturally-growing colonies at the Dekel Beach and the colonies left at the nursery, are depicted in Fig. 7. Fish activity and SCUBA divers gear or fins contacts were important factors that resulted in coral detachment. In contrast to colonies that settle naturally and expand on the natural

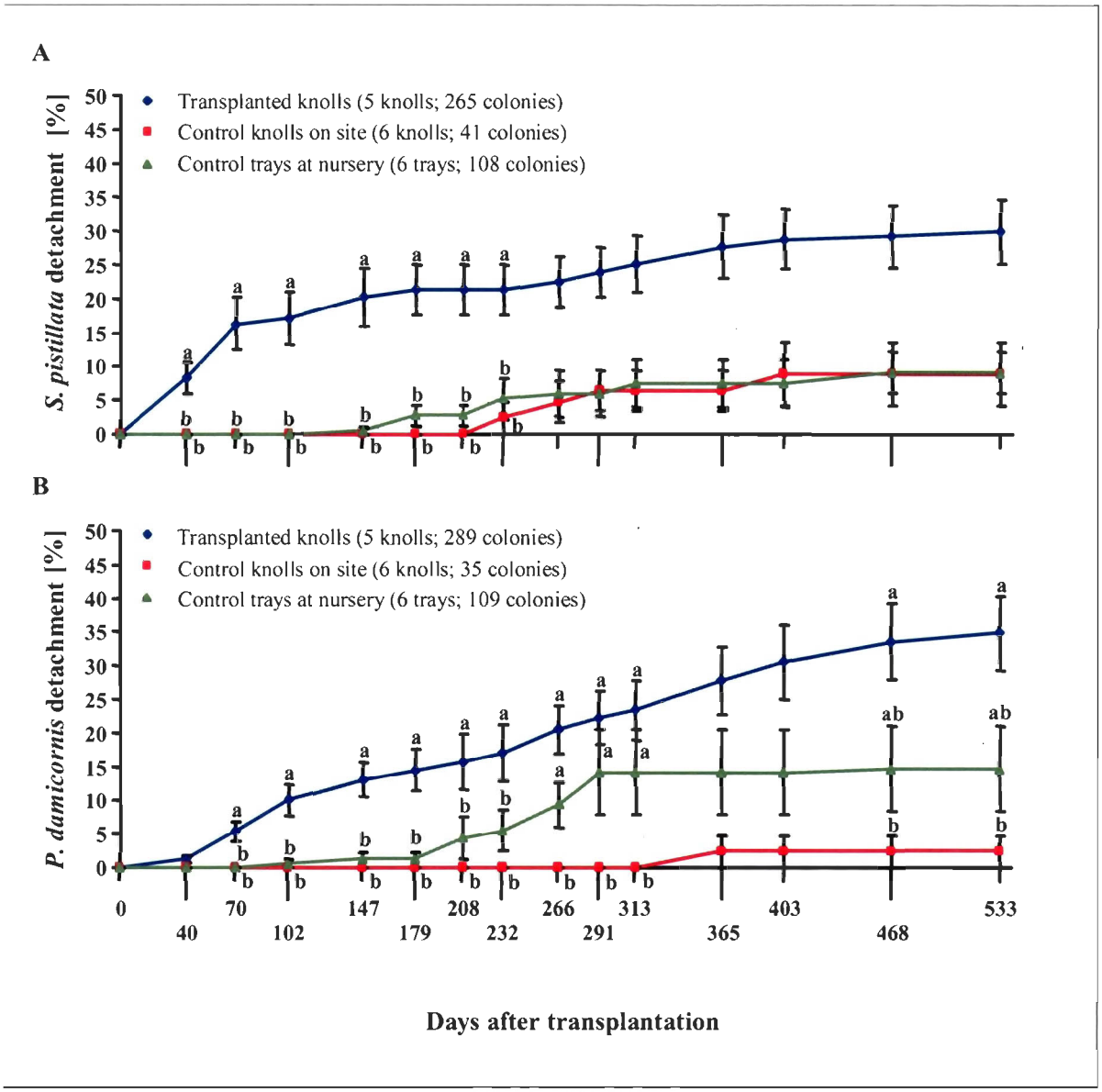

Figure 7: Detachment of nursery-grown colonies transplanted onto the 5 degraded knolls, naturally-growing control colonies on site and control colonies at the nursery. (A) *S. pistillata*; (B) *P. damicornis*. Data reported as mean ± SE. Letters denote statistically significant monthly-groups.

substrate by depositing continuous cemented calcium carbonate, the transplants that were reared at the nursery on plastic pegs were weakly attached to substrates, thus more vulnerable and potentially more susceptible to breakage.

Time impact on the detachment of the three experimental groups was observed for both species (repeated measures ANOVA, *S. pistillata*: $F_{1.72,24.11}$=13.098; p<0.001; *P. damicornis*: $F_{1.88,26.33}$= 15.378; p<0.001; Appxs. Table 7.2.1). Out of the 265 initially transplanted *S. pistillata*, 79 colonies detached during the experiment, an average of 30±4.8% per knoll (Fig. 7). *S. pistillata* transplants, naturally-growing colonies and nursery controls showed a similar trend of increase in the detachment over time (repeated measures ANOVA, $F_{3.44, 24.11}$=0.989; p=0.423; Appxs Table 7.2.1) although detachment was higher for the transplants. This difference was accentuated during the first seven months after transplantation (one way ANOVA with Bonferroni correction, p<0.003 for days 40-232) and became insignificant after 8 months (one way ANOVA with Bonferroni correction, p>0.003 for days 266-553; Appxs. Table 7.2.2). On the other hand, naturally-growing *S. pistillata* colonies revealed a low detachment rate (9.0±4.7%), similar to the rate at the nursery (9.1±3.1%), after 17 months (Fig. 7). Hence, *S. pistillata* colonies residing at the coral nursery did not detach more frequently than the natural *S. pistillata* colonies at the restoration site (one way ANOVA with Bonferroni correction, p<0.003; post hoc Bonferroni multiple comparison, p>0.05 for days 40-232; one way ANOVA with Bonferroni correction, p>0.003 for the remaining dates; Appxs. Table 7.2.2).

Of the 289 initially transplanted *P. damicornis*, 99 colonies detached during the experiment, an average of 34±5.5% per knoll (Fig. 7). The detachment increase of *P. damicornis* transplants, naturally-growing colonies and nursery controls varied significantly over time (repeated measures ANOVA, $F_{3.76,26.33}$=3.082; p=0.035; Appxs. Table 7.2.1). In general, detachment was higher for *P. damicornis* transplanted colonies in comparison with the control groups. In contrary to *S. pistillata*, during the first month after transplantation, no difference was observed between the detachment of the three *P. damicornis* experimental groups (one way ANOVA with Bonferroni correction, $F_{2,14}$=7.400; p=0.006; Appxs. Table 7.2.2). Thereafter, for the next 6 months, a significantly higher detachment was observed for *P. damicornis* transplants, that increased from 5.3±1.5% to 16.9±4.2% (one way ANOVA with Bonferroni correction, p<0.003; post hoc Bonferroni multiple comparison, p<0.05 for days 70-232), while the detachment of *P. damicornis* at the nursery was comparable to the natural reef (no detachment to 5.4±3.0% at the nursery and no detachment at the natural reef during the reported period; post hoc Bonferroni multiple comparison, p>0.05; Fig. 7, Appxs. Table 7.2.2). A physical distortion of the nursery's structure due to a technical problem in the nursery's anchoring structure led to a gradual increase in the detachment of *Pocillopora* colonies kept on trays at the nursery (this had a smaller impact on *S. pistillata* trays). A twist in the nursery's frame happened following a rupture of some of the anchoring ropes, which led to the detachment of colonies while the nursery moved in the water column (due to currents and southern storms). Few months were required to overcome this problem and rebalance the nursery's frame. This resulted in higher detachment of *P. damicornis* nursery controls as compared to *P. damicornis* colonies

at the natural reef, detachment that differed significantly since day 266 (one way ANOVA with Bonferroni correction, $p<0.003$; post hoc Bonferroni multiple comparison, $p>0.05$ for transplants and nursery, $p<0.05$ for natural colonies and transplants / nursery, until day 313, included; Appxs. Table 7.2.2). The months of increased detachment (April to June) were also characterized by increased grazer's activity following algal blooms. This led to the average detachment of 15±6.3% per tray of nursery raised *P. damicornis* after 17 months. The average detachment of the three *P. damicornis* experimental groups became comparable after 1 year, but subsequent to 468 days after transplantation, the average detachment of the transplants continued to increase, exceeding that of the natural reef (one way ANOVA with Bonferroni correction, $p<0.003$; Post hoc Bonferroni multiple comparison, $p<0.05$ for transplants and natural colonies / nursery, $p>0.05$ for natural colonies and nursery; Fig. 7, Appxs. Table 7.2.2).

A between species comparison revealed a 3.6 fold higher detachment for *S. pistillata* naturally-growing colonies (8.8±4.7%) in comparison with the naturally-growing *P. damicornis* (2.4±2.4%) after 17 month (Fig. 7). Transplanted *P. damicornis* corals had lower initial detachment as compared to *S. pistillata* transplants, but the detachment increased with time, and reached similar values towards the end of the monitored period. *S. pistillata* transplants detached 3.3 times more than the controls at the natural reef whereas *P. damicornis* transplants detached 10 times more than the naturally-growing controls.

3.1.4 Orientation on the knolls

The influence of the transplants' spatial positioning on the knolls, their survival and their detachment was analyzed on the following selected dates: 1 month, 2 months, 4 months, 6 months, 1 year and 17 months after transplantation. Knoll's orientation had no significant impact on survival and detachment measured at the northern, southern, eastern western and up surfaces of the knolls at all examined dates (repeated measures ANOVA, $P>0.05$ for both species, *S. pistillata* and *P. damicornis*; Appxs. Table 7.3.1).

3.1.5 Partial tissue death

Colonies from the three experimental groups exhibited partial-tissue death (Fig. 8). This partial mortality was attributed mainly to parrotfish predation, competition and gastropod predation (*Drupella* and *Coralliophila*). Not always the direct causes for the appearance of dead tissue surfaces were known or revealed. In both species, we observed an effect of time on the proportion of colonies of the three experimental groups experiencing partial tissue death (repeated measures ANOVA, *S. pistillata*: $F_{3.42,47.91}=9.857$; $p<0.001$; *P. damicornis*: $F_{4.43,62.05}= 6.367$; $p<0.001$; Appxs. Table 7.4.1). The transplants, the naturally-growing colonies and the colonies maintained at the nursery did not show a similar trend in the variation of the proportion of colonies suffering from partial mortality

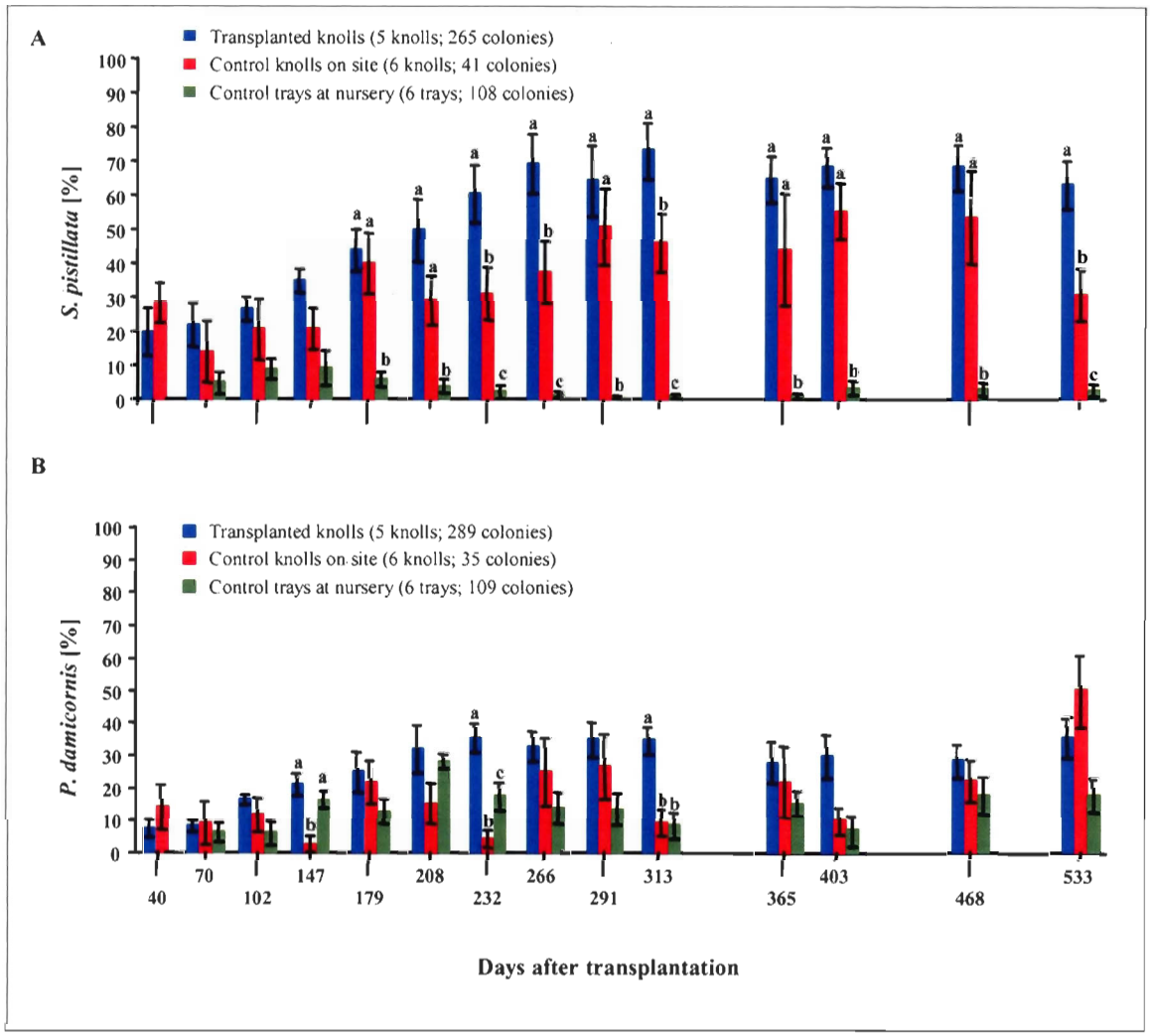

Figure 8: Partial tissue death recorded in transplants, naturally-growing control colonies and control colonies at the nursery, over time. (A) *S. pistillata*; (B) *P. damicornis*. Data reported as mean ± SE. Letters denote statistically significant monthly-groups.

over time as an interaction between the time and the different groups was documented (repeated measures ANOVA, *S. pistillata*: $F_{6.84,47.91}$=4.578; p=0.001; *P. damicornis*: $F_{8.86,62.05}$= 2.364; p=0.023; Appxs. Table 7.4.1).

Partial tissue death was common for *S. pistillata* transplants and naturally-growing controls in the reef (one way ANOVA with Bonferroni correction, p>0.003 for days 40-147; p<0.003 with Bonferroni multiple comparison post hoc, p>0.05 for days 172-208, 291, 365-468), though the transplants seemed to suffer slightly more from partial tissue loss, maximum of 72.9±8.3% compared to maximum of 55.2±8.3% (Fig. 8, Appxs. Table 7.4.3). *S. pistillata* colonies left at the nursery exhibited low partial tissue death (maximum of 8.8±2.9% per frame), in most observational time-points, significantly different than transplants and naturally-growing *S. pistillata* colonies (one way ANOVA with Bonferroni correction, p<0.003; Bonferroni multiple comparison post hoc, p<0.05 from day 179; Fig. 8, Appxs. Table 7.4.3).

In most observational time-points the proportion of *P. damicornis* colonies suffering from partial-tissue mortality did not differ significantly between the three experimental groups (one way ANOVA with Bonferroni correction, p>0.003 except for days 147, 232, 313; Fig. 8, Appxs. Table 7.4.3). *P. damicornis* transplants and naturally-growing colonies exhibited less partial tissue death at the restored site in comparison with *S. pistillata* transplants and controls (maximum of 35±4.5% per knoll for transplants and maximum of 49.7±11.4% for controls; Fig. 8). In contrast, more *P. damicornis* colonies exhibited partial-

tissue death at the nursery than *S. pistillata* colonies (maximum of 28±2.3% per *P. damicornis* tray in comparison with maximum of 8.8±2.9% per *S. pistillata* tray; Fig. 8).

The average magnitude of tissue loss, the proportion of a colony with bare skeleton due to tissue death, varied with time for the three experimental groups of both species (repeated measures ANOVA, *S. pistillata*: $F_{2.69,37.72}$=16.664; p<0.001; *P. damicornis*: $F_{2.14,29.99}$= 4.262; p=0.021; Appxs. Table 7.4.2) (Fig. 9). The treatment (transplantation or control group) had an influence on the magnitude of tissue death per *S. pistillata* colony, but did not impact the magnitude of tissue loss per *P. damicornis* colony (repeated measures ANOVA, *S. pistillata*: $F_{5.39,37.72}$=7.102; p<0.001; *P. damicornis*: $F_{4.28,29.99}$= 2.514; p=0.059; Appxs. Table 7.4.2).

S. pistillata transplants suffered from a significantly higher proportion of dead tissue per colony in comparison to the naturally-growing controls in most observational time-points (maximum of 38.0±8.4% per transplanted colony compared to maximum of 17.5±4.0% per control colony; one way ANOVA with Bonferroni correction, p<0.003; Bonferroni multiple comparison post hoc, p<0.05; Fig. 9, Appxs. Table 7.4.4). *S. pistillata* colonies exhibited low proportions of partial-tissue mortality per colony at the nursery (maximum of 2.3±1.6% per colony; Fig. 9).

The average percentage of tissue death per *P. damicornis* colony did not differ significantly among the three experimental groups (one way ANOVA with Bonferroni correction, p>0.003 except for days 147, 232) and partial tissue death did not exceed 13.7±7.4% (Fig. 9, Appxs. Table 7.4.4).

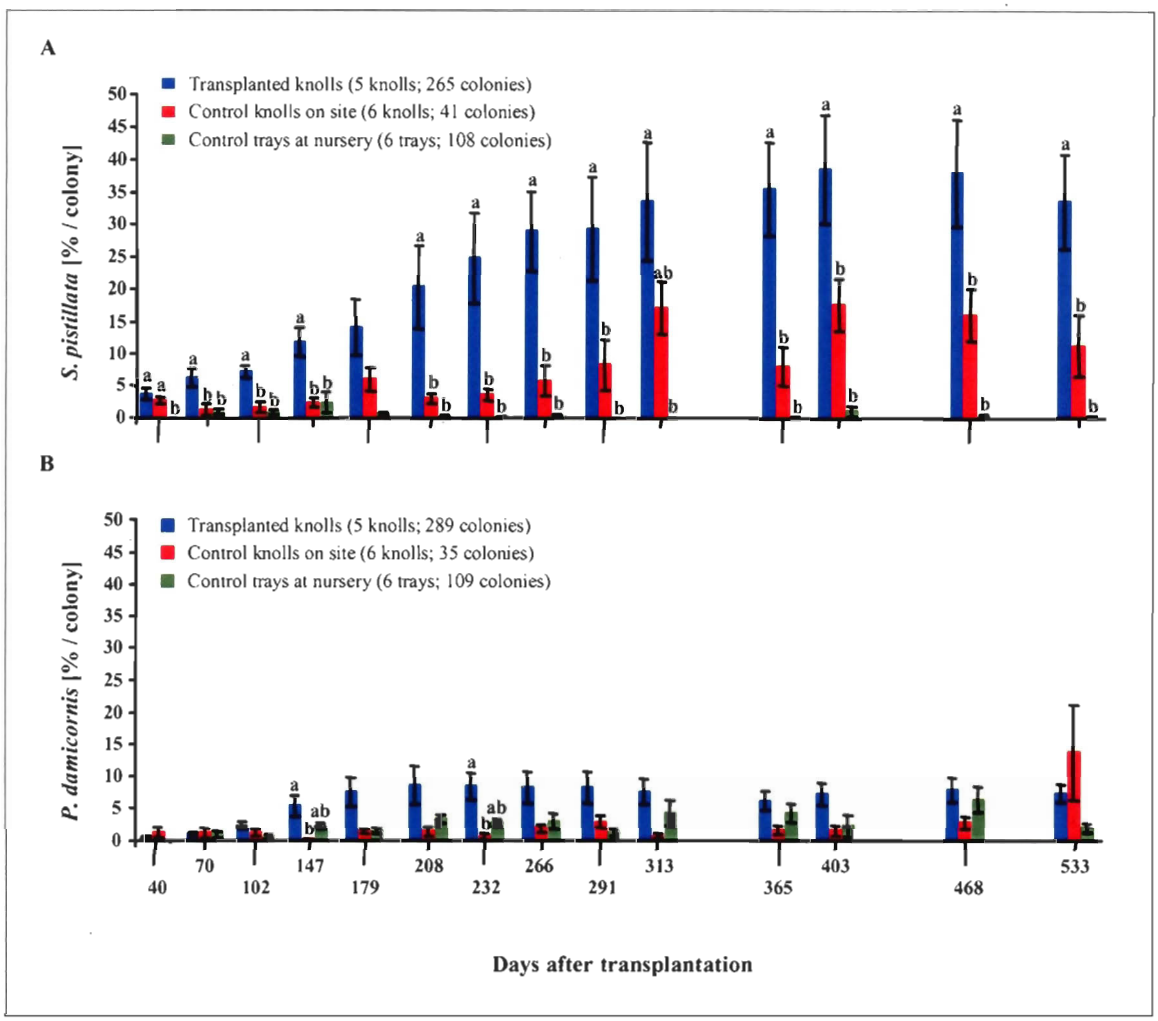

Figure 9: Average magnitude of tissue loss due to partial mortality recorded per transplanted colony, naturally-growing colony and control colony at the nursery, over time. (A) *S. pistillata*; (B) *P. damicornis*. Data reported as mean ± SE. Letters denote statistically significant monthly-groups.

3.1.6 Fish attacks

Once the transplants were attached to natural substrates, they attracted increased attention from local fish. As early as one hour after transplantation, fish bites were detectable on tissues and skeletons of transplants. Results reported are considered to be underestimated since we were not able to detect bites that regenerated rapidly between two observations. No coral predation by fish was observed in the control group at the nursery; herbivores fish grazed on algae in proximity to the colonies (sometimes pushing the corals in their search for algae and causing some coral detachment), but did not directly bite colonies.

The average percentages of *S. pistillata* and *P. damicornis* colonies attacked by fish at the restoration site are presented in Fig. 10. The damage to the corals varied as time progressed for both species (repeated measures ANOVA, *S. pistillata*: $F_{3.33,30}$=8.198; p<0.001; *P. damicornis*: $F_{2.05,18.49}$= 7.005; p=0.005; Appxs. Table 7.5.1). The trends over time were similar for *P. damicornis* colonies transplants and naturally-growing controls (repeated measures ANOVA, $F_{2.05,18.49}$= 2.346; p=0.123; Appxs. Table 7.5.1). During spring time, increased numbers of fish-attacked colonies of both *P. damicornis* transplants and naturally-growing controls were observed (Fig. 10). In contrast, the over time trend of the percentage of *S. pistillata* transplants attacked by fish differed from that observed for the naturally-growing colonies (repeated measures ANOVA, $F_{3.33,30}$=5.448; p=0.003; Appxs. Table 7.5.1). During the first months after transplantation, the nursed *S. pistillata* colonies were heavily attacked by fish (up to

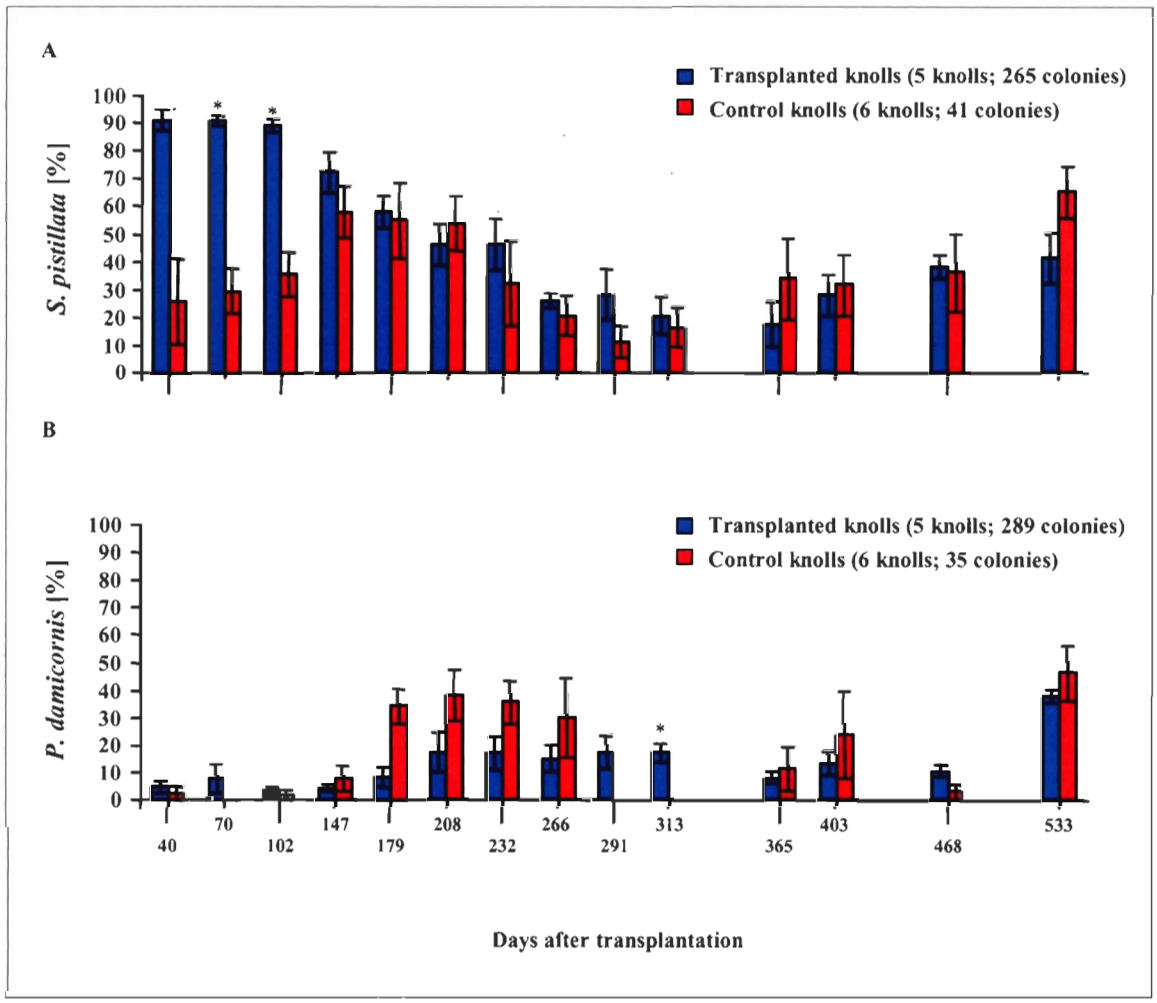

Figure 10: Percentage of transplanted colonies and naturally-grown colonies damaged by fish. (A) *S. pistillata*; (B) *P. damicornis*. Data reported as mean ± SE. Asterisks denote statistically significant monthly-groups.

90.8±3.6% of the transplants), significantly more than the naturally-grown colonies (up to 35.5±7.8% of the controls; one way ANOVA with Bonferroni correction, $p<0.001$ for days 70-102; Fig. 10, Appxs. Table 7.5.4). This feeding removed various portions of the colonies, from a single portion of a branch to all branches of a colony (up to approximately 90% of the colonies' volumes), leaving only the basal part (Fig. 11 A-C, E). In some cases, the intense feeding led to the detachment of the colony from the peg on which it had grown at the nursery (Fig. 11 D). After four months at the new site, the amount of attacked *S. pistillata* transplants decreased and leveled, in comparable to control levels (one way ANOVA with Bonferroni correction, $p>0.003$ for days 147-533; Appxs. Table 7.5.4).

The average percentage of nursery-grown *P. damicornis* prayed by fish was comparable to that of naturally-growing controls (one way ANOVA with Bonferroni correction, $p>0.003$ for days 40-291, 365-533; $p<0.003$ only for day 313; Fig. 10, Appxs. Table 7.5.4). The percentage of attacked transplants varied from 4.0±1.0% to 17.1±6.0% per knoll, in comparison with no attacks to 46.1±10% naturally-grown *P. damicornis* attacked by fish (Fig. 10). Examining the control groups of both species revealed that the amount of colonies hurt by fish has a seasonal trend, increasing during spring time (Fig. 10; red bars). The cumulative percentage of fish-eaten colonies analysis revealed an interaction between the origin of the colonies, transplanted or naturally-grown, and time in the case of *S. pistillata* but not in the case of *P. damicornis* (repeated measures ANOVA, *S. pistillata*: $F_{1.88,16.91}=10.654$; $p=0.001$; *P. damicornis*: $F_{1.58,14.19}= 2.806$; $p=0.103$; Fig. 12, Appxs. Table 7.5.2). Most of *S. pistillata* transplants were already eaten by fish during the first months of

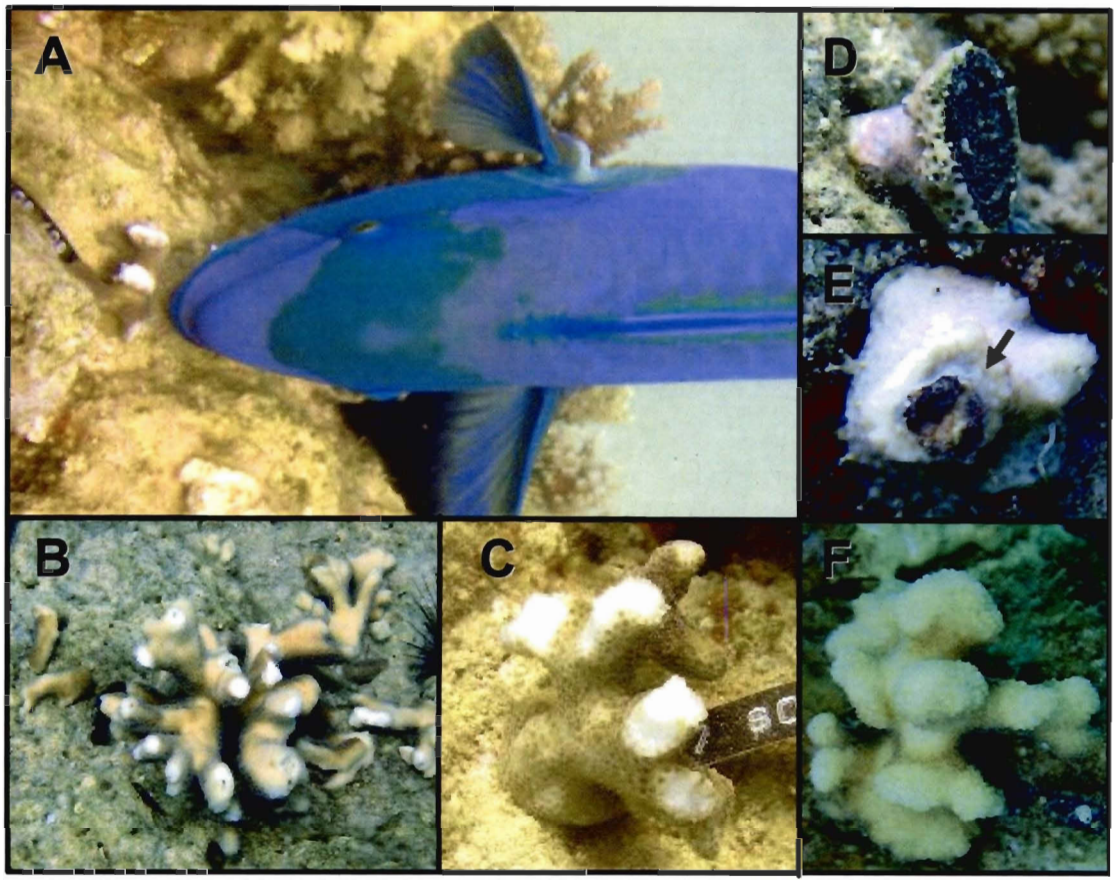

Figure 11: **Fish attacks on nursery-grown transplanted colonies. (A) A parrotfish bits *S. pistillata* transplant; (B) Several broken branches of a *S. pistillata* transplant are scattered around the damaged colony; (C) *S. pistillata* transplanted colony that has lost most of its peripheral branches; (D) An exposed peg following the detachment of a colony due to a fish attack; (E) Regeneration by the growth of tissue over damaged skeleton due to fish bites. Arrow points the new tissue growth over the exposed skeleton; (F) The complete regeneration of a damaged colony.**

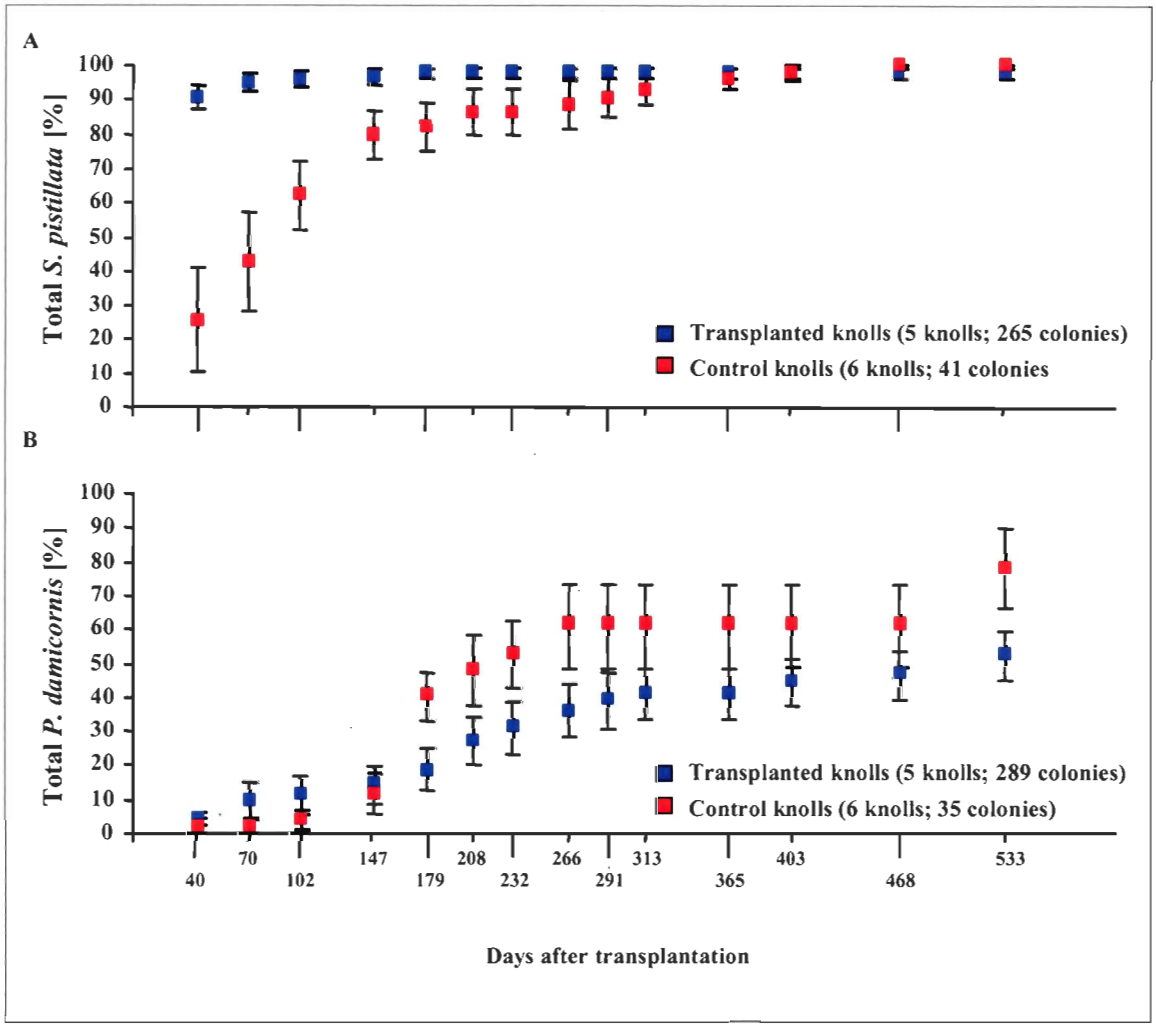

Figure 12: **The total numbers of fish-damaged transplants and naturally-grown control colonies accumulated over time. (A) *S. pistillata*; (B) *P. damicornis*. Data reported as mean ± SE.**

their reef dwelling (94.9±2.5% after 2 months), though all monitored *S. pistillata* controls (100%) and the majority of *S. pistillata* transplants (97.4±1.6) were eventually bitten (Fig. 12). On the contrary, more naturally-grown *P. damicornis* colonies suffered from fish attacks as compared to transplants (78.1±11.8% compared to 52.5±7.7%, respectively) (Fig. 12). Less colonies of *P. damicornis* were damaged by fish attacks over time, in comparison with *S. pistillata* colonies. (Fig. 12).

The average number of bites per *S. pistillata* colony was not impacted by time. An effect of time was observed though for *P. damicornis* colonies (repeated measures ANOVA, *S. pistillata*: $F_{3,40.66}$=2.535; p=0.078; *P. damicornis*: $F_{4.77,42.92}$= 1.172; p=0.017; Fig. 13, Appxs. Table 7.5.3). The trends of variations of the average fish-bites per colonies over time were similar for both *S. pistillata* and *P. damicornis* transplants and naturally-grown colonies (repeated measures ANOVA, *S. pistillata*: $F_{3,40.66}$=2.557; p=0.076; *P. damicornis*: $F_{4.77,42.92}$= 1.317; p=0.276; Fig. 13, Appxs. Table 7.5.3).

A significantly higher number of fish-bites per colony was recorded for *S. pistillata* transplants during the first month after transplantation (11.4±2.0 bites/colony), but number of fish-bites per colony decreased with time at comparable levels of the controls (one way ANOVA with Bonferroni correction, p<0.003 for day 40 and 403; p>0.003 for all other days; Fig. 13, Appxs. Table 7.5.5). The average number of bites per colony varied from 0.78±0.3 to 11.4±2 bites per transplanted *S. pistillata* colony, as compared to 0.5±0.2 to 4.7±3.7 per *S. pistillata* naturally-grown controls (Fig. 13).

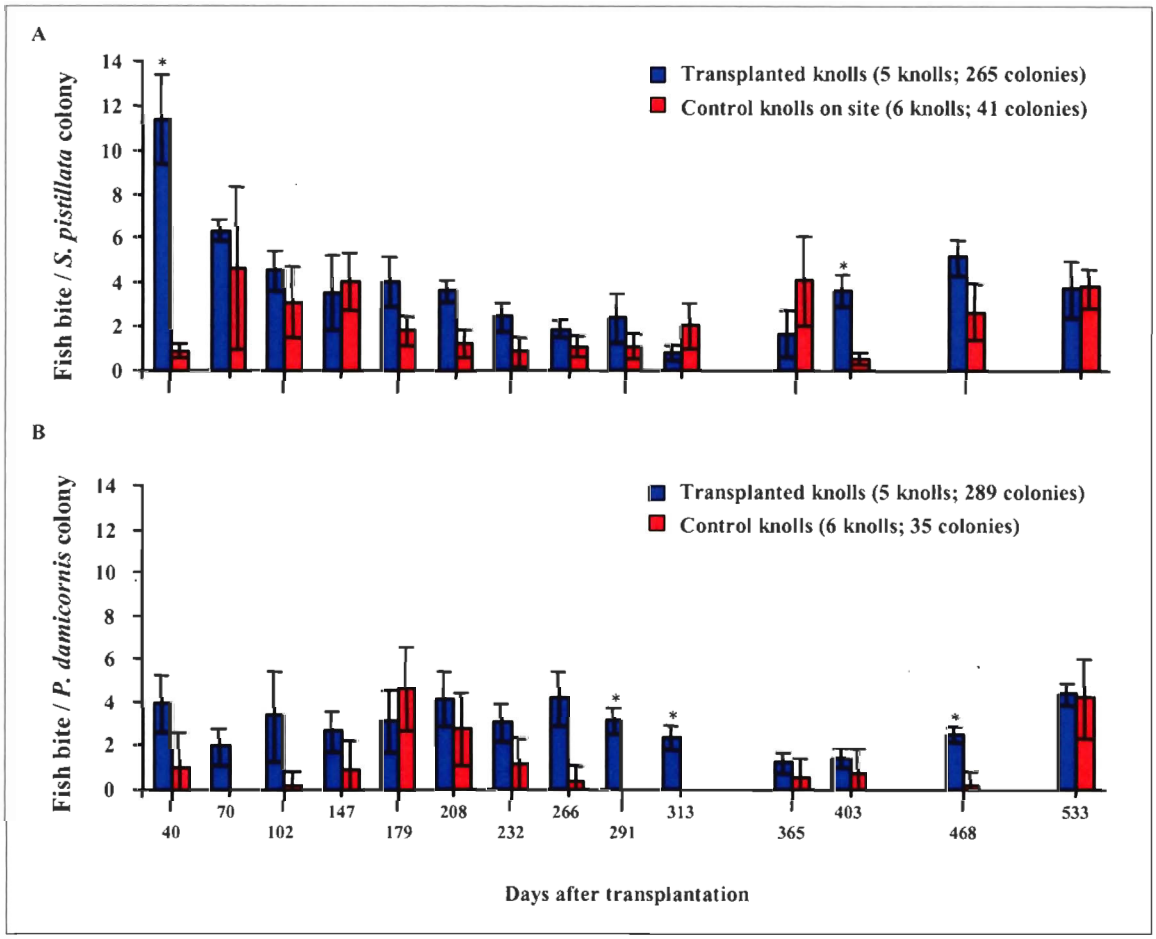

Figure 13: Fish bites per colony documented on transplanted colonies and naturally-grown control colonies. (A) *S. pistillata*; (B) *P. damicornis*. Data reported as mean ± SE. Asterisks denote statistically significant monthly-groups.

More bites per colony were observed during the first months following the transplantation of *P. damicornis* as compared to the naturally-growing colonies (2-20 times more) although no statistically significant difference was detected (one way ANOVA with Bonferroni correction, $p>0.003$ for days 40-147; Fig. 13, Appxs. Table 7.5.5). Along the observed period, the average number of fish-bites per colony did not differ significantly between the transplanted colonies and control *P. damicornis* colonies (one way ANOVA with Bonferroni correction, $p>0.003$ except for days 291, 313, 468; Fig. 13, Appxs. Table 7.5.5). The average number of bites varied from 1.2±0.5 to 4.1±1.3 bites per transplanted colony, as compared to no bites to 4.6±1.9 bites per control *P. damicornis* colony.

Most damaged corals undertook regeneration processes and regained colony spatial complexity (Fig. 11 E, F). Mortality was not linked to fish predation, as damaged colonies did not die.

3.2 Zooxanthellae densities and chlorophyll concentrations

Zooxanthellae numbers per surface area of the transplants and nursery control *S. pistillata* colonies, as well as their total chlorophyll content (chlorophyll a+c) are presented in Fig. 14. After 16 months transplanted colonies had lower numbers of zooxanthellae per area unit (22.0±3.3 $x10^3/mm^2$) than the colonies left in the nursery (36±5.2 $x10^3/mm^2$) (one-tailed *t* test, t=2.202; df=6; p=0.003) (Fig. 14). No significant difference was found when analyzing total chlorophyll concentrations per zooxanthella cell of the *S. pistillata*

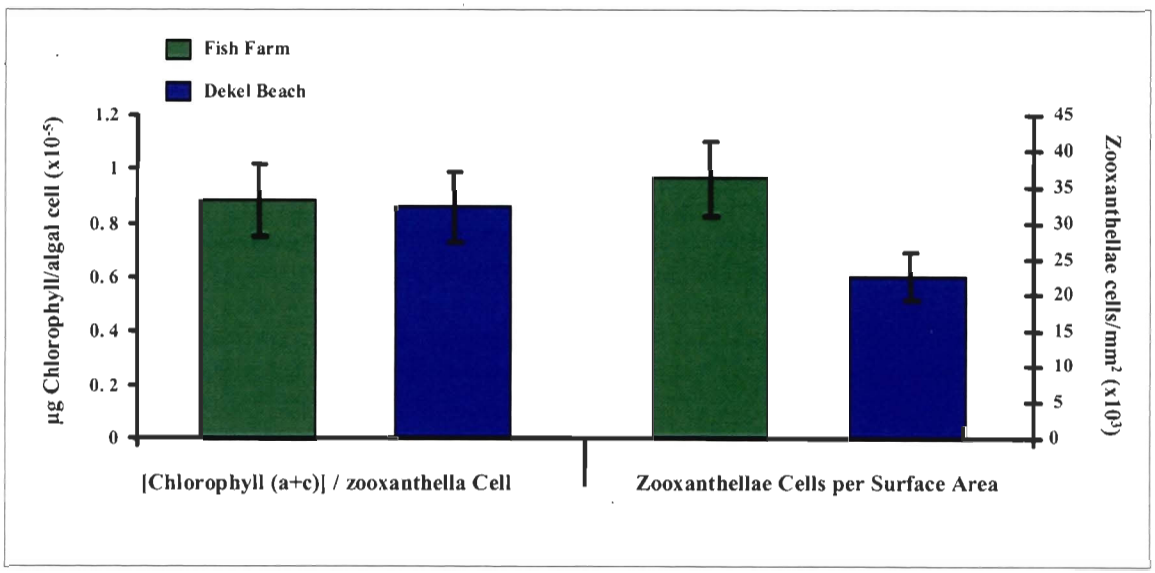

Figure 14: ***S. pistillata*** **average chlorophyll a+c concentration and zooxanthellae numbers (± SE) per nursery-control colony (Fish farm) or transplanted colony, after 16 months.**

colonies that remained under an enriched nutrient regime at the nursery (8.8±1.3 $x10^{-6}$ µg/cell) and those transferred back to the oligothrophic conditions of the reef (8.6±1.3 $x10^{-6}$ µg/cell) (two-tailed *t* test, t=0.122; df=6; p=0.907) (Fig. 14).

3.3 Growth

Total net growth of nursery-grown colonies after 18 months (543 days) is presented in Table 1. The weight added at the nursery and at the restoration site did not differ significantly, for either *S. pistillata* (one-tailed *t* test: t=-0.126, df=5, p=0.452), or for *P. damicornis* (t=-0.192, df=8, p=0.426). Similar results were obtained for the height addition (*S. pistillata*: t=0.770, df=5, p=0.238; *P. damicornis*: t=0.378, df=8, p=0.357), colony

Table 1: Growth measurements of nursery-grown colonies at transfer (day 0) and after 18 months (543 days).

Coral species	Location	N=	Day	Parameter measured				Size augmentation [x]				Growth rate constant [%/day]
				Weight [g]	Height [mm]	Diameter [mm]	Ecological volume [cm³]	Weight	Height	Diameter	Ecological volume	
S. pistillata	nursery	4	0	119.8 ± 40.1	82.9 ± 9.4	77.0 ± 14.5	465.3 ± 196.2	1.8 ± 0.2	1.5 ± 0.1	1.5 ± 0.2	3.4 ± 0.8	0.17
			543	185.0 ± 44.1	118.8 ± 9.8	109.5 ± 10.8	1186.8 ± 291.3					
	Dekel beach	3	0	101.0 ± 16.8	74.2 ± 6.1	72.2 ± 4.6	307.8 ± 48.9	1.8 ± 0.2	1.4 ± 0.1	1.5 ± 0.1	3.2 ± 0.6	0.20
			543	177.0 ± 12.3	100.6 ± 4.1	108.2 ± 5.1	922.5 ± 51.3					
P. damicornis	nursery	5	0	118.2 ± 19.7	85.2 ± 4.5	79.9 ± 7.0	453.3 ± 99.7	1.8 ± 0.1	1.3 ± 0.1	1.5 ± 0.1	2.8 ± 0.3	0.17
			543	198.6 ± 22.1	109.6 ± 5.2	114.6 ± 6.6	1163.1 ± 189.7					
	Dekel beach	5	0	94.2 ± 26.4	62.7 ± 6.3	76.9 ± 10.4	346.6 ± 133.4	1.8 ± 0.3	1.3 ± 0.1	1.3 ± 0.1	2.3 ± 0.4	0.14
			543	175.4 ± 66.0	79.3 ± 8.7	99.8 ± 14.1	753.6 ± 327.0					

diameter added (*S. pistillata*: t=-0.038, df=5, p=0.485; *P. damicornis*: t=1.285, df=8, p=0.117) and ecological volume added (*S. pistillata*: t=0.224, df=5, p=0.415; *P. damicornis*: t=0.988, df=8, p=0.176) of nursery-remaining controls and transplanted colonies. Thus, growth at both sites was similar. The ecological volume of *S. pistillata* colonies increased, on the average, 3.3 fold after 543 days. The ecological volume of *P. damicornis* colonies increased by a 2.5 factor (Fig. 15). The computed growth rate constant (k) revealed an average k of 0.17% per day for *S. pistillata* control colonies at the nursery and an average k of 0.20% per day for *S. pistillata* transplants, percentages found to be not significant (test for equality between 2 percentages, $p>0.05$). The same patterns were observed for *P. damicornis* with 0.17% per day for the nursery farmed colonies and 0.14% per day for the Dekel Beach transplants (no significant difference, test for equality between 2 percentages, $p>0.05$). Inter-species comparison confirms that there is also no difference between the k of the two species (test for equality between 2 percentages, $p>0.05$). Since no disparity was found between the localities or between the species, this represents an average ecological growth rate constant of 0.17% per day both at the nursery and at the Dekel Beach.

3.4 Transplanted corals and coral dwelling invertebrates

The average percentages of transplants recruited by invertebrates, as well as the average number of invertebrate specimens residing in each transplant, are presented in Fig. 16. As the experiment proceeded, the average percentage of nursery-grown transplanted

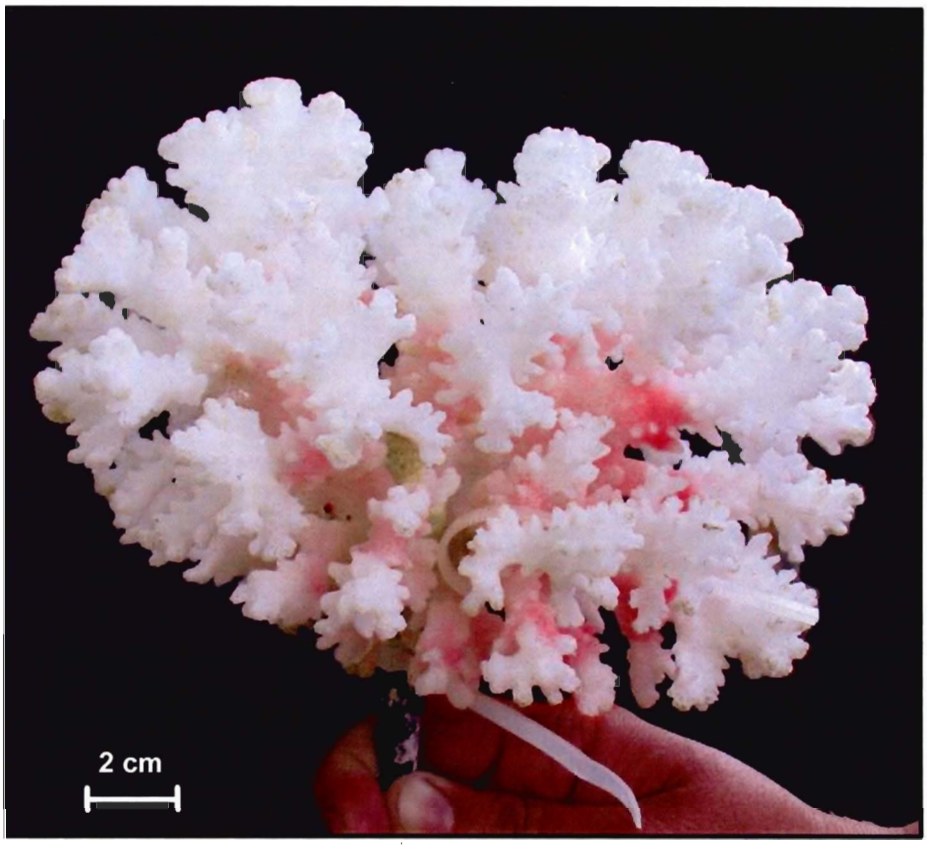

Figure 15: **Nursery-grown *P. damicornis* colony analyzed for growth 18 months after transplantation. The pink Alizarin incorporation in the coral's skeleton represents colony dimension prior to transplantation (day 0). All white skeletal additions are products of growth at the restoration site.**

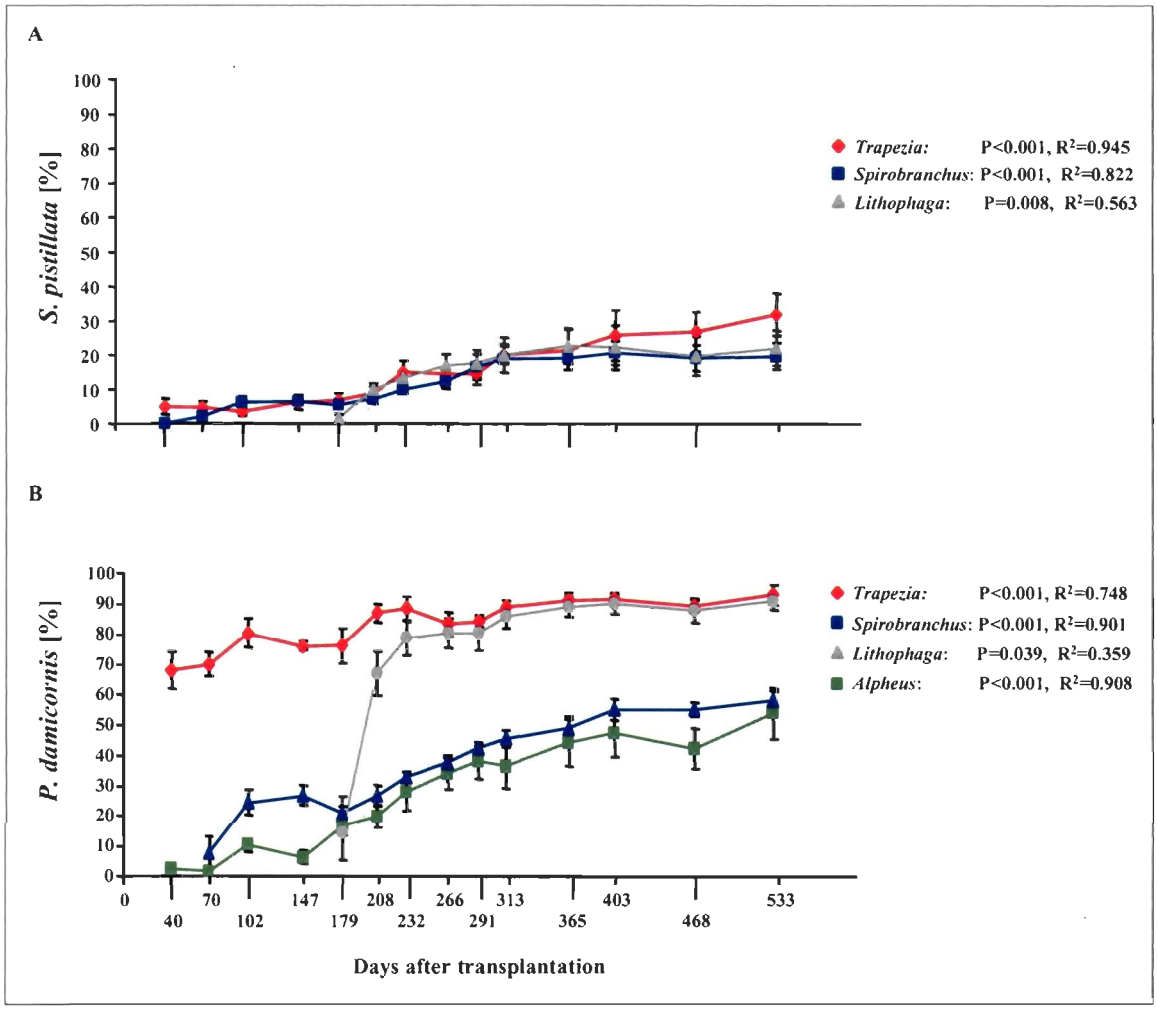

Figure 16: **Average percentage of nursery-grown transplants inhabiting *Trapezia*, *Spirobranchus*, *Alpheus* and *Lithophaga*. (A) *S. pistillata*; (B) *P. damicornis*. Data reported as mean ± SE. Pearson Correlation and *R*-square values are shown.**

colonies inhabiting obligate associates of hermatypic corals of the genus *Trapezia* and *Spirobranchus* increased from 4.9±2.3% of *S. pistillata* colonies and 68.3±6.2% of *P. damicornis* colonies inhabiting *Trapezia* at day 40, to 31.8±6.2% of *S. pistillata* colonies and 92.8±3.5% of *P. damicornis* colonies inhabiting *Trapezia* at day 533, and from 2.0±1.5% of *S. pistillata* colonies and 7.9±5.4% of *P. damicornis* colonies inhabiting *Spirobranchus* at day 70, to 19.7±3.9% of *S. pistillata* colonies and 57.9±3.1% of *P. damicornis* colonies inhabiting *Spirobranchus* at day 533.

Correlations between the average percentage of colonies recruited by the studied invertebrates and time exhibited positive and highly significant linear trend for either *S. pistillata* or *P. damicornis* ($p<0.001$ for both) (Table 2). A significant increase in the average percentage of transplants resided by *Trapezia* crabs and *Spirobranchus* worms was documented (Fig. 16, Table 2). The linear regression computed indicates that "time" explains between 75 to 94% of this increase. After 17 months at the natural reef, 31.8±6.2% of the *S. pistillata* and 92.8±3.5% of the *P. damicornis* inhabited *Trapezia* and 19.7±3.9% of the *S. pistillata* and 57.9±3.1% of the *P. damicornis* inhabited *Spirobranchus* (Fig. 16).

Alpheus shrimp represents another common invertebrate species that recruited to the new transplants. *Alpheus* shrimps were seen only on *P. damicornis* transplants, although they were spotted in colonies of both coral species naturally-grown at the restoration site. The percentage of colonies colonized by this shrimp species increased significantly with time as the correlation between the average percentage of *P. damicornis* colonies recruited

Table 2: Results of correlations and linear regression analyses between time and average percentage of *S. pistillata* and *P. damicornis* transplants inhabiting coral-dwelling invertebrates.

Transplants inhabiting invertebrates over time (Average [%])	Invertebrate species	Correlation			Linear regression	
		r	p	n	Adjusted R^2	Equation of best fit
S. pistillata	*Trapezia*	0.974	<0.001	14	0.945	y=0.062x-1.272
	Spirobranchus	0.915	<0.001	13	0.822	y=0.044x+0.389
	Lithophaga	0.782	0.008	10	0.563	y=0.046x+1.713
P. damicornis	*Trapezia*	0.876	0.001	14	0.748	y=0.047x+71.175
	Spirobranchus	0.954	<0.001	13	0.901	y=0.105x+8.308
	Lithophaga	0.656	0.039	10	0.359	y=0.13x+33.809
	Alpheus	0.957	<0.001	14	0.908	y=0.114x-2.083

by *Alpheus* and time exhibited, again, a positive and highly significant linear trend ($p<0.001$, $R^2=0.91$; Fig. 16 Table 2). After 17 months at the natural reef, 53.7±8.4% of the *P. damicornis* inhabited *Alpheus* (Fig. 16).

In April 2006, 179 days after transplantation, we witnessed settlement and metamorphosis of the boring bivalve *Lithophaga* larvae on three *S. pistillata* transplants and on 31 *P. damicornis* transplants. On the next month, the number of colonies on which *Lithophaga* had settled increased considerably (Fig. 16) and continued rising. A correlation between the average percentage of *S. pistillata* and *P. damicornis* transplants infested by *Lithophaga* over time showed "time" to be a significant variable influencing the recruitment, with a linear tendency ($p=0.008$ and $p=0.039$, respectively).

The linear regression computed revealed that other factors rather than time impacted transplants' colonization as only 56% and 35% of the increase, for *S. pistillata* and *P. damicornis*, respectively, is due to time (Fig. 16, Table 2). After 17 months at the natural

reef, 21.9±5.1% of the *S. pistillata* and 90.7±2.6% of the *P. damicornis* had new recruits of *Lithophaga* borers (Fig. 16).

The average number of *Trapezia* and *Spirobranchus* per single *S. pistillata* and *P. damicornis* transplanted colony was also strongly correlated with time and increased significantly as experiment progressed ($p<0.001$ for both) (Fig. 17, Table 3). The *Pocillopora* transplants were invaded by more individuals of studied invertebrates species per colony as compared to *Stylophora* transplants; after 17 months at the natural reef, an average of 0.6±0.3 and 1.9±0.1 *Trapezia* per colony were counted for *S. pistillata* and *P. damicornis*, respectively. An average of 0.3±0.1 and 0.9±0.01 *Spirobranchus* per colony were recorded in *S. pistillata* and *P. damicornis*, respectively (Fig. 17). The number of *Alpheus* shrimps in colonies of *P. damicornis* also correlated significantly with time and increased linearly ($p<0.001$) (Fig. 17, Table 3). After 17 months, each transplanted *Pocillopora* colony was home for one *Alpheus* (0.98 ±0.18; Fig. 17).

In general, more colonies of transplanted *P. damicornis* were colonized by coral-associated invertebrates than *S. pistillata* and they house higher number of these invertebrates per colony. Using the equations of best fit, predictions of the time required for the totality of the transplants to inhabit the above invertebrates, as well as the time required for each transplanted colony to inhabit the number of these invertebrates typically observed per colony at the natural reef are presented in Table 4.

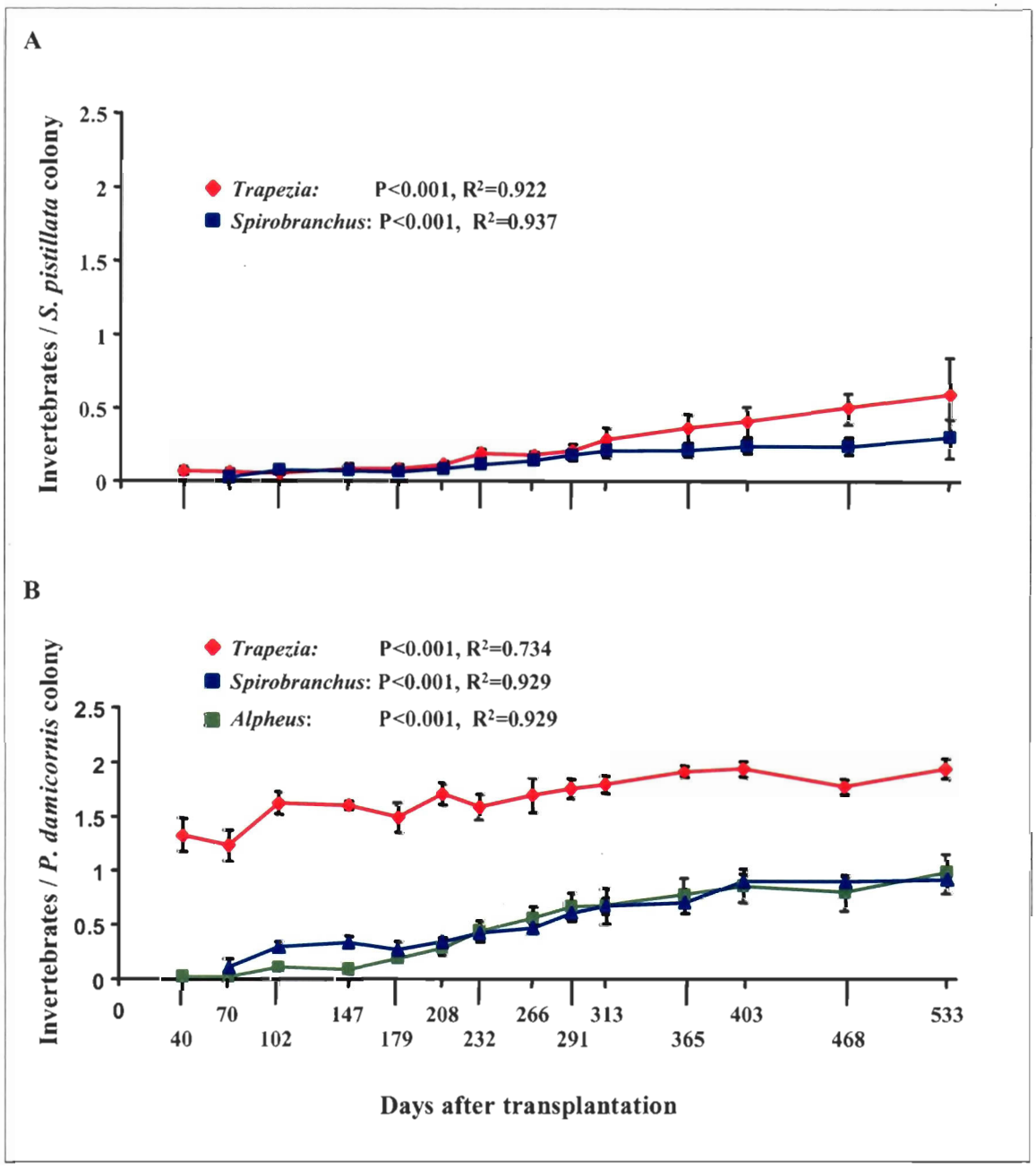

Figure 17: Average number of *Trapezia*, *Spirobranchus* and *Alpheus* counted in nursery-grown transplanted colonies. (A) *S. pistillata*; (B) *P. damicornis*. Data reported as mean ± SE. Pearson Correlation and *R*-square values are shown.

Table 3: Results of the correlation and the linear regression analysis between time and the average number of coral-associated invertebrates counted in *S. pistillata* and *P. damicornis* transplants.

Average number of invertebrate/colony over time	Invertebrate species	Correlation			Linear regression	
		r	p	n	Adjusted R^2	Equation of best fit
S. pistillata	*Trapezia*	0.963	<0.001	14	0.922	y=0.001x-0.07
	Spirobranchus	0.971	<0.001	13	0.937	y=0.001x-0.017
P. damicornis	*Trapezia*	0.869	<0.001	14	0.734	y=0.001x+1.343
	Spirobranchus	0.967	<0.001	13	0.929	y=0.002x+0.018
	Alpheus	0.967	<0.001	14	0.929	y=0.002x-0.108

Table 4: Time prediction required for all transplants of *S. pistillata* and *P. damicornis* to inhabit different species of coral-associated invertebrates, and time required for a pair of *Trapezia* and *Alpheus* to settle in all transplants.

	Predictions based on the equations of best fit - Time [years] required for:				
	100% transplants to inhabit			100% transplants to inhabit	
Coral species	*Trapezia*	*Spirobranchus*	*Alpheus*	Pair of *Trapezia*/colony	Pair of *Alpheus*/colony
S. pistillata	4.5	6.2		5.75	
P. damicornis	1.7	2.4	2.4	1.8	2.9

3.5 Larval collection

On June 19 and June 26, 2007, plankton nets were placed over five transplanted *S. pistillata* colonies and five locally-growing *S. pistillata* colonies at the site, from sunset until sunrise. Of the 10 examined *S. pistillata* transplants, eight were found to release planulae larvae (Table 5). The larvae numbers counted under a stereomicroscope varied from 1 to 15 planulae per colony (average of 3.7±1.5 planulae per transplant). Total of 37 planulae were collected from the transplants, potentially contributing to the local larval

stock. In contrast, no planulae were released from the naturally-growing *S. pistillata* at the site on both sampling events (Table 5).

Table 5: Results of larvae collection on June 19 and June 26, 2007. Planulae were collected from transplanted and naturally-growing *S. pistillata* colonies of the same size, at the Dekel Beach.

	Reef dwelling period [Years]	Colonies examined [n]	Releasing-planulae colonies [n]	releasing-planulae colonies [%]	Total number of planulae collected	Average planulae/colony
Natural colonies	5	10	0	0	0	0
Transplanted colonies	1.6	10	8	80	37	3.7±1.5

4. DISCUSSION

4.1 The acclimation of the nursery-grown coral at the degraded area

The success of coral transplantation is often evaluated by the survival and growth performance of studied species, parameters that should exhibit the values observed in naturally-growing local corals (Yap *et al.* 1992, Fahy *et al.* 2006). Here we present results showing that transplanted coral colonies of both studied species, *S. pistillata* and *P. damicornis*, did not differ during the first 9 months following the transplantation from naturally-growing control colonies. These results suggest that nursery-grown corals have a good starting point granting them a high potential to acclimate to new environments. It also indicates that a nursery phase prior to transplantation is successful in diminishing any initial stress to transplants due to their transfer or to the transplantation act, initial stress encountered in previous direct transplantation experiments (Yap *et al.* 1992, Fahy *et al.* 2006). In addition, both the average percentage of colonies with partial tissue mortality syndrome and the magnitude of tissue loss of those colonies were low in the coral nursery, indicating to the supportive conditions of our floating nursery, and enabling the corals to be maintained in good physiological state. Common stressors in the natural reef (i.e. lack of fish predation, SCUBA divers) were not recorded in the nursery due to its distance from the reef or due to the routine maintenance (removal of coralivorus gastropods and competitors). All these factors contributed to the initially high survivorship of the transplants. The overall

survival, however, is different for the two species, as *Pocillopora damicornis* exhibited a better performance than *Stylophora pistillata* at the study site.

The average percentage of survival for *P. damicornis* transplants recorded was lower than that of the natural control colonies after 17 months (78% compared to 93%), not a statistically different rate. Hence, the nursery-grown *P. damicornis* transplants have a similar survival capacity to the natural, unmanipulated local colonies. This outcome could be compared with direct fragment transplantation of *P. damicornis* performed in the northern part of the Gulf of Eilat (Red sea, Aqaba; Van Treeck and Schuhmacher 1997) that resulted in a survival rate of 36% after 1 year. This further supports the "Gardening" rational that transplantation of whole colonies rather than fragments may significantly improve the probability of survival. The high survival of *P. damicornis* recorded in this study is also higher than previously reported figures on direct transplantations of whole coral colonies (Bouchon *et al.* 1981, Clark and Edwards 1995, Akakura *et al.* 2006, Schrimm *et al.* 2006,). We also recorded that *P. damicornis* transplants showed similar partial tissue mortality rates to naturally-growing colonies, again indicating a successful integration of transplanted colonies to the natural reef.

Nine months after transplantation, the survivorship of the transplanted *S. pistillata* colonies was significantly lower than that of the natural colonies. By the end of the experiment, a difference of 30% mortality between the two groups was noticeable as 53% of the *S. pistillata* transplants survived, compared to 82% of resident colonies. The *Stylophora* transplants also suffered from a higher level of partial tissue mortality compared

to the natural colonies—up to 2.2 times more than naturally-growing colonies. Despite that, these results indicate improved survival when compared to *S. pistillata* fragment transplantation in the northern part of the Gulf of Eilat (Red sea, Aqaba; Van Treeck and Schuhmacher 1997) that resulted in a mortality rate of 48% after 1 (compared to 34% mortality rate a year recorded for the transplanted nursery-grown corals). With the aim of optimizing and increasing the survivorship of future *S. pistillata* nursery-grown transplants, a prolongation of the rearing period in the nursery prior to transplantation could be examined. The optimal culture time and colony size for transplantation should be further investigated.

Naturally-growing coral colonies, in one given location, are subject to site selection forces from early stages of settlement and growth. Resident colonies that were used as controls have already been subjected to natural selection at the restoration site and only those that best fitted local conditions survived to the state of large colonies. The cultured colonies, on the other hand, were reared under different environment set up conditions than in the experimental site and thus encountered selection only after transplantation. This might have contributed to the increased mortality observed for the *S. pistillata* transplants compared to the natural mortality occurring at the site.

It should also be noted that, none of the transplanted colonies originated from the natural reef so their appearance is a net addition to local coral populations. After 17 months, the remaining 100 live colonies of *S. pistillata* and 145 colonies of *P. damicornis* in the small area transplanted exhibit a significant add-on to local communities diversity

(see below discussion on coral-dwelling invertebrates), a conclusion that should be taken into consideration when evaluating the success of transplantation. This net profit is coupled with a "labor cost" (working days and expenditures) but not with a "nature cost" (removal of colonies from donor reef areas).

Once transferred to the restoration site, the nursery-grown transplants underwent physiological changes in accordance with local environmental conditions. High zooxanthellae abundance is often associated with increased feeding or with the state of growing in nutrient-enriched environment (Titlyanov *et al.* 2001, Grover *et al.* 2002), which characterizes coral nursery conditions (Bongiorni *et al.* 2003a, Amar *et al.* 2007). In addition, corals at the nursery show darker tissue pigmentation than naturally-growing colonies. The dark tissue-pigmentation of the transplants slowly faded and their tissue regained the typical, species specific color observed at the natural reef. This change is due to reduced numbers of endosymbionts that was recorded for the *S. pistillata* transplants, which indicates fast physiological response to the change of habitat.

Throughout the experiment, a 30% and 34% detachment was recorded for *S. pistillata* and *P. damicornis* transplants, respectively. We are not successful yet to achieve the properties of natural attachment of colonies to substrates at the reef and therefore 3.3 to 10 times enhanced detachment rates of transplants than natural detachment has been recorded for *S. pistillata* and *P. damicornis*, respectively. This issue will be further discussed in the transplantation methodology section.

Part of the coral (natural and transplanted colonies) detachment occurring at the Dekel Beach can be attributed to diving activity, which has been shown to contribute greatly to Eilat's reef degradation (Zakai and Chadwick-Furman 2002). It should also be noted that the experimental site is located in front of a diving center. Another cause for detachment is the fish predation on transplanted colonies, occasionally observed. This is also connected to higher fish attacks recorded for *S. pistillata* colonies, since 100% of the *S. pistillata* were attacked compared to 78% of natural and 53% of transplanted *P. damicornis*, as a result, *S. pistillata* colonies disconnected about 3 times more than *P. damicornis* colonies. The higher fish predation encountered for *S. pistillata* could have also potentially contributed to the higher percentage of *S. pistillata* colonies, both natural and transplanted, which suffered from partial mortality at the site. Interestingly, after transplantation, nursery-grown *S. pistillata* were particularly attacked by fish during the first month after their transfer to the natural reef. The high density of zooxanthellae in their tissue is a possible explanation as to why they have attracted more fish. The dark tissue pigmentation may have been the reason for their preference. As time went by and the corals regained a lighter pigmentation, they became equally attractive as resident colonies.

Although more attacks were documented on *S. pistillata*, both species in both experimental groups have experienced fish attacks although no direct mortality was observed following these attacks. Fish attacks of scleractinian corals are documented in the literature and various feeding behaviors of fish including browsing, grazing and corallum eating is documented in many scleractinian species, including *Stylophora* and *Pocillopora* (Neudecker 1979, Alwany *et al.* 2003, Sánchez *et al.* 2004, Rotjan and Lewis 2006). The

extent and effect of predation on live corals were the subjects of several studies, revealing that some parrotfish species can cause the destruction of entire coral heads by repeated biting (Bruckner and Bruckner 1998), and in some areas, are a major cause of chronic coral mortality (Bythell *et al.* 1993). Apart from feeding, parrotfish were also described to bite corals as part of a territorial marking behavior (Sánchez *et al.* 2004). Similar to our experiment, Neudecker (1979) has followed the feeding of piscine corallivores upon *P. damicornis* transplants that were relocated to a site where this species was absent. Analogous to the results obtained in the nursery-grown transplantation, all of the transplanted colonies were intensely attacked by fish, particularly by chaetodontid and balistid fish, but this predation pressure did not result in colonies' mortality. Neudecker (1979) further concluded that since several species of fish can jointly eat an average of one-fourth of a colony's weight, fish feeding greatly impact the growth, abundance and distribution of corals. During this study parrotfish (Scaridae) were the only family observed to physically damage the coral skeleton although other coral-eating teleosts are also abundant in the Gulf of Eilat. Chaetodon species were observed grazing on the living tissue of the colonies, but no other predation interaction was witnessed between fish and transplants.

Fish predation is seasonal, increasing for both species during spring and early summer. In such a location where fish predation is commonplace, it is wise to activate transplantation measures in seasons when coralivorous activity is lower in order to reduce this impact on the new transplants and to further optimize acclimation at the new site.

4.2 Growth and reproduction

The relocation of the colonies did not result in a reduction of growth rate which may hint at a diminished stress impact. The *S. pistillata* transplants showed an average of 2.3 fold annual increase and the *P. damicornis* transplants showed a 1.8 fold annual increase in their ecological volume. This increase was similar to that of the *S. pistillata* and *P. damicornis* colonies kept at the nursery under ideal conditions. This further demonstrates that nursery-grown colonies are capable of acclimating, growing and thriving in the new environment, in contrast with direct transplantation of whole colonies, which resulted in a reduced growth rate following transplantation (Edwards and Clark 1998). The good physiological condition of the colonies at the end of the rearing period presented a valuable advantage of nursery grown corals as a restoration material.

In addition, since the nursery is located in an enriched nutrient area at Eilat's north beach, a higher growth rate for the nursery controls was expected. This has been confirmed by previous works that have shown that the high nutrient concentrations accelerate coral growth (Bongiorni *et al.* 2003a). The growth rate constant computed for both experimental groups indicates a similar percentage of incremental growth. Consulting *The Israel National Monitoring Program of the Gulf of Eilat* 2006 report (Genin and Shaked 2007) regarding the nutrient concentration in proximity to the restoration site revealed that, on average, the quantity of nutrients observed by the Dekel Beach were lower than those observed by the North Beach. However, in some seasons it was noted that concentrations neighboring the Dekel Beach was slightly higher than the average observed at the rest of

the natural reef. This could have contributed to the high growth rates observed for the transplants.

Another potential hypothesis is that the fish bites could have in some way affected the corals' growth. All of the *S. pistillata* transplants analyzed for growth were attacked by fish, in contrast to the nursery controls. These attacks have led to the loss of various amounts of branches and skeleton. Despite this, the final colonies' incremental growth was similar to that of the nursery-kept *S. pistillata*, which encountered no losses from fish attacks. Thus, the piscivor activity might have stimulated growth. Loya (1976) indicated that during the first 2 months following injury, damaged *S. pistillata* colonies grow twice as fast as intact colonies. In addition, damaged branches grow faster than intact branches within the same colony. The hypothesis of fish attacks stimulating *S. pistillata* colonies' growth is further supported by the work of Guignard and Le Berre (2008) on *Acropora* species in the Maldives, showing cuts and scarification of corals to stimulate the formation of new peripheral branches. The cicatrisation tissue growing over the broken skeletal section had a higher probability of generating new axial polyps than an undamaged axial polyp. Hence, although fish predation contributes, to a certain extent, to the bioerosion of the reefs, at moderate levels it may have a positive effect on coral growth.

The relocation of the colonies did not result in any obvious stress affecting energy allocation from reproduction, as was observed in experiments using fragments (Zakai *et al.* 2000, Guest *et al.* 2007). *S. pistillata* transplants liberated planulae, potentially contributing to the local larval stock. Lack of planulae release observed for the resident *S. pistillata*

colonies could indicate a stress affecting the colonies' reproductive capacities. Rinkevich and Loya (1986) have shown that the decrease in reproduction rate preceded colony death in *Stylophora pistillata*. This diminution appeared up to more than 6 months before colony death, preceding any visible partial tissue mortality or signs of damage. Guest *et al.* (2007) reported that the transfer of *Goniopora columna* fragments to more disturbed sites resulted in a significant reduction in oocytes numbers and sizes, suggesting a diversion of energy from reproduction in response to stressors in the environment. Transplanting nursery-grown coral colonies can increase the local recruitment in damaged reef areas if transplants are transferred when gravid. Transplantation of nursery-grown corals just prior to reproduction season can help re-seed degraded reefs.

4.3 Impact on the local invertebrates: ecosystem engineering by branching forms

The addition of the nursery-grown coral resulted in the creation of additional space for colonization by coral-associated invertebrates. With time, more and more of these added microhabitats were indeed colonized by an increasing number of *Trapezia*, *Spirobranchus*, and *Alpheus*. This ability to influence other organisms' abundance and repartition in a habitat was defined as Ecosystem Engineering by Jones *et al.* (1994). Ecosystem engineers are organisms that regulate the availability of resources (other than themselves) to other species. They can modify the habitat via their own physical structures (creating living space, like the transplants) and / or by the transformation of materials from one physical state to another. The engineer species create, modify, or maintain the habitat (Jones *et al.*

1994) and greatly affect their communities and ecosystems due to the disproportionately large impact they have relative to their abundance (Rosemond and Anderson 2003, Stinchcombe and Schmitt 2006).

While both species had engineering capacities and increased the niches available on the experimental knolls, *P. damicornis* had a higher impact on the coral-associated invertebrates. More colonies of *P. damicornis* were colonized and the number of specimen counted in these colonies was higher than in the *S. pistillata* transplants. The predicted amount of time required for all of the *P. damicornis* transplants (100% of the colonies) to be occupied by these invertebrates was found to be shorter that that required for *S. pistillata*.

The predicted amount of time required for all the transplanted colonies to inhabit the typical observed number of invertebrates per colony of the examined species was also found to be shorter *for P. damicornis*. Usually, adult *Trapezia* are found in pairs in colonies. *Trapezia* crabs reproduce year-round (Wolodarsky and Loya 1980) and thus recruit permanently to Pocilloporid colonies. Based on the linear regression computed, 5.7 years, as compared to 1.8 years, will be needed for all the transplanted *S. pistillata* and *P. damicornis* respectively to inhabit 2 *Trapezia* per colony.

Intensive fish attacks on *S. pistillata* colonies reduced the colonies' special complexity, which might explain the differences observed between the two transplanted species. This has probably impacted the selection of the *Trapezia* and *Alpheus* for the colony in which to settle. Potentially fewer *Trapezia* and no *Alpheus* recruited to the *S.*

pistillata colonies because the protection offered by those colonies was reduced as a result of the decrease in the number of branches, effectively leaving the decapods more accessible for predators (Idjadi and Edmunds 2006). Since *Trapezia* crabs were documented to sometimes leave the host coral and settle in another (Wolodarsky and Loya 1980), they may have also migrated from the attacked *S. pistillata* colonies. The reduction of the spatial complexity altered temporarily the engineering capacity of branching *S. pistillata*.

Apart from the previously mentioned invertebrates that live on the surface of the colony, the borer bivalve *Lithophaga* also used the skeleton of the *S. pistillata* and *P. damicornis* transplants as a living space. Many studies have investigated patterns, benefits and specificity of the coral-borer association between live corals and boring bivalves (Highsmith 1980, Loya 1991, Peyrot-Clausade *et al.* 1992, Risk *et al.* 1995, Mokady *et al.* 1998, London-Cruz *et al.* 2003). Studies on the spawning, development and distribution of several *Lithophaga* species in the northern part of the Red Sea (Mokady *et al.* 1991, 1992, 1993, Mokady 1994) have demonstrated that *S. pistillata* was almost exclusively settled by *L. lessepsiana* (Vaillant 1865), for which the reproductive season occurred between December to January, attaining metamorphosis and settlement approximately one to four month thereafter. This matches with the season of settling observed in this experiment suggesting that the *Lithophaga* species recruiting to the nursery-grown transplants were most likely *L. lessepsiana*. During one reproductive season of *Lithophaga*, 30% of the *S. pistillata* transplants and 91% of the *P. damicornis* transplants had new recruits of the coral-borers. We expect that two more reproduction seasons of *Lithophaga* will be needed

for all the *Stylophora* transplants to be inhabited by new *Lithophaga* settlers and that during the next reproductive season all the *Pocillopora* colonies will contain new recruits.

In contrast to the Great Barrier Reef, *L. lessepsiana* species was not found to inhabit *P. damicornis* in the Gulf of Eilat and was rarely present in *S. pistillata* colonies shallower than 15 m (Mokady *et al.* 1993). We found *Lithophaga* settlements in very large numbers simultaneously on our shallow *S. pistillata* colonies and on the *P. damicornis* transplants. Therefore a future taxonomic identification of those *Lithophaga* settlers should reveal interesting insights.

The influence that the branching transplants had on the habitat can be a restoration benefit. The creation of the engineered space increases habitat diversity and can facilitate the presence of some species. This affects the abundance and distribution of other species and can increase the variety and diversity of species in the restored habitat (Byers *et al.* 2006).

Working on a parallel project, Nathaele Rahmani (international volunteer at the Inter-University Institute of marine science, Eilat; personal communication) observed the transplants to also affect the local fish community. More specifically, she noted an increase in the total number of individual fish on the transplanted knolls as compared to the control knoll at the site (unpublished data). This result, along with the results obtained by the transplantation study regarding the impact of the transplantation on the coral-associated invertebrates, demonstrates that the transplantation of branching species can increase the carrying capacities of a restored habitat.

Many studies have tackled the question of which species is most suitable for transplantation, usually focusing on the survival of the considered species. Using ecosystem engineering to make an initial change of the habitat in order to jumpstart a chain of events to lead the process and to reestablish the original habitat species combination, is one possible answer.

4.4 The transplantation methodology

The attachment of the colonies to the natural substrate was done using underwater drillers powered by a SCUBA diving tank. This new practice enabled the transplantation on vertical facets of the substrates, normally impossible or difficult with traditional gluing or cementing methods. The results of this experiment have showed that the spatial positioning of the farmed colony had no impact on their survival and detachments. Therefore, this method opens the door to transplanting corals onto various slopes enabling maximum coverage of the target area. In addition, this method does not require any prior preparation of the substrate (scrubbing with a wire brush, for example; Dizon *et al.* 2008) reducing the time of work and inflicting a smaller impact on the substrate adjacent to the transplants (which could theoretically have new recruits not yet easily eye-detectable).

The Gardening method changes the scale at which transplantation acts can be regarded. The coral nursery enables the generation of large stocks of new corals colonies without inflicting any harm to natural reef localities. It was estimated that a single worker can produce between 35 000 to 40 000 new colonies per year at the coral nursery (Shafir *et*

al. 2006). During this study we evaluated that a team of five untrained divers working three hours underwater per day can transplant approximately 300 colonies a week. A team of 10 experienced workers could transplant 40 000 colonies potentially generated annually by one nursery worker within one year. This would cover approximately 2 333 m^2 to 2 666 m^2 of degraded reef substrates.

The transplantation experiment has also revealed some of the drawbacks of the methodology. A detachment rate of 30-34% was observed, a problem that should be minimized. Following detachment during the monitoring revealed that, when it had occurred, the detached colony was gone, but the peg was still strongly attached to the knoll. This observation indicats that the weak point where the transplanted colonies would brake is the basal area where the colony had expended on the peg creating the peg-colony bond at the initiation of the culture in the nursery. The vulnerability of this point should be minimized and new methods that would increase the strength attachment of the corals to the nursery-support are currently under investigation.

Transplantation should follow careful planning and specific goals should be set in order to permit the evaluation of the restoration and to obtain a desired end result. Based on the results obtained during this study, we propose a transplantation compensation guideline that could potentially help obtain the desired state after a certain amount of time. The annual detachment rate (*DC*: Detachment Compensation) and the annual natural mortality rate (*MC*: Mortality Compensation) can be calculated for a specific site monitoring naturally-growing local colonies. A preliminary small scale transplantation of nursery-

grown corals should allow the calculation of the impacts of local natural selection forces by subtracting the natural mortality from that obtained for the transplants (*SC*: Selection Compensation). The total compensation to take into account when aiming towards a desired amount of transplants after one year is the addition of *DC+MC+SC*. This compensation value is the additional number of colonies that should be added to the final number of colonies desired at a specific reef location. It should be multiply be the numbers of years set ahead for the achievement of the end-product.

Additional aspects of the methodology and the gardening concept still need to be explored: the optimal transplantation size (that might vary between different species), the species composition within a transplanted plot (mono-species plots versus poly-species plots; Dizon and Yap 2005) and its impact on the fauna, the optimal spacing between the transplants and genetic factors such as potential for site adaptation (Baums 2008) for example (though in the context of restoration the latter can be debated as the appealing traits conferring a punctual advantage may not be as fit when facing other stressors). Many of these questions have already been addressed in silviculture, thus consulting forest restoration guidelines and plant restoration genetics may facilitate and inspire new ideas in dealing with these aspects (Baums 2008).

5. CONCLUSION

In order to counter the rapid destruction of coral reefs observed during the past decades across the world, active restoration methodologies and specific protocols need to be developed. This study is the first to describe the transplantation of nursery-grown corals and to confirm the feasibility of using farmed corals for denuded reef area restoration. Our results suggest that the "Gardening Coral Reefs" concept can offer an alternative technique for reef restoration, one that overcomes most of the limitations of previous methods. The two step methodology allows the generation, in a short time, of a large new stock of coral colonies capable of thriving, growing and reproducing in degraded reef areas. This enables mass-production of colonies available for restoration, potentially rendering active reef restoration applicable for large scales acts.

Both species used for the transplantation have shown the capacity to acclimate to the new environment in a degraded reef following their transfer from the coral nursery. *P. damicornis* transplants showed many identical patterns to those of the natural colonies at the site: their survival was not found to differ significantly from the natural colonies, the proportion of colonies that suffered from partial tissue death or the average magnitude of the tissue loss was comparable and fish predation did not exceed that of the natural colonies. Hence, Eilat's coral nursery is efficient in producing fit colonies of *P. damicornis* capable of integrating in the degraded reef of Eilat.

S. pistillata showed lower performance than *P. damicornis*, had a higher mortality rate than the natural colonies, suffered from relatively more partial tissue mortality, but nonetheless showed a high growth rate that was not impacted by the transplantation and was capable of reproducing. Nursery-grown *S. pistillata* contributed to the local seeding of the area even after residing 19 month in a disturbed area. Both species created new living space at the reef—niches that were used by coral associated invertebrates—and thus both species stimulated the reef associated fauna. All of the surviving colonies were a net addition to the population at a degraded reef, creating a win-win situation. All the above has led us to the conclusion that, from many aspects, the transplantation of nursery-grown corals was a success.

Even though *S. pistillata* had lower survivorship than *P. damicornis*, we do not wish to conclude that one species is more suitable for transplantation than another since in a restoration context, in order to maintain the community's integrity and diversity, all species should be considered for use. The proposed compensation guidelines can be used to calculate the amount of initial colonies needed to compensate for transplantation performance of various species at different sites in order to obtain a desired end-product.

Branching corals create a 3D structure that supports a diversity of coral reef organisms and modulates current speed, siltation rate and light. The monitoring of the nursery-grown branching colonies added onto the degraded zone showed that their presence can stimulate other coral-reef community organisms, increasing the number of coral-obligatory invertebrates and fish on the restored knolls. The ecological engineering capacity

of this group can be an important advantage for coral restoration efforts, since they restore not only the coral community but also the invertebrates communities of degraded areas.

Integrating the ecosystem engineering concept into active coral reef restoration could potentially enhance restoration and improve its chances of success and sustainability and could, in addition to the prerequisite of the control and the minimization of human pressure, facilitate the hard task of saving these tropical treasures.

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APPENDICES

7.1 Statistical analysis of survival

Table 7.1.1: Results of repeated measures ANOVA test of the average alive colonies of *S. pistillata* and *P. damicornis*.

Repeated measures ANOVA: Tests of Within-Subjects Effects							
Parameter: Survival: proportion of live colonies							
Species	Source		Type III Sum of Squares	df	Mean Square	F	Sig.
S. pistillata	time	Greenhouse-Geisser	2.843	2.641	1.076	22.134	<0.001
	time * Treatment	Greenhouse-Geisser	1.807	5.282	0.342	7.033	<0.001
	Error(time)	Greenhouse-Geisser	1.798	36.977	0.049		
P. damicornis	time	Greenhouse-Geisser	2.878	2.686	1.072	19.666	<0.001
	time * Treatment	Greenhouse-Geisser	1.233	5.371	0.230	4.213	0.003
	Error(time)	Greenhouse-Geisser	2.049	37.598	0.054		

Tables 7.1.2: Results of monthly one way ANOVA of *S. pistillata* and *P. damicornis* survival with a multiple-comparison Bonferroni correction to account for multiple testing, in order to maintain the 5% error rate (significance when $p<0.003$). When significant effects found, means are compared with a Bonferroni post hoc test (significance when $p<0.05$); T=transplanted, CD= controls on site (Dekel Beach), CN= Controls at coral nursery.

One Way ANOVA: Tests of Between-Subjects Effects
Dependent Variable: Survival Day 40 (Dec 05)

Species	Source	Type III Sum of Squares	df	Mean Square	F	Sig.
S. pistillata	Corrected Model	0.015	2	0.007	0.634	0.545
	Error	0.164	14	0.012		

**P. damicornis*: 100% colonies alive in all 3 experimental groups in Dec 05

One Way ANOVA: Tests of Between-Subjects Effects

Dependent Variable: Survival Day 70 (Jan 06)

Species	Source	Type III Sum of Squares	df	Mean Square	F	Sig.
S. pistillata	Corrected Model	0.062	2	0.031	2.392	0.128
	Error	0.182	14	0.013		
P. damicornis	Corrected Model	0.003	2	0.002	1.235	0.321
	Error	0.018	14	0.001		

One Way ANOVA: Tests of Between-Subjects Effects

Dependent Variable: Survival Day 102 (Feb 06)

Species	Source	Type III Sum of Squares	df	Mean Square	F	Sig.
S. pistillata	Corrected Model	0.103	2	0.051	3.249	0.069
	Error	0.221	14	0.016		
P. damicornis	Corrected Model	0.038	2	0.019	0.871	0.440
	Error	0.303	14	0.022		

One Way ANOVA: Tests of Between-Subjects Effects

Dependent Variable: Survival Day 147 (Mar 06)

Species	Source	Type III Sum of Squares	df	Mean Square	F	Sig.
S. pistillata	Corrected Model	0.134	2	0.067	3.985	0.043
	Error	0.235	14	0.017		

P. damicornis	Corrected Model	0.032	2	0.016	0.555	0.586
	Error	0.402	14	0.029		

One Way ANOVA: Tests of Between-Subjects Effects

Dependent Variable: Survival Day 179 (Apr 06)

Species	Source	Type III Sum of Squares	df	Mean Square	F	Sig.
S. pistillata	Corrected Model	0.266	2	0.133	4.933	0.024
	Error	0.377	14	0.027		
P. damicornis	Corrected Model	0.082	2	0.041	1.261	0.314
	Error	0.453	14	0.032		

One Way ANOVA: Tests of Between-Subjects Effects

Dependent Variable: Survival Day 208 (May 06)

Species	Source	Type III Sum of Squares	df	Mean Square	F	Sig.
S. pistillata	Corrected Model	0.283	2	0.142	5.090	0.022
	Error	0.390	14	0.028		
P. damicornis	Corrected Model	0.163	2	0.082	2.969	0.084
	Error	0.385	14	0.028		

One Way ANOVA: Tests of Between-Subjects Effects

Dependent Variable: Survival Day 232 (Jun 06)

Species	Source	Type III Sum of Squares	df	Mean Square	F	Sig.
S. pistillata	Corrected Model	0.309	2	0.154	5.315	0.019
	Error	0.407	14	0.029		
P. damicornis	Corrected Model	0.212	2	0.106	3.668	0.052

	Error	0.405	14	0.029		

One Way ANOVA: Tests of Between-Subjects Effects

Dependent Variable: Survival Day 266 (Jul 06)

Species	Source	Type III Sum of Squares	df	Mean Square	F	Sig.
S. pistillata	Corrected Model	0.481	2	0.241	7.762	0.005
	Error	0.434	14	0.031		
P. damicornis	Corrected Model	0.252	2	0.126	3.926	0.044
	Error	0.449	14	0.032		

One Way ANOVA: Tests of Between-Subjects Effects

Dependent Variable: Survival Day 291 (Aug 06)

Species	Source	Type III Sum of Squares	df	Mean Square	F	Sig.
S. pistillata	Corrected Model	0.720	2	0.360	11.322	0.001
	Error	0.445	14	0.032		
P. damicornis	Corrected Model	0.241	2	0.120	3.726	0.050
	Error	0.453	14	0.032		

Post hoc: Bonferroni Multiple Comparisons

Survival Day 291 (Aug 06)

Species	(I) Treatment	(J) Treatment	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
S. pistillata	T	CD	$-4.541E^{-1}$	0.107	0.003	$-7.475E^{-1}$	$-1.608E^{-1}$
		CN	$-4.487E^{-1}$	0.107	0.003	$-7.421E^{-1}$	$-1.554E^{-1}$

	CD	CN	0.005	0.102	1.000	$-2.743E^{-1}$	0.285

One Way ANOVA: Tests of Between-Subjects Effects

Dependent Variable: Survival Day 313 (Sept 06)

Species	Source	Type III Sum of Squares	df	Mean Square	F	Sig.
S. pistillata	Corrected Model	0.792	2	0.396	13.565	0.001
	Error	0.409	14	0.029		
P. damicornis	Corrected Model	0.229	2	0.115	2.328	0.134
	Error	0.690	14	0.049		

Post hoc: Bonferroni Multiple Comparisons

Survival Day 313 (Sept 06)

Species	(I) Treatment	(J) Treatment	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
S. pistillata	T	CD	$-4.764E^{-1}$	0.103	0.001	$-7.576E^{-1}$	$-1.952E^{-1}$
		CN	$-4.710E^{-1}$	0.103	0.001	$-7.522E^{-1}$	$-1.898E^{-1}$
	CD	CN	0.005	0.098	1.000	$-2.627E^{-1}$	0.273

One Way ANOVA: Tests of Between-Subjects Effects

Dependent Variable: Survival Day 365 (Nov 06)

Species	Source	Type III Sum of Squares	df	Mean Square	F	Sig.
S. pistillata	Corrected Model	0.938	2	0.469	10.041	0.002
	Error	0.654	14	0.047		
P. damicornis	Corrected Model	0.284	2	0.142	2.763	0.097
	Error	0.721	14	0.051		

Post hoc: Bonferroni Multiple Comparisons

Survival Day 365 (Nov 06)

Species	(I) Treatment	(J) Treatment	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
S. pistillata	T	CD	$-4.591E^{-1}$	0.130	0.010	$-8.148E^{-1}$	$-1.034E^{-1}$
		CN	$-5.563E^{-1}$	0.130	0.002	$-9.120E^{-1}$	$-2.006E^{-1}$
	CD	CN	-0.097	0.124	1.000	$-4.363E^{-1}$	0.241

One Way ANOVA: Tests of Between-Subjects Effects

Dependent Variable: Survival Day 403 (Dec 06)

Species	Source	Type III Sum of Squares	df	Mean Square	F	Sig.
S. pistillata	Corrected Model	1.091	2	0.545	11.732	0.001
	Error	0.651	14	0.046		
P. damicornis	Corrected Model	0.292	2	0.146	2.785	0.096
	Error	0.735	14	0.053		

Post hoc: Bonferroni Multiple Comparisons

Survival Day 403 (Dec 06)

Species	(I) Treatment	(J) Treatment	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
S. pistillata	T	CD	$-4.923E^{-1}$	0.130	0.006	$-8.471E^{-1}$	$-1.375E^{-1}$
		CN	$-6.011E^{-1}$	0.130	0.001	$-9.558E^{-1}$	$-2.463E^{-1}$
	CD	CN	-0.108	0.124	1.000	$-4.470E^{-1}$	0.229

One Way ANOVA: Tests of Between-Subjects Effects

Dependent Variable: Survival Day 468 (Feb 07)

Species	Source	Type III Sum of Squares	df	Mean Square	F	Sig.
S. pistillata	Corrected Model	1.138	2	0.569	15.701	<0.001
	Error	0.507	14	0.036		
P. damicornis	Corrected Model	0.352	2	0.176	3.267	0.069
	Error	0.754	14	0.054		

Post hoc: Bonferroni Multiple Comparisons

Survival Day 468 (Feb 07)

Species	(I) Treatment	(J) Treatment	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
S. pistillata	T	CD	$-4.070E^{-1}$	0.115	0.010	$-7.203E^{-1}$	$-9.370E^{-2}$
		CN	$-6.425E^{-1}$	0.115	<0.001	$-9.558E^{-1}$	$-3.291E^{-1}$
	CD	CN	-0.235	0.109	0.151	$-5.342E^{-1}$	0.063

One Way ANOVA: Tests of Between-Subjects Effects

Dependent Variable: Survival Day 533 (Apr 07)

Species	Source	Type III Sum of Squares	df	Mean Square	F	Sig.
S. pistillata	Corrected Model	1.286	2	0.643	20.876	<0.001
	Error	0.431	14	0.031		
P. damicornis	Corrected Model	0.519	2	0.260	4.624	0.029
	Error	0.786	14	0.056		

Post hoc: Bonferroni Multiple Comparisons

Survival Day 533 (Apr 07)

Species	(I) Treatment	(J) Treatment	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
S. pistillata	T	CD	$-3.619E^{-1}$	0.106	0.013	$-6.507E^{-1}$	$-7.311E^{-2}$
		CN	$-6.865E^{-1}$	0.106	<0.001	$-9.753E^{-1}$	$-3.977E^{-1}$
	CD	CN	$-3.246E^{-1}$	0.101	0.019	$-5.999E^{-1}$	$-4.920E^{-2}$

7.2 Statistical analysis of detachment

Table 7.2.1: Results of repeated measures ANOVA test of the average detached colonies of *S. pistillata* and *P. damicornis*.

Repeated measures ANOVA: Tests of Within-Subjects Effects Parameter: Detachment							
Species	Source		Type III Sum of Squares	df	Mean Square	F	Sig.
S. pistillata	date	Greenhouse-Geisser	2.392	1.722	1.389	13.098	<0.001
	date * Treatment	Greenhouse-Geisser	0.361	3.445	0.105	0.989	0.423
	Error (date)	Greenhouse-Geisser	2.557	24.112	0.106		
P. damicornis	date	Greenhouse-Geisser	2.213	1.881	1.177	15.378	<0.001
	date * Treatment	Greenhouse-Geisser	0.887	3.761	0.236	3.082	0.035
	Error (date)	Greenhouse-Geisser	2.015	26.329	0.077		

Tables 7.2.2: Results of monthly one way ANOVA of *S. pistillata* and *P. damicornis* detachment with a multiple-comparison Bonferroni correction to account for multiple testing, in order to maintain the 5% error rate (significance when $p<0.003$). When significant effects found, means are compared with a Bonferroni post hoc test (significance when $p<0.05$); T=transplanted, CD= controls on site (Dekel Beach), CN= Controls at coral nursery.

One Way ANOVA: Tests of Between-Subjects Effects
Dependent Variable: Detachment Day 40 (Dec 05)

Species	Source	Type III Sum of Squares	df	Mean Square	F	Sig.
S. pistillata	Corrected Model	0.279	2	0.139	55.555	<0.001
	Error	0.035	14	0.003		
P. damicornis	Corrected Model	0.027	2	0.013	7.400	0.006
	Error	0.025	14	0.002		

Post hoc: Bonferroni Multiple Comparisons

Detachment Day 40 (Dec 05)

Species	(I) Treatment	(J) Treatment	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
S. pistillata	T	CD	0.281	0.030	<0.001	0.198	0.363
		CN	0.281	0.030	<0.001	0.198	0.363
	CD	CN	<0.001	0.028	1.000	-0.078	0.078

One Way ANOVA: Tests of Between-Subjects Effects

Dependent Variable: Detachment Day 70 (Jan 06)

Species	Source	Type III Sum of Squares	df	Mean Square	F	Sig.
S. pistillata	Corrected Model	0.572	2	0.286	56.627	<0.001
	Error	0.071	14	0.005		
P. damicornis	Corrected Model	0.175	2	0.088	51.396	<0.001
	Error	0.024	14	0.002		

Post hoc: Bonferroni Multiple Comparisons

Dependent Variable: Detachment Day 70 (Jan 06)

Species	(I)	(J)	Mean	Std. Error	Sig.	95% Confidence Interval

						Lower Bound	Upper Bound
S. pistillata	T	CD	0.402	0.043	<0.001	0.285	0.519
		CN	0.402	0.043	<0.001	0.285	0.519
	CD	CN	<0.001	0.041	1.000	-0.111	0.111
P. damicornis	T	CD	0.222	0.024	<0.001	0.154	0.290
		CN	0.222	0.024	<0.001	0.154	0.290
	CD	CN	<0.001	0.023	1.000	-0.064	0.064

One Way ANOVA: Tests of Between-Subjects Effects

Dependent Variable: Detachment Day 102 (Feb 06)

Species	Source	Type III Sum of Squares	df	Mean Square	F	Sig.
S. pistillata	Corrected Model	0.602	2	0.301	59.428	<0.001
	Error	0.071	14	0.005		
P. damicornis	Corrected Model	0.314	2	0.157	35.475	<0.001
	Error	0.062	14	0.004		

Post hoc: Bonferroni Multiple Comparisons

Detachment Day 102 (Feb 06)

Species	(I) Treatment	(J) Treatment	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
S. pistillata	T	CD	0.412	0.043	<0.001	0.295	0.530
		CN	0.412	0.043	<0.001	0.295	0.530
	CD	CN	<0.001	0.041	1.000	-0.111	0.111
P. damicornis	T	CD	0.312	0.040	<0.001	0.203	0.422
		CN	0.281	0.040	<0.001	0.171	0.391
	CD	CN	-0.031	0.038	1.000	-0.135	0.073

One Way ANOVA: Tests of Between-Subjects Effects

Dependent Variable: Detachment Day 147 (Mar 06)

Species	Source	Type III Sum of Squares	df	Mean Square	F	Sig.
S. pistillata	Corrected Model	0.687	2	0.343	49.198	<0.001
	Error	0.098	14	0.007		
P. damicornis	Corrected Model	0.419	2	0.209	34.240	<0.001
	Error	0.086	14	0.006		

Post hoc: Bonferroni Multiple Comparisons

Detachment Day 147 (Mar 06)

Species	(I) Treatment	(J) Treatment	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
S. pistillata	T	CD	0.454	0.050	<0.001	0.317	0.592
		CN	0.425	0.050	<0.001	0.288	0.563
	CD	CN	-0.028	0.048	1.000	$-1.598E^{-1}$	0.102
P. damicornis	T	CD	0.364	0.047	<0.001	0.235	0.492
		CN	0.319	0.047	<0.001	0.191	0.448
	CD	CN	-0.044	0.045	1.000	$-1.670E^{-1}$	0.078

One Way ANOVA: Tests of Between-Subjects Effects

Dependent Variable: Detachment Day 179 (Apr 06)

Species	Source	Type III Sum of Squares	df	Mean Square	F	Sig.
S. pistillata	Corrected Model	0.653	2	0.326	34.582	<0.001
	Error	0.132	14	0.009		
P. damicornis	Corrected Model	0.465	2	0.233	34.128	<0.001

	Error	0.095	14	0.007	

Post hoc: Bonferroni Multiple Comparisons

Detachment Day 179 (Apr 06)

Species	(I) Treatment	(J) Treatment	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
S. pistillata	T	CD	0.473	0.058	<0.001	0.313	0.633
		CN	0.360	0.058	<0.001	0.200	0.520
	CD	CN	-0.113	0.056	0.189	-0.265	0.039
P. damicornis	T	CD	0.382	0.050	<0.001	0.247	0.518
		CN	0.338	0.050	<0.001	0.202	0.474
	CD	CN	-0.044	0.047	1.000	-0.173	0.085

One Way ANOVA: Tests of Between-Subjects Effects

Dependent Variable: Detachment Day 208 (May 06)

Species	Source	Type III Sum of Squares	df	Mean Square	F	Sig.
S. pistillata	Corrected Model	0.653	2	0.326	34.582	<0.001
	Error	0.132	14	0.009		
P. damicornis	Corrected Model	0.443	2	0.222	12.718	0.001
	Error	0.244	14	0.017		

Post hoc: Bonferroni Multiple Comparisons

Detachment Day 208 (May 06)

Species	(I) Treatment	(J) Treatment	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound

S. pistillata	T	CD	0.473	0.058	<0.001	0.313	0.633
		CN	0.360	0.058	<0.001	0.200	0.520
	CD	CN	-0.113	0.056	0.189	-0.265	0.039
P. damicornis	T	CD	0.396	0.079	0.001	0.179	0.613
		CN	0.277	0.079	0.011	0.060	0.494
	CD	CN	-0.118	0.076	0.423	-0.326	0.088

One Way ANOVA: Tests of Between-Subjects Effects

Dependent Variable: Detachment Day 232 (Jun 06)

Species	Source	Type III Sum of Squares	df	Mean Square	F	Sig.
S. pistillata	Corrected Model	0.492	2	0.246	9.833	0.002
	Error	0.350	14	0.025		
P. damicornis	Corrected Model	0.470	2	0.235	13.662	0.001
	Error	0.241	14	0.017		

Post hoc: Bonferroni Multiple Comparisons

Detachment Day 232 (Jun 06)

Species	(I) Treatment	(J) Treatment	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
S. pistillata	T	CD	0.409	0.095	0.002	0.148	0.669
		CN	0.318	0.095	0.015	0.058	0.578
	CD	CN	-0.090	0.091	1.000	-0.338	0.157
P. damicornis	T	CD	0.414	0.079	<0.001	0.198	0.630
		CN	0.250	0.079	0.021	0.035	0.466
	CD	CN	-0.163	0.075	0.147	-0.369	0.042

One Way ANOVA: Tests of Between-Subjects Effects

Dependent Variable: Detachment Day 266 (Jul 06)

Species	Source	Type III Sum of Squares	df	Mean Square	F	Sig.
S. pistillata	Corrected Model	0.360	2	0.180	5.364	0.019
	Error	0.470	14	0.034		
P. damicornis	Corrected Model	0.590	2	0.295	16.371	<0.001
	Error	0.252	14	0.018		

Post hoc: Bonferroni Multiple Comparisons

Detachment Day 266 (Jul 06)

Species	(I) Treatment	(J) Treatment	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
P. damicornis	T	CD	0.462	0.081	<0.001	0.241	0.683
		CN	0.210	0.081	0.065	-0.010	0.431
	CD	CN	-0.252	0.077	0.017	-0.463	-0.041

One Way ANOVA: Tests of Between-Subjects Effects

Dependent Variable: Detachment Day 291 (Aug 06)

Species	Source	Type III Sum of Squares	df	Mean Square	F	Sig.
S. pistillata	Corrected Model	0.289	2	0.145	2.903	0.088
	Error	0.698	14	0.050		
P. damicornis	Corrected Model	0.672	2	0.336	11.283	0.001
	Error	0.417	14	0.030		

Post hoc: Bonferroni Multiple Comparisons

Detachment Day 291 (Aug 06)

Species	(I) Treatment	(J) Treatment	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
P. damicornis	T	CD	0.484	0.104	0.001	0.200	0.768
		CN	0.175	0.104	0.347	$-1.087E^{-1}$	0.459
	CD	CN	$-3.095E^{-1}$	0.099	0.023	$-5.803E^{-1}$	$-3.883E^{-2}$

One Way ANOVA: Tests of Between-Subjects Effects

Dependent Variable: Detachment Day 313 (Sept 06)

Species	Source	Type III Sum of Squares	df	Mean Square	F	Sig.
S. pistillata	Corrected Model	0.309	2	0.154	3.129	0.075
	Error	0.691	14	0.049		
P. damicornis	Corrected Model	0.703	2	0.351	11.549	0.001
	Error	0.426	14	0.030		

Post hoc: Bonferroni Multiple Comparisons

Detachment Day 313 (Sept 06)

Species	(I) Treatment	(J) Treatment	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
P. damicornis	T	CD	0.497	0.105	0.001	0.210	0.784
		CN	0.188	0.105	0.289	$-9.881E^{-2}$	0.475
	CD	CN	$-3.095E^{-1}$	0.100	0.025	$-5.832E^{-1}$	$-3.585E^{-2}$

One Way ANOVA: Tests of Between-Subjects Effects

Dependent Variable: Detachment Day 365 (Nov 06)

Species	Source	Type III Sum of Squares	df	Mean Square	F	Sig.
S. pistillata	Corrected Model	0.365	2	0.182	3.637	0.053
	Error	0.702	14	0.050		
P. damicornis	Corrected Model	0.637	2	0.319	7.906	0.005
	Error	0.564	14	0.040		

One Way ANOVA: Tests of Between-Subjects Effects

Dependent Variable: Detachment Day 403 (Dec 06)

Species	Source	Type III Sum of Squares	df	Mean Square	F	Sig.
S. pistillata	Corrected Model	0.340	2	0.170	3.007	0.082
	Error	0.791	14	0.056		
P. damicornis	Corrected Model	0.721	2	0.361	8.818	0.003
	Error	0.572	14	0.041		

Post hoc: Bonferroni Multiple Comparisons

Detachment Day 403 (Dec 06)

Species	(I) Treatment	(J) Treatment	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
P. damicornis	T	CD	0.514	0.122	0.003	0.181	0.846
		CN	0.269	0.122	0.136	$-6.372E^{-2}$	0.601
	CD	CN	-0.244	0.116	0.163	$-5.622E^{-1}$	0.072

One Way ANOVA: Tests of Between-Subjects Effects

Dependent Variable: Detachment Day 468 (Feb 07)

Species	Source	Type III Sum of Squares	df	Mean Square	F	Sig.

S. pistillata	Corrected Model	0.340	2	0.170	3.551	0.057
	Error	0.671	14	0.048		
P. damicornis	Corrected Model	0.820	2	0.410	9.923	0.002
	Error	0.578	14	0.041		

Post hoc: Bonferroni Multiple Comparisons

Detachment Day 468 (Feb 07)

Species	(I) Treatment	(J) Treatment	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
P. damicornis	T	CD	0.548	0.123	0.002	0.213	0.882
		CN	0.295	0.123	0.093	$-3.912E^{-2}$	0.629
	CD	CN	-0.252	0.117	0.147	$-5.718E^{-1}$	0.066

One Way ANOVA: Tests of Between-Subjects Effects

Dependent Variable: Detachment Day 533 (Apr 07)

Species	Source	Type III Sum of Squares	df	Mean Square	F	Sig.
S. pistillata	Corrected Model	0.356	2	0.178	3.693	0.052
	Error	0.674	14	0.048		
P. damicornis	Corrected Model	0.862	2	0.431	10.523	0.002
	Error	0.574	14	0.041		

Post hoc: Bonferroni Multiple Comparisons

Detachment Day 533 (Apr 07)

Species	(I) Treatment	(J) Treatment	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
P. damicornis	T	CD	0.562	0.122	0.001	0.229	0.895
		CN	0.309	0.122	0.073	$-2.378E^{-2}$	0.642

	CD	CN	-0.252	0.116	0.145	$-5.705E^{-1}$	0.064

7.3 Statistical analysis of spatial positioning

Table 7.3.1: Results of repeated measures ANOVA test of the effect of the orientation of the transplants on the knolls

Repeated measures ANOVA: Tests of Within-Subjects Effects							
Parameter: Orientation on the knoll							
Date: month after transplantation		Source	Type III Sum of Squares	df	Mean Square	F	Sig.
1	orient	Sphericity Assumed	0.005	4	0.001	1.000	0.436
	Error(orient)	Sphericity Assumed	0.021	16	0.001		
2	orient	Sphericity Assumed	0.035	4	0.009	0.616	0.657
	Error(orient)	Sphericity Assumed	0.228	16	0.014		
4	orient	Sphericity Assumed	0.140	4	0.035	1.410	0.275
	Error(orient)	Sphericity Assumed	0.396	16	0.025		
6	orient	Sphericity Assumed	0.220	4	0.055	1.472	0.257
	Error(orient)	Sphericity Assumed	0.597	16	0.037		
12	orient	Sphericity Assumed	0.173	4	0.043	0.942	0.465
	Error(orient)	Sphericity Assumed	0.734	16	0.046		
17	orient	Sphericity Assumed	0.154	4	0.038	0.687	0.612
	Error(orient)	Sphericity Assumed	0.895	16	0.056		

7.4 Statistical analysis of partial tissue death

Table 7.4.1: Results of repeated measures ANOVA test of the average proportion of *S. pistillata* and *P. damicornis* colonies with partial tissue death.

Repeated measures ANOVA: Tests of Within-Subjects Effects							
Parameter: Average proportion of colonies with partial tissue death							
species	Source		Type III Sum of Squares	df	Mean Square	F	Sig.
S. pistillata	Time	Greenhouse-Geisser	2.035	3.422	0.595	9.857	<0.001
	Time * treatment	Greenhouse-Geisser	1.891	6.844	0.276	4.578	0.001
	Error(Time)	Greenhouse-Geisser	2.891	47.910	0.060		
P. damicornis	Time	Greenhouse-Geisser	1.213	4.432	0.274	6.367	<0.001
	Time * treatment	Greenhouse-Geisser	0.901	8.865	0.102	2.364	0.023
	Error(Time)	Greenhouse-Geisser	2.668	62.053	0.043		

Table 7.4.2: Results of repeated measures ANOVA test of the average magnitude of tissue loss of *S. pistillata* and *P. damicornis* colonies.

Repeated measures ANOVA: Tests of Within-Subjects Effects							
Parameter: Average magnitude of tissue loss							
Species	Source		Type III Sum of Squares	df	Mean Square	F	Sig.
S. pistillata	Time	Greenhouse-Geisser	7426.084	2.695	2755.839	16.664	<0.000
	Time * Treatment	Greenhouse-Geisser	6329.694	5.389	1174.483	7.102	<0.000

	Error(time)	Greenhouse-Geisser	6239.056	37.725	165.381		
P. damicornis	Time	Greenhouse-Geisser	752.284	2.142	351.188	4.262	.021
	Time * Treatment	Greenhouse-Geisser	887.459	4.284	207.146	2.514	.059
	Error(time)	Greenhouse-Geisser	2470.965	29.990	82.394		

Tables 7.4.3: Results of monthly one way ANOVA of the average proportion of *S. pistillata* and *P. damicornis* colonies with partial tissue death, with a multiple-comparison Bonferroni correction to account for multiple testing, in order to maintain the 5% error rate (significance when $p<0.003$). When significant effects found, means are compared with a Bonferroni post hoc test (significance when $p<0.05$); T=transplanted, CD= controls on site (Dekel Beach), CN Controls at coral nursery.

One Way ANOVA: Tests of Between-Subjects Effects

Dependent Variable: percentage of colonies with partial tissue death Day 40 (Dec 05)

species	Source	Type III Sum of Squares	df	Mean Square	F	Sig.
S. pistillata	Corrected Model	0.250	2	0.125	8.579	0.004
	Error	0.204	14	0.015		
P. damicornis	Corrected Model	0.057	2	0.029	2.454	0.122
	Error	0.163	14	0.012		

One Way ANOVA: Tests of Between-Subjects Effects

Dependent Variable: percentage of colonies with partial tissue death Day 70 (Jan 06)

species	Source	Type III Sum of Squares	df	Mean Square	F	Sig.
S. pistillata	Corrected Model	0.081	2	0.040	1.592	0.238
	Error	0.355	14	0.025		

P. damicornis	Corrected Model	0.003	2	0.001	0.115	0.892
	Error	0.162	14	0.012		

One Way ANOVA: Tests of Between-Subjects Effects

Dependent Variable: percentage of colonies with partial tissue death Day 102 (Feb 06)

species	Source	Type III Sum of Squares	df	Mean Square	F	Sig.
S. pistillata	Corrected Model	0.091	2	0.045	2.236	0.144
	Error	0.285	14	0.020		
P. damicornis	Corrected Model	0.030	2	0.015	1.611	0.235
	Error	0.130	14	0.009		

One Way ANOVA: Tests of Between-Subjects Effects

Dependent Variable: percentage of colonies with partial tissue death Day 147 (Mar 06)

species	Source	Type III Sum of Squares	df	Mean Square	F	Sig.
S. pistillata	Corrected Model	0.181	2	0.090	5.896	0.014
	Error	0.215	14	0.015		
P. damicornis	Corrected Model	0.104	2	0.052	11.914	0.001
	Error	0.061	14	0.004		

Post hoc: Bonferroni Multiple Comparisons

percentage of colonies with partial tissue death Day 147 (Mar 06)

species	(I) treatment	(J) treatment	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
P. damicornis	T	CD	0.184	0.039	0.001	0.075	0.293
		CN	0.047	0.039	0.773	-0.061	0.155
	CD	CN	-0.137	0.038	0.009	-0.240	-0.033

One Way ANOVA: Tests of Between-Subjects Effects

Dependent Variable: percentage of colonies with partial tissue death Day 179 (Apr 06)

species	Source	Type III Sum of Squares	df	Mean Square	F	Sig.
S. pistillata	Corrected Model	0.505	2	0.253	10.632	0.002
	Error	0.333	14	0.024		
P. damicornis	Corrected Model	0.046	2	0.023	1.255	0.315
	Error	0.256	14	0.018		

Post hoc: Bonferroni Multiple Comparisons

Dependent Variable: percentage of colonies with partial tissue death Day 179 (Apr 06)

species	(I) treatment	(J) treatment	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
S. pistillata	T	CD	0.039	0.093	1.000	-0.213	0.293
		CN	0.380	0.093	0.003	0.127	0.634
	CD	CN	0.341	0.088	0.005	0.099	0.583

One Way ANOVA: Tests of Between-Subjects Effects

Dependent Variable: percentage of colonies with partial tissue death Day 208 (May 06)

species	Source	Type III Sum of Squares	df	Mean Square	F	Sig.
S. pistillata	Corrected Model	0.581	2	0.291	12.082	0.001
	Error	0.337	14	0.024		
P. damicornis	Corrected Model	0.088	2	0.044	2.552	0.114
	Error	0.242	14	0.017		

Post hoc: Bonferroni Multiple Comparisons

percentage of colonies with partial tissue death Day 208 (May 06)

species	(I) treatment	(J) treatment	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
S. pistillata	T	CD	0.206	0.093	0.137	-0.049	0.461
		CN	0.458	0.093	0.001	0.203	0.713
	CD	CN	0.252	0.089	0.041	0.009	0.495

One Way ANOVA: Tests of Between-Subjects Effects

Dependent Variable: percentage of colonies with partial tissue death Day 232 (Jun 06)

species	Source	Type III Sum of Squares	df	Mean Square	F	Sig.
S. pistillata	Corrected Model	0.931	2	0.466	19.526	<0.001
	Error	0.334	14	0.024		
P. damicornis	Corrected Model	0.262	2	0.131	15.705	<0.001
	Error	0.117	14	0.008		

Post hoc: Bonferroni Multiple Comparisons

percentage of colonies with partial tissue death Day 232 (Jun 06)

species	(I) treatment	(J) treatment	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
S. pistillata	T	CD	0.294	0.093	0.022	0.039	0.548
		CN	0.583	0.093	<0.001	0.329	0.837
	CD	CN	0.289	0.089	0.018	0.047	0.531
P. damicornis	T	CD	0.309	0.055	<0.001	0.159	0.460
		CN	0.176	0.055	0.019	0.026	0.327
	CD	CN	-0.133	0.052	0.073	-0.276	0.010

One Way ANOVA: Tests of Between-Subjects Effects

Dependent Variable: percentage of colonies with partial tissue death Day 266 (Jul 06)

species	Source	Type III Sum of Squares	df	Mean Square	F	Sig.
S. pistillata	Corrected Model	1.265	2	0.633	21.991	<0.001
	Error	0.403	14	0.029		
P. damicornis	Corrected Model	0.102	2	0.051	1.585	0.240
	Error	0.450	14	0.032		

Post hoc: Bonferroni Multiple Comparisons

percentage of colonies with partial tissue death Day 266 (Jul 06)

species	(I) treatment	(J) treatment	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
S. pistillata	T	CD	0.319	0.102	0.023	0.040	0.598
		CN	0.678	0.102	<0.001	0.399	0.957
	CD	CN	0.359	0.097	0.008	0.093	0.625

One Way ANOVA: Tests of Between-Subjects Effects

Dependent Variable: percentage of colonies with partial tissue death Day 291 (Aug 06)

species	Source	Type III Sum of Squares	df	Mean Square	F	Sig.
S. pistillata	Corrected Model	1.277	2	0.639	15.068	<0.001
	Error	0.593	14	0.042		
P. damicornis	Corrected Model	0.128	2	0.064	2.038	0.167
	Error	0.441	14	0.032		

Post hoc: Bonferroni Multiple Comparisons

percentage of colonies with partial tissue death Day 291 (Aug 06)

species	(I) treatment	(J) treatment	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
S. pistillata	T	CD	0.135	0.124	0.885	-.2031	0.474
		CN	0.636	0.124	<0.001	.2974	0.974
	CD	CN	0.500	0.118	0.003	.1775	0.823

One Way ANOVA: Tests of Between-Subjects Effects

Dependent Variable: percentage of colonies with partial tissue death Day 313 (Sep 06)

species	Source	Type III Sum of Squares	df	Mean Square	F	Sig.
S. pistillata	Corrected Model	1.479	2	0.739	28.412	<0.001
	Error	0.364	14	0.026		
P. damicornis	Corrected Model	0.232	2	0.116	11.814	0.001
	Error	0.138	14	0.010		

Post hoc: Bonferroni Multiple Comparisons

percentage of colonies with partial tissue death Day 313 (Sep 06)

species	(I) treatment	(J) treatment	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
S. pistillata	T	CD	0.270	0.097	0.046	0.004	0.535
		CN	0.721	0.097	<0.001	0.456	0.986
	CD	CN	0.451	0.093	0.001	0.198	0.704
P. damicornis	T	CD	0.252	0.060	0.003	0.089	0.416
		CN	0.260	0.060	0.002	0.096	0.423
	CD	CN	0.007	0.057	1.000	-0.148	0.162

One Way ANOVA: Tests of Between-Subjects Effects

Dependent Variable: percentage of colonies with partial tissue death Day 365 (Nov06)

species	Source	Type III Sum of Squares	df	Mean Square	F	Sig.
S. pistillata	Corrected Model	1.177	2	0.589	9.171	0.003
	Error	0.899	14	0.064		
P. damicornis	Corrected Model	0.045	2	0.023	0.644	0.540
	Error	0.493	14	0.035		

Post hoc: Bonferroni Multiple Comparisons

percentage of colonies with partial tissue death Day 365 (Nov06)

species	(I) treatment	(J) treatment	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
S. pistillata	T	CD	0.205	0.153	0.608	-0.211	0.622
		CN	0.635	0.153	0.003	0.218	1.052
	CD	CN	0.430	0.146	0.032	0.032	0.827

One Way ANOVA: Tests of Between-Subjects Effects

Dependent Variable: percentage of colonies with partial tissue death Day 403 (Dec06)

species	Source	Type III Sum of Squares	df	Mean Square	F	Sig.
S. pistillata	Corrected Model	1.337	2	0.669	32.616	<0.001
	Error	0.287	14	0.020		
P. damicornis	Corrected Model	0.166	2	0.083	5.339	0.019
	Error	0.218	14	0.016		

Post hoc: Bonferroni Multiple Comparisons

percentage of colonies with partial tissue death Day 403 (Dec06)

species	(I) treatment	(J) treatment	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
S. pistillata	T	CD	0.128	0.086	0.482	-0.107	0.364
		CN	0.647	0.086	<0.001	0.411	0.882
	CD	CN	0.518	0.082	<0.001	0.293	0.743

One Way ANOVA: Tests of Between-Subjects Effects

Dependent Variable: percentage of colonies with partial tissue death Day 468 (Feb07)

species	Source	Type III Sum of Squares	df	Mean Square	F	Sig.
S. pistillata	Corrected Model	01.317	2	0.658	13.980	<0.001
	Error	0.659	14	0.047		
P. damicornis	Corrected Model	0.031	2	0.016	0.740	0.495
	Error	0.296	14	0.021		

Post hoc: Bonferroni Multiple Comparisons

percentage of colonies with partial tissue death Day 468 (Feb07)

species	(I) treatment	(J) treatment	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
S. pistillata	T	CD	0.147	0.131	0.845	-0.210	0.504
		CN	0.649	0.131	0.001	0.292	1.006
	CD	CN	0.502	0.125	0.004	0.161	0.842

One Way ANOVA: Tests of Between-Subjects Effects

Dependent Variable: percentage of colonies with partial tissue death Day 533 (Apr07)

species	Source	Type III Sum of Squares	df	Mean Square	F	Sig.

S. pistillata	Corrected Model	1.000	2	0.500	23.874	<0.001
	Error	0.293	14	0.021		
P. damicornis	Corrected Model	0.312	2	0.156	3.950	0.044
	Error	0.554	14	0.040		

Post hoc: Bonferroni Multiple Comparisons

percentage of colonies with partial tissue death Day 533 (Apr07)

species	(I) treatment	(J) treatment	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
S. pistillata	T	CD	0.324	0.087	0.007	0.085	0.562
		CN	0.605	0.087	<0.001	0.367	0.843
	CD	CN	0.281	0.083	0.014	0.054	0.508

Tables 7.4.4: Results of monthly one way ANOVA of the average magnitude of partial tissue mortality of *S. pistillata* and *P. damicornis* colonies, with a multiple-comparison Bonferroni correction to account for multiple testing, in order to maintain the 5% error rate (significance when $p<0.003$). When significant effects found, means are compared with a Bonferroni post hoc test (significance when $p<0.05$); T=transplanted, CD= controls on site (Dekel Beach), CN Controls at coral nursery.

One Way ANOVA: Tests of Between-Subjects Effects

Dependent Variable: Magnitude of tissue death day 40 (Dec 05)

Species	Source	Type III Sum of Squares	df	Mean Square	F	Sig.
S. pistillata	Corrected Model	40.120	2	20.060	10.364	0.002
	Error	27.096	14	1.935		
P. damicornis	Corrected Model	5.188	2	2.594	1.777	0.205
	Error	20.440	14	1.460		

Post hoc: Bonferroni Multiple Comparisons

Magnitude of tissue death day 40 (Dec 05)

Species	(I) Treatment	(J) Treatment	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
S. pistillata	T	CD	1.126	0.842	0.607	-1.163	3.415
		CN	3.687	0.842	0.002	1.397	5.976
	CD	CN	2.560	0.803	0.020	0.377	4.743

One Way ANOVA: Tests of Between-Subjects Effects

Dependent Variable: Magnitude of tissue death day 70 (Jan 06)

Species	Source	Type III Sum of Squares	df	Mean Square	F	Sig.
S. pistillata	Corrected Model	88.040	2	44.020	9.272	0.003
	Error	66.463	14	4.747		
P. damicornis	Corrected Model	0.406	2	0.203	0.106	0.900
	Error	26.859	14	1.919		

Post hoc: Bonferroni Multiple Comparisons

Magnitude of tissue death day 70 (Jan 06)

Species	(I) Treatment	(J) Treatment	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
S. pistillata	T	CD	4.867	1.319	0.007	1.281	8.452
		CN	5.111	1.319	0.005	1.525	8.697
	CD	CN	0.244	1.257	1.000	-3.174	3.663

One Way ANOVA: Tests of Between-Subjects Effects

Dependent Variable: Magnitude of tissue death day 102 (Feb 06)

Species	Source	Type III Sum of Squares	df	Mean Square	F	Sig.
S. pistillata	Corrected Model	122.028	2	61.014	19.882	<0.001
	Error	42.963	14	3.069		
P. damicornis	Corrected Model	8.912	2	4.456	3.083	0.078
	Error	20.237	14	1.446		

Post hoc: Bonferroni Multiple Comparisons

Magnitude of tissue death day 102 (Feb 06)

Species	(I) Treatment	(J) Treatment	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
S. pistillata	T	CD	5.458	1.060	<0.001	2.575	8.340
		CN	6.218	1.060	<0.001	3.335	9.101
	CD	CN	0.760	1.011	1.000	-1.988	3.508

One Way ANOVA: Tests of Between-Subjects Effects

Dependent Variable: Magnitude of tissue death day 147 (Mar 06)

Species	Source	Type III Sum of Squares	df	Mean Square	F	Sig.
S. pistillata	Corrected Model	312.347	2	156.174	11.133	0.001
	Error	196.393	14	14.028		
P. damicornis	Corrected Model	76.445	2	38.222	10.125	0.002
	Error	52.850	14	3.775		

Post hoc: Bonferroni Multiple Comparisons

Magnitude of tissue death day 147 (Mar 06)

Species	(I) Treatment	(J) Treatment	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
S. pistillata	T	CD	9.410	2.267	0.003	3.246	15.574
		CN	9.404	2.267	0.003	3.240	15.568
	CD	CN	-0.005	2.162	1.000	-5.882	5.871
P. damicornis	T	CD	5.284	1.176	0.002	2.087	8.482
		CN	3.147	1.176	0.054	-0.049	6.345
	CD	CN	-2.137	1.121	0.233	-5.185	0.911

One Way ANOVA: Tests of Between-Subjects Effects

Dependent Variable: Magnitude of tissue death day 179 (Apr06)

Species	Source	Type III Sum of Squares	df	Mean Square	F	Sig.
S. pistillata	Corrected Model	493.855	2	246.927	7.094	0.007
	Error	487.293	14	34.807		
P. damicornis	Corrected Model	130.436	2	65.218	7.850	0.005
	Error	116.314	14	8.308		

One Way ANOVA: Tests of Between-Subjects Effects

Dependent Variable: Magnitude of tissue death day 208 (May 06)

Species	Source	Type III Sum of Squares	df	Mean Square	F	Sig.
S. pistillata	Corrected Model	1255.929	2	627.964	10.372	0.002
	Error	847.619	14	60.544		
P. damicornis	Corrected Model	148.035	2	74.017	5.176	0.021
	Error	200.219	14	14.301		

Post hoc: Bonferroni Multiple Comparisons

Magnitude of tissue death day 208 (May 06)

Species	(I) Treatment	(J) Treatment	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
S. pistillata	T	CD	17.371	4.711	0.007	4.565	30.176
		CN	20.035	4.711	0.002	7.230	32.840
	CD	CN	2.664	4.492	1.000	-9.544	14.873

One Way ANOVA: Tests of Between-Subjects Effects

Dependent Variable: Magnitude of tissue death day 232 (Jun 06)

Species	Source	Type III Sum of Squares	df	Mean Square	F	Sig.
S. pistillata	Corrected Model	1895.122	2	947.561	13.087	0.001
	Error	1013.651	14	72.404		
P. damicornis	Corrected Model	174.146	2	87.073	11.540	0.001
	Error	105.631	14	7.545		

Post hoc: Bonferroni Multiple Comparisons

Magnitude of tissue death day 232 (Jun 06)

Species	(I) Treatment	(J) Treatment	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
S. pistillata	T	CD	21.238	5.152	0.003	7.235	35.241
		CN	24.671	5.152	0.001	10.668	38.674
	CD	CN	3.433	4.912	1.000	-9.918	16.784
P. damicornis	T	CD	7.812	1.663	0.001	3.291	12.332
		CN	5.669	1.663	0.013	1.149	10.190
	CD	CN	-2.142	1.585	0.594	-6.452	2.167

One Way ANOVA: Tests of Between-Subjects Effects

Dependent Variable: Magnitude of tissue death day 266 (Jul 06)

Species	Source	Type III Sum of Squares	df	Mean Square	F	Sig.
S. pistillata	Corrected Model	2466.140	2	1233.070	19.010	<0.001
	Error	908.121	14	64.866		
P. damicornis	Corrected Model	122.349	2	61.174	4.902	0.024
	Error	174.713	14	12.480		

Post hoc: Bonferroni Multiple Comparisons

Magnitude of tissue death day 266 (Jul 06)

Species	(I) Treatment	(J) Treatment	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
S. pistillata	T	CD	23.290	4.876	0.001	10.035	36.544
		CN	28.646	4.876	<0.001	15.392	41.900
	CD	CN	5.356	4.649	0.806	-7.281	17.993

One Way ANOVA: Tests of Between-Subjects Effects

Dependent Variable: Magnitude of tissue death day 291 (Aug 06)

Species	Source	Type III Sum of Squares	df	Mean Square	F	Sig.
S. pistillata	Corrected Model	2434.813	2	1217.407	9.476	0.002
	Error	1798.618	14	128.473		
P. damicornis	Corrected Model	142.698	2	71.349	6.187	0.012
	Error	161.444	14	11.532		

Post hoc: Bonferroni Multiple Comparisons

Magnitude of tissue death day 291 (Aug 06)

Species	(I) Treatment	(J) Treatment	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
S. pistillata	T	CD	21.092	6.863	0.025	2.438	39.745
		CN	29.242	6.863	0.002	10.589	47.895
	CD	CN	8.150	6.544	0.700	-9.634	25.935

One Way ANOVA: Tests of Between-Subjects Effects

Dependent Variable: Magnitude of tissue death day 313 (Sep 06)

Species	Source	Type III Sum of Squares	df	Mean Square	F	Sig.
S. pistillata	Corrected Model	3069.557	2	1534.779	10.176	0.002
	Error	2111.533	14	150.824		
P. damicornis	Corrected Model	130.001	2	65.001	4.289	0.035
	Error	212.172	14	15.155		

Post hoc: Bonferroni Multiple Comparisons

Magnitude of tissue death day 313 (Sep 06)

Species	(I) Treatment	(J) Treatment	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
S. pistillata	T	CD	16.519	7.436	0.130	-3.691	36.730
		CN	33.483	7.436	0.001	13.273	53.694
	CD	CN	16.964	7.090	0.094	-2.305	36.234

One Way ANOVA: Tests of Between-Subjects Effects

Dependent Variable: Magnitude of tissue death day 365 (Nov 06)

Species	Source	Type III Sum of Squares	df	Mean Square	F	Sig.
S. pistillata	Corrected Model	3671.260	2	1835.630	19.782	<0.001
	Error	1299.082	14	92.792		
P. damicornis	Corrected Model	61.029	2	30.514	3.281	0.068
	Error	130.216	14	9.301		

Post hoc: Bonferroni Multiple Comparisons

Magnitude of tissue death day 365 (Nov 06)

Species	(I) Treatment	(J) Treatment	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
S. pistillata	T	CD	27.475	5.832	0.001	11.622	43.328
		CN	35.366	5.832	<0.001	19.513	51.218
	CD	CN	7.890	5.561	0.533	-7.224	23.005

One Way ANOVA: Tests of Between-Subjects Effects

Dependent Variable: Magnitude of tissue death day 403 (Dec 06)

Species	Source	Type III Sum of Squares	df	Mean Square	F	Sig.
S. pistillata	Corrected Model	3811.210	2	1905.605	13.914	<0.001
	Error	1917.410	14	136.958		
P. damicornis	Corrected Model	102.006	2	51.003	4.023	0.042
	Error	177.476	14	12.677		

Post hoc: Bonferroni Multiple Comparisons

Magnitude of tissue death day 403 (Dec 06)

Species	(I) Treatment	(J) Treatment	Mean Difference	Std. Error	Sig.	95% Confidence Interval

						Lower Bound	Upper Bound
S. pistillata	T	CD	20.850	7.086	0.032	1.591	40.109
		CN	37.378	7.086	<0.001	18.119	56.637
	CD	CN	16.527	6.756	0.085	-1.835	34.890

One Way ANOVA: Tests of Between-Subjects Effects

Dependent Variable: Magnitude of tissue death day 468 (Feb 07)

Species	Source	Type III Sum of Squares	df	Mean Square	F	Sig.
S. pistillata	Corrected Model	3845.153	2	1922.577	14.006	<0.001
	Error	1921.690	14	137.264		
P. damicornis	Corrected Model	79.448	2	39.724	2.548	0.114
	Error	218.239	14	15.589		

Post hoc: Bonferroni Multiple Comparisons

Magnitude of tissue death day 468 (Feb 07)

Species	(I) Treatment	(J) Treatment	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
S. pistillata	T	CD	21.852	7.094	0.024	2.571	41.132
		CN	37.511	7.094	<0.001	18.231	56.792
	CD	CN	15.659	6.764	0.109	-2.723	34.043

One Way ANOVA: Tests of Between-Subjects Effects

Dependent Variable: Magnitude of tissue death day 533 (Apr 07)

Species	Source	Type III Sum of Squares	df	Mean Square	F	Sig.
S. pistillata	Corrected Model	3098.772	2	1549.386	12.313	0.001
	Error	1761.659	14	125.833		

P. damicornis	Corrected Model	420.190	2	210.095	1.746	0.210
	Error	1684.211	14	120.301		

Post hoc: Bonferroni Multiple Comparisons

Magnitude of tissue death day 533 (Apr 07)

Species	(I) Treatment	(J) Treatment	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
S. pistillata	T	CD	22.351	6.792	0.016	3.891	40.812
		CN	33.339	6.792	0.001	14.878	51.799
	CD	CN	10.987	6.476	0.336	-6.613	28.589

7.5 Statistical analysis of fish attacks

Table 7.5.1: Results of repeated measures ANOVA test of the average percentage of *S. pistillata* and *P. damicornis* colonies damaged by fish.

Repeated measures ANOVA: Tests of Within-Subjects Effects							
Parameter: Average percentage of colonies damaged by fish							
sp	Source		Type III Sum of Squares	df	Mean Square	F	Sig.
S. pistillata	Time	Greenhouse-Geisser	4.099	3.331	1.231	8.198	<0.001
	Time * treat	Greenhouse-Geisser	2.724	3.331	0.818	5.448	0.003
	Error(Time)	Greenhouse-Geisser	4.500	29.982	0.150		
P. damicornis	Time	Greenhouse-Geisser	1.942	2.054	0.945	7.005	0.005
	Time * treat	Greenhouse-Geisser	0.650	2.054	0.317	2.346	0.123
	Error(Time)	Greenhouse-Geisser	2.495	18.488	0.135		

Table 7.5.2: Results of repeated measures ANOVA test of the total percentage of *S. pistillata* and *P. damicornis* colonies damaged by fish over time.

Repeated measures ANOVA: Tests of Within-Subjects Effects							
Parameter: Average cumulative percentage of colonies damaged by fish							
Species	Source		Type III Sum of Squares	df	Mean Square	F	Sig.
S. pistillata	Time	Greenhouse-Geisser	2.021	1.879	1.075	14.353	<0.001
	Time * Treatment	Greenhouse-Geisser	1.500	1.879	0.798	10.654	0.001

	Error(Time)	Greenhouse-Geisser	1.267	16.913	0.075		
P. damicornis	Time	Greenhouse-Geisser	6.146	1.577	3.898	31.605	<0.001
	Time * Treatment	Greenhouse-Geisser	0.546	1.577	0.346	2.806	0.103
	Error(Time)	Greenhouse-Geisser	1.750	14.192	0.123		

Table 7.5.3: Results of repeated measures ANOVA test of the average fish bite per *S. pistillata* and *P. damicornis* colonies.

Repeated measures ANOVA: Tests of Within-Subjects Effects							
Parameter: Average fish bite per colony							
Species	Source		Type III Sum of Squares	df	Mean Square	F	Sig.
S. pistillata	time	Greenhouse-Geisser	308.844	2.996	103.088	2.535	0.078
	time * Treatment	Greenhouse-Geisser	311.546	2.996	103.989	2.557	0.076
	Error(time)	Greenhouse-Geisser	1096.374	26.963	40.661		
P. damicornis	time	Greenhouse-Geisser	168.053	4.769	35.237	3.172	0.017
	time * Treatment	Greenhouse-Geisser	69.785	4.769	14.632	1.317	0.276
	Error(time)	Greenhouse-Geisser	476.809	42.923	11.109		

Tables 7.5.4: Results of monthly one way ANOVA of the average percentages of *S. pistillata* and *P. damicornis* colonies attacked by fish at the restoration site, with a multiple-

comparison Bonferroni correction to account for multiple testing, in order to maintain the 5% error rate (significance when $p<0.003$).

One Way ANOVA: Tests of Between-Subjects Effects

Dependent Variable: percentage of colonies attacked by fish day 40 (Dec 05)

Species	Source	Type III Sum of Squares	df	Mean Square	F	Sig.
S. pistillata	Corrected Model	1.157	1	1.157	14.267	0.004
	Error	0.730	9	0.081		
P. damicornis	Corrected Model	0.001	1	0.001	0.447	0.520
	Error	0.025	9	0.003		

One Way ANOVA: Tests of Between-Subjects Effects

Dependent Variable: percentage of colonies attacked by fish day 70 (Jan 06)

Species	Source	Type III Sum of Squares	df	Mean Square	F	Sig.
S. pistillata	Corrected Model	1.014	1	1.014	48.896	<0.001
	Error	0.187	9	0.021		
P. damicornis	Corrected Model	0.016	1	0.016	2.689	0.135
	Error	0.054	9	0.006		

One Way ANOVA: Tests of Between-Subjects Effects

Dependent Variable: percentage of colonies attacked by fish day 102 (Feb 06)

Species	Source	Type III Sum of Squares	df	Mean Square	F	Sig.
S. pistillata	Corrected Model	0.779	1	0.779	36.321	<0.001
	Error	0.193	9	0.021		
P. damicornis	Corrected Model	0.001	1	0.001	0.800	0.394
	Error	0.011	9	0.001		

One Way ANOVA: Tests of Between-Subjects Effects

Dependent Variable: percentage of colonies attacked by fish day 147 (Mar 06)

Species	Source	Type III Sum of Squares	df	Mean Square	F	Sig.
S. pistillata	Corrected Model	0.056	1	0.056	1.339	0.277
	Error	0.376	9	0.042		
P. damicornis	Corrected Model	0.003	1	0.003	0.428	0.529
	Error	0.071	9	0.008		

One Way ANOVA: Tests of Between-Subjects Effects

Dependent Variable: percentage of colonies attacked by fish day 179 (Apr 06)

Species	Source	Type III Sum of Squares	df	Mean Square	F	Sig.
S. pistillata	Corrected Model	0.003	1	0.003	0.038	0.849
	Error	0.638	9	0.071		
P. damicornis	Corrected Model	0.180	1	0.180	11.529	0.008
	Error	0.140	9	0.016		

One Way ANOVA: Tests of Between-Subjects Effects

Dependent Variable: percentage of colonies attacked by fish day 208 (May 06)

Species	Source	Type III Sum of Squares	df	Mean Square	F	Sig.
S. pistillata	Corrected Model	0.016	1	0.016	0.365	0.561
	Error	0.406	9	0.045		
P. damicornis	Corrected Model	0.119	1	0.119	3.022	0.116
	Error	0.356	9	0.040		

One Way ANOVA: Tests of Between-Subjects Effects

Dependent Variable: percentage of colonies attacked by fish day 232 (Jun 06)

Species	Source	Type III Sum of Squares	df	Mean Square	F	Sig.
S. pistillata	Corrected Model	0.054	1	0.054	0.560	0.473
	Error	0.873	9	0.097		
P. damicornis	Corrected Model	0.095	1	0.095	3.425	0.097
	Error	0.251	9	0.028		

One Way ANOVA: Tests of Between-Subjects Effects

Dependent Variable: percentage of colonies attacked by fish day 266 (Jul 06)

Species	Source	Type III Sum of Squares	df	Mean Square	F	Sig.
S. pistillata	Corrected Model	0.007	1	0.007	0.371	0.558
	Error	0.179	9	0.020		
P. damicornis	Corrected Model	0.061	1	0.061	0.795	0.396
	Error	0.685	9	0.076		

One Way ANOVA: Tests of Between-Subjects Effects

Dependent Variable: percentage of colonies attacked by fish day 291 (Aug 06)

Species	Source	Type III Sum of Squares	df	Mean Square	F	Sig.
S. pistillata	Corrected Model	0.080	1	0.080	2.805	0.128
	Error	0.258	9	0.029		
P. damicornis	Corrected Model	0.080	1	0.080	9.906	0.012
	Error	0.073	9	0.008		

One Way ANOVA: Tests of Between-Subjects Effects

Dependent Variable: percentage of colonies attacked by fish day 313 (Sep 06)

Species	Source	Type III Sum of Squares	df	Mean Square	F	Sig.

S. pistillata	Corrected Model	0.004	1	0.004	0.148	0.710
	Error	0.269	9	0.030		
P. damicornis	Corrected Model	0.080	1	0.080	31.761	<0.001
	Error	0.023	9	0.003		

One Way ANOVA: Tests of Between-Subjects Effects

Dependent Variable: percentage of colonies attacked by fish day 365 (Nov 06)

Species	Source	Type III Sum of Squares	df	Mean Square	F	Sig.
S. pistillata	Corrected Model	0.073	1	0.073	0.828	0.387
	Error	0.799	9	0.089		
P. damicornis	Corrected Model	0.003	1	0.003	0.129	0.727
	Error	0.212	9	0.024		

One Way ANOVA: Tests of Between-Subjects Effects

Dependent Variable: percentage of colonies attacked by fish day 403 (Dec 06)

Species	Source	Type III Sum of Squares	df	Mean Square	F	Sig.
S. pistillata	Corrected Model	0.004	1	0.004	0.069	0.799
	Error	0.478	9	0.053		
P. damicornis	Corrected Model	0.030	1	0.030	0.340	0.574
	Error	0.793	9	0.088		

One Way ANOVA: Tests of Between-Subjects Effects

Dependent Variable: percentage of colonies attacked by fish day 468 (Feb 07)

Species	Source	Type III Sum of Squares	df	Mean Square	F	Sig.
S. pistillata	Corrected Model	0.001	1	0.001	0.013	0.912
	Error	0.621	9	0.069		
P. damicornis	Corrected Model	0.015	1	0.015	4.547	0.062

	Error	0.030	9	0.003		

One Way ANOVA: Tests of Between-Subjects Effects

Dependent Variable: percentage of colonies attacked by fish day 533 (Apr 07)

Species	Source	Type III Sum of Squares	df	Mean Square	F	Sig.
S. pistillata	Corrected Model	0.159	1	0.159	3.231	0.106
	Error	0.443	9	0.049		
P. damicornis	Corrected Model	0.021	1	0.021	0.561	0.473
	Error	0.329	9	0.037		

Tables 7.5.5: Results of monthly one way ANOVA of the average fish bites per colony of *S. pistillata* and *P. damicornis*, with a multiple-comparison Bonferroni correction to account for multiple testing, in order to maintain the 5% error rate (significance when $p<0.003$).

One Way ANOVA: Tests of Between-Subjects Effects

Dependent Variable: average bites per colony day 40 (Dec 05)

Species	Source	Type III Sum of Squares	df	Mean Square	F	Sig.
S. pistillata	Corrected Model	298.853	1	298.853	31.749	<0.001
	Error	84.717	9	9.413		
P. damicornis	Corrected Model	22.650	1	22.650	3.105	0.112
	Error	65.643	9	7.294		

One Way ANOVA: Tests of Between-Subjects Effects

Dependent Variable: average bites per colony day 70 (Jan 06)

Species	Source	Type III Sum of Squares	df	Mean Square	F	Sig.
S. pistillata	Corrected Model	7.615	1	7.615	0.166	0.693
	Error	413.025	9	45.892		

P. damicornis	Corrected Model	9.949	1	9.949	5.791	0.039
	Error	15.462	9	1.718		

One Way ANOVA: Tests of Between-Subjects Effects

Dependent Variable: average bites per colony day 102 (Feb 06)

Species	Source	Type III Sum of Squares	df	Mean Square	F	Sig.
S. pistillata	Corrected Model	5.544	1	5.544	0.517	0.490
	Error	96.454	9	10.717		
P. damicornis	Corrected Model	27.348	1	27.348	2.894	0.123
	Error	85.056	9	9.451		

One Way ANOVA: Tests of Between-Subjects Effects

Dependent Variable: average bites per colony day 147 (Mar 06)

Species	Source	Type III Sum of Squares	df	Mean Square	F	Sig.
S. pistillata	Corrected Model	0.641	1	0.641	0.052	0.825
	Error	111.981	9	12.442		
P. damicornis	Corrected Model	8.194	1	8.194	2.207	0.172
	Error	33.408	9	3.712		

One Way ANOVA: Tests of Between-Subjects Effects

Dependent Variable: average bites per colony day 179 (Apr 06)

Species	Source	Type III Sum of Squares	df	Mean Square	F	Sig.
S. pistillata	Corrected Model	13.744	1	13.744	3.333	0.101
	Error	37.109	9	4.123		
P. damicornis	Corrected Model	6.164	1	6.164	0.501	0.497
	Error	110.776	9	12.308		

One Way ANOVA: Tests of Between-Subjects Effects

Dependent Variable: average bites per colony day 208 (May 06)

Species	Source	Type III Sum of Squares	df	Mean Square	F	Sig.
S. pistillata	Corrected Model	14.848	1	14.848	8.568	0.017
	Error	15.597	9	1.733		
P. damicornis	Corrected Model	5.076	1	5.076	0.605	0.457
	Error	75.544	9	8.394		

One Way ANOVA: Tests of Between-Subjects Effects

Dependent Variable: average bites per colony day 232 (Jun 06)

Species	Source	Type III Sum of Squares	df	Mean Square	F	Sig.
S. pistillata	Corrected Model	6.837	1	6.837	2.769	0.130
	Error	22.222	9	2.469		
P. damicornis	Corrected Model	9.048	1	9.048	3.285	0.103
	Error	24.789	9	2.754		

One Way ANOVA: Tests of Between-Subjects Effects

Dependent Variable: average bites per colony day 266 (Jul 06)

Species	Source	Type III Sum of Squares	df	Mean Square	F	Sig.
S. pistillata	Corrected Model	1.603	1	1.603	1.420	0.264
	Error	10.158	9	1.129		
P. damicornis	Corrected Model	39.283	1	39.283	10.025	0.011
	Error	35.267	9	3.919		

One Way ANOVA: Tests of Between-Subjects Effects

Dependent Variable: average bites per colony day 291 (Aug 06)

Species	Source	Type III Sum of Squares	df	Mean Square	F	Sig.
S. pistillata	Corrected Model	4.460	1	4.460	1.054	0.331
	Error	38.089	9	4.232		
P. damicornis	Corrected Model	26.322	1	26.322	29.267	<0.001
	Error	8.094	9	0.899		

One Way ANOVA: Tests of Between-Subjects Effects

Dependent Variable: average bites per colony day 313 (Sep 06)

Species	Source	Type III Sum of Squares	df	Mean Square	F	Sig.
S. pistillata	Corrected Model	4.059	1	4.059	1.010	0.341
	Error	36.168	9	4.019		
P. damicornis	Corrected Model	14.800	1	14.800	21.811	0.001
	Error	6.107	9	0.679		

One Way ANOVA: Tests of Between-Subjects Effects

Dependent Variable: average bites per colony day 365 (Nov 06)

Species	Source	Type III Sum of Squares	df	Mean Square	F	Sig.
S. pistillata	Corrected Model	15.636	1	15.636	0.928	0.361
	Error	151.700	9	16.856		
P. damicornis	Corrected Model	1.336	1	1.336	1.449	0.259
	Error	8.300	9	0.922		

One Way ANOVA: Tests of Between-Subjects Effects

Dependent Variable: average bites per colony day 403 (Dec 06)

Species	Source	Type III Sum of Squares	df	Mean Square	F	Sig.
S. pistillata	Corrected Model	25.456	1	25.456	17.610	0.002

	Error	13.010	9	1.446		
P. damicornis	Corrected Model	1.249	1	1.249	0.987	0.346
	Error	11.383	9	1.265		

One Way ANOVA: Tests of Between-Subjects Effects

Dependent Variable: average bites per colony day 468 (Feb 07)

Species	Source	Type III Sum of Squares	df	Mean Square	F	Sig.
S. pistillata	Corrected Model	16.867	1	16.867	2.325	0.162
	Error	65.287	9	7.254		
P. damicornis	Corrected Model	14.427	1	14.427	37.455	<0.001
	Error	3.467	9	0.385		

One Way ANOVA: Tests of Between-Subjects Effects

Dependent Variable: average bites per colony day 533 (Apr 07)

Species	Source	Type III Sum of Squares	df	Mean Square	F	Sig.
S. pistillata	Corrected Model	0.004	1	0.004	0.001	0.980
	Error	60.934	9	6.770		
P. damicornis	Corrected Model	0.047	1	0.047	0.007	0.937
	Error	63.760	9	7.084		