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Elaborating an eco-engineering approach for stock enhanced sexually derived coral colonies

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ABSTRACT

Despite all traditional conservation management efforts, coral reefs worldwide continue to face a future of degradation and destruction. Current studies call for the augmentation of coral reef management with restoration practices, particularly alternative reef management approaches, such as the 'coral gardening' tenet of active reef restoration. This includes the stock creation of sexually derived coral colonies and their mariculture in mid-water coral nurseries. In this study, single and aggregated (resulting in non-fusion and chimeric entities) spats of the branching coral *Stylophora pistillata* were studied. Planula larvae were settled and spat were reared ex situ for 50–75 days before they were transplanted to the in situ mid-water nursery in Eilat, Israel, where they were followed for up to two years, showing a very low (<2%) detachment rate. Spats were cultured in horizontal and vertical orientations, in caged (for the first 9 nursery months) and noncaged scenarios, and on two nursery beddings (nets and ropes). Caging of horizontally situated young spats on the net substrate resulted in the highest survival (>80% after 2 years). Corals farmed in a vertical orientation had the lowest survival rate of the caged experiments (36.7%) but showed that chimeric/aggregated entities performed significantly better than the single colonies. The uncaged experiments had low (32.7%) to zero surviving spats after two years in situ. The surviving colonies reared under the uncaged conditions were significantly smaller than the caged colonies after the 9 months in situ 'caging period'. Generally, the placement of the young spats in the mid-water nursery resulted in high growth rates: After two years in situ, coral colony diameter increased from 0.1 cm to 8.16 ± 1.58 cm for the vertical caged scenario, and 7.08 ± 1.72 cm, 7.02 ± 1.48 cm for the two caged horizontal designs (HN and HR). This is nearly twice the growth rate observed in natal colonies. The midwater coral nursery is a much cheaper solution for growing corals compared to ex situ water tables, which require high maintenance and expensive facilities to mimic in situ conditions. Non-caged coral stocks showed reduced survival and growth rates, similar to previously published results. The culturing of caged spats in a horizontal position in a midwater nursery exponentially augment survival and growth rates, thus enhancing stock creation yields. This offers new possibilities for creating stocks of sexually derived spats from eco-engineering coral species such as *S. pistillata*.

1. Introduction

Coral reefs throughout the tropics continue to deteriorate (De'ath et al., 2012; Wilkinson, 2008), even with all currently implemented conservation management practices in place (Miller and Russ, 2014; Rinkevich, 2014). Many of these practices fail to prevent damages to the coral system, or to rehabilitate damages that are already widespread (Hughes and Tanner, 2000; Rinkevich, 2008; Ritson-Williams et al., 2009; van Woesik et al., 2014). On top of this, global change impacts and the expected increase in anthropogenic activities will augment reef degradation. This increase in pressure on the global ecosystem is expected to lead to a loss of about 70% of the coral biodiversity in the next four decades (Bruno and Selig, 2007). The shrinkage of global reef structural complexity is unprecedented, and many reefs experience various degrees of phase shift phenomena (Dudgeon et al., 2010).

Taking into consideration these unfavorable prospects and attempting to counteract reef-degradation trends, the literature has made suggestions for alternate reef management approaches (Graham et al., 2013; Micheli et al., 2014; Risk, 1999; Sale, 2008), including propositions for active reef restoration (Edwards et al., 2010; Mbije et al., 2013; Omori, 2005; Putchim et al., 2008; Rinkevich, 2014; Shafir and Rinkevich, 2010; Shaish et al., 2008). The methods and practices that have been put forward, all aim either to complement or to substitute currently employed conservation efforts in order to halt or reverse the coral reefs' degradation trajectory.

In order to retain the natural genetic diversity of corals (Shearer et al., 2009), active reef restoration attempts have further explored the

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use of planula larvae for the creation of coral stocks (Baria et al., 2010; Nakamura et al., 2011; Okamoto et al., 2005; Omori, 2005). Planulae are available in endless supply (Hughes et al., 2010), can be caught without damaging adult reef corals, and, if properly handled, can be utilized to create genetically polymorphic stocks that may be used to actively increase the numbers and genetic heterogeneity of reef corals in an area or as "ecologically engineered" tools for coral recruitment.

Enhanced coral recruitment is one of the main instruments for assisting the "resilience" of reefs. "Resilience" is defined as the ability of reefs to absorb recurrent disturbances and rebuild coral-dominated systems (Hughes et al., 2010). Coral recruitment is one of the most important factors driving the ecology of coral reef assemblages and is critical for maintaining viable coral populations (Hughes et al., 2010; Lukoschek et al., 2013). Low recruitment rates may further lead to reduced coral population sizes/genetic properties, low fertilization rates in gravid corals, and higher pre- or post-settlement mortality (Dizon and Yap, 2006; van Woesik et al., 2014). High coral recruitment rates, in contrast, may offset detrimental impacts of anthropogenic and natural disturbances, as local and global threats continue to decrease coral coverage and the current prognosis is that they will continue to do so (Lukoschek et al., 2013).

Through their ability to change biogeochemical services of reef habitats and to build reefs, reef corals function as a key autogenic reef engineering species and, as they modify the environment by modifying themselves, also altering the environment as allogenic reef engineering species (Wild et al., 2011). Pioneering, opportunistic, protandrous hermaphrodite coral species, such as the Indo-Pacific branching species *Stylophora pistillata* (Fadlallah, 1983; Richmond and Hunter, 1990; Rinkevich and Loya, 1979), are particularly well-suited for active reef restoration.

This study addresses three major issues associated with the creation of nursery farmed coral stocks from ~1-mm^2 coral spats: spat mariculture protocols, survival rates in the nursery, and nursery periods. The specific aims were to test conditions at the nursery phase (Baria et al., 2010; Shafir et al., 2006), using designs that could influence the growth and survival of spats *in situ*. The overall goal was to develop more effective and efficient methods for creating sexually derived coral stocks for reef restoration (Table 1). This study tested the effect of spat aggregations (Buss, 1982; Rinkevich, 2005), the effect of substrate and culture orientation (Enochs, 2012; Nozawa, 2008), and the effect of the presence/absence of caging in the nursery. These parameters were correlated with survival and growth (Baria et al., 2010; Nakamura et al., 2011; Nozawa, 2008).

2. Methods

The *in situ* study was conducted at the mid-water nursery located adjacent to the Israel Oceanographic and Limnological Research (IOLR) branch at Eilat (Linden and Rinkevich, 2011; Shafir et al., 2006). The mid-water nursery bedding was constructed by repurposing the 14-meter diameter buoyant ring of a floating fish cage. The buoyant ring was submerged, brought to a depth of 10 m, and attached to the substrate by a central anchor at a depth of 24 m. The mid-water nursery is situated at about 10–12 m depth away from the reef, 12 m above a sandy bottom. All young *Stylophora pistillata* colonies were created from planulae that had been collected *in situ* from 15 gravid colonies, each ranging between 11.5 and 29.8 cm in diameter, residing at depths of 3 to 5 m in front of the Interuniversity Institute for Marine Sciences (IUI) near Eilat, Israel. Planulae were collected at night using simple traps and were settled on Transparency Film as described in Linden and Rinkevich (2011).

After a minimum of 1–2 months growth *ex situ* in an outdoor running facility, as described in Linden and Rinkevich (2011), corals spats were moved from the Transparency Film to plastic pins, 1–4 sibling (originating from the same maternal colony) spats/pin. Spat aggregates composed of 2–4 settlers formed either naturally within a few hours of settlement (n = 42), or artificially, 30 + days after settlement (n = 104; Amar et al., 2008, Linden and Rinkevich, 2011). All plastic pins (n = 249) were randomly divided over five plastic trays (size 50 × 35 cm; 50 pins per tray). In total, 116 pins with a single spat/pin and 133 pins with aggregated colonies/pin (consisting of histocompatible and incompatible combinations) were transferred to the mid-water coral nursery at Eilat by boat and placed on the nursery bedding using SCUBA. Trays were covered with plastic mesh cages (4 cm^2 mesh size; dimensions: 50 × 35 × 10 cm) that were removed 267 days (9 months) later. The trays were distributed over two different types of nursery bedding: a recycled fish net (3.25 cm^2 mesh size) and 4–6 mm diameter ropes placed horizontally with a 20 cm spacing, parallel to each other (Fig. 1). The trays were placed on the substrates in either vertical or horizontal orientation to the seawater plane. The trays were set up, therefore, using the terms HN for "horizontal position" on the fishnet (n = 99; single = 47, aggregates = 52), HR for "horizontal position" on ropes (n =

Table 1
Literature documentations on juvenile coral survival *in situ* and *ex situ*. The header "Juvenile state" depicts the size that was classified as "juvenile" in the study. "Period" is the duration of the experiment, and "% survival" is the survivals at the end of the study (the presented order corresponds to the list of species). "Settlement" refers to the initial settlement of the coral colonies used in the described experiments, either *in situ* or *ex situ* and if/when the corals were transferred to *in situ* or *ex situ* during the experiment.

Publications	Species	Juvenile state	Period	% survival	Settlement
Sato (1985)	*Pocillopora damicornis*	3-day old spats	6 months *in situ*	16%	*In situ*
Babcock and Mundy (1996)	*Platygyra sinensis*, *Oxypora lacera*	Just settlement	4 months *in situ*	0.5 and 3.9%	*In situ*
Epstein et al. (2001)	*Stylophora pistillata*	Settlement and 3 months	1 month *in situ*	0% and 5%	*Ex situ*, then moved *in situ*
Raymundo and Maypa (2004)	*Pocillopora damicornis*	1, 3, 5, 6 month old spats	1 year *in situ*	0, 2.5, 13, 49%	*Ex situ* for 1, 3, 5, 6 months, then moved *in situ*
Wilson and Harrison (2005)	*Acanthastrea lordhowensis*, *Goniastrae australiensis*, *Montastrea curta*	Few day old spats	7–9 months *in situ*	1%, 2.8% and 0.2%	*Ex situ*, then moved *in situ*
Baria et al. (2010)	*Acropora tenuis*	1, 5–2 month old spats	3 months *in situ*	33%	*Ex situ* for 1, 5–2 months, then moved *in situ*
Linden and Rinkevich (2011)	*Stylophora pistillata*	Just settlement	1 months *ex situ*	80.80%	*Ex situ*
Nakamura et al. (2011)	*Acropora tenuis*	Just settlement	10 months *ex situ*	59%	*Ex situ*
Boch and Morse (2012)	*Acropora hyacinthus*	Just settlement	9 days *ex situ;* 1 year *in situ*	Site #1–25%, Site #2–16%	*Ex situ*
Nozawa et al. (2006)	*Alveopora japonica*, *Acropora solitaryensis*, *Cyphastrea serailia*, *Favia favus*	1, 5 month old spats	3 months *in situ*	3%, 15%, 0% and 2%	*Ex situ* for 1, 5 months, then moved *in situ*
Toh et al. (2014)	*Pocillopora damicornis*	Just settlement	6 months *ex situ*, 6 months *in situ*	45–58%, 38–63%	*Ex situ* for 6 months then moved *in situ*