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PRACTICE AND TECHNICAL ARTICLE

Enhancing coral restoration practices in Seychelles: benefits and limitations of fishing lines and rope as coral stocking methods

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Coral restoration plays a pivotal role in mitigating the decline of coral reefs, increasing the need for implementing effective techniques and methodologies. This study investigates the efficacy of stocking *Acropora muricata* and *Pocillopora grandis* using fishing line versus rope in mid-water floating nurseries, offering valuable insights for coral restoration practitioners. Over 1 year, survival, tissue cover, growth, cleaning time, cost, preparation, and stocking timing for both methods were evaluated. Fishing line reduced contact with fouling organisms, contributing to enhanced coral tissue cover and growth rates for *P. grandis* compared to rope, but no significant effect was detected for *A. muricata*. Survival differed among species, with higher rates for *P. grandis* compared to *A. muricata*, indicating no impact due to stocking methods but species-specific differences. Challenges like nursery collapses and amphipod outbreaks may have impacted survival, emphasizing the importance of consistent maintenance and accessibility of project sites. Furthermore, the fishing line method reduced cleaning effort. However, cost considerations and preparation complexities for fishing line warrant careful evaluation, particularly with regards to project budgets. The study underscores the necessity for further research, incorporating diverse genotypes, species, and initial fragment sizes to refine restoration strategies. In summary, this study provides important guidance for coral restoration practitioners, aiding informed decisions on stocking methods for different projects and species while considering the balance between coral health benefits and operational feasibility.

Key words: ***Acropora muricata*, coral restoration practitioners, nursery cleaning time, *Pocillopora grandis*, project budget**

Implications for Practice

- Rope reduces preparation and stocking time. Costs are also much lower, presenting a good option for low-budget projects.
- Fishing line reduces cleaning time and fouling impacts, offering growth and health benefits to reared fragments. This technique is particularly interesting for established, well-funded projects with long nursery phases and/or high maintenance requirements.
- Fishing line may be a good option where nurseries must be left unattended for long periods, especially for more sensitive species such as *Acropora muricata*.
- Fishing line stocking increases benefits with the increase of nursery rearing time and number of corals stocked. Ropes degrade quicker, thus ideal for a single rearing cycle, fishing line is more durable and ideal for a broodstock concept.

Introduction

Tropical coral reefs are among the most biodiverse ecosystems that provide socioeconomic benefits to local communities (Eddy et al. 2021). However, climate change is affecting coral health, causing more frequent events of mass mortality worldwide, endangering countries at risk from food insecurity, rising sea levels, increased frequency and severity of storms, and eroded shorelines (Good & Bahr 2021; Doorga et al. 2023).

Small island nations, like Seychelles, face vulnerability due to oceanic resource dependence. Coral cover decline has been severe (Bruno & Selig 2007), necessitating coral restoration to counteract degradation and preserve economic and social benefits (Etongo 2019; Edwards et al. 2024).

In this context, coral restoration techniques are constantly adapted to suit the needs of specific environments, budgets,

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and capacity (Boström-Einarsson et al. 2020; Schmidt-Roach et al. 2020).

Typical techniques are carried out in situ and rely on the "coral gardening" concept (Frias-Torres et al. 2018; Boström-Einarsson et al. 2020), where coral fragments are grown in nurseries, such as mid-water floating ropes, prior to outplanting (Shaish et al. 2008; Levy et al. 2010).

All stages of restoration efforts face limitations, such as coral mortality during the nursery stage (Boström-Einarsson et al. 2020). Therefore, adopting effective stocking methods is crucial to maintain coral health, growth, and survival (Levy et al. 2010; Frias-Torres et al. 2018). Various factors can affect survival depending on the stocking methods used, including fouling organisms out-competing coral fragments, nursery collapses due to adverse weather, or unforeseen events like a pandemic, which can make nursery sites inaccessible (Montano et al. 2022). Consequences of these limitations include time-consuming tasks, such as cleaning and structural maintenance, which can cause project target delays, loss of colonies, and even entire nurseries (Frias-Torres et al. 2018; Rinkevich 2019). Therefore, selecting the appropriate stocking method is a critical aspect to improve the effectiveness of restoration actions.

Coral restoration projects utilize various stocking methods, including ropes and fishing lines with floating nurseries (Shafir et al. 2010; Frias-Torres et al. 2018; Coral Restoration Foundation). Although the suspended stocking technique is considered advantageous over direct line attachment (Goergen et al. 2017), there is limited information on the benefits and limitations of rope and fishing line attachment. This study evaluated and discussed the performance and best practices of these two methods for two coral species in the Seychelles.

Methods

Study Design

The study was conducted on the northwest coast of Cousin Island Special Reserve in the Seychelles (Fig. 1) from December 2021 to December 2022. For the purpose of the experiment, a mid-water floating rope nursery measuring 10 m × 6 m was constructed, following the design of Frias-Torres et al. (2018). Corals of opportunity were harvested from the donor site (Fig. 1C) between 5 and 7 m. Stocking was completed from 14 to 27 December 2021 (T0) with a total of 800 fragments suspended at 6 m depth in the nursery.

Two methods of stocking were used in this study: one involved fitting fragments through a braided rope with 20 cm intervals, and the other used fishing lines (commonly found in

Figure 1. Map showing location of the sites involved in the experiment: Seychelles (A), Cousin Island Special Reserve (B), donor and nursery sites (C).

Table 1. Cost of materials used in experiment to compare two coral nursery stocking methods based on cost and currency change from 14 July 2022. Costs were recorded once.

				Fishing Line		*Rope*	
Materials	*Seychelles Rupee (SCR)/unit*	*Unit*	*Unit/ nursery*	*SCR/ rope*	*SCR/ nursery*	*SCR/ rope*	*SCR/ nursery*
1 m Sea King 4 mm Hemp Rope	10.06	12 m	96 m	120.7	965.8	120.7	965.8
1 m (1.00mm × 200 m 53.00 kg) fishing line	1.2	15 m	120 m	18	144	0	0
Copper sleeves (1.2 × 0.5 × 0.3 cm crimps)	2	100 pcs	800 pcs	200	1600	0	0
Crimping tool	140	2 pcs	2 pcs	280	280	0	0
Total costs (SCR)				618.72	2989.8	120.7	965.8
Total costs (USD)				48.16	232.7	9.4	75.2

Seychelles; further details in Table 1) threaded through rope at 20 cm intervals with copper crimps to create a loop for coral fragments (Fig. 2B). The two species of branching corals chosen were *Acropora muricata* and *Pocillopora grandis*, which had been used in previous restoration projects and had proven resilient to fragmentation and stocking.

Four ropes, each comprising 50 *A. muricata* fragments, were used to evaluate the traditional rope method (*A. muricata* rope, $n = 200$) and another four for the fishing line with crimping technique (*A. muricata* fishing line and crimping, $n = 200$). *P. grandis* ($n = 200$) was stocked in the same manner. After removing inconsistent observations, such as dead fragments at T1 and alive at T2, the final sample size was 799 fragments. Data collection and nursery maintenance were conducted monthly (excluding weather-impacted months) until December 2022. Alive corals were then successively outplanted in the neighboring reef around Cousin Island Special Reserve.

Data Collection and Analysis

Six monitoring sessions (T1–T6) were conducted at different time intervals (39, 84, 115, 149, 181, and 333 days since stocking). No monitoring occurred at stocking (T0) due to adverse weather lasting until T1. The information gathered encompassed data on coral survival (including detachment), tissue cover, growth, cleaning, material costs, and preparation and stocking time.

All 799 fragments were evaluated for survivorship. Fragments with any live tissue/polyps were deemed to be alive but otherwise dead. A Cox proportional hazard analysis evaluated how survival over time differed by coral species and stocking method (Shahbaba 2012). The model was implemented using the *coxph* procedure in the R survival package (Therneau 2022). Data for this analysis consisted of "events" recorded for each coral fragment, the event being the survey on which the fragment was first recorded as dead. Cumulative survival curves with 95% confidence intervals were calculated and visualized using the survfit function of the survival package.

Tissue cover of all coral fragments was also monitored. A ranking scale out of 4, based on alive tissue cover ($0 =$ dead; $1 \leq 50\%$; $2 \geq 50\%$; $3 = 100\%$) was used. Tissue cover categories were treated as ordered categories. The *polr* procedure in the R MASS package (Venables & Ripley 2002) was used to implement an ordered logistic model comparing tissue cover over time for each species between fishing line and rope stocking methods. Results are expressed as the probability of a fragment falling into a certain category for each treatment. Information on the presence of disease, predation, *Zanclea* spp., bleaching, and other general notes was also collected. The hydrozoan *Zanclea* spp. was recorded since Montano et al. (2017) reported lower susceptibility to corallivory and disease among corals hosting the hydrozoan compared to hydrozoan-free corals. Additional notes were recorded on the presence of fouling organisms (e.g. sponges and algae).

Growth was recorded for a subsample of 30 fragments per treatment and species (120 in total), each considered a replicate. The size of a colony was measured using its ecological volume (EV) with reference to Abdo et al. (2020). The formula below yields an approximation of the coral structures to the shape of a cylinder:

$$\mathrm{EV} = \pi r^2 h$$

where $r = (w + l)/4$ and "h" represent the longest linear extension of three perpendicular measurements (h, w, and l), yielding a single value designating the volume of the cylinder occupied by each colony. A Vernier caliper was used for measurements. A repeated measures Analysis of Variance (ANOVA) evaluated growth in EV over time and compared whether stocking methods impacted growth rates in each species. The ANOVA model was implemented using the *lme* procedure in the R nlme package (Pinheiro et al. 2022), defining random intercept terms for individual fragments. A t test was used to compare initial size (measured as longest linear axis) between treatments at T1 for the two species separately using the same subsample.

Costs and Timing Evaluation

The study compared the costs of materials used for stocking coral fragments and preparing fishing lines and ropes, but excluded maintenance costs. Experienced divers recorded the time taken to clean a single rope in minutes during calm days to minimize external effects. Each rope served as a replicate, and cleaning was timed for structures in contact with corals, as algae growth near corals can cause partial or full mortality of the fragments.

In the fishing line method, the rope carrying the fishing line was part of the structure of the nursery, thus following a less frequent cleaning schedule. Cleaning times were therefore recorded for these ropes solely as additional information. With the rope method, the rope is the substratum in contact with the corals and thus suitable for algae to grow, potentially overgrowing the fragment. A Welch two sample *t* test in R was used to compare cleaning times between stocking methods. Preparation and stocking times were also recorded. Preparation involved cutting the ropes, which was the same for both methods, and threading and crimping the fishing line into the rope for that method. Stocking consisted of fitting coral fragments onto rope or fishing line and crimping. These times were recorded by the person carrying out the activity and were considered supplementary data to explain the main findings or were a unique value.

All analyses were conducted using R Studio version 4.1.1 (R Studio Team 2020). All results are reported as mean ± standard deviation, unless differently stated.

Results

Survival

Survival of coral fragments over time was significantly different ($p < 0.0001$; Table S1; Fig. S1) between both species, with a survival at T6 of 95.7% for *Pocillopora grandis* and 54.4% for *Acropora muricata* (Table S1). No significant differences between rope and fishing line treatments within the same species were detected (Table S1; Fig. S1). Two fragments on the fishing

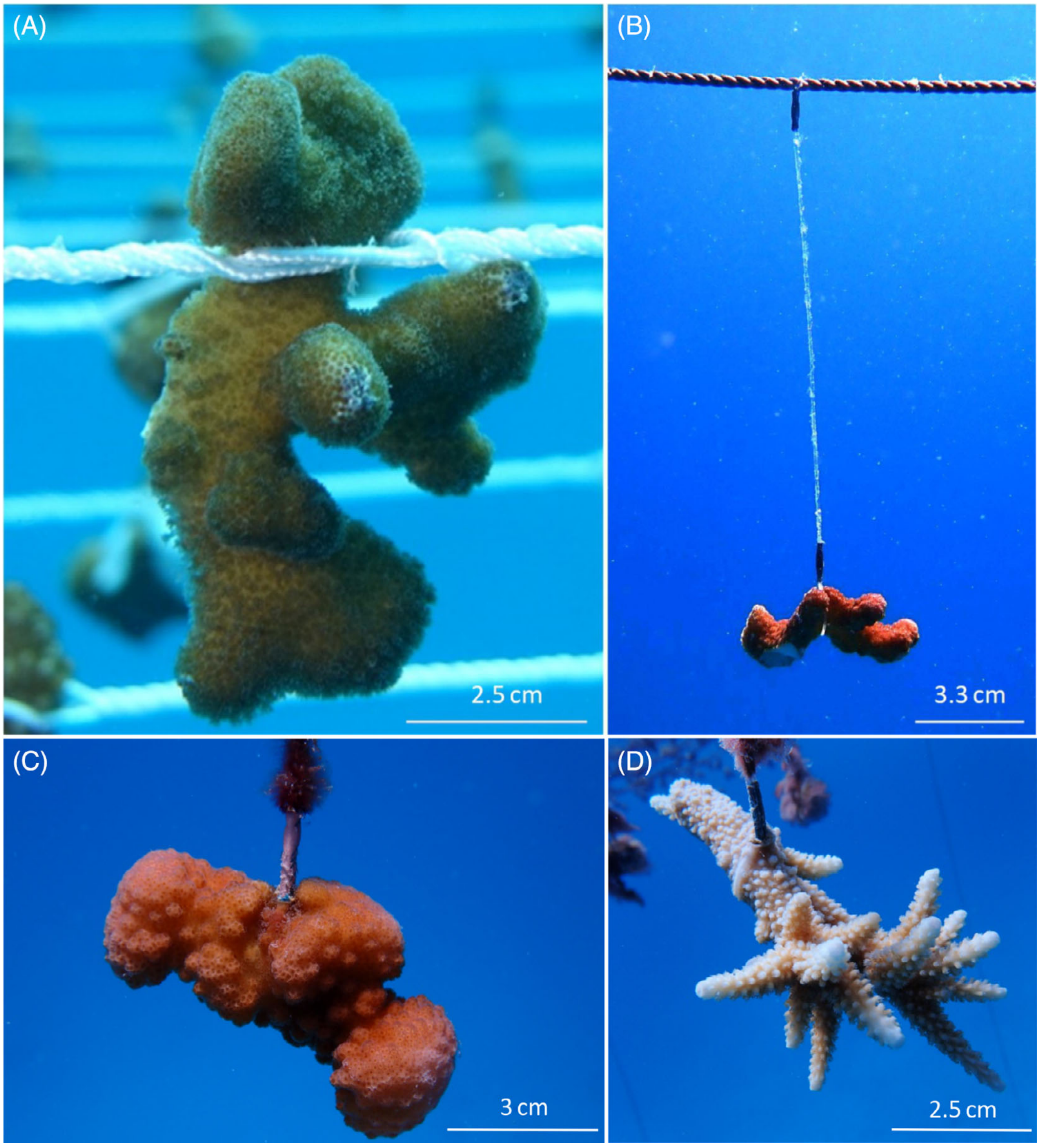

Figure 2. Image showcasing stocking methods being tested in experiment, *Pocillopora grandis* stocked on rope (A) and fishing line (B). Copper crimp acts as a barrier against algae on *P. grandis* (C) and *Acropora muricata* (D) fragments.

line became detached during T1 and T3. These were considered dead. In addition, the nursery collapsed once during T4, severely affecting the survival and tissue cover of both species.

Tissue Cover

Stocking methods affected the tissue cover of *P. grandis* (Fig. 3A) with fragments stocked on ropes exhibiting significantly lower tissue cover compared to fragments stocked on fishing line ($p < 0.0001$; Table S2). Tissue cover declined significantly over time (Fig. 3B) regardless of the stocking method ($p < 0.0001$; Table S2). The interaction between stocking method and time was also significant ($p < 0.05$; Table S2), indicating that the decrease in tissue cover over time was different between stocking methods, with lower tissue on ropes. In *A. muricata*, the effect of the stocking methods (Fig. 3C) did not differ significantly ($p > 0.5$; Table S3), although tissue cover declined significantly over time ($p < 0.0001$; Table S3) regardless of the stocking method. No significant interaction between stocking methods and time was found, suggesting that temporal decline in tissue cover did not differ between stocking methods (Fig. 3D). No fusions, entanglement, or damages from collisions were recorded, unless caused by collapses.

Amphipods (around 80 individuals on a single fragment, Fig. S2) covering the ropes and fragments were observed and recorded. In T1, 50 *A. muricata* fragments on fishing line, and 199 on rope were found covered by amphipods. One fragment was recorded for *P. grandis* on rope. For T2, two fragments were noted for *A. muricata* on fishing line and 21 on rope, while eight were recorded on *P. grandis* for fishing line and 12 on rope for this time period. In T3, the amphipods were only recorded on two *A. muricata* fragments on fishing line, with no further recording in T4–T6. Neither fish scars, *Zanclea* spp., nor diseases or bleaching were recorded throughout the study,

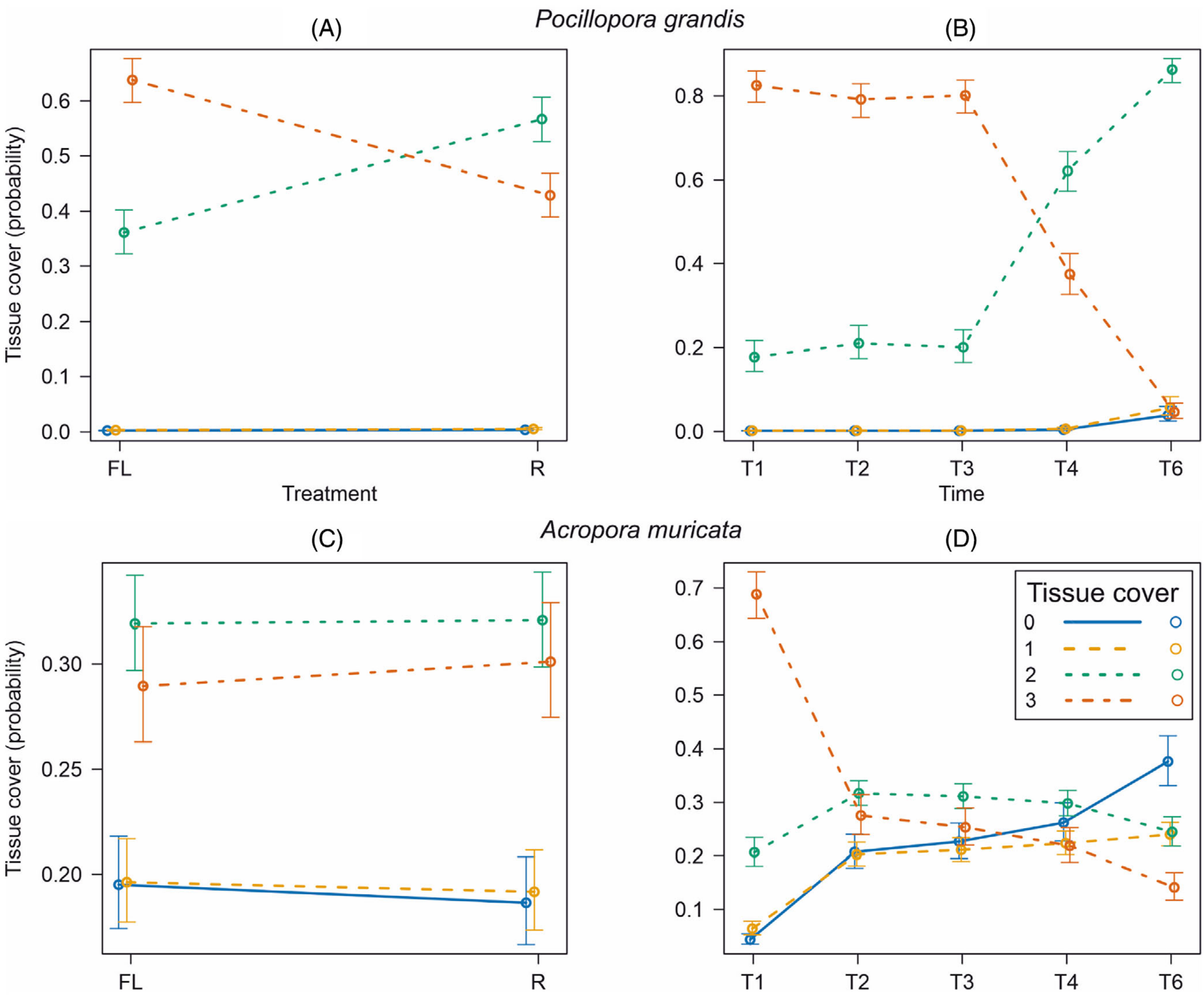

Figure 3. Comparison among the two treatments (A) and over time (B) of tissue cover of *Pocillopora grandis* and *Acropora muricata* (C and D, respectively). Data from T5 is missing due to adverse weather conditions. 0 = dead, 1 = 100%, 2 = greater than 50%, and 3 = less than 50% of tissue cover. Bars represent 95% CI.

though dark unidentified spots were observed on four *P. grandis* fragments in T1 and T2 (Fig. S3). These were no longer present at later dates. Another unidentified discoloration was observed on two *P. grandis* fragments (rope 4, fragment 45, and rope 3, fragment 42) in T2 (Fig. S4). These were yellow/white in appearance and disappeared in T3. These also disappeared, and the fragments survived to the end of the experiment.

Growth

Growth of EV of *P. grandis* was significantly greater ($p = 0.0033$; Table S4a) on fishing lines than ropes (Fig. 4A). For *A. muricata*, no significant effect of treatment (Table S4b) on growth is detected, although slightly higher EVs were estimated for the fishing line treatment for time periods T4 onwards (Fig. 4B). Treatment as a main effect in the linear mixed-effect model remains non-significant when the interaction term is removed (Table S4b, $p = 0.3615$). Initial size (at T1) did not differ significantly between treatments ($p = 0.053$ for *P. grandis*; $p = 0.15$ for *A. muricata*). The initial size range, average, and standard deviation values are presented in Table S5.

Costs and Timing Evaluation

The total cost of installing four stocked ropes in a nursery using the fishing line and crimp method was US$232.7 and US$75.2 when using the traditional rope method (Table 1). The cost to stock coral fragments using fishing line and copper crimps is 5.1 times more expensive per rope and 3.1 times more per nursery. Average cleaning time for fishing line was 7.6 ± 4.0 and 16.5 ± 5.8 min for ropes. Cleaning times were significantly shorter with fishing line ($p < 0.0001$; Table S6), taking 8.9 min less on average than when cleaning ropes. As additional information, the average cleaning time for solely the ropes holding the fishing line was 9.5 ± 6.7 min. Times taken to cut ropes were the same for both fishing lines and traditional ropes (4 min), as methods remained identical. Additional preparation times needed for the fishing line method were 41.5 ± 3.6 min, based on times taken for four ropes. Stocking a rope the traditional way took 18.7 ± 4.3 min on average when stocking 50 fragments, while stocking the fishing line with fragments took 61.2 ± 5.2 min. Results were based on times taken for eight ropes for each method.

Discussion

Fishing line method, though more expensive, showed better results for cleaning times and *Pocillopora grandis* growth and tissue cover, while rope method was more cost-effective but faced higher cleaning time and lower survival for *Acropora muricata*.

Survival rates for both methods when considering *P. grandis* were in accordance with other species of the same genus reported in literature (Schopmeyer et al. 2017; Dehnert et al. 2022*a*, 2022*b*). Contrastingly, survival rates for *A. muricata* were lower for both methods (Howlett et al. 2021; Dehnert et al. 2022*b*).

Both species experienced a reduction in survival and tissue coverage due to nursery collapses, particularly during the south-east monsoon season, which limits accessibility and hinders timely repairs. Full or partial collapses can occur when maintenance is reduced, leading to decreased coral survival, especially in exposed areas like Cousin Island (Montano et al. 2022). Furthermore, an outbreak of amphipods, which covered entire fragments, ropes, and fishing lines, particularly

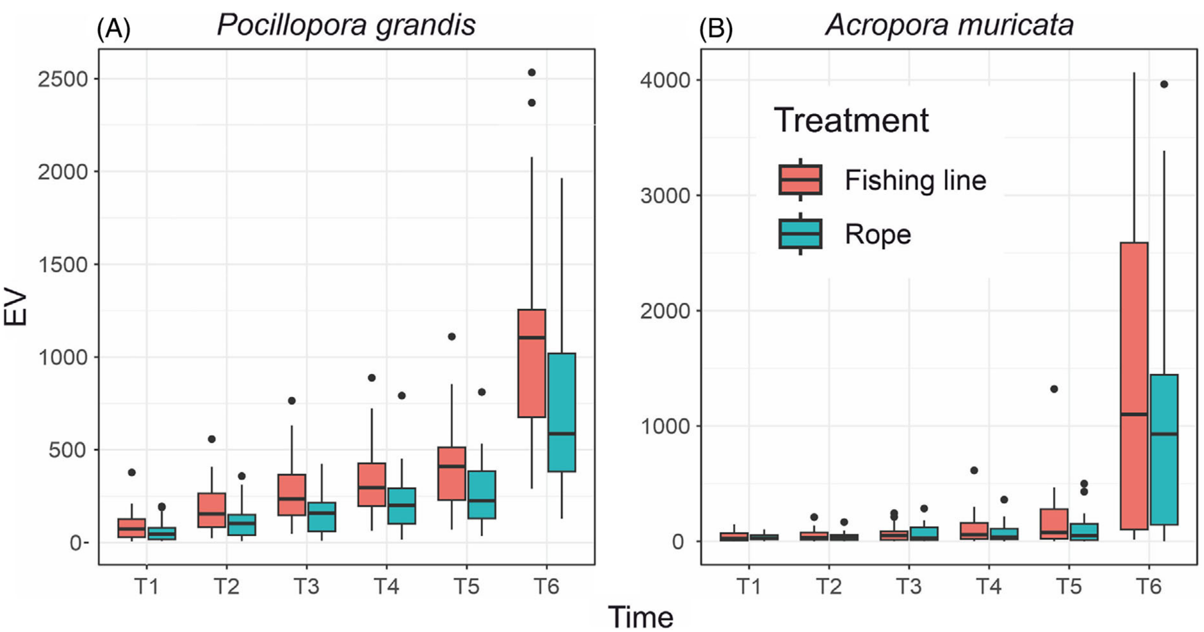

Figure 4. Patterns of growth in ecological volume (EV) of *Pocillopora grandis* (A) and *Acropora muricata* (B) over time, estimated from a repeated measures (linear mixed-effect) model, comparing between rope and fishing line treatments.

affected *A. muricata* during a specific time-window (T1–T3), suggesting a potential seasonal dependence. Amphipods could affect their hosts by feeding on the tissue, as reported for soft corals by Caulier et al. (2021). Although the effects of the amphipod outbreaks on coral mortality are difficult to measure, it is speculated that their presence created damage to live coral tissue. This phenomenon has not been previously reported for hard corals, and further studies are needed to understand its impact. Nevertheless, corals on fishing line were reported to be less exposed to the outbreak, benefitting from the protection offered by this method, which could possibly reduce exposure also against predators and disease vectors.

Pocillopora grandis generally displayed a higher rate of tissue cover than *A. muricata*, indicating a greater ability to withstand stressors, including fragmentation, fouling organisms, and nursery collapse (Dehnert et al. 2022*a*, 2022*b*). Comparison of methods showed that corals stocked on fishing lines consistently exhibited higher tissue cover compared to those on ropes for *P. grandis*. Corals on ropes are exposed to fouling organisms on two sides, whereas fishing-line exposed corals only face them on one side. Copper, used as an antifoulant, acts as a barrier and prevents algae and other organisms from coming into direct contact and competing with *P. grandis* and *A. muricata* (Dormon et al. 1996). The smaller settling area for algae and competitors on fishing line compared to rope results in faster covering of the material in contact with live tissue. Thus, the fishing line method promotes higher tissue cover by reducing proximity to fouling organisms, which may also reduce exposure to predators and disease vectors. Although copper is present in seawater, some researchers highlight its potential toxicity in the oceanic environment or to the coral itself (Blossom 2007). This study did not investigate the effects of copper, but outplanted colonies have been observed growing around the copper crimp (C. Dale, L. Saponari). Further research is needed to verify the effects of the copper crimp or other materials on coral colonies.

Pocillopora grandis's higher tissue cover with fishing line can have positive impacts on the outplanting process, which is important for the survival of healthier fragments on the reef (Reef Resilience Network 2022). Significantly higher growth rates of *P. grandis* and slightly higher, although not significant, rates of *A. muricata* on fishing line may be attributed to the healthier status of corals, which induces them to invest energy in growth instead of competing with fouling organisms (Lapid & Chadwick 2006; Knoester et al. 2019). The use of fishing line also reduces cleaning times, as it is easier to clean than a thick rope with a rugged surface. This is beneficial as 32% of project time is allocated to nursery maintenance, mainly in the form of cleaning (Nature Seychelles unpublished data). With increased time availability, practitioners can dedicate more effort to other time-consuming activities such as outplanting, which is fundamental for effective results (Jacob 2021).

In contrast, preparation and stocking of fishing line was more time-consuming than ropes, as it requires more dexterity and precision to hold the fragments in place. Similarly, the cost of materials used for fishing line was three times greater than for the rope method, making rope more economical. Therefore, proper allocation of resources is an important task (Wear 2016; Bayraktarov et al. 2019). Despite frequent budget and logistics constraints on coral restoration projects, higher fishing line costs and slower preparation/stocking time might be offset if colonies are reared as donors (e.g. Coral Restoration Foundation) due to high durability over time and reduced maintenance.

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Supporting Information

The following information may be found in the online version of this article:

Table S1. Analysis of deviance (type II tests) for Cox proportional hazard model fitted to data on survival of *Acropora muricata* and *Pocillopora grandis* fragments on rope and fishing line treatments.
Table S2. Tissue cover, ordinal logistic regression "polr" for *Pocillopora grandis* fragments on rope and fishing line treatments.
Table S3. Tissue cover, ordinal logistic regression "polr" for *Acropora muricata* fragments on rope and fishing line treatments.
Table S4. Analysis of variance table for repeated measures (linear mixed-effect) models fitted to ecological volumes of the two coral species on rope and fishing line treatments.
Table S5. Detailed information on the initial size range per species and treatment, average and SD.
Table S6. Cleaning times, Welch two sample *t* test.
Figure S1. Estimated survival curves (solid lines) with 95% confidence limits (broken lines) for *A. muricata* and *P. grandis* on rope and fishing line treatments.
Figure S2. Amphipods on *A. muricata*.
Figure S3. Black spots on *P. grandis*.
Figure S4. White spots on *P. grandis*.

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