"Adoption of coral propagation and out-planting via the tourism industry to advance site stewardship on the northern Great Barrier Reef" by Howlett et al.

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Abstract

Coral propagation via nurseries and out-planting practices has increased worldwide in the last decade to improve stakeholder-led stewardship aimed at retaining or rehabilitating local reef site health. Until 2017/18, stewardship activities by the tourism industry on the Great Barrier Reef (GBR) have been restricted to operations such as corallivore control and environmentally responsible operations. However, back-to-back bleaching events in 2016/17 catalysed implementation of coral propagation at "high-value" tourism sites, with the goal to overcome conventional cost-efficiency limitations associated with growing and re-planting (out-planting) coral via a novel tourism-research partnership model, "Coral Nurture Program" (CNP) in Far North Queensland. Staged implementation across partners (Phase 1 – "development" via 1 operator; Phase 2 – "adoption" via 4 further operators) resulted in establishment of 72 coral nurseries stocked with >4,500 coral fragments from >36 species and out-planting of 21,020 coral fragments of >29 species using a rapid deployment device (Coralclip®). Key elements to the success of CNP were identified through regular partner meetings, and included utilising complimentary expertise, resources and knowledge essential to the continued improvement of best practice and standard operating procedures from both researchers and operators. Here, we specifically examine activity of the CNP from its inception (February 2018) until December 2020, to compare and evaluate how collective propogation by multiple tourism operators coupled with research validation can collaboratively enhance site stewardship at scale across GBR high-value tourism sites. Similarities are drawn between our CNP model and other stewardship-based management models, including adherence to a "code of operation" that ensures trust and equitability across partners. Novel aspects driving CNP success include the flexibility in adoption of CNP workflows to suit individual business preferences (e.g.conducting activity during normal day to day tourism operations *versus* tourism downturns (e.g. COVID-19)), and use of research to

guide objective improvements in site (operator)-specific effectiveness of out-planting and nursery success. In doing so, we use CNP to identify how our tourism-research coral propagation approach could aid stewardship-based management of other reefs where economies are reliant on tourism.

Keywords: reef rehabilitation, coral propagation, Great Barrier Reef, coral nurseries, site stewardship, tourism

1. Introduction

Accelerating declines in coral cover from the combined stress of global climate change (Hughes et al. 2017; Hughes et al. 2018) and local pressures (e.g. pollution and overfishing; Shantz et al. 2020; Wakwella et al. 2020; Zhao et al. 2021) has catalysed reef stakeholders to explore and develop more diverse reef management approaches. Whilst traditional approaches, such as Marine Protected Areas (MPAs) and fishing regulations (Strain et al. 2019; Topor et al. 2019), remain central to safeguard reef resources, more proactive management interventions (Anthony et al. 2017; van Oppen et al. 2017; Rinkevich 2019; Duarte et al. 2020) are increasingly considered necessary to build coral and reef resilience against repeat and persistent stressors (Kleypas et al. 2021). Adoption of in-water methods for "reef restoration" has rapidly grown in the last decade to assist in the natural recovery of degenerated reef-scapes, and to maintain ecosystem functions or restore populations of endangered species (Boström-Einarsson et al. 2020; Ware et al. 2020). Coral propagation – or "coral gardening" – based methods in particular have been established in many reef regions worldwide (Rinkevich 2019; Boström-Einarsson et al. 2020) as a means to locally rebuild reefs whilst equipping stakeholders with new capacity to effectively manage high-value reef sites (referred to as "site stewardship"). Sustainable stewardship aims to maintain a range of ecosystem services, but also needs to be adaptable to cope with increasing pressures on the natural environment (Scharin et al, 2016). Engaging reef-tourism operators in stewardship practices has been explored in regions where the reef economy is sustained through tourism, yet these have mostly been limited to ecosystem monitoring and engagement in sustainable tourism (GBRMPA 2011; Wonthong & Harvey, 2014; Kelly et al, 2020). Given the recent drastic loss of coral cover on reef systems and the ecosystem services provided by these key habitats (Hughes et al. 2017; Hughes et al. 2018), there is a recognised need for reef-based tourism to contribute to more proactive and efficient reef management methods (GBRMPA 2021).

Numerous methods of coral propagation now exist (Rinkevich 2000; Rinkevich 2015), but in general, all comprise of fragmentation, and therefore asexual reproduction of existing wild coral colonies (either colonies attached to reef substrate or naturally fragmented colonies) or colonies grown on in-water (*in situ*) or land-based (*ex situ*) coral nurseries (Rinkevich 2000). Coral fragments are then "planted" (or out-planted) back onto reef sites using various attachment methods (Gomez et al. 2010; Boström-Einarsson. 2020). Such methods have been practiced at various scales in the Caribbean (e.g. Young et al. 2012; Ware et al. 2020), Red Sea (e.g. Rinkevich 2000; Epstein, Bak & Rinkevich 2001) and Indo-Pacific (e.g. Feliciano et al. 2018) for over 10-20 years, but remain a relatively new concept for the Great Barrier Reef (GBR). However, consecutive mass coral bleaching events in 2016/17 (Hughes et al. 2017) dramatically reduced GBR coral cover and capacity for natural recovery (Hughes et al. 2018; Hughes et al. 2019) leading to acknowledgement by management agencies (GBRMPA 2017) and researchers (e.g. Anthony et al. 2017) of the urgent need to explore adoption of reef restoration techniques. In 2018, the first coral nurseries and out-planting practices were implemented on the northern GBR (Suggett et al. 2019, 2020; McLeod et al. 2020; Cook et al. 2021; Howlett et al. 2021).

While in-water coral propagation is considered one of the most widely adopted methods for reef restoration, each stage of the process presents a unique challenge for scalability (Boström-Einarsson et al. 2020; Suggett & van Oppen 2022) and hence cost-effectiveness. At present, the annual median cost of restoring one hectare of coral reef habitat is US$117,000 (Bayraktarov et al. 2019; Stewart-Sinclair et al. 2021) highlighting the need for innovative and low-cost methods that return high yields of coral biomass back to the reef. Deployment, maintenance, and staff-time required for the use of nursery structures – and in turn to re-attach coral to reef substrates – are historically two of the main operational bottlenecks in cost-efficient scalability (Bayraktarov et al. 2019; Forrester et al. 2019). In the latter case, the most common technique for attachment to date has been epoxy, resulting in an average survival of 74% but limited deployment rates of ~5-10 coral fragments per diver-hour (Gomez et al. 2010; Boström-Einarsson et al. 2020). Furthermore, throughout the Indo-Pacific region (including the GBR), reefs carry higher coral diversity than other regions in which coral restoration techniques have been developed (Richards et al. 2008). Thus coral propagation operations favouring monocultures, e.g. some coral nursery designs historically used in the Caribbean (Nedimyer et al. 2011), would be unlikely to adequately achieve restoration or stewardship goals of maintaining high diversity and coral cover on the GBR.

Coral propagation activities on the northern GBR were implemented in 2018 under a novel tourism-research partnership initiative, the "Coral Nurture Program" (CNP), to directly overcome the major operational limitations conventionally associated with *in situ* coral propagation. Firstly, operations were integrated into the reef tourism industry enabling daily site visitation for routine propagation activities. On the GBR, such tour operator sites are considered of disproportionately high economic value (Spalding et al. 2017) yet have all been impacted to various degrees by recent mass bleaching events (Hughes et al. 2017, Cheung et al. 2021). Secondly, many operator staff are already trained in monitoring reef sites through Great Barrier Reef Marine Park Authority's (GBRMPA) "Eye on the Reef" program, facilitating site stewardship practices by tourism operators to obtain "trend and trigger" information at reef sites (GBRMPA 2011). In the case of CNP, nurseries were designed to be of low cost for installation and maintenance and provide a continuous source of diverse out-planting material (Suggett et al. 2019; Howlett et al. 2021). An innovative out-planting device – Coralclip® – was also conceived for low-cost high-throughput physical attachment of coral to reef substrates (up to 100 coral fragments per diver-hour at US$0.6-3.0 per deployed coral fragment; Suggett et al. 2020).

Whilst the central goals of the CNP (to overcome upscaling limitations and successfully "restore" degraded areas of reef) require long-term monitoring to determine success, in the short-term, CNP provides a unique opportunity to gauge how tourism-research partnerships can support stewardship-based management (site maintenance and/or rehabilitation) of local reef sites through coral propogation. Both researchers and operators provide complimentary expertise, resources and knowledge essential to the continued improvement of best practice and standard operating procedures (Figure 1). For example, the footprint of the tourism industry provides scale but also regular site access, and often with unprecedented local historical knowledge, to operate cost-effectively (e.g. Suggett et al. 2020). However, scientific rigour is required to determine accurate measures of survival and growth for nursery and out-planting fragments (e.g. Howlett et al. 2021) as well as identifying factors potentially regulating survivorship (e.g. coral nursery and out-plant microbiomes, Strudwick et al. 2022) and at scales not possible through conventional research frameworks. Such research can validate the effectiveness of operations or otherwise provide objective recommendations to optimise practices. Thus, the CNP model has the potential to improve current site stewardship practices on the GBR beyond corallivore control and monitoring.

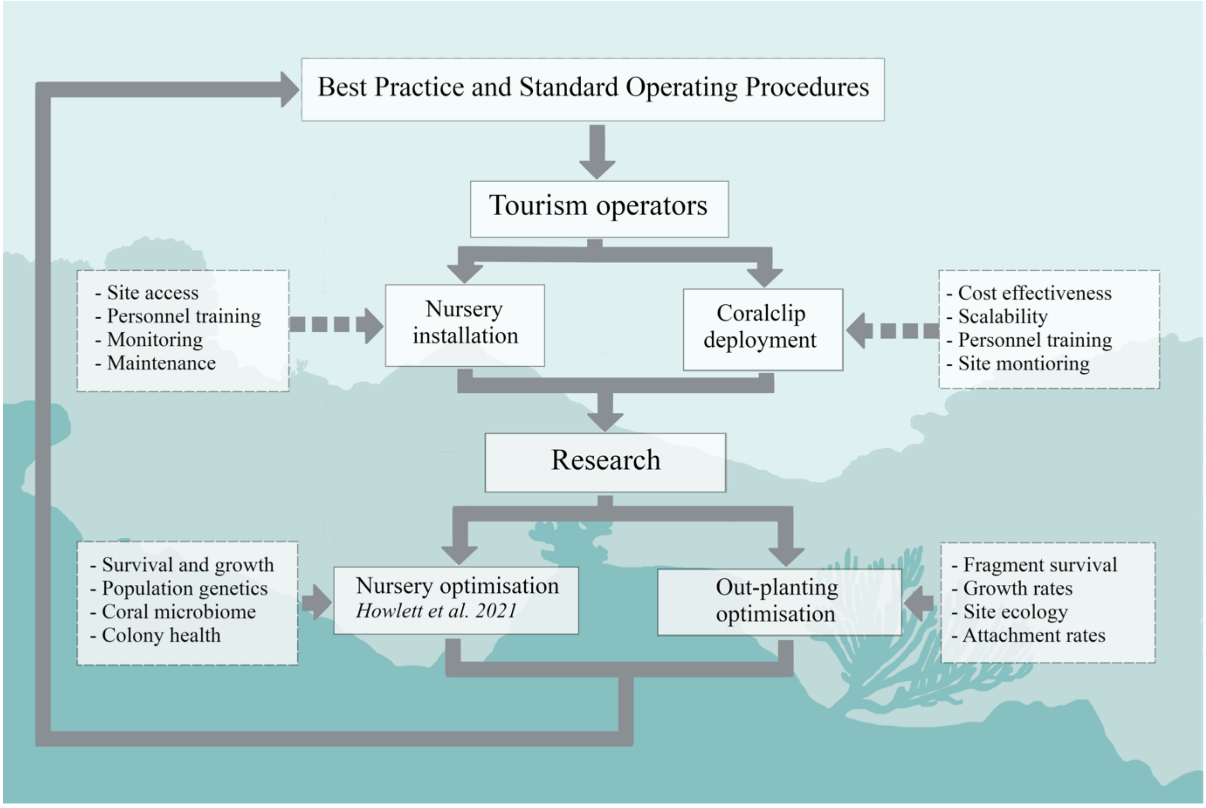

Figure 1. The Coral Nurture Program propagation-based stewardship model applies research as a positive feedback mechanism to improve the effectiveness of propogation and outplanting at scale by tourism operators. As such, the relationship between tourism operators and research and how both contribute to best practice and standard operating procedures for site stewardship and management on the Great Barrier Reef.

Here, we specifically examine activity of the CNP from its inception (February 2018) until December 2020, to evaluate how collective propogation by multiple tourism operators coupled with research validation can collaboratively enhance site stewardship at scale across GBR high-value tourism sites. Key challenges in CNP activity are discussed, where the propagation-based stewardship model is inherently dependent upon a tourism market as well as adoption by highly diverse tourism operations. Successful solutions that have been implemented over time are also highlighted and compared to those of other stewardship-based management models employed in other regions. Finally, we discuss novel aspects contributing to the success of CNP as a cost-effective method to expand site stewardship-based management on the northern GBR, and potentially become an integral part of reef management practices for other locations where the reef economy is sustained through tourism.

2. Materials and Methods

2.1 CNP sites and tourism partners

All early coral propagation and out-planting activities ("Phase 1") were conducted by a single operator (Operator A) at Opal Reef (16°13′S 145°53.5′E) under GBRMPA permit G18/40023.1 across three sites: "RayBan", "Beautiful Mooring" and "Blue Lagoon" (Figure 2; see also, Suggett et al. 2019, 2020; Howlett et al. 2021). Subsequent activity was scaled ("Phase 2") via a pool of 5 tourism operators (Operators A, B, C, D and E) under GBRMPA permit G19/42553.1, at 14 sites spanning 6 reefs (Figure 2; Table 1). Importantly, the basis for scaling through multiple operators was inclusion of different business enterprises already engaged in other GBR stewardship activities (e.g. Crown of Thorns starfish removal, "Eye on the Reef" surveying; GBRMPA 2011) (Table 1). Involvement in the CNP required all operators adhere to a "code of operation" (Appendix 2) designed to ensure activities remained focussed on stewardship values (e.g. "… maintain natural aesthetics and ecology in line with world heritage natural values"), collaborative and equitable. Benefits to the operators through engagement in the CNP include, but are not limited to, further incentive for staff retention by providing training in propagation techniques, a novel tourism attraction in the form of propagation structures (coral nurseries) installed at their sites, and the potential to increase coral cover and diversity at their chosen sites. We subsequently refer to all activities pre-August 2019 as "Phase 1" (August 2018-August 2019), and from August 2019 onwards – when CNP was officially launched – as "Phase 2" (August 2019-December 2020).

Operator ID	Size and home of enterprise	Reef location	Average % coral cover (SE)	CNP joining year
A	Small, Port Douglas	Opal Reef	33.8 (2.9)	2018, Phase 1
B	Small, Cairns	Hastings Reef	25.6 (2.5)	2019, Phase 2
C	Small, Port Douglas	Mackay Reef	27.6 (1.9)	2019, Phase 2
		Low Isles	29.6 (3.7)	
D	Small, Cairns	Upolu Reef	19.0 (4.5)	2019, Phase 2
E	Large, Cairns	Moore Reef	29.6 (2.3)	2019, Phase 2

Table 1. Summary information for five tourism operators within the Coral Nurture Program. Average coral cover was measured in August 2019 (using 3 x 30m line-intercept transects; see Appendix 1 for more information). Enterprise size was determined according to the Australian Bureau of Statistics – November 2021 – based on numbers of people employed (small business, between 5 and 19 persons; a medium business, between 20 and 199 persons; large business, over 200 persons).

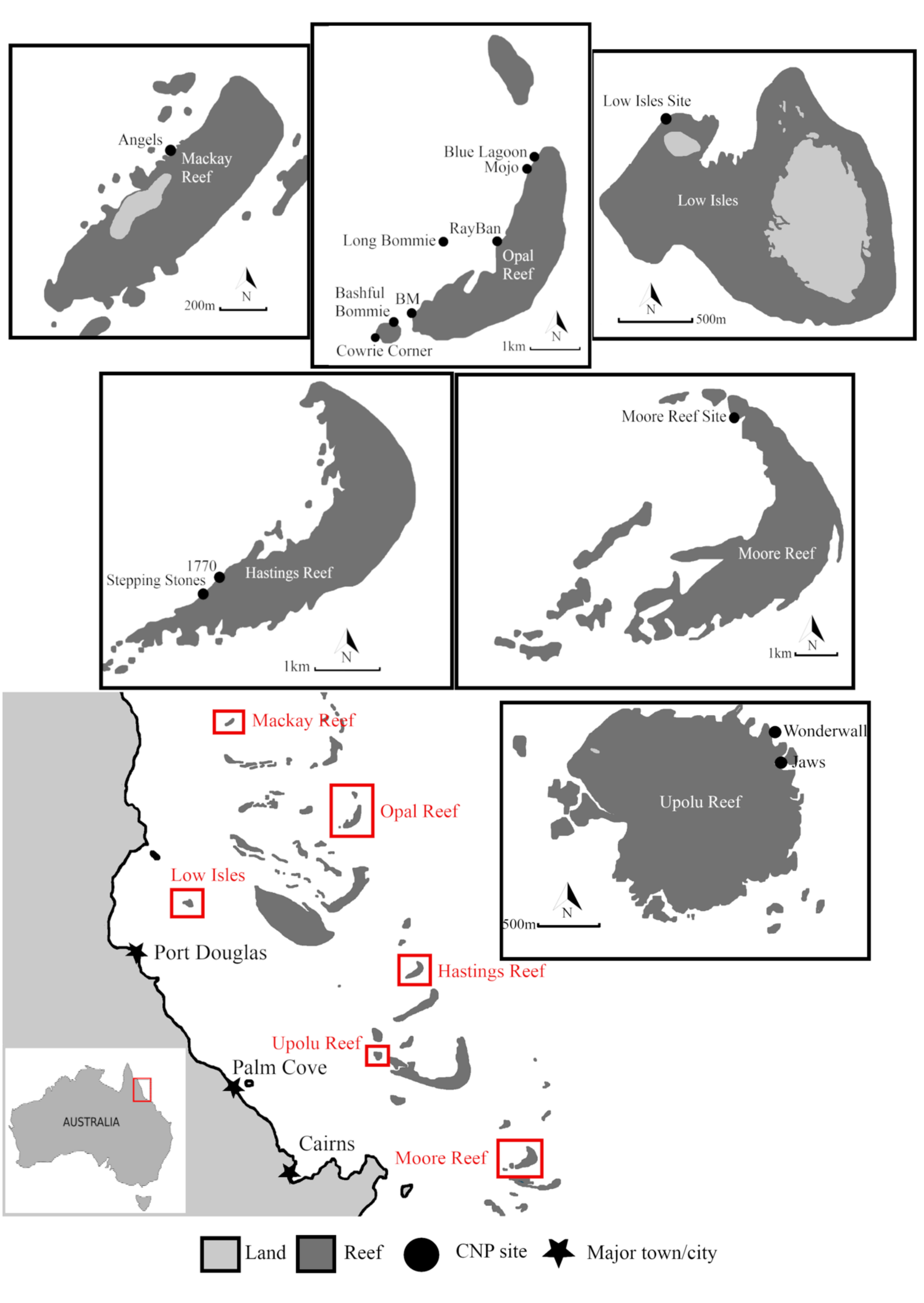

Figure 2. Map showing the locations of all 14 Coral Nurture Program sites on 6 reefs within the northern Great Barrier Reef, Cairns-Port Douglas region. Tourism operators engaged in Coral Nurture Program activities at each reef as follows - Operator A: Opal Reef, Operator B: Hastings Reef, Operator C: Mackay Reef and Low Isles, Operator D: Upolu Reef, and Operator E: Moore Reef.

Out-planting sites were chosen due to high accessibility, visitation and “high economic value” (as per Spalding et al. 2017), but also varied extent of coral cover and diversity after the bleaching events of 2016/17: Mackay Reef (16°2.8′S 145°38.8′E) “Angels”; Opal Reef (16°13′S 145°53.5′E) “Blue Lagoon”, “Mojo”, “RayBan”, “Beautiful Mooring”, “Bashful Bommie”, “Long Bommie”, “Cowrie Corner”; Low Isles (16°23.2′S 145°33.8′E) “Low Isles Site”; Hastings Reef (16°31.3′S 146°0.45′E) “1770”, “Stepping Stones”; Upolu Reef (16°40.6′S 145°56.3′E) “Wonderwall”, “Jaws”; Moore Reef (16°52.5′S 146°14.0′E) “Moore Reef Site” (Table 1; Appendix 1, Figure A.1). The diversity in coral cover between sites allowed for the assessment of CNP model adoption over a range of sites by operators. Whilst manta tow surveys conducted prior to the 2016/7 bleaching event (2015) showed hard coral cover ranged from 15.4 – 29.5% for 5 reefs (information not available for Upolu Reef), these surveys were not conducted at CNP sites (AIMS 2022). All out-planting sites were at least 100m in length and extended a minimum of 5m distance from the reef flat.

Throughout Phase 2, no specific rehabilitation goals were set at each site. Instead, operators conducted propagation activities as they saw fit for local site stewardship (within the CNP “Code of Conduct” and permitting guidelines; Appendix 2) adopted into their specific operations. The Code of Conduct was created by the operator collective, states the goals operators were willing to work towards and instilled a level of trust in the CNP partnership by ensuring active participation by all parties. Propagation and out-planting activities (number of outplants, coral taxonomy, fragment source, and dive time and number of divers for any given deployment) were logged by operators for every day of activity, and reported back to central CNP management every 21 days. The level of coral species identification possible differed between operators. For example, some operators only reported genus and growth form whereas others identified each fragment to species level. In response, a coral identification workshop was provided in June 2019 for all operators, and any unknown species were photographed to ensure consistent identification. Meetings were conducted every 4-6 months amongst all operators and research partners to document any further CNP workflow bottlenecks and identify potential solutions through more tailored practices.

2.2 CNP nursery-based propagation

Coral nurseries were initially deployed at two sites on Opal Reef by Operator A during Phase 1 (Howlett et al. 2021). Whilst the primary source of corals for CNP outplanting are "fragments of opportunity" (un-accreted coral fragments or small partial colonies found on unconsolidated substrate), coral nurseries were installed to supplement these opportunistic fragments with specific biomass, including a greater diversity of coral species (Howlett et al. 2021). At the start of Phase 2, all 5 operators were able to deploy up to 10 coral nursery platforms (frames) at each out-planting site. Each coral nursery platform consists of 2 x 9kg Besser blocks placed on sand ~1-5m from the neighbouring reef, and attached via rope to a 2.0 x 1.2m diamond-mesh aluminium frame, supported by a 20L float (Suggett et al. 2019; Howlett et al. 2021; Appendix 1, Figure A.2). Coral fragments were sourced for the nurseries from either fragments of opportunity or *in situ* fragmentation of coral colonies (<10% of parent colony, each fragment <15cm in size) on the neighbouring reef. Fragments of opportunity were selected randomly from what was naturally available at each site. Parent colonies were chosen for fragmentation based on species commonly found at nursery sites to ensure permitting requirements were met. Corals were attached to the aluminium frames via plastic cable ties or – where fragments were large enough – simply placed onto the frame (partially sitting within the spaces of the mesh frame; Appendix 1, Figure A.3). Any dead or diseased coral fragments on the nurseries were immediately removed by operators as per permitting requirements. In February 2021, fragment counts and species identification were conducted for every nursery frame at each out-planting site.

2.3 CNP out-planting activities

Out-planting was conducted using Coralclip® (Suggett et al. 2020) to re-attach coral to the neighbouring reef using material sourced as either: *in situ* colony fragmentation, fragments of opportunity, or propagation of fragments initially grown on nursery frames. Fragments were only collected for use where visual inspection indicated good coral health. Fragment species were largely dependant on the availability of fragments of opportunity and commonality, in accordance with permitting regulations. A team of divers would initially collect coral fragments or small partial colonies (sourced as per above), which were then further fragmented if necessary using cutters or a hammer and chisel. The size of resulting fragments was variable and largely dependent on species (e.g. those with delicate skeletal structures fragmented more readily, resulting in a higher number of smaller fragments) and natural availability. One diver would hammer each Coralclip® device onto an area of bare reef substrate, brush away any loose debris or algae from the immediate surrounding area and position the fragment firmly beneath the Coralclip®. The coral fragment would be repositioned or the Coralclip® replaced to ensure adequate applied pressure if necessary (as per Suggett et al. 2020). Fragment orientation was governed by growth form and the presence of lesions – where possible, fragments were positioned so axial/terminal polyps were extended upwards and any lesions were against the substrate. Intensity of out-planting and fragment concentration varied between sites (e.g. due to availability of bare substrate) and operations (e.g. site accessibility, availability of personnel) throughout Phases 1 and 2. The original intension of the CNP model was that propagation and out-planting activities would be incorporated into routine tourism day trips.

2.4 Research validation excercises: coral fragment survival and fate-tracking experiments

With the increasing scale of activity over time, it was not feasible to fate-track all out-planted coral fragments, and therefore a series of small discrete experiments were used to quantify survivorship. Firstly, we established additional triplicate 40m^2 (4m x 10m) subplots within the two Hastings Reef treatment sites ("1770", "Stepping Stones") to more intensively assess survivorship. Out-planting was concentrated within the subplots, with 75.5 ± 9.9 (mean ± SE) out-plants per subplot. Hastings Reef was chosen for this exercise due to the intensive out-planting method employed by Operator B within a short time frame (3 days, March 2020), thereby ensuring that all out-planted fragments were deployed for the same period of time (7 months). In October 2020, all fragments within each 40m^2 subplot were tallied and categorised as either "alive", "missing" (Coralclip® was still in place but fragment had become dislodged) or "dead" (fragment still in place and visibly covered in turfing algae).

A series of additional fate-tracking experiments to evaluate effectiveness of Coralclip® with specific coral fragments of different species were conducted at a single out-planting site on Opal Reef (June 2019-January 2020), "RayBan", throughout Phases 1 and 2. These experiments were conducted by researchers to further experimentally examine the effectiveness of Coralclip® on (i) the growth and survival of tracked fragments of commonly out-planted species - *Acropora gemmifera*, *Acropora intermedia*, *Acropora spathulata* and *Pocillopora meandrina*, (ii) the rate of attachment and survival of tracked fragments of *Acropora millepora* from differing size classes, and (iii) growth and survival for tracked fragments of *Pocillopora verrucosa* of differing origins (nursery-sourced or reef-sourced). Full methodologies for these various experiments are given in Appendix 1.

3. Results

CNP activity continuously grew over time from development of nursery and propagation practices in Phase 1 (August 2018; Operator A, Opal Reef) to adoption and further tailoring by a further 4 operators in Phase 2 (August 2019; Operators B-E). The resulting number of nursery-propagated and out-planted coral fragments are described below, alongside survival counts within selected out-planting sites and qualitative lessons learnt via periodic discussions with operators. We also describe the implications of unforeseen impacts to the project, such as a region-wide coral bleaching event from February to April 2020 (NOAA Coral Reef Watch, 2021) and a reduction in tourism operations in response to COVID-19 travel restrictions from March 2020 onwards, and how this required specific changes to standard operating procedures and best practices.

3.1 CNP nursery-based coral propogation

A total of 72 coral nursery frames were deployed across 6 reefs between August 2018 and December 2020 (Table 2). Two thirds (66.7%) of all frames were installed at Opal Reef, which included the 11 nursery frames deployed during Phase 1. A total of 4,638 fragments, sourced from both fragments of opportunity and *in situ* parent colony fragmentation, were reported as being placed onto nursery frames from August 2018 to December 2020 by operators. Accurate fragment numbers retained in coral nurseries could not be obtained for either Phase since, despite timely reporting of fragments placed onto nurseries for further propagation, it was not always reported how many fragments/colonies were subsequently removed from the frames for out-planting. Therefore, the resulting fragment counts of corals retained in the nursery over time are conservative. Corals were often reported to species level – or subsequently identified through photographs of the site-specific nurseries, resulting in 36 species across all 6 sites (Table 3); 66% of species were of the genus Acropora. Nurseries at most sites typically carried 17-20 species with the exception of Opal reef (31 species) and

Low Isles and Moore Reef (4-10 species). A site-wide re-assessment of all nursery frames in February 2021 was conducted to capture the net outcome of all activity from Phases 1 and 2, and identified a total of 2,219 fragments (of the 36 species) retained in the nurseries.

		Phase 1	**Phase 2**	**Total**
Total number of nursery frames		11	61	72
% of total nursery frames according to reef	Opal Reef	100	60.7	66.7
	Mackay Reef	0	13.1	11.1
	Hastings Reef	0	9.8	8.3
	Upolu Reef	0	8.2	6.9
	Low Isles	0	4.9	4.2
	Moore Reef	0	3.3	2.8

Table 2. Summary of coral nursery activities according to number of nursery frames including both the initial Phase 1 by a single operator (Aug 2018- Aug 2019) and the following Phase 2 when Coral Nurture Program included 4 additional operators (Aug 2019-Dec 2020).

Species	**Opal Reef**	**Hastings Reef**	**Low Isles**	**Mackay Reef**	**Upolu Reef**	**Moore Reef**
Acropora spp.	X	X	X	X	X	X
Acropora humilis	X	X			X	
Acropora hyacinthus	X			X		X
Acropora intermedia	X			X		X
Acropora loripes	X			X	X	X
Acropora microphthalma	X	X		X	X	
Acropora millepora	X			X		
Acropora muricata	X	X		X	X	X
Acropora florida	X			X		X
Acropora sarmentosa					X	
Acropora spathulata	X	X			X	
Acropora tenuis	X			X		X
Acropora subulata	X	X		X		
Acropora yongei	X			X	X	
Acropora gemmifera	X					
Acropora valida	X	X		X	X	
Acropora latistella	X	X		X	X	
Acropora elseyi	X	X				X
Acropora abrolhosensis	X			X	X	
Acropora cerealis	X	X		X		
Acropora torresiana	X			X		
Acropora monticulosa	X					
Acropora selago	X			X	X	
Acropora valenciennesi				X		
Acropora robusta	X	X			X	
Echinopora horrida		X		X	X	
Favia sp.					X	
Isopora prolifera				X		

Montipora spumosa	X					
Pocillopora spp.	X	X	X		X	X
Pocillopora damicornis	X	X			X	
Pocillopora meandrina	X					
Pocillopora verrucosa	X	X			X	X
Porites cylindrica	X					
Stylophora pistillata	X	X	X			
Seriatopora calliendrum		X				
Hydnophora rigida					X	
Turbinaria reniformis	X		X			
Total	31	17	4	20	19	10

Table 3. Species identified following propagation of coral fragments onto nursery frames by operators as part of the Coral Nurture Program, including both the initial Phase 1 that involved only 1 operator (Aug 2018- Aug 2019) and the following Phase 2 that included a further 4 operators (Aug 2019- Dec 2020). Total species numbers are conservative as some operators only identified fragments placed onto nurseries to genus level.

All activity was closely assessed in 2020 when subjected to a region-wide heat wave (Pratchett et al. 2021). Whilst this heat wave reached Degree Heating Weeks (DHWs) >7 for many reefs in the Cairns-Port Douglas region by March 2020 (NOAA Coral Reef Watch, 2021), only modest bleaching was reported for the region (ARC Centre of Excellence, 2020). During the heat wave, some operators sought to reduce mortality of nursery fragments/colonies by increasing coral nursery depth and, in the case of Opal Reef, designing additional nursery structures to provide shade (Appendix 1, Figure A.7). Other qualitative aspects implemented throughout Phase 2 include the periodic removal of macroalgal overgrowth on nursery frames (Low Isles and Moore Reef), and the repositioning of nursery frames closer to coral outcrops in response to reduced herbivory when located too far from the reef (Moore Reef). As per permitting requirements, any dead fragments were removed from nursery structures upon discovery and no mortality was attributed to disease throughout Phases 1 and 2.

3.2 CNP out-planting activities

A total of 21,020 coral fragments were out-planted between August 2018 and December 2020 (Phases 1 and 2 collectively) by the pool of 5 operators (Table 4; Figure 3). The most commonly out-planted genus was *Acropora* (77.7% of total out-plants) and the majority of total out-plants were sourced from fragments of opportunity (82.4%), largely since nursery stocks required time to fully establish. Throughout this time frame, 72% of all coral fragments were out-planted on Opal Reef, but it is important to note that this number is weighted by Phase 1 (20% of all coral out-planted), where the approaches were initially developed at Opal Reef.

		Phase 1	**Phase 2**	**Total**
Total number of fragments out-planted		4,580	16,440	21,020
% of total out-planted according to genus	*Acropora*	64.0	81.6	77.7
	Pocillopora	18.0	10.1	11.8
	Echinopora	0	2.0	1.6
	Turbinaria	4.6	0.6	1.5
	Seriatopora	0	1.8	1.4
	Other	13.4	3.8	5.9
% of total out-planted according to reef	Opal Reef	100	64.8	72.4
	Hastings Reef	0	17.3	13.5
	Mackay Reef	0	13.1	10.3
	Upolu Reef	0	4.1	3.2
	Low Isles	0	0.6	0.5
	Moore Reef	0	0.5	0.4
% of total out-planted according to fragment source	Fragment of opportunity	83.3	82.1	82.4
	Nursery	16.7	9.1	10.7
	In situ colony fragmentation	2.2	2.9	2.7
	Unknown*	0	5.1	4

Table 4. Summary of out-planting activities, including both the initial Phase 1 by a single operator (August 2018- August 2019) and the following Phase 2 when Coral Nurture Program included 4 additional operators (August 2019- December 2020). *Fragment source – either fragment of opportunity, nursery or *in situ* fragmentation – was not specified in reporting.

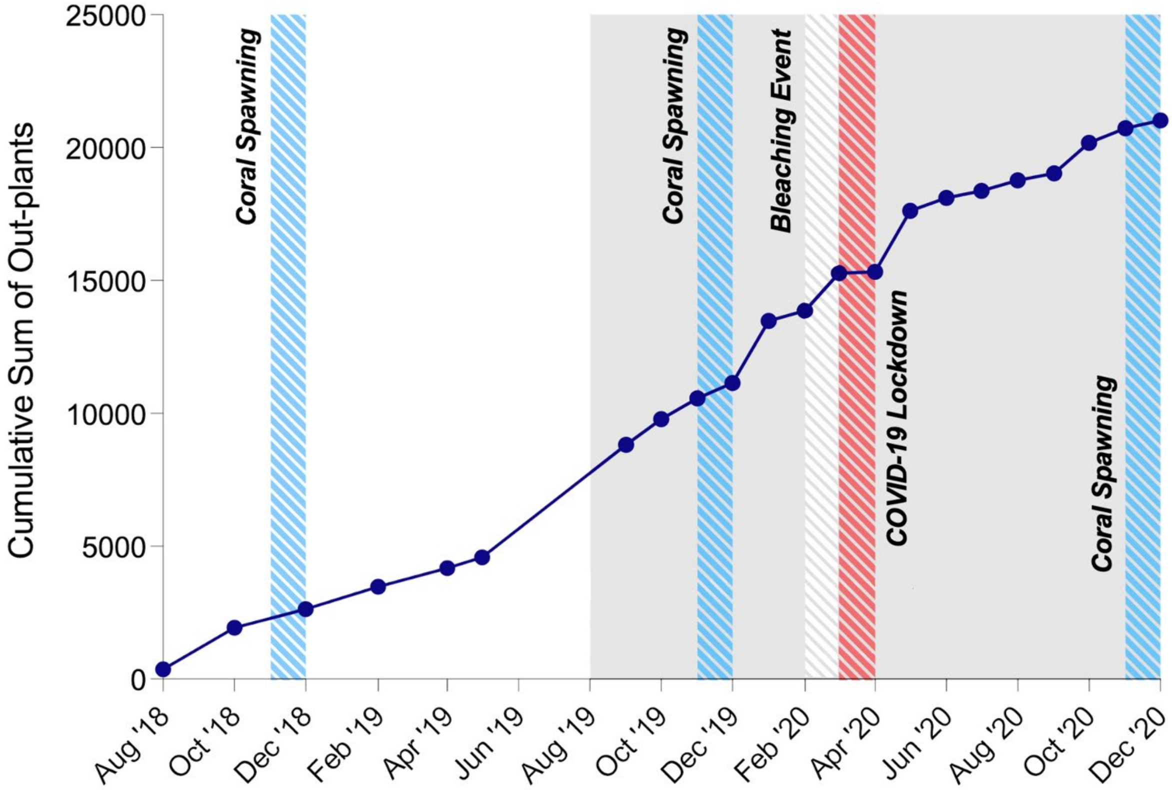

Figure 3. Cumulative count of out-planted coral fragments from August 2018 to December 2020 at all sites over Phase 1 (white background) and Phase 2 (grey background), with overlaid timeline of major events affecting Coral Nurture Program activities across all sites.

Phase 1 – August 2018 to August 2019 – resulted in 4,580 fragments out-planted over 3 sites at Opal Reef ("Beautiful Mooring", "RayBan" and "Blue Lagoon") by Operator A (Table 4). During this period, 64% of out-planted fragments were *Acropora* species. 83.3% of fragments were sourced from fragments of opportunity. During Phase 2, and following adoption by a further 4 operators (Operator B, C, D and E) alongside continued activity of Operator A, out-planting expanded to 14 sites on 6 reef systems (Figure 2). Throughout Phase 2 – August 2019 to December 2020 – a further 16,440 coral fragments were out-planted (Table 4). Again, the majority (81.6%) of out-plants were *Acropora* species and 82.1% of all fragments were sourced from fragments of opportunity. The majority of total fragments in Phase 2 were out-planted on Opal Reef (64.8%), followed by Hastings Reef (17.3%). From March to April 2020, out-planting activity was largely halted as a result of the region wide heat wave (February to April 2020; above), but was accompanied by COVID-19 lockdown restrictions within Far North Queensland, limiting access to the reef (and tourist visitation). Finally, activity was also slowed during mass coral spawning periods following observations of higher out-planted fragment mortality (JE, LH; Pers. Obs.) (Figure 3).

Species identification of fragment of opportunity out-plants was not always performed (or reported). However, of the reports throughout both Phases 1 and 2, a total of 29 species were out-planted over the 14 sites/6 reefs (Table 5); again, this is almost certainly a conservative estimate based on confidence to identify taxa, and ultimately the discrepancies between taxonomic identification level of out-planted fragments reported by operators, which were often due to time and expertise constraints. Some operators more consistently identified out-planted fragments to genus level whilst other operators identified fragments to species level, as a result of different preferences to maximise time available during operations for out-planting versus for identifying taxa. All species and/or genera reported were accompanied by reference photographs to ensure consistent identification over time.

Species	**Opal Reef**	**Hastings Reef**	**Low Isles**	**Mackay Reef**	**Upolu Reef**	**Moore Reef**
Acropora spp.	X	X	X	X	X	X
Acropora humilis	X					
Acropora hyacinthus				X		
Acropora intermedia	X					
Acropora loripes	X	X				
Acropora microphthalma						X
Acropora millepora	X			X		
Acropora muricata		X				X
Acropora nobilis						X
Acropora robusta				X		
Acropora samoensis						X
Acropora sarmentosa					X	
Acropora spathulata		X				
Acropora tenuis						X
Echinopora horrida		X	X	X	X	
Echinopora lamellosa			X			
Favites spp.					X	
Galaxia fasicularis					X	
Isopora prolifera				X		

Merulina scabricula				X		
Montipora spp.				X		
Montipora spumosa	X					
Oxypora spp.				X		
Pachyseris speciosa					X	
Pocillopora spp.	X	X				
Pocillopora damicornis		X				
Pocillopora meandrina						X
Pocillopora verucossa	X					
Porites spp.	X					
Porites cylindrica				X		
Seriatopora spp.		X		X		
Stylophora spp.		X		X		
Stylophora pistillata					X	
Turbinaria reniformis	X			X		
Total	10	9	3	13	7	7

Table 5. Species identified accompanying submission of out-plant data reporting forms by operators as part of the Coral Nurture Program, including both the initial Phase 1 that involved only 1 operator (Aug 2018- Aug 2019) and the following Phase 2 that included a further 4 operators (Aug 2019- Dec 2020). Total species numbers are conservative given some operators only identified out-planted fragments to genus level.

3.3 Research validation: survivorship, growth & attachment over time

To validate anecdotal observations of successful out-plant performance across sites, a series of small scale research exercises were conducted to fate-track survivorship and/or growth (as detailed in Appendix 1). At Hastings Reef, average out-planted fragment survival (n=329) assessed at 1770 and Stepping Stones was 70.9 and 92.9%, respectively, over 7 months (note where initial benthic surveys conducted in August 2019 identified similar hard coral cover of 15.2 ± 2.8% and 17.2 ± 3.1% for the two sites respectively). Growth rates at Opal Reef (site RayBan), over 11 months ranged from 237.5 ± 75.5 mm^2 month^{-1} for *P. meandrina* to 2736.0 ± 1034.1 mm^2 month^{-1} for *A. intermedia* (mean ± SE; absolute growth rate), and where overall survival of out-plants examined at RayBan (n=130) was 80%. No significant differences in growth rates or survivorship were found between nursery- versus reef-sourced fragments or fragments within differing size classes (see Appendix 1 for more information).

3.4 Problems encountered and lessons learnt

As part of ongoing monitoring of the CNP workflows, meetings between researchers and operators were conducted every 4-6 months. The goal of these meetings was to identify any bottlenecks that had either persistently or periodically limited nursery or out-planting practices by operator partners following the initiation of Phase 2. Changes were made throughout Phase 2 in response to problems that were subsequently identified, either by individual operators or all operators (Table 6). Upon adoption of activities by multiple operators, tourism operations and vessels, various issues impacted the speed and scale of Coralclip® deployment. For example, operators were initially asked to identify coral out-plants to species, which temporarily slowed out-planting at some sites due to a lack of capacity in confidently and consistently identifying coral fragments to species level. Furthermore, site access, and therefore operational activity, was often dependant on optimal weather conditions and fluctuations in tourism for the region. Changes to the workflows were suggested in response to such problems and are summarised in Table 6.

One of the major challenges encountered was the CNP operational model of embedding activity in regular tourism operation days. Whilst this remained the preferential mode of operation in order to maximise cost-efficiency (but also exposure of activity to tourists), it meant more limited capacity to operate during tourism downturns (e.g. normal "seasonal" tourism) but importantly under COVID-19 lockdowns and border closures (March 2020 onwards) (Table 6). In this instance, operators would themselves invest (or seek external funding) to run vessels for non-tourism "intensive CNP" days, which also enabled retention of trained staff.

Problems encountered	Potential solutions	All (A) or Individual (I) operators*

Operators at full capacity with tourism high season; no capacity for additional activities Even where funding is available to 'buy out' staff time (those trained in out-planting) for out-planting, operators with fewer crew need to prioritise their core business functions during peak season. Carrying volunteers to compensate requires logistical and Work, Health & Safety considerations.	It was always expected that most out-planting would be 'seasonal'. Focus is on preparation and training, and developing operator-specific strategies to more intensively out-plant during low season. Personnel will be "cost and time shared" amongst dual stewardship activities on dedicated days (e.g. *Acanthaster planci* control and out-planting). This means that corallivore abundance is also assessed and controlled at out-planting plots.	A I
Unexpected problems meant operators were unable to visit core out-planting sites (e.g. weather; logistics), where operators have access to more sites/moorings.	Operators have to go where the business dictates, (e.g. visiting sites with more favourable conditions for tourists). As Coral Nurture Program (CNP) develops, it is inevitable operators will out-plant at many of their sites. In the short-term, given permitting restrictions and for monitoring success, CNP has to focus on core sites. Intensive out-planting strategies will be implemented to account for this into low season, taking additional staff where required/available.	I
Lack of confidence in coral identification for reporting – limited experience in repetitive identification. Lack of effectiveness at out-planting (secureness of Coralclip®) – limited experience with substrates and species. Supply of fragments for out-planting limited. For example, specific operators had a shortage of fragments of opportunity (FoO) and been reluctant to use the permit allowance to stock the nursery with non-FoO corals due to the lack of confidence in identification.	A coral identification workshop was held for all operators and staff, and a pipeline was established to circulate photographs and evaluate assignment of species (genus, morphologies). Identification resources provided. As part of the coral identification workshop, an informal feedback session was also conducted to assess out-planting techniques with photos/demos. In one case, it was identified that substrate may have been too porous, and highlighted the need for more experience of deploying across different sites, topographies and species (as intensive out-planting begins). Confidence gained by the coral identification workshop and low season facilitated an increase in momentum. Also, as corals grow on the nurseries to the point that they can be a source of fragments for out-planting, momentum should further increase.	A I I

Trial fragmentation of nursery and parent colonies and subsequent out-planting in the immediate run-up (late October 2019) to coral spawning at Opal Reef yielded elevated mortality of fragments (likely a result of elevated “stress”). Therefore, we implemented a suspension of colony fragmentation for nursery and out-planting activates during this time operator wide. Anomalously high Sea Surface Temperatures (SSTs) resulted in some coral bleaching at most CNP sites throughout late February 2020. Fragmentation and out-planting during this time was suspended operator wide until SSTs anomalies abated.	Halting colony fragmentation did not limit out-planting of FoO; however, it is clear that this restricts activity. Further experimentation will be required throughout the spawning periods and during SST anomalies to more accurately resolve this “closure window” need in the future. Ensure documentation of the stress response of fragmentation is built into the CNP protocol to be shared with Great Barrier Reef Marine Park Authority and other parties so that this knowledge can be integrated into best practice.	A A
COVID-19 (March 2020 onwards) reduced tourism activities significantly on the Great Barrier Reef (as a result of international and domestic travel restrictions), and most operators had reduced activity and therefore site access.	All operators have a minimum number of passengers required to run financially viable tourism reef trips. Therefore, the “model” was explored whereby increased out-planting activity could be executed during these “downturns” – and therefore operators focus on stewardship activities. Despite some available funding, it was clear that in some cases, tourism numbers were still too low (and hence costs too high) for vessels to go to the reef sites. This example reinforces the need for a fund that can be accessed by tourism operators to still conduct operations (but focussed to stewardship and management) during these downturns.	A

Table 6. Problem-solution workflows encountered during Phase 2 (Aug 2019 – Dec 2020) of the Coral Nurture Program when activities were adopted by a total of 5 tourism operators. Problems were discussed at quarterly meetings amongst operator owners and staff, and solutions implemented thereafter. *Outlines whether problems were raised by All (A) or Individual (I) operators during meetings.

4. Discussion

Coral propagation activities have been increasingly established worldwide yet have partly been hindered by limited scalability and cost-efficiency (Bayraktarov et al. 2019; Boström-

Einarsson et al. 2020; Suggett & van Oppen 2022). On the GBR, the CNP has aimed to overcome such limitations through the novel partnership between local tourism operators and researchers, providing a means for reef stakeholders to contribute to the management of local reef sites (referred to as site-stewardship). Stewardship-based practices have been accepted on the GBR and elsewhere as an important aspect of resilience-based management (Breckwoldt & Seidel 2012; Helsey et al. 2017; Hein et al. 2017; Emslie et al. 2020) and identified as an important component of the GBRMPA's new management framework (GBRMPA 2017b, 2021;). Thus, integration of coral propagation activities alongside other tourism site-stewardship practices is a logical concept, and one which can be extended to other regions where reef tourism is important for the local economy.

4.1 CNP achievements and objectives

Through a collaborative partnership between GBR tourism operators and researchers, CNP demonstrated potential to upscale coral propagation through coordinated activities across multiple high-value localised reef sites. Coral restoration and rehabilitation projects have historically been restricted in spatial scale (Boström-Einarsson et al. 2020); however, in our study, local scalability was achieved through the uptake of a consistent set of tools (e.g. Coralclip®) and installation workflows integrated into the regular operations of different tour operators and locations. The median spatial scale of reef restoration projects to date using coral propagation and transplantation techniques is 100m^2 (Boström-Einarsson et al. 2020), and whilst the scale of out-planting achieved here is of variable intensity at 14 sites (over 6 reefs), each site of operation is at least 100m in length (5m minimum width) resulting in a collective scale of approximately 7,000m^2 (1.7 ha). In addition, propagation activity continued to increase throughout the timeframe outlined in this study, resulting in a total of >21, 000 out-planted coral fragments.

Improved level of scalability – which will inevitably continue as more operators and sites adopt CNP workflows – through collective operation is a well-recognised facet of reef restoration programs (Suggett & van Oppen 2022), and was enabled via consistent monitoring, regular reassessment of standard operating procedures, and optimisation of approaches through research partnerships (see also Howlett et al. 2021). Staged implementation of CNP (i.e., an initial Phase 1 whereby propagation activities were conducted on a smaller scale), allowed for preliminary activities to be tested (e.g. assessing suitability of substrate types for Coralclip® deployment; Suggett et al. 2020) and further identification of research questions that we addressed here. Our small-scale experiments suggested that fragment source (nursery versus reef) and fragment size did not affect fragment growth, survival, or attachment, which is supported by findings from similar studies conducted elsewhere (Singapore; Sam et al. 2021). However, clearly survivorship extent differs between sites (e.g. Hastings Reef of 70.9 – 92.9%, in comparison with 80% at Opal Reef; also 85-95%, Suggett et al. 2020), thus requiring continued evaluation for all locations (operations). As such, integrating evaluation procedures into routine operations is essential to ensure a balance of resources supports continued upscaling of out-planting activities versus research needed to further optimise survivorship.

Continued optimisation of the CNP model was also achieved through regular meetings with operators to discuss problem-solution workflows and any key challenges found throughout propagation activities. For example, CNP activities were initially conceived to opportunistically propagate and out-plant routinely by diverse GBR tourism businesses; however, Phase 2 – when activity was adopted across multiple operators – identified that out-planting at a meaningful scale and effectiveness within business operations was often preferably through intensive, targeted out-planting on allocated charters. Notably, this less frequent but more intensive approach was adopted by Operators A, B and C in Phase 2 (Opal, Hastings, and Mackay Reefs), and is reflected by the higher percentages of total out-plants achieved at these sites. These same operators instead focussed on other regular site maintenance activities during routine operations (e.g., nursery checks). Given that a goal of the CNP is to enable tourism operators to utilise coral propagation tools and methods to collectively contribute to local site management and stewardship, it was clear that diverse activities were of collective benefit over time. In addition, diversifying out-planting approaches (i.e., intensive versus opportunistic out-planting) between operators within the CNP captured the trade-off between greater (faster) out-planting with lower taxonomic resolution reporting versus less out-planting but capturing more species knowledge.

Underpinning this collective action was clear trust in operation amongst partners over time despite differences in extent of activity between operators and sites. Trust is a well-recognised and important factor in achieving conservation outcomes (e.g. van Putten et al. 2021), and one that is retained within CNP by all operators adhering to the Code of Conduct (Appendix 2) with a common vision to ensure focus is on retaining World Heritage values. However, it was also important that operators carried a sense of ownership of the collective successes of CNP (propagation and out-planting extent), and that CNP was a credible operation through research validation of reporting of key outcomes, such as out-planting extent and survivorship (Sayce et al. 2013; Hein et al. 2019). Aspects therefore deemed essential to the success of the CNP model were the collaboration and trust amongst tourism operators and with research partners, adoption and use of simple, low-cost propagation nurseries and out-planting devices (Coralclip®), the capacity to 'learn by doing' as well as regular site access. Such factors are amongst those recently identified as 'golden rules' for effective coral resotation (Quigley et al. 2022).

4.2 Key challenges and solutions

Upscaling CNP activity in Phase 2 – or indeed any time where new operators begin activity at new sites – relied on fragments of opportunity for source coral fragments since it can take up to 12 months for sufficient growth and acclimation where nurseries begin generating sufficient material for out-planting (Shafir et al. 2006; Howlett et al. 2021). Such reliance means coral taxa that more easily fragment (typically due to physical disturbance but also biological disturbance, e.g., large parrotfish grazing, Osborne et al. 2011; McCauley et al. 2014) will preferentially be favoured. This will also be weighted by the abundance of any given coral species at any one site. In our case, out-planting fragments of opportunity resulted in preferential deployment of *Acropora* species, which did not reflect the dominant hard coral genus at each site, except for Moore Reef. Such potential bias is highlighted in other coral restoration projects, where 36% of all out-planted fragments to date were sourced from *Acropora* species (Boström-Einarsson et al. 2020). However, this focus on *Acropora* species is logical where – on the GBR – recent large scale mortality events have largely affected *Acropora* species (Hoogenboom et al. 2017), resulting in a disproportionate loss in biomass of this important group (Hughes et al. 2018; Ortiz et al. 2021). Future work evaluating the impact of such scalable out-planting (and therefore site maintenance) is needed to fully comprehend the ecological effects of high out-planted numbers but of few coral species (Hein et al. 2017; Boström-Einarsson et al. 2020; Hein et al. 2020).

It is expected that operators will become less reliant on fragments of opportunity as a source of out-planting fragments as coral nursery stocks increase over time. Increasing the diversity of out-planted fragments by supplementing material from nursery stock (notably with non-*Acroporid* species) was not possible during the first year of the project, yet tourism operators noted that the well-maintained nurseries are an important conspicuous demonstration of activity at reef sites and appeal to visitors. This contrasts with the out-planting at scale with

Coralclip®, which is hard to differentiate from naturally established colonies given the inconspicuous nature of the device (Suggett et al. 2020). Therefore, coral nurseries remain an important facet of the CNP model.

Despite the obvious benefits of regular site access via routine tourism operations to maximise cost-efficiency of CNP workflows (e.g. Suggett et al. 2019, 2020), a reliance on tourism meant that propagation activities were greatly impacted by the broad-scale decline in tourism due to COVID-19 and associated travel restrictions. Several operators were still able to access the reef via some tourism (and complying with the evolving social distancing regulations), and it enabled operators to utilise funding through the CNP to supplement staff wages to focus on out-planting (or nursery) activities. Thus, integrating propagation and out-planting into tourism operations has arguably provided novel stewardship options in retaining or rebuilding site health, but also the capacity to re-purpose assets, infrastructure, and staff during tourism downturns towards coral propagation activity (assuming such activity could be financed). The ability of select stakeholders to re-purpose operations in the face of future tourism downturns validates the added socio-economic value of CNP, extending impact beyond that provided through adding coral into tourism sites alone (Rinkevich. 2015; Hesley et al. 2017), and enhancing social resilience (sensu Cinner et al. 2009). This also demonstrates flexibitility within the CNP model, since the management method need not be employed singularly by tourism operators. CNP methodologies may be utilised by reef stewards with regular site access, such as traditional owners and groups involved in routine monitoring, thus further enabling propagation activities that are not dependant on tourism.

4.3 Towards a site-stewardship based management tool

Enthusiasm for more diverse site stewardship tools by stakeholders has been fundamental in ensuring CNP remains cost-effective, through provision of regular access to out-planting sites, vessels, and experienced personnel, which in turn has been enhanced through regular communication between practitioners. In addition, the CNP model compliments site stewardship activities already employed by tourism operators, such as corallivore control and monitoring (GBRMPA 2011; GBRMPA 2017a; GBRMPA 2021; Emslie et al. 2020). On the GBR, where multiple regions are managed through a central agency (GBRMPA), the CNP model can therefore in effect seamlessly integrate into a wider toolbox that involves various elements of ecosystem-based, resilience focussed management (GBRMPA 2017b). Thus, in the absence of involvement from a central management agency, employment of personnel dedicated to effective communication between program partners would be beneficial.

Nevertheless, based on the proof-of-concept delivered through CNP adoption amongst multiple operators on the GBR, it is reasonable to expect that the CNP model could be incorporated into stewardship-based management practices in other regions where the reef economy is sustained through tourism. Participatory research through the shared local knowledge by tourism operators ensures that research outcomes benefit reef custodians (Turnbull et al. 2020; van Putten et al. 2021), whilst addressing research questions pertaining to efficiency and cost-effectiveness can ensure adaptation within varying locations and stakeholder operations (e.g., Suggett et al. 2020). Thus, for the CNP model to be successfully adopted elsewhere, we suggest a staged implementation and flexibility concerning best practice to ensure the model is tailored and hence equally beneficial across diverse program partner operations (capacity and sites). In our case, partner expectations were critically met by mutually adhering to an agreed-upon Code of Conduct (Appendix 2), to ensure that the overall aims of the CNP activity – and in effect “licence” to operate under CNP – remained the same across operators; as such, any new operators wishing to adopt CNP (and so leverage the collective benefits) fully understand the principles already at play. Establishing trust within a mutually beneficial partnership is a key aspect of other successful stewardship practices employed in other regions (Cinner et al. 2009; Breckwoldt & Seidel 2012; Wongthong & Harvey 2014). We additionally recommend a focus on reporting of propagation activities to continuously assess whether the aims are being met and identify potential issues or bottlenecks in operating procedures. Reducing the potential loss of genetic diversity also needs to be considered to ensure the retention of adaptive capacity within out-planted coral populations, and can extend so far as to favour traits pertaining to heat tolerance (if funding is available) (Baums 2008; Caruso et al. 2021; Camp 2022).

As a result of the capacity to operate at scale through collective activity spanning diverse reef sites and industry business modes, the CNP goals are centred on retaining and rebuilding coral cover and diversity at high value reef sites. As such, whilst research on coral growth and survivorship provides critical information towards optimising cost-effectivness over time (Suggett et al. 2019, Boström-Einarsson et al. 2020), further data will be needed to determine if these goals are being met; for example, routine ecological surveying (out-planted versus control sites), and establishing time to reproduction and reproductive capacity of outplants. Together, such ecological metrics capture the ecosystem service value (e.g. Hein et al. 2021) and therefore reconcile cost-effective propogation and planting with recovery of ecosystem service value. Support of ecological management models though continued research is a indeed a widely accepted practice in other disciplines, such as fisheries and protected species management (Mcleod et al. 2019). In the case of CNP, the socio-economic influence of propagation practices at high-value tourism sites (e.g. Spalding et al. 2017) on operators and stakeholders can be explored further, thus further informing the “success” of stewardship-based management.

5. Conclusions

We have described how adoption of coral propagation and out-planting within established northern GBR tourism operations has resulted in the up-scale of coral propagation activites (installation of >70 nursery frames seeded with >4,600 fragments covering >36 species and >20,000 outplants of >29 species) at high-value tourism sites on the northern GBR. Whilst fate-tracking the entire population of out-plants has been precluded by this scale of activity, smaller focussed experiments demonstrate that high growth and survival was achieved, in line with previous assessments of Coralclip® (Suggett et al. 2020) and coral nurseries (Howlett et al. 2021). Importantly, whilst propagation and out-planting intensity varied across different operators/sites, activities clearly provide economic, social, and ecological incentive for the employment of site stewardship approaches by tourism operators. Growth in activity over time has been enabled through a coordinated approach, identification, and resolution of operational constraints by individual or all operators, and the use and deployment of low-cost tools and workflows (but tailored across individual operations). Given the ease of implementation, this activity has potential for broader deployment across reefs where the economy is substantially dependent upon tourism industries (Spalding et al. 2017), and in doing so provides further capacity for local reef stewardship. However, we urge the importance in understanding how site ecologies and aesthetics are affected by the current practices; for example, long term reliance on fragments of opportunity lone as the main source of coral material for out-planting. Additionally, the continued success of these activities will likely be impacted by future mass bleaching events, and thus does not eliminate the need for urgent climate action. Therefore, tailoring propagation and out-planting practices to ensure resilience to future stress events is also an obvious priority as these activities continue to scale.

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