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Identifying biological and environmental drivers that underpin successful coral recruitment to inform reef restoration

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For the degree of Doctor of Philosophy in Natural and Physical Sciences

Colleges of Science and Engineering, James Cook University

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Statement on the contribution of others

Table 1. Statement of contribution to Thesis chapters. TW is Taylor Whitman, CR is Carly Randall, AN is Andrew Negri, MH is Mia Hoogenboom, SJ is Saskia Jurriaans, CL is Carine Lefevre, CS is Carrie Sims, CP is Cathie Page, CG is Christine Giuliano, GG is Gemma Galbraith, BR is Ben Radford, and MP is Marji Puotinen.

Chapter	Statement of contribution
Chapter 1: General introduction	TW wrote the section with feedback from CR, AN, and MH.
Chapter 2: Coral-seeding devices with fish-exclusion features reduce mortality on the Great Barrier Reef	TW wrote the chapter with feedback from CR, AN, and MH.
Chapter 3: Seeded *Acropora digitifera* corals survive best on wave-exposed reefs with grazing from small fishes	TW wrote the chapter with feedback from CR, AN, MH, SJ, CL, CS, BR, and MP.
Chapter 4: Variable survival of seeded corals across marine reserves on the inshore Great Barrier Reef	TW wrote the chapter with feedback from CR, AN, MH, CP, CG, and GG.
Chapter 5: General discussion	TW wrote the section with feedback from CR, AN, and MH.

Table 2. Authorship declaration for published chapters.

Chapter	Reference	Contributions of each author	Author consent to republish content in thesis
Coral-seeding devices with fish-exclusion features reduce mortality on the Great Barrier Reef	Whitman, T.N., Hoogenboom, M.O., Negri, A.P. and Randall, C.J., (2024). Coral-seeding devices with fish-exclusion features reduce mortality on the Great Barrier Reef. *Scientific Reports*, *14*(1), p.13332. https://doi-org.elibrary.jcu.edu.au/10.1038/s41598-024-64294-z	T.N.W. conceptualized and coordinated the study, with guidance provided by C.J.R., M.O.H, and A.P.N.; T.N.W. finalized the data, performed the analyses, and prepared the manuscript drafts, figures, and tables; C.J.R., M.O.H, and A.P.N. supervised the project and contributed to manuscript preparations. All authors approved the final draft.	
Seeded *Acropora digitifera* corals survive best on wave-exposed reefs with grazing from small fishes	Whitman, T.N., Jurriaans, S., Lefevre, C., Sims, C.A., Radford, B., Puotinen, M., Hoogenboom, M.O., Negri, A.P. and Randall, C.J., (2025). Seeded *Acropora digitifera* corals survive best on wave-exposed reefs with grazing from small fishes. *Restoration Ecology* https://doi.org/10.1111/rec.70016	TNW coordinated the study, collected the data, performed the analyses and prepared the manuscript; SJ, CAS, MOH, APN, CJR provided conceptual guidance; BR, MP created the spatial-habitat prediction models; SJ, CL, CJR provided field support; CL identified the fish; All authors edited and approved the manuscript.	

Abstract

Increased coral mortality, driven by climate change and exacerbated by local stressors, threatens the persistence of coral populations. Restoration approaches that seed juvenile corals onto reefs show promise as economical and scalable methods to help coral populations persist in an uncertain future. However, seeding success is threatened by high post-deployment mortality driven by many co-varying factors. For example, direct and indirect predation by reef fish can be a significant source of coral mortality during early ontogeny. My thesis disentangles the complex, context-specific drivers of post-deployment mortality in relation to fish predation to provide actionable recommendations for coral seeding for successful ecological restoration. I undertook extensive deployments of corals on engineered seeding devices at three locations in the northern, central, and southern sectors of Australia's Great Barrier Reef (GBR), including inshore and offshore reefs, and across sites with varying hydrodynamic conditions and marine reserve statuses. The growth and survival of over 25,000 spat and 692 microfragments, from two ecologically significant broadcast spawning coral species (*Acropora digitifera* and *A. millepora*) were tracked for up to two years. Coral seeding devices with fish-exclusion features were compared against featureless control devices in all experimental deployments.

In **Chapter 2**, an 8-month coral seeding trial on the central offshore GBR was used to assess the efficacy of a modular fish-exclusion device to increase the survival of captive-reared *A. digitifera* spat and microfragments. I found that devices with fish-exclusion features led to a 2-fold increase in coral survival, while most coral seeded without protection suffered mortality within 48 hours. Spat faced more grazing and higher mortality compared to microfragments, and upward-facing corals were more vulnerable than side-facing corals. Fish grazing varied by site, with lower activity in locations abundant in mat-forming cyanobacteria and Scleractinian corals. Scraping parrotfish commonly fed at the experimental sites; however, bites by *Scarus globiceps* explained the most site-related variation in grazing. Incorporating side-facing refugia in seeding devices and seeding corals to sites with nutrient-rich food sources for fish were identified as potential strategies to enhance coral survival in restoration programs.

In **Chapter 3**, a 16-month coral seeding trial on the northern offshore GBR examined the potential interactive effects of wave energy and fish grazing on *A. digitifera* spat survival. Two similar device types, one incorporating side facing fish-exclusion features and a featureless control, were deployed with coral spat to 10 sites spanning a wave-energy gradient. High-energy sites exhibited 83-91% of devices with at least one living coral and 3-times more surviving corals than low-energy sites after 16 months. Fish exclusion devices significantly improved survival at moderate-to-low flow sites where excavating parrotfish were abundant, highlighting an important interaction between wave energy and fish abundance

in driving coral survival. Site-specific biological characteristics also influenced coral survival, with more survivors at sites abundant with Labrid (*Thallasoma*, and *Gomphosus*), Acanthurid (*Acanthurus* and *Zebrasoma*) and Blennid (*Cirripectes*) fishes, encrusting non-*Acropora* corals, coralline algae, and ascidians. These findings suggest that assessing potential sites for these positive drivers of survival prior to deployment could enhance the efficacy of coral seeding efforts.

In **Chapter 4**, an 11-month coral seeding trial on the southern inshore GBR investigated the potential interactive effects of fish predation and marine reserve status on coral seeding success. The survival of *ex situ* reared *A. millepora* spat on engineered devices was tracked across six sites – three open to fishing and three within no-take marine reserves. Two seeding device designs incorporating side orientated fish-exclusion features were tested against a featureless control device. After 11 months, over 60 % of devices retained live coral and 30% of corals survived. While survival was site specific, marine reserve status had little influence. Instead, reefs with abundant small fishes (predominantly damselfish and wrasse) had higher survival than those with high macroalgae and sediments. Devices with fish-exclusion features significantly outperformed the control. This study demonstrated that site-specific ecological drivers are stronger predictors of coral survival than marine reserve status.

Taken together, this Thesis identified critical biological and environmental drivers that underpin successful coral recruitment, enhancing our foundational knowledge of coral biology and ecology throughout early ontogeny. Furthermore, insights into the role of herbivorous reef fish on seeded coral survival highlights the intricacies of ecological relationships that exist on reefs, emphasising the need to account for these dynamics when implementing coral seeding as a tool for reef restoration. Based on the deployment outcomes identified and discussed in the Thesis chapters, five criteria were developed to guide coral seeding restoration practitioners:

(1) Use differential survival data to inform appropriate seeding densities. Deploy 3-times more devices when seeding coral spat compared to microfragments and at sites with macroalgae, unconsolidated rubble and branching corals compared to reefs that have consolidated hard substratum.

(2) Devices incorporating fish exclusion features and side-facing orientations should be used over featureless and top-facing orientations to enhance coral survival.

(3) Consider the reef hydrodynamics when selecting candidate sites. Offshore sites on the reef front and flank, and inshore windward-facing reefs in marine reserves, serve as strong starting points. Spatial habitat prediction models may streamline the site selection process.

(4) Survey sites prior to deployments to identify target fish communities within candidate sites. Sites abundant in small herbivorous (damselfish, blennies), planktivorous (damselfish) and carnivorous (wrasse, surgeonfish) fishes should be prioritised, while avoiding areas with high densities of excavating parrotfish and triggerfish.

(5) Evaluate the benthic community to inform device placement within sites. Favour sites with encrusting non-*Acropora* corals, crustose algae, ascidians, and nutritious foods for fishes (cyanobacteria). Avoid or adjust seeding methods on reefs dominated by erect-fleshy macroalgae (*Sargassum*, *Padina*, *Colpomenia*, *Lobophora*), reef rubble, and deposited sediments.

These recommendations provide a roadmap to overcome grazing-related effects on coral recruitment and provide novel considerations for seeding *A. digitifera*, *A. millepora*, and other taxa that occupy similar ecological niches, effectively at scale for reef restoration.

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Chapter 1. General introduction

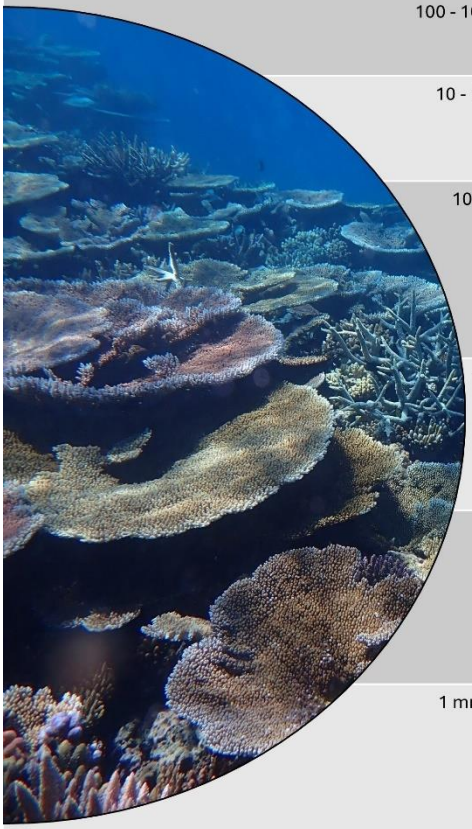
Coral populations and reef assemblages are sensitive to rapidly changing environmental conditions and are under threat from acute and chronic disturbances driven by anthropogenic activities [7,8]. Corals live in environments that are close to their upper thermal limits, thus natural fluctuations in seawater temperatures coupled with the increasing scale, magnitude, and frequency of marine heatwaves has led to a 50% to 80% decline in Scleractinian coral abundances on shallow reefs worldwide [9–15]. Although the causes of coral decline are numerous, and extend beyond heatwave-inducted mortality, the fates of disturbed coral populations are challenging to predict. Foremost, coral replenishment processes vary across connected populations that can be found in very different environments and are subject to variability in demography through space and time [16,17]. Moreover, reef ecosystems show variation in their ability to withstand and recover from disturbances since species-specific tolerances and life-history traits control natural rates of fecundity, dispersal, and adaptation [18–20]. Furthermore, rapid declines in coral cover have reduced the abundance, density, and average size of sexually mature corals [21–23], lowering gamete-fertilisation success, thereby decreasing the number of propagules able to disperse among sites and metamorphose from their free-living to attached (benthic) life stage [23,24]. Predicting the future of coral reefs therefore requires an understanding of population replenishment processes within and amongst reefs, across multiple spatial scales, and throughout coral ontogeny.

Dispersing coral offspring play a critical role in population replenishment after a disturbance [17,23,25–30]. The supply of pelagic coral larvae from sexual reproduction during broadcast spawning provides the primary means of recolonisation for most species [31,32], and larval connectivity amongst reefs can supply large numbers of offspring originating from less disturbed sites to impacted areas for recovery of coral cover and diversity [17,33,34]. A larva's ability to survive during pelagic dispersal and recruit (attach, metamorphose, and grow) on the reef is critical to generational succession, colonisation, and recovery [30,35]. On a coral-dominated reef, the robust supply of larvae can be expected to saturate the limited available free space [26,36,37]. However, on degraded reefs, larval supply can be limited, suppressing natural recovery. Furthermore, post-settlement mortality can reach up to 99% within the first six months, due to a variety of contributing factors [17,38–42]. Environmental disturbances, including changes in sea surface temperature, salinity, sedimentation, and nutrients can be linked to high mortality of corals in their early life history [23,43–45]. However, the leading cause of mortality after settlement remains uncertain, and is widely debated, as young coral settlers are subjected to numerous co-occurring biotic and environmental pressures. On degraded reefs, this high post-settlement mortality represents a rate-limiting step in the recovery of coral dominance.

Ecological factors that affect coral recruitment

Table 1.1. Critical biological and environmental drivers affecting coral populations and life histories (larval supply, post settlement to coral recruitment), and their spatial extent along the reef.

Spatial extent	Environmental drivers	Biological drivers
100 - 1000 kms	Ocean currents Geographic barriers Temperature	
10 - 100 kms	Ocean currents Geographic barriers Temperature Sound	
10 – 100 m	Ocean currents Temperature Sound Wave exposure Tidal depth Benthic colour Light (quality, intensity) Reef structure Seawater chemistry	Benthic organisms Mobile vertebrates
1 - 10 m	Ocean currents Temperature Wave exposure Tidal depth Benthic colour Light (quality, intensity) Reef structure Reef rugosity Seawater chemistry Sedimentation	Benthic organisms Mobile vertebrates Allelopathy Mobile invertebrates
1 m	Ocean currents Temperature Wave exposure Tidal depth Benthic colour Light (quality, intensity) Reef structure Reef rugosity Sea water chemistry Sedimentation Hydrostatic pressure Boundary layer dynamics	Benthic organisms Mobile vertebrates Allelopathy Mobile invertebrates
1 mm - 1 cm	Ocean currents Wave exposure Tidal depth Benthic colour Light (quality, intensity) Reef rugosity Micro-crevice structure Seawater chemistry Sedimentation Hydrostatic pressure Boundary layer dynamics	Benthic organisms Mobile vertebrates Allelopathy Mobile invertebrates



Coral larvae require and actively seek specific ecological cues to guide and initiate attachment to a substrate, metamorphose, and complete the process of settlement. These cues include a variety of physical, biological and chemical factors that act across multiple spatial scales and coincide to determine settlement success or failure (Table 1.1). At the broadest spatial scale (100-1000s km; Table 1.1), currents produced from hydrological ocean conditions and geographic barriers largely determine the delivery or retention of larvae amongst reefs [46–49]. At the finest spatial scales (< 1 m; Table 1.1), specific cues related to water flow, hydrostatic pressure, light intensity, reef sounds, substrate color, and the presence of encrusting coralline algae and bacterial biofilms, and/or their associated biochemical morphogens, attract coral larvae to the seafloor and dictate larval attachment [50–54]. Thus, the ability of larvae to disperse and come into contact with inductive substrata and exploit available space during settlement can be an important determinant of coral recovery and dominance after disturbance [55–57].

Beyond larval settlement, coral survival, growth, and recruitment through more mature life stages are influenced by the same ecological variables (Table. 1.1). First, light quality and quantity are important factors for settlement [58] and post-settlement survival [35,59]. For instance, on high-light, shallow reefs, more recruiting corals survive in microhabitats and crevices compared to exposed reef substrata. In contrast, when propagules settle in deep water with limited light, a higher proportion of corals survive in exposed habitats rather than cryptic ones [60]. Moreover, stronger waves and currents help remove excess oxygen radicals from coral tissues—which is beneficial under thermal stress [61,62] and foreseen in juvenile corals raised in high-flow aquaria [58]. Flow-induced gas exchange between coral tissues and the water column can also reduce light-induced damage, enhancing coral resistance and recovery during warming events [62–65]. Finally, in addition to physical drivers, various species of crustose coralline algae (CCA) and bacterial biofilms affect recruitment success [50–52,66–68]. Notably, only a subset of CCA (e.g., *Titanoderma*, *Porolithon*, and *Hydrolithon*) facilitate coral recruitment, while other fast growing algae that frequently shed tissue layers and/or release toxic chemicals can hinder coral recruitment [23,50,68].

Exposure of corals to a variety of ecological variables can have catastrophic outcomes during early ontogeny. For example, coral recruitment failure has been linked to the presence of fleshy algae, suspended sediments, and direct and indirect predation from reef fishes. Two primary groups of fleshy algae — macroalgae and turfs — significantly and negatively impact coral health. Macroalgae, in particular, can reduce settlement and modify recruitment patterns on reefs through allelopathy and overgrowth, resulting in negative feedback processes that promote macroalgal dominance [68–72]. Some of the most harmful macroalgal genera include *Padina*, *Sargassum*, *Glaxaura, Lobophora, Dictyota,* and *Colpomenia* [70,73–75]. Similarly, algal turfs can out-compete young corals and entrap sediments within their matrices [76–78], increasing the likelihood of negative interactions between corals and sediments. Increased sedimentation can harm coral health in three primary ways: (i) directly through coral smothering [44], (ii) indirectly by increasing water turbidity and reducing light levels [79–83], and (iii) indirectly by masking larval settlement cues [45,50,84]. Interestingly, however, sediment exposure explains less than 20% of mortality of newly settled corals [85], suggesting other drivers are also contributing to coral loss. In particular, reef fish that help control algal and sediment abundance may play a significant role in influencing coral survival.

Direct and indirect predation from reef fishes

The abundance of algae that negatively affect coral recruitment is often controlled at a fine scale by invertebrate grazers, with herbivorous and detritivorous fishes having a significant impact on the standing algal biomass present on coral reefs. More specifically, grazing herbivores from the families Labridae (parrotfish), Acanthuridae (surgeonfish), Siganidae (rabbitfish), Sciaenidae (drummers), Blenniidae

(blennies) and Pomacentridae (damselfish) play an important role in sustaining coral dominance [72,86,87]. On the Great Barrier Reef (GBR), herbivorous fish are estimated to remove > 50% of the total algal biomass GBR-wide[88] and indeed, the removal of algae is often a necessary condition for the successful settlement of coral propagules [69]. There are, however, multiple functional groups within the broad guild of herbivorous reef fish that vary in their feeding modes, and this changes the nature of their feeding impacts on the reef substratum [48].

Only recognised recently, the incidental dislodgement or removal of coral recruits by grazers can act as a major source of post-settlement mortality given their interspersion with commonly grazed algae on the benthos [40,89]. Research thus far has identified that young corals may be vulnerable to parrotfishes [40,90,91], damselfishes, blennies [92], and surgeonfishes [93]. For example, farming and territorial damselfishes (Pomacentridae), such as *Stegastes planifrons,* can use targeted biting to remove corals that settle amongst their filamentous algal lawns [94,95]. Furthermore, parrotfish (Labridae, Scarinae) that feed on the benthos can cause significant coral damage by rasping, scraping, and excavating reef substrata [96,97]. However, the balance between the net benefit of algal removal and the hazard of accidental grazing is difficult to quantify, likely varying amongst coral and fish species and habitats.

Similarly, multiple factors can influence the effects of parrotfish on coral predation and survivorship. In direct predation, corals with exposed tissues and recent bites can be targeted by parrotfish for feeding [98–102]. Corallivorous species such as *Sparisoma viride* and *S. aurofrenatum* exhibit both 'spot biting' and 'focused biting' resulting in either bite-sized lesions across coral colonies or the repeated excavation of contiguous patches of the coral tissue [70,100,103]. Indirect grazing can also impact corals, particularly those settled amongst highly nutritious epilithic, endolithic and epiphytic photosynthetic microbes (e.g., cyanobacteria), that are targeted by herbivorous and scraping parrotfish [104,105]. This can lead to incidental coral dislodgement [105–107]. However, the frequency of algal grazing from roving, herbivorous parrotfishes varies significantly across depths, peaking at the reef crest and decreasing on the slope then flat [108]. In line with this pattern, Baria et al. (2010) found that grazing-induced mortality of *Acropora tenuis* recruits was two-fold higher at 4-m depth on the crest than 9-m down the slope, but eliminating grazing through cages was successful at improving survival for up to three months in both environments [109]. Parrotfish diets and functional roles also change across the spatial gradients of a reef [110], with parrotfish grazing frequency and density peaking in offshore environments and northern sectors of the GBR [111,112].

As the density of herbivores increases offshore, the likelihood of grazing-induced mortality for corals is expected to increase, a theory tested and verified for coral fragments by Gallagher and Doropoulos (2017)[113]. Emerging evidence suggests that up to ~80% of juvenile corals raised in captivity will suffer mortality from fishes within a year of deployment onto on the reef [35]. Yet, grazing-induced coral mortality

remains poorly quantified across natural coral-fish density gradients at both broad (100s of m) and at finer spatial scales (< 1 m) on reefs, where recruiting corals compete for space.

A relatively low biomass of herbivores (< 17.7 g per m^2 in the Indian Ocean [114] and < 1.6 g per m^2 on the GBR [115]) has been reported to sustain coral recovery and equilibrium. However, the abundance of coral, macroalgae, and deposition of terrigenous sediments are shifting in the Anthropocene, having significant impacts on the functional roles of herbivores [88,116,117]. For example, as coral composition shifts, taxa such as *Pocillopora* – rather than *Acropora* – can lower fish species richness and functional diversity [118], potentially altering coral-fish interactions. Furthermore, the effects of typically less harmful grazers (e.g., blennies and surgeonfishes) are expected to increase by 40% under climate-induced changes in pCO_2 levels [93], which is predicted to increase localised pressure from herbivores on coral recovery processes. Although our potential to prevent regime shifts in highly vulnerable coral ecosystems (e.g., inshore and coastal reefs) is uncertain, it is clear that safeguarding coral dominance could benefit from a deeper understanding of coral-fish dynamics.

Management of grazers for conservation

Currently, large-scale efforts to manage fishes on coral reefs include marine protected areas that prohibit overfishing and limit habitat destruction [119–121]. In general, these protections lead to increased densities of herbivores and grazers [122–125], influencing benthic community composition and associated ecological processes. Active strategies to boost coral abundance through herbivore restocking have also been proposed and trialed at small spatial scales. For example, artificial enhancement of herbivore settlement (i.e., urchins), as well as herbivore mariculture and subsequent stocking (i.e., snails, crabs, rabbitfish), are among techniques under investigation [126,127]. However, scaling up from research trials to large-scale stocking remains challenging, and while fish functional redundancy and complementarity are considered crucial for coral reef ecosystem stability, the restoration of grazing functions and its effect on coral recovery remain largely untested.

While there are many benefits of grazers in maintaining coral competitive dominance, the negative effects of grazers on ecosystem recovery and persistence are also well-documented for many terrestrial and marine systems. In grassland restoration, grazing significantly decreases the total density of soil seed banks for up to 10 years [128]. Similarly, in terrestrial reforestation, small shelters or ‘tree guards’ are commonly used to prevent grazing and to protect growing seedlings, improving survival [129]. Analogously, small-scale experiments on coral reefs have demonstrated that physical barriers such as cages or micro-crevice structures enhance coral survival by reducing grazing pressure [90,109,113,130,131]. These barriers represent an emerging strategy to prevent herbivory on coral reefs after a disturbance. Integrating such interventions

with novel coral outplanting techniques could guide transformative change to enhance coral recruitment and ecosystem recovery in the Anthropocene. Given the unique nature of coral reef ecosystems, developing a roadmap to overcome grazing-related effects on coral recruitment, and to enhance beneficial grazers, is urgently required before human-raised corals can be deployed effectively at scale for reef restoration.

The call for active coral reef restoration

A minimum of 9 to 12 years free of major environmental perturbations is required for degraded reefs to return to a coral-dominated state [17,114,132–136]. However, as corals face increasingly frequent disturbances combined with chronic local stressors, the recovery window between events is diminishing – limiting both coral regeneration and our ability to better understand recovery dynamics. To support coral reefs into the future, three critical actions are required [137]. First, global greenhouse gas emissions need to be reduced. Second, we need to prioritise resilience-based reef management, protection, and zoning. Finally, we must develop and implement active restoration techniques to preserve and rehabilitate coral populations [2–5,138–140].

Over the past decade, restoration scientists have trialed several approaches to accelerate coral recovery [1,3,4,141], including managed relocations, coral gardening, and coral breeding (Table 1.2). Much of the science surrounding these interventions has focused on understanding the limitations to natural recovery and testing how human interventions may enhance coral resilience and cover under climate change. One emerging strategy is the large-scale production and deployment of sexually reproduced coral larvae or juveniles [1,141] via ‘coral seeding’. This approach involves breeding corals in aquaculture facilities and rearing coral recruits in large numbers for rapid deployment, at scale. Inspired by aerial reforestation methods – where small plants in protective pods are deployed to degraded forests via aircraft [142–144]– coral seeding employs similar methods to deliver sexually reproduced young (i.e., settled larvae, herein coral spat) or asexually propagated fragments (i.e., < 10 x 10 mm fragments cut from an adult colony, hereafter microfragments) in coral seeding devices via a fleet of marine vessels [1]. Coral seeding devices, designed to house and protect coral juveniles, function similarly to the protective seed pod used in terrestrial reforestation by enhancing early survival. Automated technologies are also being explored to deliver corals in devices to reefs for rehabilitation [1]. However, successful coral seeding requires restoration methods that align with the fundamental biology and ecology of the coral life cycle for effectiveness at scale.

Table 1.2 Commonly used restoration techniques to propagate and outplant corals to accelerate recovery. The information for this table was selected from a literature review of active interventions for coral restoration [1–6].

Restoration Technique	Description	Example	Mode of attachment to reef	Advantages	Disadvantages
CORAL PROPAGATION					
Assisted gene flow	The collection of mature coral colonies to selectively breed them *ex situ*. Involves controlled and manipulated breeding, fertilisation, and the optimisation of larval rearing techniques in the laboratory. Alternatively, this can involve the managed movement or translocation of individuals within a species.	Crossing gametes of *Acropora millepora* collected from the northern and southern sectors of the GBR to rear climate-hardened larvae.	Natural attachment via larval settlement. Artificial adhesives (i.e. super glue, epoxy) for fragments. Artificial coral seeding device for larvae and recruits.	(1) Has the potential to create more stress-tolerant offspring, and climate-hardened individuals will be essential for restoration.	(1) Research is still experimental and has only been tested with a small subset of coral species. (2) Possible outbreeding depression, where offspring exhibit lower fitness than parents. (3) Genetic bottlenecks if the number of individuals used for breeding is not large enough. (4) Introduction of pests and diseases. (5) Risk of altered ecological interactions.
Fragmentation	Adult colonies (> 25 cm in diameter) cut into fragments (< 1 - 5 cm).	Cutting individual branches from an *Acropora* spp. colony to create many smaller fragments of the same genotype.	Artificial adhesives (i.e. super glue, epoxy).	(1) Creates several mature individuals from one colony. (2) Accelerates growth rates. (3) Potential to reduce time to sexual reproduction and accelerate reef recovery. (4) Promising for restoration on a local scale.	(1) Not all coral species respond well to fragmentation. (2) Modes of attachment are labor intensive. (3) Large amount of donor colony material required. (5) Limited scalability.
Microfragmentation	Adult colonies (> 25 cm in diameter) cut into small, microfragments (< 1 cm).	Cutting individual fragments from a colony to create smaller fragments, then using a specialised saw (i.e., Gryphon Diamond Band Saw) to create several microfragments of the same genotype.	Artificial adhesives (i.e. super glue, epoxy).	(1) Potential for high survival and rapid growth. (2) Potential for microfragments of the same species and genotype to fuse via ‘re-skinning’ and	(1) Unknown trade-offs with high growth rates in microfragments. (2) For some massive corals, the fecundity of individual polyps will be influenced by not only colony size but also tissue depth,

				potentially accelerate time to reproductive maturity. (3) Shown some success with slow-growing, massive and encrusting corals.	which may be limited in *re-skinned* corals.
CORAL OUTPLANTING					
Transplantation	Transplanting or moving corals across or within reefs and/or populations.	Transplanting healthy or undisturbed mature corals from nearby reefs to a recently disturbed reef.	Artificial adhesives (i.e. super glue, epoxy, cable ties). Colonies can be attached directly to the reef or to artificial structures (i.e. cement blocks, plastic or metal racks).	(1) Boosts post-disturbance repair of degraded reefs. (2) Increases genetic diversity and coral abundance. (3) Can be done to reduce Allee effects by managing adult coral colony density.	(1) Increases coral abundance at the cost of the abundance of the donor reef. (2) Transplantation has only been successful across reefs with similar environmental characteristics. (3) Labor intensive, scalability and feasibility for restoration is low.
Coral seeding	Transplanting corals (larvae, recruits, microfragments, and fragments) to reefs. Involves *ex situ* or *in situ* rearing of corals. Artificial coral seeding devices are commonly used.	Releasing reared larvae as clouds over the reef substrate; releasing larvae into enclosures/tents over the reef substrate; release larvae to settle onto devices that are then seeded to the reef; collection of a natural spawning slick and transferring to a new location.	Both natural and artificial methods are used for coral attachment. Natural attachment via larval settlement. Artificial seeding devices can be fixed (i.e., attached to reef substrata via nails, cable ties, adhesives) or freely deployed.	(1) Boosts post-disturbance repair of degraded reefs. (2) Sustains genetic diversity of coral populations. (3) Promotes the generational succession of coral populations. (4) Potential to manipulate larval health and settlement success. (5) Enables control of symbiont seeding for many taxa. (5) Scalable	(1) High mortality rates may still exist after settlement. (2) Universal settlement inducer has not been identified. (3) Genetic bottlenecks depend on broodstock diversity. (4) Time sensitive and slick collection or *in situ* gamete collection is dependent on weather and oceanographic conditions. (5) Costly and labor intensive.

Coral recruitment – including larval settlement, metamorphosis, and post-settlement survival to one year – is a critical area of coral ontogeny that requires further investigation for reef restoration strategies, such as coral seeding, to be successful. A review of the restoration literature has identified 18 critical knowledge gaps (Table 1.3) that require further investigation to improve our understanding of processes driving post-settlement survival to recruitment before coral seeding can be widely implemented. The identified knowledge gaps relate to under-explored ecological drivers that can provide information on 'who', 'what', 'when', 'where', and 'how' to seed corals to inform restoration actions. This Thesis specifically examines knowledge gaps numbered 1, 4, 5, 11, and 13 to 16 in Table 1.3.

Table 1.3. Critical knowledge gaps identified from the literature pertaining to the biological and environmental drivers of coral recruitment. The 'information required for restoration action' identifies which aspect(s) of coral seeding each knowledge gap addresses. The possible categories include: who (what species), what (coral material and device), when (time of day, month or season), where (reef habitat), and how (deployment method).

Driver category	**Key knowledge gaps**	**Relevance for restoration action**
Environmental	1. Substrate orientation and fine-scale light availability interactions throughout recruitment.	How, where
	2. Recruit light thresholds post settlement.	Where
	3. The effects of nutrient delivery and heterotrophic feeding throughout recruitment.	Where, how
	4. The effects of water flow and wave exposure on coral spat growth and survival.	Where
	5. Understanding the potential interactive effects of water flow and sedimentation on coral spat survival.	Where, how
	6. Identifying species-specific LD50 thresholds of sediments.	Who, where
	7. The effect of sedimentation on coral larval settlement to recruitment.	Where, how
Biological	8. Long-term monitoring of recruiting corals and known settlement inducers on artificial substrata.	What, how, where
	9. Competition from non-algal benthic organisms throughout early ontogeny.	Where, when
	10. Long-term recruit-benthic assessments with new species combinations.	Where, when
	11. Long-term monitoring of recruiting corals (spat and microfragments) seeded on artificial substrata to degraded reefs.	Where, how
	12. The effect of benthic competition on various size-classes of young corals (spat, juveniles and microfragments).	Who, what, when
	13. Predation by corallivorous fishes and other organisms (e.g., gastropods, polychaetes and ciliates) on recruiting corals.	What, how, where
	14. The cost/benefit of grazing fishes on coral survival throughout recruitment.	Where, how
	15. Grazing pressure on degraded reefs and the impact of variable pressure on seeded corals.	Where, how
	16. The difference in grazing pressure across reef zones (back, crest, slope) and reefs with varying management strategies (fishing versus no fishing).	Where, how
	17. Long-term monitoring of grazing pressure on corals from early ontogeny to maturity.	Who, what, how
	18. Effects of climate change on coral susceptibility to grazing during early ontogeny.	Where, when, how

Research aims and objectives

Given the limited availability of resources and the impracticality of restoring all reefs, understanding the key drivers of seeded coral mortality is essential for optimising where, when, and how coral seeding is implemented most effectively. The aim of my Thesis was to characterise the complex, multivariate and non-linear relationships amongst grazing fishes, benthic competitors, seeded corals, and their physical environment, to provide practical guidance for restoration practitioners. Through three experimental chapters, I examined coral seeding outcomes across a broad spectrum of reef conditions, species, and habitats, to highlight the context-specific responses of seeded corals.

In **Chapter 2**, an 8-month coral seeding trial on the central, offshore GBR was used to assess the efficacy of a modular fish-exclusion device to increase the survival of captive-reared *Acropora digitifera*, across two life stages (spat and microfragments). The seeding trial aimed to resolve four knowledge gaps:

(2.1) How does the survival of corals differ by coral seeding device treatment?,

(2.2) How does the device type alter fish grazing attempts on corals?,

(2.3) What are the patterns of survival and grazing across seeding sites?, and

(2.4) What ecological characteristics of the seeding site influence the observed survival and grazing patterns?

In **Chapter 3**, a 16-month coral seeding trial on the northern, offshore GBR was used to examine the potential interactive effects of wave energy and fish grazing on *A. digitifera* spat survival. The study aimed to address three knowledge gaps:

(3.1) How does wave energy influence the survival of seeded spat?,

(3.2) How does the fish exclusion device interact with wave energy, fish abundance and fish grazing to influence spat survival?, and

(3.3) What are the types and abundances of fish and benthic constituents that predict high survival?

In **Chapter 4**, an 11-month coral seeding trial on the southern, inshore GBR was used to investigate the potential interactive effects of fish predation and marine reserve status on coral seeding success. The seeding trial aimed to address three questions:

(4.1) Does the survival of seeded coral spat differ between take and no-take marine reserves?,

(4.2) Do fish-exclusion devices interact with reserve status and fish communities to influence survival?, and

(4.3) Does fish abundance, fish feeding, and benthic community composition interact to predict seeded-coral survival?

My Thesis provides empirical evidence to inform the targeted deployment of corals to specific sites via coral seeding. The findings from this work on the GBR will contribute to decades of reef restoration studies around the world, enhancing the foundation of the global restoration toolkit.

Chapter 2. Coral-seeding devices with fish-exclusion features reduce mortality on the Great Barrier Reef

This chapter has been published as a peer-reviewed manuscript in the journal *Scientific Reports* and the only text alterations are with respect to thesis formatting requirements but otherwise appears as in the published version.

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2.1 Abstract

Restoration methods that seed juvenile corals show promise as scalable interventions to promote population persistence through anthropogenic warming. However, challenges including predation by fishes can threaten coral survival. Coral-seeding devices with refugia from fishes offer potential solutions to limit predation-driven mortality. In an 8-month field study, we assessed the efficacy of such devices for increasing the survival of captive-reared *Acropora digitifera* (spat and microfragments) over control devices (featureless and caged). Devices with fish-exclusion features demonstrated a 2-fold increase in coral survival, while most corals seeded without protection suffered mortality within 48 hours. Overall, spat faced more grazing and higher mortality compared to microfragments, and upward-facing corals were more vulnerable than side-facing corals. Grazing-induced mortality varied by site, with lower activity in locations abundant in mat-forming cyanobacteria or Scleractinian corals. Many scraping parrotfish were found feeding on or near the seeded corals; however, bites by *Scarus globiceps* explained the most site-related variation in grazing. Cyanobacteria may be preferred over corals as a nutritional resource for scraping parrotfish—advancing our understanding of their foraging ecology. Incorporating side-facing refugia in seeding devices and deploying to sites with nutrient-rich food sources for fish are potential strategies to enhance coral survival in restoration programs.

2.2 Introduction

Anthropogenic warming has increased the frequency of severe disturbances on reefs. As a result, coral cover, coral population sizes and colony abundances have declined, reducing population-level fecundity and gamete-fertilisation success, and thereby decreasing the number of coral propagules available for reef replenishment [21,22]. The successful dispersal and recruitment of coral propagules (via larval attachment, metamorphosis, and growth to maturity) plays a critical role in restoring coral populations after a

disturbance [17,34]. However, mortality can be extremely high for recruiting corals, particularly on degraded reefs, and a minimum of 9 to 12 years free of major environmental perturbations is often required for reef communities to reach pre-disturbance levels of coral cover and diversity [132–134]. As corals continue to be impacted by increasingly frequent and acute disturbances combined with chronic local stressors, restoration initiatives should urgently prioritise techniques that can minimise critical bottlenecks to coral recruitment, thus accelerating natural recovery potential on degraded reefs.

Restoration scientists have tested several approaches to accelerate reef replenishment via assisted coral recruitment, including methods that optimise large-scale production and deployment of sexually produced coral larvae, spat, and fragments [1,141]. Here, we define "coral seeding" as an intervention that harnesses the natural production of coral larvae from mass-spawning events, optimises larval settlement *ex situ*, then deploys or 'seeds' settled spat (< 10 mm in size) back to reefs on artificial deployment devices [131,145,146]. This also includes seeding of small fragments (< 100 mm^2, cut from mature-adult colonies; hereafter 'microfragments') that have the potential to boost growth rates and reduce time to reach size-escape thresholds from mortality and reproductive maturity [18,19,147–150]. Investigations into the feasibility of coral seeding as a tool for reef restoration are currently underway; however, research is needed to develop methods that overcome high coral mortality on devices with seeded spat, with less than 30% survival after one year being the norm [38,40,130,131,151,152].

High mortality of juvenile corals can result from both direct and indirect ecological (biological and physical) interactions [23,41,42]. One frequently reported cause of post-seeding mortality is grazing dislodgement by herbivores and corallivores. For example, biting (direct or indirect) by fishes can remove or dislodge small, vulnerable corals from exposed surfaces [35,90,109,113] and extreme, targeted grazing by territorial fishes can occur [94,153]. In response, the use of physical barriers (i.e., cages and metal spikes) to limit fish access and protect seeded corals has been explored [90,109]. Physical barriers can reduce grazing mortality but their use beyond experimental research has been intensely debated [91,154,155]. In summary, physical interventions are costly, time consuming, and not feasible to deploy over large areas—limiting their use in reef-scale restoration.

Excluding fishes clearly reduces dislodgement of vulnerable corals and increases survival, and the positive result of exclusion is evident early (i.e., within 8 days) and persists at least a year post seeding [35,113,130,131,151]. However, the complete exclusion of fish can also increase crustose, foliose, and turf algal biomass, increasing competitive interactions, partial mortality and disease susceptibility for young corals [50,70,89,115,156,157]. The environmental grazing pressure—measured as total surface area of fish bites relative to the cover of grazable substrate per year—can vary significantly by fish species, size and feeding style. For example, abundant grazers like parrotfish (Labridae, Scarinae [Scarini]) can be categorized based on two

feeding styles: “scraper”, where bites remove substrate surface material only, and “excavator”, where bites remove substantial chunks of substrate and substrate material, and this in turn dictates the ecological function of fish on reefs [158–162]. Yet functional roles of grazing fishes vary markedly due to reef hydrodynamics, structural complexity, and sediment characteristics [155,163,164]. Knowledge of these characteristics at the site level is important for understanding the interactions between grazing fishes and seeded corals because coral growth will also vary under such conditions [44,82]. Therefore, ecological assessments of coral, fish, and the biological and physical habitat are required to tailor seeding techniques to the receiving environment for effective restoration.

Although research has progressed to incorporate protective features (e.g., protrusions, indentations, and microrefugia) into the design of seeding devices [113,130,131,146,152], device designs are yet to be optimised. Consequently, the effects of fish-exclusion features across space and time are likely context specific and warrant further investigation. Furthermore, no direct comparison of early survival following deployment has been made between aquaria-reared coral spat and microfragments of the same species, and understanding coral performance across life stages can help guide restoration decisions. To address these knowledge gaps, we tested the performance of coral seeding devices with fish-exclusion features against featureless control devices and alongside fully caged controls. From this, we resolve four research questions: (1) does the survival of seeded corals differ by device treatment?; (2) do grazing attempts on corals differ among device treatments?; (3) are patterns of survival and grazing consistent across seeding sites?; and (4) do the ecological characteristics of the seeding site influence the observed survival and grazing patterns? The data from this experiment provide important insights into the complex ecological relationships that influence early coral survival. The information can be applied to coral-seeding methods being developed as a part of the global restoration toolkit.

2.3 Methods

2.3.1 Coral spawning, settlement, and grow out

Coral colonies of the species *Acropora digitifera* (Dana, 1846) were collected (permit G21/38062.1 issued by the Great Barrier Reef Marine Park Authority [GBRMPA]) from Davies Reef (central, midshelf Great Barrier Reef [GBR]) prior to the 2021 Autumn (February to March) coral-spawning event. Following collection, colonies were transported to outdoor, flow-through seawater aquaria (average light intensity 74 μmol photons m^{-1} s^{-1} and temperature 27–28 °C) in the National Sea Simulator at the Australian Institute of Marine Science (AIMS, Townsville, Queensland) and maintained until spawning. The timing of spawning and the numbers of colonies that contributed to mass cultures are reported in Appendix Table A1. Gamete bundles were collected, separated, washed, and fertilised as described in Pollock et al. (2017) [165].

Embryos were then transferred to 500 L larval rearing tanks at a stocking density of ~0.5–1 larva mL^{-1}. Culture tanks received flowthrough 0.4 µm filtered seawater (FSW) at 27.5–28.0 °C and gentle aeration began ~16 h post fertilisation. Larvae remained in rearing tanks and once they reached settlement competency (~7-12 d, as determined by daily competency assays) they were settled *en masse* on coral rearing plugs.

Coral larvae were settled on conditioned aragonite plugs that hosted a mixed community of crustose coralline algae (CCA, e.g. *Porolithon*, *Lithophyllum*, *Titanoderma;* see Appendix A section 1.1) and biofilms to induce settlement. Aragonite coral "frag plugs" (20-mm Ø; Ocean Wonders) were used as coral larval settlement substrates. Clean frag plugs were placed in well-conditioned (mixed community of CCA and biofilms), semi-recirculating indoor aquaria (280 L, flow of 5 L min^{-1}, average Photosynthetic Active Radiation [PAR] of 160 µmol m^{-2} s^{-1}) for 2 months prior to settlement. For settlement, 167 plugs were placed into clean, polyvinyl chloride (PVC) trays and trays were distributed to 50 L acrylic tanks (1 holding tray per tank, 12 trays and 12 tanks in total). Approximately 3500 larvae (~20 larvae per plug) were added per tank and allowed to settle over 72 h. Settlement success on individual plugs was then assessed under a dissecting microscope and additional larvae (up to 1500) were added to tanks with low settlement. The maximum number of larvae added to tanks during settlement was 5000. Approximately 9 larvae settled per plug (range of 0 to 46 spat per plug), totaling ~18000 individual spat on 2000 plugs.

Settled spat were maintained in a semi-recirculating indoor aquarium (280 L, flow of 5 L min^{-1}) under a daily feeding regime (unenriched *Artemia* [1 nauplius mL^{-1}], mixed microalgae [2000 cells mL^{-1}; *Nannochloropsis oceania*, *Isochrysis* sp., *Chaetoceros muelleri*, *Dunaliella* sp., *Proteomonas sulcate*], and enriched Rotifers [0.5 nauplii mL^{-1}; *Brachionus plicatilis,* 60-180 micron; SELCO© S.parkle]) and a consistent light profile (PAR, initial 20 µmol m^{-2} s^{-1} and increasing ~14 µmol m^{-2} s^{-1} weekly, with a maximum of 160 µmol m^{-2} s^{-1} by deployment). PAR was maintained at a low level to control the growth of benthic organisms that compete with spat and to mimic the low-light conditions found in crevices where spat tend to preferentially settle [35,50]. Fragments (> 10-cm branch length) of adult broodstock were placed in the aquarium with spat plugs to promote uptake of symbiotic zooxanthellae, Symbiodiniaceae. The aquarium was cleaned weekly and plug trays were rotated and repositioned fortnightly to reduce the effect of any within-tank environmental variability on spat growth. After 4 months, 260 plugs were haphazardly distributed among 130 seeding devices for deployment, resulting in 2 spat plugs per device, one upward facing and one side facing. Each plug had between 1 and 3 discrete spat that were ~ 5-10 polyps and < 8 mm (Ø) in size.

2.3.2 Coral microfragmentation

Microfragments were generated from 5 adult broodstock colonies, 3 months post spawning and 1 month prior to deployment. Colonies were first chiseled into large fragments (~10 cm length), then cut into uniform microfragments (8 x 8 mm, Gryphon Diamond Band Saw). Only branches with mature polyps (i.e., upward facing in the center of the colony) were chosen for microfragmentation [1]. Branches were first cross-sectioned; the upper facing side was then cut into microfragments. The microfragments were glued (Gorilla glue) to the centre of clean (bleached and autoclaved) aragonite coral plugs (20 mm Ø) and maintained in aquaria for approximately 1 month for grow out. Microfragments (n=692) on plugs were then distributed to 346 seeding devices (2 microfragments per device) for deployment. Individuals were evenly distributed among device treatments and orientation by genotype, and the devices were evenly seeded to the experimental sites.

2.3.3 Seeding device treatments and deployments

Reared spat and microfragments were deployed to Davies Reef (for site locations see Fig. 2.1a and Appendix Table A2) in August 2021 and placed in three experimental treatments defined by the device type (Fig. 2.1d-f). Each device had nominally different levels of grazing exclusion and coral protection: (1) a featureless device acted as a positive control (open to grazing; Fig. 2.1d); (2) a caged featureless device acted as a negative control (complete exclusion of grazing by large fishes; Fig. 1f); and (3) a device with engineered fish-exclusion features (protrusions) acted as the experimental device (i.e., device of interest; Fig. 2.1e). The experimental device was designed at AIMS as a part of the Reef Restoration and Adaptation Program (RRAP) and represents the first design to support field deployment of juvenile corals grown on standard 20-mm (Ø) coral frag plugs. The devices were made of 95% alumina ceramic, which was selected for its chemical and physical stability (e.g., high specific gravity [3.8], hardness [9.0 Mohs]), and manufactured in the People's Republic of China [Shanghai Gongtao Ceramics CO., Ltd. PRC]). The device design provided the option for controlled spatial positioning (i.e., in relation to the seafloor) and modular components where the device could be customised for specific experiments; in this case, we selected modules with and without fish exclusion features.

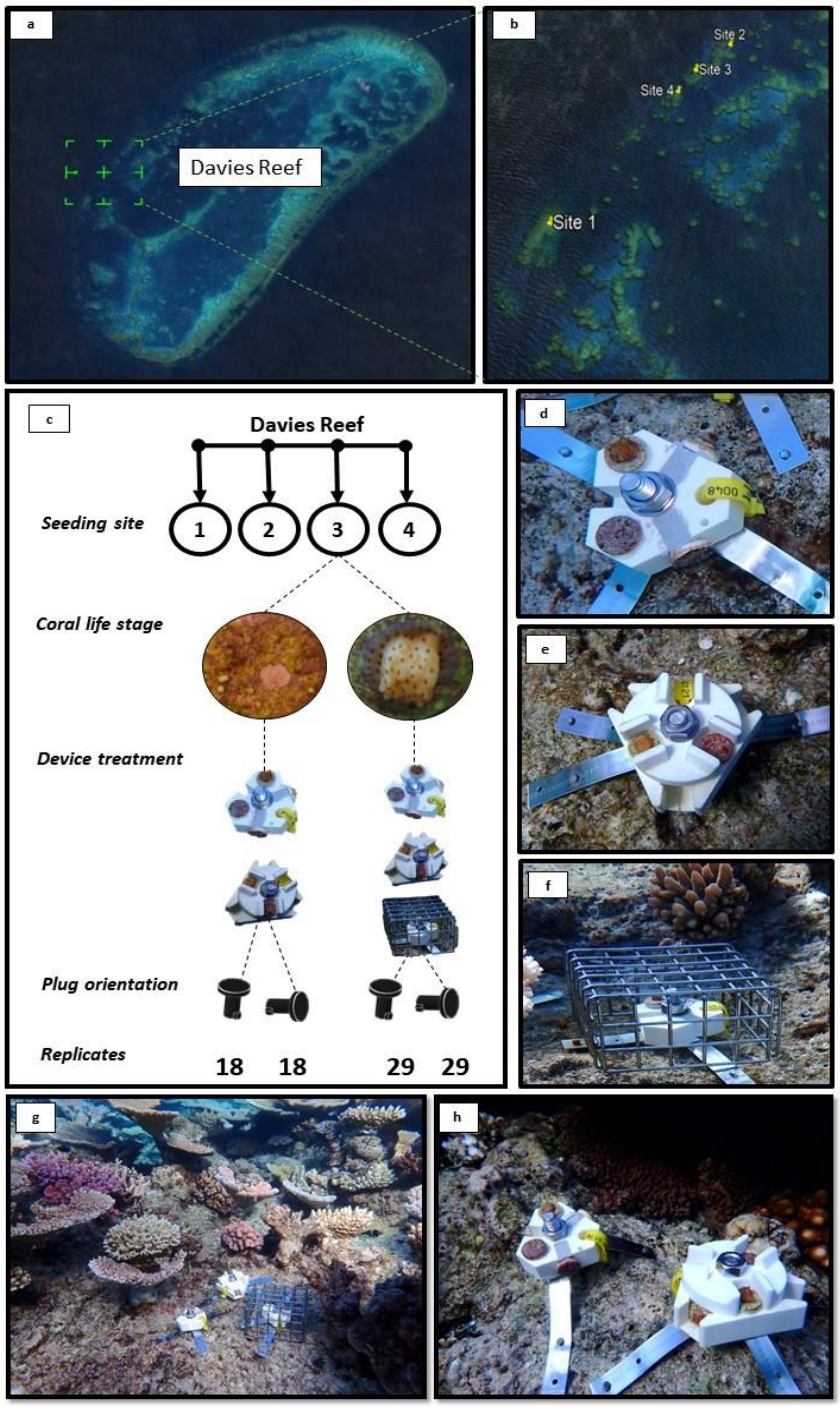


Figure 2.1 Site selection and design plan for the coral-seeding experiment. A total of 346 seeding devices were deployed to Davies Reef (a; Google Earth Image © 2023 Maxar Technologies) and fixed to the reef substrate at four sites (b; Google Earth Image © 2023 Maxar Technologies; see supplementary Tabe A2 for coordinates). The experimental design (c) included two coral life stages, three device treatments, and two plug orientations, with replication among categories. The device treatments (d-f) included featureless control devices (+ control; d), devices with fish-exclusion features (experimental treatment; e) and caged control devices (- control; f). Devices (n=76-100) were paired based on device treatment and coral life stage and deployed to 0.25 m^2 plots (n= 31-41; g-h) at each site (n=4).

Within each experimental device, there were six positions for coral plugs spread among two orientations: top and side facing. In the side orientation, the fish exclusion device had 12 mm protrusions on two sides, with open access for grazing from the top and no access from the bottom (Fig. 2.1e and 2.1h). The top orientation had 12 mm protrusions on two sides, a 10 mm protrusion at the inner edge and no protection on the outer edge (Fig. 2.1e and 2.1h). The minor differences in protection across plug orientations in the exclusion device were unavoidable due to assembly requirements but didn't appear to affect fish behavior (see results). The cage for the negative control was made from stainless steel metal fencing with a 25 x 25 mm grid (Fig. 2.1f). Devices were assembled and attached to the reef flat using a combination of metal strapping, bolts, nails, and cable ties, which were consistent among treatments (Fig. 2.1d-g). The central bolt used for device assembly provided an extra form of protection (i.e., physical barrier to large fish) to the inner edge of the coral plug on all devices (Fig. 2.1d-g). The devices were deployed onto four replicate sites at Davies Reef (Fig. 2.1a-b; Table A2) under GBRMPA permit G21/45348.1 and were removed after 8 months.

The field deployment followed a hierarchical design (Fig. 2.1c) and included: sites (4, categorical, random, and fixed), coral life stage (2, categorical, fixed), device treatment (2 or 3, categorical, fixed), plug orientation (2, categorical, fixed) and replicates for each category. Sites (> 100 m apart) were located on the reef flat in 3-m depth at high tide. Sites were selected based on their similarities in benthic community composition, their leeward location, and the presence of adult *A. digitifera* colonies. Within each site, devices (n=76-100) were paired based on device treatment and coral life stage and deployed to 0.25 m^2 plots (n= 31-41; Fig. 2.1g-h). Plots were placed haphazardly within each site and spaced at least 2-m apart. Due to the limited number of plugs with sufficient coral spat at the time of deployment, the cage treatment was only tested with microfragments. Therefore, sites had plots with paired devices (featureless and exclusion, Fig. 2.1d-e and 2.1h) and plots with all three devices (Fig. 2.1d-g). Paired plots (n=17-23 $site^{-1}$) had spat and microfragment plugs (n=2 corals $life\ stage^{-1}$, n=1 $orientation^{-1}$, n=4 $device^{-1}$), while plots with three devices (n=13-18) contained microfragments only (n=1 $orientation^{-1}$, n=2 $device^{-1}$). In total, 346 seeding devices with 98 spat- and 692 microfragment-plugs were deployed.

2.3.4 Biological and environmental data collection

Devices were monitored *in situ* during three survey time points (2, 90, and 240 days) post deployment. Data collection included a suite of quantitative and qualitative assessments to determine the influence of biological (fish abundance and grazing, benthic composition) and environmental (reef hydrodynamics and sedimentation) drivers on coral growth and survival, each of which are detailed below. More details about the data collection for this experiment can be found in Appendix Table A2.

Coral survival and grazing assessments

Coral plugs were imaged (Olympus TG6) by divers during each survey and images were assessed to determine the presence or absence of grazing marks (at time 2 d only) and surviving corals (all time points) at the level of coral plug. Corals in caged treatments were not imaged at 2 d due to the difficulty in removing and resecuring cages, and it was assumed that no grazing had occurred; corals in caged treatments were imaged at all survey timepoints thereafter. Grazing (presence or absence) was not assessed with imagery in subsequent timepoints due to the difficulty in distinguishing old from new bite marks on the plugs. Only devices that held live corals and remained fixed to the substrate for the entirety of the experiment (63 devices with spat and 275 devices with microfragments) were used to infer survival and grazing. Following the experiment, high-quality images were taken of each plug to validate *in situ* coral survival based on visual surveys.

Fish community surveys and surveillance

Fish communities were observed using *in situ* stationary point count surveys (78.5 m^2 for 5 min, 3 replicates per site) by divers at three timepoints (2, 90, and 240 d). Fish of the key grazing families (Labridae, Acanthuridae, Siganidae, Pomacentridae, Balistidae, and Chaetodontidae) were counted with total counts and relative abundance calculated for each family, timepoint, and site. When possible, the same observer completed all surveys to reduce observer bias in the data. Observer 1 completed > 55% of the surveys. The time, depth, tide, sea state, visibility,and reef complexity were also recorded during surveys. Sea state and reef complexity were scored based on descriptions from the AIMS Long Term Monitoring Program [166].

Feeding and grazing frequency within a 0.25 m^2 plot around two haphazardly selected sets of seeding devices at each site were assessed using GoPro (HERO 9) video surveillance in the morning (8:30-11:30) and afternoon (14:00-17:00) of each survey timepoint (2, 90, and 240 d). GoPro cameras were mounted to lead dive weights using cable ties and left to record for 1 - 2 h in the absence of divers. The number of videos and hours of footage were standardised across sites and the fish grazing activity was recorded. The fish found to be feeding in the plots were identified to species and the following information was collected: number of feeding forays (attempts), number of bites per foray, device grazing (yes/no, per bite), plug grazing (yes/no, per bite), plot type (devices in pairs or triplicates depending on life-stage treatment), and device treatment (exclusion, featureless, or cage). Detailed information for video assessment criteria and data collection can be found in Appendix A section 1.3 and Table A3.

Benthic habitat and community assessments

Reef habitat assessments were undertaken at four spatial scales: plug, device, plot, and site level. Images of the coral seeding devices and plugs were taken at all timepoints to track the growth of benthic competitors

across treatments and overtime. Within plots, 0.25 m^2 quadrats were used to estimate the cover of benthic community constituents (crustose coralline algae, turf algae, fleshy macroalgae [to genus], cyanobacteria, live hard coral [to genus], soft coral, other benthic invertebrates, invertebrate grazers, and 'bare' substrate [defined as recently grazed algal turfs present on hard rock or rubble]). Quadrats were placed centrally around the devices and imaged (Olympus TG6) during all three timepoints (2, 90 and 240 d; Table A2). Images were imported into the ReefCloud online database (https://reefcloud.ai/) and 25 randomly overlaid points per image were scored (human observer) to one of the benthic community categories. Image classifications (109-188 total images per site) were used for statistical analysis.

Site-level benthic data were obtained from *in situ* point-intercept surveys collected at the 2-d timepoint only (Table A2), from three replicate 30-m transects per site, with data recorded every 50 cm, allocated to the same benthic community constituent categories as above. During all three timepoints, a single 30-m video transect was recorded (Olympus TG6). Frame grabs (n=35) were taken from video transects and scored (human observer) on ReefCloud, with 10 randomly overlaid points per image. The *in situ* benthic data (at the site level) were compared to the image classifications (at the site level) and both data sets were investigated further using statistical analyses (see below).

Environmental data: wave energy and sediment

Clod cards (i.e., small blocks made of plaster of Paris) were used to compare relative water flow among sites by measuring dissolution over time and comparing Diffusion Factors (*DF* [167], defined as the ratio between the weight of material dissolved in an experimental block to a control block maintained in a stable environment) [167,168]. Clod cards were glued to the lid of a plastic food container and secured to a lead dive weight with cable ties for deployment. Five replicate clod cards were pre-weighed, then deployed to each site for 48 to 72 h (Table A2). Upon retrieval, the food containers were gently placed over the clods and secured to the lids before returning them to the surface. Clod cards were dried and the weight loss (defined as the card value [*CV*] [167], pre- minus post-deployment weight) was used to obtain the dissolution rate (g m^{-1} d^{-2}). Weight loss was also used to calculate water velocity (cm s^{-1}; V=[CV - 5.8]/0.3) [167]. Values for V were then used to obtain *DF* (*DF*=0.06V + 1.3) [167]. To reduce variability in the data due to sea state, clod cards were deployed on the same day at all sites.

Deposited sediments were assessed using two methods, 'SedPods' and 'TurfPods', that were created following techniques from Field et al. (2013) [169]. Sediment collection pods (5 replicates per type) were deployed to sites (n=4) at each survey timepoint (n=3) and collected after 5 to 7 d (Table A2). From this, the total mass of deposited sediment was quantified for each pod type, which approximates sediment deposition on massive coral surfaces and algal turf-covered substrate, respectively. Pods were stored in a small volume of seawater at -20 °C and held until processing. Sediment processing followed standard water

and wastewater methods from the American Public Health Association 2018 (see Appendix A section 1.4). Briefly, the individual samples were rinsed to eliminate salts (5-6 times with reverse osmosis water and a 3-h settlement period in between rinses), dried (24 h, 103-105 °C), and weighed to obtain the total mass per sample. Sediments were not separated by composition (organics or inorganics) or fractionated by particle size, due to the small mass obtained per sample.

2.3.5 Statistical analyses

Coral survival and predation from grazing fish

The coral survival and fish grazing data were analysed using generalized linear mixed effect models in R statistical software[170] using the 'glmer' function in the 'lme4' package [171]. To investigate the change in survival through time and among treatments and life-history stages, we first modelled survival (binomial distribution with a logit link function) against the additive effects of survey time point, coral life stage, and the interaction between device treatment and plug position, with a random effect of site. To investigate whether survival was different among sites, we then modelled survival (at the final timepoint only) against the additive effect of site, device type and life stage as fixed effects, with other variables (plug position, and device number) as random effects. Presence or absence of coral grazing after 2 d (binomial distribution with a logit link function) was modelled against coral life stage, site, and the interaction between device treatment and plug position as the fixed effects, with device number as the random effect. For each analysis, different combinations of predictors were tested, and the 'best' routine models were selected by comparing Akaike Information Criterion (AIC). Diagnostic plots of the residuals and Q-Q (DHARMa [172]) were used to validate model assumptions and test for homogeneity of variance and linearity between the predictors and the response variables. All parameters were compared and tested for significance using the 'emmeans' package [173] and model outputs were plotted against the response for data visualisation using the 'ggplot2' package [174].

Fish abundance and grazing behavior across seeding sites

Redundancy analyses (RDAs, R software [170],'rda' function of the 'vegan' package [175]) were used to explore the fish abundance and grazing data. From this, ordination plots were generated to identify the site or combinations of sites that explained the greatest differences in fish abundance and grazing intensity. Linear regression models (R software [170], 'lm' function) were used to test the significance of fish families, genera, and species (abundance and grazing) against PC1 and PC2 of the RDAs. Additive combinations of species, genera and families were also tested. Likewise, site was regressed against PC1 and PC2 to test for its significance. Three zero-inflated generalized linear mixed effects models (R software [170], 'glmmTMB' function and package [176]) were used to further explore fish abundance and grazing by site and fish

taxonomic group. First, fish abundances and bites (as the response variables) were modeled against site and fish categories (family-level identification) as predictors. Then, bites by parrotfish (Labridae, Scarini) were tested alongside site and species-level categories. A truncated Poisson distribution was used to accommodate count data that might exhibit overdispersion while still constraining the values to be non-negative. A zero-inflated component was included to address the excess zeros commonly observed in count data.

Ecological data: benthic composition, sedimentation, and wave energy

RDAs were conducted to investigate whether there was a clear separation in the benthic community composition among sites with higher and lower coral survival and grazing at the 2-d timepoint. The RDAs included abundance (percent cover of benthic community constituents per plot) against site, coral survival, or coral grazing as predictors, and visualised through ordination plots. A linear regression model was then used to investigate the relationship between PC1 and PC2, and the explanatory variables. Coral survival and grazing were also tested as the responses against PC1 and PC2 as additive predictors. Logistic regression models (glm) were used to test the abundance of significant benthic categories (groups or individual constituents) as predictors of coral survival and grazing. Models (lm and glm) were also built to investigate differences in wave energy and sedimentation among sites. Deposited sediments, diffusion rates, or diffusion factors were modeled against the predictors of site and pod type (for sediment data only). All models were run and validated as described above.

2.4 Results

Acropora digitifera survival and grazing significantly differed by device treatment, orientation, life stage, and site. Grazing pressure was also related to ecological attributes of the seeding site. Below we report the results of coral survival and grazing pressure, in turn, followed by the ecological variables that underpinned differences across sites. Please refer to Appendix Tables A4 to A10 for the full results of statistical analyses.

2.4.1 Coral survival

We identified four major results with regards to coral survival: (1) survival was highest on devices with cages followed by those with protective features, and lowest on featureless controls; (2) survival was higher on side- versus top-oriented plugs, (3) survival declined through time in all treatments; and (4) microfragments had higher survival than spat (Fig 2. 2).

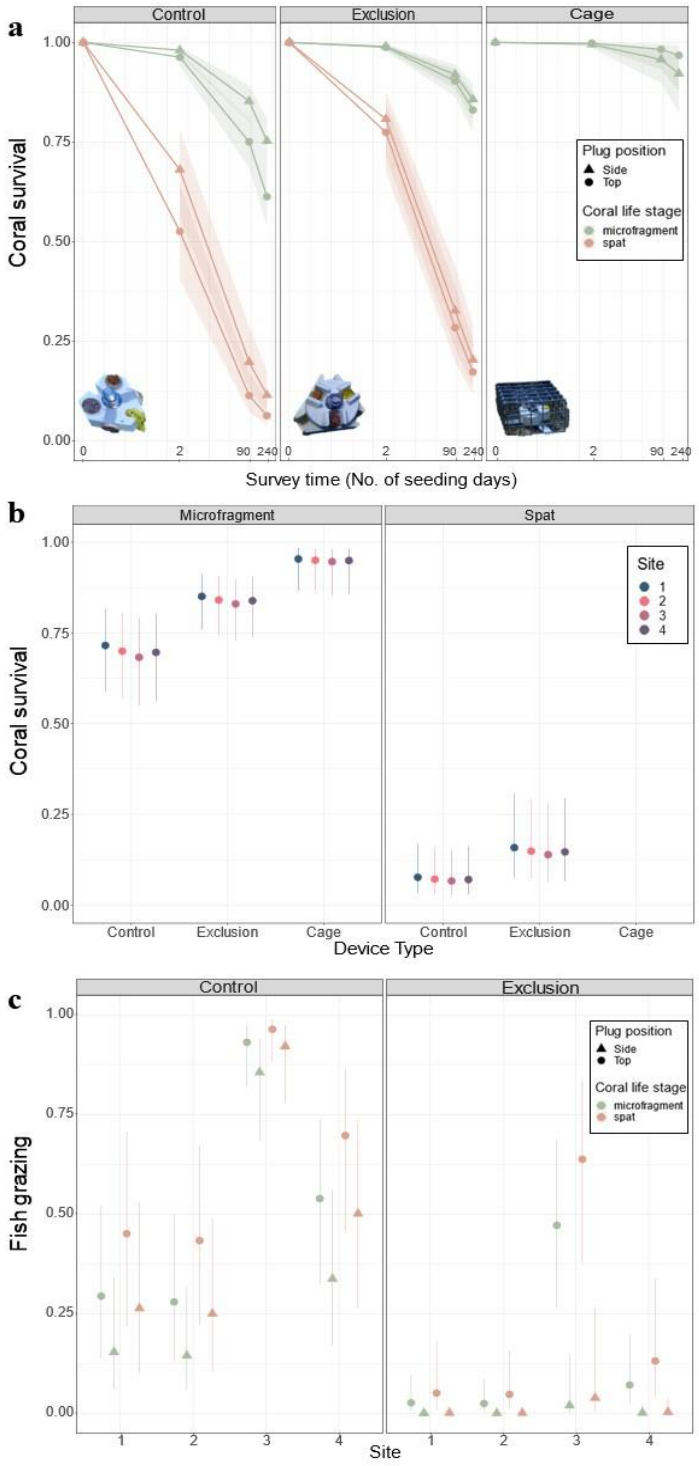


Figure 2.2 Average coral survival and grazing on seeded *Acropora digitifera*. (a) Coral survival through time by device treatment, coral orientation, and coral life stage (n_{obs}=2456, n_{groups}=4; see Appendix Table A4). (b) Coral survival at 240 d separated by site, device type, and life stage (n_{obs}=614, n_{groups}=2). (c) Grazing by fish on seeded corals at 2 d allocated by site, device treatment, orientation, and life stage (n_{obs}=380, n_{groups}=149; Table A5). Points represent the modelled estimated marginal means with 95% confidence intervals. Note that the x-axis in (a) is on a log scale.

Within 2 d of seeding, overall survival declined significantly (Fig. 2.2a). However, survival was 2-fold higher on exclusion devices than on featureless devices (GLMM, p-value=0.002, estimate=0.68, SE=0.23, z-ratio=2.98; Table A4; Fig. 2.2a). The most significant early decline was observed for coral spat on featureless devices (GLMM, p-value <0.001, estimate=-1.13, SE=0.21, z-ratio=-5.437; Table A4; Fig. 2.2a), where average survival dropped from 100% to 52%, and was as low as 0% at one site. Coral survival continued to decline over time in all treatments, with < 15% of spat in control devices surviving to 90 d (GLMM, p-value <0.001, estimate=2.15, SE=0.25, z-ratio=8.55; Table A4; Fig. 2.2a). After 240 days, there was up to 2-times higher survival in the exclusion treatment compared with featureless devices, and this result was strongest for coral spat (GLMM, p-value <0.001, estimate=-1.13, SE=0.21, z-ratio=-5.44; Table A4; Fig. 2.2a). Microfragments in caged devices had the highest survival at the end of the experiment (Fig. 2.2a).

Low survival of spat and high survival of microfragments was consistent across all sites and treatments (GLMM, p-value <0.001, estimate=-3.15, SE=0.3, z-ratio=-15.23; Table A4; Fig. 2.2a). Generally, microfragment survival remained high across the 240-d deployment. The highest survival achieved was in the caged treatment (97%) with lower survival in devices with features (85%) and significantly lower survival in control devices (60%; GLMM, p-value=0.042, estimate=-2.94, SE=0.73, z-ratio=-4.02; Table A4; Fig. 2.2a).

Average survival was significantly higher in side-facing corals than top-facing ones, and this pattern was consistent across device treatments (featureless and exclusion feature), life-history stages, and through time (GLMM, p-value=0.001, estimate=-0.65, SE=0.20, z-ratio=-3.30; Table A4; Fig. 2.2a). This result was most pronounced for microfragments, with 1.5-times more survivors on side versus top oriented corals after 240 d. However, the best performing orientation and device combination for microfragments was the upward-facing plug in the caged treatment (Fig. 2.2a). Survival in these positions was 1.6-fold higher than upward-facing plugs in featureless device (lowest performing orientation and device combination) but was not significantly different from side-facing plugs in the exclusion device.

After 240 d, there was no significant difference in spat or microfragment survival between sites (Fig. 2.2b). Site 1 had the highest number of surviving spat and microfragments at the end of the experiment, while Site 3 had the lowest (Fig. 2.2b); this result remained consistent across the device treatments.

2.4.2 Effects of fish grazing

Within 2 d of seeding, a significant number of corals on featureless devices were heavily grazed by fishes and were grazed up to 4-times more often than those in the exclusion treatment (GLMM, p-value <0.001, estimate=-2.72, SE=0.57, z-ratio=-4.78; Table A5; Fig. 2.2c). Top-orientated corals were targeted for grazing significantly more often (up to 18-times more) than side orientations (GLMM, p-value=0.035, estimate=-0.83, SE=0.39, z-ratio=-2.11; Table A5; Fig. 2.2c), and significantly more spat were grazed than microfragments (GLMM, p-value=0.03, estimate=0.77, SE=0.36, z-ratio=2.1; Table A5; Fig. 2.2c)**.** Despite protection in the exclusion devices, up to 55% of spat and 25% of microfragments in the top orientation experienced grazing (Fig. 2.2c). However, the fish bites in exclusion devices were constrained to the outer edge of the top plug and therefore never caused 100% mortality. Overall, the device and orientation combination that experienced the least grazing was the side position of the exclusion device, while the most was the top position of the featureless device (GLMM, p-value=0.01, estimate=-2.94, SE=1.18, z-ratio=-2.5; Table A5; Fig. 2.2c).

Fish grazing was also site specific. On average, corals had up to 5-times more grazing and predation attempts at Site 3 than Sites 1 and 2 (GLMM, p-value <0.001, estimate=3.48, SE=0.71, z-ratio=4.91; Table A5; Fig. 2.2c), regardless of device type, with up to 95% of spat and 75% of microfragments on featureless devices experiencing grazing there.

2.4.3 Ecological characteristics of seeding sites

Fish abundance, diversity and feeding activity

Differences in fish abundance, diversity and feeding activity among sites were evident. While some fish were consistently abundant across sites (i.e., Siganids, Balistids), others varied considerably (i.e., Pomacentrids, Labrids, Acanthurids and Chaetodontids). Site 3 had the lowest overall abundance of fish while Sites 1 and 4 had the highest abundance and diversity (Fig. 2.3a). For example, Sites 1 and 4 had nearly double the number of Chaetodontids and Acanthurids than Site 3 (GLMM, Site 1 to 3: p-value <0.001, estimate=0.4, SE=0.05, z-ratio=7.44, Site 3 to 4: p-value <0.001, estimate=-0.54, SE=0.05, z-ratio=-10.48; Table A6; Fig. 2.3a). Parrotfish abundance was also significantly higher at Sites 2 and 4 than at Site 3 (GLMM, Site 2 to 3: p-value <0.001, estimate=0.4, SE=0.05, z-ratio=7.94, Site 3 to 4: p-value <0.001, estimate=-0.5, SE=0.05, z-ratio=-10.49; Table A6; Fig. 2.3a).

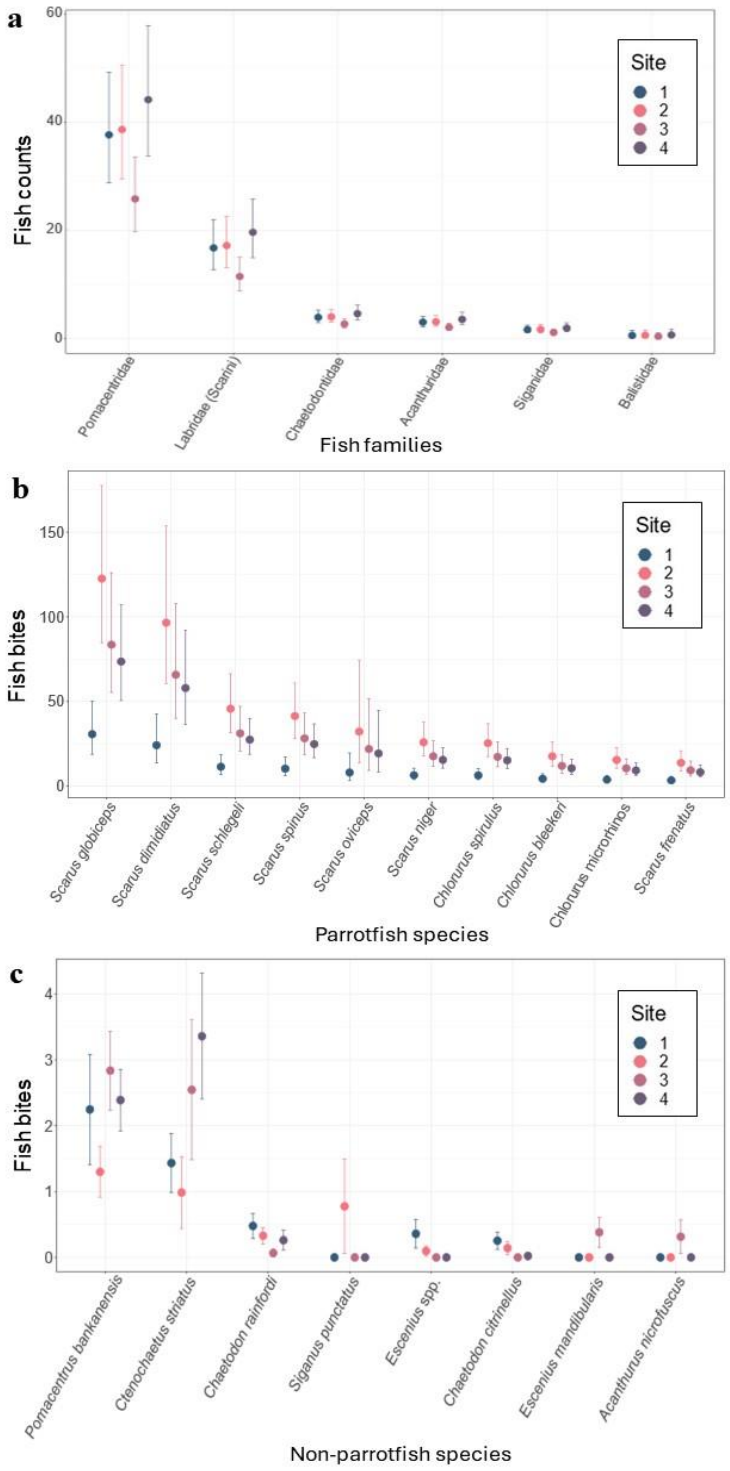


Figure 2.3 Site-level abundance and bite rates for common reef fishes. (a) Counts of fish from *in situ* stationary point count surveys and grouped by fish family (n_{obs}=354, n_{groups}=11; see Appendix Table A6). (b) Feeding (bites min^{-1}) by parrotfish, Labridae (Scarini), in 0.25 m^2 plots within sites (n_{obs}=8040, n_{groups}=134; Table A7). (c) Fish bites (min^{-1}) from non-parrotfish species in plots, separated by site. Standard error and 95% confidence intervals are displayed for each site for the observed (c) and modeled (a-b) data, respectively.

Bites by scraping and excavating parrotfish (genera *Scarus* and *Chlorurus*) accounted for 55-85% of the total bites observed in device plots (Table A8). Whilst grazing directly on coral plugs was highest at Site 3 and lowest at Site 2 (Fig. 2.2c), the grazing activity in experimental plots, recorded during video surveillance, was highest at Site 2 (Table A8). A total of 9233 bites (8480 from parrotfish) were recorded at Site 2. That is approximately 47 bites min^{-1} m^{-2}, and 2800 bites hr^{-1} m^{-2}, up to 5.6-fold higher than other sites. Site 1 had significantly fewer bites (< 600 bites hr^{-1} m^{-2}) than other sites, and this was strongest when comparing bites by parrotfish (GLMM, Site 2 to 1: p-value <0.001, estimate=1.38, SE=0.31, z-ratio=4.43, Site 3 to 1: p-value=0.002, estimate=-0.5, SE=0.33, z-ratio=3.07; Site 4 to 1: p-value=0.005, estimate=0.87, SE=0.31, z-ratio=2.78; Table A7).

Scarus globiceps had the highest number of bites by parrotfish in device plots, while *S. dimidiatus*, *S. schlegeli*, *S. spinus*, *S. oviceps*, *S. niger*, *S. frenatus*, *Chlorurus spirulus*, *C. bleekeri*, and *C. microrhinos* accounted for the rest (Fig. 2.3b). When regressed against the principal components of total bites, *Scarus globiceps*, *S. schlegeli*, and *Chlorurus spirulus* made a significant contribution to variation in bites observed among sites (lm, *S. globiceps*: p-value <0.001, estimate=0.002, SE=0, statistic=13.94, *S. schlegeli*: p-value <0.001, estimate=0.01, SE=0, statistic=19.42, *C. spirulus*: p-value <0.001, estimate=0.01, SE=0.001, statistic= 9.25; Table A7). All Scarini species were found to feed more often at Site 2 and by contrast, less often at Site 1 (Fig. 2.3b). The species *S. globiceps*, *S. dimidiatus* and *S. schlegeli* were identified as the top feeders (Fig. 2.3b).

Feeding contributions from other parrotfish (*S. altipinnis*, *S. chameleon, S. rubroviolaceus*, and *S. flavipectoralis)* and non-parrotfish species (*Pomacentrus bankanensis*, *Ctenochaetous striatus*, *Chaetodon rainfordi*, *Siganus punctatus* and two *Escenius* species) were low (6-200 bites hr^{-1} m^{-2}; Table A8; Fig. 2.3c). The parrotfish fed more often at Site 2 while feeding results from other species were variable among sites.

Benthic composition, reef hydrodynamics, and sedimentation

The composition of benthic organisms in experimental plots was related to fish grazing and coral survival. Fish grazing (on featureless devices at 2 d) was negatively related to the percentage cover of bare substrate; this was true across all sites and coral life stages (Fig. 2.4a). Increasing cover of bare substrate to 20% (0.25 m^2) reduced grazing of seeded corals to < 10% (Fig. 2.4a). The cover of hard rock rather than rubble contributed most to this. Site 1 (with low grazing-induced mortality and low parrotfish feeding; Fig. 2c and Fig. 3b, respectively) had significantly more hard rock compared to other sites (lm, Site 2 to 1: p-value=0.004, estimate=-4.18, SE=1.40, t-value=-2.98, Site 3 to 1: p-value=0.006, estimate=-4.01, SE=1.42, t-value=-2.82, and Site 4 to 1: p-value <0.001, estimate=-4.97, SE=1.40, t-value=-3.54; Table A9 and Fig. A2).

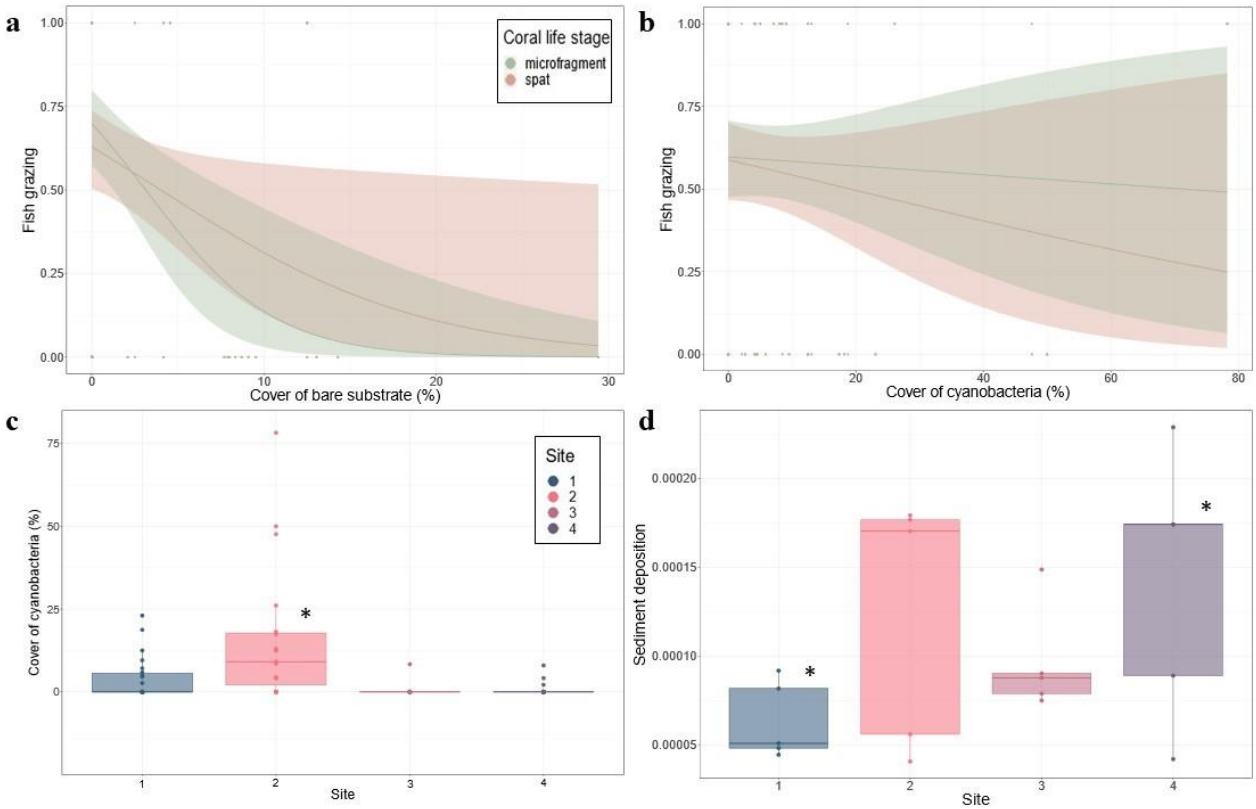


Figure 2.4 Ecological data collected across sites, compared to coral grazing and survival. Logistic relationships between the cover of bare substrate (a) or cyanobacteria (b) and the grazing of coral spat and microfragments by fishes at the 2 d timepoint. (c) Percent cover of mat-forming cyanobacteria recorded.

Site 2, with low grazing-induced mortality (Fig. 2.2c) and high parrotfish feeding (Fig. 2.3b), was the only site with a significantly different benthic community (lm, p-value <0.01, estimate=0.659 SE=0.233; Table A9). Most extreme was the difference in cyanobacteria, which was >12 times higher at Site 2 than other sites (lm, Site 2 to 1: p-value <0.001, estimate=12.05, SE=3.46, t-value=3.48, Site 2 to 3: p-value <0.001, estimate=15.64, SE=3.63, t-value=4.31, Site 2 to 4: p-value <0.001, estimate=15.35, SE=3.58, t-value=4.28; Fig. 2.4c). Fish grazing on spat was negatively related to the percent cover of cyanobacteria (Fig. 2.4b). The most extreme difference in cyanobacteria cover was observed between Sites 2 and 3; high cyanobacteria cover appeared to cause less grazing and higher survival of spat at Site 2 than Site 3 (lm, spat grazing Site 3 to 2: p-value <0.001, estimate=0.81, SE=0.17, t-value=4.88, and spat survival Site 3 to 2: p-value= 0.009, estimate=-0.54, SE=0.17, t-value=-3.21; Table A9).

Spat grazing and survival was also related to the abundance of *Acropora* corals with corymbose and digitate morphologies. For example, a 10% increase in *Acropora* corals was associated with a 10% decrease in the likelihood of grazing on spat and increased the chance of survival at Site 1 (Fig. A1). Site 1 had the highest overall cover of *Acropora* corals in plots, while Site 3 had the lowest. The influence *Acropora* coral cover on spat survival was most extreme when comparing Site 3 to Site 2 and 1, respectively (lm, Site 3 to 2: p-

value=0.01, estimate=-0.55, SE=0.18, t-value=-3.03, and Site 3 to 1: p-value=0.03, estimate=-0.28, SE=0.11, t-value=-2.65; Table A9). The abundance of non-*Acropora* corals, octocorals, algal turfs and CCA contributed to site-related differences; however, not all variables correlated with coral grazing and/or survival, and the responses weren't consistent among sites (Table A9).

There was little to no change in the composition of benthic communities on plugs throughout the experiment (including caged devices). The dominant benthic category at the time of deployment (i.e., those that developed in *ex-situ* aquaria) remained dominant at the end of the experiment.

Environmental data revealed slight variation in water movement and sediment deposition at the site level. Overall, the range of water motion was low across sites at the 2-d timepoint (*DF* of 3.68 to 5.42 on a *DF* scale of 1 [low] to 20 [high]; Table A10; Fig. A3). The total mass of deposited sediments on SedPods explained more of the among-site variation than sediment accumulation on the TurfPods. On average, the deposited sediments collected from SedPods at Site 1 were lower than sediments at other sites (Fig. 2.4d) and Site 4 had significantly more sediments (lm, Site 4 to 1: p-value=0.037, estimate=$7.8e^{-05}$, SE=$3.5e^{-05}$, statistic=2.27; Fig. 2.4d; Tabe A10).

2.5 Discussion

The experimental results indicated four ways to maximise survival of *Acropora digitifera* corals over an eight-month seeding trial: (1) deploy devices with fish-exclusion features; (2) orient corals in the side rather than top positions; (3) use differential survival data to inform appropriate microfragment and spat seeding densities to achieve target numbers; and (4) use ecological variables, like fish abundance, fish diversity and the abundance of nutrient-dense food sources for fish, to help select seeding sites. These four findings can be used to guide coral seeding methods and manage restoration outcomes.

Corals deployed on seeding devices without protection were the most vulnerable to grazing and suffered significantly higher mortality compared to those with protection. Complex device topographies, including crevices, microrefugia and those with high rugosity, have previously been shown to improve coral larval settlement and post-settlement survival [113,130,131,152]. Thus, it was not unexpected that the seeding device engineered with protective walls also enhanced coral survival after seeding. Although the caged device still resulted in higher survival of coral microfragments in our study the built-in protection provided by a fish-exclusion device offers a simple and effective alternative to reduce grazing pressure that is cheaper and far more scalable than cages. Furthermore, cages are ineffective against fish grazing after removal [154]. Nevertheless, there is room to improve the design of devices with features to offer more protection and further increase benefits over caged devices.

The orientation of corals in devices had a major influence on post-seeding survival. Coral larvae often preferentially settle on vertical surfaces to reduce the likelihood of disturbance-induced mortality during recruitment [84,177–179]. Our findings confirmed that corals (especially spat) deployed on top-facing plugs suffer higher rates of grazing and mortality than those in side-facing positions. Many species of parrotfish prefer to feed on horizontal and convex surfaces over vertical and concave surfaces [180]. Therefore, the vertical orientation of the side-facing plug may offer optimal refuge from some grazers. Our grazing results support the selection of vertical habitats by corals. However, there are also reasons beyond fish predation as to why coral larvae prefer settling in refugia. Coral spat are sensitive to high light, heavy sedimentation and excessive waterflow [45], and vertically-orientated structures provide a buffer against such conditions. Fast growing turf, crustose, and macroalgae, that tend to out-compete corals in high-light and sediment-laden environments, can also be less abundant and display different morphologies (e.g., thin- versus thick-crusted CCA) in low-light environments [70,181], relieving some competitive pressures. Regardless of the mechanisms, offering vertically oriented refugia for corals was a successful strategy for improving survival.

It was clear that coral life stage impacted survival after seeding, with significantly more *A. digitifera* microfragments surviving than spat. Spat survival was low (< 50%) on featureless devices past 2 days, and even with device protection. Low survival of spat is common in coral seeding experiments to date. For example, in French Polynesia, grazing led to mass mortality of *A. striata* spat after one week of seeding [182]. Corals in cages had the highest survival but less than 40% survived beyond the initial week of deployment Similarly, in the Philippines, survival of *A. tenuis* spat was < 25% three months post seeding and spat in partial cages outperformed those in full cages in this experiment [109]. By contrast, on the GBR, 38-65% of *A. cytherea* spat survived on reefs for one month, with caging increasing survivorship by 22% [90]. Finally, partial protection of *A. tenuis* spat in microrefugia led to 22-39% yield (e.g., device-level survival) after one year on the GBR [131,145]. Although these examples demonstrate that protection from fishes can increase survival during early ontogeny, spat survival typically remains well below 50%. We suggest that: (i) more spat per device need to be deployed to meet required survival outcomes, (ii) other device types should be trialed to improve the design of protective features, and (iii) further ecological drivers should be studied to inform optimal conditions for spat success after seeding.

While microfragmentation has almost exclusively been performed on corals with plating, massive, and sub-massive growth morphologies [149,150], our results indicate that the technique is also feasible when applied to branching taxa such as *Acropora*. Survival of *A. digitifera* microfragments was exceptionally high, greater than 75% on average and up to 97% in cages. These findings, alongside the result of previous experiments [113], confirm the benefits of physical barriers to enhance the survival of coral microfragments. In Palau, small fragments of *Porites lobata* had higher survival when fully protected (> 90%, four-sided crevices on tiles)

compared to the result of partial crevices (70%) and exposed controls (28%) after 29 days [30]. In the same study, *Pocillopora damicornis* fragments also initially benefited from protection; however, all had died after eight days. These outcomes indicate that tolerance to microfragmentation may be species specific and this will have flow-on effects to survival. Similarly, other factors including fragment health might dictate the likelihood of predation post deployment, with recently dead or dying tissues being more attractive to fishes [98]. The *A. digitifera* tested in our study may be more tolerant to microfragmentation and less palatable to fishes, making it a target candidate for seeding over other taxa such as *Pocillopora*. To ensure positive outcomes after seeding, adequate time should be provided for corals to heal after the microfragmentation process, and the palatability of a range of coral species should be examined.

We found that coral spat were also targeted for grazing more often than microfragments. Parrotfish, mainly *Scarus globiceps*, were identified as the most common and destructive grazers of seeded corals, especially spat. However, most scraping parrotfish are nominally herbivorous and therefore we hypothesise that the grazing-induced mortality of coral spat in our study is likely accidental and indirect. The morphological description of the jaw of a scraping parrotfish like *S. globiceps*, confirms their ability to graze early successional bacterial-algal biofilms growing on reef substrata [87,96]. The artificial plugs used to grow corals in our study were conditioned with similar biofilms (e.g., thin-crusted CCA, microalgae, and mixed bacteria) and these are known to be palatable to many herbivorous parrotfishes [104,183]. Thus, it is likely parrotfish were targeting the benthic community growing on the plug rather than the coral itself. Furthermore, spat plugs were held in aquaria longer than microfragment plugs prior to deployment; this likely contributed to significant differences in grazing among the coral life stage treatment. The use of less palatable benthic organisms for plug conditioning and the incorporation of an antifoulant (i.e., chemical deterrent) on plugs or devices are potential direct and indirect solutions to deter parrotfish grazing. However, we suggest these methods must be balanced against the requirement for benthic communities that: (i) are inductive for the larvae during settlement, (ii) reduce competition against spat and microfragments during recruitment, and (iii) promote coral survival to maturity.

Lastly, the influence of grazing on survival is strongly site specific, and this information may be useful to guide the selection of sites for successful seeding. Foremost, our results support growing evidence that herbivorous parrotfish may preferentially target nutrient-rich food sources (e.g., algal mats or turfs dominated by cyanobacteria), when available [184,185]. However, on reefs with high coral cover and low abundance of cyanobacteria, opportunistic grazing on less preferred food sources such as deployed corals may occur. For example, Site 2 exhibited the least grazing on coral plugs but the highest number of parrotfish bites in experimental plots, and concurrently, a notably higher (12 x) abundance of mat-forming cyanobacteria. Parrotfish consumption of nutrient-dense foods, such as endolithic algae and cyanobacteria,

has been documented in the Caribbean [184] and the northern GBR [185]. Field observations performed by Cissell et al. (2019) found that greater than 15% of the diet of parrotfishes *S. iseri* and *S. coeruleus* consisted of mat-forming cyanobacteria [184]. Similarly, stable isotope analysis of 22 species of GBR-dwelling parrotfish provided strong evidence to support the consumption and preference of microscopic cyanobacteria over other algal substrates during feeding [106]. From this, we propose a new hypothesis that deployment adjacent to nutritious foods like cyanobacteria can offer natural forms of refuge to corals from grazing after seeding.

En masse, deploying to sites with high-nutrient food sources for fish may limit both direct and indirect grazing pressure on corals, increasing the likelihood of successful restoration. However, the composition of modern reefs is expected to shift as the frequency of mild to severe disturbances increases over time. For example, sudden spikes in the abundance of mat-forming cyanobacteria are common characteristics of recently disturbed reefs [186,187]. We suspect slight increases in cyanobacteria (< 20% in 0.25 m^2) can aid coral survival after seeding; however, too much cyanobacteria can negatively impact coral dominance on disturbed reefs. For *A. digitifera* spat, we found that a minimum cover of closely related Scleractinian corals (10%) and bare rock (20%) was correlated with a reduction in grazing by 10 to 50%, respectively. Indeed, other benthic constituents, like sponges and epilithic algal communities, have been correlated with high survival of seeded corals on the GBR [145]. Therefore, a diverse group of grazing fishes at a minimum biomass may be required to mediate competition between corals and fast-growing benthic organisms after seeding. A relatively low biomass of herbivores (177 kg ha [17.7 g m^2]) has been shown to sustain community equilibrium and reduce the risk of regime shifts occurring in the Indian Ocean [114]. Defining a biomass threshold for parrotfish (e.g., where the net benefit towards coral competition outweighs the negative effects of accidental grazing), represents one tool that can be used to guide or tailor deployments of corals to specific sites. The direct manipulation of herbivore abundance (i.e., enhancing fish recruitment) could also be considered at sites with significant regime shifts. Taken together, these results highlight the importance of a holistic approach that considers multiple ecological parameters to inform the selection of candidate sites for reef restoration with coral seeding devices.

2.6 Conclusion

The addition of fish exclusion features in coral seeding devices can improve survival and lead to substantial reductions in the handling time required for coral seeding, supporting the goal of upscaling restoration initiatives. Our eight-month seeding trial with *Acropora digitifera* revealed significantly higher survival when spat and microfragments were deployed in vertical positions with protection from grazing fishes. Importantly, future coral seeding experiments need to consider biological and environmental characteristics of the receiving environment more holistically and test across ecologically important reef-building coral

taxa. Here we've identified that environmental drivers including a diverse assemblage of fishes (Labrids, Pomacentrids, Acanthurids, Chaetodontids) and low to moderate cover (< 40%) of coral, recently grazed reef rock, and nutrient-rich foods for parrotfish, could be used as visual aids (i.e., during pre-deployment assessments) to optimise the selection of sites for seeding in the future. While the role that herbivorous fish play in driving coral-seeding success requires further investigation, our results suggest that restoration research can be used both to guide the development of coral seeding techniques and to advance our fundamental understanding of reef ecology.

Chapter 3. Seeded *Acropora digitifera* corals survive best on wave-exposed reefs with grazing from small fishes

This chapter has been published as a peer-reviewed manuscript in the journal *Restoration Ecology*. The only text alterations are with respect to thesis formatting requirements but otherwise appear as in the published version.

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3.1 Abstract

Coral seeding is a restoration technique developed to replenish degraded reefs; however, grazing by herbivorous fish can impede coral survival post deployment. To investigate the impacts of hydrodynamics and fish grazing on seeded-coral survival, we deployed aquaria-reared *Acropora digitifera* spat on engineered-seeding devices across 10 sites spanning a wave-energy gradient at Moore Reef (Great Barrier Reef, Australia). Two devices were used to investigate the role of grazing: a fish-exclusion device and a featureless control. After one year, over 60% of devices had live corals. High-energy sites had 83-91% yield (i.e., device-level survival) and 3-times more survivors than low-energy sites. Exclusion devices significantly improved survival at moderate-to-low flow sites where excavating parrotfish were abundant. Survival was also influenced by the biological characteristics of the site, with more survivors at sites with Labrids (*Thallasoma*, *Gomphosus*), Acanthurids (*Acanthurus, Zebrasoma*), Blennids (*Cirripectes*), encrusting non-*Acropora* Scleractinian corals, coralline algae, and ascidians. Our study demonstrates that wave energy, fish activity, and benthic constituents all impact coral survival after seeding. Assessing potential sites for positive drivers of survival prior to deployment could improve the efficacy of coral seeding.

3.2 Introduction

The increasing frequency of marine heatwaves has led to substantial losses in global coral cover [188] and, despite best-practice reef management, the Great Barrier Reef (GBR) in Australia has suffered from five major bleaching events in the last eight years [13,189]. The current shift in reef composition and the observed decline of corals represents a window into our future, with more severe and catastrophic losses to populations and species predicted, even when full climate mitigation measures are employed [138,190]. Considering this, reef restoration has been proposed to accelerate adaptation and replenish corals on

degraded reefs [1,5,139]. However, the restoration of corals at a population scale is challenging, and the experimental testing and implementation of novel techniques, particularly with sexually-propagated corals, is in its infancy [2,191].

Coral seeding is a restoration technique currently being trialed at limited spatial scales [131,145,146] but has the potential to accelerate coral replenishment and promote adaptation as it is upscaled [1]. One way to seed corals is to captively breed them, rear larvae, settle larvae onto engineered devices (herein coral-seeding devices), and then deploy the devices, housing newly settled corals (i.e., spat), to the reef. Coral-seeding devices are evolving, with the latest designs incorporating modularity, multidimensionality, and features for improved retention and coral protection [192,193], as well as ensuring compatibility with automated production processes and robotics. To date, coral mortality on seeded devices can be high, but eliminating fish predation pressure is one way to improve survival [193].

The addition of fish-exclusion features (e.g., protrusions and microrefugia) on devices has shown clear benefits to coral survival. For example, microrefugia between 1 - 8 cm^3 on tiles increased survival of *Pocillopora damicornis* and *Porities* lobata juveniles [113]. Similarly, 2.5-cm grids on plates increased survival of *Acropora* spat [130], while vertical grooves (~4 mm) enhanced survival of *A. tenuis* spat [131]. Furthermore, fish-exclusion devices doubled the survival of *A. digitifera* spat over control devices on the offshore GBR [193]. Taken together, it is evident that coral spat can benefit from fish exclusion. However, fish grazing is often accidental, and grazing pressure can be strongly correlated to the biological and physical environment, causing site-specific coral mortality from grazing [193].

Reef hydrodynamics play a crucial role in shaping coral-fish interactions. Wind, waves, currents, and bottom friction (herein wave energy) determine the geomorphic structure of coral reefs as they grow and change over extended geological timeframes [194,195]. Moreover, the seasonal and diel variability in wave energy influence fine-scale water movement (< 2 m), temperature, dissolved nutrient content, and the delivery and resuspension of particulates on reefs (< 100 m) [196,197]. For instance, at high tide, wind-driven currents and waves can facilitate orbital motion in the water column, resuspending sediments. At low tide, water can become trapped on the reef flat, creating transient and stagnant pools of warm, nutrient-rich water. Over certain seasons, reefs with moderate-to-high wave energy experience turbulent waves, lasting 5-25 sec, that swiftly sweep water off the flat at low tide [198]. These turbulent flows differ from flows on lagoonal and sheltered reefs that take tens of minutes to move water [198]. As a result, corals and fish show fine-scale variation in their abundance and behaviour that is correlated with many of these hydrodynamic metrics.

Coral and herbivorous fish abundance often peak on the reef crest and decline on the slope [199–201]. For corals, rates of calcification, nutrient transfer, and heterotrophic feeding can increase with wave energy [202–204]. For

fish, adequate flow can enhance their swimming abilities and reduce predation risk [87]. But extreme wave energy can limit coral larval movement [205,206], increase the risk of overturning mature corals [207], and cause locomotive strain for some herbivorous fish [87]. As a result, the abundances of corals and fish plateau at specific wave-energy optima, and these optima are likely to result from complex interactions that are taxon-specific. Tracking the interactions between seeded corals and grazing fishes along a gradient of wave energy could identify wave-energy optima to improve coral-seeding efficacy.

To that end, we quantified the growth and survival of coral spat on devices, with and without protection from fish, that were seeded to sites across a predicted gradient of wave energy on Moore Reef (northern GBR). Our study aimed to address three knowledge gaps to guide coral-seeding efforts. First, we sought to identify wave-energy conditions that promote high survival of seeded *Acropora digitifera* spat. Second, we tested the effect of fish-exclusion features on devices designed to protect coral spat. Lastly, we aimed to identify the fish and benthic constituents that predict high coral survival post seeding.

3.3 Methods

3.3.1 Coral collection and rearing

Colonies of *Acropora digitifera* were collected (permit G21/45348.1, Reef Authority, Australia) from Moore Reef (Fig. 3.1a) prior to February 2022 coral spawning. Colonies were transported via boat to outdoor, flow-through, and temperature-controlled aquaria at the National Sea Simulator in the Australian Institute of Marine Science (AIMS, Townsville, Queensland) and maintained until spawning. The timing of spawning and the numbers of colonies that contributed to mass cultures are reported in Appendix Table B1. Gamete bundles were collected, separated, washed, and fertilised following Whitman et al. (2024). Embryos were then transferred to indoor larval rearing tanks where they remained until they reached settlement competency after 5-6 days.

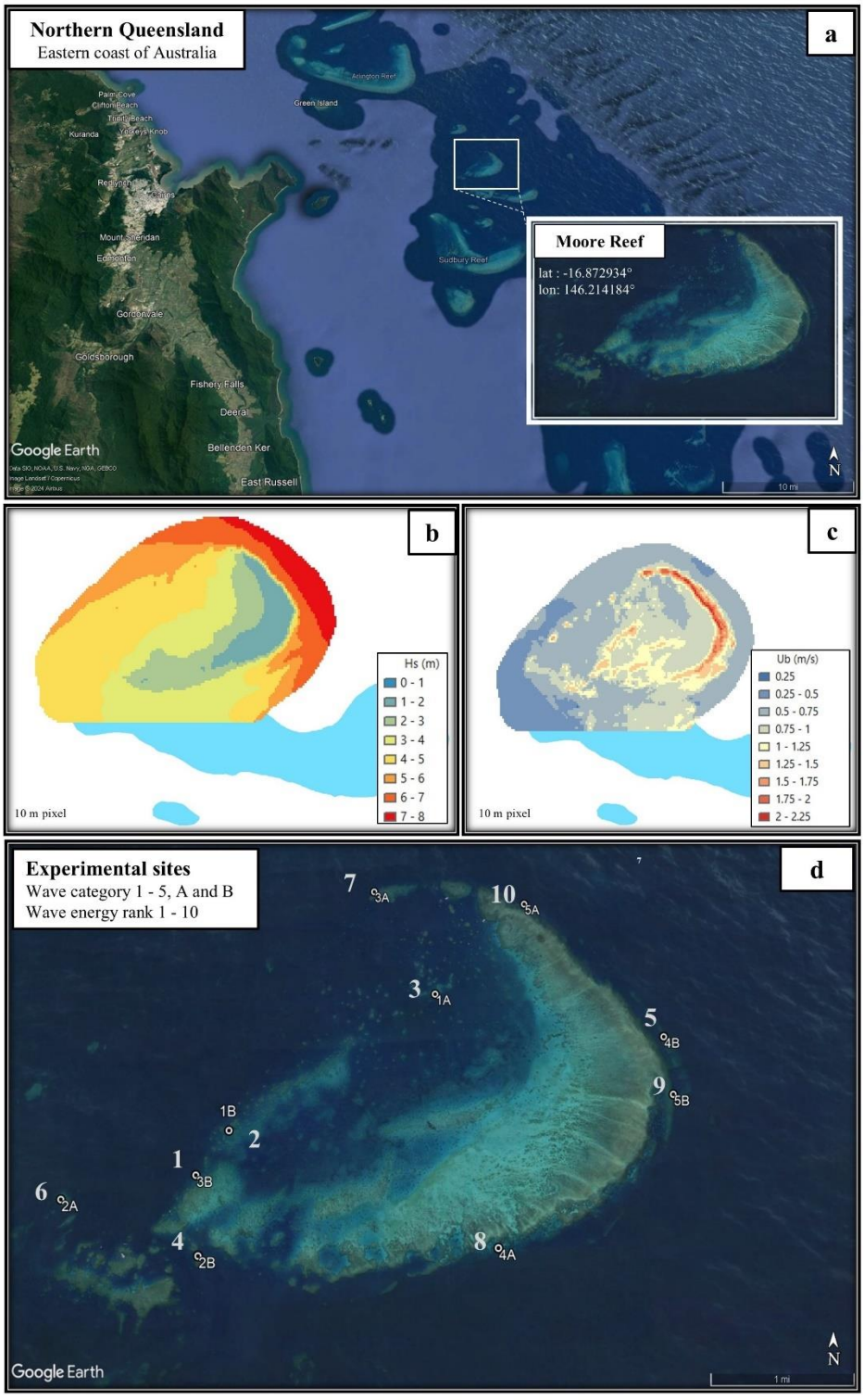


Figure 3.1 Experimental location and the site-selection process. [a] Geographic location of Moore Reef off the Queensland coast in Australia. [b] Significant wave height (Hs [m]) and [c] bottom stress (Ub [m s^{-1}]) modeled for Moore Reef. [d] 10 sites used in the coral-seeding experiment.

Conditioned concrete tabs (14 × 14 mm^2) were used as settlement substrates. Developed at AIMS under the Reef Restoration and Adaptation Program (RRAP), these tabs are cheap, small, and modular, designed to fit into coral-seeding devices (Fig. 3.2b-c). Tabs were created in sheets (1 sheet = 400 tabs; Fig. 3.2a) and conditioned in aquaria for one month to develop a biofilm known to induce larval settlement [51]. The sheets were placed in individual tanks for mass larval settlement, with larvae settling over 72 h at target densities of ~10-20 spat per tab.

The settled spat were maintained on sheets in aquaria with no light (similar to Ramsby et al. [2024] with low light conditions) [59] until seeding. At one-week pre-deployment (2-months post spawning), 1500 tabs with live spat were cut from the sheets and distributed (3-per device) to 500 devices (Fig. 3.2a-c). All corals were healthy and free from visual benthic competition at the time of deployment (Fig. 3.2d). See Appendix B1.1 for details regarding coral settlement and grow out.

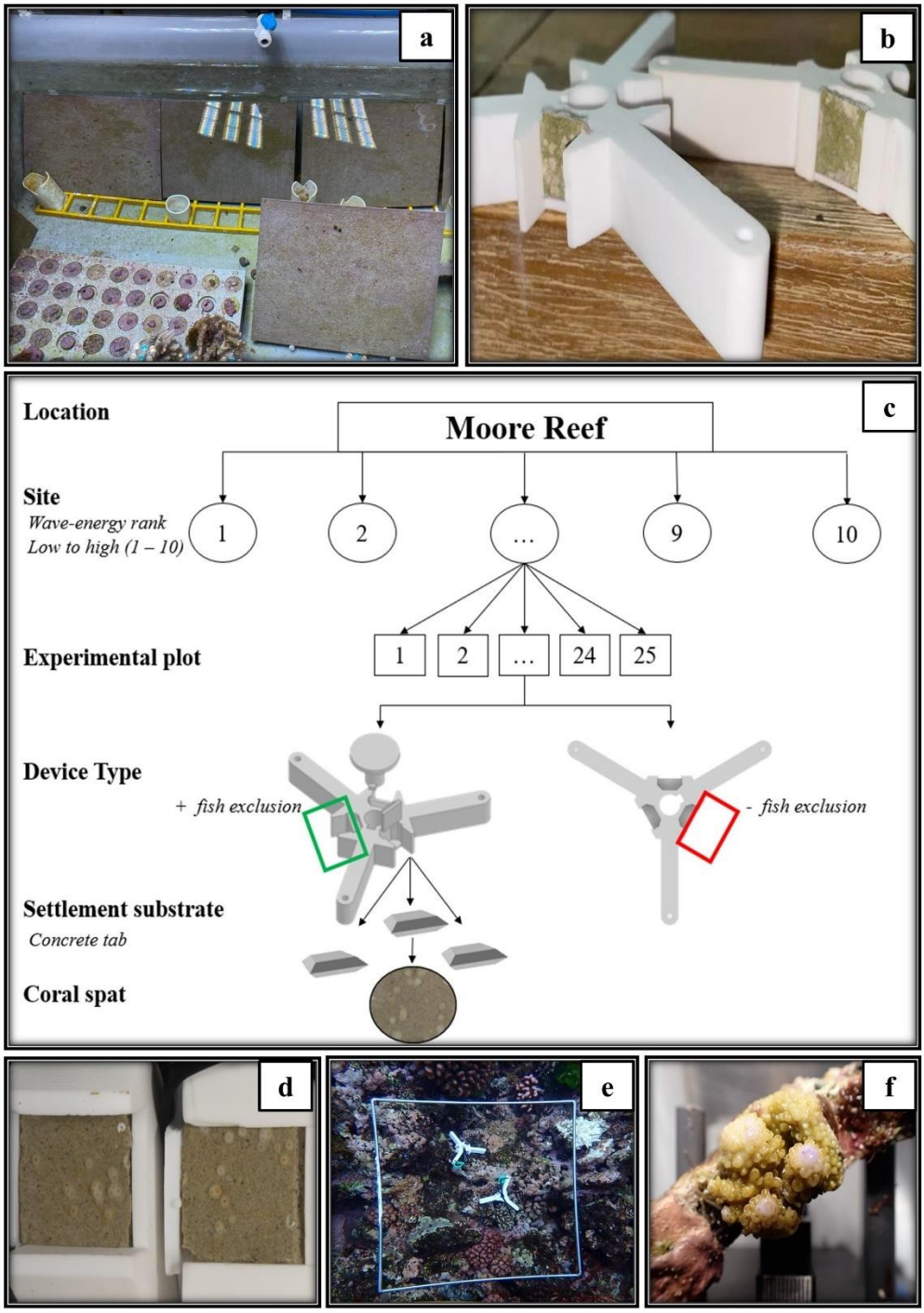


Figure 3.2 Methods used for the coral-seeding experiment. [a] Tab sheets conditioning in aquaria. [b] Coral-seeding device types: fish exclusion (left) and featureless control (right). [c] Experimental design. [d] Tabs with coral spat pre deployment. [e] Plot with devices attached to the reef. [f] 16-month-old coral post deployment.

3.3.2 Experimental design

Corals were seeded to 10 sites on Moore Reef (Fig. 3.1d) in May 2022. The field deployment followed a hierarchical design (Fig. 3.2c). Devices were deployed to the reef crest (3-5 m depth, high tide) and fixed in experimental plots with a cable tie in an upright, horizontal position (Fig. 3.2e). Devices and their fixings were removed after 16 months.

Device types

Two device types (Fig. 3.2b-c), made of 95% alumina ceramic (Shanghai Gongtao Ceramics CO., Ltd., People's Republic of China), were used to test the effect of grazing. The control was a featureless device open to grazing while the device of interest included side protrusions (1-cm length) around each tab to limit grazing from fishes with a gape > 1 cm. Both designs maintained tabs in a vertical position [192,193].

Site selection

High-resolution bathymetry maps (generated from Light Detection and Ranging and Sentinel 2 satellite products; Fig. 3.1b-c) were used to create a benthic-habitat prediction model for Moore Reef. A remote-sensing method, designed to identify habitat characteristics suitable for coral recruitment, was used following Radford et al. (2024) [208]. Bottom stress (Ub [m s^{-1}] [209,210]; Fig. 3.1c) was overlaid on a constrained (2-8m depth) habitat map and a generalized random tessellation stratified method [211] was used to identify 10 sites (and 20 reserves) across 5 classes of equally and spatially balanced bottom-stress values. The sites were assessed by divers to confirm the presence of conspecifics or morphotaxa before deployment. Reserve sites were used when the initial site failed to meet selection criteria (e.g., depth, hardbottom, presence of conspecifics/morphotaxa). Initially, two sites, A and B, were selected in each wave class, 1 to 5 (Fig. 3.1d). Wave energy was validated using current meters (Marotte HS, Marine GeoPhysics laboratory, James Cook University, Australia); sites were ranked from low to high flow (1-10), based on in-situ measurements (Fig. 3.1d) and are hereafter referred to as sites 1-10.

3.3.3 Data collection

Data were collected at six timepoints and included quantitative and qualitative assessments to determine the influence of biological (fish abundance and grazing, benthic composition) and environmental (wave energy) drivers on coral growth and survival. Assessments were categorised by spatial scale and are detailed below. See Appendix Table B2 and section B1.2 for detailed protocols.

Tab-level assessments (cm)

Coral survival (alive or dead) on tabs (i.e., tab yield) was assessed by divers *in situ*. Pre- and post-deployment images (Olympus TG6; Fig. 3.2f) were used to assess coral survival and/or size *ex situ*.

Maximum linear and maximum perpendicular lengths of the largest surviving coral on each tab were measured. ImageJ was used for the pre-deployment measurements and calipers were used post deployment. Coral growth was calculated as the change in surface area ($3\pi r^2$) over time, expressed in millimeters per year, using the average of the two lengths for the radius.

Plot-level assessments (m)

Benthic composition was assessed at deployment. Quadrats (0.25 m^2) were placed centrally around device pairs and imaged. The percent cover of benthic constituents (Table B3) was estimated for each plot using ReefCloud (https://reefcloud.ai/). Points (n=15) were randomly overlaid on images (n=25 $site^{-1}$) and labeled by an observer.

Site-level assessments (10s-of-m)

Divers conducted stationary-point-count surveys (39.25 m^2, 5-min intervals, 3 replicates $site^{-1}$ survey $time^{-1}$) to count fish of interest: Acanthuridae (surgeonfish), Balistidae (triggerfish), Chaetodontidae (butterflyfish), Labridae (Odacinae; wrasse), Labridae (Scarinae; parrotfish), Pomacentridae (damselfish), and Siganidae (rabbitfish). The time, depth, tide, sea state, visibility, and reef complexity were also recorded.

Fish grazing was quantified from video surveillance (GoPro HERO 9). Cameras were deployed to two haphazardly selected plots per site capturing 1-2 h of footage per plot. Cameras were deployed at the sites on the same day, within 1 h of each other. A quadrat (0.25 m^2) marked the plot at the start of the recording and then was removed. The hours of footage were standardised (i.e., same duration measured) and assessed for feeding activity (i.e., total bites divided by the duration, bites min^{-1}; Table B4). Fish feeding in the plots were imaged, time stampe, and identified to species by a single observer.

A Marotte current meter was deployed at each site for up to 16 months. Due to extreme weather, several meters were lost or damaged, resulting in 9 sites with data (Table B2). Current data were obtained in 1-min intervals and expressed as mean waterflow (m s^{-1}) over time.

3.3.4 Statistical analyses

Coral survival

To investigate the effects of device type and site on coral survival over time, a Bayesian hierarchical logistic mixed-effects regression model ('brms', R software [212]) with a Bernoulli distribution (logit-link function) was used. A random effect of device nested within plot nested within site was included for repeated observations. Normal priors (0, 1.7) were assigned to the intercept and regression coefficients. Student-t priors (0, 3, 1.7) were used for random effects. The model was fit using Hamiltonian Monte Carlo (HMC)

sampling (Table B5) and selected by comparing Leave-One-Out Information Criterion (LOOIC). Diagnostic tests (posterior predictive checks and hypothesis testing) were conducted to assess model fit and ensure validity. The model predictions and credible intervals were visualised using 'ggplot2' [174].

Coral growth

The effect of site, device type, and their interaction, on coral growth was modelled as above, using a Gaussian distribution (identity-link function). A normal prior (0, 10) for the intercept, normal priors (0, 2.5) for the slopes of site and device-type effects, and a student-t prior (3, 0, 1) for the site-plot-device random effect were used. HMC sampling (Table B6), diagnostic checks, and visualisations were performed as above.

Fish counts and feeding

Principal component analyses (PCAs, 'factoextra' [213]) and redundancy analyses (RDAs, 'vegan' [175]) with backwards-stepwise models were used to deduce significant predictors of survival and growth from the fish count and bite data. Survival and growth were modelled against the interactive effects of device type and fish count or bites. Separate models were run for survival and growth, and for the species- and family-level classification for each dataset (counts and bites). Multiplicative models were fit (Table B8-B10) and checked for accuracy as above. Site-related variation in fish counts and bites were investigated using a zero-inflated Poisson (identity-link function) and Gamma (log-link function) distribution model, respectively. Family-level classifications and sites were used as predictors with time-site-replicate as the random effect. Normal priors were used for the intercept (1.7, 1.25 for count data and 0, 5 for bite data) and for the regression coefficients (0, 5). The bite model included an exponential prior (rate parameter= 1) for the standard deviation of the random effects. Models were fit (Table B7), checked for accuracy, and visualisations were performed as above.

Benthic constituents

PCAs, RDAs, and backwards-stepwise models were used to reveal significant predictors in the benthic dataset. Brms models were used to predict survival and growth by device type, the benthic variables, and their interaction. Multiplicative models, including the interaction with device type and the random effect of device-plot-site were fit (Table B11), checked for accuracy, and figures created as above.

3.4 Results

After 16 months, > 50% of devices and > 25% of tabs had at least one live *Acropora digitifera* coral (Fig. 3.3a). The 10 sites captured a wave energy gradient spanning an average flow of 0.06 m s^{-1} to 0.28 m s^{-1} (Fig. B1). The spread of sites across the gradient was fairly even, with slightly more sites with lower current

speeds. Sites characterised by high wave energy on the reef front and flank had up to 90% of devices and > 50% of tabs with live corals; this was 3-times higher than sheltered sites on the back reef.

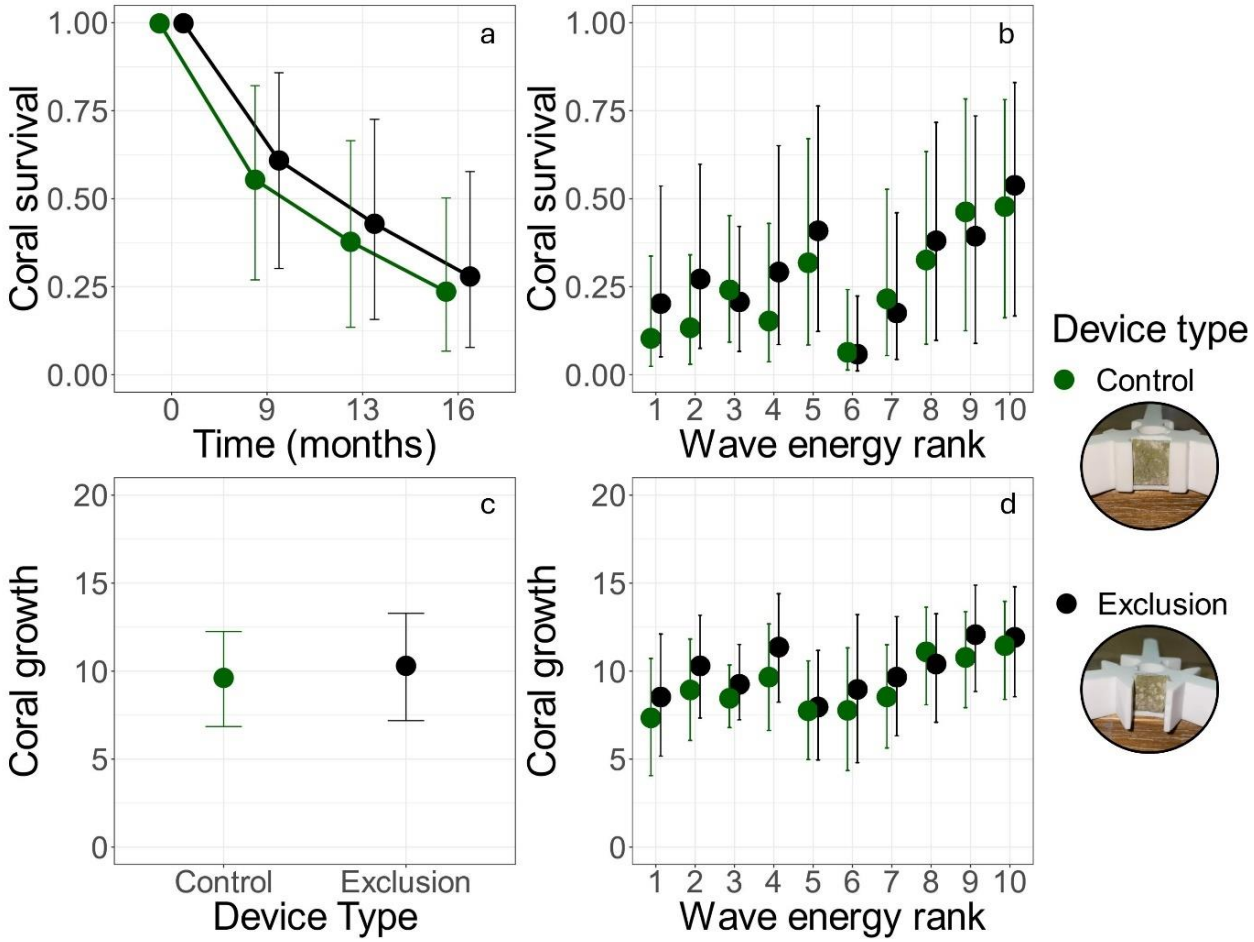


Figure 3.3 Tab-level coral survival after 16 months. [a] Survival by device type, through time. [b] Final survival by wave-energy ranked sites. [c] Coral growth (mm y^{-1}) by device type and by [d] wave-energy ranked sites. Mean estimates with 95% credible intervals are displayed. The data are jittered [a-b, d] with respect to the x-axis for ease of visualisation.

3.4.1 Coral survival

Tab-level coral survival (hereafter survival) declined through time (Fig. 3.3a). Nearly 50% of corals suffered mortality within 9 months, and the odds of survival declined further after 12 and 16 months (Table B5). Survival increased with increasing wave energy (Fig. 3.3b; Fig. B1). The odds of survival were twice as high at the highest-flow site (10) than the lowest-flow site (1), and up to 18-times lower at the moderate-flow site (6; Table B5). More corals survived on fish-exclusion devices than on control devices and this was consistent through time (Fig. 3.3a), although the best-performing device varied by site (Fig. 3.3b). Fish-exclusion devices outperformed controls at 60% of sites (Fig. 3.3b) but were only 1.25-times better

than controls, on average (Table B5). The fish-exclusion device improved survival most at low wave-energy sites (Fig. 3.3b; Table B5).

3.4.2 Coral growth

The effect of fish exclusion on *Acropora digitifera* growth was generally positive (Fig. 3c). The exclusion device resulted in faster growth for corals at 70% of sites, while the control facilitated faster or similar growth at other sites (Fig. 3.3d; Table B6). Coral growth followed a similar trend to survival, irrespective of the device treatment (Fig. 3.3d). Sites 9 and 10 had the highest growth rate (> 12 mm y^{-1}), while corals at sites 1, 5 and 6 were slow growing (< 8 mm y^{-1}; Fig. 3.3d; Table B6). The greatest benefit of fish exclusion on growth was at site 4, with low-to-moderate flow, where growth was twice as fast in exclusion than control devices (Table B6).

3.4.3 Fish activity

Fish counts

5272 fish from 5 taxa were observed. Wrasse (*Thallasoma hardwicke*, *T. nigrofasciatum* and *Gomphosus varius*) were the most abundant (> 1850 fish) and triggerfish (*Sufflamen chrysopterum*) were the least abundant (< 30 fish). *Chlorurus microrhinos* and *C. spirulus* were common parrotfish, while *Ctenochaetus striatus* and *Acanthurus nigrofuscus* were common surgeonfish. *Chaetodon trifascialis* was the most common butterflyfish. Moderate-flow sites (5-6) had the most fish, while a low-flow site (3) had the least (Fig. 3.4a). Site 6 had the highest abundance of parrotfish and triggerfishes, and this was 3.5 to 10-times more fish than site 10 (Fig. 3.4b; Table B7). Site 7 (moderate flow) had double the number of butterflyfishes over other sites (Fig. 3.4b).

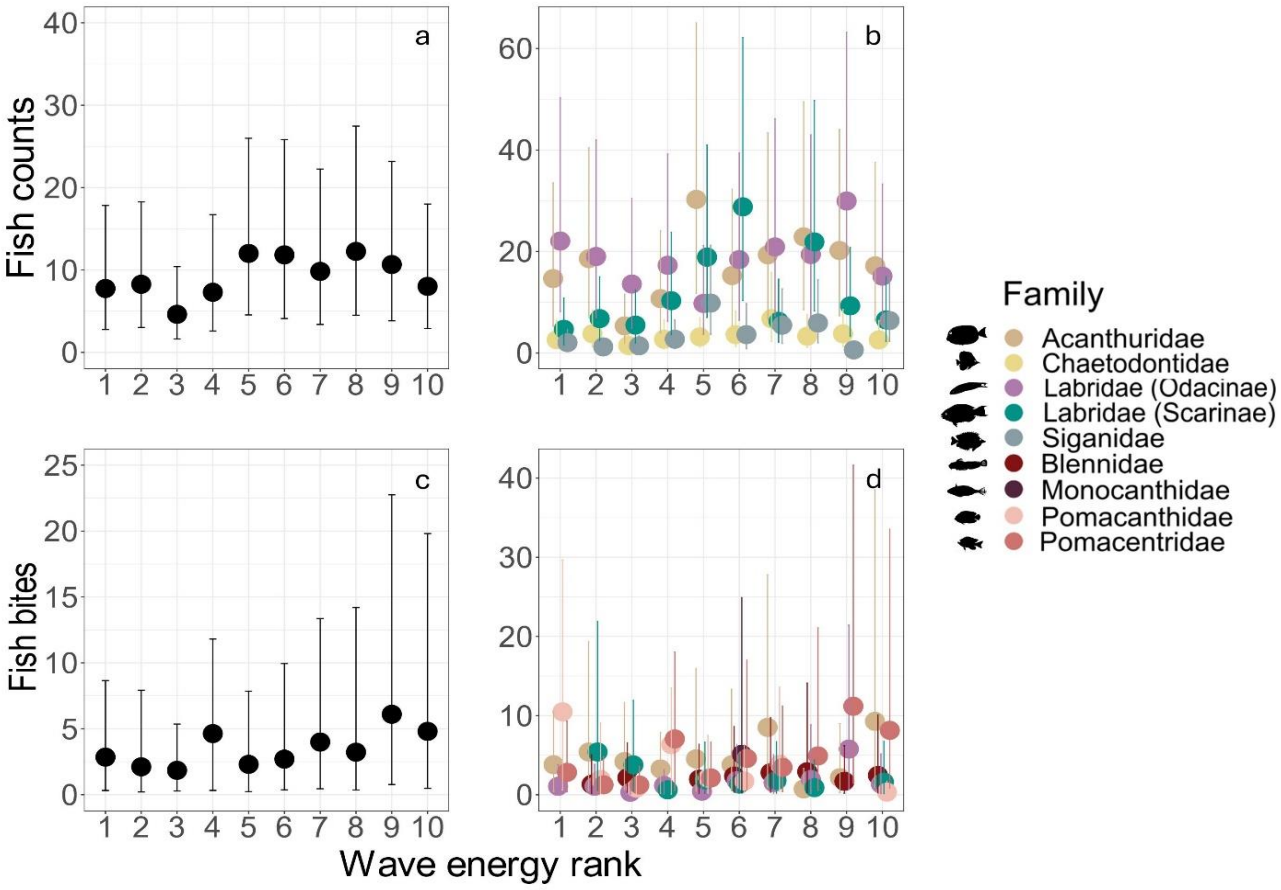


Figure 3.4 Fish activity during the deployment. [a] Fish counts (in 39.25 m^2) by wave-energy ranked sites. [b] Fish counts by site and family. [c] Fish bites (min^{-1}) by wave-energy ranked sites. [d] Fish counts by site and family. Mean estimates with 95% credible intervals are displayed. The data are jittered [b, d] with respect to the x-axis for ease of visualisation.

Coral survival increased with the abundance of *Thallasoma amblycephalum, Gomphosus varius*, and *Acanthurus lineatus,* but the result was not homogenous across device types (Fig. 3.5a-c). *T. amblycephalum* and *G. varius* increased survival 2.6-times more for corals in controls than fish-exclusion devices (Fig. 3.5a-b; Table B8). *A. lineatus* increased survival 1.6-times more in exclusion devices than controls (Fig. 3.5c; Table B8). Survival decreased as *S. chrysopterum* and *C. microrhinos* abundance increased (Fig. 3.5d-e)*;* these fishes were 3 to 4-times more detrimental to survival than *T. amblycephalum* (Table B8).

As *T. amblycephalum* and *G. varius* abundance increased, coral growth declined (Fig. 3.4f-h; Table B10). Coral growth increased with increasing abundance of *A. lineatus* (Fig. 3.5i) and decreasing abundance of *C. trifascialis* and *C. microrhinos* (Fig. 3.5j-k; Table B10).

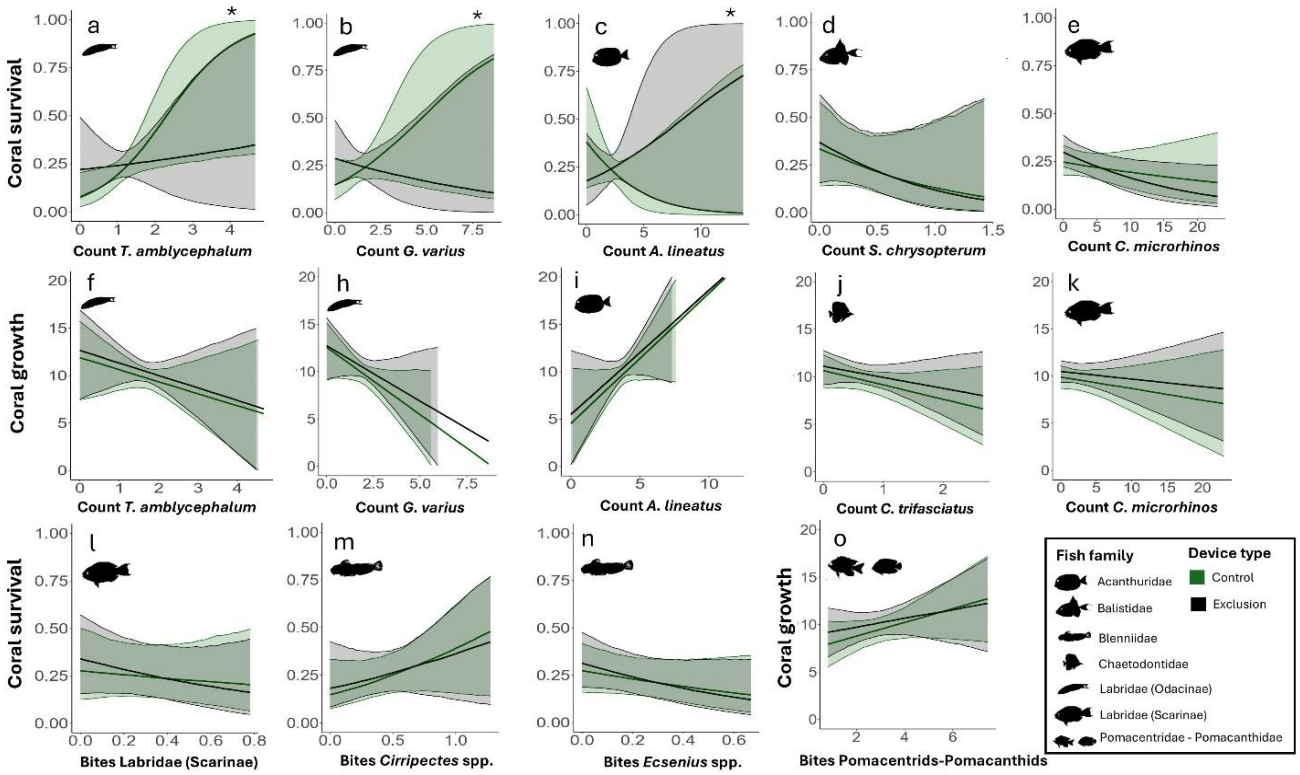


Figure 3.5 Tab-level coral survival and growth by fish activity and device type. [a - e] Survival by fish counts (in 39.25 m^2). [f - k] Growth (mm y^{-1}) by fish counts. [l - n] Survival by fish bites (min^{-1}). [o] Growth by fish bites. The " * " denotes a difference in the response by device type (see Appendix Table B9-B10). Mean estimates with 95% credible intervals are displayed.

Fish feeding

20818 bites from 72 species were recorded. Damselfish (*Pomacentrus* spp., 7911 bites,) and surgeonfish (*Ctenochaetus striatus* and *Acanthurus nigrofuscus*, 7221 bites*)* fed frequently. Parrotfish, wrasse, and blennies were also feeding (Fig. 3.4d), with 910 bites taken by *Chlorurus spirulus*, *C. microrhinos*, and *Scarus* spp., 1286 bites from *Thallasoma hardwicke*, *Gomphosus varius,* and *Halichoeres* spp., and 2033 bites from *Cirripectes* and *Ecsenius* spp. Threadfin breams (Nemipteridae) and hawkfishes (Cirrhitidae) were rarely feeding, with < 5 bites recorded. Site 9 (high flow) had the most feeding activity, while site 3 (low flow) had the least (Fig. 3.4c). *C. spirulus* and *Ecsenius* spp. fed most at low-to-moderate flow sites, with 35- and 6-times more bites than high-flow sites, respectively (Table B7).

Bites from parrotfish generally reduced survival (Fig. 3.5l), but this response was weak and species specific (Table B9). The effects of feeding by blennies on survival were also heterogenous. Survival was 11-times higher in plots with feeding from *Cirripectes* spp., but low in plots with feeding from *Ecsenius* spp. (Fig. 3.5m-n; Table B9). Other notable, yet weak relationships, include increasing survival with increased feeding from *Halichoeres* wrasse and the surgeonfish *Zebrasoma scopas* (for control devices only), and with

decreased feeding from the angelfish *Centropyge vrolikii*. Parrotfish bites were more detrimental to survival than bites from wrasse (Table B9).

Coral growth increased with feeding by damselfishes and angelfishes (Fig. 3.5o) and the *Cirripectes* blennid but decreased with feeding from the *Ecsenius* blennid (Table B10).

3.4.4 Benthic community

54 benthic categories from 6 groups were identified in device plots. CCA were the most abundant, while sponges and hard corals *Goniopora* and *Mycedium* were rare. On average, plots contained > 75% algae, > 15% hard coral, and < 10 % other organisms.

Corals were more likely to survive with increasing cover of encrusting non-*Acropora* corals (> 20% threshold), sessile invertebrates (> 10%), and CCA (> 75%; Fig. 3.6a-c; Table B11). *Acropora* coral and carbonate rubble (including mixed-algal biofilms) were negative to survival (Fig. 3.6d-e; Table B11). Encrusting *Porites* and *Platygyra* most significantly increased survival (Fig. 3.6f-g), while ascidians were the most significant non-coral invertebrate (Fig. 3.6h; Table B11). Coral responses to the benthic community were generally similar between device treatments, but the error associated with the exclusion device was higher (Fig. 3.6).

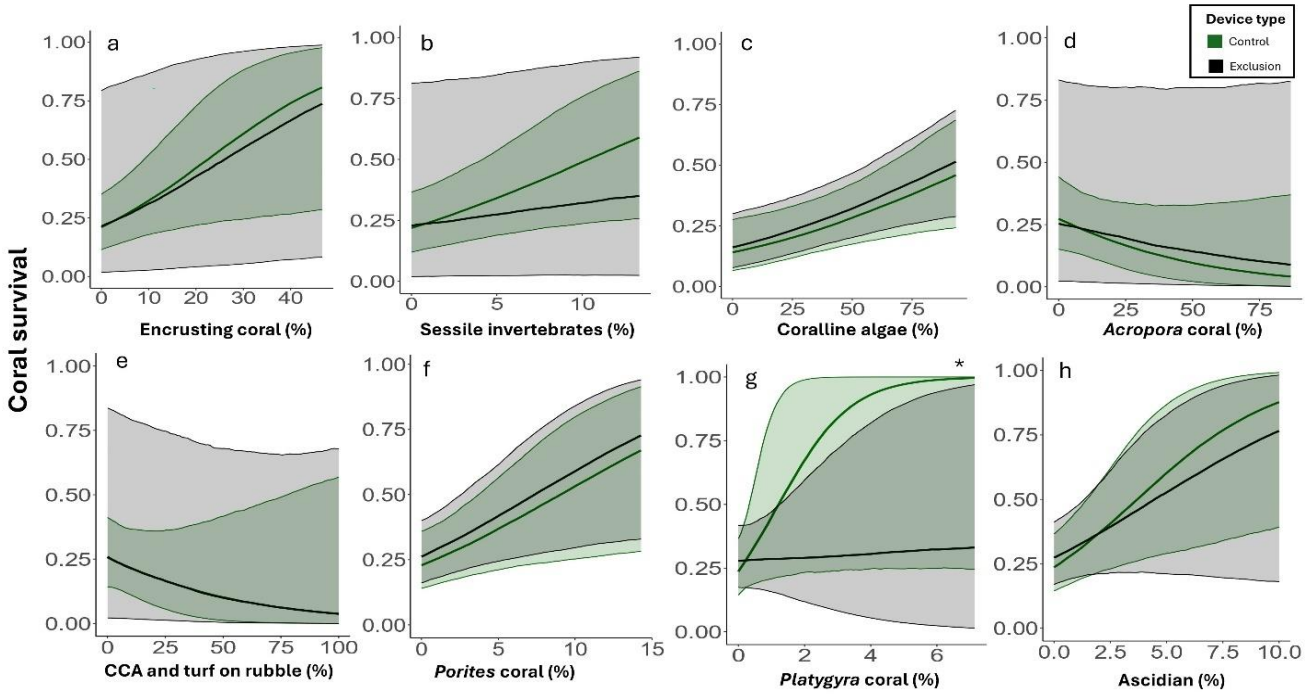


Figure 3.6 [a - h] Coral survival by benthic constituents (% cover in experimental plots) and device type. A difference in the response by device type is denoted by: " * " (see Appendix Table B11). Mean estimates with 95% credible intervals are displayed.

3.5 Discussion

We investigated the effects of wave energy, fish grazing, and their interaction on coral-seeding efficacy and identified four criteria to achieve high survival of *Acropora digitifera* spat on the northern GBR. (1) Select seeding locations on the reef flank or front with high wave energy (annual median flow > 0.28 m s^{-1}). (2) Use the abundance of small fish (Labrids, Acanthurids, Blennids, and Balistids) to guide the selection of sites. (3) Use devices with fish-exclusion features, particularly in environments with low-to-moderate wave energy. (4) Consider the abundance of Scleractinian corals, crustose algae, and ascidians, when placing devices. These findings provide clear guidelines to improve the value of coral seeding as a tool for restoration.

Our study demonstrates the direct-positive role of wave energy in supporting juvenile *A. digitifera* growth and survival; coral response was site specific but peaked at wave-exposed sites on the reef flank and front. Similar studies have found that *Montipora* juveniles [214] and adult *Montipora* [214], *Acropora* [65], *Stylophora* [64], and *Galaxea* [215] corals can grow 2-times faster in wave-exposed environments, and there are several mechanisms by which flow can increase survival. For example, wave-exposed reefs have high turbulence and more water mixing that introduce zooplankton [216] and induce phytoplankton settlement [217]; zooplankton and phytoplankton can be a potential food source for heterotrophic corals. Similarly, increased pigment concentrations, increased host tissue biomass, and up to 10-fold higher symbiont densities have been identified for *Porites* and *Diploastrea* corals in response to high wave energy [218]; these increases can improve photosynthetic output and nutrition, resulting in faster growth. Overall, high wave energy equates to high nutrient acquisition, and this facilitates growth and survival. Seeding spat to wave-exposed sites could reduce the time required to each coral size-escape thresholds [35], avoiding mortality from fish predation and increasing recruitment success.

Fish species associated with higher coral survival were more prevalent at wave-exposed reefs, while fishes that correlated with low survival were more common at sheltered sites. These results are in line with previous literature but importantly, we provide foundational evidence for the underlying role that wave energy has on the coral-fish relationship. For example, *Thallasoma* wrasse can be 15-times more abundant in wave-swept habitats over those that are sheltered [201], and sites abundant in small wrasse had more coral survivors in our study. Similarly, the parrotfish *Cholorurus microhinos* is highly associated with low-wave exposure [200]; coral survival declined with increasing abundance of this species and other excavating parrotfish. Moreover, small-bodied blennies (*Ecsenius* spp.*)* dominate on reefs where larger-bodied blennies (*Cirripectes* spp.) are absent [219]; feeding from *Cirripectes* blennies were positively related to survival in our study and they were most prevalent on wave-exposed reefs. We suspect that, at fine-spatial

scales, small-herbivorous fishes are directly feeding on turfing and filamentous algae that grow near seeded corals [220], while carnivorous fishes could indirectly remove algae and deposited sediments as they detach prey. Indeed, *Zebrasoma* surgeonfish generate thrust while feeding, using a lateral head-flick and fin movement [221]. Likewise, *Acanthurus* spp. engulf and use suction to draw algae into their mouth [222]. Together, these movements could reduce benthic competition and move sediments, helping to promote coral survival. But the influence of fish on these fine-scale variables is multifaceted and not necessarily consistent between seeding device types.

More corals survived when using fish-exclusion devices in our study, and these devices were most beneficial at sheltered sites with low-to-moderate wave energy. In a previous study, survival of 4-month-old *A. digitifera* spat doubled when fish-exclusion devices were used at sheltered sites (central, offshore, GBR) [193]. Taken together, these results suggest there are clear benefits to using protective devices in coral-seeding trials on the offshore GBR. However, the protection provided by fish-exclusion devices likely extends beyond predation and includes the moderation of other coral stressors. For example, coral survival was lowest at a moderate-flow, rubble-dominated site, with a high abundance of excavating parrotfish. Under periods of moderate-to-high flow, reef rubble can become dislodged, move, and disturb sediments; these mechanisms can increase coral abrasion, scouring, and smothering [223], hindering spat survival [224]. Furthermore, excavating parrotfish can erode > 25% of reef carbonate [97] and this bioerosion is highest in habitats dominated by rubble, *Acropora* spp., and *Pocillopora* spp. [225,226]. The reworking of coral rubble and sediments by parrotfish could produce a higher volume of small sediments that are easily mobilised by wave energy. Understanding how recruiting corals respond to increased bio-eroded sediments would provide new insights into the coral-fish relationship.

The abundance of encrusting Scleractinian corals were positively correlated with coral survival in our study but branching, corymbose, and plating corals were negatively correlated. Similarly, Page et al. (2024) found that survival of seeded *M. aequituberculata* spat declined in response to increasing branching-*Acropora* abundance. There are three plausible explanations for these findings. Firstly, corals with complex morphologies are vulnerable to high wave energy [207], which can increase rubble and sediments and negatively affect spat survival. Next, coarse obstructions like plating corals and large boulders, might alter water movement and retain sediments within their Momentum Boundary Layer (MBL) [227], hindering spat survival. In support of this, corals with rough-textured branches (e.g., *Montipora*) have been shown to produce a thicker MBL than columnar and smooth corals (e.g., *Porites*) [227]. Finally, overtopping and shading from complex corals can impact recruit growth and impede survival [228,229]. While these responses are likely species and context specific, there is growing evidence to avoid certain benthic communities when seeding coral spat to reefs.

We also found that some non-coral sessile organisms increased spat survival. Previously, two coral-seeding experiments on the GBR found that sites with more sponges, epilithic-algal communities, and cyanobacteria improved seeded *Acropora* survival [145,193]. Since sponges and ascidians can be proxies for water flow [230], high spat survival in their presence could implicate wave energy as the underlying driver. Furthermore, sponges, ascidians, and cyanobacteria, are also common on rubble reefs [230,231], and although they could be fostering survival in this habitat, their effect is weakened due to negative effects from rubble and sediment abrasion. Equally, competitive macroalgae (*Lobophora* spp.) and bryozoans, commonly found on rubble reefs [228], were observed at our rubble-dominated site. We propose low-lying brown algae and bryozoans on tabs could be early indicators of *Acropora* coral mortality since their early-successional biofilms can impede *A. kenti* survival [232] and restrict growth in shaded habitats [226]. Antifoulant coatings [233] on seeding devices and tabs could be explored to buy time for corals to reach size-escape thresholds before competitive algae begin colonisation. Site preparations, such as macroalgae removal [234] and rubble stabilisation [235], may also be required on highly degraded reefs.

3.6 Conclusion

In this study, we initially reduced grazing pressure by raising corals in no-light conditions therefore removing crustose algae, a critical food source for herbivorous fishes [193]. We then directly manipulated the odds of predation on seeded corals by deploying devices across a gradient of wave energy. While the relationship between recruiting corals, grazers, and their environment is often complex, this experimental research advances our fundamental understanding of coral reef ecology. Spatial-habitat models can be used in the site selection process with environmental and physical variables, but diver surveys will be required to ground truth in-situ biological conditions. Restoration practitioners who plan to use coral seeding as a tool to repopulate reefs should consider applying the four criteria described in our study and holistically monitor the survival outcome on an annual basis to gauge the impact of the intervention. To combat the detrimental effects of climate change, we need to prioritise research into creating and deploying thermally tolerant corals and curb our carbon emissions on a global scale.

Chapter 4. Effect of marine reserve status on coral seeding in the inshore Great Barrier Reef

4.1 Abstract

Coral seeding is an active restoration method being explored to increase resilience, promote adaptation, and repopulate reefs, amidst rapid climate change. Although several advances have been made to coral seeding methods, drivers of post-seeding survival are complex, and the criteria for device designs and receiving sites require refining to improve coral seeding efficacy. To investigate the dual impact of marine reserves and fish predation on coral seeding success, we tracked the survival of ex-situ reared *Acropora millepora* spat on engineered devices at six sites in the Keppel Islands, southern inshore Great Barrier Reef. Experimental sites were selected from marine park management zones open to fishing and no-take marine reserves (NTMRs), and two devices with fish-exclusion features were tested against a control device. After 11 months, > 60 % of devices had live corals and up to 30% of corals on settlement tabs survived. Survival was site specific with little variation across marine reserve zones. Reefs with abundant small fish (damselfish and wrasse) were more conducive to survival than those with high macroalgae and sediments. Seeding devices with fish-exclusion features outperformed the control. Our study demonstrates that while marine reserve status is not a good predictor of coral seeding success, ecological characteristics can be used to guide site selection to maximise benefit.

4.2 Introduction

Marine reserve networks are globally implemented as a strategy for marine conservation, incorporating no-take marine reserves (NTMRs), partially protected areas (PPAs), and less- or un-restricted systems open to fishing [120,125,157,236]. The networks encompass inshore and offshore habitats, including coral reefs, mangroves and seagrass beds. The primary objectives of these reserves are to: (i) promote sustainable fishing practices, (ii) manage target fish stocks, and (iii) protect and build ecosystem resilience [119–121]. However, as climate change accelerates, marine ecosystems are suffering from more frequent and severe disturbances leading to substantial losses in biodiversity despite best-practice management and the highest level of reserve protection [30,189,237–241]. Coral reef ecosystems in particular face imminent threats from ocean warming. While highly connected NTMRs have the potential to support coral reefs into the future [138,240,242], our current understanding of their role in coral community succession and natural recovery processes is limited.

The effectiveness of NTMRs in maintaining fish stocks is well documented [236,243,244]. These reserves positively influence target species, such as large predatory fish (e.g., groupers and snappers), with direct increases in biomass, density, size, and species richness [244–247]. This positive effect of NTMRs extends to non-target fish groups (e.g., mesopredators and herbivores), with spill-over effects that benefit neighbouring habitats [122–125]. In parallel with fisheries management research, numerous studies have attempted to disentangle the cascading effects of NTMRs in promoting coral persistence through space and time [240,248–253]. By protecting reefs from physical human impacts like anchor damage, or the overharvesting of large herbivores, NTMRs can stabilise coral cover and mitigate coral loss [239]. However, their effectiveness is strongly linked to the duration of protection, and even NTMRs with more than 20 years of protection can remain vulnerable to significant declines caused by natural and anthropogenic disturbances [253]. Furthermore, beneficial regime shifts are likely to occur primarily in NTMRs where destructive fishing practices (e.g., dynamite and cyanide fishing) were previously used or where a broad range of fish species with diverse ecosystem functions were historically and heavily targeted [119]. In contrast, where less invasive fishing methods (e.g., line and spear fishing) have been used, the selective removal of a narrower range of predatory fishes may limit the ecological benefits of NTMRs [119].

The primary metric for assessing coral health in marine reserves is percent cover, but this approach overlooks critical stages of early coral ontogeny (i.e., from settlement to recruitment) when corals are less visible during surveys. Furthermore, we know that survival from settlement to recruitment into the population is a major bottleneck to reef recovery, underscoring the need for targeted interventions [2,191]. Coral seeding has emerged as a promising strategy to accelerate recruitment and also to promote adaptation and increase resilience amid rapid climate change [1,131,145,146,192,193,254]. The effectiveness of this approach can be assessed by tracking the growth and survival of sexually produced coral spat deployed on engineered devices. Seeding experiments can also offer valuable ecological insights, helping to disentangle the complex relationships between coral spat and herbivorous reef fish [193]. These studies are particularly relevant in marine reserves, where conservation efforts to boost fish abundance may be changing these interactions.

Herbivory is considered a key process on coral reefs [255,256], as herbivores regulate macroalgae, mediating competition between algae and other space-holding benthic organisms [43]. While the dynamics of this balance varies across spatial and temporal scales [257,258], herbivory broadly maintains the competitive dominance of reef-building organisms like Scleractinian corals and crustose algae, in turn promoting coral-dominated states in reef ecosystems [86,259]. Herbivorous reef fish play a key role in this process, with many species grazing on algal turfs and macroalgae, directly removing algal biomass from reef substrata [260]. On the Great Barrier Reef (GBR), herbivorous fishes are estimated to remove more than 50% of the total algal

biomass [88] and indeed, the removal of algae is often a necessary condition for the successful settlement of coral propagules [69]. However, the broad guild of herbivorous reef fish comprises multiple functional groups with distinct feeding modes, each exerting different influences on benthic communities [48].

While many herbivorous reef fish graze on macroalgae and promote coral dominance, some inadvertently hinder coral recovery by indirectly removing coral spat as a result of their feeding behavior [35,90,98,109,113]. Notably, territorial damselfishes (Pomacentridae) guard and "farm" patches of turf algae, simultaneously cropping turf algal lawns and promoting algal growth through the removal of sessile organisms, including coral, that settle amongst the turf [95]. Similarly, within the parrotfishes (Labridae, Scarinae), scraping and excavating are prominent feeding modes whereby fishes mechanically remove hard substrate to target protein-rich epilithic, endolithic, and epiphytic microscopic phototrophs (i.e., cyanobacteria) [104,105]. In extreme cases, when corals are seeded to reefs without protection, over 90% of coral spat can suffer indirect predation from scraping parrotfish within 48 h [193]. Therefore, the impacts of herbivory on coral survivorship and competitive dominance varies depending on the abundance, biomass and functional-group composition of reef fish assemblages.

Managing herbivore populations using NTMRs is frequently considered an important strategy for resilience-based coral reef conservation [261,262]. However, the role of herbivore protection in maintaining coral-dominated states remains debated [263–265]. While NTMRs can protect herbivore abundance and diversity – supporting coral growth and dominance through enhanced direct grazing on algae – there might be tradeoffs. Recently disturbed reefs in NTMRs that still support a high biomass of fishes could be valuable locations for coral seeding, but seeded spat may require protection from intensified indirect predation [90,109,155,193], and there is the potential for reduced coral cover due to increased grazing pressure [72]. Although NTMRs and herbivore management are no panacea for global coral reef resilience [266], understanding the complex interactions between herbivorous fish, algae, and coral spat within NTMRs is a high priority research area for coral conservation and restoration. In particular, inshore reefs warrant investigation given their susceptibility to coral bleaching, overfishing, declining water quality, and phase shifts, yet they are also in close proximity to coral rearing facilities, making them potential sites for targeted restoration programs.

To address these critical knowledge gaps, I assessed the interactions between herbivorous reef fish and seeded coral spat within take versus NTMRs. Coral spat were reared *ex situ* and then deployed in coral-seeding devices to inshore reefs of the southern Great Barrier Reef Marine Park (GBRMP) in the Keppel Islands group. Habitat Protection Zones (i.e., 'blue zones') were selected as 'take reserves', while Marine National Park Zones (i.e., 'green zones') served as NTMRs, and two devices with fish-exclusion features were tested against a featureless control. This experiment aimed to address three questions:

(1) Does the survival of seeded coral spat differ between take and no-take marine reserves?,

(2) Does device type interact with reserve status and fish community composition to influence coral survival?, and

(3) Do fish abundance, fish feeding, and benthic community composition, predict seeded-coral survival?

Findings from this study will provide new insights into the ecological processes shaping coral reefs within marine reserves and inform the potential for reserve zones to improve the efficacy of coral seeding as a restoration tool.

4.3 Methods

4.3.1 Coral spawning and larval settlement

Gravid *Acropora millepora* coral colonies were collected by divers using a hammer and chisel from 4 sites (see Appendix Table C1) in early November 2022, prior to the full moon (November 8th, 2022). Coral colonies were transferred to a research vessel (Fig. 4.1a-b) equipped with coral holding and culturing facilities (Fig. 4.1c-d) [267]. Briefly, the onboard aquarium facility included 50-L isolation tanks for coral holding and larval settlement, 70-L conical tanks for larval culturing, and 2 work benches fitted with flow through filtered seawater (FSW, 0.1 μm), aeration and temperature control. Colonies were isolated in individual tanks until mass spawning occurred on November 16th, 2022.

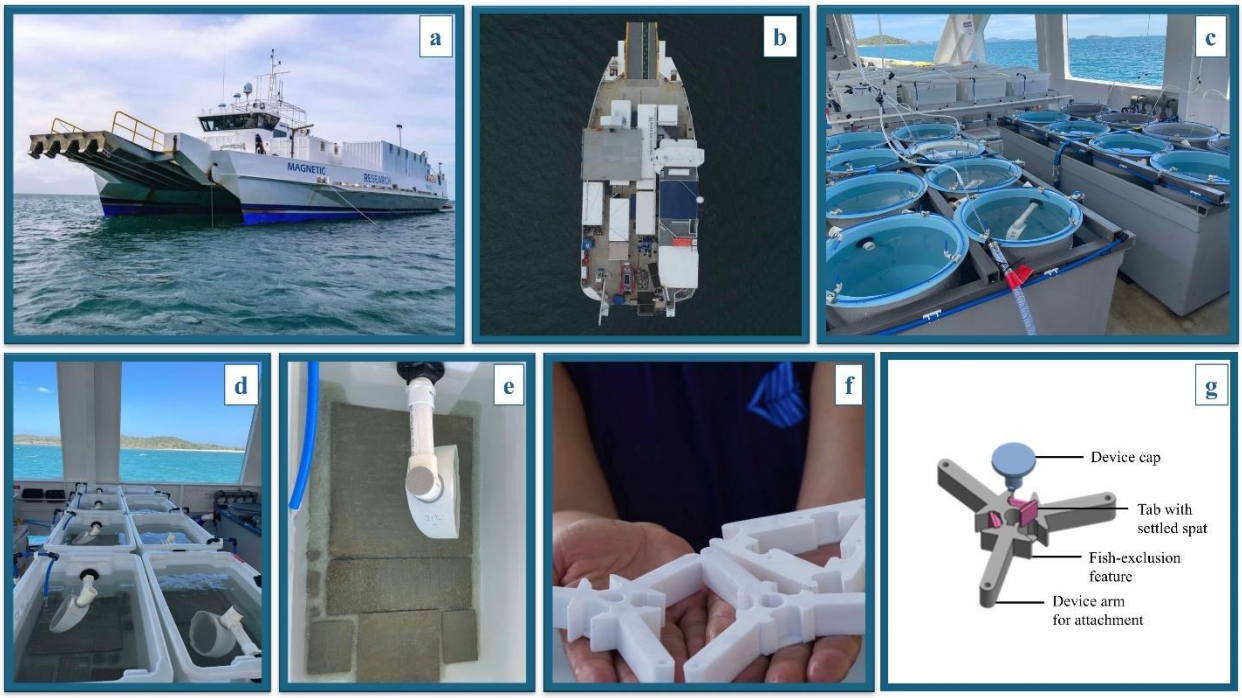


Figure 4.1 Laval culturing facilities, settlement substrates and devices used in the coral seeding experiment. [a] Lateral and [b] aerial views of the research vessel used to rear corals. [c] Laval culturing tanks. [d-e] Isolation tanks used for larval settlement. [f] Coral seeding devices: exclusion star [left], control star [middle] and exclusion triangle [right]. [g] Features of the exclusion star device.

Coral spawning times and colony contributions to mass cultures are listed in Appendix Table C1. Following spawning, coral gametes were collected, rinsed, fertiliSed *en masse*, then transferred into larval rearing tanks (1 larva mL^{-1}) following standard procedures [165]. After 5 days the larvae were free swimming and competent to settle, as determined by larval settlement assays.

Conditioned concrete tabs (14 x 14 mm) prepared from quick-dry cement (80:20 concrete: mortar) were used as settlement substrates. Tabs were produced in sheets (Fig. 1e; 400 tabs per sheet) that were pre-conditioned in aquaria at the Australian Institute of Marine Science (AIMS) National Sea Simulator for approximately 1-month prior to placement in the on-vessel system for transport. Aquaria with well-established benthic communities (crustose algae and bacterial biofilms), live reef rubble, grazing herbivores (small fishes and gastropods), recirculating FSW (~5 L min^{-1}), ambient light and temperature control to match in-situ conditions of the central GBR were used for sheet conditioning. After 1 month, the sheets supported an early successional community of crustose coralline algae (CCA) and bacteria known to induce coral settlement.

On the vessel, sheets were distributed across isolation tanks for mass settlement (Fig. 4.1d-e), placed horizontally and upward facing with small glass beads (sterile, < 2 mm Ø) filling the cavities between the

sheets and tank sides (Fig. 4.1e). The beads limited larval access to sheet undersides and constrained settlement to the upward-facing surface. Approximately 18,000 larvae were seeded to each sheet and after 48 h the glass beads were removed. Approximately ~10-12 larvae settled per tab.

4.3.2 Coral seeding devices

After larval settlement (24-48 h), individual tabs were cut from the sheets and tabs with ~12 ± 0.62 spat (range 1 to 47 spat and calculated from a subset of 214 tabs) were haphazardly placed (Fig. 4.1g) into one of three coral-seeding device types. The device designs included two devices with fish-exclusion features: (1) an exclusion star (Fig. 4.1f, Fig. 4.2d; hereafter the exclusion device) and (2) an exclusion triangle (Fig. 4.1f, Fig. 4.2f; hereafter the triangle device), and an additional device with no protection from grazing fish, the featureless-control star (Fig. 4.1f, Fig. 4.2e; hereafter the control device). Tabs were placed vertically in the devices (Fig. 4.1g). The triangle had 6 tabs (3 outward facing and 3 inward facing), which represented potentially different levels of protection, while the exclusion and control devices had 3 outward-facing tabs only. The devices were made of 95% Alumina ceramic (Shanghai Gongtao Ceramics CO., Ltd. People's Republic of China), which was selected for its high specific gravity (3.8) and hardness (9.0 Mohs). Tabs were secured in devices using a ceramic cap (for the exclusion and control, Fig. 4.1g) or glue (Gorilla glue, for the triangular device).

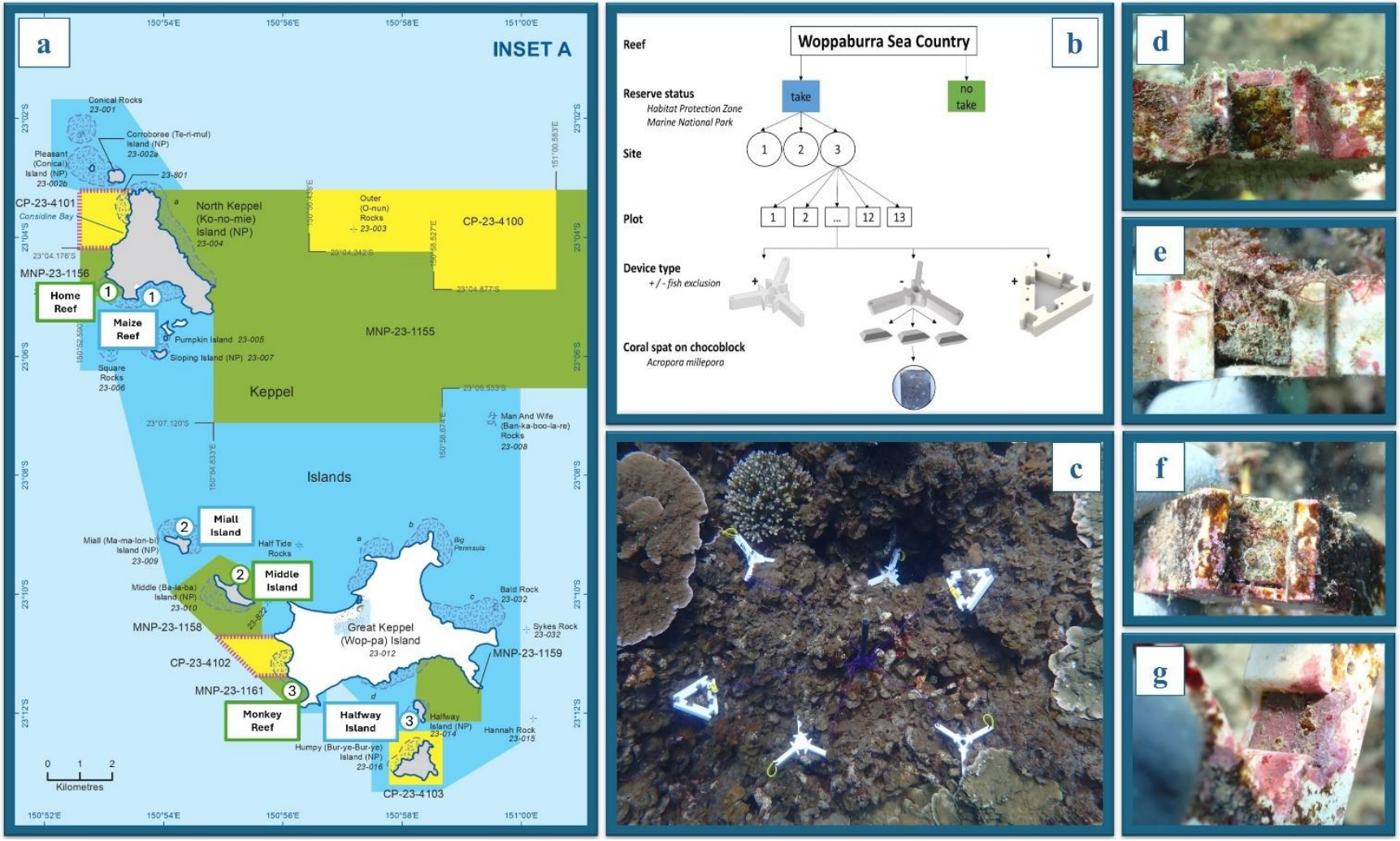


Figure 4.2 Site selection and experimental design for the coral seeding experiment. [a] Six experimental sites, three within (green) and three outside of (blue) marine reserve zones. [b] Hierarchical experimental design. [c] Experimental plot layout showing a central rod with six tethered seeding devices. [d] Corals on a tab within the exclusion star device. [e] Corals on a tab within the control star device. [f] Corals on the outward-facing tab of the exclusion triangle device. [g] Corals on the inward-facing tab of the exclusion triangle device.

4.3.3 The experimental design and deployment

Seeded devices were deployed to 6 sites in the Keppel Islands (Woppaburra sea Country, southern, inshore GBR; Table C2; Fig. 4.2a) between 23 and 27 November 2022. The field deployment followed a hierarchical design with replication at multiple scales (Fig. 4.2b). Briefly, I included 3 replicate sites in 'take reserves' (Habitat Protection Zones), which allow recreational spear and line fishing) and 3 sites in NTMRs (Marine National Park Zones) that prohibited fishing. The GBR was designated as a Marine Park in 1975 (under the GBRMP Act of 1975), the Mackay/Capricorn section, where the Keppel Islands resides, was added to this Act between 1983 and 1989 [268]. In 2003, the current GBRMP zoning plan was defined to include NTMRs, these reserves have been in effect since 2004 [268]. Devices were deployed at ~4-6 m depth (Lowest Astronomical Tide, LAT) in 13 experimental plots within each site. Fiberglass reinforced polymer rebar (Beyond Materials Group PTY LTD, 12-mm diameter, 800 and 1500-mm lengths) was hammered into the seafloor every ~2 m, constituting the centre of a plot. Within each plot, devices were tethered to the rebar with nylon rope (1-m length; Fig. 4.2c). Devices were hand placed by divers within the experimental plots, avoiding sand and coral; however, we note the devices were not fixed to the reef and had the potential to move after placement. There were 12 plots with 6 devices (2 replicates per device) and 1 plot with 3 devices (1 replicate per device, due to device limitations) per site. The experiment was permitted by the GBR Reef Authority (permit G22/47664.1), and all devices and equipment were removed after 11 months.

4.3.4 Biological and environmental data collection

Data were collected during 4 survey timepoints (Nov-22, Feb-23, May-23, Oct-23) over an 11-month period and included a suite of quantitative and qualitative assessments (Table C2) to determine the influence of biological (fish abundance, fish feeding, benthic composition) and environmental (marine reserve status and sedimentation) drivers on coral survival and size. The assessments were categorised by spatial scale (tab [mm], experimental plot [m], or site [10s m]) and are detailed below.

Tab-level assessments (mm)

Coral survival and size were visually assessed at the final timepoint following device removal. Survival was scored as a binary response from a single observer. The maximum linear length, maximum perpendicular length, and maximum height of the largest surviving coral on each tab were measured and coral size was expressed as a volume of a hemisphere (mm^3), calculated $V = \frac{2}{3}\pi r^3$.

Plot-level assessments (m)

Benthic communities in experimental plots were assessed at the time of deployment. A single quadrat image was taken 1-m above each plot. Images were assessed using the ReefCloud online database (https://reefcloud.ai/). Points (n=25) were uniformly overlaid on each image (5 x 5-point grid) and labeled by a single observer, estimating the percent cover of 72 potential benthic categories from eight classes: algae, macroalgae, hard coral, soft coral, seagrass, sponges and ascidians, abiotic, and other organisms (Table C3). Points that could not be identified (points that were blurry and those that landed on the device) were excluded from the data set.

Site-level assessments (10s m)

Stationary point-count surveys of fish (39.25 m^2, 5-min intervals, 3 replicates $site^{-1}$) were completed by a single observer at 3 timepoints (Nov-22, May-23, Oct-23; Table C2) during which count data for target fish were collected. The herbivorous fish of interest were species (Table C4) from the families Pomacentridae (damselfishes), Labridae (Scarinae, parrotfishes), Siganidae (rabbitfishes), and Acanthuridae (surgeonfishes). The time, depth, tide, sea state, visibility, and reef complexity were recorded for each survey [166].

Fish feeding surveys were recorded (GoPro HERO 9) at 2 timepoints. Cameras were stationed on the benthos to record feeding in 2 haphazardly selected quadrats (0.25 m^2, 1 camera $quadrat^{-1}$) within an experimental plot and per site. At the start of the recording, a metal quadrat frame was used to mark the boundary for data collection. Footage included 1 - 2 h of activity in the absence of divers. The feeding activity was visually assessed by a single observer (VLC media player), and a standard protocol for data collection was followed (Table C5). Briefly, fish that were biting the reef or the device were time stamped, imaged with a screenshot, and then identified to species. The hours of footage were standardised (i.e., same duration measured per site), and the bite rate (bites min^{-1}) was recorded per video. Bites on devices were included in the total but also analysed separately. Aggressive behavior by fishes were also recorded.

Sediment collection pods were deployed to quantify sedimentation within each site. Two pod types were used ‘SedPods’ and ‘TurfPods’ and were created following standard techniques [55]. Pods (replicates= 3 per type) were deployed to sites during the initial coral deployment and were collected after 5 days. The deposited sediments were rinsed (reverse osmosis [RO] water) from the pods and stored at -20°C until processing. Upon defrosting, the samples were homogenised, topped to 500 mL with RO water, and 3-times 50 mL aliquots were filtered (pre-weighed, 47-mm GFF filters) under vacuum. The filters were oven dried at 105°C for at least 24 h to determine total sediment mass. To measure organic content, the samples were combusted at 550°C for 1 h, cooled in a furnace for 5 h, then dried in a desiccator for 1 h before final weighing. See Appendix C section 1.1 for the full sediment sampling protocol.

4.3.5 Statistical analyses

Coral metrics

Bayesian hierarchical logistic mixed-effects regression models (brms, 'brms' package [212,269], R statistical software [170]) were used to investigate the effects of site, marine reserve status, and device type on device yield (binary, 0= no survivors, 1= 1 or more surviving tabs per device), coral survival (binary, 0= no survivors, 1 = 1 or more surviving spat per tab) and coral size (continuous, mm^3). The models were specified using the Bernoulli family with a logit-link function for coral survival and a Gaussian family with an identity-link function for coral size. The interactive effects of device type and site, and device type and reserve status were explored in both models. A random effect of device number nested within plot nested within site was included in the coral survival and size models. The survival model had normal priors with a mean of 0 and a standard deviation of 1.7 for the intercept and the regression coefficients and student-t priors with 3 degrees of freedom, a mean of 0, and a scale of 1.7 for random effects (reserve-site-plot-device combinations). The coral size model had a more informative normal prior for the intercept that was centred at 4.54 with a standard deviation 1.55 (based on the quantitative experimental data), a normal prior (0, 2.5) for the slopes, and a student-t prior (3, 0, 2.5) for the random effects. The models were fit using Hamiltonian Monte Carlo sampling (HMC; Table C6-S8); posterior predictive checks and leave-one-out cross-validation information criterion (LOOIC) values were used to assess model accuracy and to select best routine models. Model outputs were visualised using the 'ggplot2' package [174].

Ecological data and coral survival

Principal component analyses (PCAs; 'prcomp' function, R) were used to investigate the ecological data (fish abundance, fish feeding, benthic composition and sedimentation) with respect to the seeding site and marine reserve zone. Two-dimensional PCAs ('factoextra' package), redundancy analyses (RDAs, 'vegan' package [175]), and backwards stepwise models were used to deduce significant predictors of coral survival. Brms models, as above, were then used to model the significant ecological variables as predictors of tab-level coral survival (Table C10). Separate models were run for the fish, benthic, and sediment data because those predictors were highly correlated; models included random effects for the reserve-site-plot-device combinations for benthic data and reserve-site-survey for fish data. Group-level data (e.g., fish family and broad benthic categories) were analysed separately from species level (fish) and lowest taxonomic level (benthic) data. Total sedimentation (i.e., the data per pod type with organic and inorganic material pooled together) was used for the sediment model; random effects included reserve-site-pod number. Diagnostic tests were performed, and the significant outcomes were plotted, as above.

Biotic and abiotic community composition by site

Multiplicative brms models were used to compare fish counts, fish bites, benthic cover, and sediment deposition across sites. For fish, the models included the species or family-level identification and site and marine reserve zone as predictors with time-reserve-site-replicate as the random effect. A zero-inflated Poisson distribution (log-link function) was used for fish counts (Table S9) while a Gamma (log-link function) distribution was used for fish bites (Table C11). Normal priors were used for the intercept (count data= 0, 5; bite data= 0.58, 1.18) and the regression coefficients (0, 5). The bite model also included an exponential prior (rate parameter= 1) for the standard deviation of the random effects. For benthic data, the model included the lowest group-level identification as the response, with site and marine reserve zone as predictors and reserve-site-plot as the random effect. A zero inflated beta distribution (logit-link function) was used, with normal priors for the intercept (0.48, 1.09) and the regression coefficients (0, 5). For sediment, the total sediment deposition was modeled against the predictors (pod type, site and marine reserve zone) and the random effects (reserve-site-pod number; Table C13). A Gamma distribution and normal priors (intercept 0, 1; regression coefficients 0, 1; student-t priors for random effects 3, 0, 1) were used. Models were fit, checked for accuracy and visualised, as described above.

4.4 Results

4.4.1 Coral survival

Device yield

After 11 months, approximately 50% of devices had a live coral (Fig. 4.3a-d), with no significant differences at the device level (yield) between take and no-take marine reserves (Fig 4.3a; Table C6). Device yield was highest at Miall Is. (64 %, 95% CI: 12, 96) and lowest at Home Reef (26 %, 95% CI: 3, 76), with significant variation amongst sites (Fig. 4.3b; Table C6). The device types performed similarly in reserve zones; however, on average, the devices with fish protection yielded slightly higher survival than controls (Fig. 4.3c), and the top-performing coral-seeding device varied by site (Fig. 3d). At Miall Is. and Home Reef, 3- and 12-fold increases in coral yield were observed in the exclusion device compared with the control, respectively (Table C6). The exclusion device had the least site-related variation in yield, with approximately 50% (95% CI: 6, 92) of devices containing live corals across the deployment sites (range 38 - 64% yield; Fig. 4.3c-d).

Coral survival

Patterns in tab-level survival were similar to device-level survival. Average tab-level survival (hereafter coral survival) surpassed 25%, but survival varied across the sites (Fig. 4.3e). The highest survival was

observed at Miall Is. (33%, 95% CI: 4, 79), while survival at Home Reef was 2-times lower (Fig. 4.3e; Table C7). There was no significant effect of marine reserve status on survival (Fig. 4.3e) but the deployment device type (Fig. 4.3f) and plot within each site (Fig. C1) influenced survival. The exclusion device had the least site-related variation in survival (29-39%, 95% CI: [2, 89] and [4, 82], respectively), while the control device had the most variation (14-34%, 95% CI: [1, 60] and [4, 82], respectively; Fig. 4.3e). Device performance was significantly different at Home Reef only (Fig. 4.3e) with the exclusion device having 2-times higher survival than other device types here (Table C7). The experimental plot also influenced coral survival (Fig. C1). For example, at Maize Reef, it was 13-times more likely for tabs to host live corals in plot 5 than plot 8, indicating high variability within sites (Table C7; Fig. C1). Similarly, at Middle Is., survival was 8-times higher in plot 13 than plot 5 (Table C7; Fig. C1).

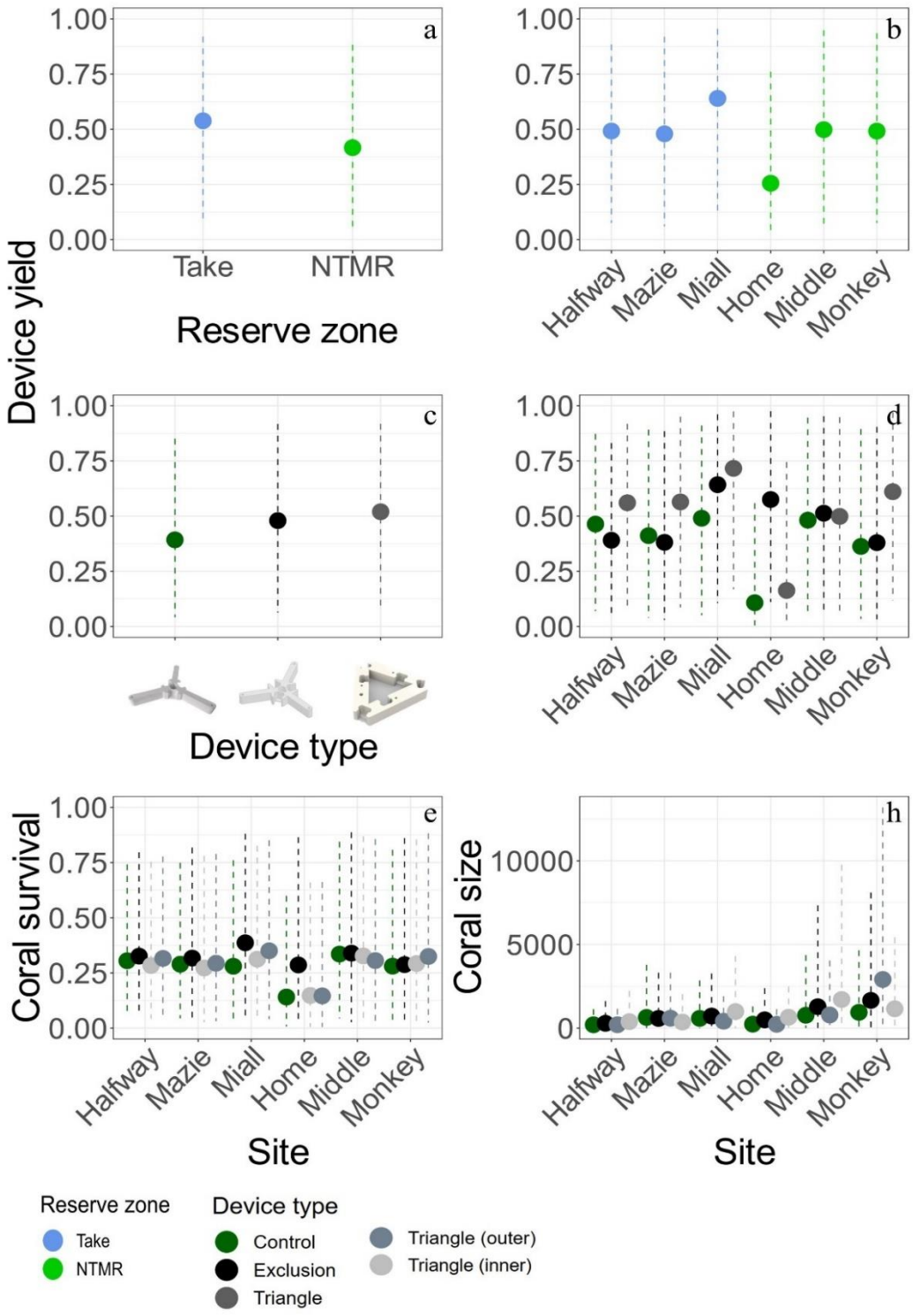


Figure 4.3 Device yield and tab-level coral survival. Device yield by [a] marine reserve zone, [b] site, [c] device type, and [d] device type and site. [e] Coral survival by site and device type. [f] Coral size by site and device type. * on plots indicate a significant result (see Appendix Table C6-C8). Mean estimates with 95% credible intervals are displayed. The data are jittered [d-e] with respect to the x-axis for ease of visualisation.

4.4.2 Coral size

Surviving corals reached an average size of 750 mm^3 (95% CI: 5, 3839), with a range of 0.03 to 5610 mm^3 (Fig. 4.3f). There was no significant effect of marine reserve status on coral size (Fig. 4.3f) but there were effects of device type on size at certain sites. At Monkey Reef, the outer-facing tabs of the triangular device yielded significantly larger corals than the control device at this site (Fig. 4.3f; Table C8).

4.4.3 Fish activity

Fish counts

A total of 5265 herbivorous Acanthurids (surgeonfish), Labrids (wrasse and parrotfish), Pomacentrids (damselfish), and Siganids (rabbitfish) were identified during the deployment. Halfway Is. had the most fish (2036 total; average 53 fish per site [39.25 m^2], 95% CI: 17, 121) while Home Reef (327 total; average 8 fish per site, 95% CI: 2, 19) had the least (Fig. 4.4a). This resulted in a maximum 11-fold decrease in fish abundance at Home Reef compared with other sites (Table C9). The damselfish *Pomacentrus wardi* and *P. adeulues* were abundant while surgeonfish were rarely observed (Fig. 4.4b). The rabbitfish *Siganus argenteus* and *S. fuscescens* were more common at Maize Reef, Middle Is. and Miall Is.; these fishes were up to 8-times more abundant than at other sites (Fig. 4.4c; Table C9). The parrotfish *Scarus rivulatus* was common at Middle Is., being up to 20-times more abundant than other sites (Fig. 4.4c; Table C9).

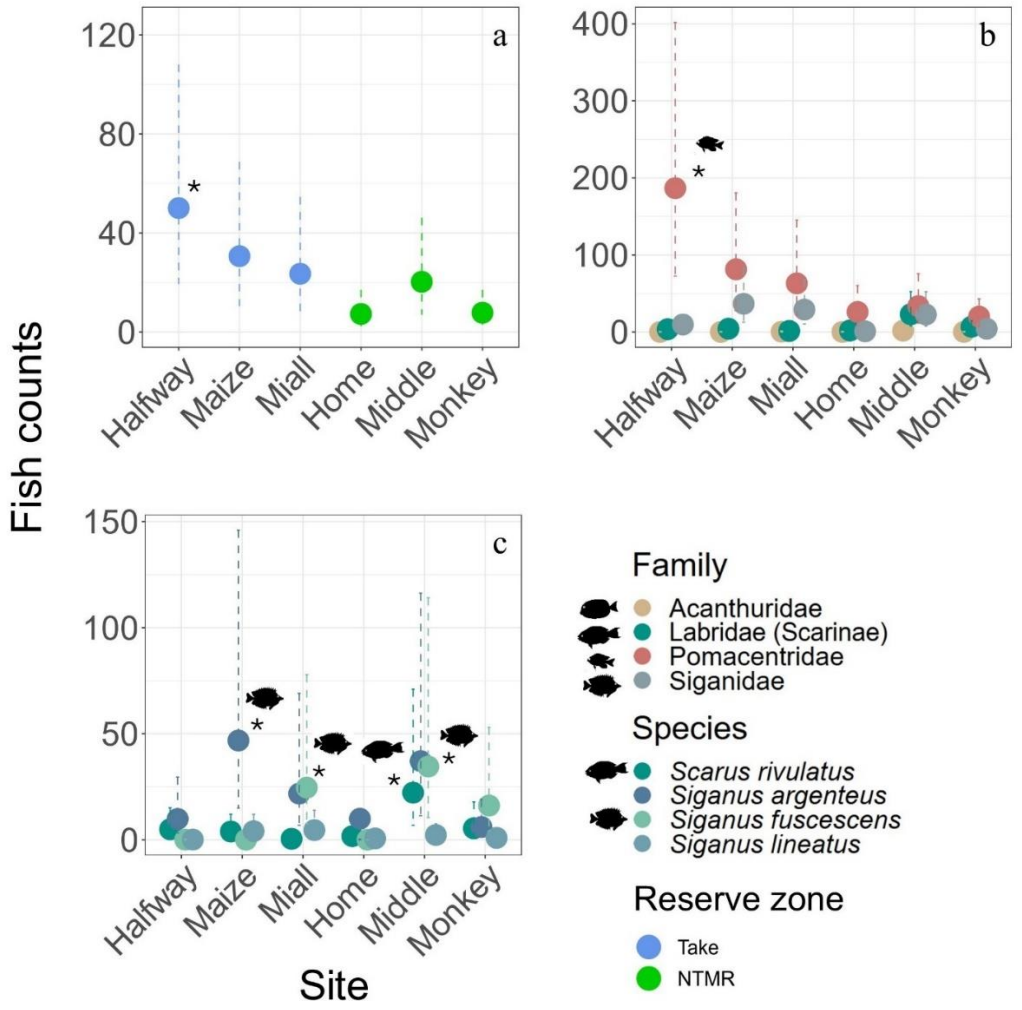


Figure 4.4 Fish abundance by [a] site, [b] fish family and site, and [c] species and site. * on plots indicate a significant result (see Appendix Table C9), while the icon represents the fish group contributing to this response. Mean estimates per site (39.25 m^2) with 95% credible intervals are displayed. The data are jittered [b-c] with respect to the x-axis for ease of visualisation.

Coral survival was positively correlated with the combined abundance of the damselfishes *Pomacentrus wardi* and *P. adelus* (Fig. 4.5a; Table C10). No significant correlations were found between coral survival and the abundance of any other fish species or genus.

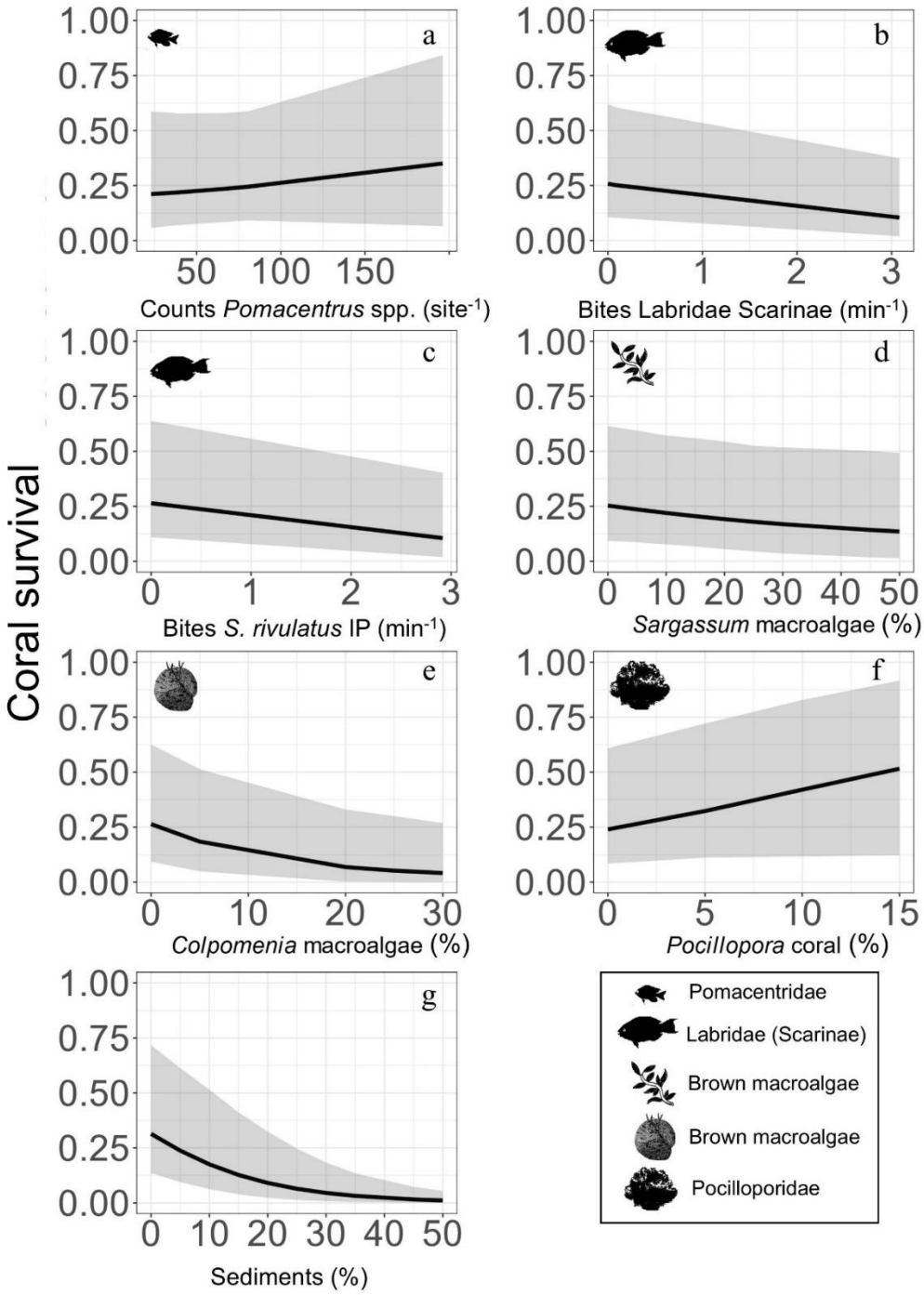


Figure 4.5 Tab-level coral survival by [a] fish abundance, [b-c] feeding, and [d-g] benthic constituents. Only significant relationships were plotted (see Appendix Table C10). Mean estimates with 95% credible intervals are displayed.

Fish bites

28 fish species from 10 families were observed to feed in the experimental plots, and feeding activity was similar across the reserve zones (Fig. 4.6a) but varied by site (Fig. 4.6b). Fish bites were highest at Middle

Is. (32 bites min^{-1} per plot [0.25 m^2], 95% CI: 2, 79), 6-times higher than Monkey Reef, which had the fewest bites observed (Table C11). Damselfish (*Pomacentrus wardi*) and wrasses (*Pseudolabrus guentheri*, *Stethojulis strigiventer, S. trilineata, Halichoeres melanurus,* and *Coris aurilineata)* commonly fed across all sites. In contrast, parrotfish (*Scarus ghobban* and *S. rivulatus*) fed less often but their bites were specific to NTMRs (Fig. 4.6c), particularly Home Reef, with significantly (20-times) more parrotfish bites than other sites (Fig. 4.6d; Table C11*).* Damselfish also fed 3-times more often than other fishes (Table C10) and were most active at Middle and Miall Is. with significantly (2- to 5-times) more bites taken there than at other sites (Table C11). Only wrasses (*P. guentheri*, *C. aurilineata*, *H. melanurus* and *S. strigiventer)* and damselfishes (*Pomacentrus australis, P. wardi* and *Chromis nititda*) were found to feed directly on devices, with 1253 total bites observed. Miall Is. had the most feeding directly on devices (613 bites), with up to 56-times more bites taken on devices there than at other sites (Fig. C2).

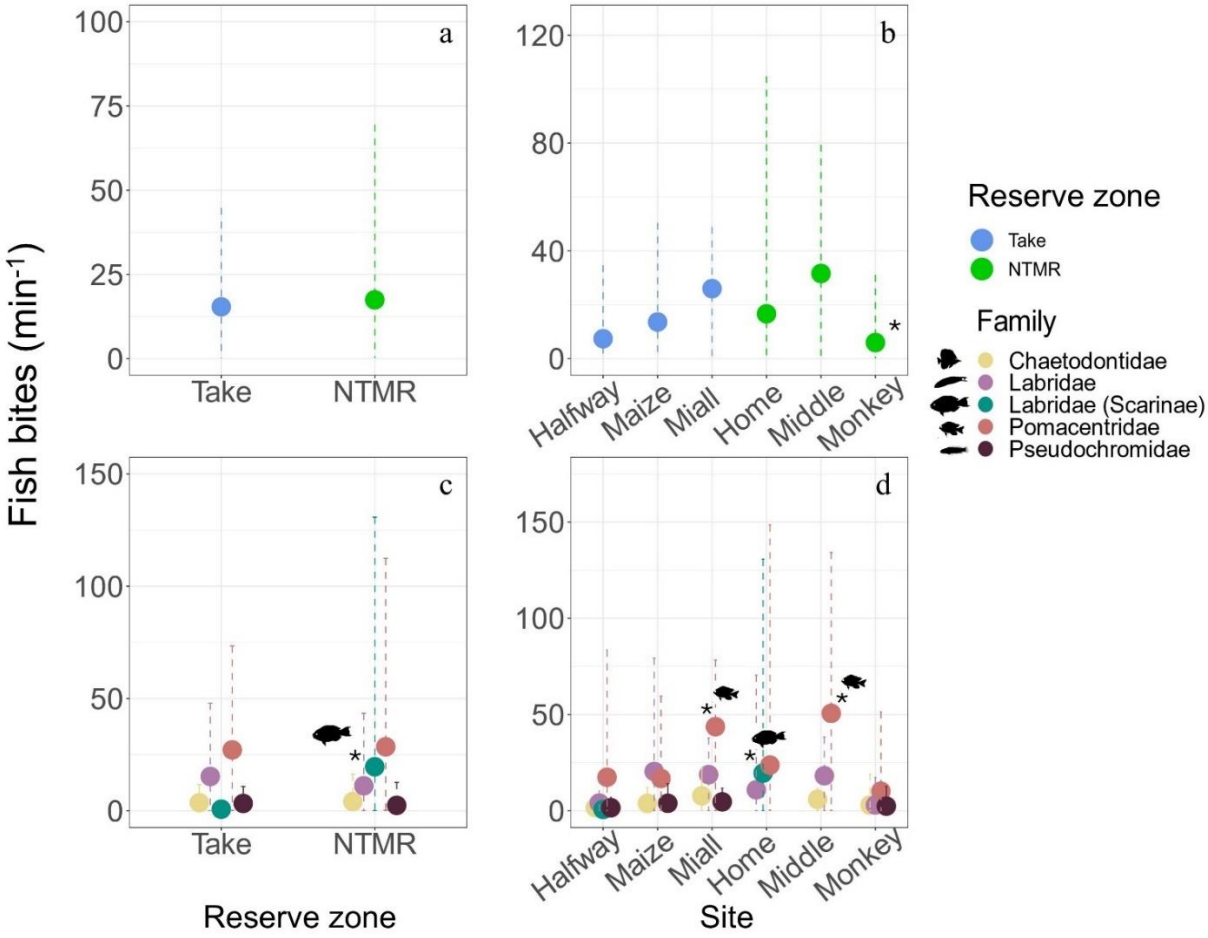


Figure 4.6 Fish feeding by [a] marine reserve zone, [b] site, [c] fish family group per reserve zone, and [d] site. * on plots indicate a significant result (see Appendix Table C11). Mean estimates per plot (0.25 m^2) with 95% credible intervals are displayed. The data are jittered [c-d] with respect to the x-axis for ease of visualisation.

Feeding activity from parrotfishes was negatively related to coral survival (Fig. 4.5b-c; Table C10). Bites from the species *S. rivulatus* were more detrimental than *S. ghobban*, particularly the initial phase variant of *S. rivulatus* (Fig. 4.5c; Table C10). Other notable, yet weak results specific to NTMRs, include a positive relationship between survival and bites from damselfish (*C. nitida*) and a negative relationship between survival and bites from wrasses (*P. guentheri* and *S. strigiventer*) (Table C10). Bites from the damselfish *P. wardi* significantly increased survival for corals in exclusion devices only (Table C10).

4.4.4 Biotic and abiotic community composition

Data on 30 benthic constituents were extracted from the experimental sites. Scleractinian corals (branching *Acropora* and encrusting *Montipora*) and low-lying macroalgae (*Lobophora*) were the most abundant, while sponges and green macroalgae were rare. Reefs in NTMRs had more macroalgae, sediments, and *Acropora* corals than take reefs (Fig. 4.7a). Home Reef had the highest abundance of erect macroalgae (*Sargassum*, *Padina*, *Colpomenia*, *Pseudochnoospora)* and branching *Acropora* (Fig. 4.7b*)*. Sediment deposited on SedPods and TurfPods averaged 0.019 and 0.048 g d^{-1}, respectively, and sediments were primarily of inorganic composition. Total sediment deposition showed minimal variation by site (Fig. C3a) and reserve zone (Fig. C3b). However notably, Miall Is. had the most deposition on TurfPods (Fig. C3c) collecting 4 times more sediment (1.37 g d^{-1}, 95% CI: 0.11, 7.51) than TurfPods at Halfway Is. (0.28 g d^{-1}, 95% CI: 0.03 – 1.32) and Middle Is. (0.35 g d^{-1}, 95% CI: 0.04, 1.63), which had the least sediment (Table C13).

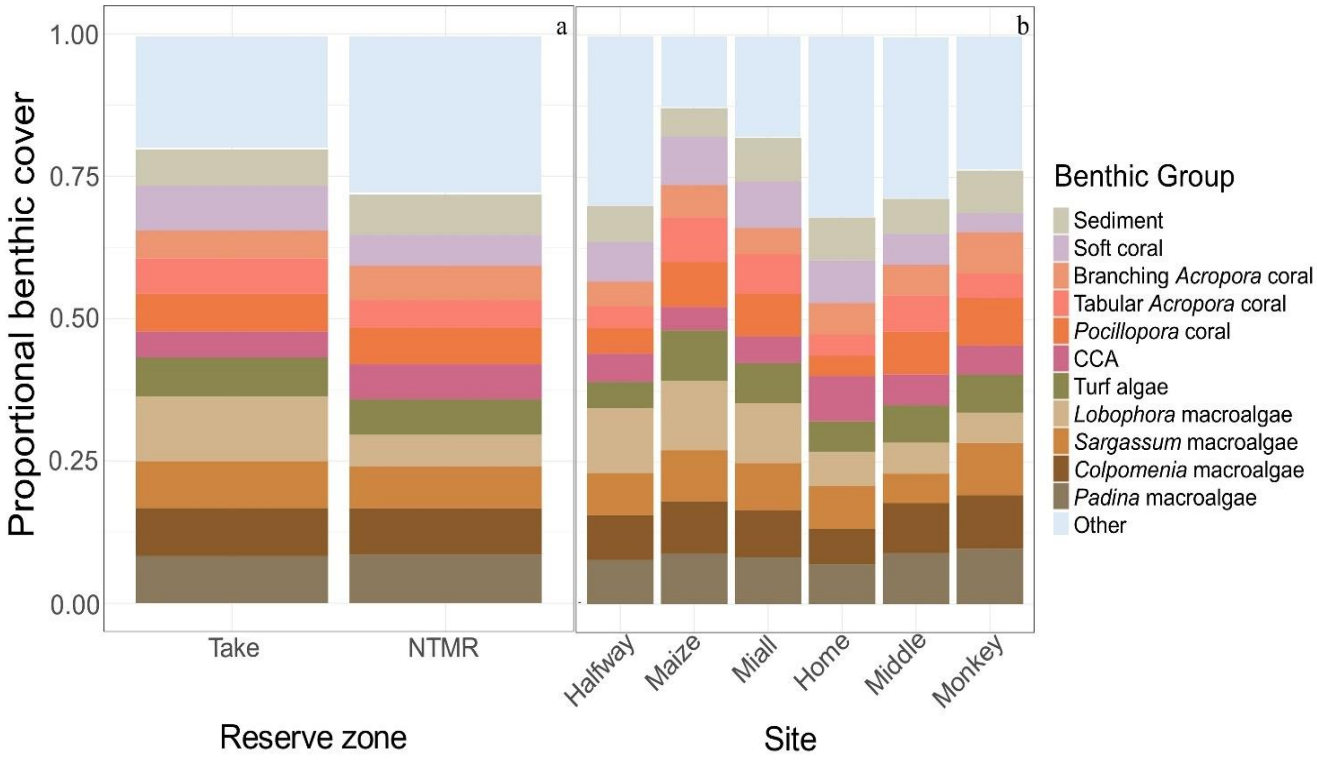


Figure 4.7 Average benthic community composition by [a] reserve zone and [b] site.

Coral survival was negatively related to the cover of macroalgae and abiotic sand, sediments and silts (Table C10). Erect brown macroalgae (*Sargassum* and *Colpomenia*) were negatively correlated with survival (Fig. 4.6d-e), but other erect (*Padina*) and low-lying (*Lobophora*) brown algae were less detrimental to survival (Table C10). The abundance of Scleractinian corals had variable effects on coral survival. Survival increased with increasing cover of *Pocillopora* corals (*P. damicornis*, *P. acuta*, or similar), while branching and tabulate *Acropora* had weakly negative effects on survival (Table C10). Crustose and turfing algae had variable effects on coral survival but in NTMRs significantly increased coral survival (Table C10). Coral survival was not correlated with sediment deposition (Fig. C3d; Table C10).

4.5 Discussion

After an 11-month coral seeding trial, the survival of *Acropora millepora* varied both within and among sites, and was generally comparable with survival reported in previous seeding experiments involving *Acropora* corals [131,145,192,193]. I initially hypothesised that the marine reserve status of coral reefs would influence spat survival. However, site-specific drivers had a more significant impact on coral seeding success than marine reserve status, with no clear patterns related to conservation status. Building on existing coral seeding research, I propose three new recommendations to improve the efficacy of seeding sexually

reproduced spat on inshore reefs. First, deploy corals to marine reserves that maintain a moderate-to-high abundance of small fishes. Second, use coral seeding devices with fish-exclusion features. Finally, within reefs, avoid substrata with erect-fleshy macroalgae, loose sediments and rubble, and high *Acropora* coral cover, while favouring sites with non-*Acropora* coral. The insights gained from this experiment broadens our understanding of the relationships amongst coral, fish and marine reserve status on inshore reefs and provides valuable guidance for coral-seeding restoration practitioners.

Select marine reserves abundant with small fishes

Site-specific fish activity were found to be more influential on seeded coral survival than marine reserve status. Notably, sites with abundant damselfishes (*Pomacentrus wardi*, *P. adelus*, and *Chromis nitida*) and large, heterospecific fish aggregations (including damselfish, parrotfish, and rabbitfish) had more coral survivors. Larger populations of herbivorous damselfish (*P. wardi* and *P. adelus*) may support coral growth and survival in several ways, including: (i) the mitigation of coral competition through the direct removal of macroalgae and turf algal maintenance [153,270,271] and (ii) through the defense and exclusion of other fishes like corallivores, scraping, and excavating parrotfish, from entering their territories [95,272–274]. The high bite-rates observed from farming damselfish on devices at Miall Is., and their increased aggression at Maize Reef, support these hypotheses. However, the relationship between coral survival and the planktivorous damselfish *Chromis nitida* requires an alternative explanation.

An increase in prey fish like *C. nitida*, could indicate a decrease in predator presence – characteristics commonly seen on reefs experiencing fishing pressure [275,276]. In the absence of predators, *C. nitida* may extend their foraging range, traveling further in the water column for food. Similarly, the "confusion effect theory" [275] states that heterospecific schooling of fish can reduce the risk of predation and extend the spatial extent of foraging. Heterospecific schools are common for *C. nitida*, other damselfish, and larger fishes like parrotfish and rabbitfish on reefs with top-down pressure [277–279]. Under either scenario, the return and extended movement of herbivores and planktivores from relaxed predation pressure could impact benthic community development and nutrient cycling over fine (< 1 m) [280] to large (10s of m) spatial scales [87,164,281], potentially supporting coral dominance in the fish foraging zone [271,282]. Moreover, an increase in the spatial extent of foraging could then minimise the likelihood of direct and indirect grazing on young corals from predatory fishes like parrotfish and other corallivores [99,100,112]. Indeed, large schools of damselfish, parrotfish and/or rabbitfish were most common at sites with the highest survival of seeded corals; however, effective coral seeding sites (Miall and Middle Is.) were variable in their marine reserve status. Taken together, these findings suggest that reefs supporting diverse communities of fish also support coral survival, regardless of whether they are inside or outside of NTMRs. Although the quality of the marine

reserve (i.e., actual versus perceived health of the NTMR) and compliance issues (i.e., unauthorised fishing) could have influenced the results [252], accounting for this variability was beyond the scope of this study.

While hydrodynamic conditions were not a focal point of this study, it's important to acknowledge that fish activity is influenced by hydrodynamic processes and wave exposure (see previous Chapters), which likely contributed to the survival patterns across sites. Indeed, sites yielding the highest spat survival were windward-facing reefs rather than leeward-facing reefs, suggesting wave exposure and its effects on reef community development could have played an important role in coral survival. Spat survival can be influenced by water flow both directly, by promoting larger spat size [64,65,214] , and indirectly, through its influence on fish populations [199,283]. Recent work in the northern GBR found the survival of *A. digitifera* spat was 3-times higher at exposed rather than sheltered sites (Chapter 3 [284]). This high survival was attributed to direct effects of water flow on coral health and size [64,65,214] and the flow-mediated effects on fish behaviour [199,283,284]. Reefs with increased water movement have a higher turnover of nutritious allochthonous materials than reefs with limited flow thereby facilitating increased abundance of planktivorous damselfish that feed on zooplankton [285]. Likewise, parrotfish that rely on water flow to control their swimming capabilities will inhabit reefs with moderate-to-high water movement [199]. Interestingly, a reduction in grazing-related coral mortality was also observed on reefs with high over low-to-moderate flow (Chapter 3 [284]), and scraping parrotfish were only observed to feed at sheltered sites in this study. Overall, the abundance of planktivorous damselfish and herbivorous parrotfish could therefore serve as proxies for increased water flow. Selecting sites based on the abundance and species composition of flow-dependent fish communities could improve coral seeding efficacy, and the enhanced water flow could also support coral nutrition and growth (Chapter 3 [284]) while alleviating stress from elevated sea surface temperatures [64,65,214].

A relationship between site exposure, coral survival, and feeding from carnivorous wrasse was also identified from this study. Small wrasse commonly fed on coral seeding devices at Miall Is., an exposed, take reef with the highest coral survival. The additional grazing likely helped reduce sediment and algal abundance near devices, supporting the notion that fine-scale feeding by small, non-herbivorous fishes may enhance spat survival on the GBR [286], a hypothesis presented by Whitman et al. (2025) in Chapter 3 [284]. Notably, wrasse and damselfish feeding were also common on devices deployed to the lowest performing site, suggesting a threshold beyond which the effects of fine-scale feeding (mm-to-cm scale) may become detrimental to seeded spat on inshore reefs. Similarly, as we move offshore, feeding by herbivorous blennies was negatively associated with *Acropora* spat survival on rubble-dominated reefs with limited waterflow and high parrotfish grazing (Chapter 3 [284]). The low performing site in our study had the only parrotfish grazing observed during video surveys and had patches of unconsolidated rubble and sediments like the

rubble-dominated site described by Whitman et al. (2025) in Chapter 3 [284]. The relationship between fishes, sedimentation, rubble formation, and coral survival warrants urgent investigation, particularly since young corals even show increased vulnerability to herbivorous blennies under experimentally elevated pCO_2 conditions [93] . It is also important to note that sites with high cover of farming damselfish territories (i.e., patch reefs, rubble reefs, etc.) could experience increased coral mortality from damselfish aggression if devices are seeded within their algal patches [95,287,288]. Taken together, these findings emphasise the importance of closely monitoring the coral-fish relationship through space and time. Modifying device designs to exclude small fishes and testing them against controls in diverse habitats, including farming damselfish territories, would help clarify these complex relationships.

Devices with fish exclusion features

The fish-exclusion device tested in this study, along with similar designs in other research (Chapter 3 [284]), improved the outcome of coral seeding in comparison to other device types. This design led to consistent survival across sites, while survival was variable in the control and triangular device types. At Home Reef, which exhibited the lowest coral survival, the exclusion device facilitated twice the survival of other device types—two factors may explain the higher performance of this device type at this site. First, devices with fish-exclusion features protect seeded corals from scraping and excavating parrotfish, which featureless control devices do not provide [113,131,193]. Interestingly, parrotfish were seen feeding in experimental plots (< 1 m from seeded corals) at Home Reef but not at other sites. The initial phase morphotype of *Scarus rivulatus* fed the most. *S. rivulatus* is a site-attached, scraping parrotfish species that typically occupies small reef areas (< 24,500 m^2) [282]; hence, their herbivory, bioerosion and broader ecosystem impacts (which may co-occur with other roving fishes and schools of fish) are more localised [282]. Likewise, smaller *S. rivulatus* can scrape disproportionately more material per unit biomass than larger fish [289]. Overall, the concentrated grazing of scraping parrotfish likely increased coral mortality at Home Reef, and the fish-exclusion features were required to prevent coral loss from accidental grazing. However, coral survival was also lower on the triangular device than the exclusion device at Home Reef, suggesting variables beyond predation are affecting survival.

It is likely that the fine-scale physical environment created by the device type drove the survival outcome. For example, fine sediments from the water column became trapped in the central cavity of the triangle device due to its hollow design, putting the inward-facing corals in contact with sediments. In contrast, the star shaped exclusion device only houses corals in outward-facing positions, avoiding this issue. Additionally, unconsolidated rubble was commonly trapped in and overtopping the triangular device, both sediments and rubble can increase coral mortality via smothering or abrasion [223,224]. The resuspension of

coral rubble and sediments by parrotfish, especially on *Acropora*-, *Pocillopora*-, and rubble-dominated reefs [97,225,226], may further drive this variation in survival between device types. Moreover, the arms of the star shaped device provided increased stability and prevented entrapment within the rubble matrix of a mobile rubble reef. Although we did not track device movement throughout this study, it appears the star design promoted faster wedging, securing devices to the substrata earlier than the triangular design. Lastly, since adhesive glue was used to secure coral tabs in the triangular device and not others, there could have been a negative effect on coral spat from chemical exposure. Further refinement of the coral seeding device design to limit the use of chemical adhesives and to promote swift cementation to the reef could improve seeding efficacy, particularly on inshore reefs or those prone to disturbances that increase with the natural accumulation of bio-eroded materials (e.g., thermal stress and cyclones).

Selection of abiotic and biotic variables to improve seeding

Sites with erect macroalgae (*Sargassum* and *Colopomenia* spp.) and sand, sediments, and silts were detrimental to seeded corals, while reefs dominated by *Pocillopora* corals promoted higher survival than those with branching *Acropora*. Given the known harmful effects of macroalgae [75,290] and sediments [44,84,291] on recruiting corals, it isn't surprising that these factors negatively impacted coral survival post seeding. For instance, foliose macroalgae such as *Sargassum* and *Dictyota* spp., can be abrasive, release toxic chemicals, and block light from reaching the understory, thereby hindering coral growth and survival [69,73,74,181]. Moreover, seasonal and fast-growing *Colopomenia* can overtop and engulf small coral colonies, increasing the likelihood of competition-driven mortality [292]. Even low-lying macroalgae (*Lobophora* spp.) that were less harmful to seeded corals in this study can vary in their impact across other coral taxa [293–295] and still be damaging when in direct contract with *Acropora* spat [232]. Furthermore, a recent study identified a 3-fold decrease in coral recruitment at macroalgal-dominated reefs compared with sites where active algal removal occurred [296]. Consequently, deployment decisions that minimise coral contact with macroalgae should improve coral seeding success.

With respect to sediments and sand, large seasonal fluctuations in particulate material are common on inshore reefs. In the Keppel Islands, plumes from the Fitzroy river transport freshwater and terrestrial sediments to the reef, and significant loss of coral cover, along with shifts to macroalgal-dominated states have been documented in this region following flood events [297–299]. Natural levels of sediment deposition, typical during the wet season in Australia, is likely to have contributed to the mortality of seeded corals at Home Reef [83]. While sediment smothering can play a major role in the coral mortality [44,83,84,300], sediment-laden surfaces are also less palatable to fishes [163], which could have led to reduced grazing and indirectly increased competitive interactions between seeded coral and algae at this site. Alternatively, seeded corals that escaped high sediment deposition could have experienced increased grazing-induced mortality from

concentrated and highly localised feeding pressure on non-sediment laden surfaces. To address these challenges, novel interventions aimed at reducing sediment exposure of seeded corals on reefs should be investigated. One potential solution is deploying devices on elevated structures [301] to prevent burial.

There is growing evidence suggesting that *Acropora*-dominated habitats are challenging for seeded corals [192,284]. However, considering the prevalence and diversity of *Acropora* species on coral reefs, this result might be driven by a small group of species with erect morphologies. For example, *Acropora* corals with branching and tabulate morphologies could outcompete young corals via overtopping and shading [192,228]. Moreover, erect corals tend to be less stable in strong currents and waves, leading to colony dislodgement and breakage [207], which in turn produces carbonate rubble and sediments [225,226]. Although *Pocillopora*-dominated reefs are also prone to breakage and bioerosion [225,226], their small-colony size and tightly packed branches may provide greater structural integrity than large *Acropora* corals, particularly under turbulent flows. Allelopathic effects of adult *Acropora* could also be indicative of spat mortality, and stronger than the effects of other non-*Acropora* coral taxa [302–304]. Moreover, reefs with greater taxonomic diversity could help alleviate predation pressure on seeded corals, as *Acropora*, *Pocillopora*, *Montipora*, and *Porites* corals are all palatable to corallivorous fishes [103]. Coral composition also plays an important role in the broad functional diversity of fishes with changes in the dominance from *Acropora* to *Pocillopora* coral lowering the species richness and functional diversity of fishes [118,305,306]. Hence, there is some evidence to suggest that reduced richness and diversity of fishes on non-*Acropora* dominant reefs is conducive to seeded spat survival at fine spatial scales. However, the implications of reduced fish functions for adult corals and benthic community development warrant additional investigation. While these responses are likely species and context specific, there is growing evidence that certain benthic communities should be avoided when seeding coral spat to reefs. Alternatively, increasing the density of seeding units could help offset the higher mortality expected in *Acropora*-dominated habitats.

Limitations to the current coral seeding toolkit

Although there have been successful attempts to improve the efficacy of coral seeding in recent years, there are still many bottlenecks to overcome. Building on the existing research, five improvements to the coral seeding technique were detailed in this study. First, modifications to the device designs to exclude small fishes should be actioned. Second, refinements to the device designs that limit the use of chemical adhesives and promote swift device cementation should be trialed. Third, novel interventions to reduce device exposure to sediments and macroalgae need to be considered. Fourth, fine-scale monitoring of coral-fish interactions should be conducted, including observations in and outside of farming damselfish territories. And, lastly, the density of seeding units should be tailored to offset the higher mortality expected in low performing habitats (*Acropora*-, rubble-, sediment-, and macroalgal-dominated habitats). Additional areas

of exploration should include environmental factors such as light intensity, nutrient availability, and reef rugosity—these variables lack ample investigation but are likely to significantly influence coral survival [192]. Moreover, coral seeding trials with non-*Acropora* taxa and multispecies device deployments warrant urgent investigation. Incorporating these additional co-variates in future studies could provide a more comprehensive understanding of the factors driving survival and improve site selection strategies.

4.6 Conclusion

The results presented in this chapter improve our understanding of how abiotic and biotic drivers influence coral seeding efficacy. Foremost, the boundaries defined by marine reserves should be considered only as a starting point in the site selection process. When evaluating the potential of NTMRs for seeding, factors such as the age of the reserve, the rationale behind its establishment, compliance with fishing regulations, and the sites ecological condition must all be considered. Coral seeding practitioners, restoration experts, and reef managers will benefit from the criteria outlined in this study. Pre-deployment planning, including monitoring and site preparations, should be conducted before direct interventions are employed. Site preparation should target the main cause of coral decline and may involve actions like macroalgae removal, rubble stabilisation, and the installation of elevated structures to support devices. To combat thermal stress, coral breeding and rearing techniques that focus on heat adaptation may also be required. While these findings are based on a single coral species and location, similar trends are emerging in experiments with different coral species and in offshore environments. Ongoing testing across new species and environments, combined with annual monitoring and knowledge sharing, will be essential for advancing coral seeding as an effective reef restoration tool. Furthermore, safeguarding the future of coral reefs will require implementing best practices in reef management and significant reductions in carbon emissions globally.

Chapter 5. General discussion

The growth and survival of over 25,000 spat and 692 microfragments, from two ecologically significant broadcast spawning coral species (*Acropora digitifera* and *A. millepora*) were tracked across three coral seeding experiments in the northern, central, and southern sectors of Australia's Great Barrier Reef (GBR). These deployments covered inshore and offshore reefs, sites with varying hydrodynamic conditions, and locations with different marine reserve statuses, enabling disentanglement of the complex, context-specific drivers of post-deployment mortality, particularly accidental grazing from reef fishes. Based on these findings, I developed five recommendations that can be used to advance our coral seeding strategies and guide future deployments of corals to reefs (Fig. 5.1). This chapter provides a detailed examination of these recommendations, their ecological context, and their practical implications for restoration practitioners.

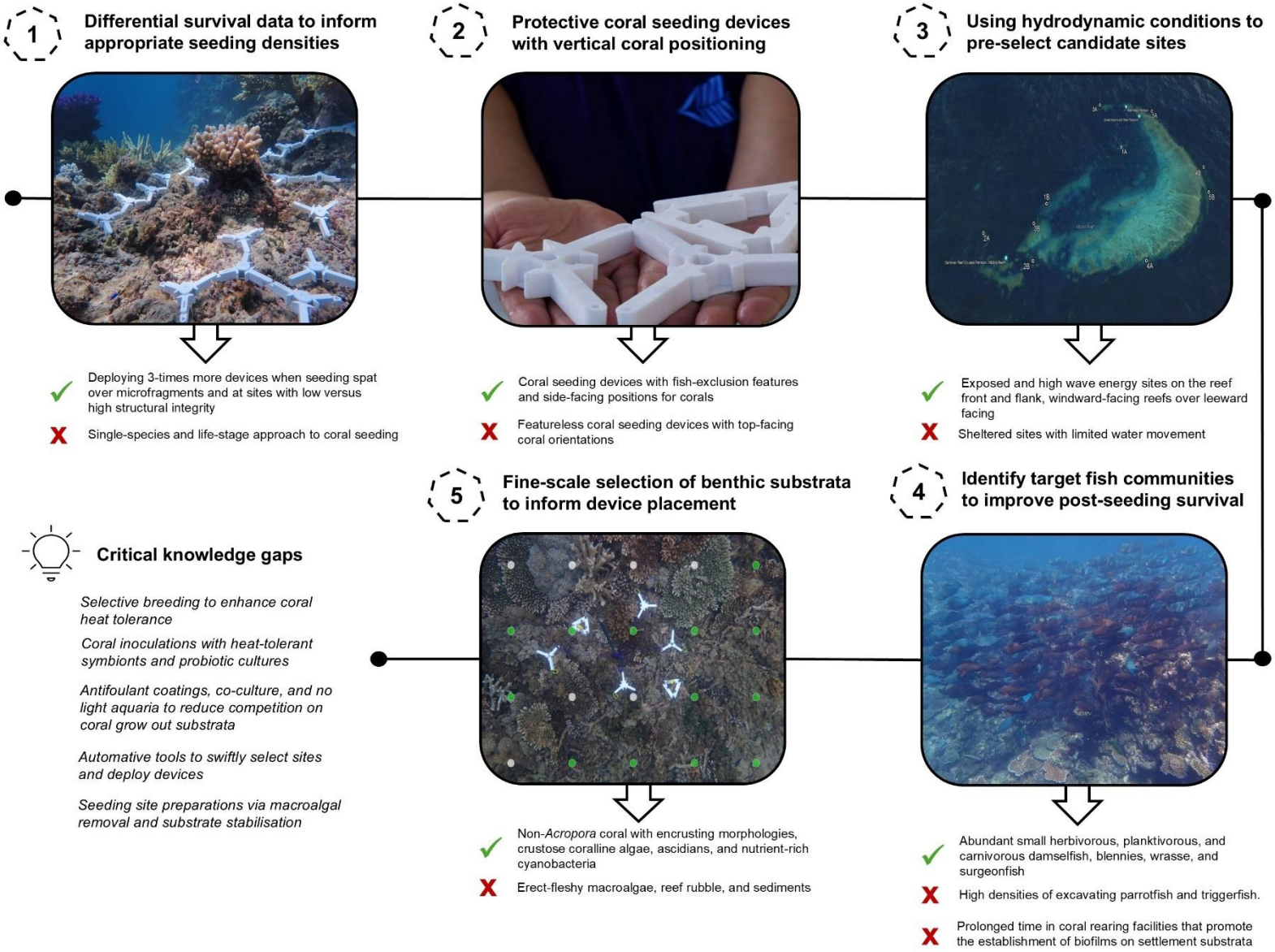


Figure 5.1 Five recommendations to improve the efficacy of coral seeding and the critical knowledge gaps that remain.

Using differential survival data to inform appropriate seeding densities

Differential survival data across coral life-history stage, species, and habitat type, can help inform optimal deployment densities to achieve target post-seeding numbers (Fig. 5.1). I found that microfragments had up to 3-times higher survival than spat (Chapter 2), suggesting that deploying 3-times more spat could compensate for their lower survival. It is likely that microfragments have higher survival over spat due to their age- and size-related tolerance of natural reef stressors [20,307]. While microfragments may be promising candidates for seeding in the future, and could be ideal for quickly re-establishing coral dominance on a site, sexually reproduced spat are preferred in the long-term to enhance a population's genetic diversity and produce heat tolerant corals at population scale [1,2,191]. Thus, spat seeding may be preferable in many scenarios despite requiring higher deployment densities. Regardless of whether spat or fragments are used, we should aim to maximise genotypic diversity in the corals we seed and enhance the capacity of corals to combat thermal stress. Strategies such as coral 're-skinning' [150,308], the inoculation of heat-tolerant symbionts [309–311], and the application of probiotics [312–315] are three examples to accelerate microfragment growth and potentially increase heat tolerance prior to seeding. Similarly, selective breeding [254,316–318], hybridisation [319,320], delivering heat-adapted symbionts, and probiotics could improve seeded spat survival. However, as demonstrated throughout this Thesis, the efficacy of such approaches are likely context specific and should be thoroughly explored before large-scale implementation.

Based on past research [131,145,146,192], I expected species-specific responses to coral seeding and differential survival with respect to seeding location. Interestingly however, I found similarly moderate survival (~30% tab yield) in both *Acropora millepora* and *A. digitifera* deployed across sheltered inshore (Chapter 4) and offshore (Chapter 2 and 3) environments. Moreover, *A. digitifera* spat had comparable survival in back reefs at two offshore locations: Davies Reef (Chapter 2) and Moore Reef (Chapter 3). However, in Chapter 3, I identified that *A. digitifera* has a survival optimum based on wave energy, with 3-times higher survival on the reef front and flank than on the back reef. Hence, to achieve a similar post-seeding target coral density, 3-times more spat could be deployed to the back reef to compensate for lower survival. Given the difference in natural abundance and spatial distribution of *A. digitifera* and *A. millepora* [321–323], their wave-energy optima are likely distinct. Indeed, a coral seeding experiment by Jurriaans et al. (submitted to *Ecology*) found that *A. millepora* survival was highest at sites with low-to-moderate flow rather than high flow environments, with survival optima varying with respect to reef latitude. Taken together, the optimal seeding density may be both species and environment specific, and prior to increasing the deployment density we should consider natural species and morphotaxon colonisation information. Identifying survival optima for diverse taxa will be critical for refining seeding densities across diverse environments.

The site, life stage, and species-level variability observed in this study can inform strategies to improve the odds of survival, by adjusting seeding densities accordingly. The biodiversity-ecosystem functioning theory suggests that greater trait and/or genetic diversity increases ecosystem functioning and stability over time [324,325]. For example, at restoration sites, different sized outplants can promote niche complementarity, facilitation, and support trophic feedback loops that flow on to maximise site and regional resilience following adequate dispersal—a theory tested and proved successful in terrestrial reforestation [324,326–329]. Therefore, to maximise reef restoration success, a multi-species and multi life-stage approach to coral seeding should be prioritised. Deploying both sexually produced spat and asexually produced fragments of various sizes at appropriate densities can increase the chances of survival. Overall, enhanced biodiversity could alleviate loss from size-specific differences in environmental responses, providing temporal insurance and protection to coral seeding initiatives from climatic extremes. However, decisions regarding 'who' (coral species) and 'what' (coral material) to deploy should be balanced with the availability and diversity of donor material. Equally, not all species may respond positively to coral seeding, necessitating further testing. In addition, developing a universal coral seeding device design to successfully transport and deploy corals to reefs represents another opportunity to maximise survival and streamline our efforts on 'what to deploy' moving forward.

Protective coral seeding devices with vertical coral positioning

Fish exclusion features on coral seeding devices doubled the chances of survival for corals within 24 h post seeding (Chapter 2), and the star-shaped fish exclusion device yielded consistently higher survival for both *Acropora* species compared with other device types (Chapter 3 and 4). These findings demonstrate that simple modifications to the design of commonly used coral seeding devices can improve the efficacy of coral seeding. However, although I was able to identify a top-performing design from the devices tested, further design modifications have the potential to boost coral spat survival beyond the 50% threshold. For example, full protection from large grazing fish, with the use of a caged device, yielded the highest survival of *A. digitifera* microfragments (Chapter 2). While the microfragment survival did not differ significantly between caged and fish-exclusion devices, the additional protection warrants further exploration with coral spat, given the small benefit observed for microfragments (Chapter 2) and for spat in other studies [109]. Coral seeding devices with larger protruding features and small micro-crevices for corals are two additional design modifications worth exploring. However, there needs to be a balance between providing greater protection, while still allowing adequate light and sufficient waterflow to support fast coral growth and high survival throughout early ontogeny. The protective aperture should be large enough to defend against parrotfish (initial phase and larger; Chapter 2 and 3), large surgeonfish and triggerfish (Chapter 3), yet should not inhibit the grazing of small wrasse, damselfish, and blennies on the surface of the device

(Chapter 3 and 4). The addition of foul-release coatings [233,330] on old and new device designs could also be trialed to eliminate the need for grazing to control algal competition (Montalvo-Proano et al. submitted to *Sci. Rep.*).

A second successful design modification in my experiments was the controlled spatial positioning of corals within the device to manipulate their orientation (i.e., vertical and side facing versus horizontal and top facing; Chapter 2). Side positions doubled the chances of survival, likely by providing refuge from fish, sediment accumulation, and potentially damaging exposure to high light levels – an effect observed for both coral spat and microfragments. Indeed, there are several studies that highlight the importance of settlement orientation during early ontogeny [35,131,177,331,332], and a recent coral seeding trial by Page et al. (2024) found that coral spat in side-facing positions outperformed those in downward-facing positions, attributing this advantage to coral size and benthic competition [192]. Bryozoans, commonly found on reef substrata in low-light environments, were found to be detrimental to coral survival in this Thesis (Chapter 3) and others [228]. Parrotfish also show an affinity towards grazing on horizontal and convex surfaces over those that are vertical and concave [180]. Collectively, these finding suggest that vertical and side-facing orientations within devices offer protective advantages, reducing mortality from benthic competitors, incidental predation, and sediment deposition, which is more likely to occur on corals in horizontal and top-facing positions [44,84,333,334].

Sediment accumulation may explain why the star-shaped fish-exclusion device outperformed the triangular-shaped design in Chapter 4. Loose sediments and rubble can accumulate in crevices causing abrasion and smothering to sessile benthic organisms inhabiting these environments [44,223,231,299]. Although I did not directly track sediment accumulation on devices, I observed particulate material becoming trapped within the central cavity of the triangular device, potentially increasing coral mortality compared to other device types without a central cavity. Similarly, in the absence of sediment accumulation, the inward facing tabs of the triangular device could have been light limited, promoting growth of highly competitive organisms (i.e., bryozoans) and promoting mortality similar to that on downward-facing device positions used by Page et al. (2024). Fine-scale observations of both sediment accumulation and light quality would be required to verify these hypotheses. However, it is important to note that on sediment- and rubble-dominated reefs, corals may experience high mortality regardless of the device type used (Chapter 3 and 4). Exploring options to encourage device cementation (i.e., devices linked in chains) and vertical relief (i.e., devices fixed above the substrata) are potential strategies to improve the fate of corals in response to excess rubble and sediments. Additional stabilisation methods, including structural frames [301], underwater adhesives, and biodegradable nets [235] may help secure mobile rubble prior to the deployment. While large-scale coral seeding is not feasible with external structures such as frames or cages, these features may be important at

local and limited scales to aid in the recovery of severely degraded reefs. An iterative design process that explores small modifications within the device structure should be prioritised, and pre-deployment assessments of the seeding site should be conducted before the devices are deployed to match device type with environment.

Using hydrodynamic conditions to pre-select candidate sites

Using spatial habitat prediction models to pre-select sites based on wave energy data proved to be a useful tool for coral seeding (Chapter 3). After one year, more than 80% of devices deployed to exposed sites on the reef front and flank yielded live *A. digitifera* corals; suggesting that prioritising these locations could reduce the number of devices required for seeding and improve survival of this species. Spatial maps that include a suite of environmental and physical data may therefore streamline site-selection decisions [208–210]. Moreover, by understating seeding site performance, we can fine-tune target numbers for the deployment and balance this information with respect to the natural distribution of a coral species or morphotaxon to achieve the same target densities across diverse habitats. Selecting sites with moderate to high exposure provides a good starting point, but there are additional considerations (e.g., coral abundance and recruitment data) that could be incorporated to further refine predictions and enhance outcomes.

Models incorporating a suite of informative data from existing recruitment literature will be essential for the future success of coral seeding. For example, coral population models that interrogate the effects of larval connectivity, reef hydrodynamics, and Allee effects on natural coral recruitment [335–338] can provide critical insights for seeding strategies. At large spatial scales (100s-of-m or more), connectivity models could identify isolated reefs and coral populations lacking natural recovery potential, highlighting areas that require human intervention. At finer, within-reef scales (100s-of-m or less), models that incorporate Allee effects on coral fertilisation, larval production, and natural recruitment [336,339,340] could help inform device positioning within reefs to ensure seeded corals improve the population's reproductive capacity. For example, placing corals less than 10-m apart could promote high fertilisation success between seeded individuals once sexual maturity has been reached (within 3-5 years of seeding) [336]. However, the spatial distribution needs to be well balanced since coral disease transmission is also spatially mediated [341–343]. Prioritising high density but isolated patches, could promote within patch reproduction and limit disease transmission to neighboring patches. Information on the main cause of coral decline within an environment, in relation to biological drivers of recruitment success or failure, should also be considered when refining these models.

Consistent with the metacommunity theory, dispersal dynamics and spatial processes influence community establishment and the long-term persistence of restored corals [324,344]. Similarly, self-organisation theory

suggests that community restoration should benefit from spatial patterning, with recovery times shortened if the spatial dynamics mimic the original pattern of the ecosystem [324,345,346]. For example, networks of marine protected areas in the United States were designed based on the spatial patterning and metacommunity framework, with the number of habitats, their size, and spacing determined by models of water movement, larval dispersal, and spatial population dynamics [324,347,348]. Spatial patterning has also proved effective in mussel restoration, where a banded outplanting pattern facilitated increased survival over random and equally-spaced patterning [349]. To optimise the conservation and economic outcomes of coral seeding on the GBR, model frameworks that rank potential restoration sites based on positive ecological (environmental and biological) drivers of coral persistence [350–352] warrant urgent investigation and testing. Beyond site selection, fine scale ecological dynamics could help to further refine the spatial positioning of corals within sites (10s-of-m or less) enhancing survival and seeding outcomes.

Identifying target fish communities to improve post-seeding survival

Critical insights into the fundamental role of grazing fish in the coral recruitment process were identified from my three experiments. Most importantly, I identified that scraping-herbivorous parrotfish which target algae and bacterial biofilms can be extremely damaging to exposed corals (Chapter 2). Coral spat and microfragments deployed in featureless control devices were severely grazed; however, the grazing was considered indirect – most bites were constrained to the conditioned settlement plug rather than the corals themselves. The fish species responsible for this grazing, *Scarus rivulatus* and *S. globiceps*, and most other scraping parrotfish, are known to be herbivorous [180,183,199]. Moreover, the conditioned settlement plugs contained a mixed community of nutritious crustose algae and bacterial biofilms, likely attracting grazing fish towards early successional biofilms (containing small spat) over larger areas of coral tissue when feeding. The high mortality of coral spat (up to 95% at one site) and minimal damage to microfragments (< 50% at the same site) supports this hypothesis (Chapter 2). Over 90% of the spat plug was covered by bacterial-algal communities in comparison to < 20% on microfragment plugs; therefore, the consumption of spat may have been merely accidental in the attempt to graze more bacterial-algal surface area. Furthermore, when more nutritious food sources, such as mat-forming cyanobacteria, were present at the seeding site, fewer seeded corals were grazed (Chapter 2). Although grazing appears largely accidental, survival odds can be improved by using fish-exclusion devices and targeting sites with abundant alternative food sources for herbivorous fish.

Reducing the cover of bacterial-algal biofilms on coral settlement plugs my further enhance coral seeding efficacy. Although I did not directly compare conditioned versus unconditioned settlement plugs in my experiments, eliminating the cover of well-established early successional biofilms on coral settlement tabs

was one aspect I explored in Chapter 3. Interestingly, I was able to reduce the growth of crustose coralline algae (CCA) on tabs by growing corals in aquaria in complete darkness. Like the results of other studies [59], I observed high survival and reduced benthic competition for corals by rearing with very little or no light; furthermore, there was reduced grazing-related mortality post seeding in this experiment (Chapter 3) compared with my previous experiment (Chapters 2). The reduction in grazing-related mortality supports the hypothesis that parrotfish are accidentally grazing corals as they bite and scrape the settlement substrate for preferable foods. Further research into biofilm reduction strategies on coral settlement substrata is urgently needed. Potential approaches include co-culturing corals with small invertebrate grazers [353–355], or applying antifoulant waxes and paints to settlement substrates, as commonly used antifoulants and foul-release coatings appear to be nontoxic to young corals to date [233,330].

Table 5.1 Reef fish, their densities, and the interactive ecological drivers that affect coral survival and growth post seeding. 'nd' signifies no available data.

Fish Group	Taxa	Relationship to survival	Relationship to growth	Relevant density	Ecological driver
Labridae (Scarinae) 	*Scarus globiceps* *Scarus dimidiatus* *Scarus schlegeli* *Scarus rivulatus* (initial phase) *Chlorurus microrhinos* All Scarini spp.	Feeding (negative) Feeding (negative) Feeding (negative) Abundance (negative) Abundance (negative) Feeding (negative)	nd nd nd Abundance (negative) Abundance (negative) Feeding (no effect)	> 25 bites min^{-1} m^2 > 25 bites min^{-1} m^2 > 25 bites min^{-1} m^2 5 fish 39.25 m^2 5 fish 39.25 m^2 > 0.2 bite min^{-1} m^2	Benthic organisms, wave exposure, sedimentation
Labridae (Odicinae) 	*Thallasoma amblycephalum* *Gomphosus varius* *Halichoeres* spp.	Abundance (positive) Abundance (positive) Feeding (positive)	Abundance (negative) Abundance (negative) Feeding (no effect)	3 fish in 39.25 m^2 5 fish in 39.25 m^2	Benthic organisms, mobile invertebrates, sedimentation, fine-scale water movement
Blennidae	*Cirripectes spp.* *Ecsenius spp.*	Feeding (positive) Feeding (negative)	Feeding (no effect) Feeding (no effect)	1.5 bites min^{-1} m^2 0.2 bites min^{-1} m^2	Benthic organisms, wave exposure, fine-scale water movement, sedimentation
Balistidae 	*Suffamen chrysopterum*	Abundance (negative)	nd	0.5 in 39.25 m^2	Wave exposure
Pomacentridae 	*Pomacentrus* spp. *Pomacentrus* & *Chromis* spp.	Feeding (no effect) Abundance (positive)	Feeding (positive) Abundance (no effect)	4 bites min^{-1} m^2 50 in 39.25 m^2	Wave exposure, benthic organisms, sedimentation
Acanthuridae 	*Acanthurus lineatus* *Zebrasoma scopus*	Abundance (positive) Feeding (positive)	Abundance (positive) Feeding (no effect)	10 in 39.25 m^2 0.2 bites min^{-1} m^2	Benthic organisms, mobile invertebrates, sedimentation, fine-scale water movement

Selecting sites based on the presence of beneficial fish communities (Table 5.1) represents another technique to improve the odds of coral survival. I found the presence of wrasse and surgeonfish, as well as feeding from large herbivorous blennies, to be positively related to coral survival (Chapter 3 and 4), while the abundance of excavating parrotfish and some species of triggerfish were harmful to corals (Chapter 3). This information can help guide the spatial deployment of devices within reefs (i.e., spatial scale 10s-of-m) to maximise survival outcomes. For example, pre-deployment surveys (i.e., by divers and video recordings) can be used to assess fish communities at potential sites identified by predictive modelling. By characterising existing fish communities, practitioners can make decisions on 'where to' and 'where not to' deploy. The abundance of target fishes and their feeding activity observed in surveys could also be used to rank sites, streamlining the selection process. Pre-deployment surveys could provide valuable information to design coral seeding devices best suited for a given site, by providing insight into the types of fish with which corals may interact.

High wave-exposed sites of the mid-shelf GBR (Chapter 3) and windward-facing reefs of the inshore GBR (Chapter 4) appear to support moderate-to-high abundance of small herbivorous and carnivorous fishes, making them promising candidates for future deployments. Similarly, prioritising sites that are well monitored and protected in reserves with healthy fish stocks (i.e., those that have recovered from overfishing or past disturbances) are preferable to deploying at locations outside of reserves, without pre-existing ecological data. Establishing new monitoring programs and marine reserves around highly damaged reefs should also be considered, and in extreme cases, boosting fish biomass via manipulations to the larval supply (i.e., enriching marine soundscapes [356,357]) could be trialed to return fish stocks to a desirable range. A diverse fish community spanning multiple functional groups, is critical to maintain coral dominance over tough benthic competitors such as macroalgae and filamentous cyanobacteria, which are expected to persist with increases to their biomass under ocean warming. However, the coral-fish relationship is multifaceted, is subject to change as climate conditions worsen [98,99,163,358], and there are some benefits of reduced fish functionality for seeded corals that I will describe in more detail in the section below. According to the food web theory, habitat equilibrium and early recovery are best maintained when producers, consumers, and predators are well balanced (i.e., top-down pressure equals bottom-up pressure) [324,359], and community equilibrium may be severely compromised with the loss of keystone and foundational species [360,361]. Therefore, ongoing monitoring programs that track fish communities and benthic trajectories will be critical to gauge the success of coral seeding interventions.

Fine-scale selection of benthic substrata to inform device placement

Incorporating the abundance of key benthic groups (e.g., Scleractinian corals, algae, and ascidians) into pre-deployment assessments can inform site selection – 'where to deploy' – at m-scales within a site. Doing so could help avoid substrata with erect-fleshy macroalgae, high-relief coral growth forms (i.e., branching and tabulate), and loose sediments and rubble, which were shown to be detrimental to corals (Chapter 3 and 4), and instead select for areas with CCA, ascidians, and encrusting corals that are beneficial to seeded coral survival (Chapter 3). Applying facilitation theory-informed approach, which takes advantages of beneficial interactions to improve efficacy in unstable and highly disturbed habitats [324,362,363], may be required for coral seeding. Indeed, stress amelioration by neighbouring organisms is critical to survival in harsh environments, and the facilitation approach to restoration has proved successful in prairie grasslands [364,365], rocky intertidal zones, and seagrass habitats [366–368]. Therefore, optimising substratum selection for device placement has the potential to significantly improve coral survival and maximise the ecological impact of restoration programs.

The mechanisms driving the relationships between benthic organisms and coral survival may primarily relate to the inequality of competitive outputs (e.g., unequal growth, allelochemical production, etc.) and the physical factors driving fine-scale light availability and water flow. Macro- and filamentous algae are particularly tough competitors, and as climate conditions worsen, shifts from coral-dominated to algal-dominated ecosystems become increasingly likely [69,70,73,75,369,370]. Competition theory suggests that manipulating both the strength and likelihood of competition is critical to reducing competitive hierarchies that would otherwise suppress restoration efficacy [324,371]. Similar principals have been applied in terrestrial ecosystems, where the removal of invasive and native competitors has proven important in restoring wetland prairie seedbanks [372–374]. Although selecting locations with naturally low macroalgal cover represents a potential strategy for coral seeding, other active interventions could also be explored [234,235]. For instance, removal of macroalgae on inshore reefs of the central GBR led to a 47% increase in coral cover, with macroalgae abundance decreasing by half and stabilising to a low abundance within three years [234,296]. Preparing a site through macroalgal removal could therefore encourage long-term coral persistence after seeding. This technique can also be low-tech and low-cost, making it accessible to local communities and coral seeding end users. Further research into repurposing removed algal biomass – such as recycling into materials for device production – could enhance the sustainability of this approach in coral seeding programs.

Automated camera surveillance with artificial intelligence (AI), offers a promising alternative to *in situ* pre-deployment surveys by divers. This technique could streamline the pre-deployment assessment process, reducing labor-intensive fieldwork, and is currently being developed and trialed on Australian reefs (e.g., ReefScan; https://www.aims.gov.au/research/technology/reefscan). However, significant AI training should be conducted prior to use. Online and user-friendly platforms such as the ReefCloud identification software (https://reefcloud.ai/ [375]) used in this Thesis, and others [376,377], can help with model training. However, to ensure accuracy, training and updates should be regularly undertaken, with new images scored to account for the seasonal- and site-specific variability that influences community composition over time. Although technological advancements may be necessary to restore reefs at large spatial scales (1 km or more), low-cost and simple techniques may remain the most practical option for local, community led restoration efforts.

Managing our expectations of reef restoration into the future

While the criteria I have identified for deploying sexually produced spat and asexually produced microfragments will enhance the efficacy of coral restoration at scale, it is important to manage expectations for active reef restoration interventions in the face of rapid climate change. The non-linear disturbance

threshold theory states that disturbance thresholds are not uniform among complex ecosystems including coral reefs, but there are both active and passive ways to influence the ecosystem tipping points [378–381]. Without intervention, abrupt and frequent change may lead to ecosystem collapse (the 'do-nothing' scenario), with even keystone grazers lowering disturbance thresholds of salt marshes [382] and temperate forests to droughts [383,384]. Active interventions that modify grazer interactions can buy time for ecosystem recovery. Given the slow natural recruitment processes on coral reefs [17,114,132–136], coral seeding – particularly when combined with grazing protection strategies – could make a significant impact. However, the measurable impact of these interventions may take longer to become evident.

It is also important to consider that many restoration tools in development are high-tech, expensive, or require specialised training, potentially limiting their use in developing nations. This is concerning, as many developing-Island communities rely heavily on coral reefs for food security and coastal protection, yet their reefs are among the most vulnerable to climate change. Therefore, the identification of cheap, simple, and low-tech methods for reef monitoring and community-led reef restoration programs needs to be explored. One promising approach is pool-based in-water rearing for coral seeding [267,385–387], which offers an alternative approach to conventional methods. When combined with insights from this Thesis, such as optimised device design, density, and location, this method represents a low-tech initiative to suit a broader suite of users across the globe. Low-tech initiatives could provide the knowledge base for future trials, with high-tech and novel technologies utilised in nations with adequate resources and funding. Discussions on equitable access to restoration tools should be prioritised to ensure developing nations have the knowledge and opportunities to achieve effective restoration outcomes moving forward.

Managing our approach to coral seeding and recalibrating our expectations of 'reef health' and 'intervention impact' will be essential to modern coral restoration. Even with intervention, coral cover will continue to decline under all future climate-change scenarios, and some restored corals and their populations will perish in severe heatwaves. However, this does not diminish their ecological value while alive – they contribute to reef structure, biodiversity and ecosystem function during their lifespan. Meaningful restoration will require best-practice management techniques that incorporate disturbance histories and future projections of candidate reefs for coral deployments. A better understanding of marine reserve compliance, reef values, and community expectations should also be defined in combination with discussions around the best way to seed corals to reefs (decisions based on resources and local reef dynamics). Continuous monitoring and possible changes to the best suited intervention should be planned for. Reef-scale restoration will require an iterative problem-solving approach, where research and development occur alongside community action to put forth best practice tools.

Concluding remarks

This research provides empirical evidence to optimise coral seeding strategies, addressing three key questions:

(1) Who to seed?,
(2) What to seed?, and
(3) Where to seed?

Both coral spat and microfragments can be used for coral seeding, but life-stage specific seeding densities should be considered. Coral seeding devices should incorporate fish-exclusion features and side-facing spatial positioning to improve survival outcomes. Site selection for coral seeding should prioritise:

(1) Using reef exposure to pre-select candidate sites,
(2) Sites with abundant small fish (Acanthurids, Blennids, Labrids, Pomacentrids), and
(3) Sites that include non-*Acropora* coral, crustose algae, and ascidians.

Site preparations may be required on severely degraded reefs and for locations abundant with erect-fleshy macroalgae, loose sediments, and unconsolidated rubble. To maximise reef restoration success, coral seeding practitioners should:

(1) Continuously monitor their interventions,
(2) Communicate findings, and
(3) Adapt/refine techniques in response to a changing climate.

An evidence-based and flexible approach will be important to ensure the enduring viability of coral seeding as a restoration tool into the future.

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Appendices

Appendix A: Supplementary Material to Chapter 2

A.1 Methods

A.1.1 Spawning, larval culture and settlement

Table A1. Spawning, larval culture and settlement information for 13 *Acropora digitifera* broodstock colonies collected for autumn coral spawning in March 2021. An asterisk * identifies the larval culture used for seeding due to high settlement success and strong post-settlement survival.

Spawning and Culture Information					
Colony	**Spawn Date (d/m/yyyy)**	**Time**	**Spawn Amount**	**Culture Number**	**Gamete Contribution**
1	9/3/2021	21:27-22:30	Partial	0*	Egg and Sperm
	10/3/2021	21:42-22:37	Partial	3	Egg and Sperm
2	10/3/2021	21:49-22:37	Full	1 (A and B)	Egg
				2 (A and B)	Sperm
3	9/3/2021	21:27-22:30	Partial	0*	Egg and Sperm
	10/3/2021	21:38-22:37	Full	1 (A and B)	Egg
				2 (A and B)	Sperm
				3	Egg and Sperm
4	10/3/2021	21:43-22:37	Full	1 (A and B)	Egg
				2 (A and B)	Sperm
				3	Egg and Sperm
5	10/3/2021	21:45-22:37	Full	1 (A and B)	Egg
				2 (A and B)	Sperm
				3	Egg and Sperm
6	10/3/2021	21:40-22:37	Partial	0*	Egg and Sperm
				2 (A and B)	Egg
				3	Egg and Sperm
7	10/3/2021	21:55-22:37	Full	1 (A and B)	Sperm
				2 (A and B)	Egg
				3	Egg and Sperm
8	10/3/2021	21:38-22:37	Full	1 (A and B)	Sperm
				2 (A and B)	Egg
				3	Egg and Sperm
9	9/3/2021	21:27-22:30	Nearly full	0*	Egg and Sperm
	10/3/2021	21:45-22:37	Full	1 (A and B)	Egg
				2 (A and B)	Sperm
				3	Egg and Sperm

10	10/3/2021	21:49-22:37	Full	1 (A and B)	Sperm
				2 (A and B)	Egg
				3	Egg and Sperm
11	10/3/2021	21:50-22:37	Partial	2 (A and B)	Egg
				3	Egg and Sperm
12	10/3/2021	21:45-22:37	Partial	1 (A and B)	Sperm
				2 (A and B)	Egg
				3	Egg and Sperm
13	10/3/2021	21:45-22:37	Full	1 (A and B)	Sperm
				2 (A and B)	Egg
				3	Egg and Sperm

Field collected CCA specimens (target genera: *Porolithon*, *Lithophyllum*, and *Titanoderma*) were used to accelerate the plug-conditioning process. The CCA specimens were collected from Davies Reef (February 2021) in compliance with permit G21/38062.1 issued by the Great Barrier Reef Marine Park Authority. After 2 months, the frag plugs comprised an early-successional and mixed community of CCA and biofilms. The CCA and bacteria were not classified to species but were sufficiently inductive, with high numbers of larvae settled on plugs after 24 h (~9 spat per plug).

A.1.2. Biological and environmental data collection

Table A2. Site location and data collection for the coral seeding experiment at Davies Reef. Data collection was attempted over three timepoints 2, 90 and 240 days after seeding and at all four sites. The "✓" reflects a successful collection of data at all sites, while the "☒" refers to an unsuccessful attempt at all four sites. Poor weather, due to winds, tides, and waves was the main cause of unsuccessful data collection.

Site Name *(Davies Reef, mid shelf, Great Barrier Reef)*	**Site Coordinates**	
	Latitude	**Longitude**
Site 1	-18.826097°	147.627017°
Site 2	-18.818100°	147.632533°
Site 3	-18.819533°	147.631233°
Site 4	-18.820600°	147.630633°

Data Collection	**Days Seeded**		
	2 days	**90 days**	**240 days**
Coral survival (plug images)	✓	✓	✓
Fish grazing (plug images)	✓	☒	☒
Fish counts (diver survey)	✓	✓	✓
Fish feeding (video survey)	✓	✓	✓
Benthic quadrat (images)	✓	✓	✓
Benthic transect (images or video)	✓	✓	✓
Benthic transect (diver survey)	✓	☒	☒
Sediment pods (deployment and retrieval)	✓	✓	☒
Clod cards (deployment and retrieval)	✓	✓	☒

A.1.3. Fish video selection process and data recording for grazing pressure

Table A3. Detailed information from the GoPro video analysis to quantify grazing pressure. Categories are explained via definitions and possible response. Data entries were taken for each individual fish that was observed to be grazing in the experimental plot. Not all categories were used in the data analysis.

GoPro Video Analysis: Data collection metrics, descriptions, and potential responses		
Metric	**Description**	**Possible Response**
Sea state	Refers to the state of the water with regards to the weather conditions due to wind, waves, and current.	Calm (0-1.1 km/h), Light (1.1-12.6 km/h), Gentle (12.6-19.8 km/h), Moderate (19.8-28.8 km/h), Fresh (28.8-38.9 km/h)
Visibility	Referring to the sea state, regarding the distance (m) a diver/data recorder can visibly see and identify objects.	< 5m, 6-10m, 11-15m, 16-20m
Family	Refers to the taxonomic family for each fish identified.	Labridae, Pomacentridae, Acanthuridae, Blastidae, Blennidae, Chaetodontidae, etc.
Interval	A number that refers to the feeding approach and start of a feeding foray for an identified fish. The interval stops when a fish swims up, away from the substrate, and can have 1 or more bites.	Integer value, ranging from 1 to 50
Bites	The number of bites a fish takes during a single feeding foray/interval.	Integer value, ranging from 1 to 75
Grazing location	The location of the identified fish bite/graze.	Substrate, device, or plug
Plot type	Refers to the number of devices in each video and experimental plot, either three devices (cage, control, and exclusion) or two devices (control and exclusion).	Triplicate or pair
Time	Refers to the time the fish swims on screen and into the video frame. Screenshot images were taken of each individual fish for identification at this time point.	Between 1-12 minutes (e.g. 01:30)
Comments	Anything worth noting that was observed in the video.	Aggressive damselfish, invertebrate grazer in plot, diver present on video, camera knocked from original placement point, transect tape or star picket in view, etc.

Replicate video clips (n=6-12; 12 min recording per clip) per replicate GoPro (n=2) per deployment (n=2, 1 morning and 1 afternoon) were captured for each site for each of three timepoints (2, 90 and 240 days) after coral seeding. In some cases, the videos files became corrupted or damaged. This resulted in a total of 33-35 replicate clips (396-420 minutes of footage) per site used from two time points (2 and 240 days) in

the final analysis, and included a minimum of six replicate video clips, one replicate GoPro and one deployment per timepoint.

Video clips were analyzed individually using VLC media player software. The first and last clip in a GoPro deployment series were avoided to ensure fish remained undisturbed by divers (i.e., only clips 2-11 were used if 12 clips were recorded on a camera). A fish of interest was defined as an individual grazing within "two device lengths" from the seeding devices in the video frame, which encompassed the 0.25 m2 experimental plot where devices were fixed to the reef. For each grazing fish seen, the following data were collected: (1) species, (2) number of bites per feeding foray (i.e., total bites per feeding attempt), (3) the location of the bite (substrate, device or plug), and (4) the plot type (triplicate or pair). Therefore, if a fish swam out of the frame and came back, it was counted as a new individual. One observer was used to reduce variability in the data. Fish images (screen grabs from video clips) and video times were used by a second observer for quality control checks and fish species identification. The data were expressed per video clip as bites per species and bites per minute. The environmental conditions were also recorded for each clip to better explain outliers in the data set (Table S3).

A.1.4. Sediment sampling and processing

Sediments deposition on deployed pods (Sed Pod and Turf Pods) were rinsed into individual clean containers (2 L plastic Tupperware). A minimum of five rinses with Reverse Osmosis (RO; 1 L) water were used to remove salts from samples. In between rinses a minimum of 3 hours settling time was used to ensure all sediment material had fallen out of suspension. Once sediments had settled out the RO water was siphoned off (Air Admiral® P-79202-05, 230V, 50Hz) and 1 L of new RO water was added. The final rinse included a 24-hr settlement period. After five rinses, the samples were placed in the oven (Microprocessor Temperature Controller, Clayson OM1000) at 103-105 °C for 24 hrs. The dried samples were then placed in a glass vacuum desiccator (United Scientific DSGL150) with silica beads for 1 hr and then weighed (analytical balance, KERN Pes version 1.6) to calculate a total mass. Prior to sample drying, aluminium dishes were pre-heated in the oven (103-105 °C for 1hr) then cooled in the desiccator for 1hr. Weight of the aluminium dishes were taken, and this was used as the pre-sample weight. Total mass was calculated by subtracting the pre-sample weight (aluminium dish only) from the end sample weight (aluminium dish with sediment sample). Prior to sampling, visual inspections of pod, pod cap and collection bags (2 L plastic freezer bags) were conducted to identify tears, leaks and/or damage to the pod, and these samples were discarded.

A.2 Results

A.2.1. Coral survival

Table A4. Model output for coral survival data. Generalized linear mixed effects (GLMM; R Software) models were used with coral survival as the response and device type, plug position, survey timepoint or site as predictors; the exact model used for each output is defined in the table. Significance codes represent p values with "*" as <0.05, "**" as <0.01, and "***" as <0.001.

Coral Survival Models					
Model 1					
GLMM fit by maximum likelihood (Laplace Approximation) Family: binomial (logit) Formula: Survival ~ DeviceType * PlugPosition + Timepoint + LifeStage + (1 | Site) No. Observations: 2456 No. Groups: Site, 4					
	estimate	**std.err**	**z.value**	**p.value**	**signif.code**
(Intercept)	21.585	24.778	0.871	0.384	
Device Type Exclusion	0.678	0.228	2.979	0.003	**
Device Type Cage	1.351	0.489	2.765	0.006	**
Plug Position Top	-0.653	0.198	-3.298	0.001	***
Timepoint 2	-17.676	24.778	-0.713	0.476	
Timepoint 90	-19.831	24.778	-0.800	0.424	
Timepoint 240	-20.472	24.778	-0.826	0.409	
Life Stage spat	-3.154	0.207	-15.232	0.000	***
Device Type Exclusion: Plug Position Top	0.452	0.304	1.485	0.138	
Device Type Cage: Plug Position Top	1.584	0.876	1.809	0.070	
Model 1: *Planned comparisons*					
Device Type					
Results for coral spat	**estimate**	**std.err**	**z.value**	**p.value**	**signif.code**
Exclusion Side - Control Top (Timepoint 2)	1.331	0.217	6.145	0.000	***
Control Top - Exclusion Top (Timepoint 2)	-1.130	0.208	-5.437	0.000	***
Control Top - Exclusion Top (Timepoint 90)	-1.130	0.208	-5.437	0.000	***
Exclusion Side - Control Top (Timepoint 240)	1.331	0.217	6.145	0.000	***
Control Top - Exclusion Top (Timepoint 240)	-1.130	0.208	-5.437	0.000	***
Results for coral microfragments	**estimate**	**std.err**	**z.value**	**p.value**	**signif.code**
Control Top - Exclusion Top (Timepoint 2)	-1.130	0.208	-5.437	0.000	***
Control Top - Cage Top (Timepoint 2)	-2.935	0.730	-4.021	0.042	*
Control Top - Exclusion Top (Timepoint 90)	-1.130	0.208	-5.437	0.000	***
Control Top - Cage Top (Timepoint 90)	-2.935	0.730	-4.021	0.042	*
Exclusion Side - Control Top (Timepoint 240)	1.331	0.217	6.145	0.000	***
Control Top - Exclusion Top (Timepoint 240)	-1.130	0.208	-5.437	0.000	***
Control Top - Cage Top (Timepoint 240)	-2.935	0.730	-4.021	0.042	*
Time					
Results for coral spat	**estimate**	**std.err**	**z.value**	**p.value**	**signif.code**
2 vs. 90 days					
Control Side - Control Side | Control Top - Control Top	2.155	0.252	8.550	0.000	***
Exclusion Side - Exclusion Side | Exclusion Top - Exclusion Top	2.155	0.252	8.550	0.000	***
90 vs. 240 days					
Control Side - Control Side | Control Top - Control Top	0.641	0.160	4.019	0.042	*
Exclusion Side - Exclusion Side | Exclusion Top - Exclusion Top	0.641	0.160	4.019	0.042	*
Results for coral microfragments	**estimate**	**std.err**	**z.value**	**p.value**	**signif.code**
2 vs. 90 days					

Control Side - Control Side | Control Top - Control Top	2.155	0.252	8.550	0.000	***
Exclusion Side - Exclusion Side | Exclusion Top - Exclusion Top	2.155	0.252	8.550	0.000	***
Cage Top - Cage Top	2.155	0.252	8.550	0.000	***
90 vs. 240 days					
Control Side - Control Side | Control Top - Control Top	0.641	0.160	4.019	0.042	***
Exclusion Side - Exclusion Side | Exclusion Top - Exclusion Top	0.641	0.160	4.019	0.042	***
Cage Side – Cage Side | Cage Top - Cage Top	0.641	0.160	4.019	0.042	***
Microfragment vs. Spat	**estimate**	**std.err**	**z.value**	**p.value**	**signif.code**
2 days					
Control Side *MF* - Control Side *S* | Control Top *MF* - Control Top *S*	3.154	0.207	15.232	0.000	***
Exclusion Side *MF* - Exclusion Side *S* | Exclusion Top *MF* - Exclusion Top *S*	3.154	0.207	15.232	0.000	***
90 days					
Control Side *MF* - Control Side *S* | Control Top *MF* - Control Top *S*	3.154	0.207	15.232	0.000	***
Exclusion Side *MF* - Exclusion Side *S*	3.154	0.207	15.232	0.000	***
240 days					
Control Side *MF* - Control Side *S* | Control Top *MF* - Control Top *S*	3.154	0.207	15.232	0.000	***
Exclusion Side *MF* - Exclusion Side *S* | Exclusion Top *MF* - Exclusion Top *S*	3.154	0.207	15.232	0.000	***
Model 2					
GLMM fit by maximum likelihood (Laplace Approximation)					
Family: binomial (logit)					
Formula: Survival ~ Site + DeviceType + LifeStage + (1/DeviceNumber) + (1 | PlugPosition)					
No. Observations: 614					
No. Groups: Plug Position, 2					
	estimate	**std.err**	**z.value**	**p.value**	**signif.code**
(Intercept)	0.921	0.290	3.180	0.002	**
Site2	-0.076	0.296	-0.255	0.798	
Site3	-0.154	0.296	-0.522	0.602	
Site4	-0.092	0.303	-0.303	0.762	
DeviceType Exclusion	0.818	0.221	3.699	2.2e-04	***
DeviceType Cage	2.105	0.536	3.928	8.6e-05	***
LifeStage spat	-3.412	0.385	-8.855	2e-16	***

A.2.2. Coral grazing

Table A5. Model output for coral grazing. Generalized linear mixed effects (GLMM; R Software) models were used with coral grazing by fishes as the response and device type (control and exclusion), plug position (top and side), survey timepoint (2, 90, and 240 days) and site (n=4) as predictors; the exact model used is defined in the table. Significance codes represent p values with "*" as <0.05, "**" as <0.01, and "***" as <0.001.

Grazing Model					
GLMM fit by maximum likelihood (Laplace Approximation)					
Family: binomial (logit)					
Formula: Grazing ~ DeviceType * PlugPosition + LifeStage + Site + (1 | DeviceNumber)					
No. Observations: 380					
No. Groups: Device Number, 149					
	estimate	**std.err**	**z.value**	**p.value**	**signif.code**
(Intercept)	-0.874	0.491	-1.779	0.075	
Device Type Exclusion	-2.722	0.570	-4.777	0.000	***
Plug Position Side	-0.830	0.393	-2.113	0.035	*
Life Stage spat	0.678	0.373	1.819	0.069	

Site2	-0.070	0.590	-0.119	0.905	
Site3	3.484	0.710	4.910	0.000	***
Site4	1.031	0.586	1.761	0.078	
Device Type Exclusion: Plug Position Side	-2.940	1.176	-2.501	0.012	*
Planned Comparisons					
Device Type					
Results for coral spat	**estimate**	**std.err**	**z.value**	**p.value**	**signif.code**
Control Top - Exclusion Top	2.722	0.570	4.777	0.001	**
Control Side - Exclusion Side	5.662	1.201	4.713	0.001	**
Results for coral microfragments	**estimate**	**std.err**	**z.value**	**p.value**	**signif.code**
Control Top - Exclusion Top	2.722	0.570	4.777	0.001	**
Control Side - Exclusion Side	5.662	1.201	4.713	0.001	**
Site					
Results for coral spat	**estimate**	**std.err**	**z.value**	**p.value**	**signif.code**
Site 1 - Site 3	-3.484	0.710	-4.910	0.000	***
Site 2 - Site 3	-3.554	0.677	-5.251	0.000	***
Site 3 - Site 4	2.453	0.618	3.967	0.026	*
Results for coral microfragments	**estimate**	**std.err**	**z.value**	**p.value**	**signif.code**
Site 1 - Site 3	-3.484	0.710	-4.910	0.000	***
Site 2 - Site 3	-3.554	0.677	-5.251	0.000	***
Site 3 – Site 4	2.453	0.618	3.967	0.026	*

A.2.3. Fish abundance and feeding

Table A6. Model output for *in situ* fish abundance data. Linear and mixed effects models (lm, glm and glmmTMB; R Software) were used with fish abundance or PC1 as the response and fish family, site, and survey timepoint as the predictors. Models are defined in the table. Significance codes represent p-values with "*" as <0.05, "**" as <0.01, and "***" as <0.001.

Fish Abundance Models							
Linear Models							
PC1 ~ Site	**estimate**	**std.err**	**statistic**	**cf.low**	**cf.high**	**p.value**	**signif.code**
(Intercept)	-0.425	0.128	-3.325	-0.681	-0.169	0.002	**
Site2	0.777	0.181	4.298	0.415	1.139	<0.001	***
Site3	0.648	0.168	3.847	0.310	0.986	<0.001	***
Site4	0.157	0.188	0.836	-0.220	0.534	0.407	
PC1 ~ Labridae[Scarini]							
(Intercept)	-0.304	0.169	-1.799	-0.642	0.034	0.077	
Labridae (Scarini)	0.017	0.008	1.990	0.000	0.034	0.051	
PC1 ~ Siganidae							
(Intercept)	-0.011	0.093	-0.117	-0.196	0.175	0.907	
Siganidae	0.010	0.052	0.196	-0.095	0.115	0.845	
PC1 ~ Acanthuridae							
(Intercept)	0.417	0.086	4.860	0.245	0.589	<0.001	

Acanthuridae	-0.161	0.025	-6.460	-0.211	-0.111	<0.001	***
PC1 ~ Chaetodonidae							
(Intercept)	0.601	0.102	5.878	0.396	0.806	<0.001	
Chaetodonidae	-0.146	0.021	-6.959	-0.188	-0.104	<0.001	***
PC1 ~ Pomacentridae							
(Intercept)	-0.117	0.110	-1.061	-0.338	0.104	0.293	
Pomacentridae	0.003	0.002	1.418	-0.001	0.007	0.162	

Generalized Linear Mixed Effects Model

Formula: Total_Count ~ Fish_Family + Site + Timepoint + (1 | Replicate)

Family: truncated poisson (log)

No. observations: 354

Groups (Replicates): 11

	coefficient	**std.error**	**z.value**	**p.value**	**signif.code**
(Intercept)	1.288	0.161	7.990	<0.001	***
Balistidae	-1.662	0.484	-3.433	0.001	***
Chaetodontidae	0.261	0.110	2.365	0.018	*
Labridae (Scarini)	1.713	0.093	18.428	<0.001	***
Pomacentridae	2.523	0.090	28.003	<0.001	***
Siganidae	-0.612	0.184	-3.327	0.001	**
Site 2	0.026	0.045	0.561	0.575	
Site 3	-0.378	0.051	-7.443	<0.001	***
Site 4	0.159	0.046	3.457	0.001	**
90 days	0.055	0.038	1.446	0.148	
240 days	-0.605	0.048	-12.646	<0.001	***

GLMM *Planned Comparisons*

Sites	**estimate**	**std.err**	**z.value**	**p.value**	**signif.code**
Site 1 – Site 3 (*All families*)	0.378	0.051	7.443	<0.001	***
Site 2 – Site 3 (*All families*)	0.404	0.051	7.938	<0.001	***
Site 3 – Site 4 (*All families*)	-0.537	0.051	-10.488	<0.001	***

Table A7. Model output for fish feeding (bite) data. Linear and mixed effects models (lm, glm and glmmTMB; R Software) were used with total bites or PC1 as the response and fish family or fish species, site, and survey timepoint as the predictors. Models are defined in the table. Significance codes represent p values with "*" as <0.05, "**" as <0.01, and "***" as <0.001.

Fish Feeding Models							
Linear Models							
PC1~Site	**estimate**	**std.err**	**statistic**	**cf.low**	**cf.high**	**p.value**	**signif.code**
(Intercept)	-0.181	0.090	-2.004	-0.360	-0.002	0.047	*
Site2	0.505	0.128	3.949	0.252	0.758	<0.001	***
Site3	0.110	0.128	0.858	-0.143	0.363	0.392	
Site4	0.114	0.126	0.905	-0.135	0.363	0.367	
PC1 ~ *Scarus globiceps*							
(Intercept)	-0.202	0.034	-6.037	-0.269	-0.136	<0.001	***
Scarus_globiceps	0.002	0.000	13.944	0.002	0.003	<0.001	***
PC1 ~ *Scarus schlegeli*							
(Intercept)	-0.146	0.025	-5.751	-0.196	-0.096	<0.001	***
Scarus_schlegeli	0.008	0.000	19.415	0.007	0.009	<0.001	***
PC1 ~ *Chlorurus spirulus*							
(Intercept)	-0.162	0.041	-3.950	-0.243	-0.081	<0.001	***
Chlorurus_spirulus	0.011	0.001	9.246	0.008	0.013	<0.001	***
PC1 ~ *Scarus dimidiatus*							
(Intercept)	0.002	0.048	0.043	-0.092	0.097	0.966	
Scarus_dimidiatus	-0.004	0.009	-0.391	-0.022	0.015	0.696	
Generalized Linear Mixed Effects Model (glmmTMB)							
Model – *Parrotfish species*							
Family: truncated_poisson (log)							
Formula: TotalBites ~ Species + Site + (1 | Video_Name)							
Zero inflation: ~1							
Number of observations: 8040							
Number of groups: 134							
	estimate	**std.err**	**z.value**	**p.value**	**signif.code**		
(Intercept)	1.486	0.261	5.704	<0.001	***		
Chlorurus_microrhinos	-0.128	0.091	-1.405	0.160			
Chlorurus_spirulus	0.366	0.078	4.690	<0.001	***		
Scarus_altipinnis	-2.431	0.283	-8.579	<0.001	***		
Scarus_chameleon	-3.467	0.933	-3.715	<0.001	***		
Scarus_dimidiatus	1.700	0.161	10.546	<0.001	***		
Scarus_flavipectoralis	-0.508	0.089	-5.734	<0.001	***		
Scarus_frenatus	-0.246	0.126	-1.952	0.051			
Scarus_globiceps	1.939	0.075	25.719	<0.001	***		
Scarus_niger	0.385	0.081	4.785	<0.001	***		
Scarus_oviceps	0.603	0.390	1.546	0.122			
Scarus_rubroviolaceus	-0.984	0.653	-1.507	0.132			
Scarus_schlegeli	0.953	0.078	12.183	<0.001	***		

Scarus_spinus	0.854	0.094	9.059	<0.001	***
Scarus_spp. unk	0.707	0.114	6.186	<0.001	***
Site2	1.384	0.313	4.426	<0.001	***
Site3	1.001	0.326	3.072	0.002	**
Site4	0.874	0.314	2.783	0.005	**
Planned Comparisons					
Site 1 - Site 2	**Estimate**	**Std.Error**	**z.value**	**p.value**	**signif.code**
Parrotfish species *(Chlorurus bleekeri, C. microrhinos, C. spirulus, Scarus chameleon, S. dimidiatus, S. flavipectoralis, S. frenatus, S. niger, S. oviceps, S. rubroviolaceus, S. schlegeli, S. spinus)*	-1.384	0.313	-4.426	0.013	*

Table A8. Observed bite data from GoPro Video footage. The table includes the number of observations (bites) separated by feeding category, functional group, and species by site. A total of 33-35 video clips (397 minutes of footage) per site were used from two time points (2 and 240 days).

		Number of observations by site			
		Feeding (Bites)			
Feeding category	**Functional group and species**	**Site 1**	**Site 2**	**Site 3**	**Site 4**
Herbivores	**Scraper**	**751**	**7363**	**3768**	**3779**
	Scarus globiceps	492	4720	2765	3134
	Scarus rubroviolaceus	0	0	3	0
	Scarus niger	85	171	415	415
	Scarus chameleon	0	0	2	1
	Scarus flavipectoralis	0	392	0	42
	Scarus altipinnis	0	23	0	0
	Scarus oviceps	8	0	0	0
	Scarus dimidiatus	0	0	7	70
	Scarus frenatus	7	96	5	54
	Scarus schlegeli	46	1771	505	29
	Scarus spinus	113	190	66	34
	Excavator	**170**	**1117**	**508**	**880**
	Scarus rubroviolaceus	0	0	3	0
	Chlorurus bleekeri	0	67	98	55
	Scarus altipinnis	0	23	0	0
	Chlorurus microrhinos	2	319	70	15
	Chlorurus spirulus	168	708	337	810
	Cropper	**20**	**148**	**94**	**38**
	Acanthurus nicrofuscus	0	0	42	0
	Siganus punctatus	0	104	0	0
	Siganus corallinus	1	17	1	1
	Siganus vulpinus	19	8	0	0
	Stegastes apicalis	0	19	0	23
	Chrysiptera rex	0	0	0	14
	Escenius mandibularis	0	0	51	0
	Browser	**2**	**4**	**0**	**0**
	Naso unicornis	2	4	0	0

	Brusher	**192**	**132**	**341**	**450**
	Ctenochaetus striatus	192	132	341	450
Corallivores	*Chaetodon baronessa*	10	32	31	12
	Chaetodon citrinellus	34	19	0	3
	Chaetodon trifasciatus	20	4	20	14
	Chaetodon rainfordi	64	44	9	35
	Chaetodon vagabondus	8	0	0	0
	Labrichthys unilineatus	0	0	0	9
	Escenius stictus	0	0	15	0
Omnivores	*Centropyge vrolikii*	14	0	0	0
	Pomacentrus bankanensis	301	174	380	320
	Amblygobius spp.	0	20	0	0
	Pomacentrus coelestis	0	15	0	0
	Amblygobius phalaena	0	0	0	4
Carnivores	*Epinephelus merra*	2	0	0	0
	Gomphosus varius	2	0	3	0
	Cheilinus chlorourus	3	0	0	0
	Halichoeres hortulanus	1	0	0	0
	Halichoeres marginatus	9	0	0	16
	Hemigymnus fasciatus	5	0	3	1
	Hemigymnus melapterus	3	22	7	5
	Thalassoma nigrofasciatum	13	46	18	12
	Sufflamen chrysopterum	19	0	7	6
	Cheilinus fasciatus	0	4	1	0
	Thalassoma hardwicke	0	2	12	0
	Epibulus insidiator	0	9	0	0
	Halichoeres margaritaceus	0	55	0	0
	Halichoeres melanurus	0	6	2	0
	Parupeneus bifasciatus	0	5	3	0
	Parupeneus multifasciatus	0	0	0	4
	Pomacanthus sextriatus	0	3	6	0
	Stethojulis bandanensis	0	8	4	25
	Chelmon rostratus	0	0	0	1
	Thalassoma lunare	0	1	0	0
	Coris gaimard	0	0	1	0
	Halichoeres nebulosus	0	0	18	6
	Oxycheilinus digrammus	0	0	1	0
	Coris aurilineata	0	0	0	9
Total bites		**1643**	**9233**	**5252**	**5629**

Family color codes		
	Labridae	Wrasse
	Labridae (Scarini)	Parrotfishes
	Blennidae	Blennies
	Pomacentridae	Damselfishes
	Balistidae	Triggerfishes

	Gobiidae	Gobbies
	Mullidae	Goatfishes
	Pomacanthiidae	Angelfishes
	Chaetodontidae	Butterflyfishes
	Serranidae	Groupers, Rockcods
	Acanthuridae	Surgeonfishes
	Siganidae	Rabbitfishes

A.2.4. Benthic composition

Table A9: Model output for benthic data. Linear models (lm aand glm; R Software) were used to identify relationships between the response and the predictors. First, we use PC1 as the response with abundance and site as the predictors. Next, we use abundance (percent cover) as the response and site as the predictor. Lastly, coral survival and grazing were used as the response variables with the interaction between site and abundance as predictors. Significance codes represent p values, with "." as <0.1, "*" as <0.05, "**" as <0.01, and "***" as <0.001.

Benthic Composition Models							
Percent Abundance data							
Linear Models	**estimate**	**std.err**	**statistic**	**cf.low**	**cf.high**	**p.value**	**signif.code**
PC1 ~ Site							
(Intercept)	-0.196	0.158	-1.238	-0.512	0.120	0.220	
Site 2	0.659	0.233	2.831	0.195	1.123	0.006	**
Site 3	0.122	0.236	0.518	-0.348	0.593	0.606	
Site 4	0.030	0.233	0.131	-0.433	0.494	0.896	
PC1 ~ Cyanobacteria							
(Intercept)	-0.106	0.091	-1.156	-0.287	0.076	0.251	
Cyanobacteria	0.020	0.007	2.926	0.006	0.033	0.005	**
PC1 ~ Octocorals							
(Intercept)	-0.071	0.078	-0.911	-0.226	0.084	0.365	
Octocorals	0.296	0.059	5.052	0.179	0.413	<0.001	***
PC1 ~ *Pocillopora*							
(Intercept)	-0.079	0.039	-2.028	-0.226	0.084	0.046	*
Pocillopora	1.418	0.079	17.914	0.179	0.413	<0.001	***
PC1 ~ *Dipsastrea*							
(Intercept)	-0.079	0.039	-2.028	-0.157	-0.001	0.046	*
Dipsastrea	0.473	0.026	17.914	1.261	1.576	<0.001	***
PC1 ~ Turf algae							
(Intercept)	0.383	0.199	1.923	-0.014	0.779	0.058	·
Turf algae	-0.010	0.005	-2.133	-0.020	-0.001	0.036	*
PC1 ~ *Acropora* digitate							
(Intercept)	0.004	0.112	0.035	-0.219	0.227	0.972	
Acropora digitate	-0.001	0.018	-0.058	-0.038	0.036	0.954	
PC1 ~ Hard rock							

(Intercept)	0.052	0.095	0.552	-0.137	0.241	0.583	
Hard rock	-0.026	0.018	-1.415	-0.062	0.010	0.161	
PC1 ~ Rubble							
(Intercept)	0.011	0.089	0.122	-0.167	0.189	0.903	
Rubble	-0.069	0.087	-0.795	-0.241	0.104	0.429	
Cyanobacteria ~ Site							
(Intercept)	4.048	2.354	1.719	-0.643	8.739	0.090	·
Site 2	12.050	3.458	3.484	5.160	18.941	0.001	**
Site 3	-3.585	3.509	-1.022	-10.578	3.408	0.310	
Site 4	-3.296	3.458	-0.953	-10.186	3.595	0.344	
Octocorals ~ Site							
(Intercept)	0.000	0.278	0.000	-0.553	0.553	1.000	
Site 2	0.229	0.408	0.561	-0.583	1.041	0.576	
Site 3	0.797	0.414	1.927	-0.027	1.621	0.058	·
Site 4	0.000	0.408	0.000	-0.812	0.812	1.000	
***Pocillopora* ~ Site**							
(Intercept)	0.000	0.105	0.000	-0.209	0.209	1.000	
Site 2	0.229	0.154	1.485	-0.078	0.536	0.142	
Site 3	0.000	0.156	0.000	-0.312	0.312	1.000	
Site 4	0.000	0.154	0.000	-0.307	0.307	1.000	
***Dipsastrea* ~ Site**							
(Intercept)	0.000	0.315	0.000	-0.627	0.627	1.000	
Site 2	0.686	0.462	1.485	-0.234	1.607	0.142	
Site 3	0.000	0.469	0.000	-0.935	0.935	1.000	
Site 4	0.000	0.462	0.000	-0.921	0.921	1.000	
Turf algae ~ Site							
(Intercept)	39.455	3.754	10.509	31.974	46.935	<0.001	***
Site 2	-10.343	5.515	-1.875	-21.332	0.646	0.065	·
Site 3	0.584	5.597	0.104	-10.568	11.736	0.917	
Site 4	-0.224	5.515	-0.041	-11.214	10.765	0.968	
Coralline algae ~ Site							
(Intercept)	31.510	3.977	7.923	23.585	39.434	<0.001	***
Site 2	0.377	5.842	0.065	-11.264	12.018	0.949	
Site 3	4.193	5.929	0.707	-7.621	16.006	0.482	
Site 4	4.542	5.842	0.777	-7.099	16.182	0.439	
Harl rock ~ Site							
(Intercept)	5.186	0.954	5.435	3.285	7.088	<0.001	***
Site 2	-4.180	1.402	-2.982	-6.973	-1.387	0.004	**
Site 3	-4.008	1.423	-2.817	-6.842	-1.173	0.006	**
Site 4	-4.967	1.402	-3.543	-7.760	-2.174	<0.001	***
Rubble ~ Site							
(Intercept)	0.198	0.220	0.899	-0.240	0.636	0.372	
Site 2	-0.198	0.323	-0.612	-0.841	0.446	0.542	
Site 3	-0.198	0.328	-0.603	-0.851	0.455	0.548	
Site 4	0.223	0.323	0.692	-0.420	0.867	0.491	

***Acropora* digitate ~ Site**							
(Intercept)	4.422	1.045	4.232	2.340	6.504	<0.001	***
Site 2	-0.952	1.535	-0.620	-4.011	2.106	0.537	
Site 3	-0.648	1.558	-0.416	-3.752	2.456	0.679	
Site 4	-1.245	1.535	-0.811	-4.304	1.813	0.420	
Planned Comparisons							
			estimate	**etd.err**	**t.value**	**p.value**	**signif.code**
Cyanobacteria	Site 2 – Site 4		15.346	3.583	4.283	<0.001	***
	Site 2 – Site 1		12.050	3.458	3.484	<0.001	***
	Site 2 – Site 3		15.635	3.632	4.305	<0.001	***
Octocorals	Site 3 – Site 4		0.797	0.428	1.862	0.067	·
	Site 3 – Site 1		0.797	0.414	1.927	0.058	·
	Site 3 – Site 2		0.568	0.428	1.327	0.188	
Turf Algae	Site 2 – Site 4		-10.118	5.713	-1.771	0.081	·
	Site 2 – Site 1		-10.343	5.515	-1.875	0.065	·
	Site 2 – Site 3		-10.927	5.792	-1.886	0.063	·
Harf Rock	Site 2 – Site 4		0.787	1.452	0.542	0.590	·
	Site 2 – Site 1		-4.180	1.402	-2.982	0.004	**
	Site 2 – Site 3		-0.173	1.472	-0.117	0.907	
	Site 3 – Site 4		0.959	1.472	0.651	0.517	
	Site 3 – Site 1		-4.008	1.423	-2.817	0.006	**
	Site 4 – Site 1		-4.967	1.402	-3.543	<0.001	***
Coral Survival							
Linear Models	**estimate**	**std.err**	**statistic**	**cf.low**	**cf.high**	**p.value**	**signif.code**
Coral Spat							
Survival ~ Cyanobacteria * Site							
(Intercept)	0.346	0.112	3.099	0.123	0.569	0.003	**
CYAN	-0.007	0.015	-0.471	-0.036	0.022	0.639	
Site 2	0.194	0.171	1.135	-0.147	0.535	0.260	
Site 3	-0.346	0.155	-2.233	-0.655	-0.037	0.029	*
Site 4	0.114	0.156	0.730	-0.197	0.425	0.468	
CYAN: Site 2	0.003	0.016	0.180	-0.028	0.034	0.858	
CYAN: Site 3	0.007	0.057	0.122	-0.106	0.120	0.903	
CYAN: Site 4	-0.045	0.053	-0.843	-0.151	0.061	0.402	
Survival ~ Hard Rock * Site							
(Intercept)	0.268	0.113	2.375	0.043	0.494	0.020	*
ROCK	0.010	0.013	0.759	-0.016	0.035	0.450	
Site 2	0.275	0.155	1.775	-0.034	0.584	0.080	·
Site 3	-0.268	0.157	-1.709	-0.582	0.045	0.092	·
Site 4	0.120	0.152	0.792	-0.183	0.424	0.431	
ROCK: Site 2	-0.079	0.040	-1.984	-0.159	0.000	0.051	*
ROCK: Site 3	-0.010	0.036	-0.270	-0.080	0.061	0.788	
ROCK: Site 4	0.137	0.107	1.278	-0.077	0.351	0.205	
Survival ~ *Acropora* digitate * site							

(Intercept)	0.150	0.117	1.281	-0.084	0.384	0.204	
ACD	0.038	0.016	2.302	0.005	0.071	0.024	*
Site 2	0.399	0.179	2.224	0.041	0.756	0.029	*
Site 3	-0.150	0.168	-0.896	-0.485	0.184	0.374	
Site 4	0.279	0.185	1.511	-0.089	0.648	0.135	
ACD: Site 2	-0.060	0.031	-1.904	-0.122	0.003	0.061	·
ACD: Site 3	-0.038	0.024	-1.609	-0.085	0.009	0.112	
ACD: Site 4	-0.041	0.036	-1.118	-0.113	0.032	0.267	
Coral Microfragments							
Survival ~ Cyanobacteria * Site							
(Intercept)	1.000	0.067	14.876	0.866	1.134	0.000	***
CYAN	0.000	0.009	0.000	-0.018	0.018	1.000	
Site 2	-0.247	0.103	-2.401	-0.452	-0.042	0.019	*
Site 3	-0.059	0.093	-0.630	-0.245	0.127	0.530	
Site 4	-0.120	0.094	-1.283	-0.307	0.067	0.204	
CYAN: Site 2	0.006	0.009	0.593	-0.013	0.024	0.555	
CYAN: Site 3	0.007	0.034	0.207	-0.061	0.075	0.837	
CYAN: Site 4	0.020	0.032	0.625	-0.044	0.084	0.534	
Survival ~ Hard Rock * Site							
(Intercept)	1.000	0.071	14.058	0.858	1.142	<0.001	***
H_ROCK	0.000	0.008	0.000	-0.016	0.016	1.000	
Site 2	-0.181	0.098	-1.857	-0.376	0.013	0.068	·
Site 3	-0.064	0.099	-0.645	-0.261	0.133	0.521	
Site 4	-0.111	0.096	-1.161	-0.302	0.080	0.250	
ROCK: Site 2	0.023	0.025	0.923	-0.027	0.073	0.359	
ROCK: Site 3	0.007	0.022	0.311	-0.038	0.052	0.756	
ROCK: Site 4	0.027	0.067	0.395	-0.108	0.161	0.694	
Survival ~ *Acropora* digitate * site							
(Intercept)	1.000	0.072	13.971	0.857	1.143	<0.001	***
ACD	0.000	0.010	0.000	-0.020	0.020	1.000	
Site 2	-0.059	0.109	-0.543	-0.277	0.159	0.589	
Site 3	-0.052	0.102	-0.510	-0.256	0.152	0.611	
Site 4	0.002	0.113	0.020	-0.223	0.227	0.984	
ACD: Site 2	-0.028	0.019	-1.487	-0.067	0.010	0.142	
ACD: Site 3	-0.001	0.014	-0.061	-0.030	0.028	0.952	
ACD: Site 4	-0.034	0.022	-1.526	-0.078	0.010	0.132	
Survival ~ Turf algae * Site							
(Intercept)	1.000	0.155	6.455	0.691	1.309	<0.001	***
TAL	0.000	0.004	0.000	-0.007	0.007	1.000	
Site 2	-0.352	0.197	-1.785	-0.746	0.041	0.079	·
Site 3	-0.063	0.223	-0.281	-0.507	0.382	0.779	
Site 4	0.076	0.205	0.372	-0.333	0.485	0.711	
TAL: Site 2	0.007	0.005	1.292	-0.004	0.017	0.201	
TAL: Site 3	0.000	0.005	0.034	-0.010	0.011	0.973	

TAL: Site 4	-0.005	0.005	-0.970	-0.014	0.005	0.335	
Survival ~ Coralline algae * Site							
(Intercept)	1.000	0.113	8.865	0.775	1.225	<0.001	***
CCA	0.000	0.003	0.000	-0.006	0.006	1.000	
Site 2	0.106	0.152	0.695	-0.198	0.409	0.489	
Site 3	0.007	0.185	0.038	-0.363	0.377	0.970	
Site 4	-0.319	0.173	-1.846	-0.665	0.026	0.069	·
CCA: Site 2	-0.008	0.004	-2.011	-0.016	0.000	0.048	*
CCA: Site 3	-0.002	0.005	-0.357	-0.012	0.008	0.722	
CCA: Site 4	0.006	0.005	1.308	-0.003	0.015	0.195	
Planned Comparisons							
	site	**estimate**	**etd.err**	**t.value**	**p.value**	**signif.code**	
Spat Survival ~ Cyano * Site	S2 – S1	0.194	0.171	1.135	0.642		
	S3 – S1	-0.346	0.155	-2.233	0.111		
	S4 – S1	0.114	0.156	0.730	0.871		
	S3 – S2	-0.540	0.168	-3.211	0.009	**	
	S4 – S2	0.460	0.153	3.008	0.016	*	
Spat Survival ~ Hard Rock * Site	S2 – S1	0.243	0.092	2.637	0.036	*	
	S3 – S1	-0.300	0.094	-3.194	0.008	**	
	S4 – S1	0.089	0.090	0.987	0.679		
	S3 – S2	-0.544	0.152	-3.573	0.003	**	
	S4 – S2	0.389	0.149	2.607	0.038	*	
Spat Survival ~ *Acropora* dig. * Site	S2 – S1	0.267	0.116	2.308	0.077	·	
	S3 – S1	-0.282	0.107	-2.645	0.034	*	
	S4 – S1	0.147	0.120	1.229	0.512		
	S3 – S2	-0.549	0.181	-3.034	0.012	*	
	S4 – S2	0.430	0.187	2.303	0.078	·	
Frag Survival ~ Cyano* Site	S2 – S1	-0.247	0.103	-2.401	0.076	·	
	S3 – S1	-0.059	0.093	-0.630	0.912		
	S4 – S1	-0.120	0.094	-1.283	0.548		
	S3 – S2	0.188	0.101	1.859	0.233		
	S4 – S2	-0.062	0.092	-0.668	0.898		
Fish Grazing							
Linear Models	**estimate**	**std.err**	**statistic**	**cf.low**	**cf.high**	**p.value**	**signif.code**
Coral Spat							
Grazing ~ Cyanobacteria * Site							
(Intercept)	0.505	0.110	4.571	0.285	0.725	<0.001	***
CYAN	-0.001	0.015	-0.086	-0.030	0.028	0.932	
Site 2	-0.317	0.169	-1.874	-0.654	0.020	0.065	·
Site 3	0.495	0.153	3.227	0.189	0.801	0.002	**
Site 4	-0.025	0.154	-0.164	-0.333	0.282	0.871	
CYAN: Site 2	0.006	0.015	0.384	-0.025	0.037	0.702	
CYAN: Site 3	0.001	0.056	0.022	-0.111	0.113	0.982	
CYAN: Site 4	0.063	0.053	1.198	-0.042	0.168	0.235	

Grazing ~ Hard Rock * Site							
(Intercept)	0.642	0.111	5.796	0.421	0.864	<0.001	***
ROCK	-0.027	0.012	-2.216	-0.052	-0.003	0.030	*
Site 2	-0.340	0.152	-2.239	-0.644	-0.037	0.028	*
Site 3	0.358	0.154	2.321	0.050	0.665	0.023	*
Site 4	-0.087	0.149	-0.583	-0.384	0.211	0.562	
ROCK: Site 2	-0.011	0.039	-0.285	-0.089	0.067	0.776	
ROCK: Site 3	0.027	0.035	0.789	-0.042	0.097	0.433	
ROCK: Site 4	-0.106	0.105	-1.007	-0.316	0.104	0.318	
Grazing ~ *Acropora* digitate * Site							
(Intercept)	0.602	0.110	5.468	0.382	0.822	<0.001	***
ACD	-0.023	0.015	-1.492	-0.054	0.008	0.140	
Site 2	-0.523	0.168	-3.113	-0.859	-0.188	0.003	**
Site 3	0.398	0.157	2.527	0.084	0.712	0.014	*
Site 4	-0.353	0.173	-2.033	-0.699	-0.007	0.046	*
ACD: Site 2	0.076	0.029	2.595	0.018	0.135	0.012	*
ACD: Site 3	0.023	0.022	1.043	-0.021	0.067	0.301	
ACD: Site 4	0.110	0.034	3.232	0.042	0.178	0.002	**
Coral Microfragments							
Grazing~ Cyanobacteria * Site							
(Intercept)	0.390	0.113	3.455	0.165	0.616	<0.001	***
CYAN	-0.018	0.015	-1.198	-0.047	0.012	0.235	
Site 2	0.067	0.173	0.388	-0.278	0.412	0.699	
Site 3	0.551	0.157	3.514	0.238	0.864	<0.001	***
Site 4	0.189	0.158	1.196	-0.126	0.503	0.236	
CYAN: Site 2	0.022	0.016	1.408	-0.009	0.053	0.164	
CYAN: Site 3	0.025	0.057	0.434	-0.089	0.139	0.666	
CYAN: Site 4	0.088	0.054	1.634	-0.019	0.195	0.107	
Grazing ~ Hard Rock * Site							
(Intercept)	0.468	0.111	4.204	0.246	0.691	<0.001	***
ROCK	-0.029	0.012	-2.324	-0.054	-0.004	0.023	*
Site 2	0.136	0.153	0.887	-0.169	0.440	0.378	
Site 3	0.468	0.155	3.021	0.159	0.777	0.004	**
Site 4	0.198	0.150	1.322	-0.101	0.497	0.191	
ROCK: Site 2	-0.048	0.039	-1.228	-0.127	0.030	0.224	
ROCK: Site 3	0.036	0.035	1.026	-0.034	0.106	0.308	
ROCK: Site 4	-0.131	0.106	-1.239	-0.342	0.080	0.219	
Grazing ~ *Acropora* digitate * Site							
(Intercept)	0.253	0.122	2.072	0.010	0.497	0.042	*
ACD	0.015	0.017	0.858	-0.020	0.049	0.394	
Site 2	0.258	0.187	1.385	-0.114	0.630	0.170	
Site 3	0.742	0.175	4.246	0.393	1.090	<0.001	***
Site 4	0.211	0.192	1.095	-0.173	0.594	0.277	
ACD: Site 2	0.000	0.017	0.005	-0.035	0.035	0.996	

ACD: Site 3	-0.010	0.023	-0.444	-0.057	0.036	0.658	
ACD: Site 4	-0.028	0.018	-1.586	-0.063	0.007	0.117	
Grazing ~ Turf Algae * Site							
(Intercept)	0.474	0.251	1.887	-0.027	0.974	0.063	*
TAL	-0.004	0.006	-0.665	-0.016	0.008	0.508	
Site 2	0.524	0.320	1.637	-0.114	1.161	0.106	
Site 3	0.549	0.361	1.520	-0.171	1.269	0.133	
Site 4	-0.204	0.332	-0.615	-0.867	0.458	0.540	
TAL: Site 2	-0.012	0.008	-1.460	-0.029	0.004	0.149	
TAL: Site 3	0.002	0.008	0.236	-0.015	0.019	0.814	
TAL: Site 4	0.013	0.008	1.706	-0.002	0.029	0.093	·
Grazing ~ Coralline algae * Site							
(Intercept)	0.099	0.199	0.499	-0.298	0.497	0.619	
CCA	0.007	0.006	1.247	-0.004	0.018	0.216	
Site 2	0.523	0.269	1.945	-0.013	1.058	0.056	·
Site 3	0.792	0.328	2.419	0.139	1.446	0.018	*
Site 4	0.921	0.306	3.012	0.311	1.531	0.004	**
CCA: Site 2	-0.010	0.007	-1.369	-0.024	0.005	0.175	
CCA: Site 3	-0.005	0.009	-0.630	-0.023	0.012	0.531	
CCA: Site 4	-0.018	0.008	-2.209	-0.034	-0.002	0.030	*

Planned Comparisons

	site	**estimate**	**etd.err**	**t.value**	**p.value**	**signif.code**
Spat Grazing ~ Cyano * Site	S2 – S1	-0.317	0.169	-1.874	0.226	
	S3 – S1	0.495	0.153	3.227	0.008	**
	S4 – S1	-0.025	0.154	-0.164	0.998	
	S3 – S2	0.812	0.166	4.879	<0.001	***
	S4 – S2	-0.520	0.151	-3.439	0.005	**
Spat Grazing ~ Hard Rock * Site	S2 – S1	-0.340	0.152	-2.239	0.108	
	S3 – S1	0.358	0.154	2.321	0.090	·
	S4 – S1	-0.087	0.149	-0.583	0.927	
	S3 – S2	0.698	0.149	4.677	<0.001	***
	S4 – S2	-0.444	0.146	-3.038	0.015	*
Spat Grazing ~ *Acropora* dig. * Site	S2 – S1	-0.524	0.168	-3.113	0.012	*
	S3 – S1	0.398	0.158	2.527	0.057	·
	S4 – S1	-0.353	0.173	-2.033	0.168	
	S3 – S2	0.921	0.170	5.428	<0.001	***
	S4 – S2	-0.751	0.175	-4.289	<0.001	***
Frag Grazing ~ Cyano * Site	S2 – S1	0.067	0.173	0.388	0.977	
	S3 – S1	0.551	0.157	3.514	0.004	**
	S4 – S1	0.189	0.158	1.196	0.603	
	S3 – S2	0.484	0.170	2.844	0.025	*
	S4 – S2	-0.362	0.155	-2.343	0.087	·
Frag Grazing ~ Hard Rock * Site	S2 – S1	0.136	0.153	0.887	0.789	
	S3 – S1	0.468	0.155	3.021	0.015	*

	S4 – S1	0.198	0.150	1.322	0.519	
	S3 – S2	0.332	0.150	2.214	0.114	
	S4 – S2	-0.270	0.147	-1.833	0.241	
Frag Grazing ~ *Acropora* dig. * Site	S2 – S1	0.258	0.187	1.385	0.485	
	S3 – S1	0.742	0.175	4.246	<0.001	***
	S4 – S1	0.211	0.192	1.095	0.670	
	S3 – S2	0.483	0.188	2.567	0.052	·
	S4 – S2	-0.531	0.194	-2.736	0.034	*
Frag Grazing ~ CCA * Site	S2 – S1	0.523	0.269	1.945	0.195	
	S3 – S1	0.792	0.328	2.419	0.072	·
	S4 – S1	0.921	0.306	3.012	0.016	*
	S3 – S2	0.270	0.316	0.853	0.806	
	S4 – S2	0.128	0.348	0.369	0.980	

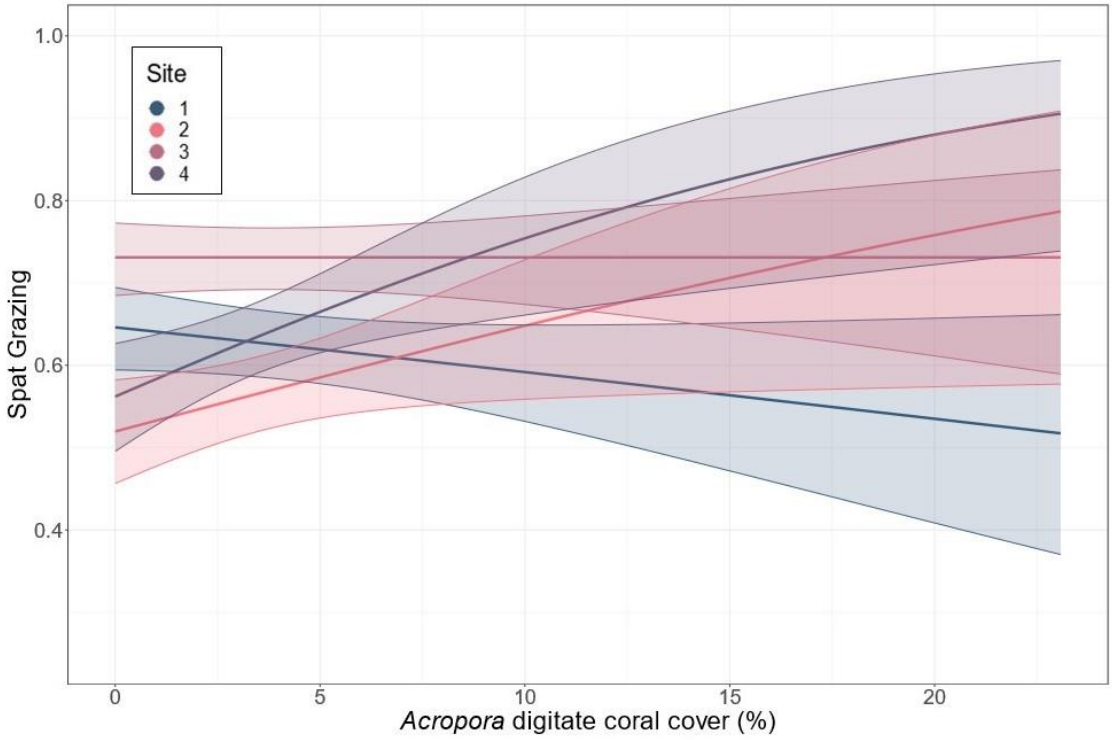


Figure A1. Logistic relationship between the percent cover of *Acropora* digitate corals (including corymbose morphology) and grazing of coral spat at the 2-d timepoint. The data was recorded from device plots (0.25 m^2, n=31-41) and separated by site (n=4).

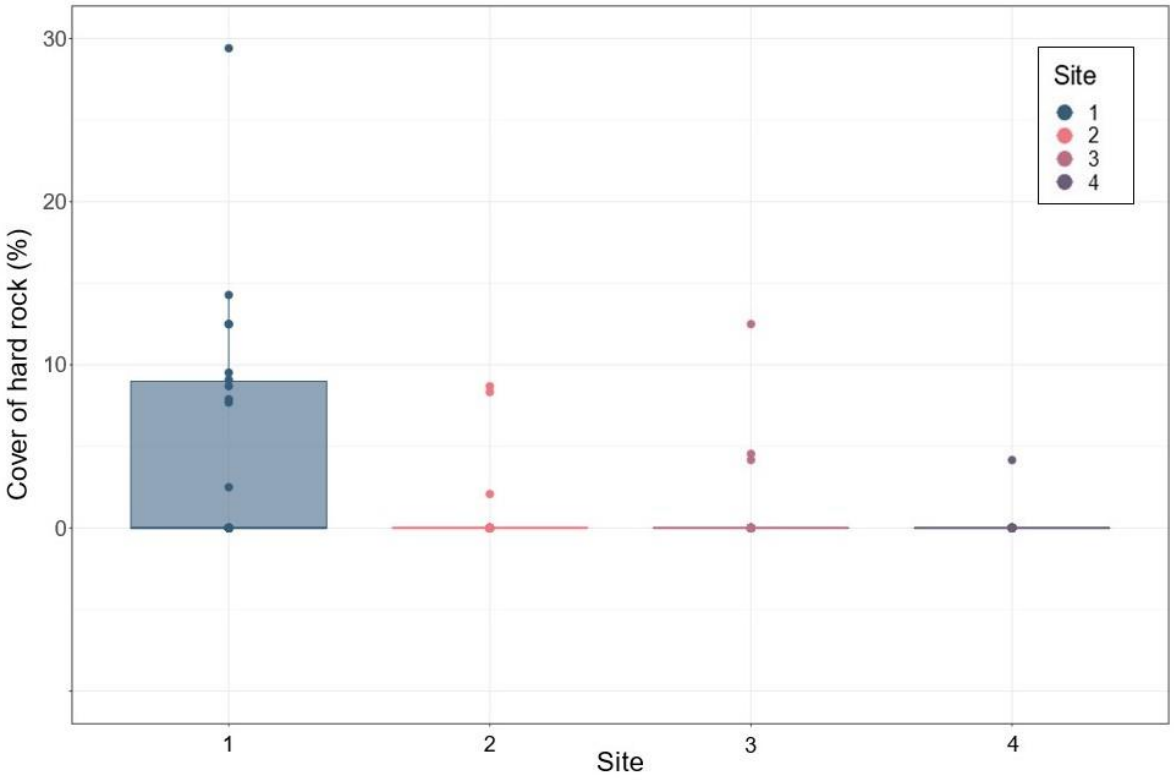


Figure A2. Percent cover of hard, bare rock at the 2-d timepoint and recorded in device plots (0.25 m^2). The data was separated by site (n=4) and annotated by plot (n=31-41).

A.2.5. Waterflow and sedimentation

Table A10. Model output for environmental data, water flow and sedimentation. Linear models (lm; R Software) were used data values (water flow or sedimentation) or PC1 as the response, with site or pod type (Sed or Turf) as the predictors. Models are defined in the table. Significance codes represent p values, with "*" as <0.05, "**" as <0.01, and "***" as <0.001.

Environmental Models

Water flow

Linear Models

Diffusion Factor

DF ~ Site	**Estimate**	**Std.Error**	**Statistic**	**Cf.Low**	**Cf.High**	**p.value**	**Significant Code**
(Intercept)	4.803	0.208	23.109	4.362	5.243	0.000	***
Site2	-0.461	0.294	-1.568	-1.084	0.162	0.136	
Site3	-0.252	0.294	-0.856	-0.875	0.371	0.405	
Site4	-0.332	0.294	-1.130	-0.955	0.291	0.275	

Residual standard error: 0.4647 on 16 degrees of freedom

Multiple R-squared: 0.1407, Adjusted R-squared: -0.02036

F-statistic: 0.8736 on 3 and 16 DF, p-value: 0.4753

Dissolution Rate

DR ~ Site	**Estimate**	**Std.Error**	**Statistic**	**Cf.Low**	**Cf.High**	**p.value**	**Significant Code**
(Intercept)	23.314	1.039	22.435	21.111	25.517	0.000	***
Site 2	-2.304	1.470	-1.568	-5.420	0.811	0.136	
Site 3	-1.258	1.470	-0.856	-4.374	1.857	0.405	
Site 4	-1.661	1.470	-1.130	-4.776	1.455	0.275	

Residual standard error: 2.324 on 16 degrees of freedom

Multiple R-squared: 0.1407, Adjusted R-squared: -0.02036

F-statistic: 0.8736 on 3 and 16 DF, p-value: 0.4753

Planned Comparisons

Site	**estimate**	**std.err**	**t.value**	**p.value**
S2 - S3	-0.209	0.294	-0.712	0.487
S2 - S4	-0.129	0.294	-0.438	0.667
S3 - S4	0.081	0.294	0.274	0.788

Sedimentation

Linear Models

Principal Component

PC1 ~ Site	**estimate**	**std.err**	**t.value**	**p.value**
(Intercept)	-0.09686	0.26219	-0.369	0.717
Site 2	0.0605	0.37079	0.163	0.872
Site 3	-0.07465	0.37079	-0.201	0.843
Site 4	0.40158	0.37079	1.083	0.295

Residual standard error: 0.5863 on 16 degrees of freedom

Multiple R-squared: 0.1079, Adjusted R-squared: -0.05942

F-statistic: 0.6448 on 3 and 16 DF, p-value: 0.5974

PC1 ~ Sed Pod	**estimate**	**std.err**	**t.value**	**p.value**	**signif.code**
(Intercept)	-0.7955	0.1773	-4.487	0.000285	***
Sed_Pod	7470.503	1467.441	5.091	7.63E-05	***

Residual standard error: 0.3747 on 18 degrees of freedom
Multiple R-squared: 0.5901, Adjusted R-squared: 0.5674
F-statistic: 25.92 on 1 and 18 DF, p-value: 7.63e-05

PC1 ~ Turf Pod	**estimate**	**std.err**	**t.value**	**p.value**	**signif.code**
(Intercept)	1.125	0.2363	4.76	0.000156	***
Turf_Pod	-1033.58	203.027	-5.091	7.6E-05	***

Residual standard error: 0.3747 on 18 degrees of freedom
Multiple R-squared: 0.5901, Adjusted R-squared: 0.5674
F-statistic: 25.92 on 1 and 18 DF, p-value: 7.63e-05

In situ deposition

Sediment ~ Site	**estimate**	**std.err**	**statistic**	**cf.low**	**cf.high**	**p.value**	**signif.code**
(Intercept)	0.00048	0.00019	2.519	0.00009	0.00086	0.016	*
Site 2	0.00022	0.00027	0.814	-0.00032	0.00076	0.421	
Site 3	0.00018	0.00027	0.664	-0.00036	0.00072	0.511	
Site 4	0.00009	0.00027	0.347	-0.00045	0.00063	0.731	

Residual standard error: 5.451e-05 on 16 degrees of freedom
Multiple R-squared: 0.2708, Adjusted R-squared: 0.134
F-statistic: 1.98 on 3 and 16 DF, p-value: 0.1576

Sed Pod ~ Site	**estimate**	**std.err**	**statistic**	**cf.low**	**cf.high**	**p.value**	**signif.code**
(Intercept)	6.34E-05	2.44E-05	2.603	1.18E-05	0.0001151	0.019	*
Site 2	6.12E-05	3.45E-05	1.776	-1.19E-05	0.0001343	0.095	
Site 3	3.27E-05	3.45E-05	0.949	-4.04E-05	0.0001058	0.357	
Site 4	7.83E-05	3.45E-05	2.270	5.18E-06	0.0001513	0.037	*

Residual standard error: 5.451e-05 on 16 degrees of freedom
Multiple R-squared: 0.2708, Adjusted R-squared: 0.134
F-statistic: 1.98 on 3 and 16 DF, p-value: 0.1576

Turf Pod ~ Site	**estimate**	**std.err**	**statistic**	**cf.low**	**cf.high**	**p.value**	**signif.code**
(Intercept)	0.00089	0.00019	4.634	0.00048	0.00129	0.0003	***
Site 2	0.00037	0.00027	1.378	-0.00020	0.00095	0.187	
Site 3	0.00032	0.00027	1.187	-0.00025	0.00090	0.252	
Site 4	0.00011	0.00027	0.395	-0.00047	0.00068	0.698	

Residual standard error: 0.0004285 on 16 degrees of freedom
Multiple R-squared: 0.1373, Adjusted R-squared: -0.02441
F-statistic: 0.8491 on 3 and 16 DF, p-value: 0.4872

Planned Comparisons

site	**pod type**	**estimate**	**std.err**	**t.value**	**p.value**

S2 - S3	Sed	-2.85E-05	3.45E-05	-0.827	0.421
	Turf	-5.16E-05	2.71E-04	-0.191	0.851
S2 - S4	Sed	1.70E-05	3.45E-05	0.494	0.628
	Turf	-0.000266	0.000271	-0.983	0.34
S3 - S4	Sed	4.55E-05	3.45E-05	1.321	0.205
	Turf	-0.000215	0.000271	-0.792	0.44

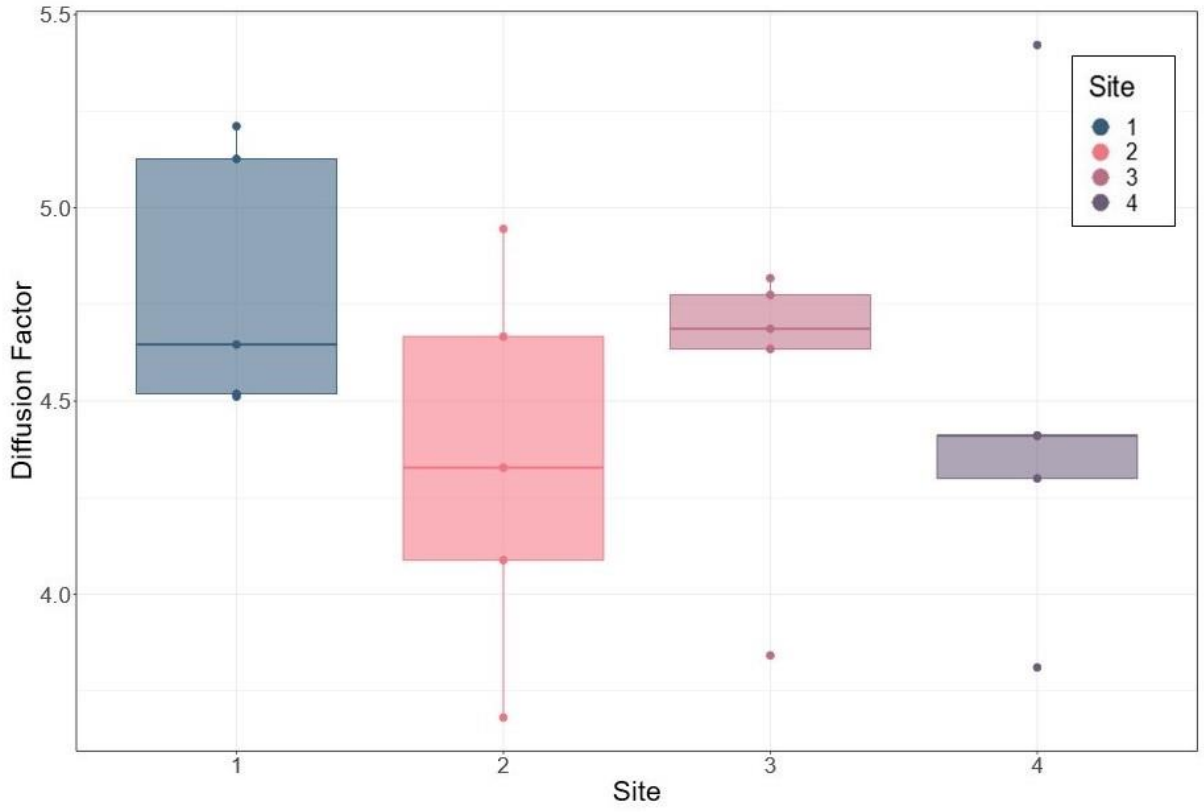


Figure A3. Water flow displayed as Diffusion Factor across sites. The values were obtained from the deployment of clod cards (n=5) at one timepoint for each experimental site (n=4).

Appendix B: Supplementary Material to Chapter 3

B.1 Supplementary Methods

B.1.1 Coral collection and rearing

Coral colonies were collected by hammer and chisel then brought to the National Sea Simulator facility at the Australian Institute of Marine Science, Townsville. Colonies were held in flow-through filtered seawater temperature and light controlled (refer to Supplementary Material section 1.1), seawater aquaria in the. The aquaria maintained an average Photosynthetic Active Radiation (PAR) of 74 µmol photons m^{-1} s^{-1} and temperature between 27 and 28 °C. 500 L larval rearing tanks were used a at a stocking density of ~ 0.5–1 larva mL^{-1}. These tanks were held indoors and received flowthrough 0.4 µm filtered seawater at 27.5–28.5 °C. Gentle aeration began ~ 16 h post fertilization.

A total of 8 sheets (3200 tabs) were distributed across 4 isolation tanks (50-L acrylic tanks, indoor aquaria systems) for mass larval settlement. Two sheets were placed at the bottom of each tank (horizontal, upward facing) and small glass beads (sterile, < 2-mm Ø) were used to fill the empty spaces between the sheets and tank sides, limiting larval access to sheet undersides. Approximately 12000 larvae were added per tank for settlement, and allowed to settle over 72 hrs.

The same tanks used for settlement were then used to maintain spat in aquaria prior to seeding. However, six modifications were made to ensure optimal grow-out conditions for spat, based on previous rearing trials and standards used in the National Sea Simulator. (1) The glass beads were removed, and aquaria were thoroughly cleaned. (2) Flowthrough FSW (0.4 µm) was set to a constant rate of 2 to 5 L min^{-1}. (3) Chocoblock sheets were orientated vertically to reduce spat contact with, and buildup of, particulate matter on sheets. (4) Individual drip feeders (Polyvinyl [PVC] cylinder with FSW lines for filling and aeration for mixing) were added to the aquaria to deliver food at a constant rate (~2 to 5 L min^{-1}, denoted by the cylinder fill rate) over a 24-h period. Corals were fed mixed microalgae (100 mL, 2000 cells mL^{-1}; *Nannochloropsis oceania*, *Isochrysis sp.*, *Chaetoceros muelleri*, *Dunaliella sp.*, *Proteomonas sulcate*) and enriched rotifers (100 mL, 0.5 nauplii mL^{-1}; *Brachionus plicatilis,* 60-180 micron; SELCO© S.parkle enrichment) twice daily, at 8:00 and 16:00. Only the afternoon feed (16:00) contained enriched rotifers. (5) *Turbo* snails (n = 10 per tank) were added to aquaria to control the growth of early successional biofilms. Lastly, (6) water circulation pumps were installed after 14 d to increase aeration and waterflow.

Routine tank maintenance included daily rinses of drip feeders, fortnightly siphoning to remove residual sediments, and fortnightly rotation of sheets within tanks. A small amount of light was introduced prior to the deployment. Light was set on a daily ramping profile: on at 11:00, ramped up (1 h) to 10-12 µmol

photons m^{-1} s^{-1} for 1 h then then ramped down (1 h) to 0 µmol photons m^{-1} s^{-1} by 14:00. The initial intensity was adjusted by 2 to 3% (for both white and blue light) in 2-d intervals to reach the daily maximum of 60 µmol photons m^{-1} s^{-1} just prior to deployment. A small percentage of spat showed visual signs of photosynthetic symbionts (originating from benthic biofilms) present within their tissues at this time; this was documented and included in the coral survival analyses. Once corals were in devices, the water temperature in aquaria was reduced to match *in-situ* conditions, decreasing from 28.4 °C by 0.1-0.2 °C every 2 d to reach 27.9°C.

B.1.2 Data collection

Disruptions due to weather and COVID-19 limited our ability to complete all biological and surveys at each timepoint. Table B2 details the attempted and completed surveys.

Tab-level assessments

Images were used to quantify the number of live spat and used to calculate coral size, pre and post deployment. Size was estimated for the largest coral present on each tab (ImageJ). Coral cover and the cover of benthic constituents on tabs were visually estimated (%) at the final timepoint.

Plot-level assessments

Quadrat images of the experimental plots were assessed for key benthic groups described in Table S3.

Site-level assessments

GoPro cameras were mounted to lead dive weights using cable ties and a PVC-holding plate, then deployed to 2 haphazardly selected plots over 2 timepoints. The data were collected from the video footage following the criteria listed in Table S4.

Table B1. Coral spawning and settlement information, including relevant dates, times and colony contributions.

Spawning Information	**Description**
Coral population	Moore Reef
Coral species	*Acropora digitifera*
Adult colony collection trip	02/02/2022 to 13/02/2022
Adult colony holding time (collection to *in-situ* return)	2.5 mo.
Full Moon	16/02/2022
Potential spawning window	25/02/2022 to 02/03/2022
Main spawning nights	01/03/2022 and 02/03/2022
Spawn time	19:50 to 21:40
Culture tanks	1 (500 L)
No. parental colonies (genotypes) used for larval culture	5
Substrate conditioning duration	30 days
Larval settlement date	6/3/2022
Spat holding time in aquaria prior to deployment	2 mo.
Deployment dates	04/05/2022 to 10/05/2022

Table B2. Field survey successes and failures. The "✓" indicates a completed deployment or data collection while the "x" indicates missing information from a failed survey attempt (i.e., weather or COVID delays) or missing data logger. For current and temperature data there are two symbols, the first indicating the collection of data and the second indicating the redeployment of the logger.

Data Collection	**Site**	**Days Seeded**					
		0 mo.	**3 mo.**	**8 mo.**	**9 mo.**	**12 mo.**	**16 mo.**
Coral survival	1A	✓	✓	✓	✓	✓	✓
Diver survey	1B	✓	✓	☒	✓	✓	✓
	2A	✓	✓	✓	✓	✓	✓
	2B	✓	☒	✓	✓	✓	✓
	3A	✓	☒	✓	✓	✓	✓
	3B	✓	✓	☒	✓	✓	✓
	4A	✓	☒	☒	✓	✓	✓
	4B	✓	☒	✓	✓	✓	✓
	5A	✓	☒	☒	✓	✓	✓
	5B	✓	☒	☒	✓	✓	✓
Fish Stationary Point Count	1A	✓	☒	✓	✓	✓	✓
Diver survey	1B	✓	☒	☒	✓	✓	✓
	2A	✓	☒	✓	✓	✓	✓
	2B	✓	☒	✓	✓	✓	✓
	3A	✓	☒	✓	✓	✓	✓
	3B	✓	☒	☒	✓	✓	✓
	4A	✓	☒	☒	✓	✓	✓
	4B	✓	☒	✓	✓	✓	✓

	5A	✓	☒	☒	✓	✓	✓
	5B	✓	☒	☒	✓	✓	✓
Fish video surveillance	1A	✓	✓	✓	✓	✓	☒
Camera survey	1B	✓	✓	☒	✓	✓	☒
	2A	✓	✓	✓	✓	✓	☒
	2B	✓	☒	✓	✓	✓	☒
	3A	✓	☒	✓	✓	✓	☒
	3B	✓	✓	☒	✓	✓	☒
	4A	✓	☒	☒	✓	✓	☒
	4B	✓	☒	☒	✓	✓	☒
	5A	✓	☒	☒	✓	✓	☒
	5B	✓	☒	☒	✓	✓	☒
Benthic Transect	1A	✓	✓	☒	✓	✓	✓
Camera survey	1B	✓	✓	☒	✓	✓	✓
	2A	✓	✓	☒	✓	✓	✓
	2B	✓	☒	☒	✓	✓	✓
	3A	✓	☒	✓	✓	✓	✓
	3B	✓	✓	☒	✓	✓	✓
	4A	✓	☒	☒	✓	✓	✓
	4B	✓	☒	☒	✓	✓	✓
	5A	✓	☒	☒	✓	✓	✓
	5B	✓	☒	☒	✓	✓	✓
Benthic Quadrat *(Camera)*	1A	✓	☒	☒	☒	☒	✓
	1B	✓	☒	☒	☒	☒	✓
	2A	✓	☒	☒	☒	☒	✓
	2B	✓	☒	☒	☒	☒	✓
	3A	✓	☒	☒	☒	☒	✓
	3B	✓	☒	☒	☒	☒	✓
	4A	✓	☒	☒	☒	☒	✓
	4B	✓	☒	☒	☒	☒	✓
	5A	✓	☒	☒	☒	☒	✓
	5B	✓	☒	☒	☒	☒	✓
Current meter data	1A	✓	☒☒	✓✓	✓✓	✓	☒
Deployment	1B	✓	✓✓	☒☒	✓✓	✓	☒
Collection	2A	✓	✓✓	✓✓	✓✓	✓	☒
	2B	✓	☒☒	✓✓	✓✓	✓	☒
	3A	✓	☒☒	✓✓	✓✓	☒	☒
	3B	✓	✓✓	☒☒	✓✓	✓	☒
	4A	✓	☒☒	☒☒	☒✓	✓	☒
	4B	✓	☒☒	☒☒	☒✓	✓	☒
	5A	✓	☒☒	☒☒	☒✓	✓	☒
	5B	✓	☒☒	☒☒	☒✓	☒	☒
Temperature data	1A	✓	☒☒	✓✓	✓✓	✓✓	✓

Deployment	1B	✓	✓✓	☒☒	✓✓	✓✓	✓
Collection	2A	✓	✓✓	✓✓	✓✓	✓✓	✓
	2B	✓	☒☒	✓✓	✓✓	✓✓	✓
	3A	✓	☒☒	✓✓	✓✓	✓✓	✓
	3B	✓	✓✓	☒☒	✓✓	✓✓	✓
	4A	✓	☒☒	☒☒	✓✓	✓✓	✓
	4B	✓	☒☒	☒☒	✓✓	✓✓	✓
	5A	✓	☒☒	☒☒	✓✓	✓✓	✓
	5B	✓	☒☒	☒☒	☒✓	✓✓	✓

Table S3. Benthic classification label set. The "Code" represents the lowest taxonomic classification given, while the "Group Code" represents the broad group that contains the codes. Descriptions were used to better define taxonomic codes within a specific group.

Group	**Group Code**	**Code**	**Description**
Algae	A	BG_AO_Cyanobacteria	Cyanobacteria (filamentous, mats)
		CA_RA_CorallineAlgae_consolidated	Corallines (encrusting CCA, branching) on consolidated reef
		CA_RA_CorallineAlgae_unconsolidated	Corallines (encrusting CCA, branching) on unconsolidated reef
		MA_BA_Brown_Algae	Phaeophyceae., all brown algae that cannot be nominated an ID
		MA_BA_*Lobophora*_spp.	*Lobophora* spp.
		MA_BA_*Turbinaria*_spp.	*Turbinaria* spp.
		MA_GA_Chlorodesmis	*Chlorodesmis* spp., green turfing algae, turtle weed
		MA_GA_Green_Algae	Chlorophyta., all green algae that cannot be nominated an ID
		MA_GA_*Halimeda*_spp.	*Halimeda* spp.
		MA_RA_*Peyssonnelia*_spp.	*Peyssonnelia* spp.
		MA_RA_Red_Algae	Rhodophyta., all red algae that cannot be nominated an ID
		TA_TurfAlgae_consolidated	EAM, short turf, filamentous, assemblages on consolidated reef
		TA_TurfAlgae_unconsolidated	EAM, short turf, filamentous, assemblages on unconsolidated reef
Hard coral	HC	ACR_ACB_*Acropora*	*Acropora* spp., branching morphology including staghorn
		ACR_ACD_*Acropora*	*Acropora* spp., digitate morphology
		ACR_ACO_ACC_*Acropora*	*Acropora* spp., corymbose and caespitose morphology
		ACR_ACT_*Acropora*	*Acropora* spp., tabulate morphology; any colony that is clearly tabular over corymbose
		AST_CM_*Astreopora*	*Astreopora* spp., massive non-*Acropora*
		COS_CE_*Coscinaraea*	*Coscinaraea* spp., encrusting non-Acropora

		CYP_CE_*Cyphastrea*	*Cyphastrea* spp., encrusting non-*Acropora*
		DIP_CE_*Dipsastraea*	*Dipsastraea* spp., encrusting non-*Acropora*
		DIP_CM_CS_*Dipsastraea*	*Dipsastraea* spp., massive and submassive non-*Acropora*
		ECH_CE_*Echinopora*	*Echinopora* spp., encrusting non-*Acropora*
		FAV_CM_CS_*Favites*	*Favites* spp., massive and submassive non-*Acropora*
		GAL_CB_*Galaxea*	*Galaxea* spp., branching non-*Acropora*
		GON_CM_*Goniopora*	*Goniopora* spp., massive non-Acropora
		GOS_CM_*Goniastrea*	*Goniastrea* spp, massive non-*Acropora*
		HC_CE_Encrusting	Hard coral, can only tell growth form: encrusting
		HC_CM_CS_Massive_Submassive	Hard coral, can only tell growth form: massive or submassive
		HYD_CE_*Hydnophora*	*Hydnophora* spp., encrusting non-*Acropora*
		LER_CM_*Leptastrea*	*Leptastrea* spp., massive non-*Acropora*
		LOB_CM_*Lobophyllia*	*Lobophyllia* spp., massive non-*Acropora*
		MER_CE_*Merulina*	*Merulina* spp., encrusting non-Acropora
		MON_CE_*Montipora*	*Montipora* spp., encrusting non-*Acropora*
		MUR_CE_Cerioid	Cerioid, shared walls, encrusting non-*Acropora*
		MUR_CM_CS_Cerioid	Cerioid, shared walls, massive and submassive non-*Acropora*
		MYC_CF_*Mycedium*	*Mycedium* spp., foliose non-Acropora
		PAV_CM_CS_*Pavona*	*Pavona* spp., massive and submassive non-*Acropora*
		PLA_CE_*Platygyra*	*Platygyra* spp., encrusting non-*Acropora*
		POC_CS_*Pocillopora*_1	*Pocillopora damicornis/acuta/brevicornis*
		POC_CS_*Pocillopora*_3	*Pocillopora verrucosa/meandrina/ankeli*
		POR_CB_*Porites*	*Porites* spp., branching non-*Acropora*
		POR_CE_*Porites*	*Porites* spp., encrusting non-*Acropora*
		POR_CM_Porites	*Porites* spp., massive non-*Acropora*
		PSA_CE_*Psammocora*	*Psammocora* spp., encrusting non-*Acropora*
		SER_CB_*Seriatopora*	*Seriatopora* spp., branching non-*Acropora*
Soft coral	SC	SC_SB_SoftCoral_other	Soft coral spp., all growth forms
Sponge	SP	SP_Sponge	Includes all sponges
Other organism	OT	OT_Ascidian	Includes all ascidians

		OT_Corallimorpharia	Includes all corallimorpharia
		OT_Hydrozoan_Hydroid	Stylasteridae, Hydrozoans and Hydriods including *Distichopora* spp. and *Millepora* spp.
		OT_Other_organisms	Other organisms, unidentifiable and/or not fitting into other categories
		OT_Zoanthid	Includes all zoanthids
Abiotic	AB	AB_S_Sand_Sediment_Silt	Sand, sediment, silt
Indeterminate	IN	IN_UNK_Device	White/bare coral seeding device
		IN_UNK_Indeterminate	Unknown, cannot be put into any other category (includes blue water, dark or blurry points)
		IN_UNK_Tape	Transect tape, quadrat bar, star picket, other foreign tools

Table B4. Detailed information from the GoPro video analysis to quantify grazing pressure. Categories are explained via definitions and possible responses. Data entries were taken for each individual fish that was observed to be grazing in the experimental plot. Not all categories were used in the data analysis.

GoPro Video Analysis: Data collection metrics, descriptions and potential responses		
Metric	**Description**	**Possible Response**
Sea state	Refers to the state of the water with regards to the weather conditions due to wind, wave and current.	Calm (0-1.1 km/h), Light (1.1-12.6 km/h), Gentle (12.6-19.8 km/h), Moderate (19.8-28.8 km/h), Fresh (28.8-38.9 km/h)
Visibility	Refers to the sea state, regarding the distance (m) a diver/data recorder can visibly see and identify objects.	< 5m, 6-10m, 11-15m, 16-20m
Family	Refers to the taxonomic family for each fish identified.	Labridae, Pomacentridae, Acanthuridae, Blastidae, Blennidae, Chaetodontidae, etc.
Interval	A number that refers to the feeding approach and start of a feeding foray for an identified fish. The interval stops when a fish swims up, away from the substrate, and can have 1 or more bites.	Integer value, ranging from 1 to 50
Bites	The number of bites a fish takes during a single feeding foray/interval.	Integer value, ranging from 1 to 75
Grazing location	The location of the identified fish bite/graze.	Substrate or device
Fish attacks	Refers to the number of attacks by individual fish in each video and experimental plot. Attacks were defined as visually aggressive swimming behavior.	Integer value, ranging from 1 to 30
Time	Refers to the time the fish swims on screen and into the video frame. Screenshot images were taken of each individual fish for identification at this time point.	Between 1-12 minutes (e.g. 01:30)
Comments	Anything worth noting that was observed in the video.	Invertebrate grazer in plot, diver present on video, camera knocked from original placement point, transect tape or star picket in view, etc.

Table B5. Coral survival (tab yield) model output. A brms model was created using R Software. The model details (variables, parameters, and output) are described, and the appropriate diagnostics were used to test for model accuracy. The estimate (Est), error (Err), and credible intervals (CI low and CI high) were calculated on an odds-ratio scale. Statistical significance was found when the CI interval excluded 1; this is identified by an * in column 'signif'. Rhat values and the effective sample size (Ess) are displayed for each predictor.

Model Information

Family: bernoulli

Links: mu = logit

Formula: Survival ~ DeviceType * Site + CensusTrip + (1 + CensusTrip | Site/Plot/DeviceNumber)

Data: sur2 (Number of observations: 5712)

Draws: 3 chains, 6000 iterations; warmup= 1500; thin = 5; post-warmup draws = 2700

Multilevel hyperparameters:

~Site (Number of levels: 10)

~Site:Plot (Number of levels: 251)

~Site:Plot:DeviceNumber (Number of levels: 503)

Model Output

Term	Est	Err	CI Low	CI High	Rhat	Ess	Signif
b_Intercept	1327.91	0.61	416.16	4505.83	1.00	2559	*
b_DeviceTypeExclusion	0.80	0.40	0.36	1.66	1.00	2491	
b_Site1B	0.43	0.74	0.10	1.92	1.00	2668	
b_Site2A	0.16	0.82	0.04	0.92	1.00	2535	*
b_Site2B	0.49	0.78	0.11	2.70	1.00	2554	
b_Site3A	0.79	0.76	0.18	3.62	1.00	2765	
b_Site3B	0.29	0.79	0.06	1.43	1.00	2519	
b_Site4A	1.50	0.76	0.31	5.90	1.00	2332	
b_Site4B	1.44	0.79	0.26	6.53	1.00	2661	
b_Site5A	3.10	0.75	0.62	12.38	1.00	2733	
b_Site5B	2.87	0.84	0.52	15.47	1.00	2543	
b_CensusTripT3	0.0012	0.44	0.0005	0.00	1.00	2340	*
b_CensusTripT4	0.0005	0.44	0.0002	0.00	1.00	2190	*
b_CensusTripT5	0.0002	0.47	0.0001	0.00	1.00	2034	*
b_DeviceTypeExclusion:Site1B	3.26	0.65	0.92	11.52	1.00	2264	
b_DeviceTypeExclusion:Site2A	1.10	0.67	0.31	4.10	1.00	2735	
b_DeviceTypeExclusion:Site2B	3.12	0.65	0.88	10.97	1.00	2508	
b_DeviceTypeExclusion:Site3A	0.94	0.61	0.28	3.05	1.00	2448	
b_DeviceTypeExclusion:Site3B	2.93	0.65	0.75	9.57	1.00	2744	
b_DeviceTypeExclusion:Site4A	1.62	0.64	0.45	5.47	1.00	2552	
b_DeviceTypeExclusion:Site4B	1.94	0.63	0.59	6.77	1.00	2549	
b_DeviceTypeExclusion:Site5A	1.64	0.65	0.49	6.32	1.00	2825	
b_DeviceTypeExclusion:Site5B	0.91	0.65	0.26	3.07	1.00	2424	

Planned Comparisons

Hypothesis	Est	Err	CI Low	CI High	Evid Ratio	Post Prob	Signif

(b_Site5A-b_Site1B) > 0	6.92	0.95	1.36	28.53	30.03	0.97	*
(b_Site5A-b_Site2B) > 0	5.94	0.94	1.18	23.47	25.73	0.96	*
(b_Site5A-b_Site2A) > 0	17.66	1.04	2.97	77.86	80.82	0.99	*
(b_Site5A-b_Site3A) > 0	3.71	0.92	0.81	15.43	14.61	0.94	
(b_Site5A-b_Site3B) > 0	9.62	0.95	1.81	37.61	40.54	0.98	*
(b_Site5A-b_Site4A) > 0	2.02	0.99	0.40	9.83	3.81	0.79	
(b_Site5A-b_Site4B) > 0	2.10	0.92	0.45	8.56	4.36	0.81	
(b_Site5A-b_Site5B) > 0	1.07	1.04	0.21	5.42	1.13	0.53	
(b_Site5B-b_Site1B) > 0	6.44	0.96	1.19	26.14	26.84	0.96	*
(b_Site5B-b_Site2B) > 0	5.53	1.10	0.87	27.73	16.20	0.94	
(b_Site5B-b_Site2A) > 0	16.44	1.07	2.43	76.86	54.10	0.98	*
(b_Site5B-b_Site3A) > 0	3.45	1.08	0.57	17.60	8.06	0.89	
(b_Site5B-b_Site3B) > 0	8.96	1.08	1.36	43.44	30.03	0.97	*
(b_Site5B-b_Site4A) > 0	1.88	0.95	0.41	8.27	3.71	0.79	
(b_Site5B-b_Site4B) > 0	1.96	1.09	0.35	10.48	3.35	0.77	
(b_Site1B-b_Site2A) > 0	2.55	0.97	0.47	10.72	5.94	0.86	
(b_Site1B-b_Site2B) > 0	0.86	0.96	0.17	3.95	0.76	0.43	
(b_Site1B-b_Site3A) > 0	0.54	0.97	0.12	2.50	0.31	0.24	
(b_Site1B-b_Site3B) > 0	1.39	0.96	0.27	6.25	2.09	0.68	
(b_Site1B-b_Site4A) > 0	0.29	0.92	0.07	1.36	0.08	0.07	
(b_Site1B-b_Site4B) > 0	0.30	0.99	0.06	1.48	0.12	0.11	
(b_Site2A-b_Site2B) > 0	0.34	0.98	0.07	1.67	0.13	0.11	
(b_Site2A-b_Site3A) > 0	0.21	0.97	0.05	1.09	0.06	0.06	
(b_Site2A-b_Site3B) > 0	0.54	0.94	0.13	2.54	0.29	0.23	
(b_Site2A-b_Site4A) > 0	0.11	1.01	0.03	0.68	0.03	0.03	
(b_Site2A-b_Site4B) > 0	0.12	1.03	0.03	0.73	0.03	0.03	
(b_Site3A-b_Site3B) > 0	2.60	0.93	0.56	11.24	6.48	0.87	
(b_Site3A-b_Site4A) > 0	0.54	1.01	0.11	2.88	0.30	0.23	
(b_Site3A-b_Site4B) > 0	0.57	0.96	0.13	2.88	0.31	0.23	
(b_Site3B-b_Site4A) > 0	0.21	1.01	0.05	1.17	0.07	0.07	
(b_Site3B-b_Site4B) > 0	0.22	0.96	0.05	1.15	0.06	0.06	
(b_Site4A-b_Site4B) > 0	1.04	1.03	0.19	5.19	1.15	0.53	
(b_CensusTripT4-b_CensusTripT5) > 0	2.15	0.21	1.52	2.92	299	1.00	*
(b_CensusTripT3-b_CensusTripT4) > 0	2.46	0.17	1.88	3.20	2699	1.00	*

Table B6. Coral growth rate model output**.** A brms model was created using R Software. The model details (variables, parameters, and output) are described, and the appropriate diagnostics were used to test for model accuracy. The estimate (Est), error (Err), and credible intervals (CI low and CI high) were calculated on an odds-ratio scale. Statistical significance was found when the CI interval excluded 1; this is identified by an * in column 'signif'. Rhat values and the effective sample size (Ess) are displayed for each predictor.

Model Information

Family: gaussian

Links: mu = identity

Formula: Growth_Rate_mm_YR ~ Site * Device_Type + (1 | Site/Plot/Device_Number)

Data: T5_growth (Number of observations: 410)

Draws: 3 chains, 6000 iterations; warmup= 1200; thin = 1; post-warmup draws = 14400

Multilevel hyperparameters:

~Site (Number of levels: 10)

~Site:Plot (Number of levels: 182)

~Site:Plot:DeviceNumber (Number of levels: 255)

Model Output

Term	Est	Err	CI Low	CI High	Rhat	Ess	Signif
b_Intercept	4581.50	0.91	845.81	28859.22	1.00	7467	*
b_Site1B	1.63	1.53	0.07	29.90	1.00	10768	
b_Site2A	0.50	1.76	0.02	15.89	1.00	14641	
b_Site2B	3.43	1.60	0.13	71.24	1.00	10866	
b_Site3A	1.10	1.53	0.05	21.06	1.00	11146	
b_Site3B	0.33	1.68	0.01	8.79	1.00	12956	
b_Site4A	15.57	1.55	0.62	267.40	1.00	7901	
b_Site4B	0.50	1.49	0.03	9.85	1.00	10205	
b_Site5A	22.53	1.57	0.77	355.15	1.00	7245	
b_Site5B	11.02	1.54	0.45	201.20	1.00	7858	
b_Device_TypeExclusion	2.20	0.87	0.44	12.75	1.00	8473	
b_Site1B:Device_TypeExclusion	1.78	1.53	0.09	34.53	1.00	13820	
b_Site2A:Device_TypeExclusion	1.48	1.98	0.03	79.80	1.00	18494	
b_Site2B:Device_TypeExclusion	2.49	1.62	0.10	56.45	1.00	13967	
b_Site3A:Device_TypeExclusion	1.38	1.67	0.06	40.20	1.00	14728	
b_Site3B:Device_TypeExclusion	1.48	1.76	0.04	46.51	1.00	14761	
b_Site4A:Device_TypeExclusion	0.23	1.46	0.01	3.65	1.00	13254	
b_Site4B:Device_TypeExclusion	0.57	1.54	0.03	10.99	1.00	13306	
b_Site5A:Device_TypeExclusion	0.72	1.48	0.04	11.82	1.00	13194	
b_Site5B:Device_TypeExclusion	1.63	1.46	0.09	27.16	1.00	12741	

Planned Comparisons

Hypothesis	Est	Err	CI Low	CI High	Evid Ratio	Post Prob	Signif
(b_Site5A-b_Site1B) > 0	12.43	1.97	0.43	280.94	9.03	0.90	
(b_Site5A-b_Site2B) > 0	5.99	2.00	0.20	141.20	4.78	0.83	
(b_Site5A-b_Site2A) > 0	39.58	2.24	0.90	1343.85	17.46	0.95	

(b_Site5A-b_Site3A) > 0	18.35	2.00	0.60	446.64	12.31	0.92	
(b_Site5A-b_Site3B) > 0	60.63	2.19	1.42	1906.38	25.04	0.96	*
(b_Site5A-b_Site4A) > 0	1.42	1.83	0.07	28.42	1.40	0.58	
(b_Site5A-b_Site4B) > 0	40.63	1.96	1.39	828.16	25.47	0.96	*
(b_Site5A-b_Site5B) > 0	1.96	1.85	0.10	39.22	1.87	0.65	
(b_Site5B-b_Site1B) > 0	6.36	1.96	0.24	142.12	5.02	0.83	
(b_Site5B-b_Site2B) > 0	3.06	2.00	0.11	75.29	2.59	0.72	
(b_Site5B-b_Site2A) > 0	20.25	2.21	0.47	678.72	10.60	0.91	
(b_Site5B-b_Site3A) > 0	9.39	1.99	0.33	227.05	6.75	0.87	
(b_Site5B-b_Site3B) > 0	31.01	2.14	0.86	916.73	16.60	0.94	
(b_Site5B-b_Site4A) > 0	0.73	1.85	0.04	15.18	0.74	0.42	
(b_Site5B-b_Site4B) > 0	20.78	1.93	0.78	409.81	15.51	0.94	
(b_Site1B-b_Site2A) > 0	3.18	2.21	0.08	116.20	2.41	0.71	
(b_Site1B-b_Site2B) > 0	0.48	2.07	0.02	14.50	0.55	0.35	
(b_Site1B-b_Site3A) > 0	1.48	2.01	0.06	40.21	1.41	0.59	
(b_Site1B-b_Site3B) > 0	4.88	2.17	0.13	162.26	3.40	0.77	
(b_Site1B-b_Site4A) > 0	0.11	1.95	0.01	3.14	0.15	0.13	
(b_Site1B-b_Site4B) > 0	3.27	1.97	0.13	79.20	2.76	0.73	
(b_Site2A-b_Site2B) > 0	0.15	2.25	0.00	6.44	0.24	0.20	
(b_Site2A-b_Site3A) > 0	0.46	2.22	0.01	18.03	0.56	0.36	
(b_Site2A-b_Site3B) > 0	1.53	2.34	0.03	69.21	1.34	0.57	
(b_Site2A-b_Site4A) > 0	0.04	2.21	0.00	1.54	0.07	0.07	
(b_Site2A-b_Site4B) > 0	1.03	2.19	0.03	40.35	0.99	0.50	
(b_Site3A-b_Site3B) > 0	3.30	2.19	0.09	116.91	2.48	0.71	
(b_Site3A-b_Site4A) > 0	0.08	1.99	0.00	2.28	0.11	0.10	
(b_Site3A-b_Site4B) > 0	2.21	1.98	0.09	56.85	1.95	0.66	
(b_Site3B-b_Site4A) > 0	0.02	2.16	0.00	0.90	0.05	0.05	
(b_Site3B-b_Site4B) > 0	0.67	2.12	0.02	21.25	0.73	0.42	
(b_Site4A-b_Site4B) > 0	28.56	1.95	1.01	576.79	19.17	0.95	*

Table B7. Fish counts and feeding by site model outputs. Brms models were created using R Software. The model details (variables, parameters, and output) are described, and the appropriate diagnostics were used to test for model accuracy. The estimate (Est), error (Err), and credible intervals (CI low and CI high) were calculated on an odds-ratio scale. Statistical significance was found when the CI interval excluded 1; this is identified by an * in column 'signif'. Rhat values and the effective sample size (Ess) are displayed for each predictor.

Model 1: Fish Counts by Site

Family: zero inflated poisson

Links: mu = log; ; zi = identity

Formula: Counts ~ Fish_Family * Site + (1 | Census_Trip/Site/Replicate)

Data: TAll_Fish_A (Number of observations: 534)

Draws: 3 chains, 8000 iterations, warmup = 2500, thin = 10, post-warmup draws=1650

Multilevel hyperparameters:

~Census_Trip (Number of levels: 4)

~Census_Trip:Site (Number of levels: 30)

~Census_Trip:Site:Replicate (Number of levels: 89)

Model Output

Term	Est	Err	CI Low	CI High	Rhat	Ess	Signif
b_Intercept	5.16	0.46	1.97	11.87	1.00	1814	*
b_Fish_FamilyBalistidae	0.06	0.56	0.02	0.17	1.00	1450	*
b_Fish_FamilyChaetodonidae	0.27	0.27	0.16	0.45	1.00	1518	*
b_Fish_FamilyLabridae	2.53	0.14	1.91	3.35	1.00	1551	*
b_Fish_FamilyScarinae	1.03	0.17	0.76	1.44	1.00	1596	
b_Fish_FamilySiganidae	0.26	0.30	0.14	0.45	1.00	1563	*
b_Site1B	3.50	0.44	1.54	8.38	1.00	1792	*
b_Site2A	2.89	0.46	1.18	7.08	1.00	1655	*
b_Site2B	2.00	0.45	0.80	4.74	1.00	1398	
b_Site3A	3.62	0.44	1.53	8.66	1.00	1959	*
b_Site3B	2.70	0.44	1.20	6.82	1.00	1695	*
b_Site4A	4.31	0.44	1.98	11.04	1.00	1576	*
b_Site4B	5.76	0.46	2.40	14.64	1.00	1723	*
b_Site5A	3.26	0.47	1.21	8.04	1.00	1801	*
b_Site5B	3.88	0.47	1.54	9.46	1.00	1694	*

Model Planned Comparisons

Hypothesis	Est	Err	CI Low	CI High	Evid Ratio	Post Prob	Signif
2A - 1A	2.89	0.46	1.18	7.08	1.00	15.81	*
2A - 2B	5.43	14.06	1.33	56.46	2.43	0.39	*
Acanthuridae 1A - Acanthuridae 1B	0.29	0.14	0.12	0.65	128.95	2.11	*
Acanthuridae 1A - Acanthuridae 2A	0.35	0.18	0.14	0.85	82.23	1.92	*
Acanthuridae 1A - Acanthuridae 3A	0.28	0.14	0.12	0.65	103.55	2.02	*
Acanthuridae 1A - Acanthuridae 3B	0.37	0.17	0.15	0.83	131.99	2.12	*
Acanthuridae 1A - Acanthuridae 4A	0.23	0.11	0.09	0.50	157.91	2.2	*
Acanthuridae 1A - Acanthuridae 4B	0.17	0.09	0.07	0.42	89.75	1.95	*
Acanthuridae 1A - Acanthuridae 5A	0.31	0.18	0.12	0.82	51.99	1.72	*
Acanthuridae 1A - Acanthuridae 5B	0.26	0.14	0.11	0.65	71.95	1.86	*

Balistidae 1A - Balistidae 2B	777.12	24622767	1.31	96521262	1.00	0	*
Chaetodonidae 1A - Chaetodonidae 1B	0.38	0.22	0.14	0.99	57.46	1.76	*
Chaetodonidae 1A - Chaetodonidae 3A	0.22	0.13	0.08	0.60	44.39	1.65	*
Scarinae 2A - Scarinae 1A	0.19	0.10	0.08	0.49	62.30	1.79	*
Scarinae 1A - Scarinae 4A	0.25	0.13	0.11	0.61	92.03	1.96	*
Scarinae 1A - Scarinae 4B	0.28	0.16	0.12	0.75	59.15	1.77	*
Siganidae 1A - Siganidae 3A	0.25	0.18	0.10	0.80	25.32	1.4	*
Siganidae 1A - Siganidae 4A	0.24	0.16	0.09	0.71	32.27	1.51	*
Siganidae 1A - Siganidae 4B	0.14	0.09	0.05	0.39	40.90	1.61	*
Siganidae 1A - Siganidae 5A	0.22	0.16	0.07	0.68	24.55	1.39	*

Model 2: Fish Bites by Site

Family: gamma

Links: mu = log; shape= identity

Formula: Total_Bites ~ FishFamily * Site + (1 | Site/UNI_VideoFileName)

Data: BitesPerMin_family_long (Number of observations: 799)

Draws: 3 chains, 8000 iterations, warmup = 2500, thin = 10, post-warmup draws=1650

Multilevel hyperparameters:

~Site (Number of levels: 10)

~Site:UNI_VideoFileName (Number of levels: 259)

Model Output

Term	Est	Err	CI Low	CI High	Rhat	Ess	Signif
b_Intercept	3.48	0.68	0.65	11.37	1.00	1222	
b_FishFamilyBalistidae	0.17	2.82	0.00	50.78	1.00	1609	
b_FishFamilyBlennidae	0.48	0.36	0.23	0.98	1.00	1598	*
b_FishFamilyChaetodontidae	0.13	0.35	0.06	0.25	1.00	1561	*
b_FishFamilyCirrhitidae	0.28	3.42	0.00	208.13	1.00	1449	
b_FishFamilyLabridae	0.07	0.27	0.04	0.12	1.00	1487	*
b_FishFamilyLabridaeScarinae	0.83	0.46	0.34	2.08	1.00	1646	
b_FishFamilyMonocanthidae	0.95	3.57	0.00	1053.16	1.00	1657	
b_FishFamilyMullidae	0.14	0.41	0.07	0.32	1.00	1473	*
b_FishFamilyNemioteridae	0.07	1.00	0.01	0.47	1.00	1557	*
b_FishFamilyPomacanthidae	0.20	0.29	0.12	0.35	1.00	1479	*
b_FishFamilyPomacentridae	0.29	0.22	0.19	0.47	1.00	1654	*
b_FishFamilySiganidae	0.11	0.52	0.04	0.31	1.00	1482	*
b_FishFamilyTetraodontidae	0.38	3.62	0.00	269.80	1.00	1474	
b_Site1B	1.02	1.05	0.12	11.48	1.00	1413	
b_Site2A	0.77	1.01	0.11	8.10	1.00	1429	
b_Site2B	0.31	1.07	0.05	3.64	1.00	1244	
b_Site3A	1.56	1.02	0.22	15.21	1.00	1428	
b_Site3B	0.60	1.02	0.06	5.52	1.00	1430	
b_Site4A	0.12	1.13	0.01	1.51	1.00	1266	
b_Site4B	0.84	1.01	0.15	13.61	1.00	1241	
b_Site5A	1.61	1.03	0.17	14.79	1.00	1627	
b_Site5B	0.41	1.08	0.05	4.90	1.00	1188	

Model Planned Comparisons

Hypothesis	Est	Err	CI Low	CI High	Evid Ratio	Post Prob	Signif
Labridae 1A - Labridae 5B	0.07	0.11	0.00	0.44	3.93	0.60	*
Labridae (Scarinae) 1A - Labridae (Scarinae) 2B	15.24	39.14	1.42	154.83	2.45	0.39	*
Labridae (Scarinae) 1B - Labridae (Scarinae) 2B	16.87	76.74	1.14	301.98	1.66	0.22	*
Acanthuridae 3A - Acanthuridae 4A	13.27	28.17	1.02	111.45	2.96	0.47	*
Pomacanthidae 3B - Pomacanthidae 5A	40.16	243.91	1.80	957.91	1.46	0.17	*
Labridae 4B - Labridae 5B	0.08	0.22	0.01	0.86	2.22	0.35	*

Table B8. Coral survival by fish count model outputs. Brms models were created using R Software. The model details (variables, parameters, and output) are described, and the appropriate diagnostics were used to test for model accuracy. The estimate (Est), error (Err), and credible intervals (CI low and CI high) were calculated on an odds-ratio scale. Statistical significance was found when the CI interval excluded 1; this is identified by an * in column 'signif'. Rhat values and the effective sample size (Ess) are displayed for each predictor.

Model 1: Family-level groupings

Family: bernoulli

Links: mu = logit

Formula: Survival_Tfinal ~ Device_Type * Abun_Scarinae + Device_Type * Abun_Labridae +
Device_Type * Abun_Balistidae + Device_Type * Abun_Acanthuridae +
(1 | Site/Plot/Device_Number)

Data: Fish_CoralSurvival (Number of observations: 1344)

Draws: 3 chains, 5000 iterations; warmup= 1000; thin = 5; post-warmup draws = 2400

Multilevel hyperparameters:

~Site (Number of levels: 10)

~Site:Plot (Number of levels: 241)

~Site:Plot:Device_Number (Number of levels: 456)

Model 1 Output

Term	Est	Err	CI Low	CI High	Rhat	Ess	Signif
b_Intercept	0.20	1.94	0.00	9.06	1.00	2494	
b_Device_TypeExclusion	1.02	0.78	0.24	4.99	1.00	2317	
b_Abun_Scarinae	1.00	0.06	0.88	1.13	1.00	2442	
b_Abun_Labridae	1.03	0.09	0.86	1.22	1.00	2020	
b_Abun_Balistidae	0.30	1.12	0.03	2.71	1.00	2417	
b_Abun_Acanthuridae	1.03	0.10	0.85	1.27	1.00	1809	
b_Device_TypeExclusion:Abun_Scarinae	0.99	0.03	0.93	1.05	1.00	2328	
b_Device_TypeExclusion:Abun_Labridae	0.99	0.04	0.92	1.06	1.00	2463	
b_Device_TypeExclusion:Abun_Balistidae	0.77	0.64	0.21	2.57	1.00	2470	
b_Device_TypeExclusion:Abun_Acanthuridae	1.02	0.04	0.94	1.11	1.00	2346	

Model 1 Planned Comparisons

Hypothesis	Est	Err	CI Low	CI High	Evid Ratio	Post Prob	Signif
(b_Abun_Balistidae-b_Abun_Acanthuridae) > 0	0.31	1.09	0.05	1.90	0.17	0.14	
(b_Abun_Balistidae-b_Abun_Scarinae) > 0	0.31	1.16	0.05	2.28	0.18	0.16	
(b_Abun_Balistidae-b_Abun_Labridae) > 0	0.31	1.13	0.05	2.14	0.17	0.15	

(b_Abun_Scarinae-b_Abun_Acanthuridae) > 0	0.98	0.13	0.78	1.21	0.73	0.42	
(b_Abun_Scarinae-b_Abun_Labridae) > 0	0.98	0.10	0.83	1.14	0.64	0.39	
(b_Abun_Labridae-b_Abun_Acanthuridae) > 0	1.00	0.16	0.77	1.28	1.03	0.51	

Model 2: Species-level groupings

Family: bernoulli

Links: mu = logit

Formula: Survival_Tfinal ~ Abun_Chs_micr * Device_Type + Abun_Aca_line * Device_Type +
Abun_Sca_fren * Device_Type + Abun_Tha_ambl * Device_Type +
Abun_Gom_vari * Device_Type + Abun_Cha_tlis * Device_Type +
(1 | Site/Plot/Device_Number)

Data: Fish_CoralSurvival (Number of observations: 1344)

Draws: 3 chains, 5000 iterations; warmup= 1000; thin = 5; post-warmup draws = 2400

Multilevel hyperparameters:

~Site (Number of levels: 10)

~Site:Plot (Number of levels: 241)

~Site:Plot:Device_Number (Number of levels: 456)

Model 2 Output

Term	Est	Err	CI Low	CI High	Rhat	Ess	Signif
b_Intercept	0.10	0.53	0.04	0.26	1.00	2161	*
b_Abun_Chs_micr	0.97	0.04	0.90	1.04	1.00	2199	
b_Device_TypeExclusion	2.96	0.49	1.17	7.91	1.00	2051	*
b_Abun_Aca_line	0.73	0.27	0.44	1.24	1.00	2142	
b_Abun_Sca_fren	1.22	0.23	0.79	1.92	1.00	2347	
b_Abun_Tha_ambl	2.98	0.48	1.18	7.29	1.00	2219	*
b_Abun_Gom_vari	1.45	0.27	0.87	2.50	1.00	2110	
b_Abun_Cha_tlis	0.79	0.36	0.38	1.57	1.00	2234	
b_Abun_Chs_micr:Device_TypeExclusion	0.96	0.04	0.89	1.03	1.00	2414	
b_Device_TypeExclusion:Abun_Aca_line	1.66	0.25	1.05	2.85	1.00	2166	*
b_Device_TypeExclusion:Abun_Sca_fren	1.07	0.22	0.70	1.65	1.00	2252	
b_Device_TypeExclusion:Abun_Tha_ambl	0.38	0.45	0.15	0.91	1.00	2157	*
b_Device_TypeExclusion:Abun_Gom_vari	0.60	0.26	0.35	0.97	1.00	2148	*
b_Device_TypeExclusion:Abun_Cha_tlis	0.72	0.36	0.36	1.47	1.00	2214	

Model 2 Planned Comparisons

Hypothesis	Est	Err	CI Low	CI High	Evid Ratio	Post Prob	Signif
(b_Abun_Chs_micr-b_Abun_Sca_fren) > 0	0.79	0.23	0.56	1.12	0.16	0.14	
(b_Abun_Chs_micr-b_Abun_Tha_ambl) > 0	0.33	0.46	0.16	0.66	0.01	0.01	
(b_Abun_Chs_micr-b_Abun_Gom_vari) > 0	0.67	0.26	0.45	1.00	0.05	0.05	
(b_Abun_Chs_micr-b_Abun_Aca_line) > 0	1.32	0.29	0.83	2.06	5.69	0.85	
(b_Abun_Chs_micr-b_Abun_Cha_tlis) > 0	1.23	0.36	0.71	2.17	2.74	0.73	
(b_Abun_Tha_ambl-b_Abun_Sca_fren) > 0	2.42	0.59	0.97	5.78	17.60	0.95	
(b_Abun_Tha_ambl-b_Abun_Gom_vari) > 0	2.04	0.30	1.32	3.21	76.42	0.99	*
(b_Abun_Tha_ambl-b_Abun_Aca_line) > 0	4.03	0.73	1.28	12.22	31.00	0.97	*

(b_Abun_Tha_ambl-b_Abun_Cha_tlis) > 0	3.74	0.49	1.73	7.83	95.00	0.99	*
(b_Abun_Gom_vari-b_Abun_Sca_fren) > 0	1.19	0.38	0.65	2.14	2.33	0.70	
(b_Abun_Gom_vari-b_Abun_Cha_tlis) > 0	1.83	0.28	1.17	2.88	59.00	0.98	*
(b_Abun_Aca_line-b_Abun_Sca_fren) > 0	0.60	0.34	0.36	1.03	0.06	0.06	
(b_Abun_Aca_line-b_Abun_Cha_tlis) > 0	0.93	0.57	0.39	2.37	0.75	0.43	

Table B9. Coral survival by fish feeding model outputs. Brms models were created using R Software. The model details (variables, parameters, and output) are described, and the appropriate diagnostics were used to test for model accuracy. The estimate (Est), error (Err), and credible intervals (CI low and CI high) were calculated on an odds-ratio scale. Statistical significance was found when the CI interval excluded 1; this is identified by an * in column 'signif'. Rhat values and the effective sample size (Ess) are displayed for each predictor.

Model 1: Family-level groupings

Family: bernoulli

Links: mu = logit

Formula: Survival_Tfinal ~ Device_Type * Bites_Min_Labridae +

Device_Type * Bites_Min_Labridae_Scarinae +

Device_Type * Bites_Min_Pomacentridae_Pomacanthidae + (1 | Site/Plot/Device_Number)

Data: Fish_CoralSurvival (Number of observations: 1344)

Draws: 3 chains, 5000 iterations; warmup= 1000; thin = 5; post-warmup draws = 2400

Multilevel hyperparameters:

~Site (Number of levels: 10)

~Site:Plot (Number of levels: 241)

~Site:Plot:Device_Number (Number of levels: 456)

Model 1 Output

Term	Est	Err	CI Low	CI High	Rhat	Ess	Signif
b_Intercept	0.21	0.84	0.04	1.02	1.00	2375	*
b_Device_TypeExclusion	1.83	0.44	0.79	4.31	1.00	2232	
b_Bites_Min_Labridae	1.38	1.08	0.17	11.91	1.00	2513	
b_Bites_Min_Labridae_Scarinae	0.60	1.12	0.07	5.36	1.00	2501	
b_Bites_Min_Pomacentridae_Pomacanthidae	1.19	0.30	0.69	2.23	1.00	2341	
b_Device_TypeExclusion:Bites_Min_Labridae	1.24	0.62	0.38	4.07	1.00	1941	
b_Device_TypeExclusion:Bites_Min_Labridae_Scarinae	0.48	0.69	0.13	1.94	1.00	2318	
b_Device_TypeExclusion: Bites_Min_Pomacentridae_Pomacanthidae	0.87	0.16	0.63	1.16	1.00	2170	

Model 1 Planned Comparisons

Hypothesis	Est	Err	CI Low	CI High	Evid Ratio	Post Prob	Signif
(b_Bites_Min_Pomacentridae_Pomacanthidae- b_Bites_Min_Labridae_Scarinae) > 0	1.95	1.10	0.32	11.36	2.81	0.74	
(b_Bites_Min_Labridae- b_Bites_Min_Labridae_Scarinae) > 0	2.26	1.60	0.16	27.01	2.42	0.71	
(b_Bites_Min_Pomacentridae_Pomacanthidae- b_Bites_Min_Labridae) > 0	0.86	1.31	0.11	7.37	0.83	0.46	

Model 2: Species-level groupings

Family: bernoulli

Links: mu = logit

Formula: Survival_Tfinal ~ Bites_Min_Gomphosus_varius * Device_Type +
Bites_Min_Cirripectes_sp * Device_Type + Bites_Min_Halichoeres_sp * Device_Type +
Bites_Min_Escenius_sp * Device_Type + Bites_Min_Chlorurus_spirulus * Device_Type +
Bites_Min_Pomacentrus_sp * Device_Type + Bites_Min_Centropyge_vrolikii * Device_Type +
Bites_Min_Chromis_sp * Device_Type + Bites_Min_Zebrasoma_scopas * Device_Type +
(1 | Site/Plot/Device_Number)

Data: Fish_CoralSurvival (Number of observations: 1344)

Draws: 3 chains, 5000 iterations; warmup= 1000; thin = 5; post-warmup draws = 2400

Multilevel hyperparameters:

~Site (Number of levels: 10)

~Site:Plot (Number of levels: 241)

~Site:Plot:Device_Number (Number of levels: 456)

Model 2 Output

Term	Est	Err	CI Low	CI High	Rhat	Ess	Signif
b_Intercept	0.19	0.67	0.05	0.68	1.00	2415	*
b_Bites_Min_Gomphosus_varius	2.98	1.70	0.12	77.12	1.00	2348	
b_Device_TypeExclusion	2.05	0.47	0.87	5.35	1.00	2122	
b_Bites_Min_Cirripectes_sp	3.62	0.84	0.61	16.61	1.00	2311	
b_Bites_Min_Halichoeres_sp	2.51	1.55	0.09	37.53	1.00	2345	
b_Bites_Min_Escenius_sp	0.31	1.01	0.04	2.13	1.00	2013	
b_Bites_Min_Chlorurus_spirulus	2.29	1.16	0.22	20.52	1.00	2264	
b_Bites_Min_Pomacentrus_sp	0.98	0.27	0.61	1.77	1.00	2216	
b_Bites_Min_Centropyge_vrolikii	0.46	1.17	0.06	6.34	1.00	2226	
b_Bites_Min_Chromis_sp	0.51	1.29	0.05	7.21	1.00	2121	
b_Bites_Min_Zebrasoma_scopas	3.80	1.35	0.28	48.08	1.00	2178	
b_Bites_Min_Gomphosus_varius:Device_TypeExclusion	0.74	1.59	0.04	19.40	1.00	2332	
b_Device_TypeExclusion:Bites_Min_Cirripectes_sp	0.69	0.68	0.19	2.47	1.00	2196	
b_Device_TypeExclusion:Bites_Min_Halichoeres_sp	1.13	1.41	0.07	18.11	1.00	2214	
b_Device_TypeExclusion:Bites_Min_Escenius_sp	0.53	0.83	0.10	2.62	1.00	2317	
b_Device_TypeExclusion:Bites_Min_Chlorurus_spirulus	0.89	0.96	0.16	6.78	1.00	2462	
b_Device_TypeExclusion:Bites_Min_Pomacentrus_sp	0.94	0.21	0.62	1.45	1.00	1910	
b_Device_TypeExclusion:Bites_Min_Centropyge_vrolikii	0.64	0.97	0.10	4.34	1.00	2178	
b_Device_TypeExclusion:Bites_Min_Chromis_sp	1.26	1.10	0.15	11.02	1.00	2270	
b_Device_TypeExclusion:Bites_Min_Zebrasoma_scopas	0.31	1.10	0.03	2.14	1.00	2317	

Model 2 Planned Comparisons

Hypothesis	Est	Err	CI Low	CI High	Evid Ratio	Post Prob	Signif
(b_Bites_Min_Cirripectes_sp-b_Bites_Min_Escenius_sp) > 0	10.99	1.25	1.29	68.85	25.97	0.96	*
(b_Bites_Min_Cirripectes_sp-b_Bites_Min_Chlorurus_spirulus) > 0	1.48	1.40	0.15	13.78	1.57	0.61	
(b_Bites_Min_Cirripectes_sp-b_Bites_Min_Halichoeres_sp) > 0	1.38	1.64	0.10	21.26	1.37	0.58	
(b_Bites_Min_Cirripectes_sp-b_Bites_Min_Zebrasoma_scopas) > 0	0.98	1.29	0.13	8.76	0.91	0.48	
(b_Bites_Min_Cirripectes_sp-b_Bites_Min_Centropyge_vrolikii) > 0	7.01	1.74	0.35	102.86	6.43	0.87	

(b_Bites_Min_Pomacentrus_sp-b _Bites_Min_Chlorurus_spirulus) > 0	0.43	1.14	0.07	2.95	0.27	0.22	
(b_Bites_Min_Pomacentrus_sp -b_Bites_Min_Halichoeres_sp) > 0	0.40	1.74	0.02	7.31	0.39	0.28	
(b_Bites_Min_Pomacentrus_sp- b_Bites_Min_Zebrasoma_scopas) > 0	0.29	1.44	0.03	3.43	0.24	0.19	
(b_Bites_Min_Pomacentrus_sp- b_Bites_Min_Escenius_sp) > 0	3.21	1.04	0.60	17.94	7.45	0.88	
(b_Bites_Min_Pomacentrus_sp- b_Bites_Min_Centropyge_vrolikii) > 0	2.05	1.08	0.31	11.15	3.21	0.76	
(b_Bites_Min_Chromis_sp- b_Bites_Min_Chlorurus_spirulus) > 0	0.23	1.77	0.01	4.75	0.24	0.19	
(b_Bites_Min_Chromis_sp- b_Bites_Min_Halichoeres_sp) > 0	0.22	1.88	0.01	4.54	0.25	0.20	
(b_Bites_Min_Chromis_sp- b_Bites_Min_Zebrasoma_scopas) > 0	0.15	2.07	0.01	5.13	0.22	0.18	
(b_Bites_Min_Chromis_sp- b_Bites_Min_Escenius_sp) > 0	1.71	1.64	0.12	26.56	1.63	0.62	
(b_Bites_Min_Chromis_sp- b_Bites_Min_Centropyge_vrolikii) > 0	1.09	1.43	0.10	11.58	1.16	0.54	
(b_Bites_Min_Gomphosus_varius- b_Bites_Min_Chlorurus_spirulus) > 0	1.28	2.05	0.04	35.24	1.23	0.55	
(b_Bites_Min_Gomphosus_varius- b_Bites_Min_Halichoeres_sp) > 0	1.20	2.35	0.03	59.67	1.10	0.52	
(b_Bites_Min_Gomphosus_varius- b_Bites_Min_Zebrasoma_scopas) > 0	0.85	2.09	0.03	27.05	0.83	0.45	
(b_Bites_Min_Gomphosus_varius- b_Bites_Min_Escenius_sp) > 0	9.54	1.90	0.37	186.42	7.48	0.88	
(b_Bites_Min_Gomphosus_varius- b_Bites_Min_Centropyge_vrolikii) > 0	6.09	2.04	0.19	144.41	4.26	0.81	
(b_Bites_Min_Halichoeres_sp- b_Bites_Min_Zebrasoma_scopas) > 0	0.71	1.82	0.04	14.14	0.71	0.42	
(b_Bites_Min_Centropyge_vrolikii- b_Bites_Min_Zebrasoma_scopas) > 0	0.14	1.99	0.01	4.48	0.20	0.16	
(b_Bites_Min_Halichoeres_sp- b_Bites_Min_Escenius_sp) > 0	7.96	1.91	0.32	166.15	6.16	0.86	
(b_Bites_Min_Centropyge_vrolikii- b_Bites_Min_Escenius_sp) > 0	1.57	1.68	0.11	25.41	1.49	0.60	
(b_Bites_Min_Halichoeres_sp- b_Bites_Min_Chlorurus_spirulus) > 0	1.07	2.03	0.04	29.87	1.05	0.51	
(b_Bites_Min_Centropyge_vrolikii- b_Bites_Min_Chlorurus_spirulus) > 0	0.21	1.56	0.02	3.04	0.18	0.15	

Table B10. Coral growth by fish count and feeding model outputs. Brms models were created using R Software. The model details (variables, parameters, and output) are described, and the appropriate diagnostics were used to test for model accuracy. The estimate (Est), error (Err), and credible intervals (CI low and CI high) were calculated on an odds-ratio scale. Statistical significance was found when the CI interval excluded 1; this is identified by an * in column 'signif'.

Model 1: Fish Counts (family-level groupings)

Family: gaussian

Links: mu = identity; sigma = identity

Formula: Growth_Rate_mm_YR ~ Device_Type * Abun_Scarinae + Device_Type * Abun_Labridae + Device_Type * Abun_Balistidae + Device_Type * Abun_Acanthuridae + (1 | Site/Plot/Device_Number)

Data: Fish_CoralGrowth (Number of observations: 410)

Draws: 3 chains, 5000 iterations; warmup= 1000; thin = 5; post-warmup draws = 2400

Multilevel hyperparameters:

~Site (Number of levels: 10)

~Site:Plot (Number of levels: 181)

~Site:Plot:Device_Number (Number of levels: 255)

Model 1 Output

Term	Est	Err	CI Low	CI High	Rhat	Ess	Signif
b_Intercept	991.26	3.78	0.33	1122498	1.00	2348	
b_Device_TypeExclusion	2.89	1.86	0.08	124.03	1.00	2472	
b_Abun_Scarinae	1.05	0.13	0.80	1.34	1.00	2375	
b_Abun_Labridae	1.08	0.13	0.82	1.37	1.00	2218	
b_Abun_Balistidae	0.13	1.99	0.00	5.83	1.00	2218	
b_Abun_Acanthuridae	1.05	0.13	0.79	1.35	1.00	2311	
b_Device_TypeExclusion:Abun_Scarinae	0.96	0.11	0.76	1.16	1.00	2362	
b_Device_TypeExclusion:Abun_Labridae	1.06	0.08	0.91	1.25	1.00	2470	
b_Device_TypeExclusion:Abun_Balistidae	1.92	1.81	0.05	54.60	1.00	2400	
b_Device_TypeExclusion:Abun_Acanthuridae	0.94	0.10	0.77	1.14	1.00	2465	

Model 1 Planned Comparisons

Hypothesis	Est	Err	CI Low	CI High	Evid Ratio	Post Prob	Signif
(b_Abun_Balistidae-b_Abun_Acanthuridae) > 0	0.1331	1.9380	0.0058	3.6573	0.1759	0.1496	
(b_Abun_Balistidae-b_Abun_Scarinae) > 0	0.1331	2.0503	0.0050	4.4084	0.1923	0.1613	
(b_Abun_Balistidae-b_Abun_Labridae) > 0	0.1289	2.0115	0.0052	4.1486	0.1788	0.1517	
(b_Abun_Scarinae-b_Abun_Acanthuridae) > 0	0.9999	0.2328	0.6821	1.4651	1.0374	0.5092	
(b_Abun_Scarinae-b_Abun_Labridae) > 0	0.9690	0.1670	0.7355	1.2644	0.7316	0.4225	
(b_Abun_Labridae-b_Abun_Acanthuridae) > 0	1.0319	0.1931	0.7499	1.4029	1.3622	0.5767	

Model 2: Fish Counts (species-level groupings)

Family: gaussian

Links: mu = identity; sigma = identity

Formula: Growth_Rate_mm_YR ~ Abun_Chs_micr * Device_Type + Abun_Aca_line * Device_Type + Abun_Sca_fren * Device_Type + Abun_Tha_ambl * Device_Type + Abun_Gom_vari * Device_Type + Abun_Cha_tlis * Device_Type + (1 | Site/Plot/Device_Number)

Data: Fish_CoralGrowth (Number of observations: 410)

Draws: 3 chains, 5000 iterations; warmup= 1000; thin = 5; post-warmup draws = 2400

Multilevel hyperparameters:

~Site (Number of levels: 10)

~Site:Plot (Number of levels: 181)
~Site:Plot:Device_Number (Number of levels: 255)

Model 2 Output

Term	Est	Err	CI Low	CI High	Rhat	Ess	Signif
b_Intercept	0.10	0.53	0.04	0.26	1.00	2161	*
b_Abun_Chs_micr	0.97	0.04	0.90	1.04	1.00	2199	
b_Device_TypeExclusion	2.96	0.49	1.17	7.91	1.00	2051	*
b_Abun_Aca_line	0.73	0.27	0.44	1.24	1.00	2142	
b_Abun_Sca_fren	1.22	0.23	0.79	1.92	1.00	2347	
b_Abun_Tha_ambl	2.98	0.48	1.18	7.29	1.00	2219	*
b_Abun_Gom_vari	1.45	0.27	0.87	2.50	1.00	2110	
b_Abun_Cha_tlis	0.79	0.36	0.38	1.57	1.00	2234	
b_Abun_Chs_micr:Device_TypeExclusion	0.96	0.04	0.89	1.03	1.00	2414	
b_Device_TypeExclusion:Abun_Aca_line	1.66	0.25	1.05	2.85	1.00	2166	*
b_Device_TypeExclusion:Abun_Sca_fren	1.07	0.22	0.70	1.65	1.00	2252	
b_Device_TypeExclusion:Abun_Tha_ambl	0.38	0.45	0.15	0.91	1.00	2157	*
b_Device_TypeExclusion:Abun_Gom_vari	0.60	0.26	0.35	0.97	1.00	2148	*
b_Device_TypeExclusion:Abun_Cha_tlis	0.72	0.36	0.36	1.47	1.00	2214	

Model 2 Planned Comparisons

Hypothesis	Est	Err	CI Low	CI High	Evid Ratio	Post Prob	Signif
(b_Abun_Gom_vari-b_Abun_Sca_fren) > 0	0.09	0.98	0.02	0.49	0.01	0.01	*
(b_Abun_Gom_vari-b_Abun_Tha_ambl) > 0	0.86	0.77	0.23	2.98	0.72	0.42	
(b_Abun_Gom_vari-b_Abun_Aca_line) > 0	0.07	1.38	0.01	0.76	0.04	0.04	*
(b_Abun_Gom_vari-b_Abun_Chs_micr) > 0	0.28	0.66	0.10	0.90	0.04	0.04	*
(b_Abun_Sca_fren-b_Abun_Chs_micr) > 0	3.33	0.64	1.12	9.15	27.24	0.96	*

Model 3: Fish Bites (family-level groupings)

Family: gaussian

Links: mu = identity; sigma = identity

Formula: Growth_Rate_mm_YR ~ Device_Type * Bites_Min_Labridae + Device_Type * Bites_Min_Labridae_Scarinae +

Device_Type * Bites_Min_Pomacentridae_Pomacanthidae + (1 | Site/Plot/Device_Number)
Data: Fish_CoralGrowth (Number of observations: 410)

Draws: 3 chains, 5000 iterations; warmup= 1000; thin = 5; post-warmup draws = 2400

Multilevel hyperparameters:

~Site (Number of levels: 10)

~Site:Plot (Number of levels: 181)
~Site:Plot:Device_Number (Number of levels: 255)

Model 3 Output

Term	Est	Err	CI Low	CI High	Rhat	Ess	Signif

b_Intercept	3040.27	1.47	174.02	52673.92	1.00	2495	*
b_Device_TypeExclusion	2.28	1.24	0.21	24.01	1.00	2529	
b_Bites_Min_Labridae	0.64	1.66	0.02	17.47	1.00	2325	
b_Bites_Min_Labridae_Scarinae	0.19	1.84	0.01	6.84	1.00	2458	
b_Bites_Min_Pomacentridae_Pomacanthidae	2.06	0.49	0.73	4.99	1.00	2430	
b_Device_TypeExclusion:Bites_Min_Labridae	2.71	1.63	0.13	86.09	1.00	2536	
b_Device_TypeExclusion:Bites_Min_Labridae_Scarinae	1.92	1.81	0.06	63.69	1.00	2450	
b_Device_TypeExclusion: Bites_Min_Pomacentridae_Pomacanthidae	0.78	0.45	0.32	1.86	1.00	2524	

Model 3 Planned Comparisons

Hypothesis	Est	Err	CI Low	CI High	Evid Ratio	Post Prob	Signif
(b_Bites_Min_Labridae_Scarinae-b_Bites_Min_Labridae) > 0	0.31	2.55	0.00	22.81	0.47	0.32	
(b_Bites_Min_Labridae_Scarinae- b_Bites_Min_Pomacentridae_Pomacanthidae) > 0	0.09	1.77	0.01	1.73	0.10	0.09	
(b_Bites_Min_Labridae- b_Bites_Min_Pomacentridae_Pomacanthidae) > 0	0.31	2.03	0.01	10.02	0.38	0.28	

Model 4: Fish Bites (species-level groupings)

Family: gaussian

Links: mu = identity; sigma = identity

Formula: Growth_Rate_mm_YR ~ Bites_Min_Gomphosus_varius * Device_Type + Bites_Min_Cirripectes_sp * Device_Type +

Bites_Min_Halichoeres_sp * Device_Type + Bites_Min_Escenius_sp * Device_Type +

Bites_Min_Chlorurus_spirulus * Device_Type + Bites_Min_Pomacentrus_sp * Device_Type +

Bites_Min_Centropyge_vrolikii * Device_Type + Bites_Min_Chromis_sp * Device_Type +

Bites_Min_Zebrasoma_scopas * Device_Type + (1 | Site/Plot/Device_Number)

Data: Fish_CoralGrowth (Number of observations: 410)

Draws: 3 chains, 5000 iterations; warmup= 1000; thin = 5; post-warmup draws = 2400

Multilevel hyperparameters:

~Site (Number of levels: 10)

~Site:Plot (Number of levels: 181)

~Site:Plot:Device_Number (Number of levels: 255)

Model 4 Output

Term	Est	Err	CI Low	CI High	Rhat	Ess	Signif
b_Intercept	12469	1.23	1393	178538	1.00	2214	*
b_Bites_Min_Gomphosus_varius	1.88	2.42	0.02	199.29	1.00	2076	
b_Device_TypeExclusion	1.89	1.17	0.22	20.35	1.00	2069	
b_Bites_Min_Cirripectes_sp	3.49	1.36	0.27	49.47	1.00	2298	
b_Bites_Min_Halichoeres_sp	0.70	2.23	0.01	54.36	1.00	2538	
b_Bites_Min_Escenius_sp	0.44	1.79	0.01	12.24	1.00	2411	
b_Bites_Min_Chlorurus_spirulus	0.27	1.87	0.01	10.38	1.00	2395	
b_Bites_Min_Pomacentrus_sp	1.18	0.42	0.53	2.73	1.00	2249	
b_Bites_Min_Centropyge_vrolikii	0.03	1.93	0.00	1.07	1.00	2190	
b_Bites_Min_Chromis_sp	2.72	1.97	0.07	124.08	1.00	2442	
b_Bites_Min_Zebrasoma_scopas	0.27	1.98	0.01	20.50	1.00	2331	
b_Bites_Min_Gomphosus_varius: Device_TypeExclusion	0.65	2.43	0.00	58.94	1.00	2442	

Model 4 Planned Comparisons							
Hypothesis	**Est**	**Err**	**CI Low**	**CI High**	**Evid Ratio**	**Post Prob**	**Signif**
(b_Bites_Min_Cirripectes_sp-b_Bites_Min_Chlorurus_spirulus) > 0	12.73	2.21	0.30	485.64	7.08	0.88	
(b_Bites_Min_Cirripectes_sp-b_Bites_Min_Halichoeres_sp) > 0	4.95	2.57	0.07	300.79	2.86	0.74	
(b_Bites_Min_Cirripectes_sp-b_Bites_Min_Zebrasoma_scopas) > 0	12.71	2.13	0.38	379.81	7.82	0.89	
(b_Bites_Min_Cirripectes_sp-b_Bites_Min_Escenius_sp) > 0	7.54	2.12	0.24	234.55	5.11	0.84	
(b_Bites_Min_Cirripectes_sp-b_Bites_Min_Centropyge_vrolikii) > 0	110.86	2.71	1.29	8826.54	24.81	0.96	*
(b_Bites_Min_Pomacentrus_sp-b_Bites_Min_Chlorurus_spirulus) > 0	4.35	1.84	0.20	83.94	3.92	0.80	
(b_Bites_Min_Pomacentrus_sp-b_Bites_Min_Halichoeres_sp) > 0	1.69	2.51	0.02	99.67	1.42	0.59	
(b_Bites_Min_Pomacentrus_sp-b_Bites_Min_Zebrasoma_scopas) > 0	4.34	2.05	0.13	124.79	3.40	0.77	
(b_Bites_Min_Pomacentrus_sp-b_Bites_Min_Escenius_sp) > 0	2.57	1.83	0.14	50.37	2.22	0.69	
(b_Bites_Min_Pomacentrus_sp-b_Bites_Min_Centropyge_vrolikii) > 0	37.84	1.80	1.73	668.09	37.71	0.97	*
(b_Bites_Min_Chromis_sp-b_Bites_Min_Chlorurus_spirulus) > 0	9.71	2.72	0.11	793.08	4.18	0.81	
(b_Bites_Min_Chromis_sp-b_Bites_Min_Halichoeres_sp) > 0	3.77	2.61	0.05	283.73	2.27	0.69	
(b_Bites_Min_Chromis_sp-b_Bites_Min_Zebrasoma_scopas) > 0	9.69	2.95	0.07	1090.90	3.72	0.79	
(b_Bites_Min_Chromis_sp-b_Bites_Min_Escenius_sp) > 0	5.75	2.69	0.07	546.12	2.79	0.74	
(b_Bites_Min_Chromis_sp-b_Bites_Min_Centropyge_vrolikii) > 0	84.51	2.42	1.53	4667.10	25.67	0.96	*
(b_Bites_Min_Gomphosus_varius-b_Bites_Min_Chlorurus_spirulus) > 0	6.59	3.07	0.04	1115.38	2.68	0.73	
(b_Bites_Min_Gomphosus_varius-b_Bites_Min_Halichoeres_sp) > 0	2.56	3.34	0.01	641.33	1.58	0.61	
(b_Bites_Min_Gomphosus_varius-b_Bites_Min_Zebrasoma_scopas) > 0	6.58	3.16	0.04	1094.34	2.63	0.72	
(b_Bites_Min_Gomphosus_varius-b_Bites_Min_Escenius_sp) > 0	3.90	2.96	0.03	440.01	2.10	0.68	
(b_Bites_Min_Gomphosus_varius-b_Bites_Min_Centropyge_vrolikii) > 0	57.39	3.00	0.40	7342.76	9.96	0.91	
(b_Bites_Min_Halichoeres_sp-b_Bites_Min_Zebrasoma_scopas) > 0	2.57	2.87	0.02	277.51	1.69	0.63	
(b_Bites_Min_Centropyge_vrolikii-b_Bites_Min_Zebrasoma_scopas) > 0	0.11	2.84	0.00	12.43	0.27	0.21	
(b_Bites_Min_Halichoeres_sp-b_Bites_Min_Escenius_sp) > 0	1.52	2.96	0.01	225.29	1.21	0.55	
(b_Bites_Min_Centropyge_vrolikii-b_Bites_Min_Escenius_sp) > 0	0.07	2.84	0.00	7.87	0.22	0.18	
(b_Bites_Min_Halichoeres_sp-b_Bites_Min_Chlorurus_spirulus) > 0	2.57	2.99	0.02	341.64	1.69	0.63	
(b_Bites_Min_Centropyge_vrolikii-b_Bites_Min_Chlorurus_spirulus) > 0	0.11	2.52	0.00	8.15	0.23	0.19	

Table B11. Coral survival and benthic composition model outputs. Brms models were created using R Software. The model details (variables, parameters, and output) are described, and the appropriate diagnostics were used to test for model accuracy. The estimate (Est), error (Err), and credible intervals (CI low and CI high) were calculated on an odds-ratio scale. Statistical significance was found when the CI interval excluded 1; this is identified by an * in column 'signif'.

Model 1: Morphological grouping

Family: bernoulli

Links: mu = logit

Formula: Survival ~ CCA_Turf_consolidated*Device_Type + Macroalgae*Device_Type + OT_Other * Device_Type + Coral_Encrusting*Device_Type + Coral_Branching*Device_Type + Coral_Acropora * Device_Type + CCA_Turf_unconsolidated * DeviceType + Coral_Pocillopora * Device_Type + (1 | site/image_name/Device)

Data: Quadrat (Number of observations: 1307)

Draws: 3 chains, 8000 iterations; warmup= 2000; thin = 5; post-warmup draws = 3600

Multilevel hyperparameters:

~site (Number of levels: 10)

~site:image_name (Number of levels: 257)

~site:image_name:Device (Number of levels: 442)

Model 1 Output

Term	Est	Err	CI Low	CI High	Rhat	Ess	Signif
b_Intercept	0.16	1.21	0.01	1.53	1.00	3214	
b_CCA_Turf_consolidated	1.01	0.01	0.99	1.04	1.00	3297	
b_CCA_Turf_consolidated	1.11	1.38	0.08	15.97	1.00	3421	
b_Macroalgae	1.01	0.02	0.99	1.05	1.00	3334	
b_OT_Other	1.13	0.05	1.02	1.25	1.00	3587	*
b_Coral_Encrusting	1.06	0.03	1.01	1.12	1.00	3305	*
b_Coral_Branching	0.99	0.08	0.83	1.14	1.00	3520	
b_Coral_Acropora	0.98	0.02	0.94	1.01	1.00	3511	
b_CCA_Turf_unconsolidated	0.98	0.02	0.94	1.02	1.00	3284	
b_Coral_Pocillopora	0.99	0.02	0.95	1.03	1.00	3352	
b_CCA_Turf_consolidated:Device_TypeExclusion	1.00	0.01	0.97	1.03	1.00	3230	
b_Device_TypeExclusion:Macroalgae	0.98	0.02	0.95	1.01	1.00	3442	
b_Device_TypeExclusion:OT_Other	0.93	0.07	0.79	1.06	1.00	3307	
b_Device_TypeExclusion:Coral_Encrusting	0.99	0.03	0.94	1.06	1.00	3505	
b_Device_TypeExclusion:Coral_Branching	0.93	0.14	0.68	1.21	1.00	3626	
b_Device_TypeExclusion:Coral_Acropora	1.01	0.02	0.97	1.06	1.00	3256	
b_CCA_Turf_unconsolidated:DeviceTypeExclusion	1.03	0.02	0.99	1.08	1.00	3358	
b_Device_TypeExclusion:Coral_Pocillopora	1.00	0.02	0.96	1.05	1.00	3217	

Model 1 Planned Comparisons

Hypothesis	Est	Err	CI Low	CI High	Evid Ratio	Post Prob	Signif
(b_OT_Other-b_Coral_Acropora) > 0	1.16	0.05	1.06	1.27	299.00	1.00	*
(b_Coral_Encrusting-b_Coral_Acropora) > 0	1.09	0.03	1.04	1.14	1799.00	1.00	*

(b_OT_Other-b_CCA_Turf_unconsolidated) > 0	1.16	0.06	1.06	1.27	239.00	1.00	*
(b_Coral_Encrusting-b_CCA_Turf_unconsolidated) > 0	1.09	0.03	1.04	1.14	899.00	1.00	*
(b_OT_Other-b_Coral_Branching) > 0	1.15	0.10	1.00	1.37	18.46	0.95	
(b_Coral_Encrusting-b_Coral_Branching) > 0	1.08	0.09	0.96	1.26	4.73	0.83	

Model 2: Lowest grouping

Family: bernoulli

Links: mu = logit

Formula: Survival ~ CA_RA_CorallineAlgae_consolidated * Device_Type + OT_Ascidian * Device_Type + MA_RA_Red_Algae * Device_Type + POR_CE_Porites * Device_Type + ACR_ACO_ACC_Acropora * Device_Type + SP_Sponge * Device_Type + TA_TurfAlgae_consolidated * Device_Type + PLA_CE_Platygyra * Device_Type + POC_CS_Pocillopora_3 * Device_Type + ACR_ACB_Acropora * Device_Type + (1 | site/image_name/Device)

Data: Quadrat (Number of observations: 1307)

Draws: 3 chains, 8000 iterations; warmup= 2000; thin = 5; post-warmup draws = 3600

Multilevel hyperparameters:

~site (Number of levels: 10)

~site:image_name (Number of levels: 257)

~site:image_name:Device (Number of levels: 442)

Model 2 Output

Term	Est	Err	CI Low	CI High	Rhat	Ess	Signif
b_Intercept	0.12	0.60	0.04	0.37	1.00	3105	*
b_Device_TypeExclusion	1.25	0.65	0.31	3.82	1.00	3135	
b_CA_RA_CorallineAlgae_consolidated	1.02	0.01	1.00	1.03	1.00	3165	*
b_OT_Ascidian	1.37	0.13	1.09	1.83	1.00	3590	*
b_MA_RA_Red_Algae	1.00	0.02	0.96	1.03	1.00	3332	
b_POR_CE_Porites	1.14	0.06	1.03	1.29	1.00	3412	*
b_ACR_ACO_ACC_Acropora	0.99	0.02	0.95	1.02	1.00	3607	
b_SP_Sponge	1.10	0.07	0.97	1.26	1.00	3474	
b_TA_TurfAlgae_consolidated	1.01	0.01	0.99	1.03	1.00	3181	
b_PLA_CE_Platygyra	2.54	0.73	0.84	12.29	1.00	3312	
b_POC_CS_Pocillopora_3	1.01	0.02	0.96	1.05	1.00	3702	
b_ACR_ACB_Acropora	0.85	0.21	0.54	1.18	1.00	3448	
b_CA_RA_CorallineAlgae_consolidated: Device_TypeExclusion	1.00	0.01	0.98	1.02	1.00	3195	
b_Device_TypeExclusion:OT_Ascidian	0.91	0.18	0.64	1.28	1.00	3632	
b_Device_TypeExclusion:MA_RA_Red_Algae	1.03	0.02	0.99	1.08	1.00	3311	
b_Device_TypeExclusion:POR_CE_Porites	1.01	0.08	0.87	1.19	1.00	3424	
b_Device_TypeExclusion: ACR_ACO_ACC_Acropora	1.00	0.02	0.96	1.04	1.00	3477	
b_Device_TypeExclusion:SP_Sponge	0.96	0.09	0.80	1.16	1.00	3478	
b_Device_TypeExclusion: TA_TurfAlgae_consolidated	0.99	0.01	0.97	1.01	1.00	3308	
b_Device_TypeExclusion:PLA_CE_Platygyra	0.40	0.76	0.08	1.41	1.00	3287	

b_Device_TypeExclusion:POC_CS_Pocillopora_3	1.00	0.03	0.95	1.06	1.00	3568	
b_Device_TypeExclusion:ACR_ACB_Acropora	1.04	0.25	0.68	1.77	1.00	3432	
Model 2 Planned Comparisons							
Hypothesis	**Est**	**Err**	**CI Low**	**CI High**	**Evid Ratio**	**Post Prob**	**Signif**
(b_OT_Ascidian-b_ACR_ACB_Acropora) > 0	1.66	0.25	1.15	2.54	127.57	0.99	*
(b_POR_CE_Porites-b_ACR_ACB_Acropora) > 0	1.38	0.22	1.01	2.04	22.38	0.96	*
(b_SP_Sponge-b_ACR_ACB_Acropora) > 0	1.33	0.22	0.96	1.99	11.95	0.92	
(b_OT_Ascidian-b_ACR_ACO_ACC_Acropora) > 0	1.40	0.13	1.14	1.76	449.00	1.00	*
(b_POR_CE_Porites-b_ACR_ACO_ACC_Acropora) > 0	1.16	0.06	1.05	1.28	256.14	1.00	*
(b_SP_Sponge-b_ACR_ACO_ACC_Acropora) > 0	1.12	0.07	1.00	1.25	18.78	0.95	*

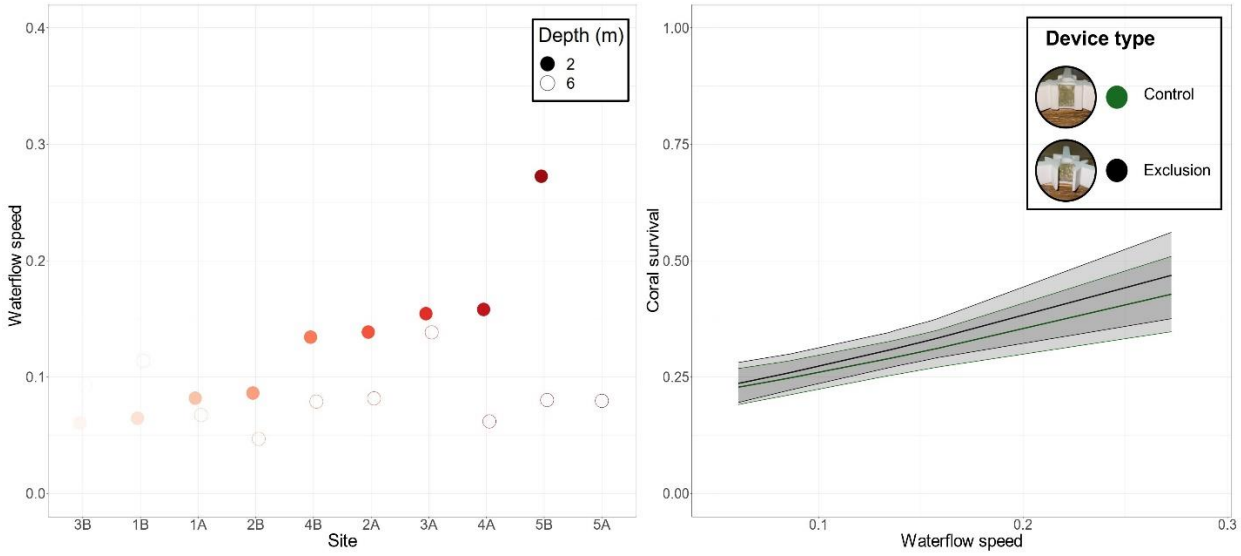


Figure B1. Mean current speed (m s^{-1}) ranked by site, lowest to highest (wave energy rank 1 - 10). Currents were recorded at two depths, 2 and 6 meters.

Appendix C: Supplementary Material to Chapter 4

C.1 Supplementary Methods

C.1.1 Sediment collection and sampling

Sediment collection pods (Sed and Turf Pods) were deployed to the reef for 5 days then collected for sampling. After collection, the sediments were immediately rinsed from the collection pods using Reverse Osmosis water (RO; < 500 mL) and stored in the freezer (- 20 °C) until processing. For processing, the samples were first defrosted (up to 24 hrs.) then 3 replicate 50 mL aliquots of the defrosted material were filtered (47 mm GFF filters, vacuum filtration). Prior to filtration the samples were topped up to 500 mL with RO water and fully homogenized. Inversion was used between aliquots to ensure sediments were adequately mixed. The filters were pre weighed before use then moistened to establish suction in the vacuum apparatus before the sediments were passed through; individual filter papers were used for each sample and aliquot. The filtration apparatus was rinsed (Mille-Q water) 3 times to ensure all sediments passed through the filter paper. After filtration, the filter papers were folded (in half, 2 times) then oven dried (105 °C) for a minimum of 24 hours. The dried samples were left to cool at room temperature and weighed to obtain the total mass of deposited sediments. To deduce the weight of organic material, the samples were placed in a furnace (550 °C) for 1 hr then left to cool within the furnace for 5 hrs. at 30 °C. When cool, the samples were removed from the furnace and placed in a desiccator for 1 hr. The filter papers were again weighed to obtain the total organic weight.

Table C1. Coral spawning and settlement information.

Event	**Description**
Full moon	Nov 8 2022
Coral species	*Acropora millepora*
Collection sites (n= number of colonies)	Halfway Island ($n = 10$), North Keppel Island ($n = 12$), Great Keppel Island ($n = 9$), and Pumpkin Island ($n = 6$)
Spawn date	Nov 6 2022
No. parent contributors	27 (partial and full spawn)
Larval culture temperature	24.7 - 25.1 ° C
Larval settlement date	Nov 20 and Nov 21, 2022
Larval stocking	Nov 20: ~10,000 larvae per 2 x settlement sheets, ~11.3 per tab, Nov 21: topped up with ~5000 larvae per 2x settlement sheets
Settlement tank temp	25.3 - 25.7 ° C
Substrate conditioning duration	Sep 26th to Nov 20th 2022

Table C2. Coral deployment sites, census trips and data collection.

Site name	Lattitude	Longitute	Reserve status	Reef exposure	Deployment date
Halfway	-23.20092299	150.969082	Blue	Leeward	27-Nov-22
Maize	-23.08593501	150.896416	Blue	Leeward	23-Nov-22
Miall	-23.14974703	150.903941	Blue	Windward	24-Nov-22
Middle	-23.16170398	150.920475	Green	Windward	24-Nov-22
Monkey	-23.19768799	150.937758	Green	Leeward	24-Nov-22
Home	-23.08553402	150.886304	Green	Leeward	23-Nov-22

Survey technique	**Survey time**			
	Nov-22	**Feb-23**	**May-23**	**Oct-23**
Benthic quadrat	✓	☒	☒	✓
Benthic transect	✓	✓	☒	✓
Fish counts	✓	☒	✓	✓
Fish feeding	✓	✓	☒	☒
Sediment collections	✓	☒	☒	☒
Temperature data	✓	✓	✓	✓
Hydrophone data	☒	✓	✓	✓

Table C3. Benthic community composition label set used for identification.

Functional group	**Lowest taxanomic code**	**Description**
Algae (A)	CA	Coralline Algae
	Pey	*Peyssonnelia*
	TA	Turf algae
Macroalage (MA)	Asp	*Asparagopsis*
	Caul	*Caulerpa*
	Colp	*Colpomenia*
	Dicty	*Dictyopteris*
	Dict	*Dictyota*
	Lobo	*Lobophora*
	MA_Brown	Other brown macroalgae
	MA_Green	Other green Macroalgae
	MA_Other	Other Macroalgae
	MA_Red	Red Macroalgae
	Padina	*Padina*
	Pseu	*Pseudochnoospora*
	Sar	*Sargassum*
Hard coral (HC)	ACBX	*Acropora* branching & bottlebrush
	ACD	*Acropora* digitate
	ACTO	*Acropora* tabulate & corymbose
	F_AGA_CEMS	Agariciidae encrusting & submassive
	F_AGA_CF	Agariciidae foliose
	G_AST	*Astreopora*
	F_DEN_CF	Dendrophyllidae foliose

	F_DEN_CMCE	Dendrophyllidae massive & encrusting
	G_ECH_CB	*Echinopora* branching
	G_ECH_OTH	*Echinopora* other
	F_EUPH	Euphyllidae
	F_FAV_CEMS	Faviidae encrusting, massive & sub-massive
	F_FUN_CMR	Fundiidae free-living
	F_FUN_CECF	Fungiidae encrusting & foliose
	G_GON_ALV	*Goniopora* & *Alveopora*
	G_HYD_CB	*Hydnophora* branching & *Paraclavarina*
	G_HYD_OTH	*Hydnophora* other
	G_ISO_CE	*Isopora* encrusting
	G_ISO_CS	*Isopora* sub-massive
	G_ISO_SUB	*Isopora* sub-massive
	G_MER	*Merulina* & *Scaphophyllia*
	Meru	Merulinidae Family
	G_MON_CEMS	*Montipora* encrusting
	G_MON_CF	*Montipora* foliose
	F_MUS	Mussidae
	COR_CBCF	non-*Acropora* coral branching & foliose
	COR_CE	non-*Acropora* coral encrusting
	COR_CMCS	non-*Acropora* coral massive & sub-massive
	F_OCU	Oculinidae
	F_PEC	Pectiniidae
	S_POC_DAM	*Pocillopora damicornis*
	G_POC_OT	*Pocillopora* other
	G_POR_B	*Porites* branching
	G_POR_CECS	*Porites* encrusting & sub-massive
	G_POR_M	*Porites* massive
	S_POR_RUS	*Porites rus*
	G_SER	*Seriatopora*
	F_SID	Siderastreidae
	G_STY	*Stylophora*
Soft coral (SC)	F_SC_ALC	Soft coral Alcyoniidae
	F_SC_BRI	Soft coral Briareidae & Rhytisma
	F_SC_NEP	Soft coral Neptheidae
	SC_OTH	Soft coral Other
	F_SC_XEN	Soft coral Xeniidae
Seagrass (SG)	SG	All seagrass
Sponges and Ascidians (SP)	SP	All sponges and ascidians
Other ogranism (OT)	Anem	Anemone
	Cyano	Cyanobacteria
	F_MIL	*Millepora*
	OT	Other organisms
	ZOA	Zoanthids
Abiotic (AB)	AB	Abiotic

	Device	Device/String/Reo
	Rec	Recently dead
	S	Sediment
	U	Unknown

Table C4. The list of target fish species identified during in-situ stationary point count surveys by divers.

Family	Genus	Species	Common name	Description
Pomacentridae	*Pomacentrus*	*P. wardi*	Damselfish	Farming damselfish
	Pomacentrus	*P. adelus*	Damselfish	Farming damselfish
	Stegastes	*S. apicalis*	Damselfish	Farming damselfish
Labridae (Scarinae)	*Chlorourus*	*C. spilurus*	Parrotfish	Excavating parrotfish
	Chlorourus	*C. microrhinos*	Parrotfish	Excavating parrotfish
	Scarus	*S. rivulatus*	Parrotfish	Scraping parrotfish
	Scarus	*S. ghobban*	Parrotfish	Scraping parrotfish
	Scarus	*S. chameleon*	Parrotfish	Scraping parrotfish
	Scarus	*S. globiceps*	Parrotfish	Scraping parrotfish
Siganidae	*Siganus*	*S. argenteus*	Rabbitfish	Forktail rabbitfish
	Siganus	*S. doliatus*	Rabbitfish	Blue-lined, barred rabbitfish
	Siganus	*S. fuscescens*	Rabbitfish	Black rabbitfish
	Siganus	*S. lineatus*	Rabbitfish	Goldlined rabbitfish
Acanthuridae	*Acanthurus*	*A. blochii*	Surgeonfish	Dark surgeonfish
	Acanthurus	*A. grammoptilus*	Surgeonfish	Inshore surgeonfish
	Acanthurus	*A. dussumieri*	Surgeonfish	Pencil, eyestripped surgeonfish
	Naso	*N. unicornis*	Surgeonfish	Bluespine unicornfish
	Prionurus	*Prionurus* spp.	Surgeonfish	Sawtail surgeonfish

Table C5. Detailed information from the GoPro video analysis to quantify grazing pressure. Categories are explained via definitions and possible responses. Data entries were taken for each individual fish that was observed to be grazing in the experimental plot. Not all categories were used in the data analysis.

GoPro Video Analysis: Data collection metrics, descriptions and potential responses		
Metric	**Description**	**Possible Response**
Sea state	Refers to the state of the water with regards to the weather conditions due to wind, wave and current.	Calm (0-1.1 km/h), Light (1.1-12.6 km/h), Gentle (12.6-19.8 km/h), Moderate (19.8-28.8 km/h), Fresh (28.8-38.9 km/h)
Visibility	Refers to the sea state, regarding the distance (m) a diver/data recorder can visibly see and identify objects.	< 5m, 6-10m, 11-15m, 16-20m
Family	Refers to the taxonomic family for each fish identified.	Labridae, Pomacentridae, Acanthuridae, Blastidae, Blennidae, Chaetodontidae, etc.

Interval	A number that refers to the feeding approach and start of a feeding foray for an identified fish. The interval stops when a fish swims up, away from the substrate, and can have 1 or more bites.	Integer value, ranging from 1 to 50
Bites	The number of bites a fish takes during a single feeding foray/interval.	Integer value, ranging from 1 to 75
Grazing location	The location of the identified fish bite/graze.	Substrate or device
Fish attacks	Refers to the number of attacks by individual fish in each video and experimental plot. Attacks were defined as visually aggressive swimming behavior.	Integer value, ranging from 1 to 30
Time	Refers to the time the fish swims on screen and into the video frame. Screenshot images were taken of each individual fish for identification at this time point.	Between 1-12 minutes (e.g. 01:30)
Comments	Anything worth noting that was observed in the video.	Invertebrate grazer in plot, diver present on video, camera knocked from original placement point, transect tape or star picket in view, etc.

Table C6. Device yield model parameters and output. The 'est' is the estimate, 'err' is error, 'CI low' and 'CI high' are 95% credible intervals, 'ess' is the sample size, and 'signf' is the significance.

Model: Device yield

Family: bernoulli
Links: mu = logit
Formula: Yield ~ DeviceType * ReserveStatus + DeviceType * Site + (1 | ReserveStatus/Site/Plot)
Data: device_yield_T (Number of observations: 1746)
Draws: 3 chains, each with iter = 5000; warmup = 1000; thin = 5;
total post-warmup draws = 2400

Multilevel Hyperparameters:
~ReserveStatus (Number of levels: 2)

	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
sd(Intercept)	1.22	1.11	0.04	4.00	1.00	2199	2178

~ReserveStatus:Site (Number of levels: 6)

	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
sd(Intercept)	0.82	0.68	0.03	2.55	1.00	2064	2346

~ReserveStatus:Site:Plot (Number of levels: 78)

	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
sd(Intercept)	1.81	0.22	1.42	2.31	1.00	1714	2019

Term	Est	Err	CI low	CI high	Rhat	Ess	Signf
Intercept	0.88	1.12	0.08	6.96	1.00	2394	
DeviceTypeExclusion	0.69	0.33	0.36	1.31	1.00	2297	.
DeviceTypeTriangle	1.61	0.30	0.92	2.89	1.00	2012	.
ReserveStatusGreen	0.46	1.36	0.04	7.93	1.00	2415	
SiteHome	0.15	1.26	0.02	2.00	1.00	2360	
SiteMazie	0.74	1.05	0.09	5.68	1.00	1995	
SiteMiall	1.09	1.00	0.15	8.52	1.00	2055	
SiteMiddle	2.33	1.19	0.20	19.96	1.00	2254	
SiteMonkey	1.25	1.16	0.15	14.22	1.00	2434	
DeviceTypeExclusion:ReserveStatusGreen	3.12	0.93	0.48	19.45	1.00	2138	
DeviceTypeTriangle:ReserveStatusGreen	1.20	0.90	0.22	7.35	1.00	2015	
DeviceTypeExclusion:SiteHome	12.33	0.98	1.92	89.98	1.00	2178	*
DeviceTypeTriangle:SiteHome	0.96	0.96	0.14	5.76	1.00	2219	
DeviceTypeExclusion:SiteMazie	1.23	0.50	0.47	3.24	1.00	2218	
DeviceTypeTriangle:SiteMazie	1.38	0.45	0.58	3.41	1.00	2250	
DeviceTypeExclusion:SiteMiall	3.32	0.47	1.26	7.81	1.00	2410	*
DeviceTypeTriangle:SiteMiall	2.18	0.44	0.94	5.25	1.00	2160	
DeviceTypeExclusion:SiteMiddle	0.55	0.95	0.09	3.60	1.00	2209	
DeviceTypeTriangle:SiteMiddle	0.56	0.89	0.10	3.21	1.00	2051	
DeviceTypeExclusion:SiteMonkey	0.51	0.94	0.07	2.89	1.00	2184	
DeviceTypeTriangle:SiteMonkey	1.94	0.92	0.35	12.34	1.00	2146	

Planned comparisons

Hypothesis	Est	Err	CI low	CI high	Evid ratio	Post prob	Signf

(SiteMazie-SiteHome) > 0	4.92	1.60	0.35	61.41	5.45	0.85	
(SiteMiall-SiteHome) > 0	7.36	1.60	0.48	97.54	8.64	0.90	
(SiteMiddle-SiteHome) > 0	15.23	1.43	1.03	119.13	19.87	0.95	*
(Intercept-SiteHome) > 0	5.37	1.81	0.24	95.58	5.06	0.84	
(SiteMonkey-SiteHome) > 0	8.09	1.39	0.68	66.20	12.64	0.93	
(DeviceTypeExclusion:SiteHome-DeviceTypeTriangle:SiteHome) > 0	12.63	1.26	1.57	98.07	41.86	0.98	*
(DeviceTypeExclusion:SiteHome-Intercept) > 0	14.82	1.50	1.26	170.06	25.37	0.96	*
(DeviceTypeExclusion:SiteMiall-DeviceTypeTriangle:SiteMiall) > 0	1.51	0.46	0.70	3.17	4.42	0.82	
(DeviceTypeTriangle:SiteMonkey-Intercept) > 0	2.36	1.44	0.24	26.54	2.73	0.73	
(DeviceTypeTriangle:SiteMonkey-DeviceTypeExclusion:SiteMonkey) > 0	3.82	1.24	0.49	29.29	6.29	0.86	

Table C7. Tab-level survival model parameters and output. The ‘est’ is the estimate, ‘err’ is error, ‘CI low’ and ‘CI high’ are 95% credible intervals, ‘ess’ is the sample size, and ‘signf’ is the significance.

Model: Tab yield

Family: bernoulli
Links: mu = logit
Formula: Survival ~ DeviceType * ReserveStatus + DeviceType * Site + Site * Plot + (1 + DeviceType | ReserveStatus/Site/Plot/DeviceNumber)
Data: survival_final (Number of observations: 1746)
Draws: 4 chains, each with iter = 7000; warmup = 1000; thin = 5;
total post-warmup draws = 4800

Multilevel Hyperparameters:
~ReserveStatus (Number of levels: 2)

	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
sd(Intercept)	1.08	0.92	0.04	3.40	1.00	4875	4726
sd(DeviceTypeExclusion)	0.68	0.62	0.02	2.32	1.00	4701	4796
sd(DeviceTypeTriangle_Outer)	0.65	0.60	0.03	2.16	1.00	4786	4611
sd(DeviceTypeTriangle_Inner)	0.68	0.63	0.02	2.22	1.00	4694	4407
cor(Intercept,DeviceTypeExclusion)	0.00	0.45	-0.80	0.81	1.00	4757	4731
cor(Intercept,DeviceTypeTriangle_Outer)	0.01	0.44	-0.78	0.80	1.00	4768	4376
cor(DeviceTypeExclusion,DeviceTypeTriangle_Outer)	-0.00	0.45	-0.81	0.82	1.00	4491	4549
cor(Intercept,DeviceTypeTriangle_Inner)	0.00	0.45	-0.81	0.81	1.00	4867	4133
cor(DeviceTypeExclusion,DeviceTypeTriangle_Inner)	0.01	0.45	-0.80	0.82	1.00	3914	4425
cor(DeviceTypeTriangle_Outer,DeviceTypeTriangle_Inner)	0.01	0.45	-0.81	0.83	1.00	4801	4520

~ReserveStatus:Site (Number of levels: 6)

	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
sd(Intercept)	0.62	0.51	0.03	1.92	1.00	4434	4597
sd(DeviceTypeExclusion)	0.53	0.43	0.02	1.59	1.00	4544	4383
sd(DeviceTypeTriangle_Outer)	0.44	0.37	0.02	1.34	1.00	4703	4757
sd(DeviceTypeTriangle_Inner)	0.45	0.38	0.01	1.44	1.00	4686	4416
cor(Intercept,DeviceTypeExclusion)	-0.09	0.45	-0.85	0.77	1.00	4469	4649
cor(Intercept,DeviceTypeTriangle_Outer)	-0.01	0.45	-0.81	0.82	1.00	5075	4837
cor(DeviceTypeExclusion,DeviceTypeTriangle_Outer)	0.02	0.45	-0.79	0.82	1.00	4571	4498
cor(Intercept,DeviceTypeTriangle_Inner)	-0.02	0.45	-0.82	0.80	1.00	4718	4732

cor(DeviceTypeExclusion,DeviceTypeTriangle_Inner) 0.02 0.45 -0.81 0.82 1.00 4607 4158
cor(DeviceTypeTriangle_Outer,DeviceTypeTriangle_Inner) 0.02 0.45 -0.80 0.83 1.00 4708 4671

~ReserveStatus:Site:Plot (Number of levels: 78)
Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
sd(Intercept) 0.29 0.21 0.01 0.76 1.00 3313 4262
sd(DeviceTypeExclusion) 0.34 0.26 0.01 0.95 1.00 3960 4177
sd(DeviceTypeTriangle_Outer) 0.26 0.19 0.01 0.72 1.00 3982 4073
sd(DeviceTypeTriangle_Inner) 0.46 0.33 0.02 1.21 1.00 3553 4498
cor(Intercept,DeviceTypeExclusion) -0.05 0.44 -0.82 0.78 1.00 4892 4685
cor(Intercept,DeviceTypeTriangle_Outer) -0.06 0.44 -0.84 0.78 1.00 4686 4677
cor(DeviceTypeExclusion,DeviceTypeTriangle_Outer) -0.00 0.45 -0.82 0.81 1.00 4823 4550
cor(Intercept,DeviceTypeTriangle_Inner) 0.00 0.44 -0.81 0.82 1.00 4236 4445
cor(DeviceTypeExclusion,DeviceTypeTriangle_Inner) 0.01 0.45 -0.82 0.80 1.00 4288 4757
cor(DeviceTypeTriangle_Outer,DeviceTypeTriangle_Inner) 0.17 0.46 -0.74 0.89 1.00 4044 4462

~ReserveStatus:Site:Plot:DeviceNumber (Number of levels: 436)
Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
sd(Intercept) 1.14 0.20 0.75 1.52 1.00 3001 4159
sd(DeviceTypeExclusion) 0.70 0.51 0.03 1.91 1.00 1154 1220
sd(DeviceTypeTriangle_Outer) 0.35 0.26 0.01 0.97 1.00 3465 4018
sd(DeviceTypeTriangle_Inner) 0.44 0.32 0.02 1.17 1.00 3560 4146
cor(Intercept,DeviceTypeExclusion) 0.00 0.42 -0.74 0.79 1.00 1977 2144
cor(Intercept,DeviceTypeTriangle_Outer) -0.24 0.43 -0.88 0.70 1.00 3736 4509
cor(DeviceTypeExclusion,DeviceTypeTriangle_Outer) -0.01 0.44 -0.81 0.79 1.00 4802 4404
cor(Intercept,DeviceTypeTriangle_Inner) 0.13 0.42 -0.70 0.83 1.00 4076 4733
cor(DeviceTypeExclusion,DeviceTypeTriangle_Inner) 0.01 0.45 -0.81 0.81 1.00 4322 4603
cor(DeviceTypeTriangle_Outer,DeviceTypeTriangle_Inner) 0.07 0.45 -0.80 0.85 1.00 3752 4276

Term	Est	Err	CI low	CI high	Rhat	Ess	Signf
Intercept	0.32	0.88	0.07	2.18	1.00	4716	
DeviceTypeExclusion	1.08	0.61	0.32	3.62	1.00	4392	
DeviceTypeTriangle_Outer	1.03	0.60	0.31	3.36	1.00	4393	
DeviceTypeTriangle_Inner	0.84	0.61	0.25	2.89	1.00	4833	
ReserveStatusGreen	0.62	0.86	0.12	3.50	1.00	4892	
SiteHome	0.35	0.81	0.08	1.77	1.00	4741	
SiteMazie	0.65	0.69	0.19	3.07	1.00	4688	
SiteMiall	0.90	0.67	0.26	3.85	1.00	4683	
SiteMiddle	1.47	0.74	0.33	5.94	1.00	5003	
SiteMonkey	1.22	0.75	0.27	5.01	1.00	4639	
Plot2	0.48	0.52	0.16	1.31	1.00	4776	.
Plot3	1.39	0.48	0.53	3.60	1.00	4818	
Plot4	1.23	0.48	0.49	3.19	1.00	4899	
Plot5	1.42	0.49	0.54	3.69	1.00	4622	
Plot6	1.40	0.49	0.54	3.63	1.00	4646	
Plot7	1.60	0.49	0.62	4.04	1.00	4712	
Plot8	1.10	0.48	0.46	3.00	1.00	4522	
Plot9	0.91	0.50	0.34	2.40	1.00	4679	

Plot10	1.07	0.50	0.41	2.94	1.00	4760	
Plot11	0.88	0.49	0.33	2.27	1.00	4810	
Plot12	0.81	0.51	0.27	1.98	1.00	4854	
Plot13	2.21	0.53	0.79	6.31	1.00	4163	
DeviceTypeExclusion:ReserveStatusGreen	1.22	0.78	0.28	5.87	1.00	4568	
DeviceTypeTriangle_Outer:ReserveStatusGreen	0.91	0.75	0.23	4.37	1.00	4625	
DeviceTypeTriangle_Inner:ReserveStatusGreen	1.05	0.76	0.22	4.38	1.00	4935	
DeviceTypeExclusion:SiteHome	2.35	0.79	0.47	10.26	1.00	4493	
DeviceTypeTriangle_Outer:SiteHome	0.89	0.78	0.19	3.92	1.00	4618	
DeviceTypeTriangle_Inner:SiteHome	0.97	0.78	0.22	4.69	1.00	4607	
DeviceTypeExclusion:SiteMazie	1.11	0.67	0.29	3.91	1.00	4545	
DeviceTypeTriangle_Outer:SiteMazie	0.99	0.64	0.28	3.41	1.00	4519	
DeviceTypeTriangle_Inner:SiteMazie	1.02	0.66	0.27	3.68	1.00	4456	
DeviceTypeExclusion:SiteMiall	1.61	0.69	0.40	6.12	1.00	4431	
DeviceTypeTriangle_Outer:SiteMiall	1.37	0.62	0.40	4.64	1.00	4714	
DeviceTypeTriangle_Inner:SiteMiall	1.34	0.65	0.39	5.08	1.00	4833	
DeviceTypeExclusion:SiteMiddle	0.74	0.74	0.18	3.25	1.00	4765	
DeviceTypeTriangle_Outer:SiteMiddle	0.82	0.73	0.21	3.71	1.00	4704	
DeviceTypeTriangle_Inner:SiteMiddle	1.02	0.73	0.26	4.49	1.00	4939	
DeviceTypeExclusion:SiteMonkey	0.70	0.75	0.17	3.20	1.00	4772	
DeviceTypeTriangle_Outer:SiteMonkey	1.27	0.71	0.31	5.07	1.00	4853	
DeviceTypeTriangle_Inner:SiteMonkey	1.11	0.73	0.27	4.72	1.00	4747	
SiteHome:Plot2	0.65	0.89	0.12	3.75	1.00	4963	
SiteMazie:Plot2	0.88	0.77	0.22	4.34	1.00	4716	
SiteMiall:Plot2	1.23	0.75	0.28	5.32	1.00	5062	
SiteMiddle:Plot2	1.06	0.78	0.24	4.92	1.00	4911	
SiteMonkey:Plot2	0.99	0.77	0.21	4.19	1.00	4819	
SiteHome:Plot3	0.48	0.86	0.09	2.57	1.00	4849	
SiteMazie:Plot3	2.77	0.71	0.71	10.87	1.00	4534	
SiteMiall:Plot3	0.42	0.74	0.10	1.80	1.00	4546	
SiteMiddle:Plot3	0.98	0.73	0.22	3.81	1.00	4744	
SiteMonkey:Plot3	0.74	0.75	0.16	3.01	1.00	4824	
SiteHome:Plot4	0.89	0.84	0.17	4.75	1.00	4620	
SiteMazie:Plot4	0.84	0.75	0.19	3.46	1.00	4638	
SiteMiall:Plot4	1.03	0.70	0.27	4.02	1.00	4949	
SiteMiddle:Plot4	1.45	0.73	0.34	6.04	1.00	4858	
SiteMonkey:Plot4	1.68	0.72	0.41	6.71	1.00	4805	
SiteHome:Plot5	1.56	0.78	0.34	7.28	1.00	4743	
SiteMazie:Plot5	4.11	0.71	1.01	16.31	1.00	4930	*
SiteMiall:Plot5	0.49	0.72	0.11	1.81	1.00	4634	
SiteMiddle:Plot5	0.28	0.80	0.06	1.26	1.00	4861	.
SiteMonkey:Plot5	1.35	0.72	0.32	5.15	1.00	4591	
SiteHome:Plot6	2.31	0.79	0.47	10.36	1.00	4058	
SiteMazie:Plot6	1.48	0.71	0.39	6.01	1.00	4392	
SiteMiall:Plot6	0.81	0.70	0.21	3.10	1.00	4418	
SiteMiddle:Plot6	0.29	0.80	0.06	1.39	1.00	4565	.
SiteMonkey:Plot6	1.03	0.74	0.25	4.32	1.00	4671	

SiteHome:Plot7	1.40	0.78	0.32	6.64	1.00	5285	
SiteMazie:Plot7	0.86	0.74	0.20	3.80	1.00	4388	
SiteMiall:Plot7	1.74	0.71	0.45	7.15	1.00	4683	
SiteMiddle:Plot7	2.05	0.71	0.49	7.82	1.00	4801	
SiteMonkey:Plot7	0.42	0.77	0.10	2.02	1.00	4854	
SiteHome:Plot8	2.14	0.77	0.45	8.92	1.00	4536	
SiteMazie:Plot8	0.33	0.80	0.07	1.59	1.00	4905	
SiteMiall:Plot8	0.74	0.71	0.19	3.06	1.00	4245	
SiteMiddle:Plot8	1.13	0.74	0.27	4.55	1.00	4941	
SiteMonkey:Plot8	1.61	0.76	0.34	6.42	1.00	5251	
SiteHome:Plot9	0.55	0.86	0.11	3.10	1.00	4921	
SiteMazie:Plot9	0.65	0.75	0.14	2.67	1.00	4864	
SiteMiall:Plot9	0.64	0.75	0.15	2.73	1.00	4582	
SiteMiddle:Plot9	2.34	0.73	0.58	9.84	1.00	4530	
SiteMonkey:Plot9	0.78	0.77	0.16	3.33	1.00	4932	
SiteHome:Plot10	1.35	0.82	0.26	6.26	1.00	4677	
SiteMazie:Plot10	1.20	0.72	0.29	4.91	1.00	4850	
SiteMiall:Plot10	0.93	0.73	0.22	3.85	1.00	4868	
SiteMiddle:Plot10	1.71	0.73	0.41	7.15	1.00	4729	
SiteMonkey:Plot10	1.57	0.74	0.36	6.64	1.00	4364	
SiteHome:Plot11	0.55	0.85	0.11	2.82	1.00	4951	
SiteMazie:Plot11	1.48	0.73	0.38	6.39	1.00	4324	
SiteMiall:Plot11	1.42	0.72	0.34	5.63	1.00	4476	
SiteMiddle:Plot11	1.58	0.73	0.40	6.80	1.00	4409	
SiteMonkey:Plot11	0.81	0.77	0.18	3.70	1.00	4623	
SiteHome:Plot12	0.92	0.83	0.17	4.62	1.00	4686	
SiteMazie:Plot12	1.46	0.74	0.33	6.04	1.00	4818	
SiteMiall:Plot12	0.94	0.71	0.24	3.85	1.00	4414	
SiteMiddle:Plot12	1.26	0.74	0.30	5.25	1.00	4649	
SiteMonkey:Plot12	2.20	0.77	0.46	9.31	1.00	4734	
SiteHome:Plot13	0.87	0.86	0.17	4.82	1.00	4872	
SiteMazie:Plot13	1.04	0.79	0.22	4.63	1.00	4842	
SiteMiall:Plot13	1.57	0.78	0.35	7.31	1.00	4620	
SiteMiddle:Plot13	2.39	0.78	0.48	9.72	1.00	4776	
SiteMonkey:Plot13	0.39	0.85	0.07	2.05	1.00	4571	
Planned comparisons							
Hypothesis	**Est**	**Err**	**CI low**	**CI high**	**Evid ratio**	**Post prob**	**Signf**
(SiteMazie-SiteHome) > 0	1.88	0.99	0.36	9.15	2.89	0.74	
(SiteMiall-SiteHome) > 0	2.58	1.01	0.47	12.94	5.00	0.83	
(SiteMiddle-SiteHome) > 0	4.10	0.95	0.76	16.79	12.48	0.93	
(Intercept-SiteHome) > 0	0.96	1.25	0.12	7.36	0.96	0.49	
(SiteMonkey-SiteHome) > 0	3.36	0.95	0.66	14.36	9.23	0.90	
(DeviceTypeExclusion:SiteHome-DeviceTypeTriangle_Inner:SiteHome) > 0	2.39	1.08	0.40	13.77	3.83	0.79	
(DeviceTypeExclusion:SiteHome-DeviceTypeTriangle_Outer:SiteHome) > 0	2.64	1.06	0.47	14.96	4.57	0.82	
(DeviceTypeExclusion:SiteHome-Intercept) > 0	6.77	1.18	0.95	45.73	17.53	0.95	

(DeviceTypeExclusion:SiteMiall-DeviceTypeTriangle_Inner:SiteMiall) > 0	1.21	0.89	0.28	5.23	1.46	0.59	
(DeviceTypeExclusion:SiteMiall-DeviceTypeTriangle_Outer:SiteMiall) > 0	1.16	0.87	0.27	4.75	1.33	0.57	
(DeviceTypeTriangle_Inner:SiteMonkey-Intercept) > 0	3.21	1.14	0.47	19.61	5.67	0.85	
(DeviceTypeTriangle_Outer:SiteMonkey-Intercept) > 0	3.71	1.13	0.53	22.39	7.32	0.88	
(DeviceTypeTriangle_Inner:SiteMonkey-DeviceTypeExclusion:SiteMonkey) > 0	1.56	1.02	0.28	8.11	2.02	0.67	
(DeviceTypeTriangle_Outer:SiteMonkey-DeviceTypeExclusion:SiteMonkey) > 0	1.80	1.00	0.34	9.20	2.63	0.72	
(SiteMazie:Plot5-SiteMazie:Plot8) > 0	12.81	1.04	2.33	70.72	191.00	0.99	*
(SiteMiall:Plot13-SiteMiall:Plot3) > 0	3.78	1.05	0.66	21.17	8.32	0.89	
(SiteMiall:Plot7-SiteMiall:Plot3) > 0	4.17	0.99	0.81	20.62	12.48	0.93	
(SiteHome:Plot6-SiteHome:Plot2) > 0	3.60	1.18	0.50	25.08	6.20	0.86	
(SiteMiddle:Plot13-SiteMiddle:Plot5) > 0	8.43	1.10	1.36	52.30	33.53	0.97	*
(SiteMonkey:Plot4-SiteMonkey:Plot2) > 0	1.70	1.02	0.32	9.23	2.29	0.70	

Table C8. Coral size model parameters and output. The ‘est’ is the estimate, ‘err’ is error, ‘CI low’ and ‘CI high’ are 95% credible intervals, ‘ess’ is the sample size, and ‘signf’ is the significance.

Model: Coral size

Family: gamma

Links: mu = log; shape = identity

Formula: CoralSize_Volume ~ DeviceType * ReserveStatus + DeviceType * Site +

Site * Plot + (1 | ReserveStatus/Site/Plot/DeviceNumber)

Data: growth_final (Number of observations: 357)

Draws: 3 chains, each with iter = 7500; warmup = 1200; thin = 3;

total post-warmup draws = 6300

Multilevel Hyperparameters:

~ReserveStatus (Number of levels: 2)

	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
sd(Intercept)	1.45	1.35	0.05	4.87	1.00	6101	5552

~ReserveStatus:Site (Number of levels: 6)

	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
sd(Intercept)	0.94	0.81	0.04	3.00	1.00	5925	5646

~ReserveStatus:Site:Plot (Number of levels: 68)

	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
sd(Intercept)	0.28	0.21	0.01	0.79	1.00	3778	4607

~ReserveStatus:Site:Plot:DeviceNumber (Number of levels: 202)

	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
sd(Intercept)	0.50	0.16	0.11	0.78	1.00	2801	3234

Term	**Est**	**Err**	**CI low**	**CI high**	**Rhat**	**Ess**	**Signf**
Intercept	62.09	1.32	4.84	927.74	1.00	6538	

DeviceTypeExclusion	1.14	0.46	0.47	2.97	1.00	5866	
DeviceTypeTriangle_Outer	0.90	0.44	0.38	2.10	1.00	5736	
DeviceTypeTriangle_Inner	1.46	0.48	0.58	3.72	1.00	6030	
ReserveStatusGreen	1.12	1.85	0.03	37.98	1.00	6261	
SiteHome	0.49	1.76	0.02	14.62	1.00	6617	
SiteMazie	1.41	1.34	0.10	21.72	1.00	6375	
SiteMiall	2.09	1.27	0.15	26.36	1.00	6276	
SiteMiddle	2.00	1.64	0.09	55.72	1.00	6501	
SiteMonkey	1.03	1.63	0.04	25.21	1.00	6252	
Plot2	1.07	0.80	0.22	5.19	1.00	5332	
Plot3	0.74	0.64	0.21	2.51	1.00	6255	
Plot4	1.30	0.66	0.37	4.87	1.00	5899	
Plot5	1.17	0.65	0.33	4.06	1.00	6140	
Plot6	1.26	0.71	0.31	5.10	1.00	5962	
Plot7	1.45	0.65	0.41	5.36	1.00	6144	
Plot8	2.49	0.65	0.76	9.81	1.00	5926	
Plot9	0.55	0.68	0.15	2.16	1.00	6307	
Plot10	1.21	0.80	0.27	5.94	1.00	6093	
Plot11	0.25	0.77	0.06	1.19	1.00	6179	.
Plot12	0.40	0.95	0.07	2.66	1.00	6278	
Plot13	1.95	0.70	0.47	7.45	1.00	6068	
DeviceTypeExclusion:ReserveStatusGreen	0.81	1.33	0.06	10.04	1.00	6220	
DeviceTypeTriangle_Outer:ReserveStatusGreen	0.98	1.34	0.06	12.22	1.00	5990	
DeviceTypeTriangle_Inner:ReserveStatusGreen	0.82	1.38	0.05	10.36	1.00	6056	
DeviceTypeExclusion:SiteHome	0.99	1.52	0.05	22.31	1.00	6392	
DeviceTypeTriangle_Outer:SiteHome	0.31	1.62	0.01	6.29	1.00	5841	
DeviceTypeTriangle_Inner:SiteHome	0.53	1.61	0.02	10.53	1.00	6271	
DeviceTypeExclusion:SiteMazie	0.81	0.66	0.21	2.80	1.00	6125	
DeviceTypeTriangle_Outer:SiteMazie	0.92	0.64	0.29	3.57	1.00	5376	
DeviceTypeTriangle_Inner:SiteMazie	0.28	0.68	0.07	1.06	1.00	6323	.
DeviceTypeExclusion:SiteMiall	0.95	0.62	0.28	3.12	1.00	5990	
DeviceTypeTriangle_Outer:SiteMiall	0.84	0.62	0.26	2.89	1.00	5878	
DeviceTypeTriangle_Inner:SiteMiall	1.01	0.67	0.27	3.60	1.00	6101	
DeviceTypeExclusion:SiteMiddle	1.10	1.36	0.09	16.48	1.00	6407	
DeviceTypeTriangle_Outer:SiteMiddle	1.16	1.37	0.09	18.89	1.00	6132	
DeviceTypeTriangle_Inner:SiteMiddle	1.93	1.39	0.12	28.74	1.00	6201	
DeviceTypeExclusion:SiteMonkey	0.78	1.36	0.06	11.35	1.00	6069	
DeviceTypeTriangle_Outer:SiteMonkey	2.58	1.38	0.18	37.47	1.00	5989	
DeviceTypeTriangle_Inner:SiteMonkey	0.84	1.40	0.05	12.48	1.00	6139	
SiteHome:Plot2	0.99	2.50	0.01	123.00	1.00	8034	
SiteMazie:Plot2	0.07	1.37	0.01	1.20	1.00	5924	.
SiteMiall:Plot2	0.17	1.12	0.02	1.69	1.00	5707	
SiteMiddle:Plot2	0.10	1.25	0.01	1.20	1.00	6037	.

SiteMonkey:Plot2	0.05	1.33	< 0.01	0.65	1.00	6471	*
SiteHome:Plot3	0.98	2.47	0.01	104.9	1.00	7398	
SiteMazie:Plot3	3.99	1.02	0.47	26.58	1.00	5831	
SiteMiall:Plot3	1.74	1.06	0.22	13.02	1.00	6126	
SiteMiddle:Plot3	1.96	1.08	0.25	16.84	1.00	6465	
SiteMonkey:Plot3	1.86	1.08	0.23	15.07	1.00	5537	
SiteHome:Plot4	0.33	1.59	0.02	9.01	1.00	6436	
SiteMazie:Plot4	0.86	1.15	0.09	7.82	1.00	6168	
SiteMiall:Plot4	0.71	0.92	0.12	4.49	1.00	5791	
SiteMiddle:Plot4	2.31	1.07	0.27	18.87	1.00	6181	
SiteMonkey:Plot4	2.59	1.00	0.40	20.22	1.00	6089	
SiteHome:Plot5	2.94	1.30	0.23	38.02	1.00	6363	
SiteMazie:Plot5	2.28	1.03	0.31	17.01	1.00	6030	
SiteMiall:Plot5	0.41	0.99	0.06	2.89	1.00	6593	
SiteMiddle:Plot5	0.96	2.48	0.01	119.4	1.00	7006	
SiteMonkey:Plot5	1.36	0.99	0.20	9.42	1.00	5972	
SiteHome:Plot6	1.74	1.30	0.14	21.09	1.00	6245	
SiteMazie:Plot6	2.75	1.08	0.29	20.70	1.00	6220	
SiteMiall:Plot6	1.54	0.99	0.22	10.49	1.00	6328	
SiteMiddle:Plot6	0.98	2.49	0.01	151.3	1.00	6921	
SiteMonkey:Plot6	0.66	1.10	0.09	5.80	1.00	6457	
SiteHome:Plot7	0.56	1.33	0.05	8.58	1.00	6511	
SiteMazie:Plot7	0.49	1.16	0.06	5.51	1.00	6565	
SiteMiall:Plot7	1.02	0.89	0.19	6.32	1.00	6328	
SiteMiddle:Plot7	0.38	1.00	0.05	2.72	1.00	6279	
SiteMonkey:Plot7	0.11	1.62	0.01	2.85	1.00	6798	
SiteHome:Plot8	0.41	1.23	0.04	5.22	1.00	6505	
SiteMazie:Plot8	0.89	2.51	0.01	106.8	1.00	7428	
SiteMiall:Plot8	0.24	0.99	0.04	1.92	1.00	6408	
SiteMiddle:Plot8	0.18	1.12	0.02	1.63	1.00	6020	
SiteMonkey:Plot8	4.60	1.08	0.62	40.40	1.00	6137	
SiteHome:Plot9	0.97	2.51	0.01	141.0	1.00	7740	
SiteMazie:Plot9	1.70	1.27	0.17	23.82	1.00	6571	
SiteMiall:Plot9	2.37	1.02	0.35	18.98	1.00	6497	
SiteMiddle:Plot9	1.88	1.02	0.24	12.67	1.00	6141	
SiteMonkey:Plot9	0.69	1.22	0.07	7.52	1.00	6408	
SiteHome:Plot10	0.31	1.38	0.02	5.06	1.00	6528	
SiteMazie:Plot10	1.31	1.16	0.14	14.11	1.00	6223	
SiteMiall:Plot10	0.76	1.06	0.09	6.08	1.00	6147	
SiteMiddle:Plot10	0.70	1.13	0.07	5.66	1.00	6262	
SiteMonkey:Plot10	2.70	1.11	0.32	22.80	1.00	6477	
SiteHome:Plot11	0.96	2.58	0.01	205.1	1.00	7711	
SiteMazie:Plot11	0.83	1.14	0.10	8.14	1.00	5918	

SiteMiall:Plot11	2.28	0.98	0.34	16.26	1.00	5959	
SiteMiddle:Plot11	3.37	1.10	0.37	26.12	1.00	6035	
SiteMonkey:Plot11	1.13	1.22	0.10	12.13	1.00	6264	
SiteHome:Plot12	10.42	1.50	0.59	189.5	1.00	6415	
SiteMazie:Plot12	3.37	1.26	0.28	39.73	1.00	6641	
SiteMiall:Plot12	1.38	1.13	0.15	12.76	1.00	6108	
SiteMiddle:Plot12	5.65	1.23	0.53	66.56	1.00	6066	
SiteMonkey:Plot12	1.56	1.18	0.14	14.84	1.00	6398	
SiteHome:Plot13	0.36	1.58	0.02	8.61	1.00	6664	
SiteMazie:Plot13	0.24	1.20	0.02	2.46	1.00	5949	
SiteMiall:Plot13	0.89	1.00	0.13	6.64	1.00	6517	
SiteMiddle:Plot13	0.29	1.04	0.04	2.35	1.00	6268	
SiteMonkey:Plot13	1.03	2.49	0.01	116.1	1.00	7547	
Model: Planned comparisons							
Hypothesis	**Est**	**Err**	**CI low**	**CI high**	**Evid ratio**	**Post prob**	**Signf**
(SiteMiddle-SiteHome) > 0	3.99	1.87	0.17	79.77	3.63	0.78	
(SiteMiddle-SiteMazie) > 0	1.47	2.05	0.05	41.72	1.34	0.57	
(SiteMiddle-Intercept) > 0	0.03	2.30	< 0.001	1.29	0.07	0.06	.
(SiteMiddle-SiteMiall) > 0	1.02	2.03	0.04	28.30	1.02	0.50	
(SiteMiddle-SiteMonkey) > 0	1.92	1.62	0.14	25.34	2.12	0.68	
(SiteMiall-SiteHome) > 0	3.90	2.16	0.10	122.87	3.06	0.75	
(SiteMiall-SiteMazie) > 0	1.44	1.61	0.10	17.92	1.55	0.61	
(SiteMiall-Intercept) > 0	0.03	2.13	< 0.001	0.94	0.05	0.05	*
(SiteMiall-SiteMonkey) > 0	1.88	2.01	0.06	46.67	1.75	0.64	
(DeviceTypeExclusion:SiteHome - DeviceTypeTriangle_Inner:SiteHome) > 0	1.95	1.90	0.09	47.95	1.76	0.64	
(DeviceTypeExclusion:SiteHome - DeviceTypeTriangle_Outer:SiteHome) > 0	3.37	1.93	0.14	81.62	2.78	0.74	
(DeviceTypeExclusion:SiteHome-DeviceTypeControl:SiteHome) > 0	0.02	2.02	< 0.001	0.45	0.02	0.02	*
(DeviceTypeExclusion:SiteMiall - DeviceTypeTriangle_Inner:SiteMiall) > 0	0.95	0.66	0.32	2.80	0.87	0.46	
(DeviceTypeExclusion:SiteMiall - DeviceTypeTriangle_Outer:SiteMiall) > 0	1.14	0.60	0.42	3.06	1.45	0.59	
(DeviceTypeTriangle_Inner:SiteMonkey - DeviceTypeControl:SiteMonkey) > 0	0.01	1.92	< 0.001	0.30	0.01	0.01	*
(DeviceTypeTriangle_Outer:SiteMonkey - DeviceTypeControl:SiteMonkey) > 0	0.04	1.89	< 0.001	0.96	0.05	0.05	*
(DeviceTypeTriangle_Inner:SiteMonkey - DeviceTypeExclusion:SiteMonkey) > 0	1.08	1.85	0.05	22.47	1.07	0.52	
(DeviceTypeTriangle_Outer:SiteMonkey - DeviceTypeExclusion:SiteMonkey) > 0	3.34	1.85	0.16	72.86	2.96	0.75	

Table C9. Fish count by site model parameters and output. The 'est' is the estimate, 'err' is error, 'CI low' and 'CI high' are 95% credible intervals, 'ess' is the sample size, and 'signf' is the significance.

Model 1: Fish counts by site (family-level data)

Family: zero_inflated_poisson
Links: mu = log; zi = identity
Formula: Total_Count ~ Site * Family + (1 | Timepoint/ ReserveStatus/Site/Replicate)
Data: Fish_SPC_Fam_long (Number of observations: 208)
Draws: 3 chains, each with iter = 8500; warmup = 2500; thin = 5;
total post-warmup draws = 3600

Multilevel Hyperparameters:
~Timepoint (Number of levels: 4)

	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
sd(Intercept)	0.46	0.46	0.02	1.64	1.00	3502	3319

~Timepoint:Site (Number of levels: 20)

	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
sd(Intercept)	0.50	0.17	0.20	0.85	1.00	2932	2584

~Timepoint:Site:Replicate (Number of levels: 52)

	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
sd(Intercept)	0.46	0.07	0.34	0.61	1.00	2785	3190

Term	Est	Err	CI low	CI high	Rhat	Ess	Signf
Intercept	0.13	0.78	0.03	0.56	1.00	2629	*
SiteHome	1.30	1.13	0.14	11.03	1.00	2993	
SiteMaize	0.85	1.24	0.07	8.64	1.00	3533	
SiteMiall	3.31	0.97	0.54	24.70	1.00	2956	
SiteMiddle	14.55	0.88	2.94	91.50	1.00	2729	*
SiteMonkey	1.40	1.09	0.16	11.29	1.00	2715	
Labridae_Scarinae	30.50	0.70	8.45	124.24	1.00	2524	*
Pomacentridae	1566.83	0.68	456.38	6.3 e3	1.00	2542	*
Siganidae	80.96	0.69	23.10	336.93	1.00	2455	*
SiteHome:Labridae_Scarinae	0.41	1.06	0.06	3.99	1.00	3184	
SiteMaize:Labridae_Scarinae	1.37	1.21	0.17	19.88	1.00	3444	
SiteMiall:Labridae_Scarinae	0.11	0.96	0.02	0.78	1.00	2896	*
SiteMiddle:Labridae_Scarinae	0.43	0.77	0.09	1.77	1.00	2598	
SiteMonkey:Labridae_Scarinae	1.32	1.02	0.16	9.80	1.00	2615	
SiteHome:Pomacentridae	0.11	1.04	0.02	0.92	1.00	3084	*
SiteMaize:Pomacentridae	0.50	1.18	0.06	6.02	1.00	3502	
SiteMiall:Pomacentridae	0.10	0.87	0.02	0.54	1.00	2859	*
SiteMiddle:Pomacentridae	0.01	0.76	0.00	0.05	1.00	2606	*
SiteMonkey:Pomacentridae	0.08	1.01	0.01	0.60	1.00	2578	*
SiteHome:Siganidae	0.07	1.13	0.01	0.57	1.00	3142	*

SiteMaize:Siganidae	4.39	1.19	0.50	56.91	1.00	3442	
SiteMiall:Siganidae	0.90	0.89	0.15	4.72	1.00	2850	
SiteMiddle:Siganidae	0.16	0.77	0.04	0.71	1.00	2565	*
SiteMonkey:Siganidae	0.31	1.02	0.04	2.26	1.00	2639	

Model 1: Planned comparisons

Hypothesis	**Est**	**Err**	**CI low**	**CI high**	**Evid ratio**	**Post prob**	**Signf**
(SiteMiddle-SiteHome) > 0	11.73	1.03	2.36	66.79	162.6	0.99	*
(SiteMaize-SiteHome) > 0	0.62	1.42	0.06	6.03	0.61	0.38	
(SiteMiall-SiteHome) > 0	2.62	1.15	0.43	17.98	3.97	0.80	
(SiteMonkey-SiteHome) > 0	1.10	1.24	0.15	8.42	1.16	0.54	
(SiteMiddle:Labridae_Scarinae - SiteMaize:Labridae_Scarinae) > 0	0.29	1.14	0.04	1.52	0.15	0.13	
(SiteMiddle:Labridae_Scarinae - SiteMiall:Labridae_Scarinae) > 0	3.92	0.76	1.08	13.46	23.6	0.96	*
(SiteMiddle:Labridae_Scarinae - SiteMonkey:Labridae_Scarinae) > 0	0.31	0.88	0.07	1.20	0.09	0.08	.
(SiteMiddle:Labridae_Scarinae - SiteHome:Labridae_Scarinae) > 0	1.03	0.93	0.20	4.38	1.15	0.54	

Model 2: Fish counts by site (species-level data)

Family: zero_inflated_poisson
Links: mu = log; zi = identity
Formula: Total_Count ~ Site * Species + (1 | Timepoint/ReserveStatus/Site/Replicate)
Data: Fish_SPC_Spp_long (Number of observations: 936)
Draws: 3 chains, each with iter = 8500; warmup = 2500; thin = 5;
total post-warmup draws = 3600

Multilevel Hyperparameters:
~Timepoint (Number of levels: 4)

	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
sd(Intercept)	0.54	0.57	0.02	2.07	1.00	3257	3217

~Timepoint:Site (Number of levels: 20)

	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
sd(Intercept)	0.58	0.16	0.33	0.96	1.00	3354	3504

~Timepoint:Site:Replicate (Number of levels: 52)

	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
sd(Intercept)	0.34	0.05	0.25	0.46	1.00	3159	3388

Term	**Est**	**Err**	**CI low**	**CI high**	**Rhat**	**Ess**	**Signf**
Intercept	0.02	0.98	< 0.001	0.15	1.00	3249	*
SiteHome	0.23	1.42	0.02	4.13	1.00	3349	
SiteMaize	1.16	1.29	0.08	11.68	1.00	3384	
SiteMiall	1.30	1.25	0.11	13.92	1.00	3440	
SiteMiddle	3.63	1.16	0.36	34.12	1.00	3382	
SiteMonkey	0.69	1.29	0.05	8.26	1.00	3177	

Acanthurus dussumieri	0.31	2.06	0.01	16.69	1.00	2865	
Acanthurus grammoptilus	0.60	1.88	0.02	18.87	1.00	3465	
Chlorourus spilurus	56.82	0.94	10.35	417.98	1.00	3301	*
Chlorurus microrhinos	0.11	2.30	< 0.001	6.71	1.00	3567	
Naso unicornis	0.10	2.40	< 0.001	6.56	1.00	3436	
Pomacentrus adelus	5.9 e3	0.85	1.2 e3	3.5 e4	1.00	3124	*
Pomacentrus wardi	4.7 e3	0.85	958.39	2.7 e4	1.00	3125	*
Prionurus spp.	0.80	1.72	0.02	18.71	1.00	3111	
Scarus chameleon	30.82	1.07	4.13	271.07	1.00	3264	*
Scarus ghobban	10.57	1.22	0.89	107.29	1.00	3278	
Scarus globiceps	1.80	1.52	0.08	30.04	1.00	3157	
Scarus rivulatus	279.01	0.88	52.18	1.7 e3	1.00	3069	*
Siganus argenteus	559.17	0.86	113.75	3.5 e3	1.00	3137	*
Siganus doliatus	1.16	1.69	0.04	24.68	1.00	3213	
Siganus fuscescens	2.00	1.52	0.09	35.17	1.00	3346	
Siganus lineatus	3.08	1.43	0.18	50.73	1.00	3214	
Stegastes apicalis	0.81	1.80	0.02	20.99	1.00	3685	
SiteHome:Acanthurus dussumieri	0.28	3.95	< 0.001	491.51	1.00	3566	
SiteMaize:Acanthurus dussumieri	0.20	3.83	< 0.001	116.66	1.00	3423	
SiteMiall:Acanthurus dussumieri	57.06	2.26	0.83	5.6 e3	1.00	3169	
SiteMiddle:Acanthurus dussumieri	25.22	2.24	0.46	2.1 e3	1.00	3117	
SiteMonkey:Acanthurus dussumieri	0.15	3.86	0.00	118.91	1.00	3771	
SiteHome:Acanthurus grammoptilus	40.54	2.39	0.40	4.6 e3	1.00	3362	
SiteMaize:Acanthurus grammoptilus	0.11	3.63	< 0.001	63.63	1.00	3795	
SiteMiall:Acanthurus grammoptilus	0.10	3.65	< 0.001	66.55	1.00	3260	
SiteMiddle:Acanthurus grammoptilus	10.57	2.06	0.25	773.77	1.00	3536	
SiteMonkey:Acanthurus grammoptilus	34.30	2.17	0.66	3.4 e3	1.00	3497	
SiteHome:Chlorourus spilurus	0.02	3.14	< 0.001	3.66	1.00	3431	
SiteMaize:Chlorourusspilurus	0.71	1.45	0.05	13.60	1.00	3401	
SiteMiall:Chlorourusspilurus	0.25	1.50	0.01	4.97	1.00	2910	
SiteMiddle:Chlorourus spilurus	0.40	1.20	0.04	4.05	1.00	3102	
SiteMonkey:Chlorourus spilurus	1.00	1.44	0.06	17.21	1.00	3022	
SiteHome:Chlorurus microrhinos	0.41	4.17	< 0.001	600.36	1.00	3507	
SiteMaize:Chlorurus microrhinos	647.47	2.49	7.01	1.2 e5	1.00	3642	*
SiteMiall:Chlorurus microrhinos	0.21	4.01	< 0.001	181.11	1.00	3703	
SiteMiddle:Chlorurus microrhinos	0.12	3.75	< 0.001	106.71	1.00	3266	
SiteMonkey:Chlorurus microrhinos	0.29	3.97	< 0.001	183.38	1.00	3488	
SiteHome:Naso unicornis	0.43	4.18	< 0.001	567.68	1.00	3613	
SiteMaize:Naso unicornis	0.26	3.98	< 0.001	473.85	1.00	3551	
SiteMiall:Naso unicornis	0.25	3.90	< 0.001	236.44	1.00	3724	
SiteMiddle:Naso unicornis	178.38	2.53	2.00	4 e4	1.00	3375	*
SiteMonkey:Naso unicornis	0.28	4.09	< 0.001	322.53	1.00	3519	
SiteHome:Pomacentru sadelus	0.85	1.34	0.06	12.74	1.00	3460	

SiteMaize:Pomacentrus adelus	0.26	1.23	0.03	3.35	1.00	3392	
SiteMiall:Pomacentrus adelus	0.11	1.16	0.01	1.35	1.00	3381	.
SiteMiddle:Pomacentrus adelus	0.02	1.09	< 0.001	0.16	1.00	3156	
SiteMonkey:Pomacentrus adelus	0.05	1.24	< 0.001	0.65	1.00	3232	
SiteHome:Pomacentrus wardi	0.70	1.34	0.05	10.13	1.00	3447	
SiteMaize:Pomacentrus wardi	0.57	1.23	0.05	5.50	1.00	3387	
SiteMiall:Pomacentrus wardi	0.48	1.16	0.06	5.83	1.00	3373	
SiteMiddle:Pomacentrus wardi	0.08	1.09	0.01	0.79	1.00	3190	*
SiteMonkey:Pomacentrus wardi	0.30	1.23	0.03	3.72	1.00	3225	
SiteHome:Prionurus spp.	26.88	2.29	0.25	2.5 e3	1.00	3492	
SiteMaize:Prionurus spp.	6.57	2.26	0.10	721.23	1.00	3515	
SiteMiall:Prionurus spp.	5.49	2.20	0.07	386.21	1.00	3257	
SiteMiddle:Prionurus spp.	5.79	1.99	0.12	262.76	1.00	3172	
SiteMonkey:Prionurus spp.	0.13	3.72	< 0.001	92.35	1.00	3554	
SiteHome:Scarus chameleon	2.28	1.69	0.09	63.36	1.00	3503	
SiteMaize:Scarus chameleon	0.56	1.59	0.02	11.57	1.00	3481	
SiteMiall:Scarus chameleon	0.16	1.71	< 0.001	3.72	1.00	3470	
SiteMiddle:Scarus chameleon	0.38	1.35	0.03	5.37	1.00	3471	
SiteMonkey:Scarus chameleon	0.01	3.02	< 0.001	1.73	1.00	3312	
SiteHome:Scarus ghobban	0.06	3.37	< 0.001	14.57	1.00	3513	
SiteMaize:Scarus ghobban	0.66	1.82	0.01	17.68	1.00	3352	
SiteMiall:Scarus ghobban	2.99	1.55	0.12	50.42	1.00	3690	
SiteMiddle:Scarus ghobban	1.74	1.45	0.12	31.98	1.00	3152	
SiteMonkey:Scarus ghobban	0.03	3.20	0.00	5.89	1.00	3405	
SiteHome:Scarus globiceps	86.86	1.89	2.18	3.3 e3	1.00	3202	*
SiteMaize:Scarus globiceps	12.44	1.81	0.36	409.36	1.00	3647	
SiteMiall:Scarus globiceps	2.56	2.03	0.05	144.76	1.00	3178	
SiteMiddle:Scarus globiceps	6.54	1.74	0.25	223.57	1.00	3287	
SiteMonkey:Scarus globiceps	14.71	1.83	0.49	519.62	1.00	3278	
SiteHome:Scarus rivulatus	1.52	1.37	0.11	26.09	1.00	3502	
SiteMaize:Scarus rivulatus	0.64	1.27	0.06	9.44	1.00	3454	
SiteMiall:Scarus rivulatus	0.06	1.31	0.01	0.85	1.00	3416	*
SiteMiddle:Scarus rivulatus	1.25	1.11	0.14	11.01	1.00	3106	
SiteMonkey:Scarus rivulatus	1.66	1.27	0.14	19.80	1.00	3218	
SiteHome:Siganusargenteus	0.00	2.88	0.00	0.52	1.00	3205	*
SiteMaize:Siganus argenteus	4.10	1.23	0.41	49.52	1.00	3409	
SiteMiall:Siganus argenteus	1.69	1.17	0.18	18.21	1.00	3375	
SiteMiddle:Siganus argenteus	1.02	1.10	0.13	8.87	1.00	3302	
SiteMonkey:Siganus argenteus	0.84	1.29	0.08	11.43	1.00	3179	
SiteHome:Siganus doliatus	183.49	2.09	3.58	1.4 e4	1.00	3557	*
SiteMaize:Siganus doliatus	67.93	1.90	2.18	3.3 e3	1.00	3513	*
SiteMiall:Siganus doliatus	0.08	3.49	0.00	36.36	1.00	3595	
SiteMiddle:Siganus doliatus	0.04	3.38	< 0.001	8.59	1.00	3502	

SiteMonkey:Siganus doliatus	182.10	1.94	5.49	1 e4	1.00	3472	
SiteHome:Siganus fuscescens	0.12	3.69	< 0.001	57.54	1.00	3694	
SiteMaize:Siganus fuscescens	0.06	3.39	< 0.001	26.05	1.00	3368	
SiteMiall:Siganus fuscescens	577.81	1.71	22.35	1.7 e4	1.00	3574	*
SiteMiddle:Siganus fuscescens	288.21	1.65	13.35	7.8 e3	1.00	3512	*
SiteMonkey:Siganus fuscescens	708.42	1.79	30.64	3.2 e4	1.00	3492	*
SiteHome:Siganus lineatus	47.42	1.82	1.21	1.4 e3	1.00	3614	*
SiteMaize:Siganus lineatus	67.65	1.69	2.92	1.9 e3	1.00	3531	*
SiteMiall:Siganus lineatus	65.59	1.63	3.05	1.7 e3	1.00	3433	*
SiteMiddle:Siganus lineatus	11.38	1.56	0.53	225.60	1.00	3345	
SiteMonkey:Siganus lineatus	23.73	1.73	1.04	835.92	1.00	3366	*
SiteHome:Stegastes apicalis	0.21	3.90	< 0.001	224.73	1.00	3339	
SiteMaize:Stegastes apicalis	0.10	3.71	< 0.001	57.45	1.00	3556	
SiteMiall:Stegastes apicalis	97.44	1.95	3.20	5.7 e3	1.00	3579	*
SiteMiddle:Stegastes apicalis	59.42	1.92	2.18	3.5 e3	1.00	3587	*
SiteMonkey:Stegastes apicalis	8.39	2.26	0.16	988.71	1.00	3521	
Model 2: Planned comparisons							
Hypothesis	**Est**	**Err**	**CI low**	**CI high**	**Evid ratio**	**Post prob**	**Signf**
(SiteMiall:Siganus argenteus-SiteMonkey:Siganus argenteus) > 0	1.99	1.64	0.12	28.27	2.12	0.68	
(SiteMiall:Siganus argenteus-SiteHome:Siganus argenteus) > 0	626.28	3.06	7.59	1.5 e5	155.5	0.99	*
(SiteMiall:Siganus fuscescens-SiteMonkey:Siganus fuscescens) > 0	0.81	1.64	0.05	11.73	0.83	0.45	
(SiteMiall:Siganus fuscescens-SiteHome:Siganus fuscescens) > 0	7.5 e3	3.84	28.37	7.5 e6	899	1.00	*
(SiteMiall:Siganus fuscescens-SiteMaize:Siganus fuscescens) > 0	1.3 e4	3.53	85.30	8.3 e6	∞	1.00	*
(SiteMiddle:Siganus fuscescens-SiteMonkey:Siganus fuscescens) > 0	0.41	1.58	0.03	5.15	0.41	0.29	
(SiteMiddle:Siganus fuscescens-SiteMiall:Siganus fuscescens) > 0	0.50	1.47	0.05	5.34	0.46	0.31	
(SiteMiddle:Siganus fuscescens-SiteMaize:Siganus fuscescens) > 0	6.6 e3	3.52	39.15	4 e7	∞	1.00	*
(SiteMiddle:Siganus fuscescens-SiteHome:Siganus fuscescens) > 0	3.8 e3	3.79	14.78	3.5 e6	449	1.00	*
(SiteMiddle:Siganus argenteus-SiteMonkey:Siganus argenteus) > 0	1.21	1.57	0.09	15.67	1.23	0.55	
(SiteMiddle:Siganus argenteus-SiteMiall:Siganus argenteus) > 0	0.61	1.46	0.05	6.50	0.59	0.37	
(SiteMiddle:Siganus argenteus-SiteHome:Siganus argenteus) > 0	381.27	3.06	4.37	1.0 e5	80.8	0.99	*
(SiteMiddle:Scarus rivulatus-SiteMonkey:Scarus rivulatus) > 0	0.75	1.54	0.06	9.20	0.77	0.43	
(SiteMiddle:Scarus rivulatus-SiteMiallScarus rivulatus) > 0	20.84	1.57	1.64	257.22	32.6	0.97	*
(SiteMiddle:Scarus rivulatus-SiteHome:Scarus rivulatus) > 0	0.82	1.69	0.05	13.64	0.88	0.45	
(SiteMiddle:Scarus rivulatus-SiteMaizeScarus rivulatus) > 0	1.90	1.54	0.15	24.27	1.9	0.66	
(SiteMaize:Siganus argenteus-SiteMiall:Siganus argenteus) > 0	2.41	1.60	0.16	32.89	2.41	0.71	

(SiteMaize:Siganus argenteus-SiteMiddle:Siganus argenteus) > 0	3.96	1.51	0.33	47.34	4.57	0.82	
(SiteMaize:Siganus argenteus-SiteHome:Siganus argenteus) > 0	1.5 e3	3.07	16.77	3.6 e5	449	1.00	*
(SiteMaize:Siganus argenteus-SiteMonkey:Siganus argenteus) > 0	4.80	1.69	0.29	76.35	4.53	0.82	

Model 3: Fish attacks or chases

Family: zero_inflated_poisson
Links: mu = log; zi = identity
Formula: Total_Chases ~ Site + (1 | Site/Video_UNI)
Data: Fish_Chases_long (Number of observations: 116)
Draws: 3 chains, each with iter = 8000; warmup = 2500; thin = 10;
total post-warmup draws = 1650

Multilevel Hyperparameters:
~Site (Number of levels: 6)
Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
sd(Intercept) 2.72 2.85 0.08 9.85 1.00 1580 1440

~Site:Video_UNI (Number of levels: 116)
Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
sd(Intercept) 2.21 2.21 0.08 7.95 1.00 1611 1480

Term	**Est**	**Err**	**CI low**	**CI high**	**Rhat**	**Ess**	**Signf**
Intercept	1.02	1.97	0.02	38.19	1.00	1577	
SiteHome	1.03	4.96	0.00	3.6 e4	1.00	1761	
SiteMaize	0.89	3.54	0.00	1026.9	1.00	1630	
SiteMiall	0.86	5.04	6.5 e-5	1.7 e4	1.00	1609	
SiteMiddle	1.10	5.14	8.7 e-5	4.9 e4	1.00	1542	
SiteMonkey	1.01	5.00	1.7 e-4	5.3 e4	1.00	1795	

Model 3: Planned comparisons

Hypothesis	**Est**	**Err**	**CI low**	**CI high**	**Evid ratio**	**Post prob**	**Signf**
(SiteMiall-SiteHome) > 0	0.91	7.12	7.6 e-6	1.2 e5	0.95	0.49	
(SiteMiall-SiteMaize) > 0	1.23	5.70	1.8 e-4	1.4 e4	1.00	0.50	
(SiteMiall-SiteMiddle) > 0	0.94	7.08	8 e-6	1 e5	1.00	0.50	
(SiteMiall-SiteMonkey) > 0	0.94	7.06	6.2 e-6	1.3 e5	0.98	0.50	
(SiteMiddle-SiteHome) > 0	0.97	7.35	7.7 e-6	1.9 e5	1.01	0.50	
(SiteMiddle-SiteMaize) > 0	1.31	5.68	1 e-4	1.4 e4	1.04	0.51	
(SiteMiddle-SiteMonkey) > 0	1.00	7.38	6.1 e-6	1.7 e5	1.01	0.50	
(SiteMonkey-SiteHome) > 0	0.97	7.26	4.5 e-6	1.8 e5	1.03	0.51	
(SiteMonkey-SiteMaize) > 0	1.32	5.70	1 e-4	1.4 e4	1.07	0.52	

Table C10. Model parameters and output for the influence of abiotic and biotic variables on coral survival by ecological variables. The 'est' is the estimate, 'err' is error, 'CI low' and 'CI high' are 95% credible intervals, 'ess' is the sample size, and 'signf' is the significance.

Models: Coral survival by fish feeding

Group level models

Model 1: Labridae (Scarinae)

Family: bernoulli
Links: mu = logit
Formula: Survival ~ Bites_Labridae_Scarinae + (1 | ReserveStatus/Site/Plot/DeviceNumber)
Data: survival_final (Number of observations: 1746)
Draws: 3 chains, each with iter = 5000; warmup = 1000; thin = 5;
total post-warmup draws = 2400

Multilevel Hyperparameters:
~ReserveStatus (Number of levels: 2)

	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
sd(Intercept)	0.81	0.68	0.04	2.55	1.00	1797	2193

~ReserveStatus:Site (Number of levels: 6)

	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
sd(Intercept)	0.29	0.29	0.01	0.97	1.00	1824	1767

~ReserveStatus:Site:Plot (Number of levels: 78)

	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
sd(Intercept)	0.63	0.17	0.26	0.94	1.00	1426	1322

~ReserveStatus:Site:Plot:DeviceNumber (Number of levels: 436)

	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
sd(Intercept)	1.16	0.15	0.88	1.46	1.00	1636	2228

Term	Est	Err	CI low	CI high	Rhat	Ess	Signf
Intercept	0.28	0.66	0.10	1.26	1.00	2041	.
Bites_Labridae_Scarinae	0.66	0.20	0.44	0.95	1.00	2227	*

Model 2: Multi-family model

Family: bernoulli
Links: mu = logit
Formula: Survival ~ DeviceType * ReserveStatus * Bites_Blenniidae + DeviceType * ReserveStatus * Bites_Pseudochromidae + DeviceType * ReserveStatus * Bites_Labridae + DeviceType * ReserveStatus * Bites_Pomacentridae + (1 | ReserveStatus/Site/Plot/DeviceNumber)
Data: survival_final (Number of observations: 1746)

Draws: 3 chains, each with iter = 5000; warmup = 1000; thin = 5;
total post-warmup draws = 2400

Multilevel Hyperparameters:
~ReserveStatus (Number of levels: 2)
Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
sd(Intercept) 1.47 1.42 0.07 4.78 1.00 2258 2314

~ReserveStatus:Site (Number of levels: 6)
Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
sd(Intercept) 0.98 0.83 0.03 3.01 1.00 2157 2283

~ReserveStatus:Site:Plot (Number of levels: 78)
Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
sd(Intercept) 0.69 0.18 0.31 1.05 1.00 1295 1122

~ReserveStatus:Site:Plot:DeviceNumber (Number of levels: 436)
Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
sd(Intercept) 1.23 0.15 0.93 1.54 1.00 2050 2243

Term	**Est**	**Err**	**CI low**	**CI high**	**Rhat**	**Ess**	**Signf**
Intercept	0.17	4.76	3.8 e-5	2.9 e3	1.00	2496	
DeviceTypeExclusion	0.99	1.58	0.04	18.23	1.00	2531	
DeviceTypeTriangle_Inner	1.07	1.53	0.04	16.47	1.00	2446	
DeviceTypeTriangle_Outer	1.05	1.62	0.05	30.51	1.00	2112	
ReserveStatusGreen	0.84	1.62	0.03	18.01	1.00	2468	
Bites_Blenniidae	1.52	1.19	0.13	13.77	1.00	2091	
Bites_Pseudochromidae	0.98	1.68	0.04	25.57	1.00	2312	
Bites_Labridae	0.92	0.85	0.15	4.15	1.00	2480	
Bites_Pomacentridae	1.16	0.60	0.35	3.65	1.00	2500	
DeviceTypeExclusion:ReserveStatusGreen	1.39	1.52	0.06	22.22	1.00	2133	
DeviceTypeTriangle_Inner:ReserveStatusGreen	1.16	1.49	0.07	22.09	1.00	1867	
DeviceTypeTriangle_Outer:ReserveStatusGreen	1.24	1.52	0.06	21.36	1.00	2237	
DeviceTypeExclusion:Bites_Blenniidae	0.52	0.58	0.16	1.58	1.00	2426	
DeviceTypeTriangle_Inner:Bites_Blenniidae	0.56	0.58	0.19	2.01	1.00	2614	
DeviceTypeTriangle_Outer:Bites_Blenniidae	0.59	0.59	0.18	1.80	1.00	2393	
ReserveStatusGreen:Bites_Blenniidae	1.51	1.53	0.07	26.47	1.00	2451	
DeviceTypeExclusion:Bites_Pseudochromidae	1.05	1.56	0.05	20.15	1.00	2397	
DeviceTypeTriangle_Inner:Bites_Pseudochromidae	1.07	1.59	0.05	29.02	1.00	2437	
DeviceTypeTriangle_Outer:Bites_Pseudochromidae	1.09	1.60	0.04	23.02	1.00	2426	
ReserveStatusGreen:Bites_Pseudochromidae	0.82	1.65	0.03	19.95	1.00	2404	
DeviceTypeExclusion:Bites_Labridae	1.00	0.42	0.44	2.23	1.00	2523	
DeviceTypeTriangle_Inner:Bites_Labridae	0.95	0.41	0.45	2.25	1.00	2442	
DeviceTypeTriangle_Outer:Bites_Labridae	0.93	0.42	0.42	2.18	1.00	2084	
ReserveStatusGreen:Bites_Labridae	0.30	1.27	0.03	3.93	1.00	2178	

DeviceTypeExclusion:Bites_Pomacentridae	1.13	0.23	0.72	1.77	1.00	2538	
DeviceTypeTriangle_Inner:Bites_Pomacentridae	1.04	0.23	0.69	1.67	1.00	2479	
DeviceTypeTriangle_Outer:Bites_Pomacentridae	1.08	0.23	0.71	1.76	1.00	2441	
ReserveStatusGreen:Bites_Pomacentridae	1.24	0.63	0.35	4.17	1.00	2253	
DeviceTypeExclusion:ReserveStatusGreen:Bites_Blenniidae	0.71	1.21	0.08	8.10	1.00	2300	
DeviceTypeTriangle_Inner:ReserveStatusGreen:Bites_Blenniidae	1.17	1.18	0.14	13.70	1.00	2463	
DeviceTypeTriangle_Outer:ReserveStatusGreen:Bites_Blenniidae	1.22	1.22	0.12	13.16	1.00	2434	
DeviceTypeExclusion:ReserveStatusGreen:Bites_Pseudochromidae	1.36	1.57	0.07	31.07	1.00	2325	
DeviceTypeTriangle_Inner:ReserveStatusGreen:Bites_Pseudochromidae	1.12	1.55	0.05	20.22	1.00	2509	
DeviceTypeTriangle_Outer:ReserveStatusGreen:Bites_Pseudochromidae	1.21	1.59	0.06	28.20	1.00	2493	
DeviceTypeExclusion:ReserveStatusGreen:Bites_Labridae	3.61	1.02	0.52	27.01	1.00	2423	
DeviceTypeTriangle_Inner:ReserveStatusGreen:Bites_Labridae	1.16	1.02	0.17	9.51	1.00	2387	
DeviceTypeTriangle_Outer:ReserveStatusGreen:Bites_Labridae	1.23	1.07	0.14	8.53	1.00	2535	
DeviceTypeExclusion:ReserveStatusGreen:Bites_Pomacentridae	0.68	0.46	0.26	1.61	1.00	2486	
DeviceTypeTriangle_Inner:ReserveStatusGreen:Bites_Pomacentridae	0.94	0.46	0.38	2.22	1.00	2468	
DeviceTypeTriangle_Outer:ReserveStatusGreen:Bites_Pomacentridae	0.83	0.47	0.33	2.01	1.00	2427	

Model 3: Scarus spp.

Family: bernoulli

Links: mu = logit

Formula: Survival ~ Combined_Scarus + (1 | ReserveStatus/Site/Plot/DeviceNumber)

Data: survival_final (Number of observations: 1746)

Draws: 3 chains, each with iter = 5000; warmup = 1000; thin = 5;

total post-warmup draws = 2400

Multilevel Hyperparameters:

~ReserveStatus (Number of levels: 2)

	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
sd(Intercept)	0.85	0.71	0.05	2.64	1.00	2165	1993

~ReserveStatus:Site (Number of levels: 6)

	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
sd(Intercept)	0.29	0.28	0.01	0.99	1.00	1953	2043

~ReserveStatus:Site:Plot (Number of levels: 78)

	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
sd(Intercept)	0.64	0.17	0.30	0.95	1.00	1481	1661

~ReserveStatus:Site:Plot:DeviceNumber (Number of levels: 436)

	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
sd(Intercept)	1.15	0.15	0.88	1.44	1.00	1937	2037

Term	**Est**	**Err**	**CI low**	**CI high**	**Rhat**	**Ess**	**Signif**
Intercept	0.28	0.66	0.11	1.29	1.00	2010	.

Combined_Scarus	0.66	0.21	0.44	0.97	1.00	1836	*

Individual models

Model 1: Stethojulis strigiventer (initial phase)

Family: bernoulli
Links: mu = logit
Formula: Survival ~ DeviceType * ReserveStatus * Bites_Stethojulis_strigiventer_IP + (1 | ReserveStatus/Site/Plot/DeviceNumber)
Data: survival_final (Number of observations: 1746)
Draws: 3 chains, each with iter = 5000; warmup = 1000; thin = 5;
total post-warmup draws = 2400

Multilevel Hyperparameters:
~ReserveStatus (Number of levels: 2)

	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
sd(Intercept)	0.91	0.80	0.03	3.05	1.00	2220	2327

~ReserveStatus:Site (Number of levels: 6)

	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
sd(Intercept)	0.53	0.42	0.03	1.64	1.00	2046	2370

~ReserveStatus:Site:Plot (Number of levels: 78)

	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
sd(Intercept)	0.66	0.18	0.29	1.00	1.00	1453	1445

~ReserveStatus:Site:Plot:DeviceNumber (Number of levels: 436)

	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
sd(Intercept)	1.18	0.15	0.91	1.48	1.00	1847	2057

Term	**Est**	**Err**	**CI low**	**CI high**	**Rhat**	**Ess**	**Signf**
Intercept	0.34	0.77	0.09	1.91	1.00	2134	
DeviceTypeExclusion	1.18	0.32	0.63	2.18	1.00	2200	
DeviceTypeTriangle_Outer	1.07	0.32	0.58	2.02	1.00	2157	
DeviceTypeTriangle_Inner	0.86	0.31	0.47	1.58	1.00	2114	
ReserveStatusGreen	0.59	0.81	0.14	3.35	1.00	2321	
Bites_Stethojulis_strigiventer_IP	0.99	0.03	0.94	1.05	1.00	2314	.
DeviceTypeExclusion:ReserveStatusGreen	1.11	0.44	0.46	2.59	1.00	2327	
DeviceTypeTriangle_Outer:ReserveStatusGreen	0.80	0.44	0.34	1.82	1.00	2225	
DeviceTypeTriangle_Inner:ReserveStatusGreen	1.15	0.44	0.48	2.63	1.00	2257	
DeviceTypeExclusion:Bites_Stethojulis_strigiventer_IP	1.00	0.02	0.96	1.04	1.00	2245	.
DeviceTypeTriangle_Outer:Bites_Stethojulis_strigiventer_IP	1.00	0.02	0.96	1.04	1.00	2063	.
DeviceTypeTriangle_Inner:Bites_Stethojulis_strigiventer_IP	1.00	0.02	0.96	1.04	1.00	2146	.
ReserveStatusGreen:Bites_Stethojulis_strigiventer_IP	0.41	1.02	0.06	2.79	1.00	2255	
DeviceTypeExclusion:ReserveStatusGreen:Bites_Stethojulis_strigiventer_IP	2.26	0.90	0.38	12.10	1.00	2143	

DeviceTypeTriangle_Outer:ReserveStatusGreen:Bites_Stethojulis_strigiventer_IP	0.68	0.92	0.11	3.71	1.00	2365	
DeviceTypeTriangle_Inner:ReserveStatusGreen:Bites_Stethojulis_strigiventer_IP	0.76	0.91	0.13	4.47	1.00	2461	

Model 2: Chromis nitida

Family: bernoulli

Links: mu = logit

Formula: Survival ~ DeviceType * ReserveStatus * Bites_Chromis_nitida + (1 | ReserveStatus/Site/Plot/DeviceNumber)

Data: survival_final (Number of observations: 1746)

Draws: 3 chains, each with iter = 5000; warmup = 1000; thin = 5; total post-warmup draws = 2400

Multilevel Hyperparameters:

~ReserveStatus (Number of levels: 2)

	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
sd(Intercept)	0.93	0.82	0.03	3.07	1.00	2044	2162

~ReserveStatus:Site (Number of levels: 6)

	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
sd(Intercept)	0.61	0.46	0.04	1.72	1.00	1803	2020

~ReserveStatus:Site:Plot (Number of levels: 78)

	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
sd(Intercept)	0.66	0.18	0.26	0.99	1.00	1298	1357

~ReserveStatus:Site:Plot:DeviceNumber (Number of levels: 436)

	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
sd(Intercept)	1.20	0.15	0.92	1.50	1.00	1894	2250

Term	**Est**	**Err**	**CI low**	**CI high**	**Rhat**	**Ess**	**Signf**
Intercept	0.19	0.90	0.04	1.39	1.00	2061	.
DeviceTypeExclusion	1.44	0.43	0.59	3.22	1.00	2249	
DeviceTypeTriangle_Outer	1.16	0.43	0.46	2.47	1.00	2238	
DeviceTypeTriangle_Inner	1.04	0.43	0.46	2.51	1.00	1881	
ReserveStatusGreen	0.67	0.84	0.13	3.48	1.00	2372	
Bites_Chromis_nitida	1.13	0.14	0.89	1.57	1.00	1892	
DeviceTypeExclusion:ReserveStatusGreen	1.30	0.54	0.49	3.86	1.00	2207	
DeviceTypeTriangle_Outer:ReserveStatusGreen	0.92	0.52	0.32	2.49	1.00	2249	
DeviceTypeTriangle_Inner:ReserveStatusGreen	1.07	0.52	0.38	2.94	1.00	2237	
DeviceTypeExclusion:Bites_Chromis_nitida	0.96	0.09	0.80	1.14	1.00	2055	.
DeviceTypeTriangle_Outer:Bites_Chromis_nitida	0.98	0.09	0.83	1.17	1.00	2238	.
DeviceTypeTriangle_Inner:Bites_Chromis_nitida	0.95	0.09	0.80	1.13	1.00	2091	.
ReserveStatusGreen:Bites_Chromis_nitida	1.45	0.41	0.64	3.27	1.00	2174	
DeviceTypeExclusion:ReserveStatusGreen:Bites_Chromis_nitida	0.75	0.31	0.41	1.38	1.00	2152	.

DeviceTypeTriangle_Outer:ReserveStatusGreen:Bites_Chromis_nitida	0.79	0.32	0.42	1.46	1.00	2310	.
DeviceTypeTriangle_Inner:ReserveStatusGreen:Bites_Chromis_nitida	0.94	0.31	0.50	1.69	1.00	2416	

Model 3: Ogilbyina queenslandiae

Family: bernoulli

Links: mu = logit

Formula: Survival ~ DeviceType * ReserveStatus * Bites_Ogilbyina_queenslandiae + (1 | ReserveStatus/Site/Plot/DeviceNumber)

Data: survival_final (Number of observations: 1746)

Draws: 3 chains, each with iter = 5000; warmup = 1000; thin = 5;
total post-warmup draws = 2400

Multilevel Hyperparameters:

~ReserveStatus (Number of levels: 2)

	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
sd(Intercept)	1.09	0.97	0.03	3.60	1.00	2223	2158

~ReserveStatus:Site (Number of levels: 6)

	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
sd(Intercept)	0.76	0.43	0.13	1.85	1.00	2030	2100

~ReserveStatus:Site:Plot (Number of levels: 78)

	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
sd(Intercept)	0.67	0.18	0.29	1.02	1.00	1475	1347

~ReserveStatus:Site:Plot:DeviceNumber (Number of levels: 436)

	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
sd(Intercept)	1.19	0.15	0.92	1.49	1.00	2103	2410

Term	**Est**	**Err**	**CI low**	**CI high**	**Rhat**	**Ess**	**Signf**
Intercept	0.28	1.37	0.02	5.12	1.00	2264	
DeviceTypeExclusion	1.19	0.64	0.35	4.24	1.00	2540	
DeviceTypeTriangle_Outer	0.94	0.66	0.27	3.56	1.00	2339	
DeviceTypeTriangle_Inner	0.87	0.65	0.25	3.07	1.00	2440	
ReserveStatusGreen	0.73	0.94	0.12	4.87	1.00	2315	
Bites_Ogilbyina_queenslandiae	1.03	0.25	0.60	1.61	1.00	2442	
DeviceTypeExclusion:ReserveStatusGreen	1.46	0.67	0.44	5.73	1.00	2343	
DeviceTypeTriangle_Outer:ReserveStatusGreen	0.73	0.68	0.18	2.57	1.00	2335	
DeviceTypeTriangle_Inner:ReserveStatusGreen	1.06	0.67	0.32	4.10	1.00	2385	
DeviceTypeExclusion:Bites_Ogilbyina_queenslandiae	1.00	0.11	0.81	1.25	1.00	2481	.
DeviceTypeTriangle_Outer:Bites_Ogilbyina_queenslandiae	1.02	0.11	0.83	1.29	1.00	2368	.
DeviceTypeTriangle_Inner:Bites_Ogilbyina_queenslandiae	1.00	0.11	0.82	1.25	1.00	2361	.
ReserveStatusGreen:Bites_Ogilbyina_queenslandiae	1.14	0.46	0.42	2.79	1.00	2338	

DeviceTypeExclusion:ReserveStatusGreen:Bites_Ogilbyina_queenslandiae	0.74	0.33	0.38	1.36	1.00	2064	.
DeviceTypeTriangle_Outer:ReserveStatusGreen:Bites_Ogilbyina_queenslandiae	1.21	0.32	0.67	2.33	1.00	2013	
DeviceTypeTriangle_Inner:ReserveStatusGreen:Bites_Ogilbyina_queenslandiae	1.04	0.31	0.57	1.91	1.00	2424	

Model 4: Pomacentrus wardi

Family: bernoulli

Links: mu = logit

Formula: Survival ~ DeviceType * ReserveStatus * Bites_Pomacentrus_wardi + (1 | ReserveStatus/Site/Plot/DeviceNumber)

Data: survival_final (Number of observations: 1746)

Draws: 3 chains, each with iter = 5000; warmup = 1000; thin = 5;
total post-warmup draws = 2400

Multilevel Hyperparameters:

~ReserveStatus (Number of levels: 2)

	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
sd(Intercept)	1.01	0.90	0.03	3.32	1.00	2229	2256

~ReserveStatus:Site (Number of levels: 6)

	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
sd(Intercept)	0.84	0.50	0.15	2.08	1.00	2006	1699

~ReserveStatus:Site:Plot (Number of levels: 78)

	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
sd(Intercept)	0.66	0.18	0.26	0.99	1.00	1256	894

~ReserveStatus:Site:Plot:DeviceNumber (Number of levels: 436)

	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
sd(Intercept)	1.19	0.15	0.90	1.49	1.00	1880	1966

Term	**Est**	**Err**	**CI low**	**CI high**	**Rhat**	**Ess**	**Signf**
Intercept	0.32	1.52	0.02	6.67	1.00	1923	
DeviceTypeExclusion	0.70	0.58	0.22	2.18	1.00	2043	
DeviceTypeTriangle_Outer	0.82	0.59	0.27	2.67	1.00	2205	
DeviceTypeTriangle_Inner	0.67	0.59	0.20	1.98	1.00	2276	
ReserveStatusGreen	0.84	0.92	0.15	4.98	1.00	2507	
Bites_Pomacentrus_wardi	1.00	0.03	0.94	1.06	1.00	1900	.
DeviceTypeExclusion:ReserveStatusGreen	1.16	0.75	0.31	5.49	1.00	2360	
DeviceTypeTriangle_Outer:ReserveStatusGreen	1.31	0.75	0.30	5.53	1.00	2541	
DeviceTypeTriangle_Inner:ReserveStatusGreen	1.10	0.76	0.24	4.69	1.00	2391	
DeviceTypeExclusion:Bites_Pomacentrus_wardi	1.01	0.01	0.99	1.04	1.00	1893	.
DeviceTypeTriangle_Outer:Bites_Pomacentrus_wardi	1.01	0.01	0.98	1.03	1.00	2029	.
DeviceTypeTriangle_Inner:Bites_Pomacentrus_wardi	1.01	0.01	0.98	1.03	1.00	2202	.

ReserveStatusGreen:Bites_Pomacentrus_wardi	1.00	0.03	0.95	1.05	1.00	2026	.
DeviceTypeExclusion:ReserveStatusGreen:Bites_Pomacentrus_wardi	0.99	0.01	0.97	1.02	1.00	2118	.
DeviceTypeTriangle_Outer:ReserveStatusGreen:Bites_Pomacentrus_wardi	0.99	0.01	0.97	1.01	1.00	2144	.
DeviceTypeTriangle_Inner:ReserveStatusGreen:Bites_Pomacentrus_wardi	1.00	0.01	0.98	1.02	1.00	2059	.

Model 5: Scarus rivulatus

Family: bernoulli
Links: mu = logit
Formula: Survival ~ Combined_Scarus_rivulatus + (1 | ReserveStatus/Site/Plot/DeviceNumber)
Data: survival_final (Number of observations: 1746)
Draws: 3 chains, each with iter = 5000; warmup = 1000; thin = 5;
total post-warmup draws = 2400

Multilevel Hyperparameters:
~ReserveStatus (Number of levels: 2)

	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
sd(Intercept)	0.84	0.69	0.04	2.56	1.00	1907	1949

~ReserveStatus:Site (Number of levels: 6)

	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
sd(Intercept)	0.28	0.26	0.01	1.00	1.00	2065	2143

~ReserveStatus:Site:Plot (Number of levels: 78)

	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
sd(Intercept)	0.62	0.18	0.23	0.98	1.00	1374	923

~ReserveStatus:Site:Plot:DeviceNumber (Number of levels: 436)

	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
sd(Intercept)	1.15	0.15	0.87	1.44	1.00	1730	2127

Term	**Est**	**Err**	**CI low**	**CI high**	**Rhat**	**Ess**	**Signf**
Intercept	0.28	0.65	0.11	1.42	1.00	1964	.
Combined_Scarus_rivulatus	0.66	0.19	0.44	0.94	1.00	2419	*

Model 5: Scarus rivulatus (initial phase)

Family: bernoulli
Links: mu = logit
Formula: Survival ~ Bites_Scarus_rivulatus_IP + (1 | ReserveStatus/Site/Plot/DeviceNumber)
Data: survival_final (Number of observations: 1746)
Draws: 3 chains, each with iter = 5000; warmup = 1000; thin = 5;
total post-warmup draws = 2400

Multilevel Hyperparameters:
~ReserveStatus (Number of levels: 2)

	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
sd(Intercept)	0.89	0.81	0.05	2.90	1.00	2136	2354

~ReserveStatus:Site (Number of levels: 6)

	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
sd(Intercept)	0.28	0.26	0.01	0.98	1.00	2073	2214

~ReserveStatus:Site:Plot (Number of levels: 78)

	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
sd(Intercept)	0.63	0.17	0.28	0.97	1.00	1497	1146

~ReserveStatus:Site:Plot:DeviceNumber (Number of levels: 436)

	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
sd(Intercept)	1.15	0.15	0.87	1.45	1.00	1439	1777

Term	Est	Err	CI low	CI high	Rhat	Ess	Signf
Intercept	0.28	0.68	0.11	1.50	1.00	2309	
Bites_Scarus_rivulatus_IP	0.64	0.20	0.41	0.93	1.00	2419	*

Models: Coral survival by fish counts

Group level models

Model 1: Parrotfish

Family: bernoulli
Links: mu = logit
Formula: Survival ~ AvgFish_Parrotfish + (1 | ReserveStatus/Site/Plot/DeviceNumber)
Data: survival_final (Number of observations: 1746)
Draws: 3 chains, each with iter = 5000; warmup = 1000; thin = 5;
total post-warmup draws = 2400

Multilevel Hyperparameters:
~ReserveStatus (Number of levels: 2)

	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
sd(Intercept)	1.05	0.79	0.10	3.18	1.00	2131	2341

~ReserveStatus:Site (Number of levels: 6)

	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
sd(Intercept)	0.50	0.38	0.03	1.42	1.00	2142	2162

~ReserveStatus:Site:Plot (Number of levels: 78)

	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
sd(Intercept)	0.64	0.17	0.29	0.96	1.00	1520	1148

~ReserveStatus:Site:Plot:DeviceNumber (Number of levels: 436)

	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
sd(Intercept)	1.15	0.15	0.87	1.46	1.00	1756	2349

Term	Est	Err	CI low	CI high	Rhat	Ess	Signf
Intercept	0.20	0.80	0.05	1.11	1.00	2217	.
Parrotfish	1.38	0.31	0.71	2.51	1.00	2160	

Model 1: Damselfish (Pomacentrids)

Family: bernoulli
Links: mu = logit
Formula: Survival ~ Combined_Poms + (1 | ReserveStatus/Site/Plot/DeviceNumber)
Data: survival_final (Number of observations: 1746)
Draws: 3 chains, each with iter = 5000; warmup = 1000; thin = 5;
total post-warmup draws = 2400

Multilevel Hyperparameters:
~ReserveStatus (Number of levels: 2)

	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
sd(Intercept)	0.87	0.77	0.04	2.73	1.00	2160	2393

~ReserveStatus:Site (Number of levels: 6)

	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
sd(Intercept)	0.67	0.38	0.13	1.55	1.00	1446	1458

~ReserveStatus:Site:Plot (Number of levels: 78)

	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
sd(Intercept)	0.66	0.17	0.33	0.98	1.00	1493	1727

~ReserveStatus:Site:Plot:DeviceNumber (Number of levels: 436)

	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
sd(Intercept)	1.14	0.15	0.87	1.44	1.00	1914	2108

Term	**Est**	**Err**	**CI low**	**CI high**	**Rhat**	**Ess**	**Signf**
Intercept	0.19	0.88	0.04	1.31	1.00	2119	
Combined_Poms	1.00	0.01	0.99	1.00	1.00	2198	*

Individual models

Model 1: Scarus rivulatus

Family: bernoulli
Links: mu = logit
Formula: Survival ~ AvgFish_Sca_rivu + (1 | ReserveStatus/Site/Plot/DeviceNumber)
Data: survival_final (Number of observations: 1746)
Draws: 3 chains, each with iter = 5000; warmup = 1000; thin = 5;
total post-warmup draws = 2400

Multilevel Hyperparameters:
~ReserveStatus (Number of levels: 2)

	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
sd(Intercept)	0.93	0.75	0.05	2.84	1.00	2228	2217

~ReserveStatus:Site (Number of levels: 6)

	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
sd(Intercept)	0.54	0.35	0.06	1.38	1.00	1925	2143

~ReserveStatus:Site:Plot (Number of levels: 78)

	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
sd(Intercept)	0.65	0.17	0.27	0.98	1.00	1449	1621

~ReserveStatus:Site:Plot:DeviceNumber (Number of levels: 436)

	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
sd(Intercept)	1.15	0.15	0.86	1.44	1.00	1999	2225

Term	Est	Err	CI low	CI high	Rhat	Ess	Signf
Intercept	0.30	0.72	0.09	1.62	1.00	2295	
Sca_rivu	0.56	0.87	0.10	3.03	1.00	2237	

Model 2: Pomacentus wardi

Family: bernoulli
Links: mu = logit
Formula: Survival ~ AvgFish_Pom_ward + (1 | ReserveStatus/Site/Plot/DeviceNumber)
Data: survival_final (Number of observations: 1746)
Draws: 3 chains, each with iter = 5000; warmup = 1000; thin = 5;
total post-warmup draws = 2400

Multilevel Hyperparameters:
~ReserveStatus (Number of levels: 2)

	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
sd(Intercept)	0.83	0.77	0.03	2.73	1.00	2288	2286

~ReserveStatus:Site (Number of levels: 6)

	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
sd(Intercept)	0.38	0.30	0.02	1.11	1.00	1991	2162

~ReserveStatus:Site:Plot (Number of levels: 78)

	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
sd(Intercept)	0.65	0.18	0.26	0.97	1.00	1243	956

~ReserveStatus:Site:Plot:DeviceNumber (Number of levels: 436)

	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
sd(Intercept)	1.15	0.15	0.87	1.46	1.00	1861	2102

Term	Est	Err	CI low	CI high	Rhat	Ess	Signf
Intercept	0.04	1.13	0.01	0.56	1.00	2286	*
Pom_ward	1.05	0.03	0.99	1.11	1.00	2323	.

Model 3: Siganus fuscescens

Family: bernoulli
Links: mu = logit
Formula: Survival ~ AvgFish_Sig_fusc + (1 | ReserveStatus/Site/Plot/DeviceNumber)
Data: survival_final (Number of observations: 1746)
Draws: 3 chains, each with iter = 5000; warmup = 1000; thin = 5;

total post-warmup draws = 2400

Multilevel Hyperparameters:
~ReserveStatus (Number of levels: 2)

	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
sd(Intercept)	1.00	0.83	0.06	2.99	1.00	2204	2217

~ReserveStatus:Site (Number of levels: 6)

	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
sd(Intercept)	0.58	0.35	0.07	1.41	1.00	1690	1919

~ReserveStatus:Site:Plot (Number of levels: 78)

	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
sd(Intercept)	0.65	0.18	0.29	0.99	1.00	1485	1437

~ReserveStatus:Site:Plot:DeviceNumber (Number of levels: 436)

	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
sd(Intercept)	1.15	0.15	0.87	1.44	1.00	1801	1960

Term	**Est**	**Err**	**CI low**	**CI high**	**Rhat**	**Ess**	**Signf**
Intercept	0.31	0.72	0.10	1.60	1.00	2225	
Sig_fusc	0.70	0.56	0.23	2.16	1.00	1999	

Model 4: Siganus argenteus

Family: bernoulli
Links: mu = logit
Formula: Survival ~ AvgFish_Sig_arg + (1 | ReserveStatus/Site/Plot/DeviceNumber)
Data: survival_final (Number of observations: 1746)
Draws: 3 chains, each with iter = 5000; warmup = 1000; thin = 5;
total post-warmup draws = 2400

Multilevel Hyperparameters:
~ReserveStatus (Number of levels: 2)

	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
sd(Intercept)	1.05	0.77	0.08	3.01	1.00	2340	2238

~ReserveStatus:Site (Number of levels: 6)

	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
sd(Intercept)	0.56	0.40	0.05	1.56	1.00	2116	2080

~ReserveStatus:Site:Plot (Number of levels: 78)

	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
sd(Intercept)	0.65	0.18	0.27	0.99	1.00	1375	1461

~ReserveStatus:Site:Plot:DeviceNumber (Number of levels: 436)

	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS

sd(Intercept) 1.15 0.15 0.88 1.46 1.00 2067 2119

Term	Est	Err	CI low	CI high	Rhat	Ess	Signf
Intercept	0.23	0.78	0.06	1.18	1.00	2266	
Sig_arg	1.03	0.03	0.97	1.09	1.00	2233	.

Models: Coral survival by benthic groups

Group level data

Model 1: Multi- group model

Family: bernoulli
Links: mu = logit
Formula: Survival ~ Quadrat_A + Quadrat_HC + Quadrat_AB +
Quadrat_MA + Quadrat_SC + (1 | ReserveStatus/Site/Plot/DeviceNumber)
Data: survival_final (Number of observations: 1695)
Draws: 3 chains, each with iter = 5000; warmup = 1000; thin = 5;
total post-warmup draws = 2400

Multilevel Hyperparameters:
~ReserveStatus (Number of levels: 2)
Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
sd(Intercept) 1.09 0.80 0.15 3.05 1.00 2382 1974

~ReserveStatus:Site (Number of levels: 6)
Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
sd(Intercept) 0.25 0.24 0.01 0.89 1.00 2276 2150

~ReserveStatus:Site:Plot (Number of levels: 75)
Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
sd(Intercept) 0.53 0.18 0.12 0.88 1.00 1430 1306

~ReserveStatus:Site:Plot:DeviceNumber (Number of levels: 422)
Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
sd(Intercept) 1.17 0.15 0.88 1.47 1.00 2019 2202

Term	Est	Err	CI low	CI high	Rhat	Ess	Signf
Intercept	79.78	2.82	0.32	1.7 e4	1.00	2169	
A	0.95	0.03	0.90	1.00	1.00	2147	*
HC	0.95	0.03	0.90	1.00	1.00	2154	*
AB	0.87	0.03	0.82	0.93	1.00	2182	*
MA	0.95	0.03	0.90	1.00	1.00	2123	*
SC	0.94	0.03	0.89	1.00	1.00	2071	*

Model 2: Multi- group model by reserve status and device

Family: bernoulli
Links: mu = logit
Formula: Survival ~ DeviceType * ReserveStatus * Quadrat_A +
(1 | ReserveStatus/Site/Plot/DeviceNumber)

Data: survival_final (Number of observations: 1695)
Draws: 3 chains, each with iter = 5000; warmup = 1000; thin = 5;
total post-warmup draws = 2400

Multilevel Hyperparameters:
~ReserveStatus (Number of levels: 2)
Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
sd(Intercept) 1.18 0.90 0.06 3.33 1.00 2306 2070

~ReserveStatus:Site (Number of levels: 6)
Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
sd(Intercept) 0.39 0.32 0.01 1.25 1.00 2172 2170

~ReserveStatus:Site:Plot (Number of levels: 75)
Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
sd(Intercept) 0.68 0.18 0.33 1.02 1.00 1464 1597

~ReserveStatus:Site:Plot:DeviceNumber (Number of levels: 422)
Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
sd(Intercept) 1.21 0.15 0.92 1.53 1.00 1908 2040

Term	Est	Err	CI low	CI high	Rhat	Ess	Signf
Intercept	0.38	0.82	0.09	2.21	1.00	2092	
DeviceTypeExclusion	0.88	0.37	0.43	1.78	1.00	2439	
DeviceTypeTriangle_Outer	0.79	0.38	0.38	1.67	1.00	2201	
DeviceTypeTriangle_Inner	0.70	0.38	0.33	1.47	1.00	2234	.
ReserveStatusGreen	0.49	0.92	0.09	3.06	1.00	2261	
A	0.98	0.01	0.95	1.00	1.00	2189	*
DeviceTypeExclusion:ReserveStatusGreen	1.37	0.61	0.44	4.57	1.00	2303	
DeviceTypeTriangle_Outer:ReserveStatusGreen	0.91	0.61	0.26	2.84	1.00	2266	
DeviceTypeTriangle_Inner:ReserveStatusGreen	1.29	0.60	0.39	3.99	1.00	2296	
DeviceTypeExclusion:A	1.02	0.02	0.99	1.06	1.00	2323	.
DeviceTypeTriangle_Outer:A	1.02	0.02	0.99	1.06	1.00	2082	.
DeviceTypeTriangle_Inner:A	1.02	0.02	0.98	1.05	1.00	2148	.
ReserveStatusGreen:A	1.05	0.02	1.00	1.09	1.00	2245	.
DeviceTypeExclusion:ReserveStatusGreen:A	0.97	0.02	0.93	1.02	1.00	2220	.
DeviceTypeTriangle_Outer:ReserveStatusGreen:A	0.98	0.03	0.93	1.03	1.00	2241	.
DeviceTypeTriangle_Inner:ReserveStatusGreen:_A	0.98	0.02	0.93	1.02	1.00	2115	.

Individual models

Model 1: Abiotic material

Family: bernoulli
Links: mu = logit
Formula: Survival ~ Quadrat_AB + (1 | ReserveStatus/Site/Plot/DeviceNumber)
Data: survival_final (Number of observations: 1695)
Draws: 3 chains, each with iter = 5000; warmup = 1000; thin = 5;

total post-warmup draws = 2400

Multilevel Hyperparameters:
~ReserveStatus (Number of levels: 2)
Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
sd(Intercept) 0.88 0.74 0.06 2.71 1.00 2005 2018

~ReserveStatus:Site (Number of levels: 6)
Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
sd(Intercept) 0.25 0.23 0.01 0.84 1.00 1966 2216

~ReserveStatus:Site:Plot (Number of levels: 75)
Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
sd(Intercept) 0.50 0.19 0.10 0.84 1.00 1077 1096

~ReserveStatus:Site:Plot:DeviceNumber (Number of levels: 422)
Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
sd(Intercept) 1.17 0.15 0.89 1.48 1.00 1508 2240

Term	**Est**	**Err**	**CI low**	**CI high**	**Rhat**	**Ess**	**Signf**
Intercept	0.37	0.69	0.13	1.88	1.00	2092	
AB	0.92	0.02	0.89	0.95	1.00	2264	*

Model 2: Pocillopora corals

Family: bernoulli
Links: mu = logit
Formula: Survival ~ Quadrat_G_POC_OT + (1 | ReserveStatus/Site/Plot/DeviceNumber)
Data: survival_final (Number of observations: 1695)
Draws: 3 chains, each with iter = 5000; warmup = 1000; thin = 5;
total post-warmup draws = 2400

Multilevel Hyperparameters:
~ReserveStatus (Number of levels: 2)
Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
sd(Intercept) 1.00 0.79 0.06 3.01 1.00 2193 2097

~ReserveStatus:Site (Number of levels: 6)
Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
sd(Intercept) 0.64 0.37 0.10 1.51 1.00 1967 1977

~ReserveStatus:Site:Plot (Number of levels: 75)
Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
sd(Intercept) 0.67 0.18 0.31 1.00 1.00 1666 1709

~ReserveStatus:Site:Plot:DeviceNumber (Number of levels: 422)
Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS

sd(Intercept) 1.17 0.15 0.89 1.48 1.00 1998 2326

Term	Est	Err	CI low	CI high	Rhat	Ess	Signf
b_Intercept	0.26	0.71	0.09	1.42	1.00	2406	.
G_POC_OT	1.09	0.06	0.97	1.24	1.00	2217	.

Model 3: Sargassum macroalgae

Family: bernoulli
Links: mu = logit
Formula: Survival ~ Quadrat_Sar + (1 | ReserveStatus/Site/Plot/DeviceNumber)
Data: survival_final (Number of observations: 1695)
Draws: 3 chains, each with iter = 5000; warmup = 1000; thin = 5;
total post-warmup draws = 2400

Multilevel Hyperparameters:
~ReserveStatus (Number of levels: 2)
Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
sd(Intercept) 0.95 0.79 0.07 2.93 1.00 2129 2301

~ReserveStatus:Site (Number of levels: 6)
Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
sd(Intercept) 0.53 0.35 0.05 1.35 1.00 1902 2180

~ReserveStatus:Site:Plot (Number of levels: 75)
Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
sd(Intercept) 0.68 0.18 0.32 1.03 1.00 1369 1378

~ReserveStatus:Site:Plot:DeviceNumber (Number of levels: 422)
Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
sd(Intercept) 1.16 0.15 0.88 1.47 1.00 1700 1850

Term	Est	Err	CI low	CI high	Rhat	Ess	Signf
Intercept	0.27	0.69	0.10	1.48	1.00	2219	.
Sar	0.98	0.02	0.95	1.00	1.00	2325	*

Model 4: Colpomenia macroalgae

Family: bernoulli
Links: mu = logit
Formula: Survival ~ Quadrat_Colp + (1 | ReserveStatus/Site/Plot/DeviceNumber)
Data: survival_final (Number of observations: 1695)
Draws: 3 chains, each with iter = 5000; warmup = 1000; thin = 5;
total post-warmup draws = 2400

Multilevel Hyperparameters:
~ReserveStatus (Number of levels: 2)
Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
sd(Intercept) 1.04 0.77 0.10 2.95 1.00 1797 2159

~ReserveStatus:Site (Number of levels: 6)

	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
sd(Intercept)	0.42	0.32	0.02	1.21	1.00	1864	2047

~ReserveStatus:Site:Plot (Number of levels: 75)

	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
sd(Intercept)	0.66	0.18	0.29	1.01	1.00	1337	1638

~ReserveStatus:Site:Plot:DeviceNumber (Number of levels: 422)

	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
sd(Intercept)	1.17	0.15	0.89	1.47	1.00	1912	2058

Term	**Est**	**Err**	**CI low**	**CI high**	**Rhat**	**Ess**	**Signf**
Intercept	0.29	0.73	0.10	1.54	1.00	2220	
Colp	0.90	0.06	0.81	1.00	1.00	2379	*

Model 5: Acropora coral

Family: bernoulli
Links: mu = logit
Formula: Survival ~ Combined_Acro + (1 | ReserveStatus/Site/Plot/DeviceNumber)
Data: survival_final (Number of observations: 1746)
Draws: 3 chains, each with iter = 5000; warmup = 1000; thin = 5;
total post-warmup draws = 2400

Multilevel Hyperparameters:
~ReserveStatus (Number of levels: 2)

	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
sd(Intercept)	0.96	0.80	0.06	3.02	1.00	1934	1815

~ReserveStatus:Site (Number of levels: 6)

	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
sd(Intercept)	0.66	0.37	0.14	1.56	1.00	1946	1970

~ReserveStatus:Site:Plot (Number of levels: 78)

	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
sd(Intercept)	0.64	0.18	0.25	0.99	1.00	1331	1127

~ReserveStatus:Site:Plot:DeviceNumber (Number of levels: 436)

	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
sd(Intercept)	1.15	0.15	0.86	1.45	1.00	1919	2271

Term	**Est**	**Err**	**CI low**	**CI high**	**Rhat**	**Ess**	**Signf**
Intercept	0.33	0.72	0.10	1.57	1.00	2031	
Combined_Acro	0.99	0.01	0.97	1.00	1.00	2270	*

Model: Coral survival by total sediment deposition

Family: bernoulli
Links: mu = logit

Formula: Survival ~ Sed_Total + (1 | ReserveStatus/Site/Plot/DeviceNumber)
Data: survival_final_TotalSed (Number of observations: 1746)
Draws: 3 chains, each with iter = 5000; warmup = 1000; thin = 5;
total post-warmup draws = 2400
Multilevel Hyperparameters:
~ReserveStatus (Number of levels: 2)

	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
sd(Intercept)	1.00	0.76	0.07	2.80	1.00	2239	2328

~ReserveStatus:Site (Number of levels: 6)

	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
sd(Intercept)	0.60	0.36	0.09	1.50	1.00	1962	1776

~ReserveStatus:Site:Plot (Number of levels: 78)

	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
sd(Intercept)	0.65	0.17	0.29	0.98	1.00	1592	1684

~ReserveStatus:Site:Plot:DeviceNumber (Number of levels: 436)

	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
sd(Intercept)	1.15	0.15	0.87	1.43	1.00	1892	2127

Term	**Est**	**Err**	**CI low**	**CI high**	**Rhat**	**Ess**	**Signf**
Intercept	0.27	0.73	0.08	1.27	1.00	2300	.
Sed_Total	1.10	0.84	0.22	5.85	1.00	2381	

Table C11. Fish feeding by site model parameters and output. The 'est' is the estimate, 'err' is error, 'CI low' and 'CI high' are 95% credible intervals, 'ess' is the sample size, and 'signf' is the significance.

Model 1: Fish bites by site

Family: gamma
Links: mu = log; shape = identity
Formula: Total_Bites ~ Family * ReserveStatus +
Family * Site + (1 | ReserveStatus/Site/Video_UNI)
Data: Bites_family_long (Number of observations: 293)
Draws: 3 chains, each with iter = 8000; warmup = 2500;
thin = 10; total post-warmup draws = 1650
Multilevel Hyperparameters:
~ReserveStatus (Number of levels: 2)

	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
sd(Intercept)	1.95	2.23	0.06	7.64	1.00	1691	1669

~ReserveStatus:Site (Number of levels: 6)

	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
sd(Intercept)	1.32	1.22	0.04	4.55	1.00	1580	1617

~ReserveStatus:Site:Video_UNI (Number of levels: 116)

	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
sd(Intercept)	0.34	0.12	0.07	0.53	1.00	1251	1458

Term	Est	Err	CI low	CI high	Rhat	Ess	Signf
Intercept	1.56	2.35	0.02	306.96	1.00	1440	
FamilyChaetodontidae	0.23	0.59	0.08	0.84	1.00	1661	*
FamilyLabridae	0.78	0.38	0.37	1.63	1.00	1791	
FamilyLabridaeScarinae	0.08	1.02	0.02	0.77	1.00	1538	*
FamilyPomacanthidae	0.26	3.16	< 0.001	76.42	1.00	1488	
FamilyPomacentridae	3.35	0.37	1.64	6.76	1.00	1609	*
FamilyPseudochromidae	0.30	0.39	0.14	0.62	1.00	1636	*
FamilySerranidae	0.49	4.01	< 0.001	851.81	1.00	1411	
FamilySiganidae	0.15	0.99	0.03	1.21	1.00	1542	.
FamilySynodontidae	0.39	4.26	< 0.001	1.8 e3	1.00	1708	
ReserveStatusGreen	0.93	3.34	< 0.001	599.89	1.00	1487	
SiteHome	1.81	3.42	< 0.001	1.2 e3	1.00	1707	
SiteMaize	1.06	2.69	0.01	325.91	1.00	1602	
SiteMiall	1.26	2.68	0.01	246.96	1.00	1425	
SiteMiddle	0.47	3.00	< 0.001	204.46	1.00	1600	
SiteMonkey	0.85	2.94	< 0.001	334.98	1.00	1493	
FamilyChaetodontidae:ReserveStatusGreen	1.80	2.91	< 0.001	841.62	1.00	1606	
FamilyLabridae:ReserveStatusGreen	1.46	2.68	0.01	252.40	1.00	1658	
FamilyLabridaeScarinae:ReserveStatusGreen	4.05	3.80	< 0.001	8.8 e3	1.00	1657	
FamilyPomacanthidae:ReserveStatusGreen	1.06	5.06	< 0.001	7.7 e3	1.00	1569	

FamilyPomacentridae:ReserveStatusGreen	1.12	2.62	0.01	320.08	1.00	1518	
FamilyPseudochromidae:ReserveStatusGreen	1.29	3.58	< 0.001	968.69	1.00	1541	
FamilySerranidae:ReserveStatusGreen	0.53	4.02	< 0.001	925.85	1.00	1715	
FamilySiganidae:ReserveStatusGreen	2.15	3.81	< 0.001	4 e3	1.00	1670	
FamilySynodontidae:ReserveStatusGreen	0.39	4.16	< 0.001	1.2 e3	1.00	1274	
FamilyChaetodontidae:SiteHome	0.93	4.92	< 0.001	1.3 e3	1.00	1682	
FamilyLabridae:SiteHome	1.00	3.15	< 0.001	593.33	1.00	1482	
FamilyLabridaeScarinae:SiteHome	4.18	3.80	< 0.001	7.1 e3	1.00	1611	
FamilyPomacanthidae:SiteHome	1.16	5.15	< 0.001	3.1 e4	1.00	1668	
FamilyPomacentridae:SiteHome	0.70	3.27	< 0.001	484.48	1.00	1459	
FamilyPseudochromidae:SiteHome	0.83	4.96	< 0.001	3.7 e4	1.00	1700	
FamilySerranidae:SiteHome	1.06	5.03	< 0.001	3.4 e4	1.00	1468	
FamilySiganidae:SiteHome	1.48	3.83	< 0.001	1.9 e3	1.00	1501	
FamilySynodontidae:SiteHome	0.38	4.23	< 0.001	1.2 e3	1.00	1455	
FamilyChaetodontidae:SiteMaize	1.41	2.22	0.02	94.99	1.00	1520	
FamilyLabridae:SiteMaize	2.65	2.19	0.03	167.71	1.00	1556	
FamilyLabridaeScarinae:SiteMaize	1.11	4.93	< 0.001	1.1 e4	1.00	1567	
FamilyPomacanthidae:SiteMaize	0.64	3.34	< 0.001	355.52	1.00	1315	
FamilyPomacentridae:SiteMaize	0.47	2.20	0.01	28.10	1.00	1534	
FamilyPseudochromidae:SiteMaize	1.27	2.21	0.01	68.29	1.00	1564	
FamilySerranidae:SiteMaize	1.03	4.99	< 0.001	1.7 e4	1.00	1547	
FamilySiganidae:SiteMaize	1.17	5.14	< 0.001	1.8 e4	1.00	1490	
FamilySynodontidae:SiteMaize	0.92	4.88	< 0.001	10 e3	1.00	1618	
FamilyChaetodontidae:SiteMiall	1.32	2.32	0.02	131.57	1.00	1572	
FamilyLabridae:SiteMiall	1.63	2.15	0.02	107.79	1.00	1588	
FamilyLabridaeScarinae:SiteMiall	1.08	4.98	< 0.001	1.9 e4	1.00	1507	
FamilyPomacanthidae:SiteMiall	0.56	3.31	< 0.001	335.92	1.00	1567	
FamilyPomacentridae:SiteMiall	0.87	2.15	0.01	43.45	1.00	1574	
FamilyPseudochromidae:SiteMiall	1.30	2.16	0.01	55.61	1.00	1580	
FamilySerranidae:SiteMiall	1.09	4.88	< 0.001	3 e4	1.00	1713	
FamilySiganidae:SiteMiall	0.93	4.97	< 0.001	6.6 e3	1.00	1671	
FamilySynodontidae:SiteMiall	0.97	5.07	< 0.001	1.3 e4	1.00	1626	
FamilyChaetodontidae:SiteMiddle	1.81	2.93	< 0.001	541.61	1.00	1562	
FamilyLabridae:SiteMiddle	2.40	2.65	0.01	348.68	1.00	1658	
FamilyLabridaeScarinae:SiteMiddle	0.79	5.07	< 0.001	2.3 e4	1.00	1470	
FamilyPomacanthidae:SiteMiddle	0.82	5.18	< 0.001	7.6 e3	1.00	1695	
FamilyPomacentridae:SiteMiddle	2.40	2.64	0.02	762.63	1.00	1618	
FamilyPseudochromidae:SiteMiddle	0.88	4.99	< 0.001	3.5 e4	1.00	1677	
FamilySerranidae:SiteMiddle	0.91	4.90	< 0.001	2.9 e4	1.00	1649	
FamilySiganidae:SiteMiddle	0.85	4.85	< 0.001	6.6 e3	1.00	1596	
FamilySynodontidae:SiteMiddle	1.11	5.14	< 0.001	1.5 e4	1.00	1391	
FamilyChaetodontidae:SiteMonkey	1.14	2.92	0.01	542.48	1.00	1624	
FamilyLabridae:SiteMonkey	0.49	2.67	< 0.001	75.51	1.00	1649	

FamilyLabridaeScarinae:SiteMonkey	1.02	4.92	< 0.001	1.2 e4	1.00	1598	
FamilyPomacanthidae:SiteMonkey	0.89	4.91	< 0.001	8.6 e3	1.00	1557	
FamilyPomacentridae:SiteMonkey	0.47	2.64	< 0.001	82.75	1.00	1475	
FamilyPseudochromidae:SiteMonkey	1.01	3.56	< 0.001	1.2 e3	1.00	1488	
FamilySerranidae:SiteMonkey	0.61	4.09	< 0.001	1.6 e3	1.00	1472	
FamilySiganidae:SiteMonkey	0.96	4.88	< 0.001	5.7 e3	1.00	1629	
FamilySynodontidae:SiteMonkey	0.94	5.02	< 0.001	3 e4	1.00	1555	
Model 1: Planned comparisons							
Hypothesis	**Est**	**Err**	**CI low**	**CI high**	**Evid ratio**	**Post prob**	**Signf**
(SiteMiddle-SiteHome) > 0	0.27	3.29	< 0.001	63.51	0.50	0.33	
(SiteMiddle-SiteMaize) > 0	0.44	4.00	< 0.001	317.39	0.72	0.42	
(SiteMiddle-Intercept) > 0	0.32	4.11	< 0.001	296.18	0.62	0.38	
(SiteMiddle-SiteMiall) > 0	0.39	3.94	< 0.001	257.28	0.69	0.41	
(SiteMiddle-SiteMonkey) > 0	0.55	2.13	0.02	18.13	0.48	0.32	
(SiteMiall-SiteHome) > 0	0.69	4.32	< 0.001	872.93	0.92	0.48	
(SiteMiall-SiteMaize) > 0	1.14	3.52	< 0.001	389.79	1.06	0.51	
(SiteMiall-Intercept) > 0	0.83	3.89	< 0.001	428.85	0.89	0.47	
(SiteMiall-SiteMonkey) > 0	1.41	3.85	< 0.001	690.04	1.15	0.53	
(FamilyPomacentridae:SiteMiall-FamilyPomacentridae:SiteMaize) > 0	1.83	3.00	0.01	251.73	1.39	0.58	
(FamilyPomacentridae:SiteMiall-FamilyPomacentridae:SiteMonkey) > 0	1.75	3.43	0.01	429.03	1.28	0.56	
(FamilyPomacentridae:SiteMiall-FamilyPomacentridae:SiteHome) > 0	1.33	3.94	< 0.001	928.77	1.15	0.54	
(FamilyPomacentridae:SiteMiddle-FamilyPomacentridae:SiteMaize) > 0	5.40	3.43	0.02	1.4 e3	2.21	0.69	
(FamilyPomacentridae:SiteMiddle-FamilyPomacentridae:SiteMonkey) > 0	5.16	0.82	1.31	18.79	36.50	0.97	*
(FamilyPomacentridae:SiteMiddle-FamilyPomacentridae:SiteHome) > 0	3.93	2.81	0.04	370.26	2.22	0.69	
(FamilyPomacentridae:SiteMiddle-FamilyPomacentridae:SiteMiall) > 0	2.95	3.44	0.01	837.14	1.67	0.63	
(FamilyLabridaeScarinae:SiteHome-FamilyLabridaeScarinae:SiteMonkey) > 0	4.41	6.06	< 0.001	1.3 e5	1.51	0.60	
(FamilyLabridaeScarinae:SiteHome-FamilyLabridaeScarinae:SiteMaize) > 0	4.13	6.23	< 0.001	1.1 e5	1.38	0.58	
(FamilyLabridaeScarinae:SiteHome-FamilyLabridaeScarinae:SiteMiall) > 0	3.84	6.18	< 0.001	8 e4	1.46	0.59	
(FamilyLabridaeScarinae:SiteHome-FamilyLabridaeScarinae:SiteMiddle) > 0	4.90	6.29	< 0.001	9.5 e4	1.43	0.59	
Model 2: Fish feeding on devices							

Family: zero_inflated_poisson

Links: mu = log; zi = identity

Formula: Total_BitesDevices ~ Site + (1 | Site/Video_UNI)

Data: Device_Grazing_long (Number of observations: 116)

Draws: 3 chains, each with iter = 8000; warmup = 2500; thin = 10;

total post-warmup draws = 1650

Multilevel Hyperparameters:

~Site (Number of levels: 6)

Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS

sd(Intercept) 1.28 1.09 0.05 4.01 1.00 1708 1668

~Site:Video_UNI (Number of levels: 116)

Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS

sd(Intercept) 1.83 0.30 1.33 2.50 1.00 1350 1355

Term	**Est**	**Err**	**CI low**	**CI high**	**Rhat**	**Ess**	**Signf**
b_Intercept	3.94	1.26	0.32	53.38	1.00	1663	
b_SiteHome	1.24	1.86	0.03	53.07	1.00	1703	
b_SiteMaize	0.26	1.83	0.01	11.11	1.00	1711	
b_SiteMiall	4.81	1.86	0.10	223.25	1.00	1594	
b_SiteMiddle	1.23	1.86	0.03	53.20	1.00	1397	
b_SiteMonkey	0.29	1.94	0.01	16.27	1.00	1686	

Model 2: Planned comparisons

Hypothesis	**Est**	**Err**	**CI low**	**CI high**	**Evid ratio**	**Post prob**	**Signf**
(SiteMiall-SiteHome) > 0	3.72	2.15	0.10	92.19	4.16	0.81	
(SiteMiall-SiteMaize) > 0	16.08	2.17	0.40	451.51	11.79	0.92	
(SiteMiall-SiteMiddle) > 0	3.62	2.17	0.11	103.61	3.71	0.79	
(SiteMiall-SiteMonkey) > 0	14.60	2.22	0.33	419.21	9.93	0.91	

Table C12. Benthic constituents by site model parameters and output. The 'est' is the estimate, 'err' is error, 'CI low' and 'CI high' are 95% credible intervals, 'ess' is the sample size, and 'signf' is the significance.

Model 1: Benthic groups by site

Family: zero_inflated_beta
Links: mu = logit; phi = identity; zi = identity
Formula: percent ~ ReserveStatus * point_human_classification +
site_name * point_human_classification + (1 | site_name/image_name)
Data: AVG_OG_ReefCloud_filled (Number of observations: 2160)
Draws: 3 chains, each with iter = 8500; warmup = 2500; thin = 5;
total post-warmup draws = 3600
Multilevel Hyperparameters:
~site_name (Number of levels: 6)

	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
sd(Intercept)	1.71	1.35	0.07	4.91	1.00	3668	3485

~site_name:image_name (Number of levels: 90)

	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
sd(Intercept)	0.05	0.04	0.00	0.14	1.00	3294	3523

Term	Est	Err	CI low	CI high	Rhat	Ess	Signf
Intercept	0.16	1.60	0.01	7.08	1.00	3542	
ReserveStatusGreen	1.65	2.83	0.01	407.22	1.00	3514	
ACTO	0.78	0.74	0.17	3.06	1.00	3070	
CA	1.30	0.51	0.46	3.28	1.00	2788	
Colp	2.29	4.11	<0.001	5.4 e3	1.00	3571	
Cyano	1.67	4.09	<0.001	4.5 e3	1.00	3650	
Device	0.93	0.62	0.28	2.87	1.00	3435	
F_FUN_CMR	1.68	3.52	<0.001	1.4 e3	1.00	3605	
G_GON_ALV	1.38	4.10	<0.001	4.6 e3	1.00	3798	
G_MON_CEMS	3.78	0.39	1.80	8.56	1.00	3131	*
G_POC_OT	1.08	0.51	0.39	2.94	1.00	3460	
G_POR_CECS	0.84	3.18	<0.001	412.66	1.00	3566	
G_STY	0.80	0.63	0.24	2.67	1.00	3254	
Lobo	10.73	0.38	5.06	22.92	1.00	2954	*
Meru	0.83	3.22	<0.001	488.78	1.00	3541	
OT	1.03	4.04	<0.001	3 e3	1.00	3526	
Padina	2.22	4.16	<0.001	9.2 e3	1.00	3665	
Pey	0.57	2.67	<0.001	136.89	1.00	3537	
Pseu	1.07	4.09	<0.001	2.6 e3	1.00	3717	
S	1.07	3.03	<0.001	396.82	1.00	3318	
Sar	1.66	3.90	<0.001	3.6 e3	1.00	3748	
SC_OTH	1.56	3.05	0.01	633.05	1.00	3561	
SP	0.71	3.07	<0.001	213.32	1.00	3664	

TA	1.12	0.47	0.48	2.95	1.00	3051	
U	0.96	3.98	<0.001	2 e3	1.00	3542	
Home	0.99	2.85	<0.001	242.99	1.00	3436	
Mazie	1.91	2.07	0.02	122.10	1.00	3645	
Miall	1.11	2.20	0.01	112.07	1.00	3706	
Middle	0.93	2.91	<0.01	302.78	1.00	3551	
Monkey	1.76	2.86	0.01	466.39	1.00	3560	
ReserveStatusGreen: ACTO	0.84	2.57	0.01	149.95	1.00	3562	
ReserveStatusGreen: CA	0.67	2.88	<0.001	196.85	1.00	3672	
ReserveStatusGreen: Colp	0.97	4.10	<0.001	1.5 e3	1.00	3430	
ReserveStatusGreen: Cyano	0.73	4.12	<0.001	2.7 e3	1.00	3674	
ReserveStatusGreen:Device	0.50	2.51	<0.001	88.75	1.00	3586	
ReserveStatusGreen: F_FUN_CMR	1.85	4.87	<0.001	2.6 e4	1.00	3765	
ReserveStatusGreen: G_GON_ALV	0.65	4.13	<0.001	1249.73	1.00	3696	
ReserveStatusGreen: G_MON_CEMS	0.29	2.54	<0.001	53.84	1.00	3502	
ReserveStatusGreen: G_POC_OT	0.63	3.52	<0.001	677.65	1.00	3456	
ReserveStatusGreen: G_POR_CECS	0.74	3.86	<0.001	1.4 e3	1.00	3422	
ReserveStatusGreen: G_STY	0.99	3.53	<0.001	1.8 e3	1.00	3684	
ReserveStatusGreen: Lobo	0.15	2.56	<0.001	25.86	1.00	3544	
ReserveStatusGreen: Meru	0.77	3.84	<0.001	1.4 e3	1.00	3304	
ReserveStatusGreen: OT	0.49	4.06	<0.001	1.1 e3	1.00	3321	
ReserveStatusGreen: Padina	1.32	4.14	<0.001	4.6 e3	1.00	3285	
ReserveStatusGreen: Pey	0.90	3.38	<0.001	859.23	1.00	3411	
ReserveStatusGreen: Pseu	0.52	4.11	<0.001	2.4 e3	1.00	3395	
ReserveStatusGreen: S	1.17	3.40	<0.001	897.43	1.00	3462	
ReserveStatusGreen: Sar	0.91	3.87	<0.001	1.8 e3	1.00	3719	
ReserveStatusGreen: SC_OTH	0.44	3.53	<0.001	476.99	1.00	3384	
ReserveStatusGreen: SP	1.02	3.48	<0.001	904.49	1.00	3373	
ReserveStatusGreen: TA	0.96	2.54	0.01	116.27	1.00	3629	
ReserveStatusGreen: U	0.57	3.98	<0.001	1 e3	1.00	3356	
ACTO: Home	0.65	2.55	<0.001	83.03	1.00	3507	
CA: Home	1.37	5.02	<0.001	2.9 e3	1.00	3695	
Colp: Home	0.64	3.96	<0.001	2 e3	1.00	3585	
Cyano: Home	1.27	5.01	<0.001	1.8 e3	1.00	3848	
Device: Home	0.91	2.55	0.01	167.12	1.00	3589	
F_FUN_CMR: Home	1.22	4.98	<0.001	4.5 e4	1.00	3717	
G_GON_ALV: Home	0.42	4.16	<0.001	1.3 e3	1.00	3447	
G_MON_CEMS: Home	1.37	2.57	0.01	194.81	1.00	3612	
G_POC_OT: Home	0.46	3.49	<0.001	272.96	1.00	3546	
G_POR_CECS: Home	1.32	5.00	<0.001	2.1 e4	1.00	3379	
G_STY: Home	1.31	4.98	<0.001	2.3 e4	1.00	3729	
Lobo: Home	0.73	2.56	<0.001	77.94	1.00	3511	
Meru: Home	1.33	5.02	<0.001	3.1 e4	1.00	3820	

OT: Home	1.21	4.95	<0.001	2.2 e4	1.00	3697	
Padina: Home	0.75	4.13	<0.001	1.3 e3	1.00	3585	
Pey: Home	1.34	5.09	<0.001	2.7 e4	1.00	3727	
Pseu: Home	1.37	4.90	<0.001	3.5 e4	1.00	3662	
S: Home	1.50	2.65	0.01	310.71	1.00	3530	
Sar: Home	1.17	3.15	<0.001	538.41	1.00	3675	
SC_OTH: Home	1.15	5.12	<0.001	3.7 e4	1.00	3525	
SP: Home	1.20	5.04	<0.001	1.9 e4	1.00	3378	
TA: Home	0.83	2.56	<0.001	121.05	1.00	3556	
U: Home	1.30	4.96	<0.001	3 e4	1.00	3509	
ACTO: Mazie	1.37	4.97	<0.001	4.1 e4	1.00	4009	
CA: Mazie	0.38	0.71	0.09	1.56	1.00	3318	
Colp: Mazie	1.49	4.93	<0.001	1.7 e4	1.00	3210	
Cyano:Mazie	1.14	5.07	<0.001	1.4 e4	1.00	3407	
Device: Mazie	0.49	0.74	0.13	2.20	1.00	3302	
F_FUN_CMR: Mazie	1.18	4.98	<0.001	1.8 e4	1.00	3533	
G_GON_ALV: Mazie	1.22	4.86	<0.001	8.8 e3	1.00	3762	
G_MON_CEMS: Mazie	0.15	1.03	0.02	0.90	1.00	3378	
G_POC_OT: Mazie	1.07	5.01	<0.001	1.7 e4	1.00	3551	
G_POR_CECS: Mazie	1.34	4.97	<0.001	2.3 e4	1.00	3968	
G_STY: Mazie	1.45	5.07	<0.001	1.9 e4	1.00	3667	
Lobo: Mazie	0.74	0.48	0.30	1.94	1.00	2933	
Meru:Mazie	0.73	3.24	<0.001	334.25	1.00	3574	
OT: Mazie	1.22	4.95	<0.001	1.4 e4	1.00	3312	
Padina: Mazie	1.31	4.95	<0.001	2.7 e4	1.00	3795	
Pey: Mazie	0.53	2.79	<0.001	92.87	1.00	3485	
Pseu: Mazie	1.35	4.89	<0.001	1.2 e4	1.00	3050	
S: Mazie	0.66	3.04	<0.001	225.22	1.00	3459	
Sar: Mazie	1.47	5.00	<0.001	1.4 e4	1.00	3707	
SC_OTH: Mazie	1.19	4.93	<0.001	1.3 e4	1.00	3847	
SP: Mazie	1.40	5.00	<0.001	2.1 e4	1.00	3629	
TA: Mazie	2.53	0.58	0.85	8.04	1.00	3096	
U: Mazie	1.17	4.99	<0.001	2.1 e4	1.00	3462	
ACTO: Miall	3.33	0.82	0.75	18.44	1.00	3119	
CA: Miall	0.84	0.68	0.21	3.08	1.00	2876	
Colp: Miall	1.03	5.08	<0.001	3.1 e4	1.00	3705	
Cyano: Miall	1.23	4.98	<0.001	2 e4	1.00	3571	
Device: Miall	0.86	0.87	0.17	5.02	1.00	3309	
F_FUN_CMR: Miall	0.56	3.50	<0.001	495.31	1.00	3595	
G_GON_ALV: Miall	1.21	5.02	<0.001	1.1 e4	1.00	3640	
G_MON_CEMS: Miall	0.25	0.58	0.07	0.72	1.00	3059	
G_POC_OT: Miall	1.26	5.05	<0.001	1.3 e4	1.00	3541	
G_POR_CECS: Miall	0.58	3.24	<0.001	291.29	1.00	3610	

G_STY: Miall	1.37	4.96	<0.001	4.8 e4	1.00	3264	
Lobo: Miall	1.31	4.99	<0.001	3.5 e4	1.00	3403	
Meru: Miall	1.32	4.94	<0.001	1.9 e4	1.00	3417	
OT: Miall	1.26	4.99	<0.001	3.8 e4	1.00	3715	
Padina: Miall	1.15	4.96	<0.001	2 e4	1.00	3030	
Pey: Miall	0.82	2.81	<0.001	160.70	1.00	3613	
Pseu: Miall	1.33	5.02	<0.001	5.2 e4	1.00	3508	
S:Miall	1.20	4.98	<0.001	2.1 e4	1.00	3604	
Sar: Miall	1.17	4.98	<0.001	2.3 e4	1.00	3404	
SC_OTH: Miall	2.36	3.07	0.01	1.1 e3	1.00	3568	
SP: Miall	0.66	3.15	<0.001	328.53	1.00	3651	
TA: Miall	2.31	0.58	0.73	7.28	1.00	2808	
U: Miall	1.18	5.03	<0.001	2 e4	1.00	3776	
ACTO: Middle	2.27	2.53	0.02	286.12	1.00	3438	
CA: Middle	1.17	2.88	<0.001	275.45	1.00	3686	
Colp: Middle	1.37	4.92	<0.001	2 e4	1.00	3493	
Cyano: Middle	0.57	4.03	<0.001	1.1 e3	1.00	3841	
Device: Middle	1.13	2.52	0.01	181.74	1.00	3556	
F_FUN_CMR: Middle	1.32	5.01	<0.001	1.9 e4	1.00	3422	
G_GON_ALV: Middle	1.45	5.10	<0.001	3.8 e4	1.00	3520	
G_MON_CEMS: Middle	0.75	2.54	0.01	127.17	1.00	3393	
G_POC_OT: Middle	1.09	5.03	<0.001	1.4 e4	1.00	3651	
G_POR_CECS: Middle	1.31	4.98	<0.001	1.4 e4	1.00	3611	
G_STY: Middle	0.54	3.53	<0.001	460.86	1.00	3654	
Lobo: Middle	0.57	2.66	<0.001	102.49	1.00	3505	
Meru: Middle	0.51	3.86	<0.001	1.7 e3	1.00	3316	
OT: Middle	1.38	4.99	<0.001	1.8 e4	1.00	3653	
Padina: Middle	1.15	4.95	<0.001	1.3 e4	1.00	3656	
Pey: Middle	1.17	3.09	<0.001	511.69	1.00	3197	
Pseu: Middle	1.22	4.99	<0.001	1.5 e4	1.00	3226	
S: Middle	0.94	2.68	<0.001	122.03	1.00	3510	
Sar: Middle	0.57	3.16	<0.001	417.85	1.00	3658	
SC_OTH: Middle	1.55	3.08	<0.001	457.45	1.00	3274	
SP: Middle	1.30	3.12	<0.001	582.70	1.00	3440	
TA: Middle	1.47	2.53	0.01	287.83	1.00	3618	
U: Middle	1.40	4.95	<0.001	2.5 e4	1.00	3431	
ACTO: Monkey	0.49	2.51	<0.001	50.81	1.00	3508	
CA: Monkey	0.50	2.87	<0.001	137.20	1.00	3739	
Colp: Monkey	1.38	5.01	<0.001	2 e4	1.00	3595	
Cyano: Monkey	1.54	5.04	<0.001	3.1 e4	1.00	4090	
Device: Monkey	0.52	2.51	<0.001	63.54	1.00	3663	
F_FUN_CMR:site_nameMonkey	1.37	5.03	<0.001	2.4 e4	1.00	3597	
G_GON_ALV: Monkey	1.26	5.02	<0.001	2.6 e4	1.00	3529	

G_MON_CEMS: Monkey	0.33	2.53	<0.001	50.73	1.00	3527	
G_POC_OT:Monkey	1.19	4.97	<0.001	1.2 e4	1.00	3725	
G_POR_CECS: Monkey	0.44	3.84	<0.001	454.70	1.00	3373	
G_STY: Monkey	1.50	4.98	<0.001	3.8 e4	1.00	3651	
Lobo: Monkey	0.31	2.56	<0.001	38.19	1.00	3496	
Meru: Monkey	1.24	4.85	<0.001	2.6 e4	1.00	3293	
OT: Monkey	0.29	4.05	<0.001	674.28	1.00	3088	
Padina: Monkey	1.24	4.88	<0.001	1.9 e4	1.00	3620	
Pey: Monkey	0.62	3.05	<0.001	193.09	1.00	3226	
Pseu: Monkey	0.27	4.07	<0.001	537.63	1.00	3549	
S: Monkey	0.82	2.65	<0.001	134.09	1.00	3514	
Sar: Monkey	1.23	5.07	<0.001	1.9 e4	1.00	3908	
SC_OTH: Monkey	0.23	3.15	<0.001	122.84	1.00	3130	
SP: Monkey	0.45	3.13	<0.001	236.65	1.00	3476	
TA: Monkey	0.75	2.53	<0.001	96.97	1.00	3572	
U: Monkey	0.35	4.14	<0.001	1.1 e3	1.00	3089	
Model 1: Planned comparisons							
Hypothesis	**Est**	**Err**	**CI low**	**CI high**	**Evid ratio**	**Post prob**	**Signf**
(Middle-Home) > 0	0.93	2.49	0.01	61.55	0.88	0.47	
(Middle-Mazie) > 0	0.52	3.43	<0.01	123.51	0.72	0.42	
(Middle-Miall) > 0	0.86	3.55	<0.01	284.53	0.90	0.48	
(Middle-Monkey) > 0	0.51	2.58	0.01	40.04	0.44	0.31	
(Miall-Home) > 0	1.09	3.51	<0.01	316.26	1.05	0.51	
(Miall-Mazie) > 0	0.60	2.47	0.01	35.53	0.53	0.35	
(Miall-Monkey) > 0	0.59	3.53	<0.01	178.77	0.79	0.44	
(Home-Mazie) > 0	0.55	3.43	<0.01	140.30	0.72	0.42	
(Home-Monkey) > 0	0.54	2.48	0.01	36.94	0.47	0.32	
(Sar:Home - Sar:Miall) > 0	0.96	5.83	6.6 e-5	1.1 e4	0.98	0.50	
(Sar:Home - Sar:Middle) > 0	2.15	0.51	0.93	5.04	14.13	0.93	
(Sar:Home - Sar:Mazie) > 0	0.91	5.99	4.2 e-5	1.4 e4	1.01	0.50	
(Sar:Home -Sar:Monkey) > 0	0.98	5.94	5.6 e-5	1.4 e4	1.02	0.50	
(Padina:Home - Padina:Miall) > 0	0.58	6.50	7.7 e-6	1.9 e4	0.90	0.47	
(Padina:Home -Padina:Middle) > 0	0.61	6.56	1.36 e-6	3.6 e4	0.87	0.47	
(Padina:Home - Padina:Mazie) > 0	0.56	6.38	1.8 e-5	1.8 e4	0.85	0.46	
(Padina:Home - Padina:Monkey) > 0	0.53	6.55	1.4 e-5	3.2 e4	0.86	0.46	
(Pseu:Home - Pseu:Miall) > 0	1.00	6.91	9.5 e-6	6.4 e4	1.01	0.50	
(Pseu:Home - Pseu:Middle) > 0	1.03	7.07	8 e-6	1.2 e5	1.03	0.51	
(Pseu:Home-Pseu:Mazie) > 0	0.99	6.91	1.4 e-5	9.2 e4	0.98	0.49	
(Pseu:Home - Pseu:Monkey) > 0	4.78	6.38	<0.001	1.6 e5	1.46	0.59	
(Colp:Home - Colp:Miall) > 0	0.60	6.42	1.3 e-5	2.8 e4	0.89	0.47	
(Colp:Home - Colp:Middle) > 0	0.52	6.29	2.1 e-5	1.7 e4	0.82	0.45	
(Colp:Home - Colp:Mazie) > 0	0.44	6.30	1.4 e-5	1.3 e4	0.80	0.44	
(Colp:Home - Colp:Monkey) > 0	0.52	6.44	1.6 e-5	2.4 e4	0.84	0.46	

(ACTO:Home-ACTO:Miall) > 0	0.19	2.63	<0.01	15.37	0.36	0.27	
(ACTO:Home - ACTO:Middle) > 0	0.28	0.82	0.07	0.95	0.04	0.04	
(ACTO:Home - ACTO:Mazie) > 0	0.46	5.60	5.3 e-5	490.12	0.81	0.45	
(ACTO:Home - ACTO:Monkey) > 0	1.29	0.80	0.31	4.33	1.89	0.65	
(CA:Miall - CA:Home) > 0	0.61	5.07	<0.001	2.7 e3	0.86	0.46	
(CA:Miall - CA:Middle) > 0	0.73	2.93	<0.01	106.15	0.84	0.46	
(CA:Miall - CA:Mazie) > 0	2.25	0.68	0.74	6.95	8.09	0.89	
(CA:Miall- CA:Monkey) > 0	1.66	2.92	0.02	229.13	1.33	0.57	
(TA:Miall -TA:Home) > 0	2.82	2.61	0.04	202.80	1.87	0.65	
(TA:Miall -TA:Middle) > 0	1.57	2.57	0.02	106.74	1.33	0.57	
(TA:Miall -TA:Mazie) > 0	0.91	0.49	0.41	2.08	0.72	0.42	
(TA:Miall - TA:Monkey) > 0	3.02	2.57	0.05	221.92	1.98	0.66	
(SC_OTH:Miall - SC_OTH:Home) > 0	2.21	5.98	<0.001	4.4 e4	1.21	0.55	
(SC_OTH:Miall - SC_OTH:Middle) > 0	1.62	3.55	<0.01	603.30	1.24	0.55	
(SC_OTH:Mial - SC_OTH:Mazie) > 0	2.31	5.82	<0.001	4 e4	1.26	0.56	
(SC_OTH:Miall - SC_OTH:Monkey) > 0	10.60	3.65	0.03	4210.94	2.85	0.74	
(CA:Middle - CA:Home) > 0	0.83	5.81	<0.001	1.1 e4	0.95	0.49	
(CA:Middle - CA:Mazie) > 0	3.06	2.92	0.02	322.33	1.90	0.66	
(CA:Middle - CA:Monkey) > 0	2.25	0.54	0.94	5.72	15.00	0.94	
(TA:Middle - TA:Home) > 0	1.79	0.74	0.59	6.56	3.71	0.79	
(TA:Middle - TA:Mazie) > 0	0.58	2.57	<0.01	37.77	0.72	0.42	
(TA:Middle -TA:Monkey) > 0	1.92	0.46	0.92	4.15	11.81	0.92	
(Lobo:Miall - Lobo:Home) > 0	1.73	5.63	<0.001	2.2 e4	1.16	0.54	
(Lobo:Miall - Lobo:Middle) > 0	2.25	5.67	<0.001	2.4 e4	1.24	0.55	
(Lobo:Miall - Lobo:Mazie) > 0	1.77	5.01	<0.001	6.8 e3	1.19	0.54	
(Lobo:Mial - Lobo:Monkey) > 0	4.15	5.64	<0.001	5 e4	1.52	0.60	
(Lobo:Middle - Lobo:Home) > 0	0.77	1.07	0.12	3.51	0.76	0.43	
(Lobo:Middle - Lobo:Mazie) > 0	0.79	2.68	<0.01	60.64	0.87	0.47	
(Lobo:Middle - Lobo:Monkey) > 0	1.84	1.04	0.29	8.09	3.26	0.77	
(G_POC_OT:Miall - G_POC_OT:Home) > 0	2.62	6.14	<0.001	7.2 e4	1.30	0.56	
(G_POC_OT:Miall - G_POC_OT:Middle) > 0	0.97	7.18	5.8 e-6	9.4 e4	1.02	0.50	
(G_POC_OT:Miall - G_POC_OT:Mazie) > 0	1.09	6.99	1 e-5	1 e5	1.02	0.51	
(G_POC_OT:Miall - G_POC_OT:Monkey) > 0	0.97	7.12	9 e-6	8.5 e4	1.01	0.50	
(G_POC_OT:Middle - G_POC_OT:Home) > 0	2.70	6.07	<0.001	6.3 e4	1.29	0.56	
(G_POC_OT:Middle - G_POC_OT:Mazie) > 0	1.13	7.09	9 e-6	1.3 e5	1.01	0.50	
(G_POC_OT:Middle -G_POC_OT:Monkey) > 0	1.01	7.09	1 e-5	1.2 e5	1.00	0.50	
(S:Home - S:Miall) > 0	1.22	5.64	<0.001	1.4 e4	1.06	0.52	
(S:Home - S:Middle) > 0	1.57	0.73	0.48	5.41	2.69	0.73	
(S:Home - S:Mazie) > 0	2.32	3.43	<0.001	634.42	1.50	0.60	
(S:Home - S:Monkey) > 0	1.89	0.62	0.71	5.29	5.82	0.85	

Table C13. Sediment deposition by site model parameters and output. The 'est' is the estimate, 'err' is error, 'CI low' and 'CI high' are 95% credible intervals, 'ess' is the sample size, and 'signf' is the significance.

Model: Sediment deposition by site and reserve zone

Family: gamma
Links: mu = log; shape = identity
Formula: Total_TotalWeight ~ Reserve * SedPodType + Site * SedPodType + (1 | Reserve/Site/SedPodID)
Data: Ch3_Sediment (Number of observations: 71)
Draws: 3 chains, each with iter = 5000; warmup = 1000; thin = 5; total post-warmup draws = 2400
Multilevel Hyperparameters:
~Reserve (Number of levels: 2)

	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
sd(Intercept)	0.98	0.85	0.05	3.03	1.00	2285	2198

~Reserve:Site (Number of levels: 6)

	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
sd(Intercept)	0.50	0.41	0.02	1.53	1.00	2374	2080

~Reserve:Site:SedPodID (Number of levels: 35)

	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
sd(Intercept)	0.53	0.08	0.40	0.71	1.00	2137	2143

Term	Est	Err	CI low	CI high	Rhat	Ess	Signf
Intercept	0.08	0.97	0.02	0.72	1.00	2360	*
ReserveGreen	1.46	0.85	0.24	6.73	1.00	2276	
SedPodTypeTurf	1.65	0.33	0.93	3.21	1.00	2355	
SiteHome	0.82	0.70	0.21	2.85	1.00	2537	
SiteMazie	1.60	0.61	0.40	4.35	1.00	2451	
SiteMiall	1.68	0.64	0.41	5.01	1.00	2308	
SiteMiddle	1.06	0.69	0.29	4.04	1.00	2431	
SiteMonkey	1.62	0.70	0.38	5.78	1.00	2336	
ReserveGreen:SedPodTypeTurf	1.24	0.58	0.38	3.81	1.00	2342	
SedPodTypeTurf:SiteHome	1.81	0.61	0.55	5.68	1.00	2502	
SedPodTypeTurf:SiteMazie	1.36	0.47	0.55	3.37	1.00	2190	
SedPodTypeTurf:SiteMiall	2.71	0.49	1.03	6.78	1.00	2548	*
SedPodTypeTurf:SiteMiddle	0.71	0.62	0.21	2.31	1.00	2490	
SedPodTypeTurf:SiteMonkey	0.96	0.62	0.27	3.10	1.00	2358	

Model: Planned comparisons

Hypothesis	Est	Err	CI low	CI high	Evid ratio	Post prob	Signf
(SiteMiall - SiteMiddle) > 0	1.51	0.92	0.32	6.98	2.20	0.69	
(SiteMiall - SiteMazie) > 0	1.06	0.73	0.31	3.28	1.27	0.56	
(SiteMiall - SiteMonkey) > 0	0.99	0.91	0.21	4.26	1.02	0.50	

(SiteMiall - SiteHome) > 0	1.98	0.96	0.37	8.78	3.41	0.77	
(SedPodTypeTurf:SiteMiall - SedPodTypeTurf:SiteMiddle) > 0	3.84	0.76	1.07	12.71	23.00	0.96	*
(SedPodTypeTurf:SiteMiall - SedPodTypeTurf:SiteMonkey) > 0	2.75	0.75	0.80	9.48	9.96	0.91	
(SedPodTypeTurf:SiteMiall - SedPodTypeTurf:SiteMazie) > 0	1.98	0.58	0.77	5.20	7.76	0.89	
(SedPodTypeTurf:SiteMiall - SedPodTypeTurf:SiteHome) > 0	1.49	0.75	0.45	5.06	2.35	0.70	
(SedPodTypeTurf:SiteMiall - Intercept) > 0	27.86	1.07	4.18	133.46	341.86	1.00	*

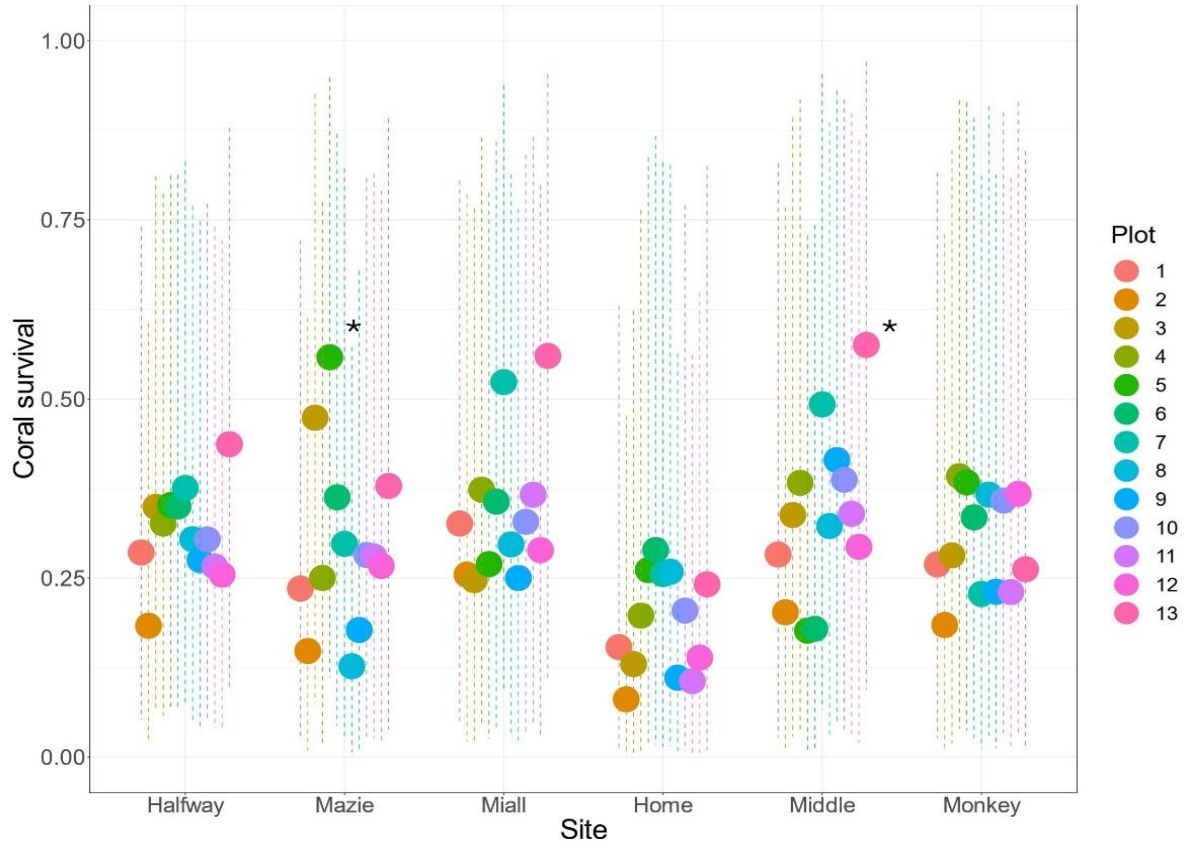


Figure C1. Tab-level coral survival by experimental plot and site. The values represent averages with 95% credible intervals. * on plots indicate a significant result.

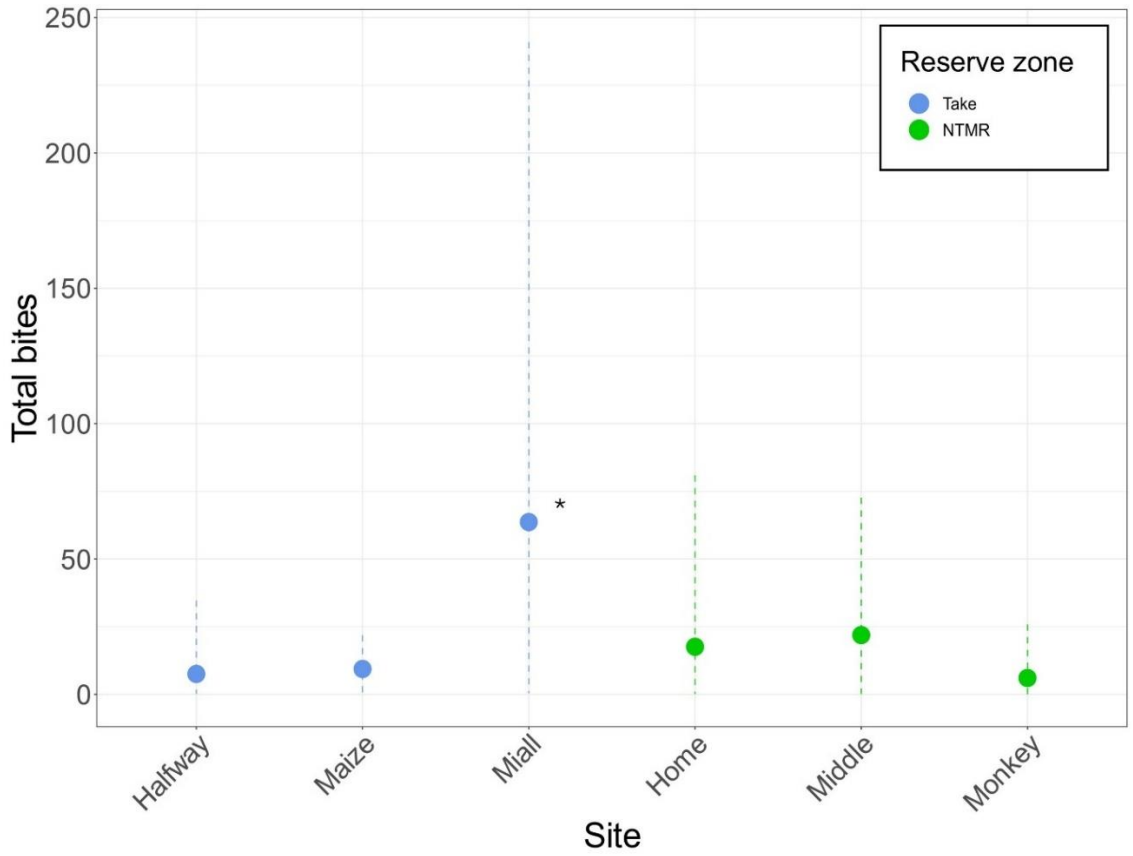


Figure C2. Total bites taken by fish on coral-seeding devices by the experimental site. The values represent average bites with 95% credible intervals. * on plot indicate a significant result.

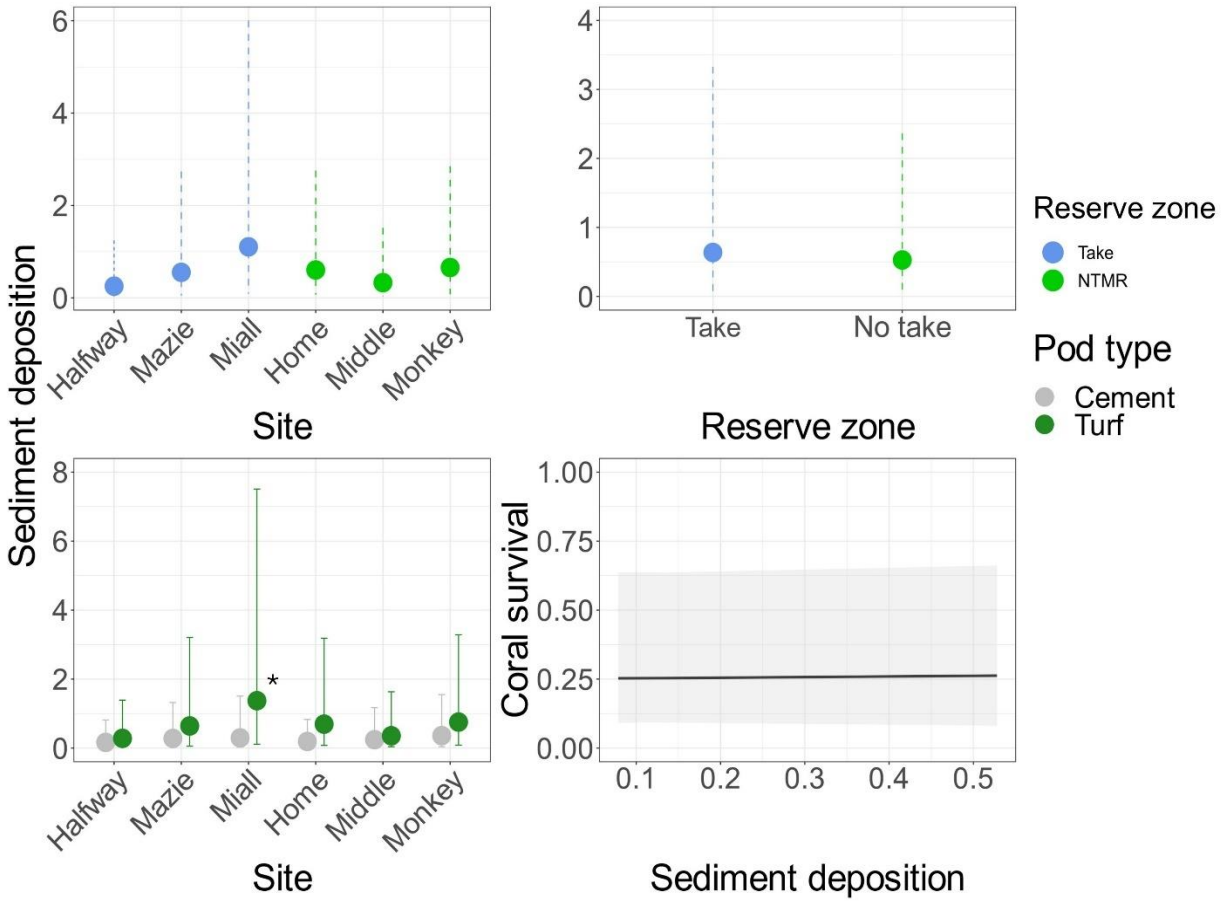


Figure C3. Total sediment deposition (g d^{-1}) by site [a], reserve zone [b], site and device type [c], then displayed as a predictor of tab-level coral survival [d]. The values represent averages with 95% credible intervals. * on plots indicate a significant result.

Appendix D: Other peer-reviewed manuscripts published during candidature

Randall CJ, Giuliano C, Stephenson B, Whitman TN, Page CA, Treml EA, Logan M, Negri AP. Larval precompetency and settlement behaviour in 25 Indo-Pacific coral species. Communications Biology. 2024 Jan 31;7(1):142. https://doi.org/10.1038/s42003-024-05824-3

Smith HA, Brown DA, Arjunwadkar CV, Fulton SE, Whitman T, Hermanto B, Mastroianni E, Mattocks N, Smith AK, Harrison PL, Boström-Einarsson L. Removal of macroalgae from degraded reefs enhances coral recruitment. Restoration Ecology. 2022 Sep;30(7):e13624. https://doi.org/10.1111/rec.13624

Smith HA, Prenzlau T, Whitman T, Fulton SE, Borghi S, Logan M, Heron SF, Bourne DG. Macroalgal canopies provide corals limited protection from bleaching and impede post-bleaching recovery. Journal of Experimental Marine Biology and Ecology. 2022 Aug 1;553:151762. https://doi.org/10.1016/j.jembe.2022.151762