A PRELIMINARY SURVEY OF THE CORAL REEFS AT PULAU BAWAH

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BACKGROUND

By virtue of their proximity to the Coral Triangle, the Anambas islands are endowed with exceptional marine biodiversity (Ng et al 2002). However, this small archipelago still has pockets of biodiversity that remain undocumented. Pulau Bawah (2°30'55.57"N, 106° 2'47.10"E), situated at the southern reaches of the Anambas, is one such area. To date, 240 species of reef fish have been recorded from its southeastern reefs (Asian Development Bank 2013), but there is a paucity of information on other reef organisms such as the hard corals.

Spanning an area of approximately 300 hectares, Pulau Bawah (hereon referred as 'Bawah') consists of a cluster of five islands encircling three shallow lagoons. Opened in July 2017, Bawah accommodates a maximum of 70 guests daily and is marketed as an eco-friendly private resort committed to biodiversity conservation.

A research team from the Reef Ecology Lab (National University of Singapore) surveyed the western and southeastern fringing reefs from 24 to 26 February 2018 as part of a preliminary assessment of Bawah's reef biodiversity, and identified sites that could be targeted for reef restoration. As quantitative biodiversity surveys of this cluster of islands have not been carried out to date, the findings will provide baseline data for future studies of the area.

BIODIVERSITY OF BAWAH'S REEFS

Methods

Reef surveys were carried out at Lidi (2°30'30.60"N, 106° 2'21.27"E), Satigi (2°31'8.13"N, 106° 2'29.35"E) and Turtle Reef (2°30'3.89"N, 106° 3'10.98"E) from 24 to 26 February 2018 (Fig. 1a). At each site, a 120-m long transect was deployed parallel to shore (Fig. 1b), at approximately 5-8 m depth where coral cover was perceived to be the highest.

The benthic communities at each site were documented via five 20-m point intercept transects (PITs). Following established methods (English et al 1997), the lifeform at each 10-cm interval was recorded (Fig. 1c). This was converted to obtain the percentage cover of benthic categories per site. Hard corals were identified to genus following Veron (2000). Surveys of reef fishes were carried out at each site by traversing the length of the tape and recording all fishes within three 20 m x 4 m belt transects with a handheld GoPro camera. The fishes were then identified following Allen et al (2007).

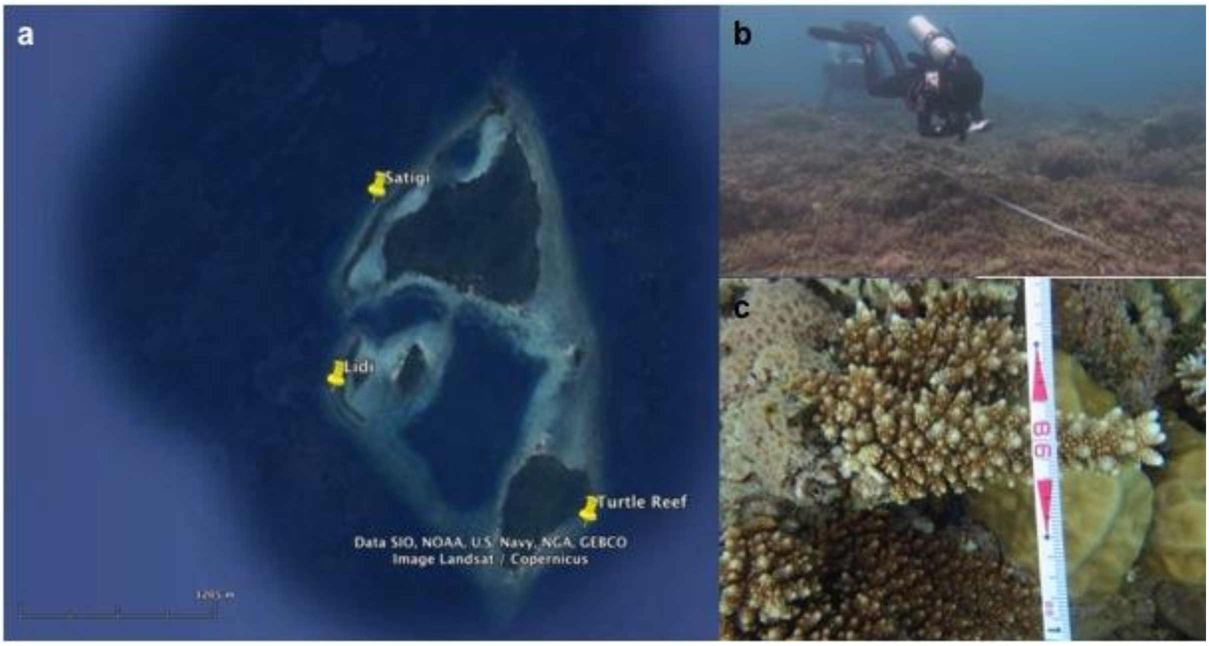

Fig. 1 a) Map of Bawah with study sites indicated; b) researchers carrying out surveys; c) transect tape laid over a branching *Acropora* colony

The Shannon diversity index for benthic and fish communities at each site were calculated and compared using SPSS v21. As the data for benthic communities did not meet the assumptions for normality and homogeneity of variance, the non-parametric Kruskal Wallis test was used. For fish communities, a one-way ANOVA followed by post-hoc Tukey's test was used. Non-multidimensional scaling analyses were carried out with PRIMER to compare the biological communities across the three sites; SIMPER analyses were conducted to identify groups that contributed to dissimilarity across sites.

Benthos

Each site was composed of different proportions of benthic lifeforms (Fig. 2a; Fig 3). Lidi was dominated by rubble (32.3% cover), soft corals (15.9%) and dead corals (14.5%). Impacts from fishing were also evident, as self-made fishing weights were strewn around the site, with some landing on live coral colonies (Fig. 4). In spite of the impacts, coral recruitment was high and many juvenile corals had settled on the loose rubble. Although these juveniles can perish easily when the rubble is overturned by strong currents, they – also known as 'corals of opportunity' (Ng & Chou (2014) – can be collected and used as material for reef restoration.

Despite being dominated by soft corals (60.9% cover), reef substrate was generally unstable at Satigi as most of it comprised loose rubble that could be easily toppled. Soft corals (mainly family Xeniidae) formed a thin layer on top of the rubble, helping to bind some of the rubble pieces. Anecdotal accounts by some of the Bawah staff indicate that the area had a history of blast fishing, which could explain our observations. Coral bleaching was patchy, suggesting that stressors were localized

(Fig. 4). Hard corals at the site comprised mainly free-living ones, such as the mushroom corals (family Fungiidae) and coralliths (e.g. *Cyphastrea*).

While Turtle Reef also had significant proportions of rubble (22.4% cover), it also supported many massive (i.e. boulder-shaped) corals (15.9%) and branching *Acropora* colonies (13.7%). Human impacts were minimal at this area. Turtle Reef was the most diverse in terms of benthic lifeforms, and there was a statistically significant difference in Shannon diversity index between the benthic communities of each site ($\chi^2 = 9.98$, $p = 0.007$). Turtle registered the highest Shannon index (2.28), followed by Lidi (2.18), and Satigi (1.56).

The benthic communities among the sites also differed (ANOSIM Global R = 0.632, p = 0.001) (Fig. 2b). Between Lidi and Satigi, soft corals and massive corals were the main groups that contributed close to 30% of the dissimilarity between both sites. Lidi and Turtle were mainly differentiated by soft corals, branching *Acropora* and submassive corals, which collectively accounted for nearly 30% of the dissimilarity. For Satigi and Turtle, soft corals and massive corals contributed more than 30% of the dissimilarity.

A total of 22 hard coral genera were recorded from the surveys (Appendix Table 1). Taxonomic richness was highest at Turtle (17 genera), followed by Lidi (13) and lowest at Satigi (4). Live hard coral cover at the three sites followed a similar trend. The highest cover was recorded from Turtle (54.5%), followed by Lidi (22.5%), and Satigi (3.9%).

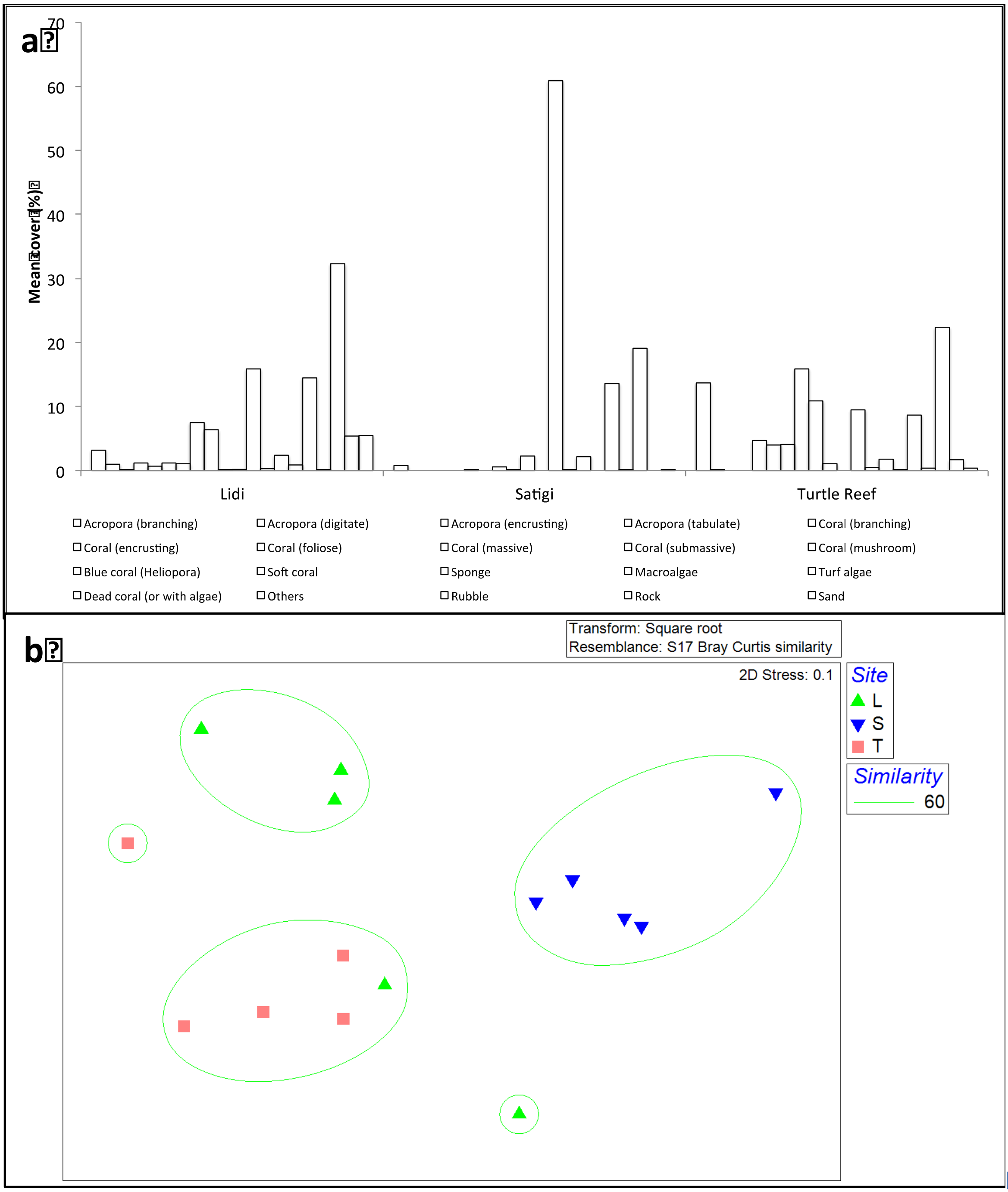

Fig. 2 a) Mean percentage cover of benthic lifeforms at Lidi, Satigi and Turtle; and b) non-multidimensional scaling plot comparing benthic communities at the three sites

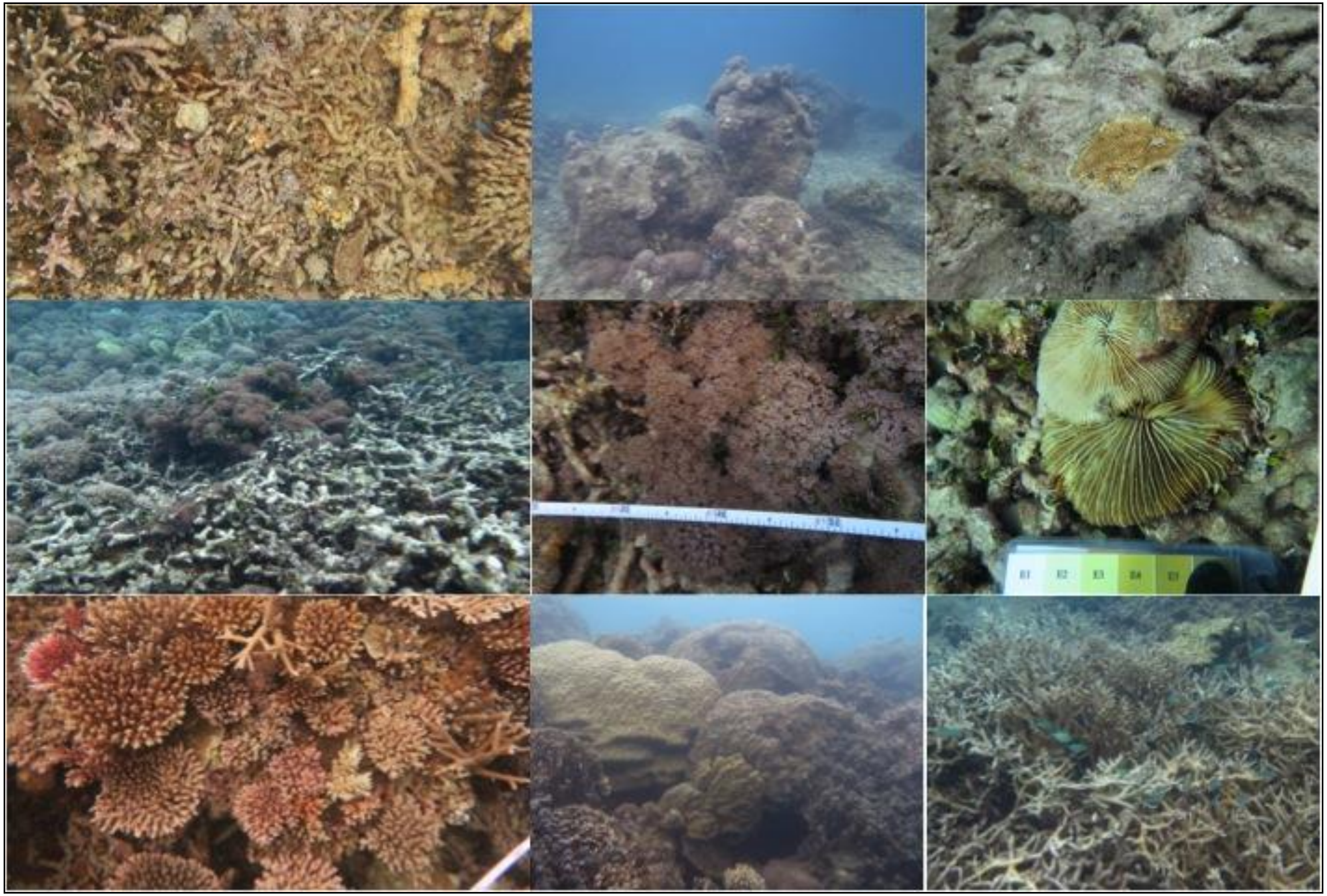

Fig. 3 Reefscapes of Lidi (top row), Satigi (middle row) and Turtle Reef (bottom row)

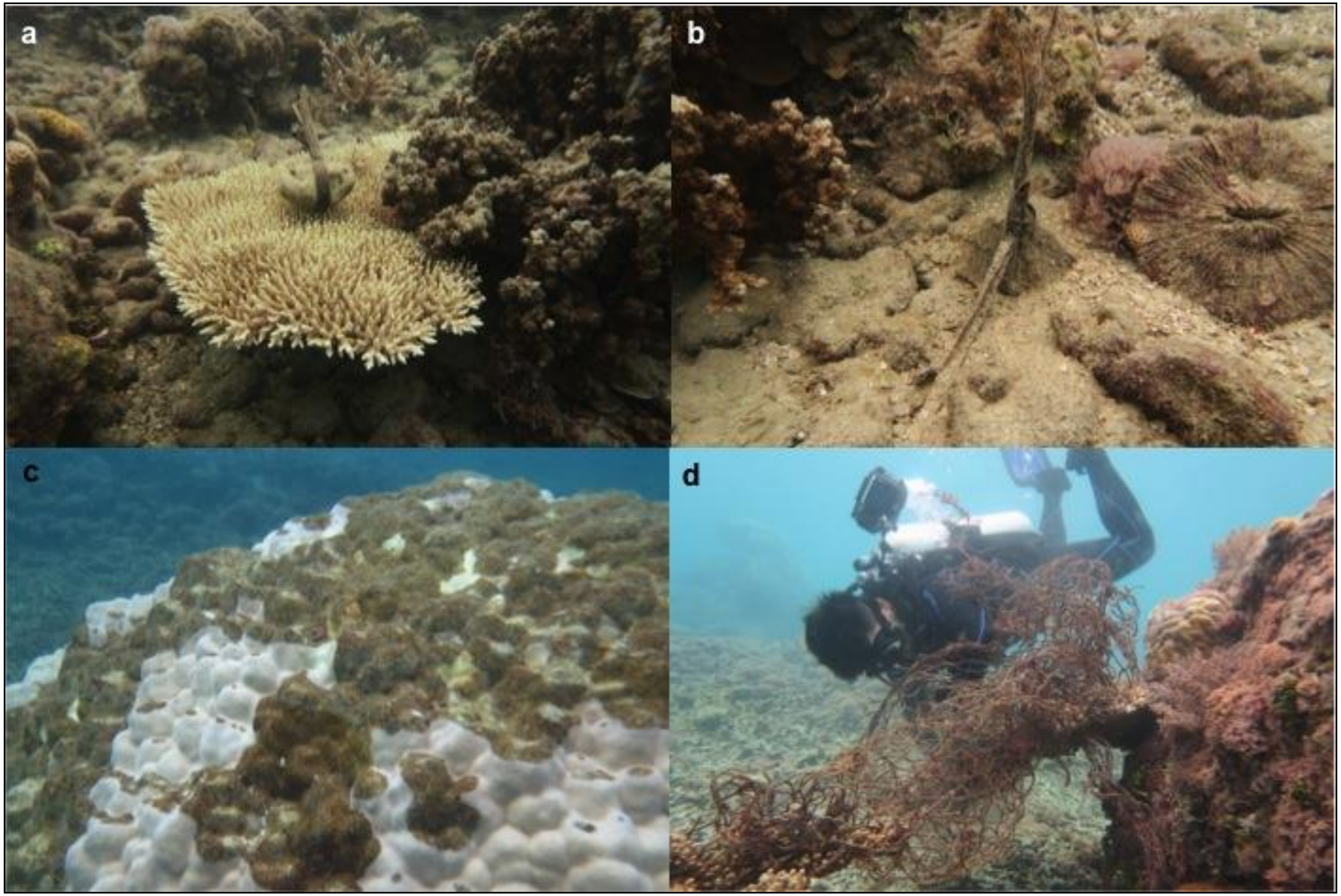

Fig. 4 Impacts observed at Bawah: abandoned home-made fishing weights on a) live coral and b) the seabed; c) bleached massive coral with dead areas colonized by algae; d) discarded fishing net entangled on a coral colony

Reef fishes

A total of 611 fishes from 30 genera were recorded from the three sites (Appendix Table 2). Most fishes were recorded at Turtle (457 individuals), followed by Lidi (84) and Satigi (70). Taxonomic richness was also highest at Turtle (23 genera), followed by Lidi (15) and Satigi (14). Damselfishes of the genus *Pomacentrus* were the most common at all sites (Turtle, 28.8%; Lidi, 42.2%; Satigi, 34.4%). Turtle was also dominated by other damselfishes (*Neoglyphidodon,* 11.3%) and juvenile fairy wrasses (*Cirrhilabrus*, 18.7%). At Satigi, damselfishes of the genera *Neoglyphidodon* (27.6%) and *Plectroglyphidodon* (20.5%) were abundant. Lidi was characterized by large numbers of *Dascyllus* (damsels; 31.3%) and *Lutjanus* (snappers; 16.11%). While mean fish abundance differed significantly ($F_{2,8} = 16060$, $p < 0.01$; Turtle > Lidi = Satigi), the Shannon diversity index was not significantly different among sites (Satigi = 2.26; Turtle = 2.24; Lidi = 1.94) ($F_{2,8} = 0.229$, $p = 0.359$).

The reef fish communities among the three dive sites were significantly different (ANOSIM Global R = 0.918, p = 0.004) (Fig. 5). Turtle supported more fairy wrasses (*Cirrhilabrus* sp) and damselfishes (*Pomacentrus* spp, *Neoglyphidodon* spp) that Lidi, and these three genera accounted for 33% of the dissimilarity between both sites. Turtle was also differentiated from Satigi as the former supported more fairy wrasses (*Cirrhilabrus* sp), damselfishes (*Pomacentrus* spp) and wrasses (*Halichoeres* spp) (38% dissimilarity). Between Lidi and Satigi, the former supported more *Dascyllus* sp while the latter had more *Plectroglyphidodon* spp and *Neoglyphidodon* spp (36% dissimilarity)

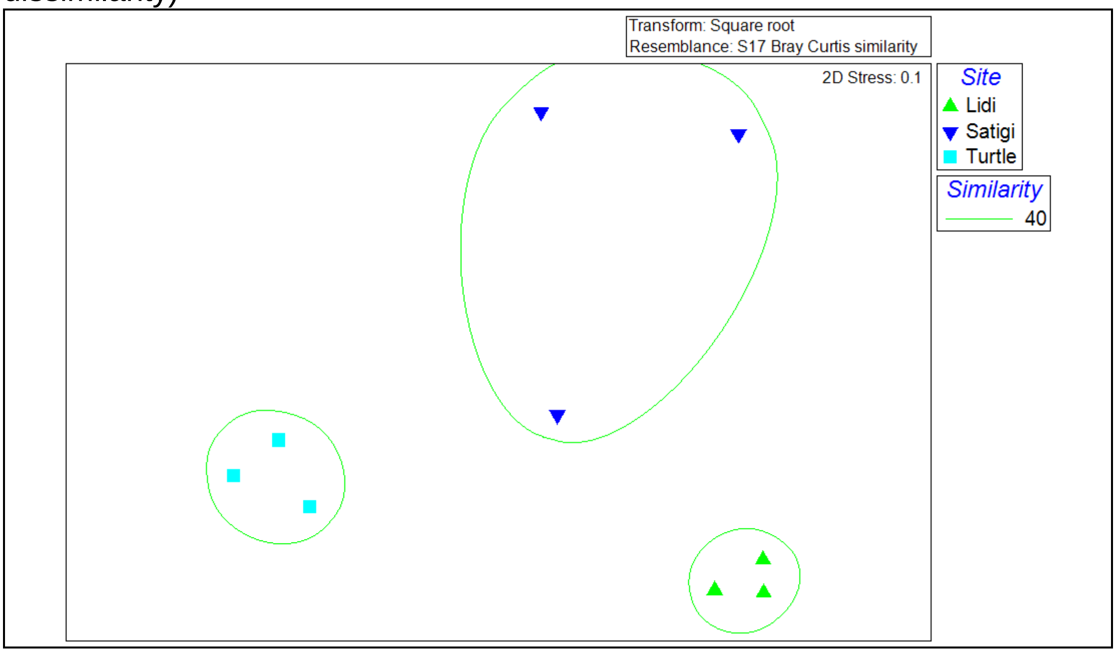

Fig. 5 Non-multidimensional scaling plot comparing fish communities at Lidi, Satigi and Turtle

Across all sites, most fishes were small (<10cm) (Fig. 6). At Turtle, fishes smaller than 5 cm were the majority (58.0%) of those recorded from the transects. More than half of the fishes in Satigi were between 6 – 10 cm. Larger fishes were more abundant at Lidi (26.2%).

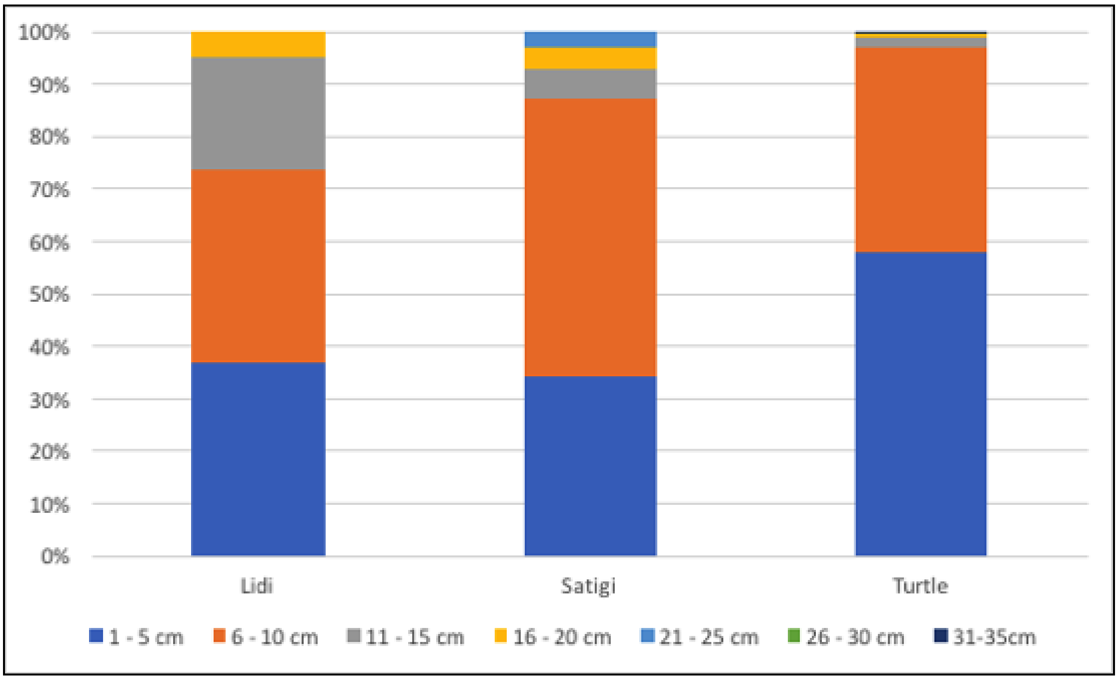

Fig. 6 Size distribution of reef fishes across the three study sites

The number of carnivorous fish species were similar across sites (Lidi = 27.4%; Satigi = 21.4%; Turtle = 26.9%) (Fig. 7). There were more omnivores at Satigi (74.3%) and Turtle (71.3%) than at Lidi (64.3%). Lidi had a higher abundance of herbivores (9.5%) compared to Satigi (4.3%) and Turtle (1.3%). Corallivores were only recorded from Turtle (0.4%).

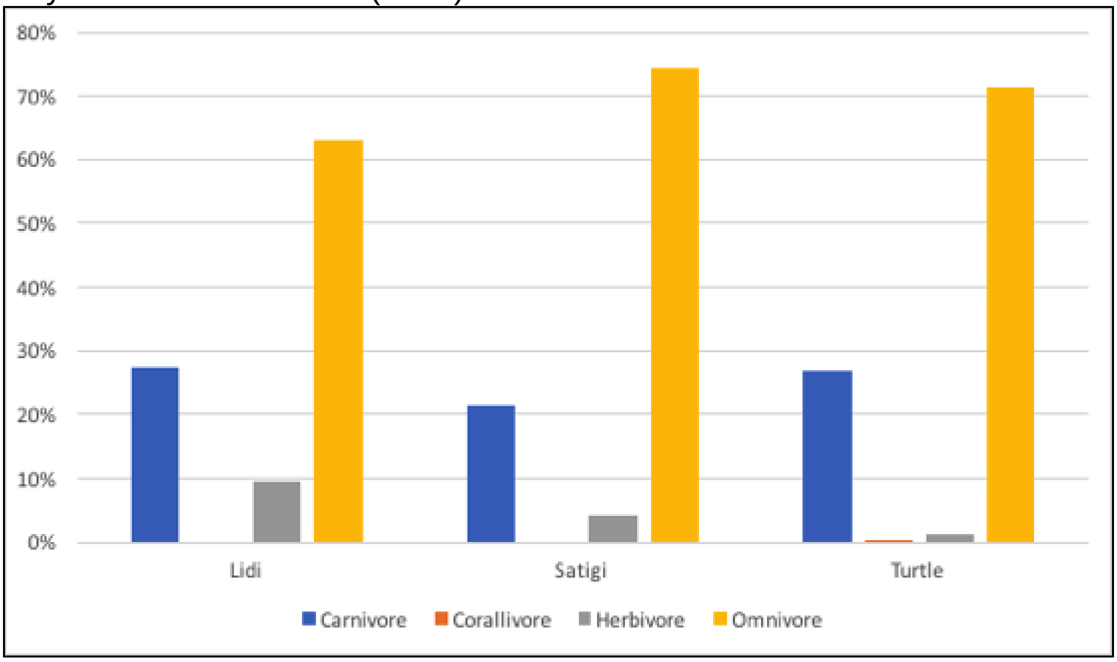

Fig. 7 Diet types of reef fishes at the three study sites

REEF REHABILITATION

A reef rehabilitation and restoration programme aims to bring a degraded ecosystem back to its original condition, or replace the structural and functional features that have been lost (Edwards & Gomez 2010). Efforts should be monitored over time as damaged reefs take many years to recover and establish (e.g. some species grow at rates of only 1 cm/yr). This will also facilitate the rectification of issues such as the dislodgement of coral transplants. To achieve this, a reef rehabilitation programme should be based on sound scientific principles and techniques, and designed to involve the relevant stakeholders over the long term.

Site-specific strategies

In the case of Bawah, the varying levels of biodiversity and disturbance at Lidi, Satigi and Turtle Reef indicate that different management approaches may be required for each area (Table 1). The surveys showed that Turtle was least disturbed and supported the highest biodiversity, while Satigi was heavily degraded and had low levels of biodiversity. Rehabilitation efforts can focus more on Satigi, which has existing dead coral boulders onto which coral fragments can be transplanted with the use of marine epoxy. The fragments can be sourced from Lidi, which is a short distance away. It also has a high abundance of 'corals of opportunity' (recruits settled on loose rubble). Both, coral fragments and 'corals of opportunity' can be relocated from Lidi to a coral nursery for a period of rearing, then transplanted onto the large boulders at Satigi once they have grown to a suitable size. In the case of 'corals of opportunity', they can also be secured directly to boulders without being raised in the nursery.

Coral nursery site

The establishment of a coral nursery allows corals to grow to suitable sizes and enhances their survival chances after they are transplanted to target areas (Epstein et al 2003; Afiq-Rosli et al 2017). As the corals grow in the nursery, other reef fauna such as butterflyfishes will also benefit from the food and habitat provided by the structures (Taira et al 2016).

The nursery should be built in an environment that is sheltered from strong waves and boat activity, and yet be accessible and safe for the resort staff and guests. This will facilitate easy monitoring of coral health as well as guest engagement programmes. It should be sited deep enough to receive sufficient light for coral photosynthesis and also allow good water exchange so that salinity is maintained regardless of freshwater inputs from land-based sources or thunderstorms. The nursery frames can be built from simple but sturdy materials such as PVC pipes or stainless steel bars (Fig. 8).

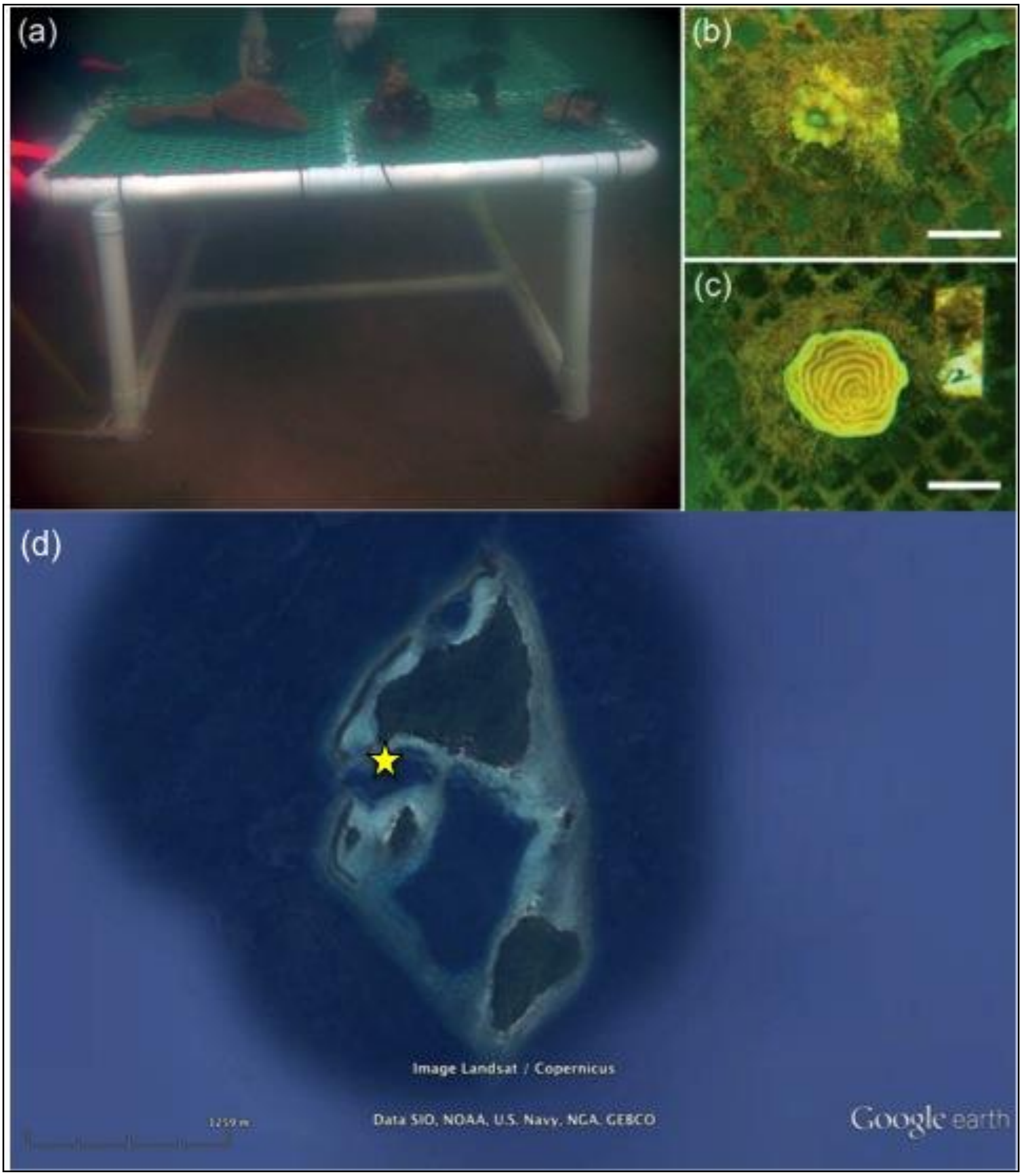

Fig. 8 a) Example of coral nursery in Singapore with (b & c) corals of opportunity; d) proposed coral nursery site at Bawah indicated with a star

Based on these criteria, the shallow lagoon just at the front of the western Overwater Suites could be designated as a coral nursery site (Fig. 8). The area has a gentle slope with sandy substrate at about 3-4 m depth that is suitable for anchoring coral nursery frames (each approximately 1m x 1m x 0.5m). The calm conditions will allow the resort staff or guests to access the site safely by snorkeling or SCUBA diving to monitor the coral rearing process. The construction of the nursery and techniques for coral monitoring can be customized to suit the goals of the Resort.

Monitoring

Monitoring for all sites should be conducted to track reef health and evaluate the success of the rehabilitation efforts. If possible, greater protection should be accorded to Bawah's reefs by increasing surveillance (e.g. aerial drones) and by educating the relevant stakeholders.

Table 1 Summary of recommendations for Bawah's reef rehabilitation programme

<table>
<tr><th>Site</th><th>Characteristics</th><th>Recommendations</th></tr>
<tr><td>Turtle</td><td>- Highest diversity and abundance of hard corals and reef fishes
- Minimal human impacts</td><td rowspan="2">- Leave the site(s) as is
- Regular monitoring programme focusing on reef health
- Ensure protection from damage by human activities</td></tr>
<tr><td>Lidi</td><td>- Moderate reef biodiversity
- Some impacts evident e.g. from fishing activities
- Good source of coral material in the form of 'corals of opportunity'</td></tr>
<tr><td>Satigi</td><td>- Lowest reef biodiversity (rubble fields and dead coral boulders)
- Extensive degradation by human activities</td><td>- Pilot site for direct transplantation on dead coral boulders
- Regular monitoring programme focusing on reef health and transplantation outcome
- Ensure protection from damage by human activities</td></tr>
<tr><td>Lagoon</td><td>- Sheltered, good water exchange
- Seabed suitable for anchoring of nursery</td><td>- As coral nursery site
- Accessible to stakeholders for community engagement activities</td></tr>
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ACKNOWLEDGEMENTS

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APPENDIX

Table 1. Checklist of hard corals recorded from surveys at Bawah

Family	**Genus**	**Lidi**	**Satigi**	**Turtle**
Acroporidae	*Acropora*	✔		✔
	Anacropora			✔
	Astreopora	✔		✔
	Montipora	✔		✔
Agariciidae	*Pachyseris*	✔		✔
Faviidae	*Diploastrea*		✔	
	Echinopora			✔
	Favia	✔		✔
	Favites	✔		
	Goniastrea	✔		✔
	Leptastrea	✔		
	Platygyra			✔
Fungiidae	*Ctenactis*			
	Fungia	✔	✔	✔
	Herpolitha			✔
Merulinidae	*Hydnophora*			✔
Mussidae	*Symphyllia*	✔		✔
Oculinidae	*Galaxea*	✔	✔	✔
Pocilloporidae	*Pocillopora*			✔
Poritidae	*Porites*	✔	✔	✔
Siderastreidae	*Coscinaraea*	✔		
	Psammocora			✔

Table 2. Checklist of reef fishes recorded from surveys at Bawah

Family	Genus	Species	Common name	Lidi	Satigi	Turtle
Acanthuridae	*Naso*	*Naso lituratus*	Orangespine unicornfish			✔
Chaetodontidae	*Chatetodon*	*Chaetodon triangulum*	Triangular butterflyfish			✔
	Heniochus	*Heniochus varius*	Humphead bannerfish	✔	✔	
Gobiidae	*Koumansetta*	*Koumansetta hectori*	Yellowstripe goby			✔
Labridae	*Cheilinus*	*Cheilinus fasciatus*	Redbreasted wrasse	✔		
	Cirrhilabrus	*Cirrhilabrus ryukyuensis*	Yellowflanked fairy wrasse		✔	✔
	Epibulus	*Epibulus brevis*	Latent slingjaw wrasse			✔
	Gomphosus	*Gomphosus caeruleus*	Green birdmouth wrasse		✔	
	Halichoeres	*Halichoeres hortulanus*	Checkerboard wrasse	✔		
		Halichoeres leucurus	Chain-lined wrasse		✔	
		Halichoeres kneri	Kner's wrasse			✔
	Labroides	*Labroides dimidiatus*	Bluestreak cleaner wrasse	✔		✔
	Thalassoma	*Thalassoma hardwicke*	Sixbar wrasse	✔		
		Thalassoma lunare	Crescent wrasse		✔	✔
	Unidentified genus	Unidentified species	-		✔	
Lutjanidae	*Lutjanus*	*Lutjanus decussatus*	Checkered snapper	✔		
		Lutjanus rufolineatus	Yellow-lined snapper	✔		
		Lutjanus decussatus	Checkered snapper		✔	✔
Nemipteridae	*Scolopsis*	*Scolopsis bilineata*	Bridled monocle bream	✔		
Pomacanthidae	*Pygoplites*	*Pygoplites diacanthus*	Regal angelfish			✔
Pomacentridae	*Abudefduf*	*Abudefduf sexfasciatus*	Scissortail sergeant			✔
	Amblyglyphidodon	*Amblyglyphidodon curacao*	Staghorn damsel	✔	✔	✔
		Amblyglyphidodon leucogaster	Whitebelly damsel			✔
		Amblyglyphidodon aureus	Golden damsel			✔
	Chromis	*Chromis viridis*	Blue green chromis			✔
	Chrysiptera	*Chrysiptera rollandi*	Rolland's damsel			✔
	Dascyllus	*Dascyllus reticulatus*	Reticulated dascyllus	✔		✔

	Dischistodus	*Dischistodus melanotus*	Blackvent damsel	✔		
	Neoglyphidodon	*Neoglyphidodon nigroris*	Yellowtail damsel		✔	✔
		Neoglyphidodon thoracotaneniatus	Western barhead damsel			✔
	Neopomacentrus	*Neopomacentrus cyanomos*	Regal demoiselle	✔		
		Neopomacentrus violascens	Violet demoiselle			✔
	Plectroglyphidodon	*Plectroglyphidodon lacrymatus*	Jewel damsel		✔	✔
	Pomacentrus	*Pomacentrus moluccensis*	Lemon damsel	✔		✔
		Pomacentrus chrysurus	Whitetail damsel	✔	✔	✔
		Pomacentrus taeniometopon	Brackish damsel	✔	✔	
		Pomacentrus moluccensis	Lemon damsel		✔	
		Pomacentrus lepidogenys	Scaly damsel		✔	✔
		Pomacentrus armillatus	Borneo damsel		✔	✔
Ptereleotridae	*Ptereleotris*	*Ptereleotris evides*	Twotone dartfish		✔	
Scaridae	*Chlorurus*	*Chlorurus oedema*	Black parrotfish	✔		
		Chlorurus sordidus	Bullethead parrotfish		✔	✔
		Chlorurus bowersi	Bower's parrotfish		✔	
		Chlorurus microrhinos	Steephead parrotfish			✔
	Scarus	*Scarus quoyi*	Quoy's parrotfish	✔		
		Scarus niger	Swarthy parrotfish			✔
		Scarus oviceps	Darkcapped parrotfish			✔
Serranidae	*Cephalopholis*	*Cephalopholis polyspila*	Starry grouper			✔
Siganidae	*Siganus*	*Siganus doliatus*	Barred rabbitfish	✔		
		Siganus vulphinus	Foxface rabbitfish			✔