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1 **Coral recruitment and recovery after the 2004 Tsunami around the**
2 **Phi Phi Islands (Krabi Province) and Phuket, Andaman Sea, Thailand**

3

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18 **Keywords:** recovery, recruitment, corals, tsunami, destruction, tourism

19

20 **Abstract**

21 The 2004 tsunami left a discontinuous pattern of destruction in the reefs along Andaman Sea coast of

22 Thailand. Here, a comparative assessment of coral recruitment was carried out to assess differences in

23 recovery between damaged and undamaged sites in near-shore fringing reefs one year and three years

24 after the tsunami. Settlement plates showed high frequencies of coral spat after 4 months (< 17 spat tile⁻¹)

25 in both, damaged and undamaged locations. Field surveys carried out 3 years after the tsunami on natural

26 substrate confirmed that tsunami damage did not suppress recruitment in damaged sites relative to no

27 impacted controls. New and stable settlement space along with unabated larval supply supported post-

28 tsunami recruit densities up to 7.2 m⁻² year⁻¹. Mean recruit densities were found at the level of post-storm

29 situations with rapid recovery success, suggesting that the duration of disturbance, degree of sorting and,

1 hence, stability of coral rubble is a key determinant of recruitment success. Low regeneration success of
2 some species e.g. branching acroporids and rebounding tourism industry at sites like Patong and partly
3 around the Phi Phi Islands (dense carpets of filamentous algae) led to the assumption of selectivity and
4 eventually to an alternation of the coral community even though live coral cover might be recovered soon.

5

6 **Introduction**

7 The 26 December 2004 hitting the west coast of Thailand had a much higher impact on land than in the
8 sea (DMCR 2005). During a rapid assessment three weeks after the event, only about 13 % of the coral
9 reefs in the Andaman Sea were found to be highly damaged (>50 % of corals destroyed), while almost 40
10 % showed no measurable impact by the tsunami (DMCR 2005). The degree of damage on coral reefs was
11 found to be related to exposure to and amplification of the incident wave due to local differences in
12 bathymetry and coastline leading to a localized pattern of destruction (Allen and Stone 2005; DMCR
13 2005). Generally, the highest impact was found between adjacent islands (funneling effect) and in areas
14 with shallow embayments or shallow exposed reefs (Phongsuwan et al. 2006). Corals were overturned
15 (the massive *Porites lutea* and table corals such as some *Acropora* and *Montipora* spp.), broken
16 (branching species e. g., *Acropora* spp.) or buried by debris or sediment, while less consolidated colonies
17 slid away with the substrate (DMCR 2005).

18 So far, there is no precedent in the scientific literature for a coral recovery study after tsunami. Time
19 spans for recovery after other large-scale mechanical disturbances such as tropical storms are highly
20 variable, e. g. from only few years in storm-beaten reefs in Florida (Shinn 1976) and Phuket Island
21 (Phongsuwan 1991), from few year to several decades in Heron Island, Australia (Woodhead quoted by
22 Pearson 1981, Connell et al. 1997) and Hawaii (Dollar and Tribble 1993), and up to a century in British
23 Honduras (Stoddart 1974). Other reefs may fail to recover altogether under continued unfavorable
24 combinations of natural and anthropogenic stressors (Woodley et al. 1981; Woodley 1989; Rogers and
25 Miller 2006).

26 Reef recovery is driven by two processes: sexual propagation with re-colonization of freshly exposed
27 substrate by new recruits and asexually, by regeneration of damaged coral colonies or fragments. The
28 success of re-colonization is dependent on larval supply, suitability of substrate as well and competition
29 and predation (Pearson 1981). It is not known at present to what extent the tsunami may have affected any
30 of these factors governing coral recruitment.

1 On the one hand, the small-scale patchiness of destruction both between and within reefs (DMCR 2005)
2 may allow for an uninterrupted supply of larvae from undamaged to adjacent damaged reefs. On the other
3 hand, the loss of more than half of the colonies in heavily impacted reefs may have rendered reproductive
4 success critically low (Allee effect; Stephens and Sutherland 1999), particularly for short range dispersing
5 species. Although connectivity between reefs has been emphasized for many reef organisms at various
6 scales (e.g., Williams et al. 1984; Roberts 1997), self-seeding with a significant fraction of propagules
7 settling within the natal reef has been shown, as well, in studies of larval dispersal (Sammarco and
8 Andrews 1989; Black et al. 1990; Jones et al. 1999).

9 The success of re-colonization is also governed by the substrate composition. Well-sorted rubble
10 following tropical cyclones in response to a high number (>1,000) of huge waves, may provide a “killing
11 field” for coral recruits (Thongtham and Chansang 1999, Tamelander 2002; Fox and Caldwell 2006). By
12 contrast, unsorted rubble of various sizes, broken and overturned corals generated by large but few (<10)
13 tsunami waves may provide an interlocking framework, thus enhancing substrate stability and, hence,
14 coral recruitment. These different substrate characteristics need to be considered in the recruitment
15 process, together with the abundance of potential space competitors such as algae, expanding adult coral
16 colonies and bryozoans. In terms of predation, corallivore fishes were rare and herbivore fishes were
17 abundant in ‘normal densities’ before, as well as after the tsunami (Allen & Stone 2005).

18 Generally, the asexual process of regeneration proceeds smoothly, if the lesion is not too large and the
19 coral is healthy (Knowlton et al. 1981; Woodley et al. 1981). For some branching species (e.g., *Acropora*
20 spp.), mechanical fragmentation and subsequent regeneration is the dominant way of reproduction
21 (Highsmith 1982), but also massive corals, such as *Porites lutea* dominating in the Andaman Sea of
22 Thailand, are known for their rapid regeneration after damage (Highsmith 1980; Phongsuwan 1991;
23 Brown et al. 2002).

24 The degree of damage determines the favorable mode of recovery, while heavy damage with high coral
25 mortality results in a rather slow recovery process of re-colonization (Connell et al. 1997).

26 The aim of this study was to assess the recovery of tsunami impacted reefs relative to reefs less affected
27 by destruction. Recruitment success was hypothesized to be high in areas with large areas of freshly
28 exposed solid substrate in spite of a potentially patchy larval supply. Also regeneration was expected to
29 be rapid compared to results of previous studies (Phongsuwan 1991; Brown et al. 2002). The following
30 variables influencing coral recruitment and potential reef recovery were investigated: (1) Recruitment in

1 damaged and undamaged sites, (2) abundance of suitable substrate for planula larvae to settle on, (3)
2 abundance of potential space competitors of coral recruits and (4) survival of damaged corals. Two depths
3 were chosen due to a much higher tsunami impact in the shallow reef (< 4m deep) compared to deeper
4 areas.

5 The results of this study are discussed in the light of previous storm recovery studies in order to provide a
6 baseline for conservation and management of the tsunami affected areas.

7

8 **Materials and methods**

9 **Study sites**

10 The study was carried out in reefs fringing the island of Phuket as well as the Phi Phi Islands in Phang
11 Nga Bay, which were affected to various degrees by the 2004 tsunami. Two depths were chosen in the
12 context of higher tsunami impact in the shallow reef area (< 4m). The Thai region features a monsoonal
13 climate, where the wet and stormy SW monsoon season is from May to November and the dry season
14 with the calm NE monsoon is from December to April. In 2005 the SW monsoon was exceptionally dry
15 in the beginning (except May) and above-average rainfall occurred during the end of the season
16 (September – November) (Southern Meteorological Center, Thailand). The Andaman Sea is
17 comparatively nutrient rich, due to upwelling and land run-off (Janekarn and Hylleberg 1989; Brown et
18 al. 1999). In spite of growing anthropogenic pressures the coral reefs are still in a fairly good condition
19 (Brown 2007).

20

21 *Phi Phi Islands (Krabi Province):*

22 The Phi Phi Islands consist of 6 limestone islands located 40 km southeast of Phuket and about 30 km
23 west of Krabi in Phang Nga Bay, a large shallow bay not deeper than 30 m (Fig. 1). Well developed
24 fringing coral reefs are found on the eastern sides of the islands or in areas protected from SW storms. At
25 most sites, coral grow down to about 8 - 10 m depth, but to about 15 - 20 m at Ko Phi Phi Lae. The
26 visibility ranges from 5 - 25 m. Massive *P. lutea*, branching *Acropora* spp., such as *A. formosa*, *A.*
27 *grandis*, *A. subulata* and *A. austera* and the tabular *A. hyacinthus* and *A. subulata* are the dominant
28 species.

29 Although the Phi Phi Islands were declared a marine national park in 1983, unrestricted access by the
30 tourism industry has led to the degradation of the surrounding reefs (Chou et al. 2002). There is no

1 sewage treatment plant, only some collecting ponds and it remains unclear, where the wastewater enters
2 the sea. Some of the coral reefs were strongly hit by the tsunami in December 2004 and suffered severe
3 damage, while other areas remained untouched, providing an ideal setting for testing small scale
4 differences (<10 km) in coral recruitment as a function of reef damage.
5 Seven study sites were chosen, three damaged (marked with a 'D' superscript in the following) and four
6 undamaged sites (Fig. 1). Highest tsunami damage occurred at Ko Pai and at Lolana Bay (up to 50 %
7 damage), and at the northern end of Ko Phi Phi Lae (30 – 50 % damage) (DMCR 2005).
8 The remaining study sites Ko Yoong, Leam Tong, Hin Phae and Ko Phi Phi Lae SE were only slightly
9 damaged or completely untouched (DMCR 2005).

10

11 *Phuket:*

12 Coral reefs are well developed on the west coast in protected bays and on some areas along the southern
13 coast. The study site South Patong in the Southwest of Phuket (Fig. 1) is a tourist hotspot with over
14 30,000 hotel bedrooms. Corals grow to about 7 m depth and the dominant species are *P. lutea*, *D.*
15 *heliopora*, *Millepora* sp., *H. coerulea*, *Lobophyllia* sp., few branching corals such as *A. formosa*, few
16 table corals and encrusting corals. About 30 % of waste waters of the city of Patong are untreated and
17 being discharged into the bay only a few hundred meters away from the investigated reef smothering the
18 corals. The visibility is 5 – 10 m.

19 South Patong is the only reef area on Phuket, which was severely impacted by the tsunami (DMCR 2005).

20

[Insert Fig. 1 about here]

21

22 **Settlement plates**

23 A settlement experiment was carried out one year after the tsunami to evaluate coral larvae distribution
24 between damaged and undamaged sites and to quantify space-competing algae and fouling organisms. 12
25 x 12 cm plates were cut from acrylic board (2.5 mm thick), roughened with a metal brush and fixed in
26 triplicates in a vertical position on 1 m iron rods. Six rods were fixed in an upright position for every
27 location and depth (shallow: reef edge ~3 m and deep: lower reef slope ~7 - 10 m) resulting in 2 depths x
28 6 rods x 3 plates = 36 plates per study site. Although acrylic shares the disadvantages of all artificial
29 settlement plate material compared so far in being highly selective for certain taxa (Harriott & Fisk 1987;
30 Dunstan & Johnson 1998; Heyward and Negri 1999; Petersen et al. 2005; Mangubhai et al. 2007), as

1 opposed to natural reef substrate (e.g. Morse and Morse et al. 1996), they are nevertheless useful in
2 detecting differences in coral recruitment in both, space and time.

3 All the settlement plates were deployed early November 2005. For a given site and depth the triplicate
4 plates of rod number one were replaced after one month, the plates of rod number two after two months,
5 etc., resulting in a time series of settlement of varying exposure period (up to four months, early
6 November 2005 to early March 2006; Tab.1).

7 After removal, plates were allowed to dry in the sun for 2-3 days for examination with a magnifying glass
8 and stereo microscope. Settlement plates were searched for coral spat and specimens identified to family
9 level according to Babcock et al. (2003). The abundance of fouling organisms (filamentous algae,
10 crustose coralline red algae and sessile fauna such as barnacles, bivalves, bryozoans and spirorbid worms)
11 was recorded on an ordinal scale between 0 (absent) and 5 (replete). Category 5 applied to high densities
12 of filamentous algae featuring long filaments; crustose coralline algae covering most of the plate in thick
13 patches; bryozoans covering more than 40 % of the plate; spirorbid worms in excess of 40 individuals per
14 plate; bivalves and barnacles with more than 25 individuals per plate, respectively.

15 Statistical analyses were conducted with the software SAS. The data collected on one rod (3 plates) were
16 treated as one replicate. A Poisson regression was carried out since the coral spat densities followed a
17 Poisson distribution. The data set of the four month period was used to assess the effects of three indicator
18 variables (1) 'status' (damaged, undamaged), (2) reef 'sites' (Ko Yoong, Leam Tong, Hin Phae, Phi Phi
19 Lae SE, Phi Phi Lae N, Ko Pai, Lolana, Patong) and (3) 'depth' (shallow, deep) on the response variable
20 'coral spat' density, whereas 'sites' were nested within 'status'. The effects of filamentous and crustose
21 coralline red algae and of fouling organisms (additional indicator variables) on coral spat densities were
22 analyzed in a separate run of Poisson Regression.

23 To test for differences in coral spat abundances between the two seasons (November – January end of
24 rainy season, January – March dry season) data of the two month period were used and Poisson
25 Regression was applied. The additional indicator variables was 'season', however the variable 'site' was
26 eliminated, because each site was represented by only two data points (one deep rod, one shallow rod).

27 The effect of seasonality on algae and fouling organisms was tested with univariate ANOVA using season
28 and depth as fixed factors and the sites were treated as replicates. Levene's test was applied to test
29 homogeneity of residuals.

30 Succession over the four month period was analyzed graphically.

1 *[Insert Tab. 1 about here]*

2

3 **Visual census of coral recruits *in situ***

4 In this paper, we distinguish between newly settled corals (“coral spat”) on settlement plates, and the
5 young corals (“coral recruits”) in the field.

6 Visual census of coral recruits was done one year (January / February 2006) as well as three years
7 (November 2007) after the tsunami in proximity to the settlement plates at all sites, along the reef edge
8 and the lower reef slope in order to quantify the success of coral recruitment. Recruits were counted on
9 natural substrate using a 0.5 x 0.5 m square (0.25 m²) placed at random (n=10) in areas dominated by
10 dead coral substrate and summed up (recruits 2.5 m²). Within the quadrates 0.5 - 2.0 cm coral recruits
11 (diameter) were recorded. Visual census with unaided eye allowed undoubted recruit identification only
12 for the genus *Pocillopora*; all other scleractinians were recorded as “other”. Given linear extension rates
13 of >1 cm year⁻¹ even for slow-growing taxa in the area (Phongsuwan 1991; Scoffin et al. 1992), it was
14 assumed that the bulk of the recruits had settled after the tsunami.

15 For statistical analyses Levene’s test was applied to test homogeneity of residuals and univariate ANOVA
16 was used to compare recruit abundances. Status and depth were fixed factors and the sites were treated as
17 replicates.

18

19 **Line intercept transects**

20 Line intercept transects (English et al. 1994) were carried out in January / February 2006 (i.e. one year
21 after the tsunami) to determine live coral cover and the availability of suitable substrate for coral larvae
22 settlement. 20 m transects (n=3) were laid out with a measuring tape along the reef edge and the lower
23 reef slope in proximity to the settlement plates at all sites. The substrate directly under the tape was
24 assigned to the following categories - live coral (LC), dead coral (DC), other organisms (including soft
25 coral, sponges and giant clams), coral rubble (RB), sand (SA), macroalgae and categories recorded to the
26 nearest cm. RB included small pieces of coral skeleton (<10 cm long), while DC was composed of coral
27 skeleton pieces larger than RB, dead patches on coral colonies and entire dead colonies up to few meters
28 in diameter. The respective mean percentage cover of each component was calculated for each location
29 and depth.

30

1 **Results**

2 **Settlement plates**

3 *Coral spat*

4 Pocilloporids dominated by far the coral spat on the settlement plates, in spite of the dominance of adult
5 Acroporidae and Poritidae in the reefs. Spat were patchily distributed between the plates, ranging from 0
6 to 17 spat plate⁻¹ and a total of 394 spat for all plates. Coral spat densities were lower during the first two
7 months of the experiment (November 2005 – January 2006), compared to the last two months (January –
8 March 2006) (Table 3, Fig. 2). There was no detectable difference between damaged and undamaged sites
9 after 4 months. More coral spat were found in the deeper areas; however the difference between the 2
10 depths varied between damaged and undamaged sites (Table 3) and the high number of coral spat at Ko
11 Yoong deep (Table 2) strongly influenced this result. The high variations in spat abundances between the
12 sites led to site effects at all sites in damaged as well as in undamaged reefs (Table 3, Online Resource 1
13 shows graphical illustration of spat densities).

14 Coral recruitment showed a functional response to filamentous algae with highest coral spat densities on
15 plates with intermediate algae cover (Online Resource 2). A positive relationship between crustose
16 coralline red algae and coral spat (Morse and Morse et al. 1996) was not detectable.

17 *[Insert Fig.2 and Tab. 2 and 3 about here]*

18

19 *Algae and fouling organisms*

20 Filamentous and crustose coralline red algae showed a clear seasonality with a higher abundance within
21 the first two months (Fig. 2, ANOVA $p < 0.001$ for both). Depth had no effect on the distribution of
22 filamentous algae (ANOVA $p > 0.05$). However, crustose red algae were significantly more abundant in
23 the shallow reefs (ANOVA $p = 0.016$). There were pronounced differences in algal cover between sites:
24 Lolana^D had the highest abundance of filamentous algae followed by Patong^D, while the lowest densities
25 were found at Leam Tong and Phi Phi Lae SE (Online Resource 3). Sediment was trapped between the
26 algal filaments of densely covered plates especially in the deeper area of Ko Yoong and Lolana^D.

27 Highest abundances of crustose algae were found at Ko Pai^D and Lolana^D displaying thick algae crusts on
28 the plates.

29 Although the abundance of fouling organisms (bryozoans, spirorbid worms, bivalves, barnacles) was
30 generally low, some plates had high abundances of certain groups (e.g., spirorbid worms) and variation

1 was sometimes high on the level of a single rod. Peak abundances were visible in the deeper area of
2 Patong^D, where bryozoans (>40 % coverage) and bivalves (9 – 15 ind. plate⁻¹) showed the highest
3 abundances. Seasonality was not significant, but showed a similar pattern as filamentous and crustose
4 algae (Fig. 2, ANOVA p>0.05). An overgrowth of spat by bryozoans was observed in some cases.
5 Succession took place following the expected pattern, in which filamentous algae and crustose coralline
6 red algae are the first settlers being then gradually replaced by sessile animals, such as bryozoans and
7 bivalves and finally by corals (Online Resource 4).

8

9 **Coral recruits on natural substrate**

10 There was a significant increase in coral recruitment between one and three years after the tsunami
11 (ANOVA p=0.016), but no differences between either damaged and undamaged or shallow and deep
12 reefs (ANOVA p>0.05). One year after the tsunami the highest density of recruits was found at Lolana
13 Bay^D with more than 6 recruits m⁻² in the shallow reef area followed by Leam Tong. Almost 2 yrs later
14 Ko Yoong showed the highest recruit density and Lolana Bay^D was situated around the average of all
15 sites (Table 4). Generally, pocilloporids contributed the bulk of the recruits; but variation between sites
16 was very large ranging from 0 % pocilloporids in shallow Hin Phae after 1 yr to 100 % in shallow Leam
17 Tong after 3 yrs (Table 4).

18 No relationship was visible between the number of spat and the number of recruits for either pocilloporid
19 corals alone or the ensemble of corals. At Ko Yoong, which showed an extremely high abundance of
20 pocilloporids on the plates, the number of recruits was found within the range of other sites (Table 2 and
21 4). Also no connection between recruit densities and algae abundance (on plates) could be found (Online
22 Resource 5).

23 Additionally to the < 1 year old recruits some older recruits (1 - 3 yrs), in particular fast growing
24 *Acropora* spp. (10 - 20 cm in diameter), were observed during the November 2007 survey on tsunami
25 generated dead corals at Lolana Bay^D and Patong^D.

26 *[Insert Tab. 4 about here]*

27

28 **Substrate composition and survival of damaged corals**

29 Highest LC cover was found at Ko Yoong in the shallow reef (57 %). In five out of eight cases a higher
30 LC cover was found in the shallow area; the opposite situation was observed at Lolana^D and Patong^D and

1 Hin Phae. The cover by DC was highest in the shallow areas of damaged reefs in particular at Ko Pai^D
2 and Lolana^D with 59 % largely due to overturned *Porites* heads. But also the deeper reef areas showed a
3 higher abundance of DC compared to the undamaged sites. In contrast, we found no relation between RB
4 cover and tsunami impact. The only site with high rubble cover was Phi Phi Lae SE deep with 49 %,
5 while the other sites were lying generally between 10 and 20 % at other sites (Fig.3, Online Resource 6
6 presentation in numbers). No correlation was found between LC and coral recruit densities.

7 Many of the overturned or toppled *Porites* heads survived, showing partial re-growth around the edges.
8 Branching coral species such as *Acropora* spp. were severely impacted in some areas; many fragments
9 were dead in the shallow water, particularly on the reef flat. Some fragments on the reef slope survived
10 and showed new outgrowth, unless covered by sand or debris. Dead *Acropora* table corals were found
11 uprooted in the sand, and toppled over specimens in no direct contact with the sediment were found alive
12 even in an upside down position. New little outgrowths directed to the light could be observed.

13 *[Insert Fig.3 about here]*

15 **Discussion**

16 The densities of coral spat recorded on the settlement tiles as well as the recruit abundances on the natural
17 substrates indicate a successful supply of coral larvae and subsequent recruitment not only in the
18 undamaged but also in the damaged reef areas. Although the predominance of pocilloporids on the
19 settlement plates is likely biased, similar to the overrepresentations found in other settlement plate studies
20 (Bak and Engel 1979; Harriott and Fisk 1987; Dunstan and Johnson 1998), the high densities show that
21 these monthly reproducing brooders (Fadlallah 1983) are able to disperse to sites featuring only sparse
22 adult brood stock over a range of several kilometers (cf. Tab. 5).

23 The high spat densities are reflected also in the densities of coral recruits on natural substrate which
24 increased from an average $3.2 \pm 1.6 \text{ m}^{-2}$ in damaged areas and to $4.15 \pm 1.3 \text{ m}^{-2}$ after 3 years. While these
25 findings suggest successful recovery, it must be kept in mind that the natural variability in recruitment
26 between years can be pronounced (Dunstan and Johnson 1998). These results are lying within the recruit
27 densities found during a 30-year study in the Great Barrier Reef ($1.8 - 30.3 \text{ recruits yr}^{-1}$). The high
28 fluctuation in the GBR was partly attributed to storm events and partly to natural temporal variability,
29 while the recovery success after different storms was found to be strongly influenced by the severity of
30 storm impact (Connell et al. 1997). At a storm- beaten reef in the Andaman Sea of Thailand high

1 recruitment success was found (17 – 19 recruits m⁻², size <5 cm Ø) due to the abundance of solid
2 substrate (Phongsuwan 1991). Nevertheless our results are outstanding compared to another storm-
3 shattered reef in the area, where low recruitment success was the consequence of long lasting
4 unconsolidated rubble (2 – 4 recruits m⁻², size <5 cm Ø) (Thongtham and Chansang 1999). This leads to
5 the suggestion that substrate stability plays a decisive role in recovery after large-scale disturbance. In the
6 context of tsunami few but very energetic waves creates a heterogeneous and interlocking framework
7 with coral debris of various forms and sizes, This was typical for reefs strongly hit by the tsunami such as
8 Lolana^D and Ko Pai^D, where dead corals (59%) provide a solid foundation with a high variation of
9 substrate orientation and surface complexity, which is known to be supportive for larval settlement and
10 survival (Pearson 1981; Thongtham and Chansang 1999).

11 [Insert Tab. 5 about here]

12
13 Space competing organisms such as algae and a range of small filter feeders did not seem to have a
14 negative impact on coral spat- and recruit densities leading to the conclusion of a rather high resilience of
15 corals in the Andaman Sea being able to successfully compete with other organisms. This idea is further
16 supported by other studies in this area, in which high recruitment success and regeneration of damaged
17 coral colonies after storms, sediment plumes from dredging, negative sea level anomalies and increased
18 sea surface temperatures were found (Phongsuwan 1991; Brown et al. 2002; Brown and Phongsuwan
19 2004). Additional evidence for the corals ability to persist and / or recover quickly are: (1) high growth
20 rates (Phongsuwan 1991; Scoffin et al. 1992), (2) high tolerance for sedimentation and elevated nutrient
21 levels (Brown 2007) and (3) preferred spawning during the end of the dry season when algae growth is
22 suppressed as shown in our results of the settlement plates and also found by Chanmethakul (2001) and
23 Guest et al. (2005). Latter might also be a reason for the low contribution of many coral species on the
24 settlement tiles, where plates were removed (March) just after the onset of the spawning period
25 (February).

26 After demonstrating all the positive features of corals in this region, some weakness in the recovery of
27 branching acroporids was found. In contrast to massive (e.g. *Porites lutea*, faviids) and table like corals
28 (e.g. *Acropora hyacinthus*, *A. clathrata*, *Montipora* spp.), regeneration by tissue re-sheeting was hardly
29 visible in branching *Acropora* spp. resulting in high mortality rates. Only few coral fragments were still
30 alive after three years - in spite of its alleged fast fixation (Phongsuwan 2006) and their naturally high

1 recovery potential (Highsmith 1982; Veron 1993). This goes in line with the findings at a reef off Phuket,
2 where recovery of branching acroporids after stress from low sea levels and increased temperature was
3 unsuccessful in contrast to other species (Brown and Phongsuwan 2004).
4 After all, this might lead to selection of coral species not only concerning the regeneration process but
5 consequently also the recruitment diversity. Unfortunately, the recruitment diversity has not been
6 assessed; however the relatively high contribution of pocilloporids and the intermediate numbers of coral
7 recruits support the idea of selectivity. Even though the percentages of live coral cover might be restored,
8 lower diversity in areas with strongly degrading water quality such as Patong and partly around the Phi
9 Phi Islands (Chou et al. 2002; Yeemin 2004) might be the consequence.
10 Therefore, higher sensitivity of the coral community can not be ruled out, which leads to a higher
11 vulnerability of a reef ecosystem to natural disturbances e.g. heavy storms. This emphasizes the need of
12 further monitoring activities and the need of effective coastal management to maintain viable conditions
13 for Andaman Sea coral reefs, especially where tourism is growing in great numbers.

14

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22

1 **References**

- 2 Allen GR, Stone GS (2005) Rapid assessment survey of tsunami-affected reefs of Thailand. New England
3 Aquarium Technical Report 02-05, Boston, USA, 122 pp.
- 4 Babcock RC, Baird AH, Piromvaragorn S, Thomson DP, Willis BL (2003) Identification of scleractinian
5 coral recruits from Indo-Pacific reefs. *Zool Stud* 42:211-226
- 6 Bak RPM, Engel MS (1979) Distribution, abundance and survival of juvenile hermatypic corals
7 (Scleractinia) and the importance of life-history strategies in the parent coral community. *Mar Biol*
8 54:341-352
- 9 Black KP, Gay SL, Andrews JC (1990) Residence times of neutrally-buoyant matter such as larvae,
10 sewage or nutrients on coral reefs. *Coral Reefs* 9:105-114
- 11 Brown BE (2007) Coral reefs of the Andaman Sea - an integrated perspective. *Oceanogr Mar Biol Annu*
12 *Rev* 45:173-194
- 13 Brown BE, Phongsuwan N (2004) Constancy and change on shallow reefs around Leam Panwa, Phuket,
14 Thailand over a twenty year period. *Phuket Mar Biol Cent Res Bull* 65:61-73
- 15 Brown BE, Clarke KR, Warwick RM (2002) Serial patterns of biodiversity change in corals across
16 shallow reef flats in Ko Phuket, Thailand, due to the effects of local (sedimentation) and regional
17 (climatic) perturbations. *Mar Biol* 141:21-29
- 18 Brown BE, Dunne RP, Ambarsari I, Le Tissier MDA, Satapoomin U (1999) Seasonal fluctuations in
19 environmental factors and variations in symbiotic algae and chlorophyll pigments in four Indo-
20 Pacific coral species. *Mar Ecol Prog Ser* 191:53-69
- 21 Chanmethakul (2001) Spawning season of scleractinian corals on Phuket Island. M.Sc. thesis, Prince of
22 Songkla University, Thailand, 82 pp.
- 23 Chou LM, Tuan VS, Reefs P, Yeemin T, Cabanban A, Kessna S, Kessna I (2002) Status of Southeast
24 Asia coral reefs. In: Wilkinson C (ed) Status of coral reefs of the world. Australian Institute of
25 Marine Science, Townsville, pp 123-153
- 26 Connell JH, Hughes TP, Wallace CC (1997) A 30-year study of coral abundance, recruitment, and
27 disturbance at several scales in space and time. *Ecol Monog* 67: 461-488
- 28 DMCR - Department of Marine and Coastal Resources (2005) Rapid assessment of the tsunami impact on
29 marine resources in the Andaman Sea, Thailand. Phuket Marine Biological Center, Thailand

- 1 Dollar SJ, Tribble GW (1993) Recurrent storm disturbance and recovery - a long-term study of coral
2 communities in Hawaii. *Coral Reefs* 12:223-233
- 3 Dunstan PK, Johnson CR (1998) Spatio-temporal variation in cores recruitment at different scales on
4 Heron Reef, southern Great Barrier Reef. *Coral Reefs* 17:71-81
- 5 English S, Wilkinson C, Baker V (eds) (1994) Survey manual for tropical marine resources. Australian
6 Institute of Marine Science, Townsville
- 7 Fadlallah YH (1983) Sexual reproduction, development and larval biology in scleractinian corals. *Coral*
8 *Reefs* 2:129-150
- 9 Fox HE, Caldwell RL (2006) Recovery from blast fishing on coral reefs: a tale of two scales. *Ecol Appl*
10 16:1631-1635
- 11 Guest JR, Baird AH, Goh BPL, Chou LM (2005) Seasonal reproduction in equatorial reef corals.
12 *Invertebr Reprod Dev* 48:207-218
- 13 Harriott VJ, Fisk DA (1987) A comparison of settlement plate types for experiments on the recruitment of
14 scleractinian corals. *Mar Ecol Prog Ser* 37:201-208
- 15 Heyward AJ and Negri AP (1999) Natural inducers for coral larval metamorphosis. *Coral Reefs* 18:273-
16 279
- 17 Highsmith RC (1980) Passive colonization and asexual colony multiplication in the massive coral *Porites*
18 *lutea* Milne Edwards and Haime. *J Exp Mar Biol Ecol* 47:55-67
- 19 Highsmith RC (1982) Reproduction by fragmentation in corals. *Mar Ecol Prog Ser* 7:207-226
- 20 Janekarn V, Hylleberg J (1989) Coastal and offshore primary production along the west coast of Thailand
21 (Andaman Sea) with notes on physical-chemical variables. *Phuket Mar Biol Cent Res Bull* 51:1-20
- 22 Jones GP, Milicich MJ, Emslie MJ, Lunow C (1999) Self-recruitment in a coral reef fish population.
23 *Nature* 402:802-804
- 24 Knowlton N, Lang JC, Rooney MC, Clifford P (1981) Evidence for delayed mortality in hurricane-
25 damaged Jamaican staghorn corals. *Nature* 294:251-252
- 26 Mangubhai S, Harrison PL, Obura DO (2007) Patterns of coral larval settlement on lagoon reefs in the
27 Mombasa Marine National Park and Reserve, Kenya. *Mar Ecol Prog Ser* 348:140-150
- 28 Morse ANC and Morse DE (1996) Flypapers for coral and other planktonic larvae. *BioScience* 46:254-
29 262
- 30 Pearson RG (1981) Recovery and recolonization of coral reefs. *Mar Ecol Prog Ser* 4:105-122

- 1 Petersen D, Laterveer M, Schuhmacher H (2005) Innovative substrate tiles to spatially control larval
2 settlement in coral culture. *Mar Biol* 146: 937-942
- 3 Phongsuwan N (1991) Recolonization of a coral reef damaged by a storm on Phuket Island, Thailand.
4 *Phuket Mar Biol Cent Res Bull* 56:75-83
- 5 Phongsuwan N (2006) The use of coral transplantation in the rehabilitation of coral reefs affected by the
6 2004 tsunami. In: Plathong S (ed) *Coral reef rehabilitation after the tsunami 2004 - case studies*
7 from Thailand. Department of Marine and Coastal Resources, Bangkok, pp. 60-72
- 8 Phongsuwan N, Yeemin T, Worachananant S, Duangsawasdi M, Chotiyaputta C, Comley J (2006) Post-
9 tsunami status of coral reefs and other coastal ecosystems on the Andaman Sea Coast of Thailand.
10 In: Wilkinson C, Souter D, Goldberg J (eds) *Status of coral reefs in tsunami affected countries:*
11 *2005*. Australian Institute of Marine Science, Townsville, pp 63-77
- 12 Rinkevich B (1996) Do reproduction and regeneration in damaged corals compete for energy allocation?
13 *Mar Ecol Prog Ser* 143:297-302
- 14 Roberts CM (1997) Connectivity and management of Caribbean coral reefs. *Science* 278:1454-1457
- 15 Rogers CS, Miller J (2006) Permanent 'phase shifts' or reversible declines in coral cover? Lack of
16 recovery of two coral reefs in St. John, US Virgin Islands. *Mar Ecol Prog Ser* 306:103-114
- 17 Sammarco PW, Andrews JC (1989) The Helix Experiment - differential localized dispersal and
18 recruitment patterns in Great Barrier-Reef corals. *Limnol Oceanogr* 34:896-912
- 19 Scoffin TP, Tudhope AW, Brown BE, Chansang H, Cheeney RF (1992) Patterns and possible
20 environmental controls of skeletogenesis of *Porites lutea*, South Thailand. *Coral Reefs* 11:1-11
- 21 Sheppard CRC, Spalding M, Bradshaw C, Wilson S (2002) Erosion vs. recovery of coral reefs after 1998
22 El Niño: Chagos Reefs, Indian Ocean. *Ambio* 31:40-48
- 23 Shinn EA (1976) Coral reef recovery in Florida and Persian Gulf. *Environ Geol* 1:241-254
- 24 Stephens PA, Sutherland WJ (1999). Consequences of the Allee effect for behavior, ecology and
25 conservation. *Trends Ecol Evol* 14:401-405
- 26 Stoddart DR (1974) Post-hurricane changes on the British Honduras reefs: re-survey of 1972. *Proc 2nd*
27 *Int Coral Reef Symp* 2:473-483
- 28 Tamelander J (2002) Coral recruitment following a mass mortality event. *Ambio* 31:551-557
- 29 Thongtham N, Chansang H (1999) Influence of surface complexity on coral recruitment at Maiton Island,
30 Phuket, Thailand. *Phuket Mar Biol Cent Res Bull* 20:93-100

- 1 Veron JEN (1993) Corals of Australia and the Indo Pacific. University of Hawai'i Press, Honolulu
- 2 Williams DM, Wolanski E, Andrews JC (1984) Transport mechanisms and the potential movement of
3 planktonic larvae in the Central Region of the Great Barrier-Reef. *Coral Reefs* 3:229-236
- 4 Woodley JD (1989) The effects of hurricane Gilbert on coral reefs at Discovery Bay. In: UNEP:
5 Assessment of the economic impacts of Hurricane Gilbert on coastal and marine resources in
6 Jamaica. CEP Technical Report No. 4. UNEP Caribbean Environment Programme, Kingston,
7 Jamaica, Appendix 9
- 8 Woodley JD, Chornesky EA, Clifford PA, Jackson JBC, Kaufman LS, Knowlton N, Lang JC, Pearson
9 MP, Porter JW, Rooney MC, Rylaarsdam KW, Tunnicliffe VJ, Wahle CM, Wulff JL, Curtis ASG,
10 Dallmeyer MD, Jupp BP, Koehl MAR, Neigel J, Sides EM (1981) Hurricane Allens impact on
11 Jamaican coral reefs. *Science* 214:749-755
- 12 Yeemin T (2004) Status of coral reefs in Southeast Asian countries: Thailand. In: Japan Wildlife
13 Research Center (ed.) Status of coral reefs in East Asian seas region: 2004. Ministry of
14 Environment, Tokyo, Japan, pp. 71-94
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1 **Figure Legends**

2 Fig. 1: Map of middle section of the Andaman coast of Thailand (7.57°N – 8.60°N) (1a)
3 and the Phi Phi Islands (1b), indicating the study sites.

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6 Fig. 2: Abundance of coral spat, filamentous algae, crustose algae and fouling
7 organisms after 2 month: Nov 05 – Jan 06 (blank), Jan – Mar 06 (dotted), indicates
8 seasonality. The y-axis represents the categories of abundance/density: 1= very low, 5=
9 very dense / high abundance. Box: lower / upper quartile and median (bold black line);
10 whisker (vertical line): extend of rest of the data; outliers: circle: measured value is
11 higher/smaller than the upper/lower quartile + 1.5x quartile distance, star: measured
12 value is higher/smaller than the upper/lower quartile + 3x quartile distance.

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14 Fig. 3: Substrate composition at different sites and depths.

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19 Fig. S1: Abundance of coral spat in undamaged and damaged sites after 4 months. Box:
20 lower / upper quartile and median (bold black line); whisker (vertical line): extend of
21 rest of the data; outliers: circle: measured value is higher/smaller than the upper/lower
22 quartile + 1.5x quartile distance, star: measured value is higher/smaller than the
23 upper/lower quartile + 3x quartile distance.

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1 Fig. S2: Coral spat density vs. filamentous algal density after 4 months. The x-axis
2 represents the categories of density: 1= very low density, 5= dense carpet of algae. Box:
3 lower / upper quartile and median (bold black line); whisker (vertical line): extend of
4 rest of the data; outliers: circle: measured value is higher/smaller than the upper/lower
5 quartile + 1.5x quartile distance, star: measured value is higher/smaller than the
6 upper/lower quartile + 3x quartile distance.

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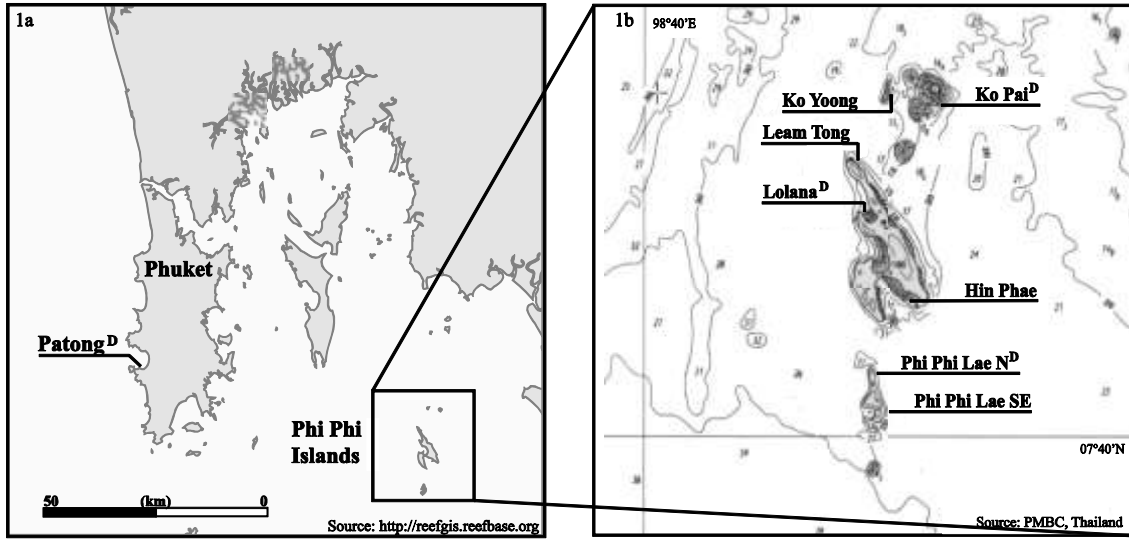
8 Fig. S3: Abundance of filamentous algae at undamaged and damaged sites after 4
9 months. The y-axis represents the categories of density: 1= very low density, 5= dense
10 carpet of algae. Box: lower / upper quartile and median (bold black line); whisker
11 (vertical line): extend of rest of the data; outliers: circle: measured value is
12 higher/smaller than the upper/lower quartile + 1.5x quartile distance, star: measured
13 value is higher/smaller than the upper/lower quartile + 3x quartile distance.

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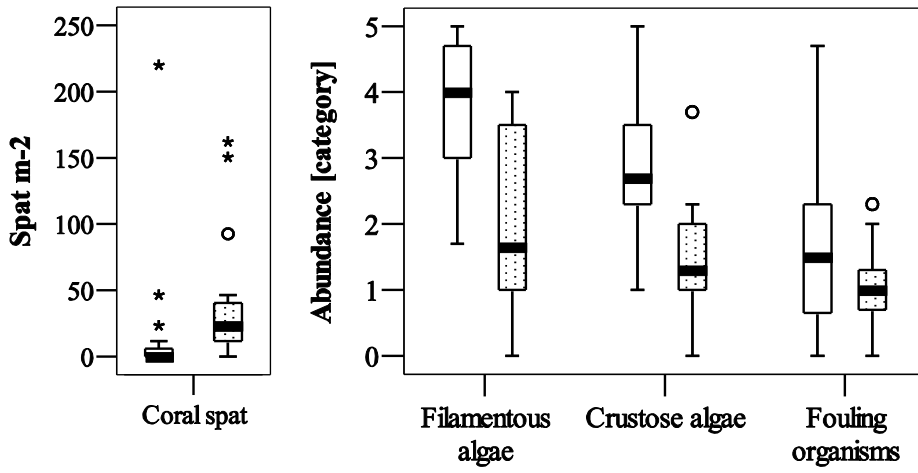
15 Fig. S4: Abundance of coral spat, filamentous algae, crustose algae and fouling
16 organisms after 1, 2, 3 and 4 months to visualize succession. The y-axis represents the
17 categories of abundance/density: 1= very low, 5= very dense / high abundance. Box:
18 lower / upper quartile and median (bold black line); whisker (vertical line): extend of
19 rest of the data; outliers: circle: measured value is higher/smaller than the upper/lower
20 quartile + 1.5x quartile distance, star: measured value is higher/smaller than the
21 upper/lower quartile + 3x quartile distance.

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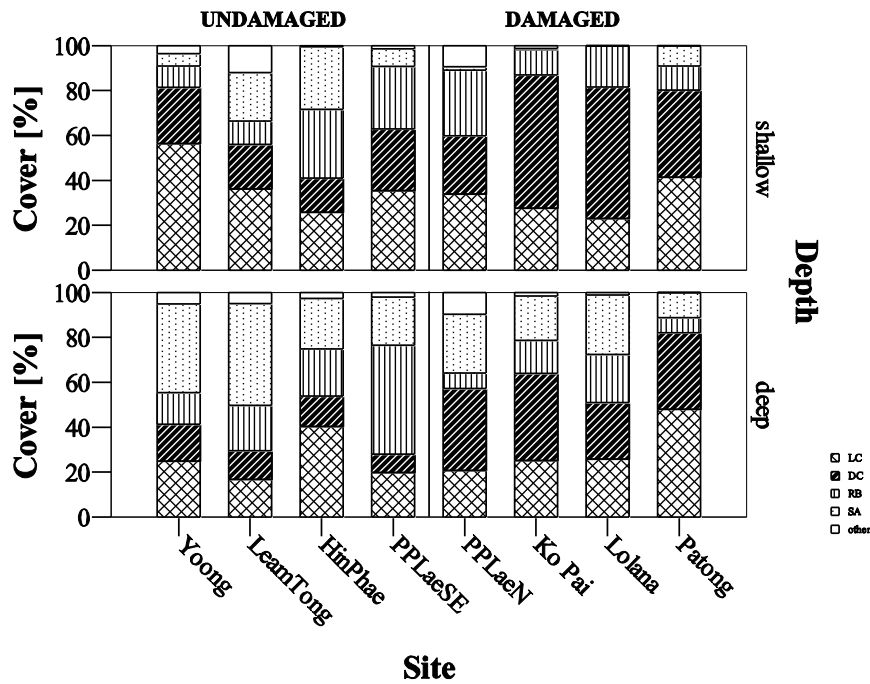
23 Fig. S5: Coral recruit density vs. abundance of filamentous algae. The x-axis represents
24 the categories of density: 1= very low density, 5= dense carpet of algae.



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2 Tab. 1: Experiment design for one study site und depth including the intervals of plate
 3 replacements. Exchanged plates (grey).

	exposure time			
	Nov - Dec	Dec - Jan	Jan - Feb	Feb - Mar
rod 1	1 month	3 months		
rod 2	2 months		2 months	
rod 3	3 months			1 month
rod 4	4 months			
rod 5	4 months			
rod 6	4 months			

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8 Tab. 2: Coral spat abundances on settlement tiles with an exposure time of 4 months.

9 Average \pm standard deviation.

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	spat tile ⁻¹		<i>Pocilloporidae</i> [%]		<i>Acroporidae</i> [%]		<i>Poritidae</i> [%]		others [%]	
	shallow	deep	shallow	deep	shallow	deep	shallow	deep	shallow	deep
Ko Yoong	0	8.9 \pm 4.7	0	97	0	0	0	3	0	0
Leam Tong	2.8 \pm 2.4	0.3 \pm 1.0	96	100	0	0	0	0	4	0
Hin Phae	0.6 \pm 0.9	2.6 \pm 1.9	100	88	0	0	0	9	0	3
PP Lae SE	1.6 \pm 2.3	0	100	0	0	0	0	0	0	0
PP Lae N ^D	0.7 \pm 1.4	0	77	0	8	0	0	0	15	0
Ko Pai ^D	1.2 \pm 1.9	0.6 \pm 0.7	94	100	0	0	0	0	6	0
Lolana ^D	0.7 \pm 1.1	0.3 \pm 0.5	81	67	0	17	13	17	6	0
Patong ^D	3.3 \pm 2.4	0.6 \pm 1.1	95	33	0	33	4	17	2	17

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2 Tab. 3: Results of Poisson Regression: coral spat dependency on status
3 (damaged/undamaged), depth and site (nested within status), using the 4 month data;
4 effect of season, using 2 month data; effect of algae and fouling organisms on coral spat
5 abundances, using 4 month data. ns (not significant). $p < 0.05$ significant.

Source	df	SE	χ^2	p
Coral spat (status & depth)				
Status	1	0.2443	0.20	ns
Depth	1	0.1782	19.00	<0.0001
Status x Depths	1	0.3571	37.33	<0.0001
site (status) Ko Yoong	0	0.0000	-	-
site (status) Leam Tong	1	0.2196	22.86	<0.0001
site (status) Hin Phae	1	0.2327	26.76	<0.0001
site (status) PPLae SE	1	0.2897	36.20	<0.0001
site (status) PPLae N ^D	1	0.4419	15.93	<0.0001
site (status) Ko Pai ^D	1	0.3018	6.73	0.0095
site (status) Lolana ^D	1	0.3737	13.20	0.0003
site (status) Patong ^D	0	0.0000	-	-
Coral spat (season)				
Season	1	0.2367	11.00	0.0009
Coral spat (algae and fouling organisms)				
Filamentous algae	1	0.1395	55.27	<0.0001
Crustose algae	1	0.1318	8.64	0.0038
Fouling organisms	1	0.1809	0.08	ns

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Tab. 4: Coral recruit abundances on natural substrate.

	Jan/Feb 2006						Nov 07					
	recruits m ⁻²		Pocilloporidae m ⁻²		others m ⁻²		recruits m ⁻²		Pocilloporidae m ⁻²		others m ⁻²	
	shallow	deep	shallow	deep	shallow	deep	shallow	deep	shallow	deep	shallow	deep
Ko Yoong	2.8	2.8	1.6	1.6	1.2	1.2	7.2	5.6	4.8	3.2	2.4	2.4
Leam Tong	4.8	3.2	3.6	1.6	1.2	3.2	2.8	4.0	2.8	0.8	0.0	3.2
Hin Phae	1.2	2.0	0.0	0.0	1.2	1.2	3.2	3.2	1.2	1.2	2.0	2.0
PPLae SE	2.4	1.6	1.6	0.8	0.8	1.2	6.4	2.4	4.0	0.0	2.4	2.4
PPLae N ^D	3.2	3.2	0.4	0.4	2.8	2.8	2.8	4.4	0.8	0.4	2.0	4.0
Ko Pai ^D	2.4	1.2	0.8	0.4	1.6	0.8	3.2	4.4	1.6	1.6	1.6	2.8
Lolana ^D	6.4	3.2	2.4	0.8	4.0	2.4	4.8	4.8	2.4	0.4	2.4	4.4
Patong ^D	4.0	2.0	1.2	0.8	2.8	1.2	6.4	2.4	2.8	0.0	3.6	2.4

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9 Tab. 5: Abundance of Pocilloporidae adults, spat and recruits. Damaged sites (^D). No
10 data (n. d.).

	Adult [% of LC]	Spat [no. m ⁻²]	Recruits [no. m ⁻²]
Ko Yoong	10.96	137	1.5
Leam Tong	1.80	48	1.8
Hin Phae	0.51	42	0.4
PPLaeSE	n. d.	25	1.0
PPLaeN ^D	n. d.	11	0.4
Ko Pai ^D	0.00	23	0.6
Lolana ^D	0.00	16	1.5
Patong ^D	0.46	52	1.0

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