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Report on The Littoral and Coral Reef Mapping

Project Beau Vallon Bay, Mahé

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None of the original data presented here have been published so far.

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List of abbreviations

A	*Acropora* sp.	Fav	*Favites* sp.
A1	*Acropora* sp. 1	Fp	*Favites pentagona*
A2	*Acropora* sp. 2	Fs	*Favites spinosa*
A3	*Acropora* sp. 3	Fv	*Favites vasta*
A4	*Acropora* sp. 4	G	*Goniastrea* sp.
A5	*Acropora* sp. 5	Ga	*Galaxea astreata*
A6	*Acropora* sp. 6	Gf	*Galaxea fascicularis*
A7	*Acropora* sp. 7	Ge	*Goniastrea edwardsi* oder *G. retiformis*
aA	abgestorbene *Acropora* sp.	Gm	*Goniastrea minuta*
Aap	*Acropora appressa*	Gal	*Goniopora albiconus*
Abr	*Acanthastrea brevis*	Gdj	*Goniopora djiboutiensis*
Adi	*Acropora digitifera*	Gmin	*Goniopora minor*
Adiv	*Acropora divaricata*	Go	*Goniopora* sp.
Ae	*Acanthastrea echinata*	Gor	*Gorgonaria* gen. sp.
Afo	*Acropora formosa*	Gp	*Goniastrea pectinata*
aG	abgestorbene *Galaxea* sp.	Gpl	*Goniopora cf. planulata*
Agem	*Acropora gemmifera*	He	*Hydnophora exesa*
Air	*Acroproa irregularis*	Hlx	*Herpolitha limax*
Al	*Alveopora* sp.	Hm	*Hydnophora microconos*
Ald	*Alveopora daedalea*	L	*Leptastrea* sp.
Alo	*Acropora longicyathus*	Lh	*Lobophyllia hemprichii*
Amth	*Acropora microthalma*	Li	*Leptoria irregularis*
Amyr	*Astreapora myriopthalma*	Lo	*Lobophytum* sp.
Ana	*Acropora nasuta*	Lp	*Leptoria phrygia*
Anf	*Acropora nobilis* o. *A. formosa*	Lp	*Leptastrea purpurea*
Ano	*Acropora nobilis*	Lph	*Leptoria phrygia*
aP	abgestorbene *Pocillopora* sp.	Lt	*Leptastrea transversa*
Api	*Acropora pinguis*	M	*Montipora* sp.
aPor	abgestorbene *Porites* sp.	Mcoe	*Montastrea coelemani*
aPrus	abgestorbene *Porites rus*	Me	*Montipora efflorescens*
aSt	abgestorbene *Stylophora* sp.	Met	*Metarhodactis* sp.
Ate	*Acropora tenuis*	Mg	*Montipora grisea*
Av	*Acropora vermiculata*	Mi	*Montipora informis*
Avrl	*Acropora verweyi* o. *A. rosaria* o. *A. loripes*	Mm	*Montipora monateriata*
Ay	*Acropora* sp. Young	Mo	*Montastrea* sp.
C	*Cycloseris* sp.	Moc	*Montastrea curta*
Co	Corallimorpharia	Mov	*Montastrea valenciennsi*
Cym	*Cyphastrea microphtalma*	Mova	*Montastrea valenciennesi*
dC	dead coral	Mtub	*Montipora tuberculosa*
Dh	*Diploastrea heliopora*	Mtur	*Montipora turgescens*
Di	*Discosoma* sp.	Mv	*Montipora venosa*
Div	*Distichopora violacea*	P	*Pocillopora* sp.
Egl	*Euphyllia glaberescens*	Pal	*Palythoa* sp.
Eh	*Echinopora hirsutissima*	Pt	*Palythoa tuberculosa*
El	*Echionopora lamellose*	Pa	*Pavona* sp.
F	*Fungia* sp.	Pde	*Pavona decussata*
F	Faviidae gen. sp.	*Pdu*	*Pavona duerdeni*
Fa	*Favia* sp.	Pex	*Pavona explanulata*
Fac	*Favites abdita* oder *F. complanata*	Pfr	*Pavona frondifera*
Fap	*Favia pallida*	Pvar	*Pavona varians*
Fas	*Favia speciosa*	Pven	*Pavona venosa*

Pav	*Pavona venosa* o. *P. varians*	Sa	*Sarcophython* sp.
Pd	*Pocillopora damicornis*	Sae	*Sarcophython elegans*
Pe	*Pocillopora eydouxi*	Sat	*Sarcophyton trocheliophorum*
Pm	*Pocillopora meandrina*	Si	*Sinularia* sp.
Pv	*Pocillopora verrucosa*	Sp	*Stylophora pistillata*
Pla	*Platygyra acuta*	S	*Stylophora* sp.
Plc	*Platygyra carnosus*	Ss	*Stylophora subseriata*
Pli	*Physogyra lichtensteini*	Tis	*Turbinaria irregularis* oder *T. stellulata*
Pl	*Porites lobata* oder *P. lutea*	ToD	*Tubastrea* sp. oder *Dendrophyllia* sp.
Prus	*Porites rus*	Tup	*Turbinais irregularis* o. *T. peltata*
Ppt	*Protopalythoa* sp.	Ud	unidentifed
Pdi	*Psammocora digitata*	Zo	*Zoanthus* sp.
Po	*Psammocora obtusangula*		

Summary of study goals

The Department of Animal Systematics and Morphology of Goettingen University conducts a detailed coral biotope mapping in selected sections of two fringing reefs in the Bay of Beau Vallon on Mahe, Seychelles. The biodiversity and composition of scleractinian corals in these specific parts is investigated in order to trace developments both on long-term and short-term scales. The first detailed maps along transects of the reef near Beau Vallon/Mare Anglaise (Mahé) have been first steps of a research program which shall help to understand natural dynamics of coral reefs and their alterations due to human interventions on short and long term levels.

In 2010, in Mai/June, 2011 and in April/Mai 2012 six transects (total area: 1311m²) were mapped in detail in the northern fringing reef of Beau Vallon Bay (Mare Anglaise) (see our previous reports). In April/Mai 2013 another three transects (total area: 576m^2) were documented in the south-eastern reef of the Bay (Bel Ombre). The maps show the distribution and exact location of coral specimens. In the six transects of the Mare Anglaise fringing reef 102 species were identified, while in the selected sections in the Bel Ombre fringing reef 100 species were detected. Additional species were identified next to our transects.

Understanding the coral communities and their dynamics require studies of the species composition. Tracing the fate of certain species in small areas may shed light on the background of changes, be they natural or caused by climate change or through more immediate human impact. As the coral species composition determines the occurrence and abundance of other organisms, the studies are combined with research on (changing) species abundance and studies on various aspects of the biology of additional selected taxa (e.g. of echinoderms, fish, molluscs). A survey of the species occurring in nearby areas will help to understand biological dynamics and future changes in species association in the study areas.

So far one transect (E1) in the northern part of the study area was investigated for a census of echinoderms from near shore to the reef edge in April 2011 (see report 2011).
In September 2012 reef associated fishes were observed at snorkelling depth, as this is the main study depth for our investigation of coral communities. A few species have been added to the fish species observed on the reef flat based on short dives along the reef front. We have begun to prepare a catalogue of the diurnal reef associated fishes which occur in and near the mapped areas, i.e. from the shoreline to the reef edge (see report 2012).
In 2011, a general biotope map of the study area along the coast of Mare Anglaise near Beau Vallon was also prepared. It includes the area between the six transects (T1-T6) in the fringing reef and shows the

reef zonation from the shore to the reef edge (see our 2011 report). Small areas in the north and in the south are not contained in the map as well as portions of the reef deeper than snorkelling depth. The latter are not mapped as our work is restricted to the upper most vulnerable reef zones.

Coral Reef Monitoring and detailed mapping of coral distribution in the fringing reefs of Beau Vallon Bay require determination down to the species level because even closely related species may react differentially to environmental factors. (Such reactions are for example successful reproduction, growth, uptake and loss of zooxanthellae and recovering from environmental stress). However, macromorphological analyses using digital photography, which is a standard method today, are not sufficient for species identification of quite a number of corals. In these cases micromorphological investigations and molecular analyses are inevitable. Molecular analysis has shown that coral systematic is far from clarified. As this is a presupposition for any biological study we have extended our investigations to this field as well. We want to use a combination of traditional morphological analysis and alternative molecular analysis. Molecular analysis (barcoding) may become a useful tool for coral reef conservation. For these analyses we took 90 small fragments from 50 colonies that occur in the transects or nearby in September 2013.

Biotope Mapping Methods were described in the 2011 report and will be summarized here only briefly, see below.

All our data and results will be freely available on the internet.
Here, we report on the results of our investigations in the Beau Vallon-Mare Anglaise reef and -Bel Ombre fringing reef from October, 2012 to Mai, 2013.

- In April/May 2013 three transect were mapped in detail in the Bel Ombre fringing reef.
- One more transect (T3) of the six transects in the Mare Anglaise fringing reef, which was already mapped in 2010, was analyzed and summarised below.
- In September 2012 and in September 2013 we re-mapped parts of transect 2 in order to trace changes in the composition of the coral fauna and/or in single coral colonies (evaluations are in progress).

Outlook

Tasks remaining for near future field work include comparison of the state of the coral fauna as it was in the first years of investigation with the state in subsequent years. A first such study has shown remarkable changes in the composition of the coral associations in a short period of time.

In the future, the initial studies as outlined above should be extended by repeated detailed faunal surveys. It is especially important to re-study the areas both on a short term scale (e.g., after 0,5-1 year) and in long-term intervals (after ten, twenty etc. years). The high accuracy of the studies may make them models for biotope surveys in marine realms in general.

Mapping rock pools at a site north of Glacis, Mahé
An entirely different biologically interesting study is the examination of the fauna of a species-rich rock pool area in the north of Mahé's west coast. This project has not been begun so far. For methods and study goals see the 2011 report.

Morphological and molecular analysis
The ability to assess and respond to changes in coral reef communities is also limited by the current state of taxonomy and systematics. Macromorphological analysis using digital photography has proven unreliable to determine some scleractinian corals traditional approaches based on. For the identification of corals down to species level and for phylogenetic studies micromorphological and molecular methods are needed. Therefore, our work may contribute to taxonomical problems.

Field work from September 2012 to October 2013 was conducted by Jessica Macken, Sophia Willmann, Alica Ohnesorge, Celine Mäder, Lisa Röpke, Mirella Hofmeister, Shauna Grassmann and the senior author.

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1 Introduction

The coral reefs of Seychelles were heavily damaged by the 1998 bleaching event. Living coral cover of the granitic islands was reduced to less than 10% on most reefs. Coral species richness and coral coverage have improved since 1998, although recovery is slow (Turner, 2000). Furthermore human impact on the reefs continues to rise e. g. by building activity and tourism. The fates of the reefs along the coastal lines of the more populated islands of Seychelles are difficult to foresee. However, once they are well studied and remain well surveyed, they may provide good examples for developing nature conservation recommendations and conservation activities in general. In the granitic Seychelles, there are both coastal sections which are severely affected by man as well as others which have remained almost natural. Some of the latter may stay so if nature management allows. The importance of reefs have been considered in many publications and have become major political topics: Reefs protect the coasts, they are important for fishery, and their biological diversity attracts tourists. However, the reefs of the Inner Islands are threatened by coastal development, fisheries (Jennings et al., 2000), tourism and, one should add, recent 'modern' touristic activities such as the use of jet ski and boats, as well as climate change.

For comparative studies, the first and most important step to be taken is to list what is there. While working out biotope maps has become a standard for terrestrial areas including urban areas, detailed maps of marine localities are scarce. They are, however, the basics for comparisons with the situation in the future, i.e. for the study of any development of the respective communities. This, in turn, allows for generalizations and general conclusions on reef endangering and reef management.

In our studies we examine the biodiversity and distribution of corals in two fringing reefs of Beau Vallon Bay and the changes of the coral composition over time. The detailed mapping of coral distribution requires determination down to the species level. We used digital photography for macromorphological analyses so far. However, this approach has proved insufficient for species identification of quite a number of corals owing to several ecological and life history traits of corals. In these cases micromorphological investigations and molecular analyses are inevitable. To contribute to coral systematic makes the combined use traditional morphological analysis and alternative molecular analysis necessary anyway. Reliable species identification (and, hence both morphological and molecular methods) is a prerequisite for coral reef conservation.

1.1 Morphological analysis

Stony corals which belong to Scleractinia are generally responsible for reef formation. The framework builders deserve special attention due to the decline of coral reefs worldwide. The construction of coral reefs is composed of hundreds of thousands of scleractinian coral polyps that live together in colonies. There is a high variability of growth forms of coral colonies that is used to distinguish different taxa (fig.1).

The diversity of Scleractinia at various levels has traditionally been investigated on skeletal characters. Although morphological characters have been the basis of traditional classification in the group, they are relatively few in number. In addition, our current understanding of skeletal growth and homology is limited, and homoplasy is extensive, limiting the usefulness of morphological phylogenetics.

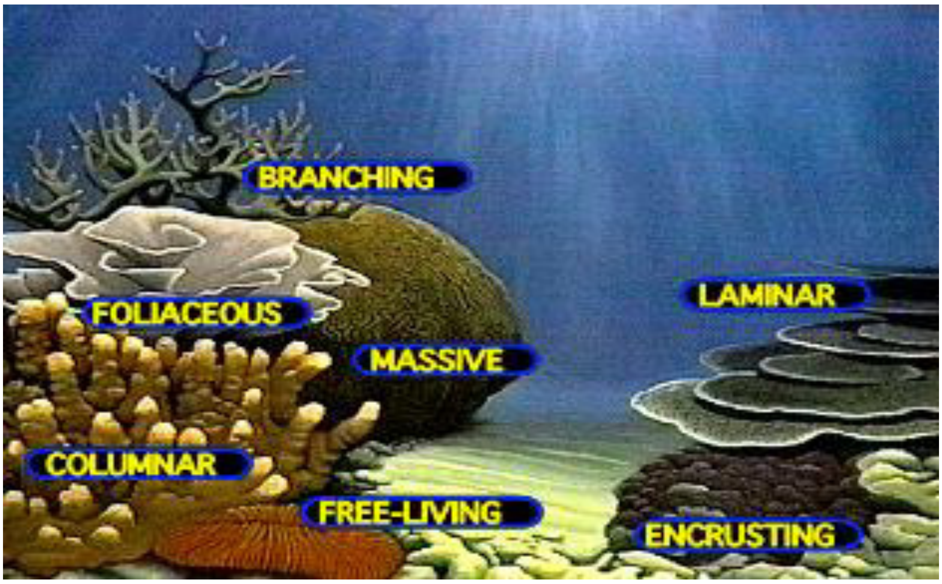


Fig. 1: Growth forms of coral colonies (http://www.endangeredspeciesinternational.org/images/coralreefs_side35.jpg).

Skeletal morphological features can be broadly grouped into three categories (Budd, 2009):

(1) *Macromorphology:* the size and shape of many features related to corallite structure and the integration of corallites within colonies (3D observations made using an optical microscope); (2) *Micromorphology:* the shapes of teeth and granules along the margins and surface area of septa (3D observations made using regular light or scanning electron microscopy of calical surfaces);

(3) *Microstructure:* the arrangements of centers and fibers within septa and the corallite wall (2D observations made using transverse thin sections and scanning electron microscopy of polished and etched transverse sections) (fig.2).

Of these three categories, macromorphological characters are important in traditional taxonomy at the generic and specific levels, whereas micromorphological characters are also important at the familial level and above (Wells, 1956).

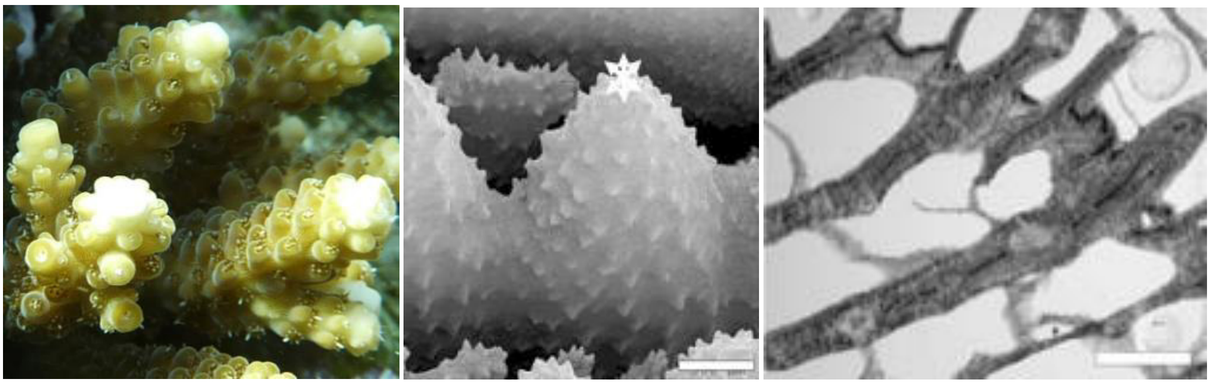


Fig. 2: left: Macromorphological features. (picture: J. Macken). Middle: Micromorphological features. SEM picture. Right: Microstructure features. Transverse petrographic thin section picture, and on polished and etched cuts using SEM (middle and right: Stolarski, 2009).

Almost all zooxanthallate coral species display a wide range of morphological variation (Veron, 1995). Phenotypic plasticity is high and either caused by genetic variation or by environmental influences. Factors as exposure to wave action, light and space availability and predation pressure may cause high morphological variations i. e. differences in skeletal structure (corallite) between individual coral polyps or varying parts within the same colony. In the contrary, morphological variations in corals occurring within the same environmental region are commonly genetically driven (Veron, 1995; Flot et al., 2007). Thus, each ecomorph is a product of genotype and the surrounding environment. Because of the high variability coral identification down to species level on the basis of morphological traits is difficult, in some cases even impossible. In recent years, species identification has been supported by molecular character states.

1.2 Molecular analysis.

In recent decades molecular methods became more and more important for species identification and for phylogentetic analysis. Molecular phylogenetic investigations have revolutionized our understanding of scleractinian evolution at all levels. Molecular data have provided new insight into scleractinian systematics and thus provided new hypotheses for the evolution of corals which has challenged traditional views on the ecology, evolution and biodiversity of these organisms (Frank, 2001; Fukami, 2008).

Molecular phylogenetic analyses have provided new perspectives on scleractinian evolution but they can also be problematic. Reef-building corals have been the focus of the majority of scleractinian molecular phylogenetic studies. Because of the symbiotic relationship of corals with zooxanthellae caution must be used in collecting sequence data from whole tissue. Mitochondrial DNA markers that have been useful for phylogenetic studies in most other organisms have low rates of molecular evolution in anthozoan mitochondrial DNA (Shearer 2002, 2008; Huang 2009). Thus, resolution of higher level relationships has been difficult. The majority of reef-building corals are broadcast spawners and hybridization seems to be common (Baird et al. 2009). Because of the possibility of interspecific hybridization and introgression it is difficult to clear up relationships at the generic level and below and questions the validity of species consepts applied so far. Another flaw of molecular analyses is the impossibility to collect molecular data from fossil samples.

1.3 Combination of morphological and molecular analysis

Comprehension of relationships at lower taxonomic levels will be best clarified by combined analyses of morphological and molecular characters. Integrating diverse types of data is critical for understanding the physical and biological events that have shaped scleractinian evolution. Molecular phylogenies are being used to inform our understanding of the evolution of morphological characters in the Scleractinia. Phylogenetic hypotheses for the Scleractinia based on molecular data provide a more complex

perspective on interrelationships of scleractinian families and genera than morphological hypotheses, yet still uncertainties remain at all levels. Finer-scale analyses of clades towards the tips of the trees, using morphological and molecular data, should lead to a better understanding both of relationships among genera as well as of the evolution of morphological characters (Budd, 2010).
Another advantage for combining molecular and morphological datasets of scleractinian corals is the implication of the diverse scleractinian fossil record.

Molecular analyses could be the basis for further morphological analyses. Novel relationships detected by molecular phylogenies suggest the presence of hitherto disregarded morphological characters that may diagnose the same clades (Fukami et al. 2008) ("reverse taxonomy"). Comparative methods to map morphological traits onto molecular "scaffold" trees should be used.

The identification of corals and the reconstruction of their phylogeny are aggravated due to the highly homoplastic morphology of this taxon. Coral skeletal micromorphology and skeletal microstructure may be less homoplastic than traditional skeletal macromorphology. Phylogenies based on a combination of macromorphology and micro-features are more consistent with molecular phylogenies than phylogenetic analysis based on traditional macromorphological characters alone.

The combination of morphological and molecular analysis will help to indentify corals down to species level and solve the relationships at any taxonomic level and may lead to ending confusion in scleractinian systematics. That is why we use both molecular and morphological methods for the investigation of coral biodiversity.

1.3 Study area

In the focus of our studies are two fringing reefs at Beau Vallon Bay in the northwest of Mahé, the largest of the granitic islands. One of the reefs is located along the coast of Mare Anglaise north of Beau Vallon the other fringing reef is at the southeastern end of the bay along the cost of Bel Ombre (fig. 3). The examined reef sections lie in shallow water areas down to about 5 m water depth (snorkelling depth). We have not worked in greater depths, because reef areas in shallow water are the most vulnerable ones.

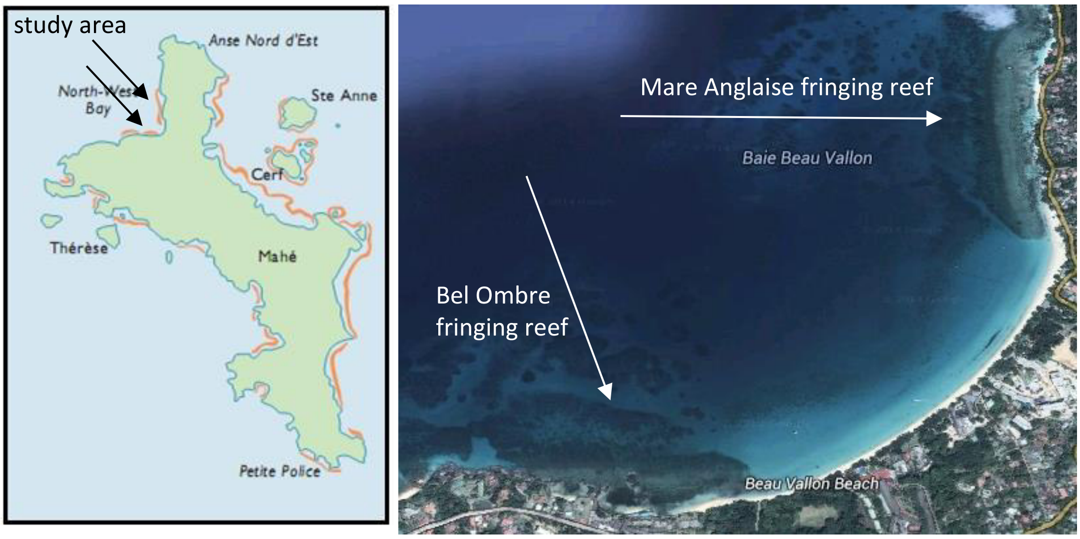


Fig. 3: Left: Mahé. Fringing reefs are shown in red. The study areas are the northern and the southeastern reefs of the North-West Bay (Beau Vallon Bay) (Turner et al., 2000). Right: The Beau Vallon Bay (North-West Bay) with the two fringing reefs along the coast of Mare Anglaise and Bel Ombre (google maps, 05.05.2014).

In June-September 2010, in Mai/June, 2011 and in April/Mai 2012 six transects with a total area of 1311m²) were mapped in detail in the northern fringing reef of Beau Vallon Bay (Mare Anglaise) (fig. 4; see report 2011 and 2012). Another transect in the northern part of the study area was investigated for a census of echinoderms from near shore to the reef edge (transect E 1) (see report, 2011). The transects T1-T5 run from east to west while T6 runs nearly from south to north with a divergent of 15° to the east. A total area of 1311m² was mapped in detail in this fringing reef.

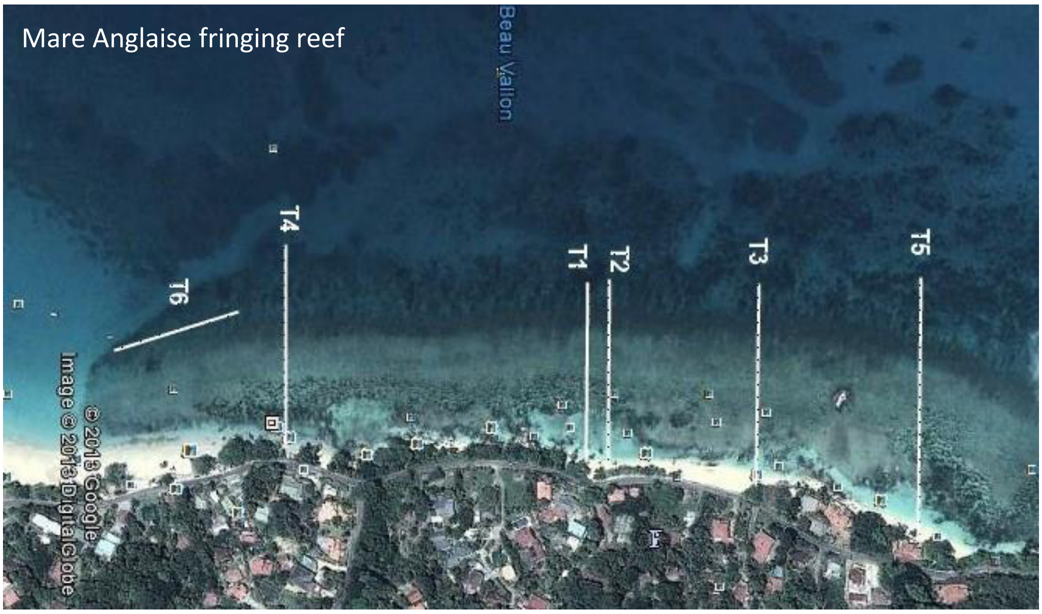


Fig. 4: The Mare Anglaise fringing reef (northern reef) at the Beau Vallon Bay and the position of transects T1-T6 (google maps, 12/2013). North is to the right.

In April/Mai 2013 another three transects (T7-T9) covering an area 576m^2 of were documented in the south-eastern reef of the Beau Vallon Bay along the coast of Bel Ombre (Bel Ombre fringing reef). T7 and T8 run from the beach to the reef edge (south to north), while T9 runs along the reef edge from east to west (fig. 5).

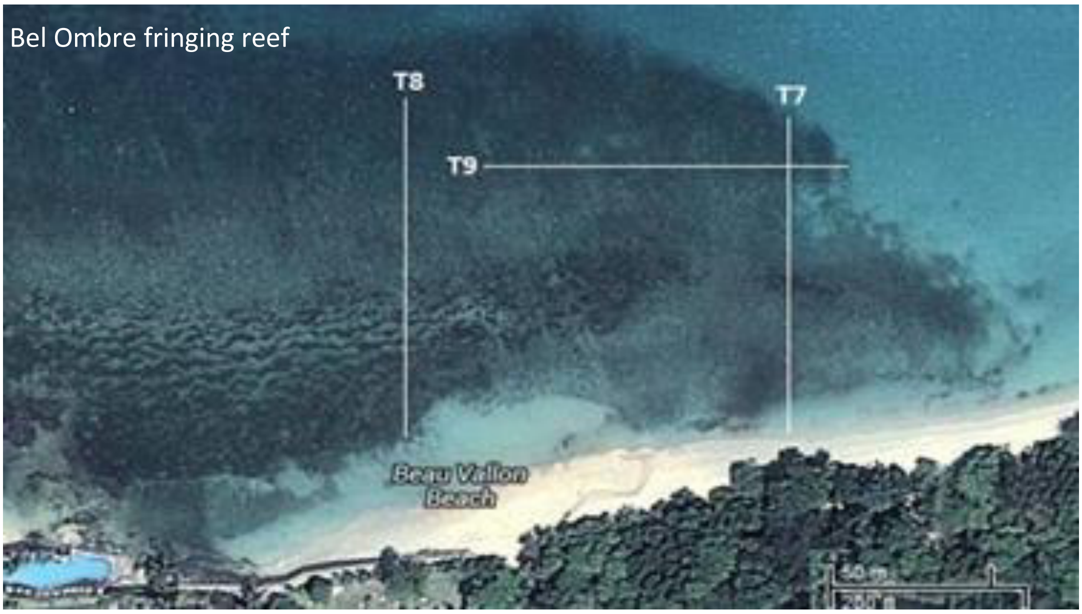


Fig. 5: The Bel Ombre fringing reef at the Beau Vallon Bay and the position of transects T7-T9 (google maps, 12/2013).

A brief general introduction including aspects of the biology of important reef organisms, a review of earlier studies on Seychelles' fringing reefs along the inner granitic islands and of the study goals was given in the 2011/2012 report and need not be repeated here.

2 Methods

During the last three years we have conducted Coral Reef Monitoring to investigate the diversity of corals and repeated the detailed mapping of selected sections of the study area to show changes in the coral composition over time.

In April 2013 three linear transects that cover a total area of 576m^2 were laid out in the fringing reefs of Bel Ombre, documented in detail and analyzed. Two of the three transects (T7 and T8) were laid out from south to north such that all zones (from the beach to the reef edge and occasionally upper parts of the reef front) were covered (fig 5). The other transect (T9) runs along the reef edge from west to east. As the focus is on the coral species mapping was begun only after the first coral colony was met. For a brief description of the reef zones, see Taylor 1968, Pillai 1973 or our 2011 report. For a detailed introduction into the biotope mapping methods see our report 2012.

In order to visualize the distribution and abundance of corals in the selected sections of the reef, four major methods were used: (1) photos; (2) silhouettes on the basis of photographs, (3) symbols for each species (symbols do not reflect the size of colonies accurately), indicating the position and number of corals per quadrant and (4) graphs summarizing the occurrence of species and the number of specimens per species.

Our investigations have been non invasive for the first three years (April 2010- April 2013). But now we have reached our limits in terms of identification corals using macromorphological features. The application of digital photography for macromorphological analyses is insufficient for species discrimination of quite a number of corals. In these cases micromorphological investigations and molecular analyses are inevitable. Therefore we took 90 small fragments from 50 colonies that occur in the examined transects or nearby in September 2013. But still the method is non invasive in so far as sample size does not cause any harm to the colonies.

2.1 Sampling Methods

Small fragments (0,5-2cm) from 45 coral colonies (two fragments of each colony) of 11 taxa (2 *Acanthastrea*, 26 *Acropora*, 11 *Favia*, 7 *Favites*, 6 *Goniastrea*, 2 *Goniopora*, 1 *Montastrea*, 10 *Montipora*, 4 *Pocillopor*a, 18 *Porites*, 3 *Stylophora*) were collected during snorkeling in selected sections oo the fringing reef of Beau Vallon Bay between 1-5m depth in September 2013. Each colony sampled was photographed in detail under water. Coral fragments were stored in 100% alcohol.

2.2 DNA Sequence analysis

The molecular analyses have been carried out in the laboratories at the Department of Phycology at Goettingen University (head: Prof. Dr. Th. Friedl). Mitochondrial genomes (mtDNA) are commonly utilized as adequate examination features for the investigation of species relations among animals. For species identification and their allocation into the "tree of life" we have amplified and sequenced the ITS2 region and parts of the COI region of 58 coral fragments (fig.6). The ITS2 region is a high variable region and is used for coral identification. It is allocated between the small (18S) and the large unit (26S) of the ribosomal DNA.

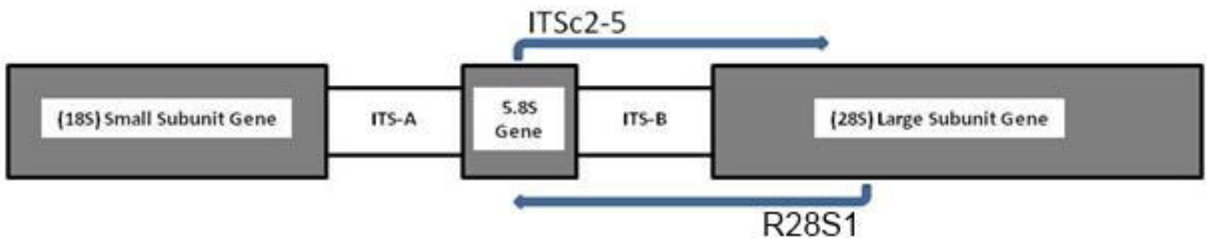


Fig. 6: Overview of the molecular marker (ITS2 region) of the mitochondrial DNA (rDNA). In this case the ITS2 region is named ITS-B. The blue arrows show the attachment point of the forward primer (ITSc2-5) and backward primer (R28S1) (changed according to: http://www.biotechniques.org/students/2008/tarbell/figure1).

Fig. 7: Overview of the molecular marker cytochrome c oxidase 1 gene ("CO1") of the mitochondrial DNA (mtDNA). The black arrows show the attachment point of the forward primer (LCO1490) and backward primer (HCO219) which amplify parts of the COI region during PCR (changed according to: http://tardigradebarcoding.org/images/coi-primer.gif).

The gene region that is being used as the standard barcode for almost all animal groups is a 648 base-pair region in the mitochondrial cytochrome c oxidase 1 gene ("CO1"). COI is not an effective barcode region for identifying corals because it evolves too slowly (fig. 7). The COI region is more conservative and is suitable for phylogenetic analysis. We have amplified and sequenced parts of this region from the coral samples as well.

Genomic DNA was extracted from the 58 coral samples by using a DNA extraction protocol (Waynes protocol) that we got from Jean-François Flot from the Max Planck Institute of Biotechnology in Goettingen and checked on a agarose gel. 7 samples of the 58 extracted samples failed.

The coral specific primer ITSc2-5 (5'-AGCCAGCTGCGATAAGTAGTG-3' and the reverse primer R28S1 (5'-GCTGCAATCCCAAACAACCC-3' were used to amplify the ITS2 region of rDNA, while for the COI region the foreward primer LCO1490 (5'-GGTCAACAAATCATAAAGATATTGG-3') and the reverse primer HCO2198 (5'-TAAACTTCAGGGTGACCAAAAAATCA-3') were used. Amplification were performed in 49µl reaction mix containing 37.75µl HPLC water, 10µl Ready Reaction Buffer (dNTP and $MgCl_2$ are included), 0.5µl Primer, 0.25µl Taq DNA Polymerase and 1µl (1:100, 1:50, 1:20, 1:10, 1)-5µl DNA template. For amplifying the ITS2 region PCR conditions comprised an initial denaturation step 60s at 94°C, followed by 40 cycles (30s denaturation at 94°C, 30s annealing at 56°C, 75s elongation at 72°C) and a final 5 min elongation step at 72°C. For amplifying parts of the COI region by PCR the thermal cycle included an initial denaturation step at 94°C for 60s, followed by 5 cycles composed of (30s denaturation at 94°C, 90s annealing 45°C for a few initial cycles to allow the primers to bind to the template, 60s extension at 72°C). Then 36 cycles following (30s denaturation at 94°C, 90s annealing at 52°C and 60s elongation at 72°C) and a final 5min elongation step at 72°C.

To check whether the PCR generated the anticipated DNA fragment, agarose gel electrophoresis was used for size separation of the PCR products. The size of PCR products is determined by comparison with a DNA ladder (a molecular weight marker), which contains DNA fragments of known size, run on the gel alongside the PCR products

PCR products were sequenced with the same primers as for amplifying. Detection of the fragments was done with the ABI Capilary-Sequencer by use of nucleotides marked with fluorescence.
Not all samples worked well for amplifying and sequencing (tab.1). If the forward primer didn't work for sequencing the reverse primer were used. But in some cases the reverse primer failed as well.

Tab. 1: Number of samples that worked well for amplifying (PCR) and sequencing

Process	Primer	No. of samples that worked
DNA-Extraction	-----	51
PCR	LCO1490/HCO2198	48
PCR	ITSc2-5/R28S1	42
Sequencing	LCO1490	41
Sequencing	HCO2198	3
Sequencing	ITSc2-5	28
Sequencing	R28S1	14

3 Results

A total of 116 coral species have been identified by morphological analyses from our transects in the two fringing reefs of Beau Vallon Bay until now (tab2-4). In the Transects (T1-T9) of the two fringing reefs of Beau Vallon Bay 30 coral species were newly identified, fourteen species in the Mare Anglaise fringing reef (T2 and T3) and sixteen species in the Bel Ombre-fringing reef (see tab. 2 and 4). In the Mare Anglaise fringing reef 97 species, in the Bel Ombre fringing reef 94 coral species were identified. A few species have not been determined with certainty, and in a few cases, two similar species had to be grouped as one taxon as their exact determination using photographs was not possible (e. g. *Goniastrea edwardsi* or *G. retiformis*). Ten additional species have been identified from outside the mapped areas. The colony number of some species e. g. *Discosoma* is just an estimated value, because it is not possible to distinguish between single colonies that clump together. Of a few species only one specimen was found (fig. 11, 14, 22 and 33).

3.1.1 The Mare Anglaise fringing reef

In July-September 2010, in Mai/June, 2011 and in April/Mai 2012 six transects (total area: 1311m²) were mapped in detail in the northern fringing reef fringing (GPS coordinates: S04° 35.923' / E055° 25.947'; S04° 36.412' / E055° 25.820') of Beau Vallon Bay (Mare Anglaise). Until now, the data from five (T1-T3, T5 and T6) of the six transects in the Mare Anglaise fringing reef have been studied in detail. Another transect (E1) in the northern part of the study area was investigated for a census of echinoderms from near shore to the reef edge (see report 2011). Their fauna and flora was documented by more than 25.000 photographs. Due to the amount of material not all of the data has been investigated in detail until now, i.e. transects 1 and 2, 3, 5 and 6. Transects 1 and 2 lie close to each other and cover an area of 479m^2 (T1: 160m^2, T2 319m^2), T3 covers an area about 318m^2, T5 covers 187m² and T6 covers 160m². In this report only T3 will be explained in more detail as the other transects (T1, T2, T5, T6 and E1) are already illustrated in the reports 2011 and 2012.

3.1.1.2 Lists of coral species in the Mare Anglaise fringing reef

In transects T1-T3, T5 and T6 82 coral species (42 genera) have been identified so far (tab. 2 and 3). Fourteen of these coral species were newly identified in the last year during new investigations of the photographic documentation (11 species in T3, 3 species in T2). Of a few species one specimen only was found (fig. 11). The coral species are listed below. The newly identified species were described and shown with pictures in a catalogue below. For detailed descriptions of the coral species already detected in the last three years and of the composition and abundance of the species in these transects see our 2011 and 2012 reports.

Tab. 2: List of corals found in T1-T3, T5 and T6 in the Mare Anglaise-frining reef.

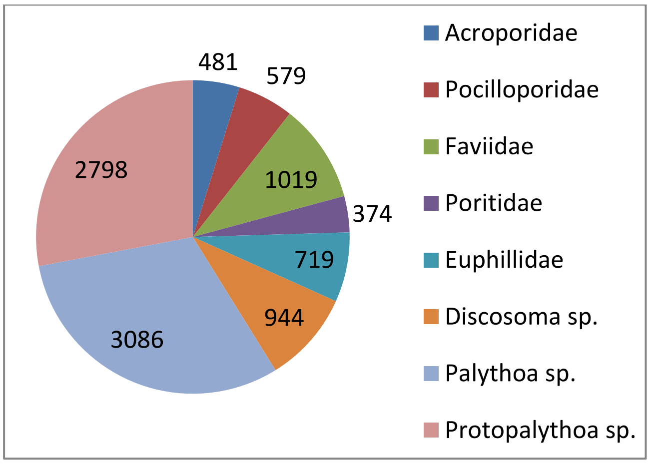
Acanthastrea brevis	*Favites* cf. *complanata*	*Montipora* spp.
Acanthastrea echinata	*Favites flexuosa*	*Montipora tuberculosa*
Acropora appressa	*Favites pentagona*	*Montipora turgescens*
Acropora cuneata or *A. palifera*	*Favites spinosa*	*Palythoa* cf. *tuberculosa*
Acropora digitifera	*Favites* spp.	*Pavona duerdeni*
Acropora divaricata	*Favites vasta*	*Pavona explanulata*
Acropora formosa	*Fungia* spp.	*Pavona frondifera*
Acropora humilis	*Galaxea astreata*	*Pavona* sp.
Acropora irregularis	*Galaxea fascicularis*	*Pavona varians*
Acropora longicyathus	*Gardineroseris planulata*	*Pavona venosa*
Acropora monticulosa	*Goniasstrea pectinata*	*Physiogyra lichtensteini*
Acropora pinguis	*Goniastrea edwardsi* or *G. retiformis*	*Platygyra acuta*
Acropora robusta	*Goniastrea* spp.	*Platygyra carnosus*
Acropora spp.	*Goniopora minor*	*Platygyra* sp.
Acropora tenuis	*Goniopora planulata*	*Plesiastrea versipora*
Acropora vermiculata or *A. verweyi*	*Goniopora* sp.	*Pocillopora damicornis*
Alveopora sp.	*Gorgonaria* gen. sp.	*Pocillopora eydouxy*
Astreopora myriopthalma	*Hydnophora excesa*	*Pocillopora meandrina*
Blastomussa cf. *merleti*	*Hydnophora microconos*	*Pocillopora verrucosa*
Corallimorpharia gen. spp.	*Leptastrea purpurea*	*Porites lobata or Porites lutea*
Cycloseris spp.	*Leptastrea transversa*	*Porites rus*
Cyphastrea micropthalma	*Leptoria phrygia*	*Protopalythoa* spp.
Discosoma spp.	*Lobophyllia hemprichii*	*Psammocora obtusangula*
Distichopora violacea	*Metarhodactis* sp.	*Sarcphyton cf. trocheliophorum*
Echinopora hirsutissima	*Millepora* sp.	*Sinularia* spp.
Echinopora lamellosa	*Montastrea curta*	*Stylocoeniella* sp.
Favia pallida	*Montastrea* spp.	*Stylophora pistillata*
Favia speciosa	*Montastrea valenciennesi*	*Stylophora subseriata*
Favia spp.	*Montipora grisea*	*Tubastrea sp.* or *Dendrophyllia sp.*
Faviidae gen. sp.	*Montipora informis*	*Turbinara stellulata or T. irregularis*
Favitea abdita or *F. complanata*	*Montipora monasteriata*	*Zoanthus* spp.

Tab. 3: Fourteen newly identified coral species in the Mare Anglaise-fringing reef (T1-T3).

Acropora appressa	*Aropora vermiculata* or *A verweyi*	*Goniopora* sp.
Acropora cuneata or *A. palifera*	*Blastomussa* cf. *merleti*	*Lobophyllia hemprichii*
Acropora humilis	*Favites flexuosa*	*Stylocoeniella* sp.
Acropora robusta	*Favia pallida*	*Millepora* sp.
Acroproa monticulosa	*Gardineroseris planulata*	

3.1.1.3 Transect 3. Diversity, abundance and distribution of coralsl species

Transect 3 runs exactly from west (near shore) to east (reef edge) and covers an area of 318m^2. More than 7.100 photographs were analyzed and 72 coral species (32 genera) were identified from which 11 coral species were newly identified. These 11 coral species do only occur in T3 but not in the other transects of the Mare Anglaise fringing reef.



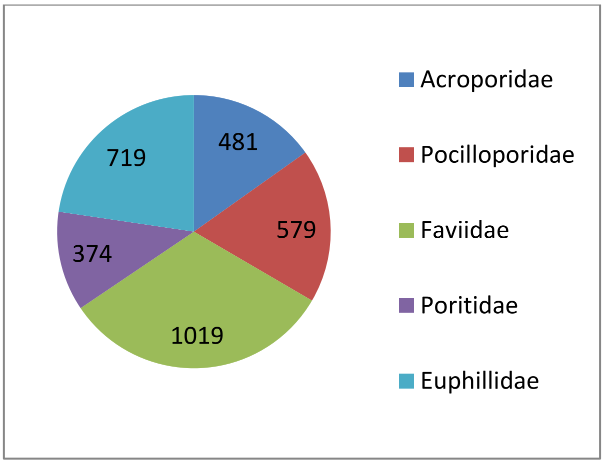


Fig. 8: Left: The eight most numerous coral taxa in transect 3. Right: The 5 most coral taxa of T3 without Protopalythoa sp., Palythoa sp. and Discosoma sp..

A total number of 10.994 coral colonies was counted in T3. There are 35 coral colonies in average in any square meter. Fig. 8 left shows the eight most dominant taxa in T3. These taxa provide 84% of all identified coral colonies. The colony number of *Discosoma* is just an estimated value, because it is not possible to distinguish between single colonies that clump together. *Palythoa* sp. is with 3086 colonies (9,7/m^2) and a percentage of 28,1% the most common species in number in this mapped section, followed by the Zoanthidea *Protopalythoa sp.* with 2798 coral colonies (8,8/m^2) and a percentage of 25,5%. These two taxa provide numerical more than 50% of all taxa found in T3. Fig. 8 right show the same taxa but without *Palythoa* sp., *Protopalythoa* sp. and the mushroom polype *Discosoma* sp. This three taxa are the most numerous taxa in T3, but also she smallest ones in diameter, especially *Protopalythoa* sp.. Large parts of the reef edge are covered with colonies of Discosoma sp. (926 colonies) and the Euphillidae *Galaxea fascicularis* (719 colonies).

The third common taxon is Faviidae with 1019 coral colonies (3.2/m^2) and 9,3%, followed by *Discosoma* sp. with 944 colonies (3/m^2) and 8,6%. The group *Goniastrea edwardsi* or *G. retiformis* which belongs to the Faviidae as well as *Pocillopora damicornis (Pocilloporidae)* are with 702 and 509 one of the most dominant species in T3. *Acropora* sp. is with 317 (without 126 colonies of *Acropora* sp. recruits) colonies stand-forming just as *Porites rus* and *Porites lutea* or *P. lobata* with 363 colonies due to their size (fig. 8 and 9).

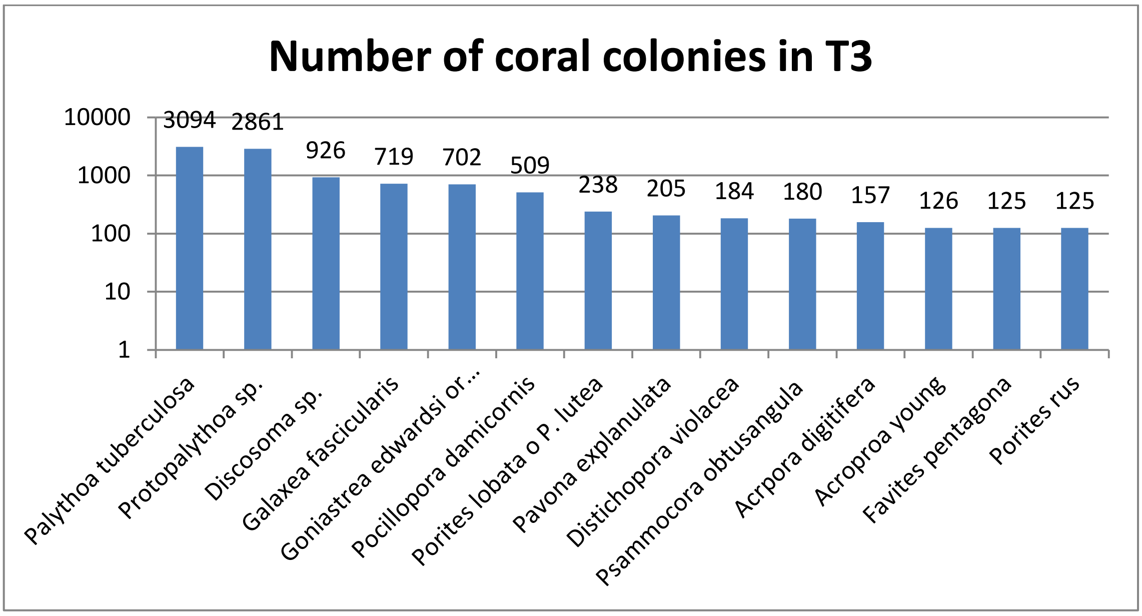


Fig. 9: The fourteen most common coral taxa in transect 3 and their number of coral colonies.

From the beginning of the reef flat to the reef edge, numbers in coral species and individuals increase continuously. Figure 10 visualizes the increase in number of coral colonies in T3 in relation the distance from shore. This does not apply to species which occur with one specimen only.

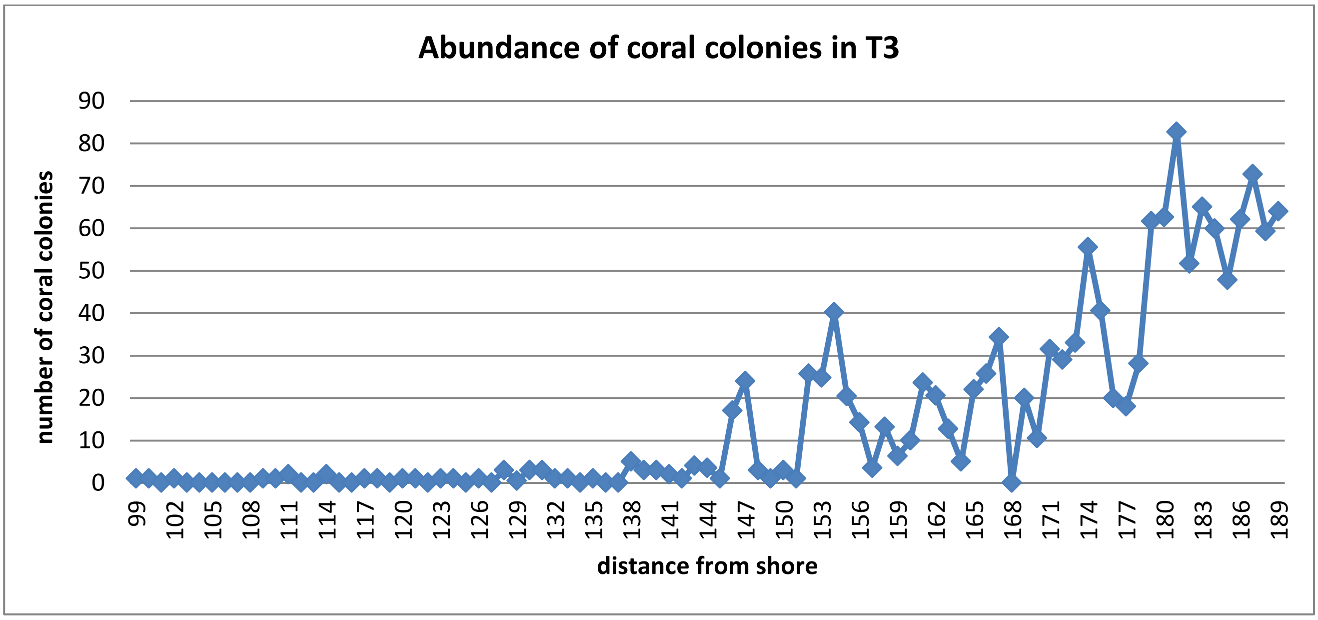


Fig. 10: Increasing abundance of coral colonies in T3 from east (reef flat) to west (reef edge).

In the following two figures all taxa found in T3 and their number of colonies is shown. For taxa with less than 40 colonies in T3, see fig. 12, for taxa with more than 40 colonies see fig. 11.

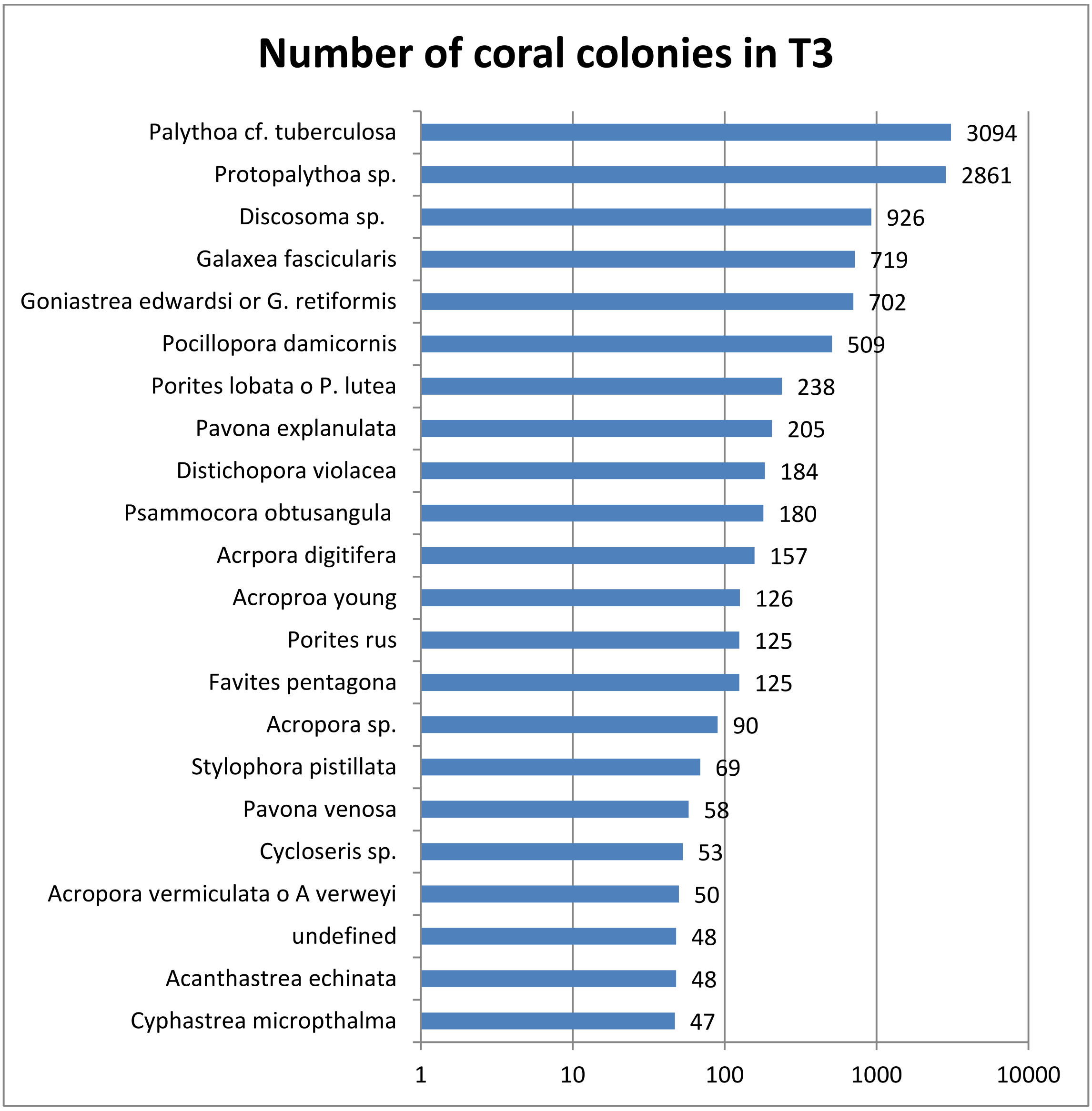


Fig. 11: Taxa which occur with more than 40 colonies in T3 and the number of colonies per taxa.

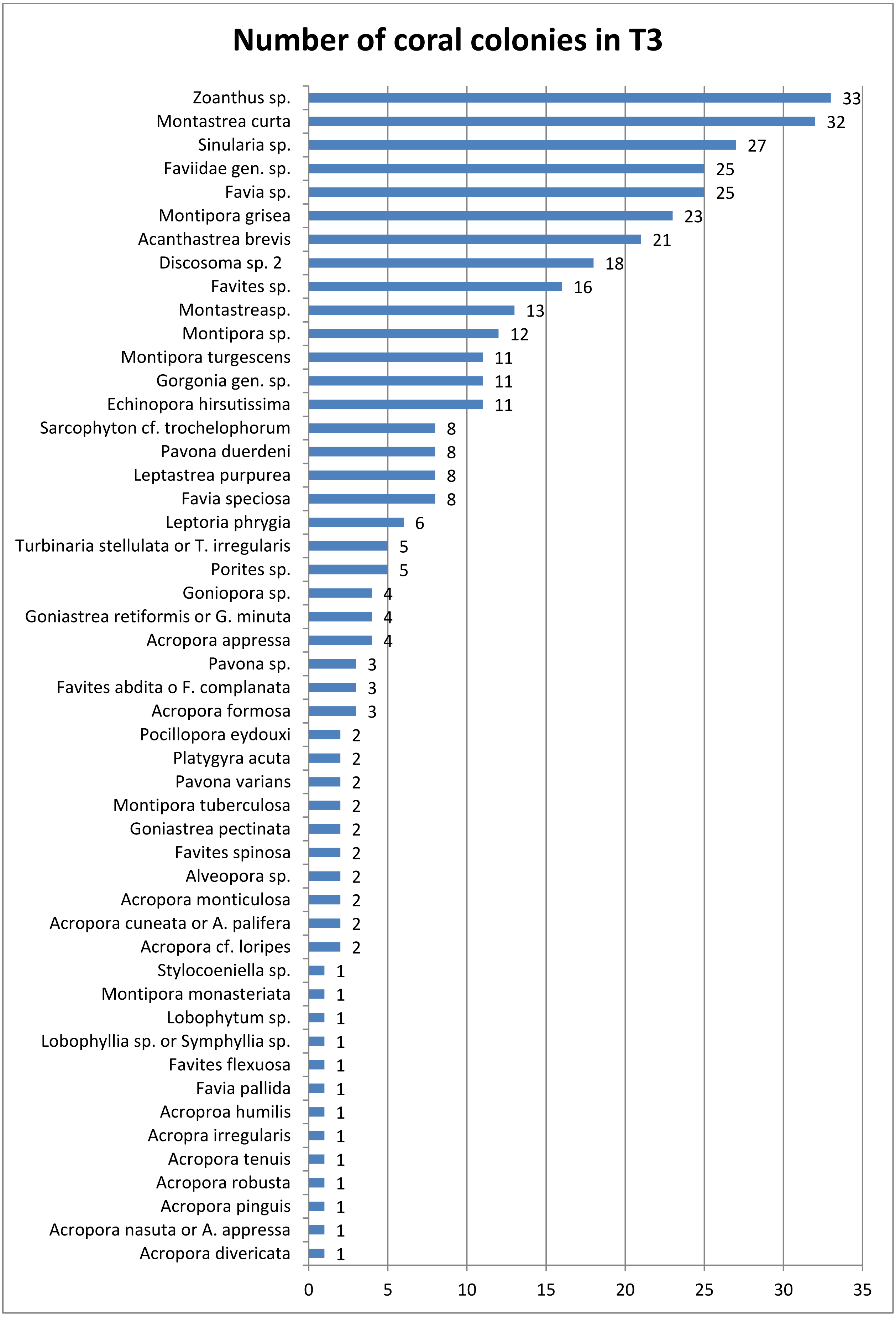


Fig. 12: Taxa which occur with less than 40 colonies in T3 and the number of colonies per taxa.

3.2.1 The Bel Ombre fringing reef

In April/Mai 2013 three transects (T7-T9) with a total area of 576m^2 were documented in the Bel Ombre-fringing reef (GPS coordinates: S04° 36.866' / E055° 25.422'; S04° 36.868' / E055° 25.370') and ca. 23.000 photographs were analyzed. Due to the amount of material the data of the eastern part of transect 8 has not been investigated in detail so far. This part will be analyzed in 2014. T7 and T8 runs from the shore (south) to the reef edge (north) and cover an area of 193 m^2 and 185 m². T9 runs from east to west along the reef edge and cover an area of 198 m². In this report T7, the western part of T8 and T9 will be explained in more.

3.2.1.1 Lists of coral species in the Bel Ombre fringing reef

In transects T7-T9 82 coral species (45 genera) have been identified so far (tab. 4). Seventy of these species were newly identified and have not been found in the six transects of the Mare-Anglaise fringing reef (tab. 5). The newly identified species are described and pictured in a catalogue below.

Tab. 4: List of corals found in T7-T9 in the Bel Ombre-frining reef.

Acanthastrea brevis	*Favites* cf. *spinosa*	*Pavona decussata*
Acanthastrea echinata	*Favites pentagona*	*Pavona duerdeni*
Acropora appressa	*Favites* spp.	*Pavona explanulata*
Acropora formosa	*Favites vasta*	*Pavona frondifera*
Acropora cf. *nana*	*Fungia* spp.	*Pavona* sp.
Acropora digitifera	*Galaxea astreata*	*Pavona varians*
Acropora divaricata	*Galaxea fascicularis*	*Pavona venosa*
Acropora gemmifera	*Gardineroseris planulata*	*Physogyra lichtensteini*
Acroproa humilis	*Goniastrea edwardsi* or *G. retiformis*	*Platygyra acuta*
Acropora irregularis	*Goniastrea* spp.	*Platygyra carnosus*
Acropora loripes	*Goniopora* cf. *planulata*	*Platygyra crosslandi*
Acropora nobilis or Acropora formosa	*Goniopora lobata* or *G. columna*	*Plesiastrea versipora*
Acropora spp.	*Goniopora minor*	*Pocillopora damicornis*
Acroproa tenuis	*Goniopora* sp.	*Pocillopora eydouxi*
Acropora verweyi or *A. rosaria* or *A. loripes*	*Gorgonaria* gen. sp.	*Pocillopora meandrina*
Alveopora cf. *daedalea*	*Heliofungia actiniformis*	*Pocillopora verrucosa*
Alveopora spp.	*Herpolitha limax*	*Porites lobat* or *Porites lutea*
Astreopora cf. *listeri*	*Hydnophora exesa*	*Porites rus*
Astreopora myriophthalma	*Hydnophora microconos*	*Protopalythoa* sp.
Corallimorpharia gen. spp.	*Leptastrea purpurea*	*Psammocora digitata*
Cycloseris sp.	*Leptastrea transversa*	*Psammocora obtusangula*
Cyphastrea microphtalma	*Leptoria phrygia*	*Psammocora superficialis*
Dendrophyllia or Tubastrea sp.	*Lobophyllia hemprichii*	*Sarcophyton* spp.
Diploastrea heliopora	*Metarhodactis* spp.	*Sarcophyton* cf. *trocheliophorum*
Discosoma spp.	*Montastrea* cf. *curta*	*Stylocoeniella* sp.
Distichopora violacea	*Montastrea* spp.	*Stylophora pistillata*
Echinopora hirutissima	*Montastrea vallenciennesi*	*Stylophora subseriata*
Echinopora lamellosa	*Montipora monasteriata*	*Tubastrea* or *Dendrophyllia*
Edwardsiidae gen. sp.	*Montipora* spp.	*Turbinaria irregularis* or *T. stellulata*
Favia spp.	*Palythoa* cf. *tuberculosa*	*Turbinaria* spp.
Faviidae gen. sp.	*Pavona cactus*	*Zoanthus* spp.
Favites abdita or *F. complanata*	*Pavona clavus*	

Tab. 5: List of newly identified corals found in three transects (T7-T9) in the Bel Ombre-frining reef.

Acropora gemmifera	*Astreopora* cf. *listeri*	*Pavona cactus*
Acropora microphthalma	*Corallimorpharia* gen. spp.	*Pavona clavus*
Acropora cf. *nana*	*Diploastrea heliopora*	*Pavona decussata*
Acroproa nasuta	*Edwardsiidae* gen. sp.	*Plesiastrea versipora*
Acropora verweyi or *A. rosaria* or *A. loripes*	*Heliofungia actiniformis*	*Psammocora digitata*
Alveopora cf. *daedalea*	*Goniopora* sp.	*Sarcophyton* sp.
Alveopora sp.	*Herpolitha limax*	

3.2.1.2 Transect 7. Diversity, abundance and distribution of coral species

Transect 7 runs from south (near shore) to north (reef edge) and covers an area of 193m^2. More than 7.300 photographs were analyzed and 72 coral species (32 genera) were identified. A total number of 10288 coral colonies were counted in T7. In the following two figures all taxa found in T7 and their number of coral colonies is shown. Taxa which appear with more than 40 colonies in T7 are illustrated in fig. 13, taxa with less than 40 colonies are shown in fig. 14.

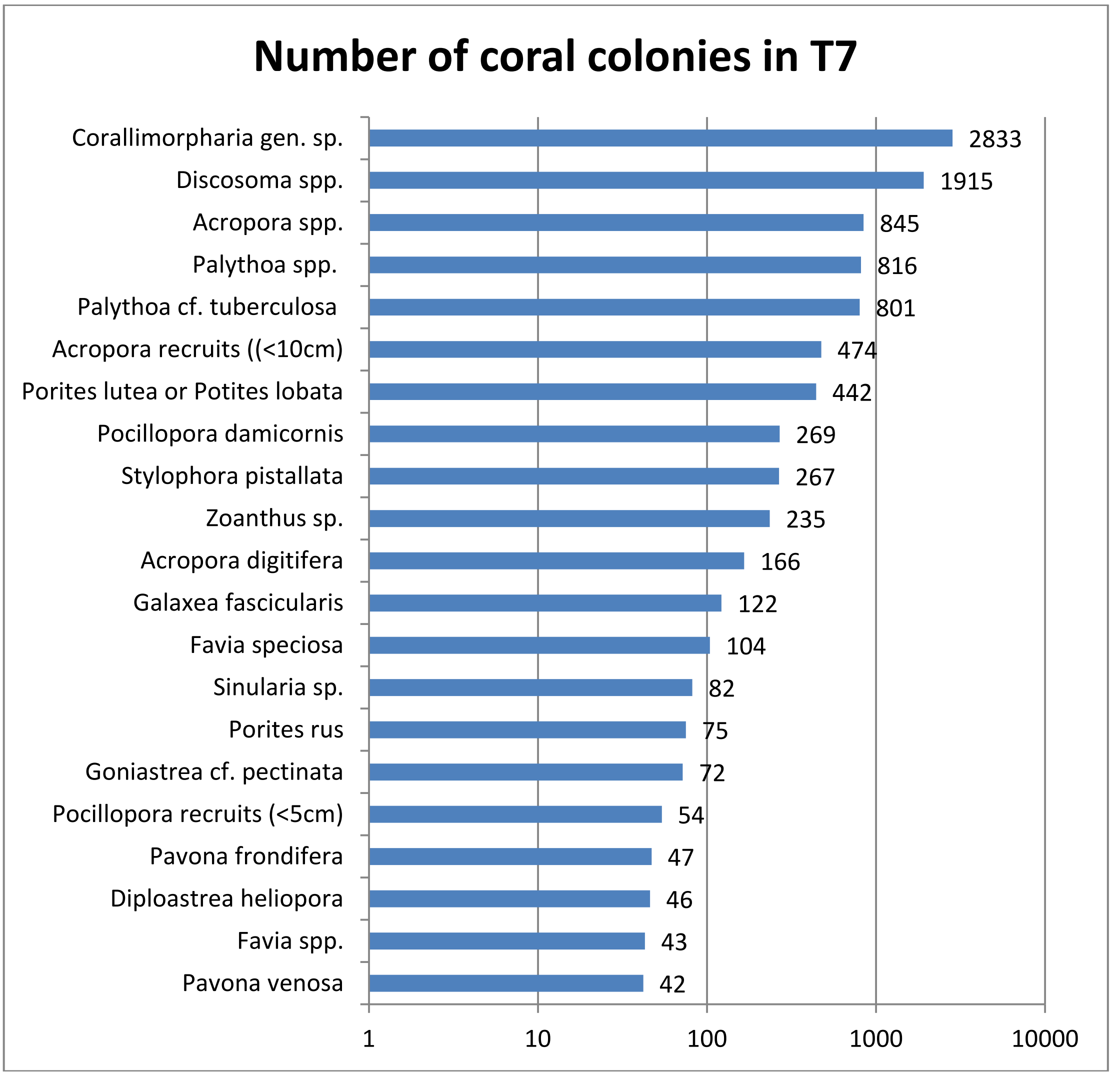


Fig. 13: Taxa which occur with more than 400 colonies in T7 and the number of colonies per taxa.

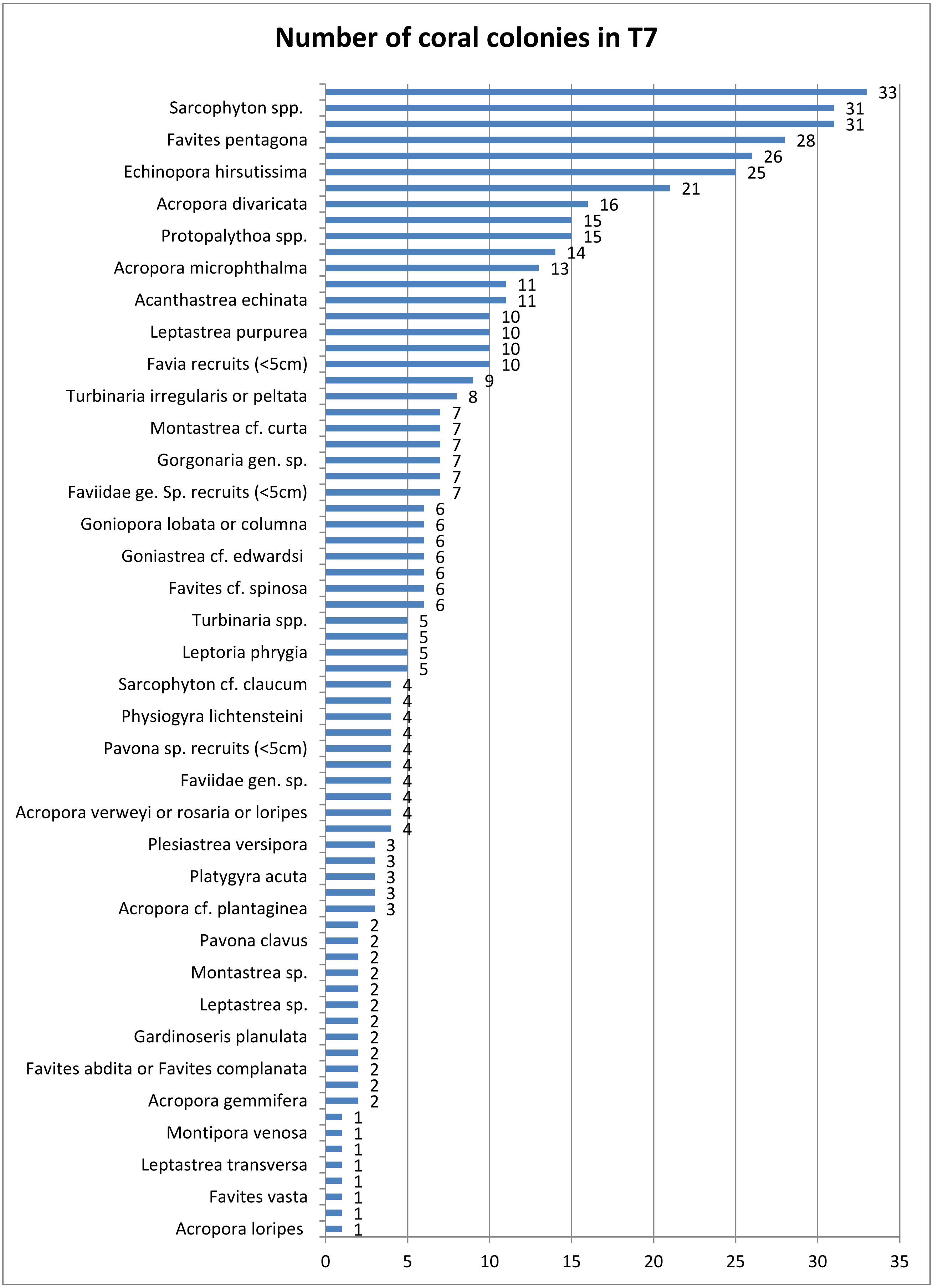
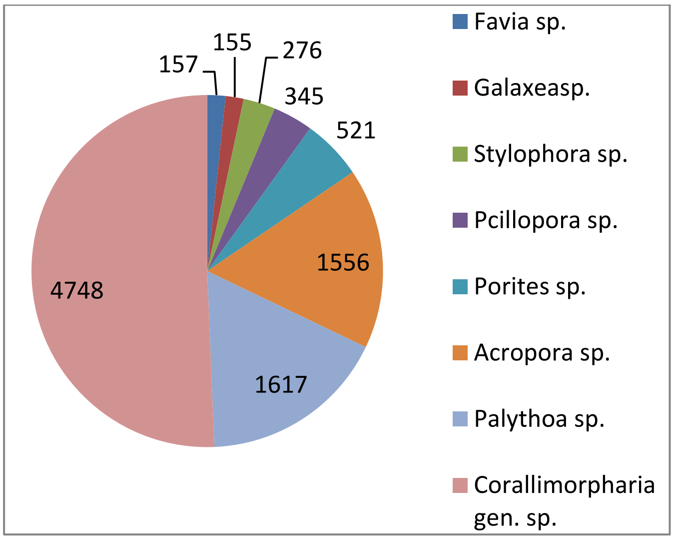


Fig. 14: Taxa which occur with less than 40 colonies in T7 and the number of colonies per taxa.

Figure 15 left shows the eight most common taxa of T7. These eight taxa provide 90% of all identified coral colonies, whereby Corallimorpharia gen. sp. is represented with 45%. With 1915 colonies *Discosoma* sp. is the most common mushroom polype in number. The second most common taxon is the Zoanthidea *Palythoa* spp. with 1617 coral colonies. Together they provide nearly one third of the counted colonies. Large parts of the reef edge are covered with colonies of Corallimorpharia gen. sp.. Fig. 15 right shows the same taxa without the mushroom polype Corallimorpharia gen. sp. and *Palythoa* spp.. These taxa are the most numerous taxa in T7, but also she smallest ones in diameter. *Acropora* spp. is stand-forming, whereby *Acropora digitifera* is the most common taxon with 166 colonies. The group *Porites lutea* or *P. lobata* (442 colonies) as well as *Pocillopora damicorni* (269 colonies) and *Stylophora pistillata* (267 colonies) are one of the most dominant species and characterized for T7 due to their size.



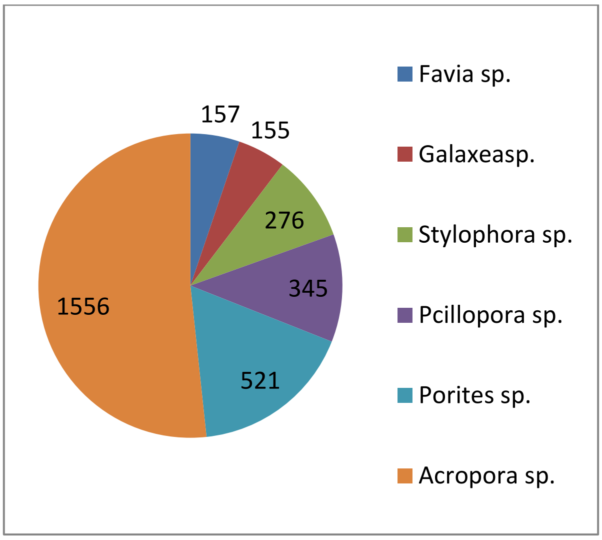


Fig. 15: The eight most numerous coral taxa in transect 7. Right: The six most coral taxa of T7 without Corallimorpharia gen. sp. and Palythoa spp. which are the most common but also the smallest colonies in diameter.

From the beginning of the reef flat to the reef edge, numbers in coral species and individuals increase continuously. Fig. 16 and 17 describe the coral diversity (number of coral taxa) and the abundance and distribution of coral colonies in the quadrants from near shore to the reef edge in T7. The biodiversity and the abundance of corals increase with the distance from shore. In average there are 13 coral colonies and 6 different taxa in a quadrant. In the first quadrants (99m-113) the number of coral colonies as well as the number of coral taxa is low, in four of them (100l and 100r, 108l and 108r) no single coral colony was found. An increase of coral colonies as well as coral taxa with general fluctuations is recorded from quadrant 109 on. A maximum of coral diversity is reached in the two quadrants 142.1l 150.1r and 150.2r, 154.2l with 15 different taxa whereas quadrant 144l exhibit with 379 coral colonies (12 taxa) the highest abundance. In some quadrants a relatively high number of coral colonies occurs but diversity is low, e.g. quadrant 140 compounds of 53 coral colonies but only six taxa. A marked decline of coral diversity and abundance is indicated in a few quadrants, e.g. 141, 147, 147.156).

Quadrants with an extra high density of coral colonies and a low number of coral taxa can be pronounced with a very high number of Corallimorpharia gen. sp., *Discosoma* sp. und *Palythoa* sp.

The taxa are relative equally allocated in the transect but the abundance changed toward the reef edge. At the beginning of the reef a few small colonies of *Acropora* sp. and *Pocillopora damicornis* as well as *Favia* sp. and *Stylophora pistallata* are common but rare in number. The number of coral colonies and coral species increase towards the reef edge. Large parts of the reef edge are covered with Corallimorpharia gen. sp., *Discosoma* sp. und *Palythoa* sp.

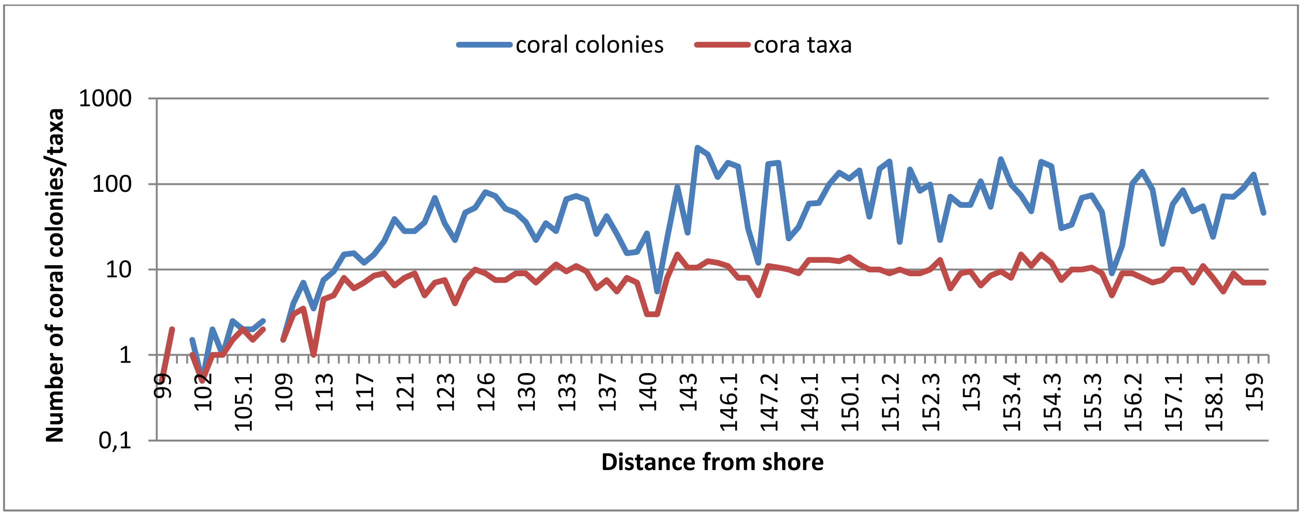


Fig. 16: Number of coral colonies (blue line) and number of taxa (red line) in T7 from near shore to the reef edge.

Transect 7 is separated in an eastern and a western half. In the field, the two halves were separated by a marked rope that was laid out for exact measurements. Following graphics show the coral coverage and recruitment of the eastern side of transect7.

3.2.1.3 Coral coverage of transect 7

The living coral coverage per quadrant of T7 (eastern side) from near shore to the reef edge is demonstrated in figure 17. At the beginning of the reef (near shore) is the coral coverage low (less than 1%). The coverage increases and reaches a maximum in quadrant 126r (45%). Furthermore there is a strong decline of coverage in the quadrants 140r and 141r recorded. Afterwards the coverage rises up to 40 % till in quadrant 150.1r the highest peak (77 %) is reached. In average there is a living coral coverage of 35.3 % per quadrant on the eastern side of T7.

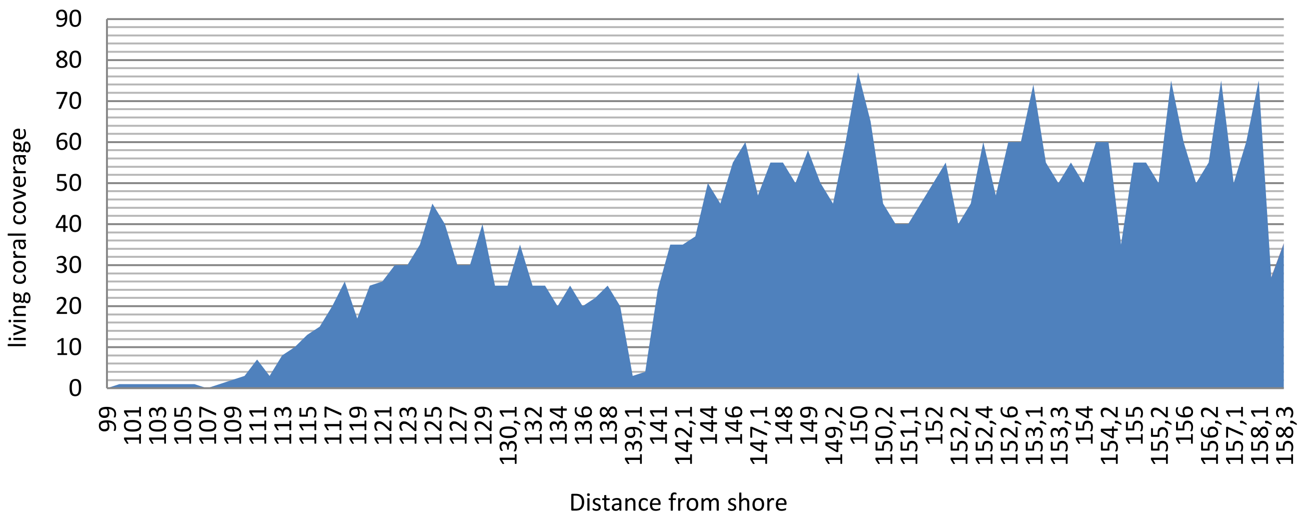


Fig. 17: Living coral coverage per quadrant in the eastern side of transect 7 from near shore to the reef edge.

3.2.1.4 Coral recruitment in transect 7

Coral recruitment is an important factor in coral reef stability and in recovery following disturbances as well as for future growth of a reef. The abundance of coral recruits and their growth can be observed with the remapping of the selected sections in the reefs.

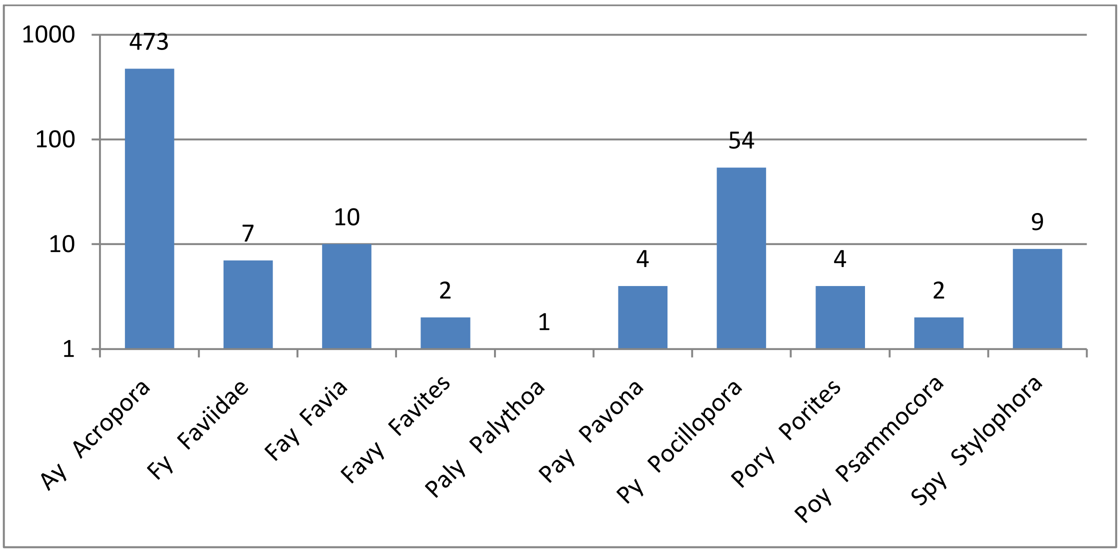


Fig. 18: Number of recruits of different coral taxa in transect 7(eastern side).

In 96 quadrants on the eastern side of T7 566 coral recruits were observed. The most abundant recruits are *Acropora* sp. with 473 colonies followed by *Pocillopora* sp. with 54 colonies. The number of recruits of other taxa is low (Fig. 18). In average 6 recruits are located per quadrant. Probably not all coral recruits were recognized, because of their size.

Recruitment is very variable in the single quadrants of the transect. Figure 19 shows the distribution of recruits in the quadrants of T7 (eastern side). The highest occurrence of recruits is in the quadrants 126r-135r whereby the highest frequency is in quadrant 127r with 57 colonies. In 22 quadrants no recruits were found.

The number of dead corals and their distribution in T7 is represented in figure 20. A total of 280 dead coral were found in the 96 quadrants. Most of the dead corals occur in the quadrants 122r-134r similar to the abundance of coral recruits shown in the graphic above. The highest frequency is in quadrant 131 with 27 dead colonies. In 36 quadrants no dead corals were found. In average 3 dead corals were detected per quadrant.

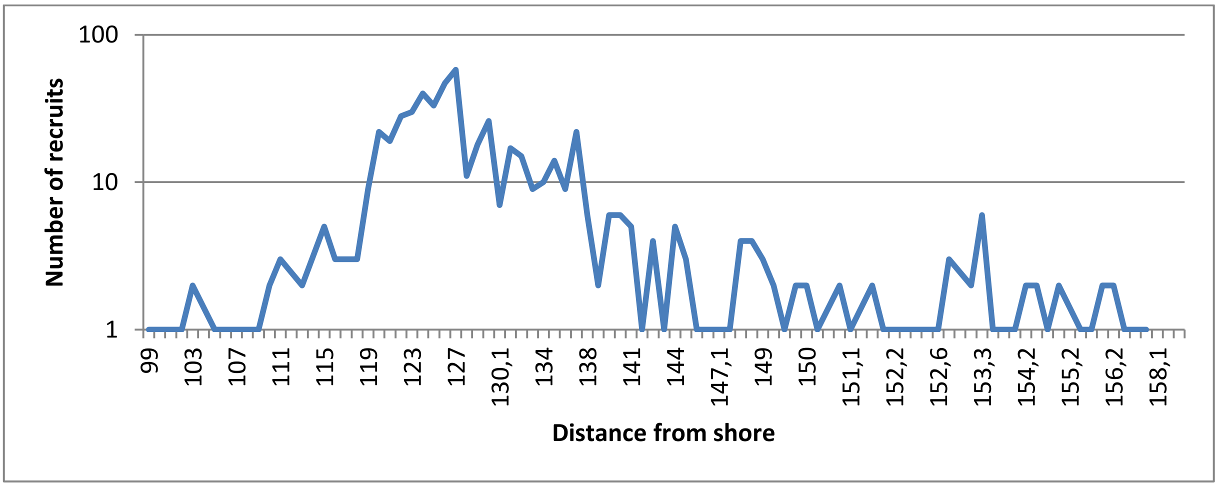


Fig. 19: Number of coral recruits and their abundance in the quadrants of T7 (eastern side).

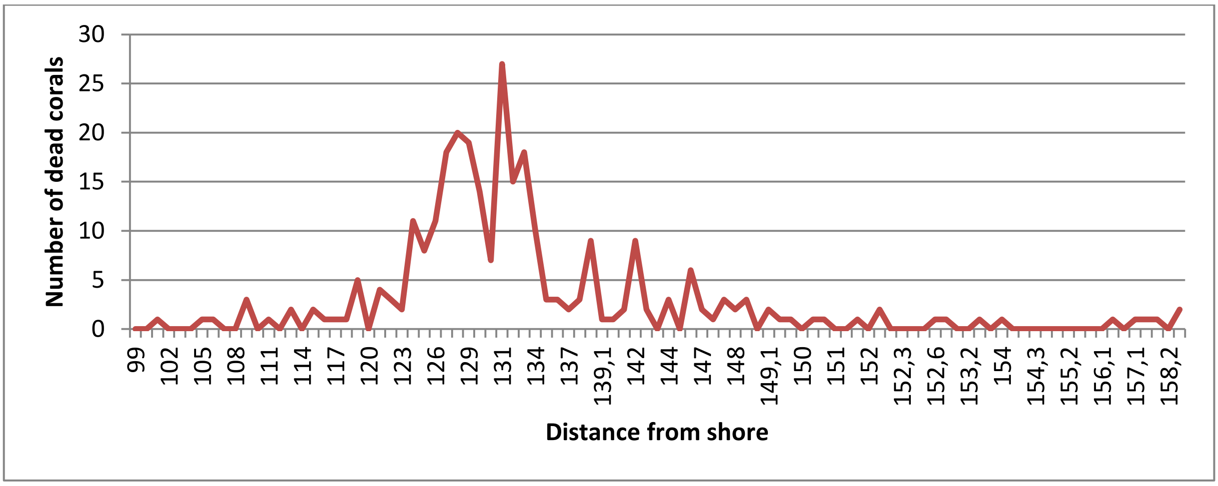


Fig. 20: Number of dead corals and their abundance in the quadrants of T7 (eastern side).

3.2.2.1 Transect 8. Diversity, abundance and distribution of coral species

Transect 8 (T8) is allocated ca. 100m to the west of transect 7 and runs from south (near shore) to north (reef edge). It covers an area of 185m^2. T8 is separated in a western and an eastern part by a marked rope. More than 7.700 photographs were taken. Only the western side of the transect that covers an area of 90 m^2 was analyzed so far. More than 3600 photographs were analyzed in detail. 47 coral species (33 genera) were identified. A total number of 3229 coral colonies were counted in T8.

3.2.2.2 Coral abundance and biodiversity of transect 8

In the following two figures all the taxa found in T8 and their number of coral colonies is shown. All taxa with more than 40 colonies in T7 are shown in fig. 21, taxa with less than 40 colonies in fig. 22.

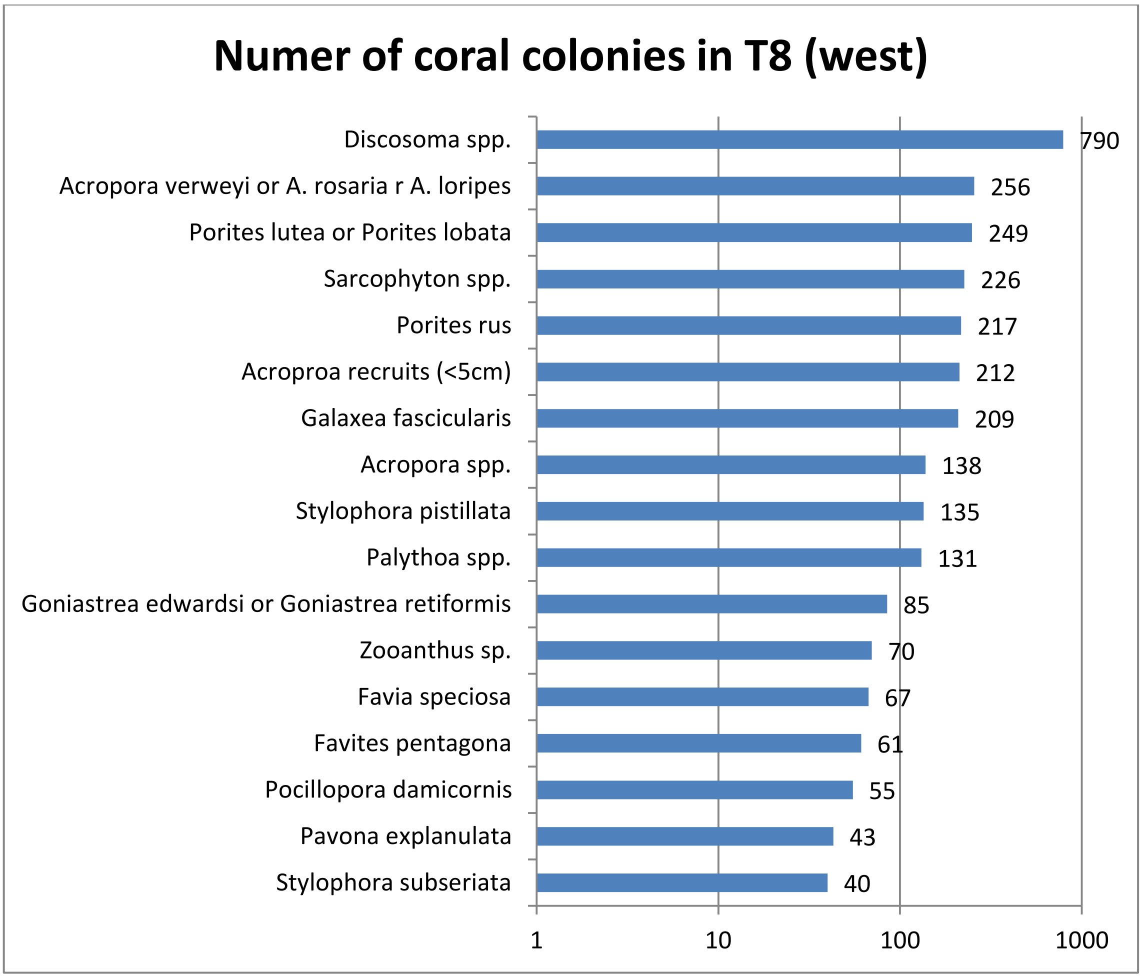


Fig. 21: Taxa which occur with more than 40 colonies in the western side of T8 and number of colonies per taxa.

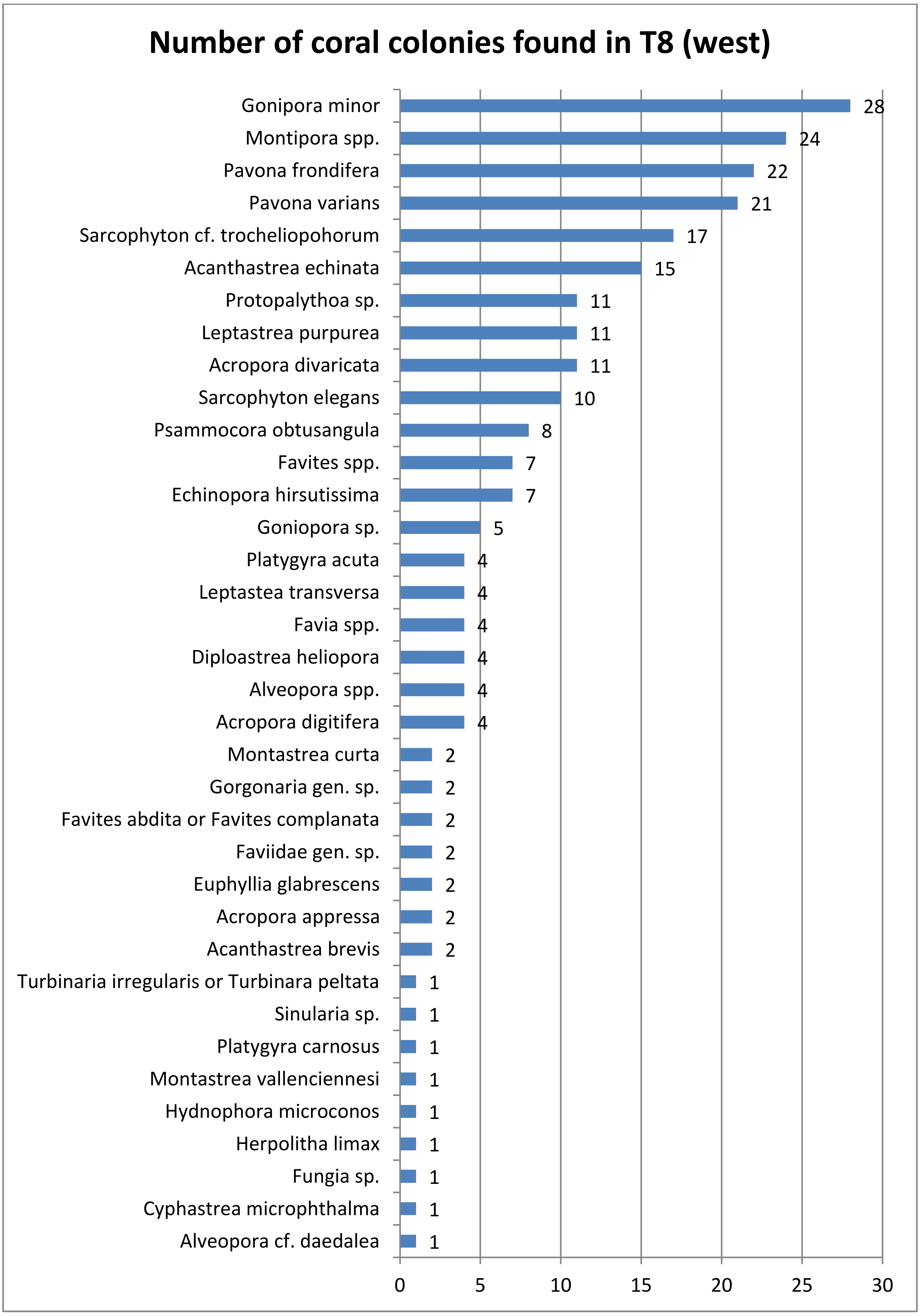


Fig. 22: Taxa which occur with less than 40 colonies in the western part of T8 and number of colonies per taxa.

Figure 23 shows the eight most common taxa in the western part of transect 8. They provide 82% of all identified coral colonies. With 790 colonies *Discosoma* -one of the smallest colonies in size- is the most common species in number in this mapped section, followed by *Acropora* with 606 colonies, *Porites* (466 colonies) and *Sarcophyton* (226). These three taxa provide numerical 58% of all taxa found in the western part of T8. *Galaxea* (209), *Stylophor*a (135), *Palythoa* (131) and *Goniastrea* (85) provide 24% of all coral colonies found in T8 (west). Figure 24 shows eight taxa which cover the largest area in the western side of T8. These eight taxa occupy 35.5% of the surface in the western part of T8, where by *Porites* cover with 15.8% almost half of it. Hence, *Porites* is the most dominant taxon and is together with *Acropora* (5.6%), *Sarcophyton* (5.2%) and *Goniastrea* (3.2%) stand forming. *Stylophora* (1.7%) and *Galaxea* (0.8%) is a common taxon in the middle section of T8 (quadrant 119-142). The estimated colony number of *Discosoma* leads to a coverage of 2.4%. This taxon covers large parts at the reef edge.

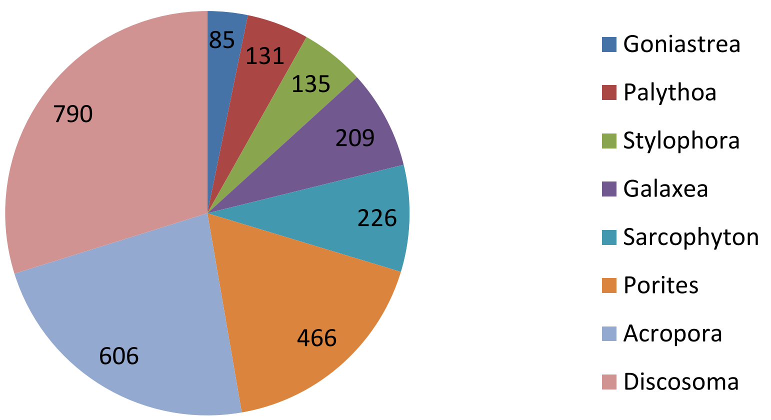


Fig. 23: The eight most numerous coral taxa in the western part of T8.

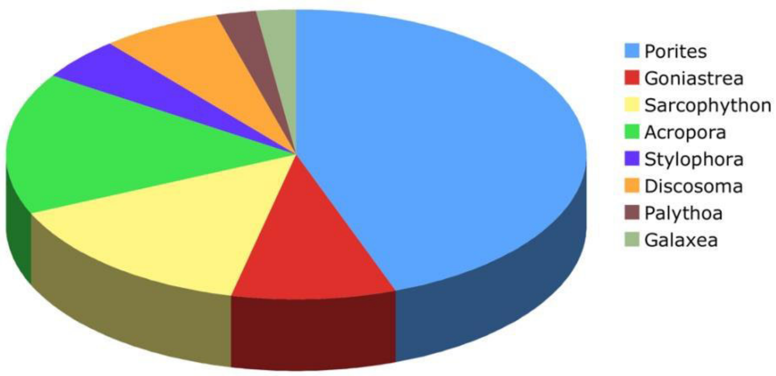


Fig. 24: Percentage amount of the eight most common coral in the western part of T8.

The western part of T8 is dominated by *Porites lutea* or *P. lobata*, S*arcophython* sp., *Acropora verweyi* or *A. rosaria* or *A. loripes*, *Goniastrea edwardsi* or *G. retiformis*, *Stylophora pistillata*, *Porites rus*, *Galaxea fascicularis*, *Discosoma* sp. and *Palythoa* sp.. These nine taxa are spread variously along the transect. While *Acropora verweyi* or *A. rosaria* or *A. loripes* is only represented at the beginning of the transect in the first 35 meters *Porites lutea* or *P. lobata*, *Porites rus*, S*arcophython* sp. and *Discosoma* sp, are dominant in the last third of the transect. *Galaxea fascicularis and Stylophora pistillata* appear particularly in the middle of the T8. *Goniastrea edwardsi* or *G. retiformis* is common on the reef flat with two agglomerations in the middle of T8 in quadrants 123-146.2 as well as in the backward reef in quadrants 98-105. This taxon is variably distributed over the entire section.

3.2.2.3 Coral coverage of T8 (western side)

From the beginning of the reef flat to the reef edge, numbers in coral species and individuals and the coral coverage increase. The living coral coverage per quadrant of T8 (western side) from near shore to the reef edge is shown in figure 25. At the beginning of the reef (near shore) coral coverage is low (less than 1% in quadrant 94). Coverage increases and is highest at the reef edge whereby the quadrant 145.3 exhibits with 100% the highest coverage of living corals. Furthermore there is a strong decline of coverage in quadrants 137, 146 and 151r.

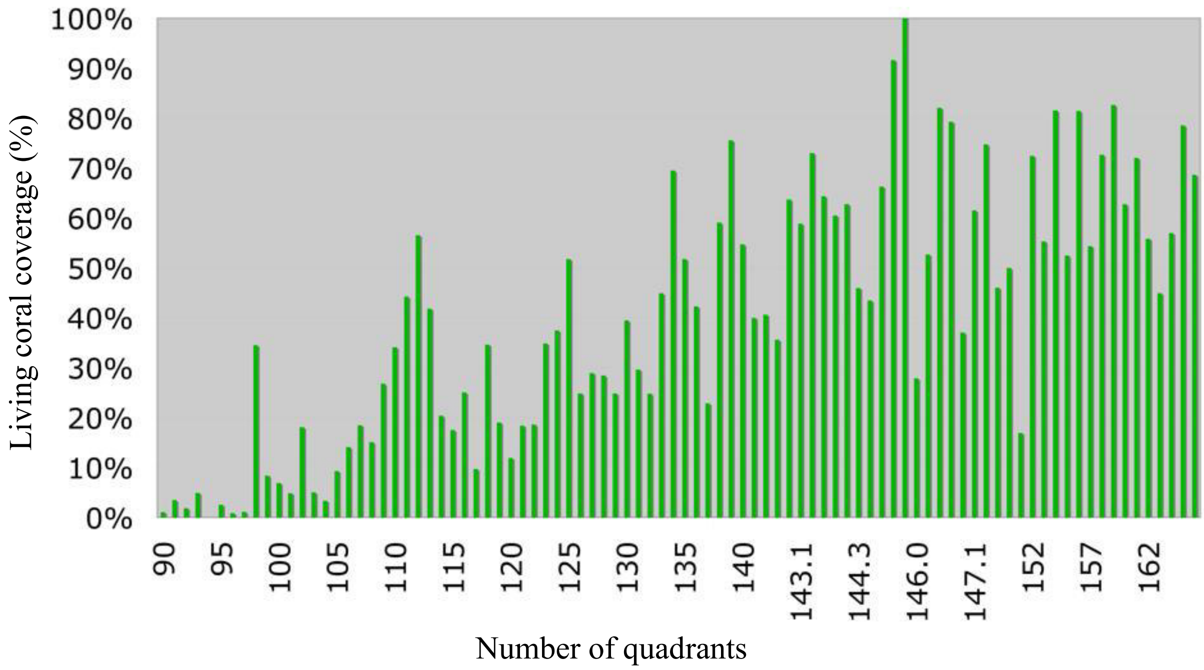


Fig. 25: Distribution of living coral coverage per quadrant in the western part of T8 from near shore (left) to reef edge.

Figure 26 indicates the coral coverage per quadrant and the distribution of all coral species in the quadrants of transect 8.

The percentage of dead corals and their distribution in the western part of T8 is represented in figure 27. Most of the dead corals occur in the middle section of T8 in the quadrants 142.0 (13.6%) and 143.0 (13.7%). The number of dead corals decreases to the reef edge as well as the backward reef. The number of dead coral colonies is lower near shore than at the reef edge like the number of living coral colonies. There is no distinct correlation between the living and the dead coral coverage.

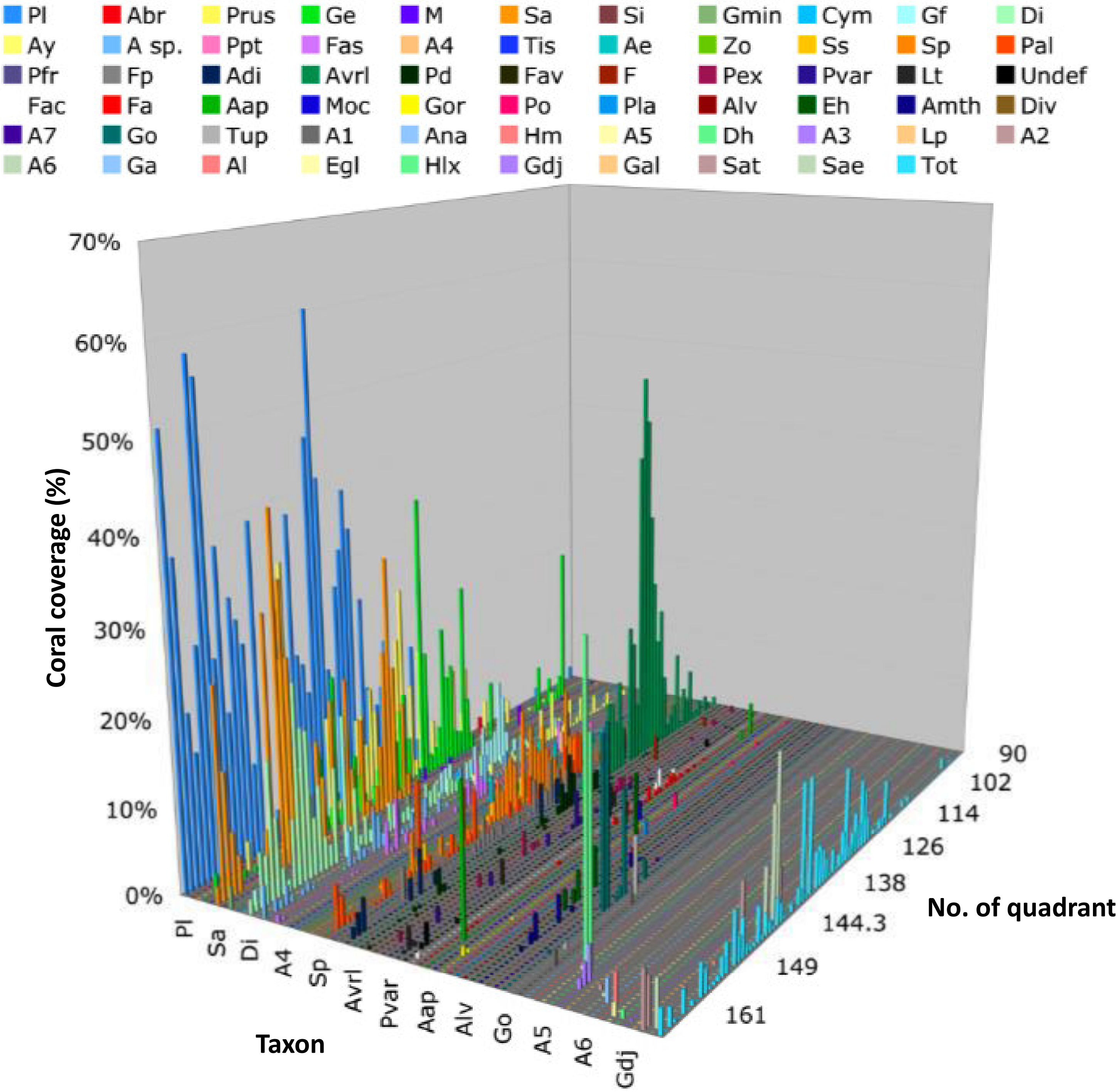


Fig. 26: Coral coverage (%) of all coral species per quadrant in the western part of T8.

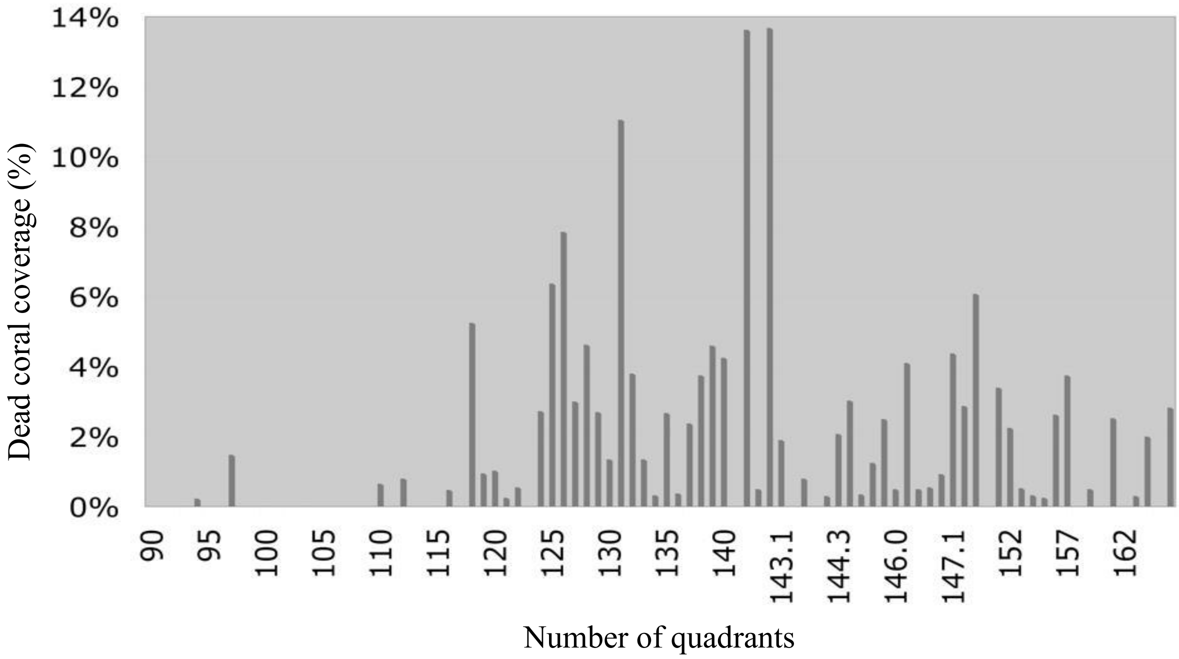


Fig. 27: Distribution of dead corals per quadrant in the western part of T8.

3.2.2.4 Coral bleaching and coral disease

Coral colonies are strongly affected by Coral bleaching in the last three decades. This phenomenon is related to higher water temperatures. Corals rely on unicellular algae (Zooxanthellae) that live inside each coral polyp and provide nutrients and supplemental oxygen. Bleaching occurs when these colorful algae die or leave the polyps, often in response to warmer conditions. Without their brightly colored algae, the coral's skeleton becomes visible through its transparent tissue and appears white. If the conditions do not enhance in time, the colonies can`t recover and die off. Furthermore, bleaching can make corals more susceptible to disease and, in turn, coral disease can compound the negative effects of bleaching.

In the western part of transect 8 a total of 240 dead coral colonies were found. In addition there are a lot of coral colonies which show partial mortality. Damaged coral colonies and coral bleaching were observed as well. However, it should be noted that not all damaged colonies and coral diseases were recognized, because often the analyzed pictures do not show all sides of the colonies.

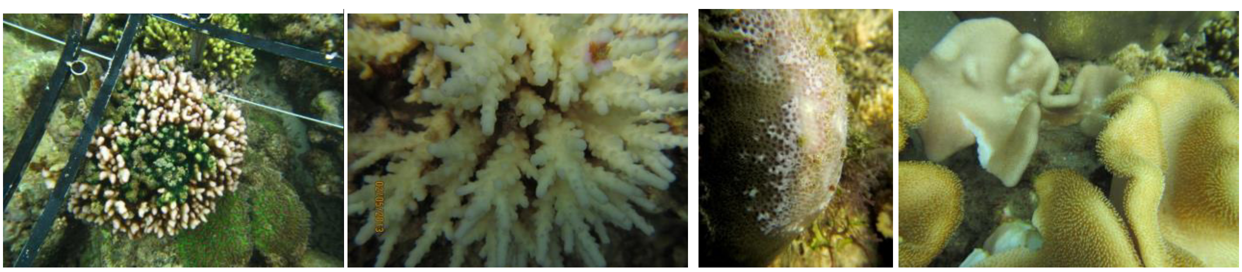


Fig. 28: Partly damaged *Stylophora pistillata* in quadrant 139l. Middle left: bleached *Acropora* in quadrant 124l. Middle right: A coral disease on *Porites lutea/P. lobata* in quadrant 102l. Right: damaged *Sarcophyton* in quadrant 152l.

Figure 28 illustrates the number of coral colonies that are dead, damaged, bleached or exhibit recognized diseases. Most of the coral colonies show partial mortality. Coral bleaching is the second most harm. Some coral colonies reveal coral diseases but this is not further analyzed. Damaged corals are distributed in the transect due to snorkeler or fishermen.

But there are positive developments in T8 as well with respect to coral recruitment. Coral recruitment is an important factor in coral reef stability and in recovery following disturbances as well as for future growth of a reef. In the western part of the transect a total of 573 coral recruits were counted (colony size: <10cm), from which 184 coral recruits are between 5-10cm in size and 389 colonies are less than 5 cm.

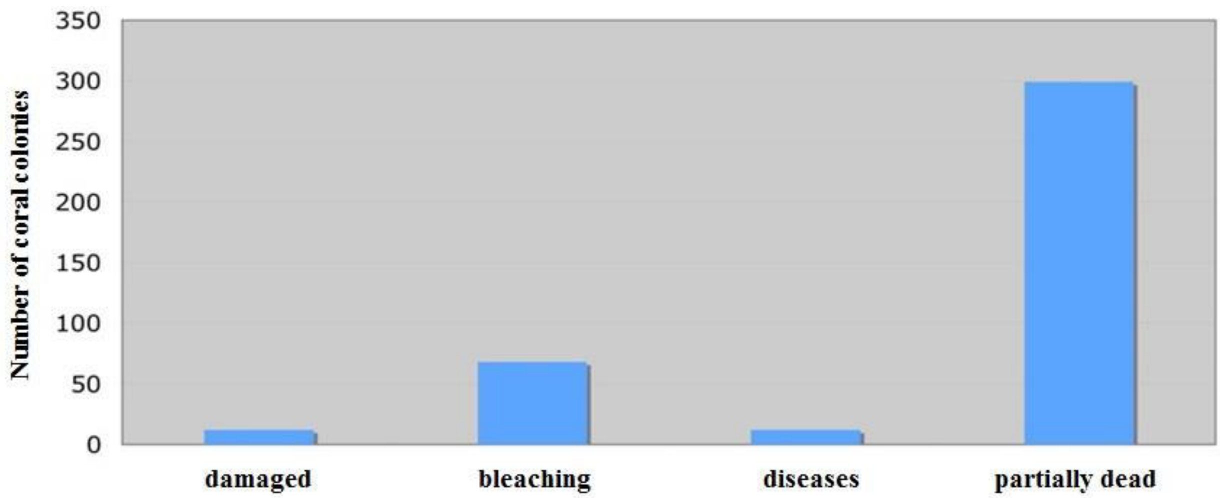


Fig. 29: Number of coral colonies with bleached, damaged, invalid or dead parts in T8.

3.2.3.1 Transect 9. Diversity, abundance and distribution of coral species

Transect 9 (T9) runs along the reef edge from east to west and covers an area of 198m^2. More than 8.600 photographs were taken and analyzed. 79 coral species (39 genera) were identified. A total number of 11939 coral colonies were counted in T9 with an average of 67 coral colonies per quadrant. This high number of colonies is correlated with the high estimated number of Corallimorpharia. Without this mushroom polype the average of coral colonies per quadrant is 30. Fig. 30 shows the eleventh most dominant taxa in T9. These taxa provide 96.9% of all identified coral colonies. The colony number of Corallimorpharia is just an estimated value, because it is not possible to distinguish between single colonies that clump together. This taxon is with a number of 6637 colonies (37.1/m^2) and a percentage of 55.6% the most common species in number in transect 9, followed by the Zoanthidea *Palythoa* with 1405 coral colonies (7.9/m^2) and a percentage of 11.8%. This both taxa provide numerical one third of all taxa found in T9. Fig. 31 show the same taxa but without Corallimorpharia and *Palythoa.* This both taxa are the most numerous taxa in T9, but also she smallest ones in diameter, especially Corallimopharia. Most of the Corallimorpharia belongs to the taxon *Discosoma*. Large parts of the reef edge are covered with colonies of the mushroom polype *Disocsoma sp*. (5549 colonies). The most common Scleractinia is *Acropora* with 928 colonies (5.2/m^2) and a percentage of 7.8%. *Stylophora* (708 colonies), *Porites* (679 colonies) and *Pocillopora* (246) are together with *Acropora* stand forming and belongs to the most represented taxa in T9.

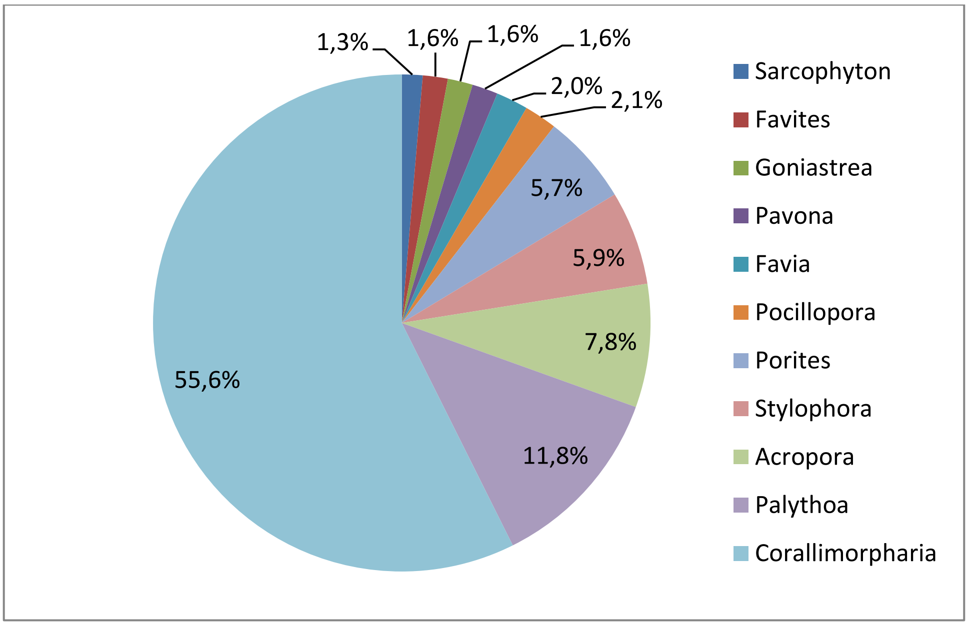


Fig. 30: Percentage amount of the eleven most common coral taxa in T9.

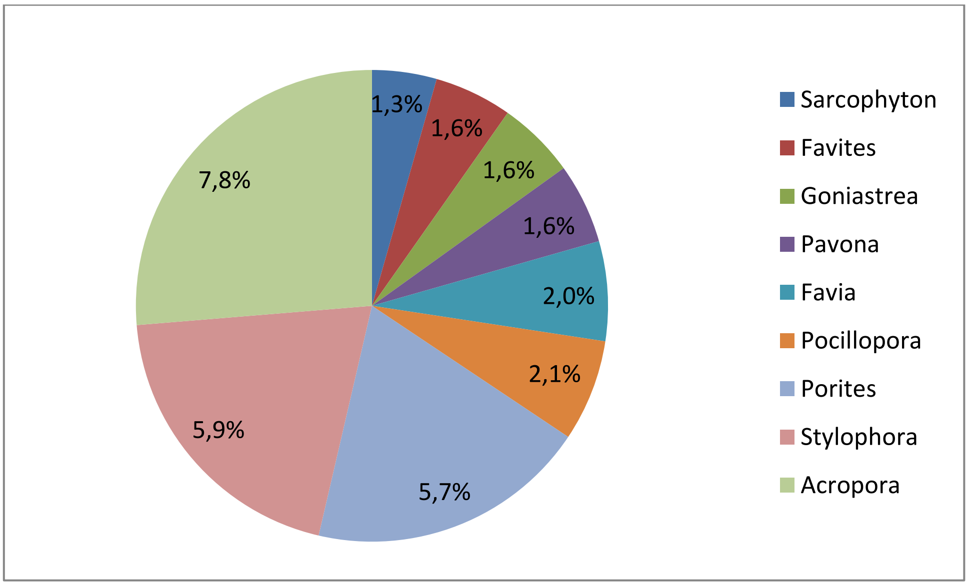


Fig. 31: Percentage amount of the most common coral taxa without Corallimorpharia and *Palythoa* in T9.

The next two figures display all taxa found in T9 and their number of coral colonies. Taxa which appear with more than 10 colonies in T9 are illustrated in fig. 32. All taxa with less than 11 colonies are shown in fig. 33.

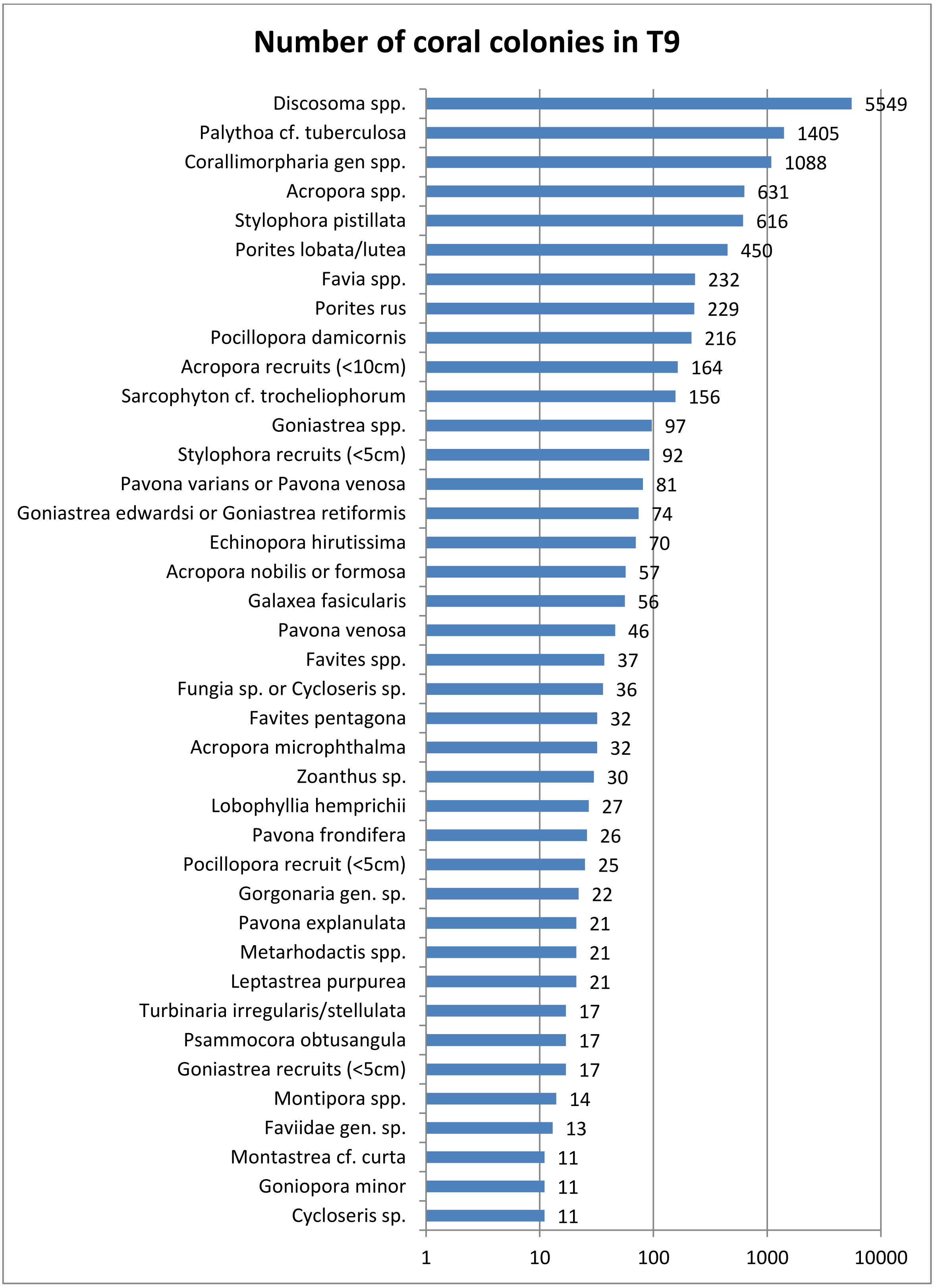


Fig. 32: Taxa which occur with more than 10 colonies in T9 and number of colonies per taxa.

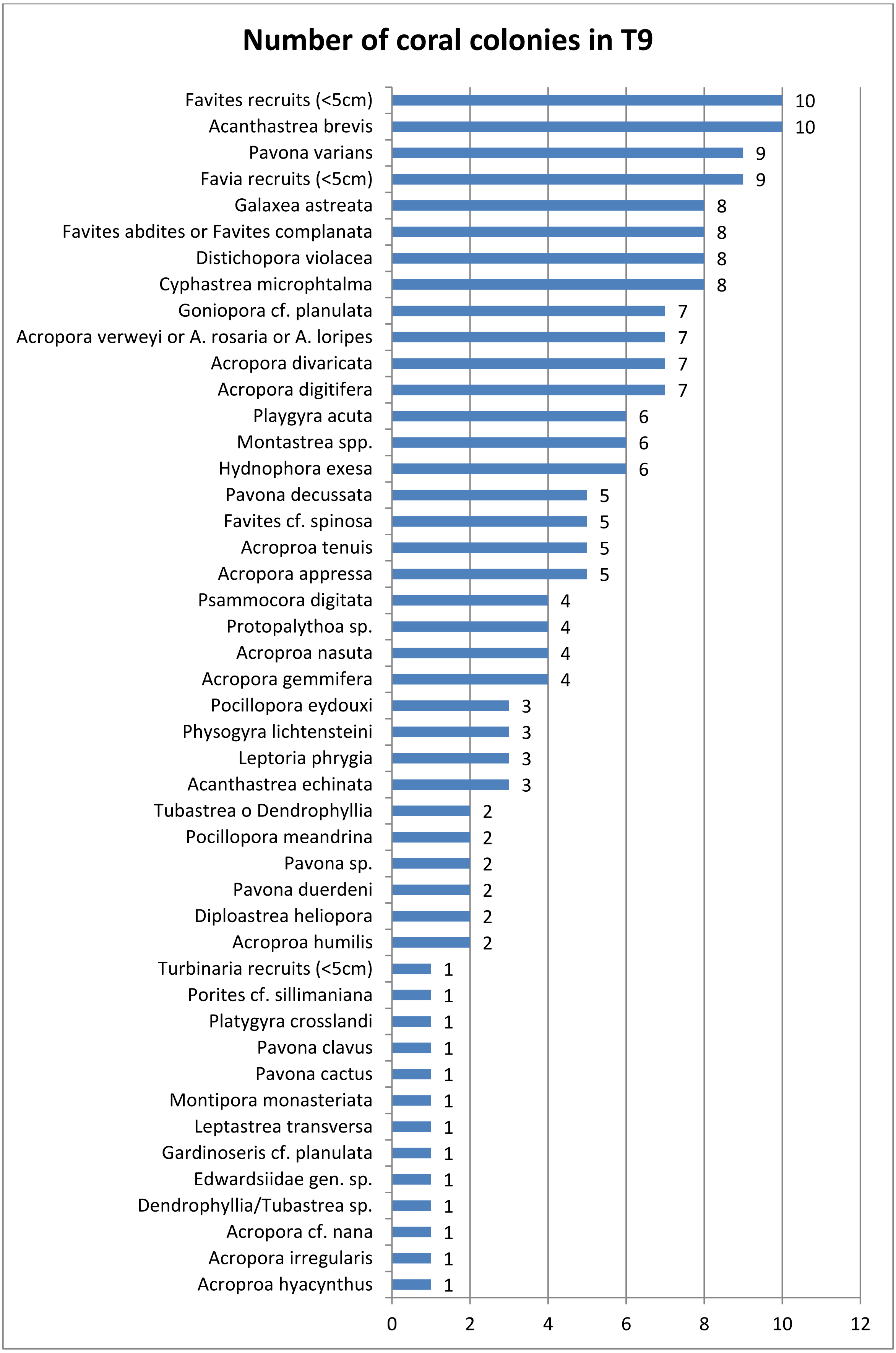


Fig. 33: Taxa which occur with less than 11 colonies in T9 and number of colonies per taxa.

Transect 9 is divided in a northern and a southern part separated by a marked rope.
Both sections have a size of $99m^2$ but of the northern part only $80m^2$ of the $99m^2$ were analyzed so far. In the following both sections were analyzed separately of one another.

3.2.3.2 Biodiversity, abundanc and distribution of coral species of the northern part of T9

Table 5 show all information about the composition and abundance of coral species found in the northern part of T9. A total of 9269 coral colonies (in average 116 colonies per quadrant) were detected in the 80 quadrants in this section. The most common taxon in number is *Discosoma* sp. with 4353 colonies (54.41/m²) and a percentage of 50.56%. But it only occurs in 31 of the 80 quadrants. At the reef the colonies of *Disocoma* sp. usually clump together. The second most taxon is the Zoantharia *Palythoa* cf. *tuberculosa* with 1046 colonies (13.08/m²) and an amount of 12.25% followed by the mushroom polype Corallimorpharia with 1005 colonies (12.56/m²) and a percentage of 11.77% that occur only in 23 of the 80 analyzed quadrants. The most common and stand forming scleractinian corals are *Acropora* with 533 colonies (6.66/m²) and a percentage of 6.24%, *Stylophora pistillata* with 340 colonies (4.25/m²) and a percentage of 3.98%, *Porites lobata/lutea* with 261 colonies (3.26/m²) and a percentage of 2.06%. *Acropora* occur evenly in 74 of the 80 quadrants. *Stylophora pistillata* were found in 52 quadrants and *Porites lobata/lutea* were located in 64 quadrants while Porites rus occur with 177 colonies (2.21/m²) and a percentage 2.07% in 27 quadrants. *Pocillopora damicornis* are represented quite frequently with 116 colonies (1.45/m²) and a percentage of 1.36% in 45 of the 80 quadrants. The soft coral *Sarcophyton* cf. *trocheliophorum* are only present in 27 quadrants with 111 colonies (1.39/m²) and a percentage of 1.30%. The other taxa only appear with less than 100 colonies. Further information about the biodiversity and abundance of all taxa found in T9 are represented in tab. 1.

The biodiversity of coral taxa and their distribution in the quadrants of the northern part of T9 is demonstrated in figure 34. An average of 8.8 taxa per quadrant could be calculated. The highest number of taxa (up to 15 taxa) occurs in the quadrants 36-43. Additional peaks with up to 15 taxa arise in the quadrants between 17-21 and with up to 12 taxa between quadrant 64 and 68. An area with a small number of taxa was found in the quadrants 46-52 (6-8 taxa/quadrant) due to the dead field of *Acropora* spp. But in general there is no correlation established with the number of taxa and the living coral coverage comparing figure 38 and 39. The highest taxa diversity often occurs in areas with less living coral coverage.

Tab. 6: Composition and abundance of the coral taxa found in the northern part of T9.

	Number of colonies	Percentage (%)	Number of coloneis per quadrant	Average frequency (n/m^2)
Total living coral colonies	9269	100,0	80	116
Unidentified living coral colonies	727	7,8	66	9
Identified living coral colonies	8542	92,2	80	107
Taxon				
Discosoma sp.	4353	50,96	31	54,41
Palythoa tuberculosa	1046	12,25	49	13,08
Corallimorpharia gen. spp.	1005	11,77	23	12,56
Acropora spp.	533	6,24	74	6,66
Stylophora pistillata	340	3,98	52	4,25
Porites lobata/lutea	261	2,06	64	3,26
Porites rus	177	2,07	27	2,21
Pocillopora damicornis	116	1,36	43	1,45
Sarcophyton trocheliophorum	111	1,30	27	1,39
Goniastrea spp.	97	1,14	44	1,21
Favia spp.	86	1,01	33	1,08
Pavona varians/venosa	81	0,95	42	1,01
Galaxea fascicularis	38	0,44	14	0,48
Echinopora hirutissima	38	0,44	26	0,48
Favites spp.	33	0,39	18	0,41
Zoanthus sp.	30	0,35	1	0,38
Fungia spp.	25	0,29	14	0,31
Metarhodactis spp.	21	0,25	2	0,26
Lobophyllia hemprichii	20	0,23	9	0,25
Favites pentagona	13	0,15	12	0,16
Pavona frondifera	11	0,13	8	0,14
Pavona explanulata	11	0,13	8	0,14
Turbinaria irregularis/stellulata	11	0,13	10	0,14
Gorgonaria gen. sp.	11	0,13	10	0,14
Leptastrea purpurea	9	0,11	9	0,11
Montipora spp.	8	0,09	7	0,10
Psammocora obtusangula	8	0,09	5	0,10
Goniopora minor	8	0,09	8	0,10
Montastrea spp.	6	0,07	5	0,08
Hydnophora exesa	5	0,06	5	0,06
Acanthastrea brevis	5	0,06	4	0,06
Cyphastrea microphtalma	5	0,06	2	0,06
Pocillopora eydouxi	3	0,04	3	0,04
Galaxea astreata	3	0,04	2	0,04
Pavona decussata	3	0,04	2	0,04
Platygyra acuta	2	0,02	2	0,03
Leptoria phrygia	2	0,02	2	0,03
Distichopora violacea	2	0,02	1	0,03
Physogyra lichtensteini	1	0,01	1	0,01
Psammocora digitata	1	0,01	1	0,01
Pavona sp.	1	0,01	1	0,01
Tubastrea/Dendrophyllia sp.	1	0,01	1	0,01
Leptastrea transversa	1	0,01	1	0,01

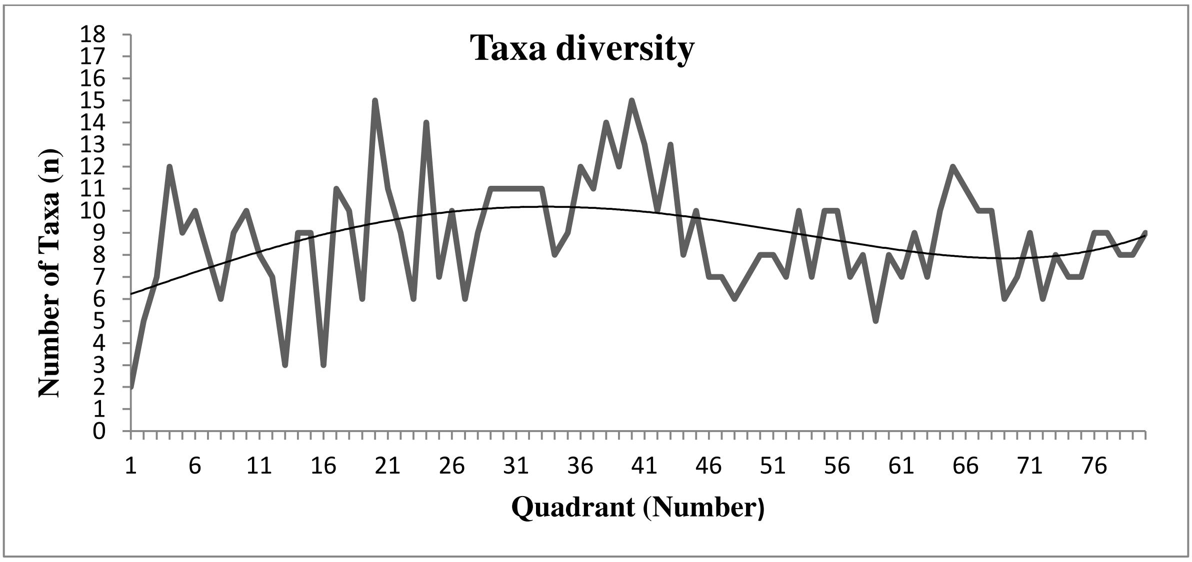


Fig. 34: Number of taxa per quadrant in the northern part of T9 with trend curve (Polynom 4. degree)

The abundance of coral colonies is very variable in the quadrants of T9 (fig. 35). In the first part of the transect there are three areas with a high density of coral colonies. Quadrant 2-11 exhibit a 50-260 colonies, quadrants 18-30 show up to 340 colonies while in the quadrants 34-40 20-450 colonies were found. In these three sections the most common taxa are Corallimorpharia gen. spp., *Discosoma* sp. and *Palythoa cf. tuberculosa.*In the quadrants of the second part of T9 the number of coral colonies is lower (50-60 colonies/quadrant) with some exceptions (quadrant 47, 48, 60 and 67) and the coral compositions changed. Often the high number of coral colonies correlates with a high abundance of taxa (fig. 34).

Figure 36 represent the relative frequency of coral composition in the northern part of T9. The first part of the transect is dominated by Actiniaria like Corallimorpharia gen. sp., *Discosoma* sp. and *Palythoa tuberculosa.* The second half is manly covered with Scleractinia like *Acropora* spp., *Stylophora pistillata* and *Porites rus* as well as *Pocillopora damicornis.*

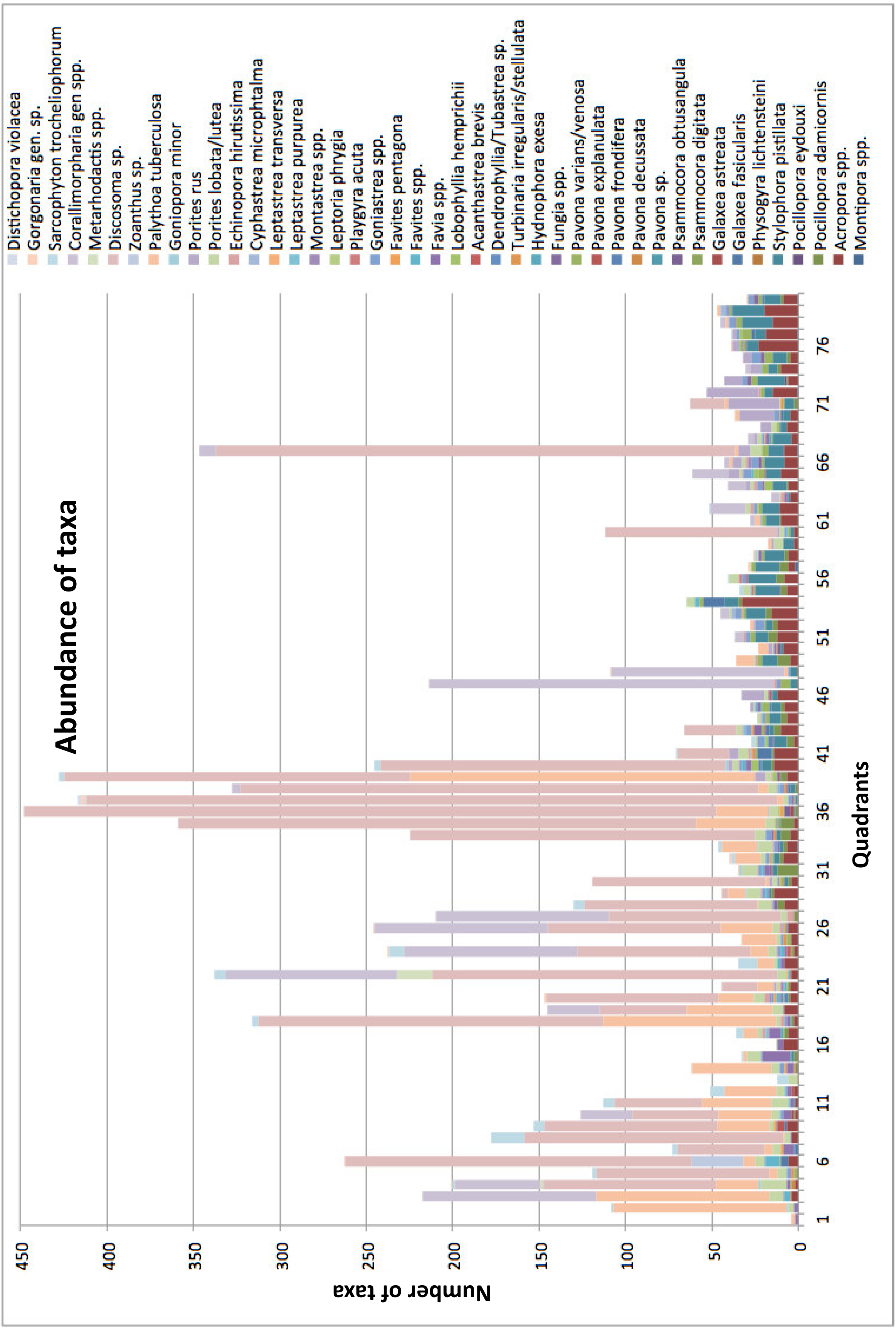


Fig. 35: Number of coral taxa and their abundance in the northern part of T9.

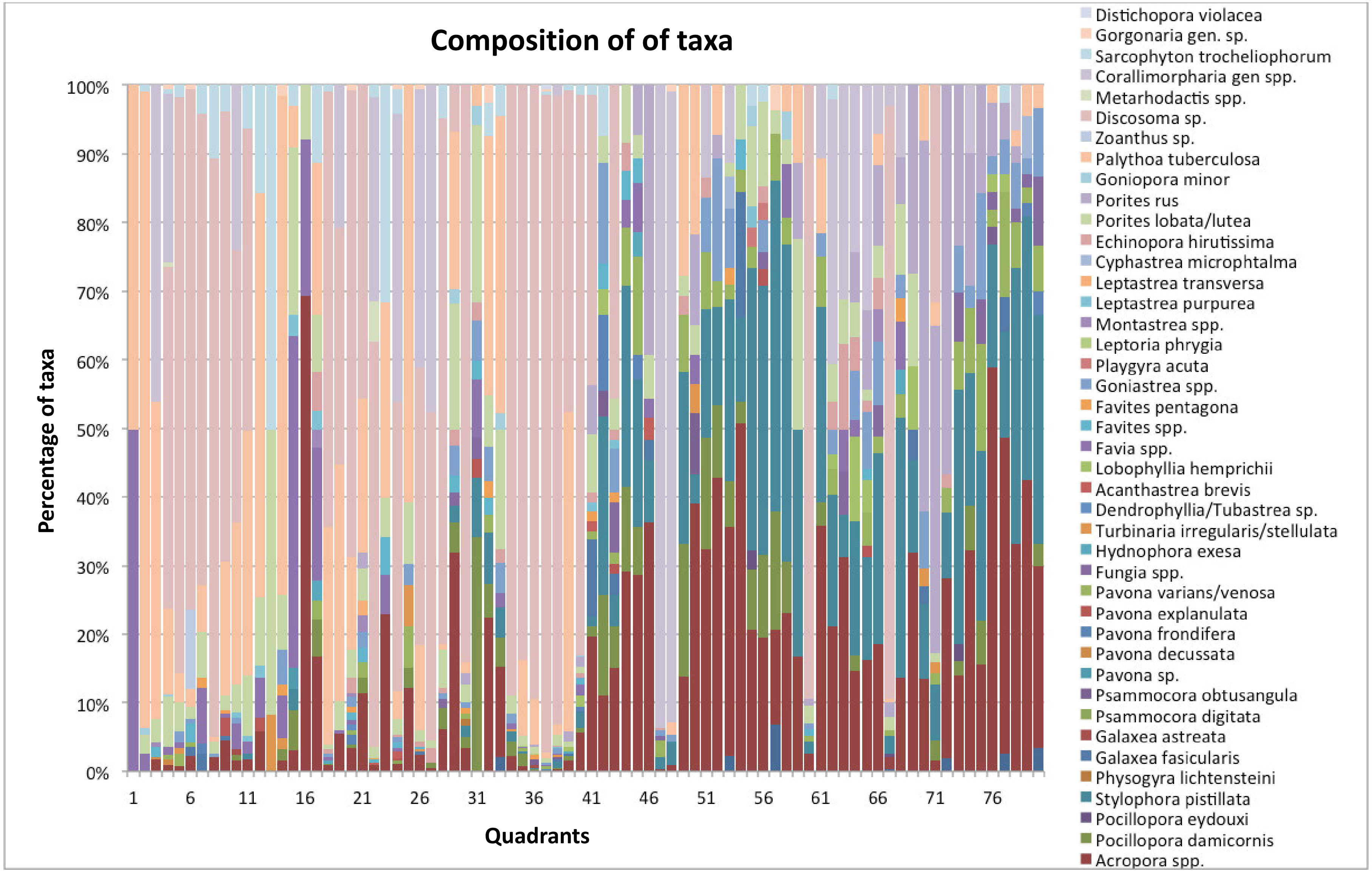


Fig. 36: relative frequency of all coral taxa in the northern part of T9.

The average frequency of coral taxa in T9 is shown in fig. 37 (logarithmic display of the y-axis). Three taxa occur with more than ten colonies per quadrant, eight taxa are represented between 1-10 colonies per quadrant while fourteen taxa have an average frequency between 0.1 and 1 and five taxa show only a frequency of 0.01 colonies per quadrant.

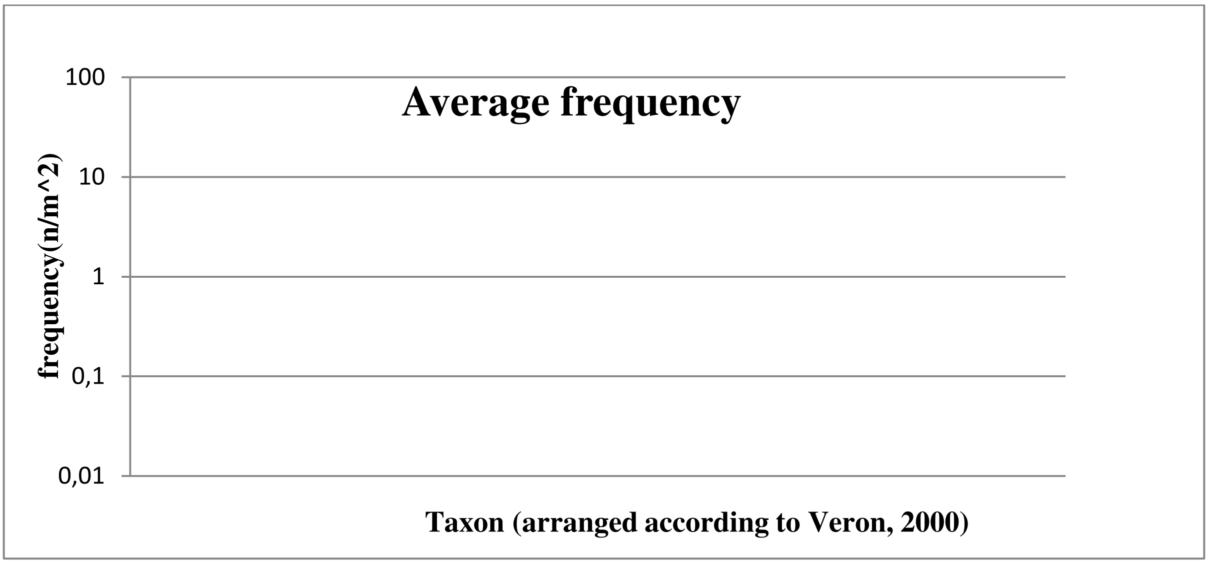


Fig. 37: Average frequency of the taxa in the northern part of T9 (logarithmic display of the x-axis).

Tab. 7: Number of quadrants of the northern part of T9 in which a taxon occur and the percentage (%) of the quadrants.

Taxon	Number of quadrants	Percentage of quadrants (%)
Acropora spp.	56	70,0
Porites lobata or *P. lutea*	41	51,3
Porites rus	14	17,5
Goniastrea spp.	13	16,3
Sarcophyton trocheliophorum	12	15,0
Echinopora hirutissima	12	15,0
Stylophora pistillata	12	15,0
Pocillopora damicornis	8	10,0
Lobophyllia hemprichii	5	6,3
Palythoa tuberculosa	4	5,0
Turbinaria irregularis or *T. stellulata*	3	3,8
Goniopora minor	2	2,5
Discosoma sp.	2	2,5
Hydnophora exesa	2	2,5
Corallimorpharia gen. spp.	1	1,3
Psammocora obtusangula	1	1,3
Pavona frondifera	1	1,3
Pavona varians or *P. venosa*	1	1,3
Galaxea fascicularis	1	1,3
Pavona explanulata	1	1,3
Montipora spp.	1	1,3
Cyphastrea microphtalma	1	1,3

Tab. 6 shows in how many quadrants a taxon occur and the percentage (%) with respect to the amount of analyzed quadrants (80). Acropora spp. covers the biggest area and is high in number. This Taxon occur in 56 of 80 quadrants (70%) followed by *Porites lobata/lutea* (51.3%) which appear in 41 quadrants. *Porites rus* (17.5%), *Goniastrea* spp. (16.3%), *Sarcophyton trocheliophorum* (15%), *Echinopora hirutissima* (15%), *Stylophora pistillata* (15%) und *Pocillopora damicornis* (10%) occur in less quadrants. The both taxa *Discosoma* sp. (2.5%) und *Palythoa* cf. *tuberculosa* (5%) capture just a small area -compared with the high number of coral colonies- and are of no great importance.

3. 2.3.4 Coral coverage in the northern part of T9

The number of living coral colonies and their abundance in the quadrants of the northern part of T9 is shown in fig 38. In average 40% of the northern part of T9 is covered with living coral colonies. In the first quadrants, which are situated at the reef edge, the number of living coral colonies and their coverage is low. In the following quadrants an increase of the number of coral colonies and their coverage is recorded. In many quadrants the coverage reach 50-80%, but there are repeatedly quadrants with low coral coverage (less than 30%). In quadrants with low number of living coral colonies many dead corals occur (fig. 39).

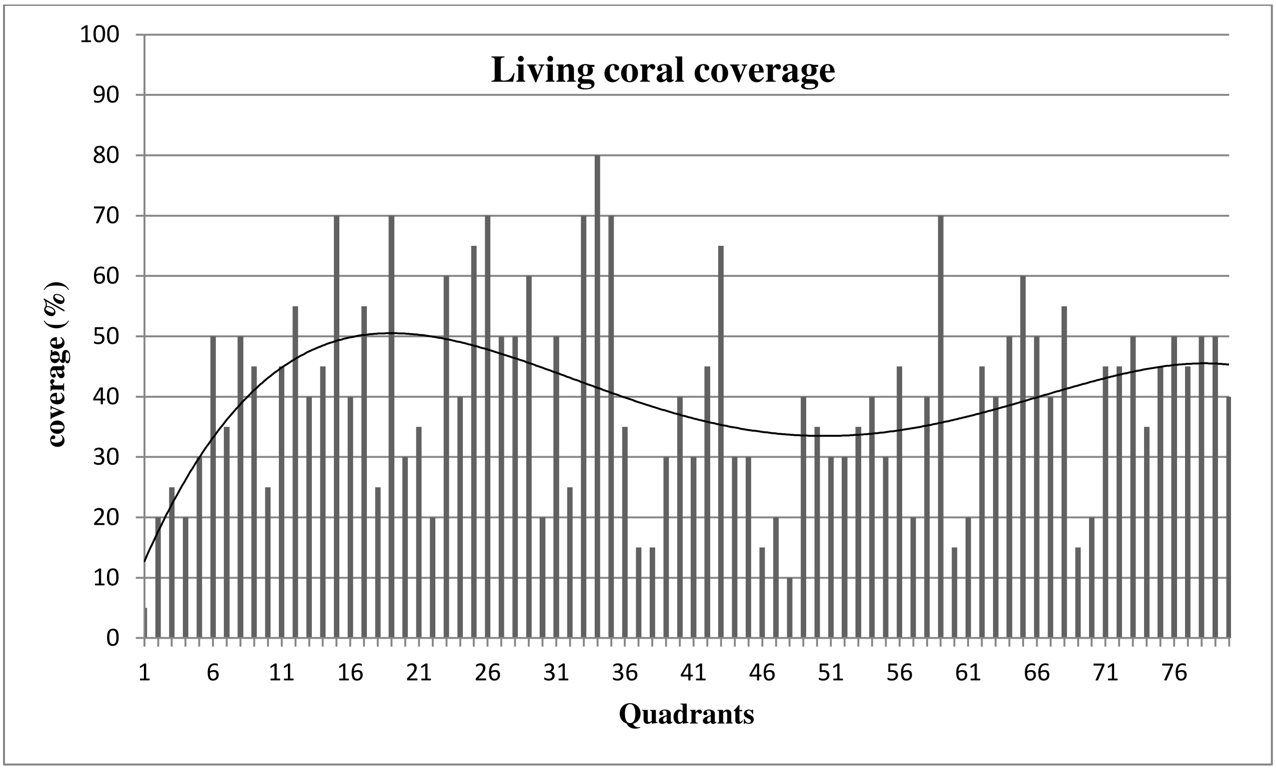


Fig. 38: Living coral coverage in the 80 quadrants of the northern part of T9 with trend curve (Polynom fourth degree)

60% of the quadrants of T9 are covered with dead corals or limestone (tab. 7). A total of 4286 dead coral colonies (54 colonies/m²) were estimated, whereby 98.4% are unidentified. Only 67 of the 4286 dead coral colonies have been identified. The most common Taxon is *Acropora* spp. with 40 colonies (60% of the dead identified colonies), followed by *Porites lobata* or *P. lutea* (25%) and *Pocillopora* spp. (15%). In average 0.8 dead identified coral colonies per quadrant were found.

Tab. 8: Inanimate surface area in the quadrants in the northern part of T9.

	Number of colonies	Percentage (%)	arithmetic average (n/m²)
Dead/sedimented surface area (%)	----	----	60
Total of dead corals	4286	100	54
Total of unidentified dead corals	4219	98,4	53
Total of identified dead corals	67	1,6	0,8
Porites lobata or *P. lutea*	17	25	0,2
Acropora spp.	40	60	0,5
Pocillopora spp.	10	15	0,1

The number of dead coral colonies and their abundance in the quadrants of the northern part of T9 is shown in figure 39. The number of dead colonies is low in the first 27 quadrants (0-15 dead colonies/m^2) and increase from quadrants 28 (50-100 tote Kolonien/m²). A peak of dead coral is distinguishable between the quadrants 47 and 49. In these quadrants up to 200 dead colonies per m² were estimated. A dead field of *Acropora* was noticed in this part of the transect. A high number of coral colonies (150-200 colonies/m²) were also found in the quadrants 70-72 due to a dead field of *Porites rus* and 76-80 with dead colonies of different taxa.

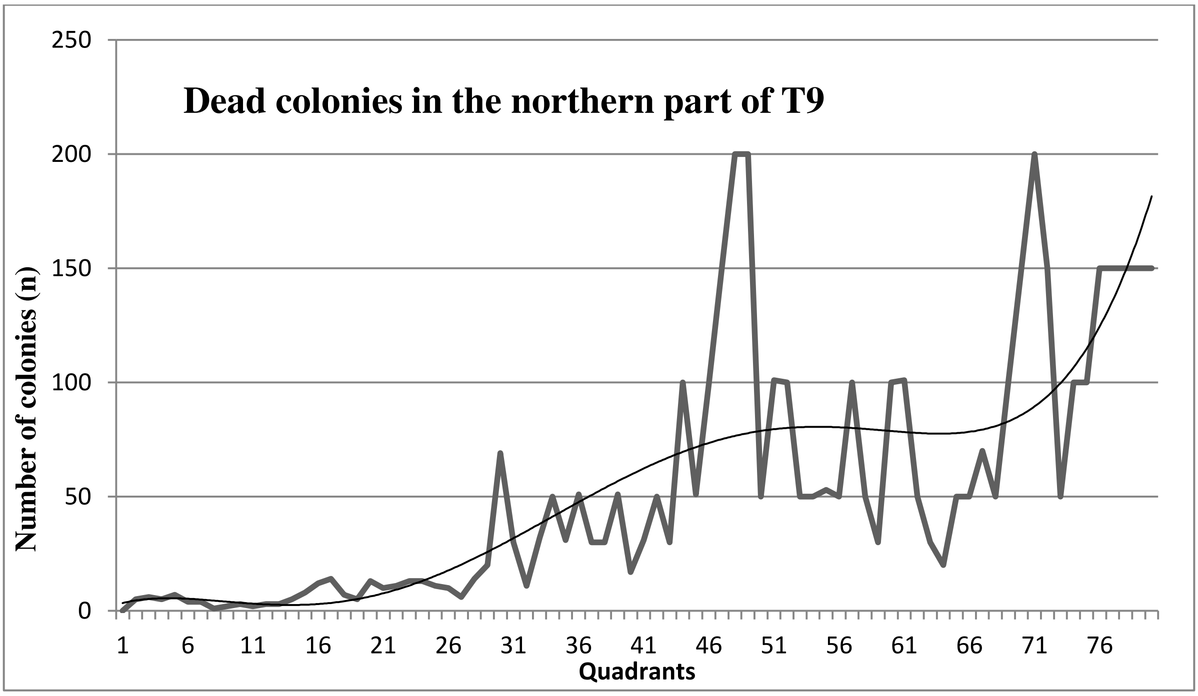


Fig. 39: Number of dead coral colonies and their abundance in the northern part of T9 with trend curve (black line).

3.2.3.5 Diversity, abundance and distribution of coral species of the southern part of T9

A list of coral taxa found in the northern part of T9 is shown in Tab. 8. A total of 3555 coral colonies from 70 species (38 taxa) were detected in 99 quadrants in this section with an average of 36 colonies per quadrant. The abundance of all taxa of the southern part of T9 is presented in figure 40. Sixteen of the 38 taxa occur only one time in the transect.

Tab. 9: List of coral species found in the southern part of T9.

Acanthastrea brevis	*Goniopora minor*
Acanthastrea echinata	Gorgonaria gen. sp.
Acropora sp.	*Hydnophora exesa*
Acropora appressa	*Hydnophora microconos*
Acropora digitifera	*Leptastrea purpurea*
Acropora divaricata	*Leptoria phrygia*
Acropora gemmifera	*Lobophyllia hemprichii*
Acropora humilis	*Montastrea* cf. *curta*)
Acropora hyacynthus	*Montipora* sp.
Acropora irregularis	*Montipora monasteriata*
Acropora microphthalma	*Palythoa* cf. *tuberculosa*
Acropora cf. *nana*	*Pavona* sp.
Acropora cf. nasuta	*Pavona cactus*
Acropora nobilis	*Pavona decussata*
Acropora tenuis	*Pavona duerdeni*
Acropora verweyi or A. rosaria or A. loripes	*Pavona explanulata*
Corallimorpharia gen. sp.	*Pavona frondifera*
Cycloseris sp.	*Pavona varians*
Cyphastrea micropthalma	*Pavona venosa*
Diploastrea heliopora	*Physogyra lichtensteini*
Discosoma sp.	*Platygyra acuta*
Distichopora violacea	*Platygyra crosslandi*
Echinopora hirsutissima	*Pocillopora damicornis*
Edwardsiidae gen. sp.	*Pocillopora meandrina*
Faviidae gen. sp.	*Porites lutea*
Favia sp.	*Porites rus*
Favites sp.	*Porites* cf. *sillimaniana*
Favites abdita or *F. complanata*	*Protopalythoa* sp.
Favites pentagona	*Psammocora contigua* or *P. obtusangula*
Favites cf. *spinosa*	*Psammocora digitata*
Fungia sp.	*Sarcophyton* cf. *trocheliophorum*
Galaxea astreata	*Sinularia* sp.
Galaxea fascicularis)	*Stylocoeniella armata*
Gardinoseris cf. *planulata*	*Stylophora pistillata*
Goniastrea edwardsi or *G. retiformis*	*Tubastrea* sp. oder *Dendrophyllia* sp.
Goniopora cf. *planulata*	*Turbinaria stellulata* or *T. irregularis*

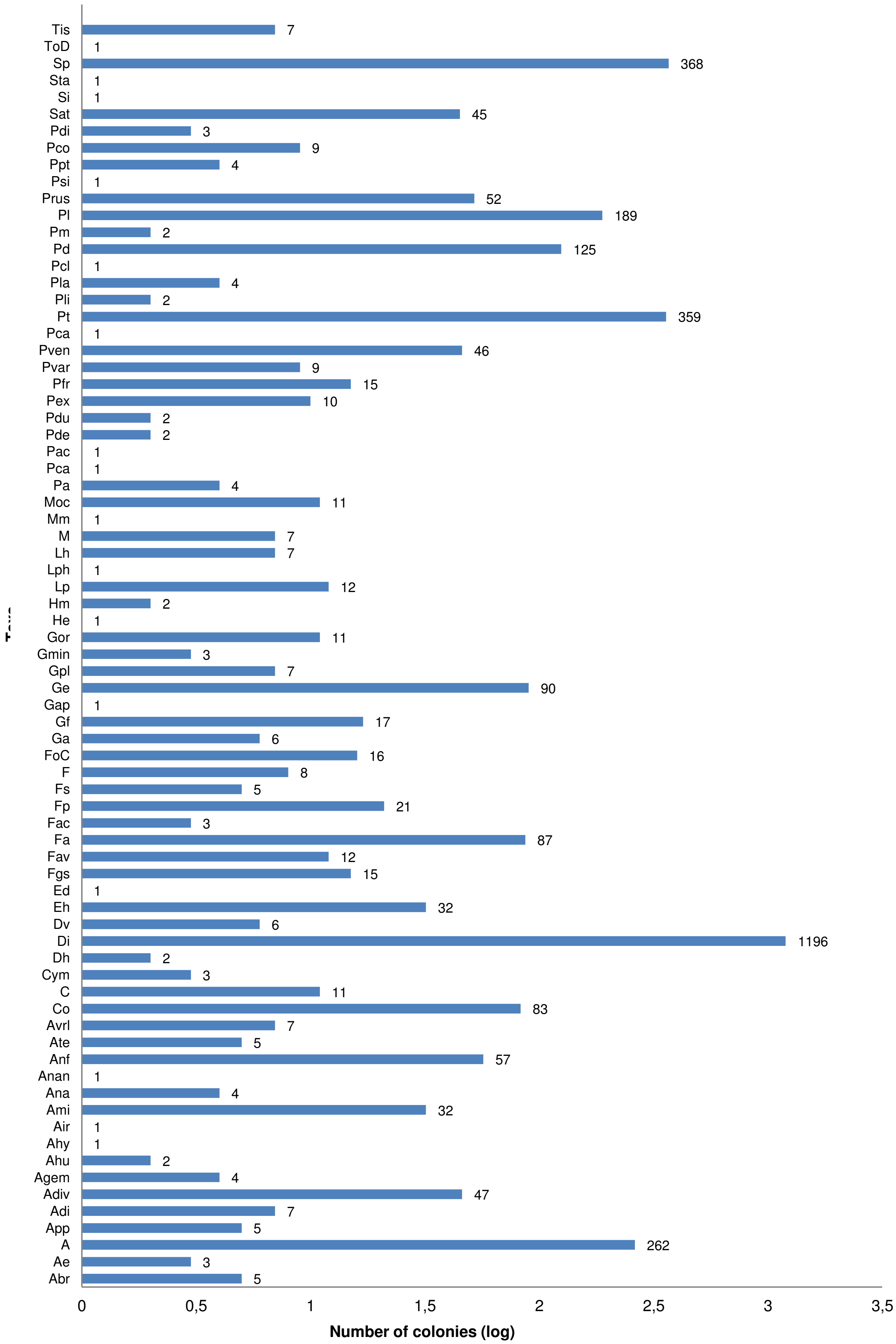


Fig. 40: Number coral colonies per taxa in the southern part of T9.

Figure 42 show the percentage of the six most common coral taxa of the southern part of transect 9. These taxa are represented with more than hundred colonies in the southern part while the remaining taxa exist with less than hundred colonies. The six most frequent taxa provide with a number of 3385 coral colonies a percentage of 73.8% of all identified coral colonies. *Discosoma* is with 1196 (35.3%) coral colonies the most common coral taxon in number in the southern part of T9 and represents one third of the total colony number (3385) found in this section. *Stylophora pistillata* and *Palythoa sp.* are with 368 colonies (10.9%) and 359 colonies (10.6%) the second and third most common species in number in this mapped section, followed by *Acropora* sp. with 262 coral colonies and a percentage of 7.7% and *Porites lutea* or *P. lobata* with 189 colonies and a percentage of 5.6%. *Pocillopora damicornis* is with 125 colonies (3.7%) the sixth most frequent taxon. The remaining taxa with an amount of 886 coral colonies provide 26.2% of all counted colonies.

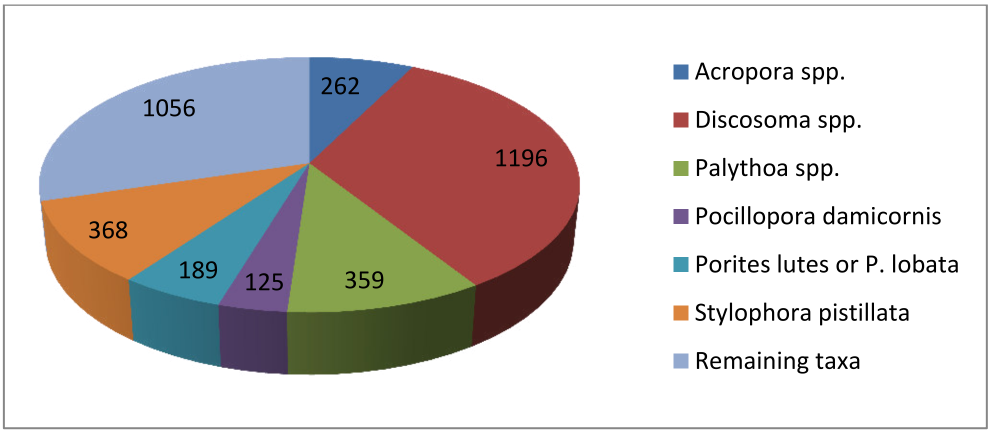


Fig. 41: The six most frequent coral taxa (>100 colonies) in the southern part of T9, the remaining taxa occur with less than 100 colonies.

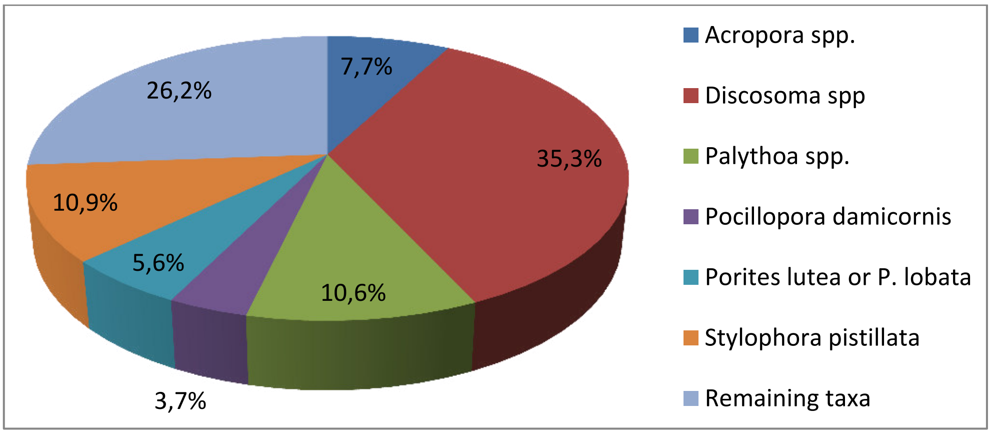


Fig. 42: Percentage of the six most frequent coral taxa and the remaining taxa in the southern part of T9.

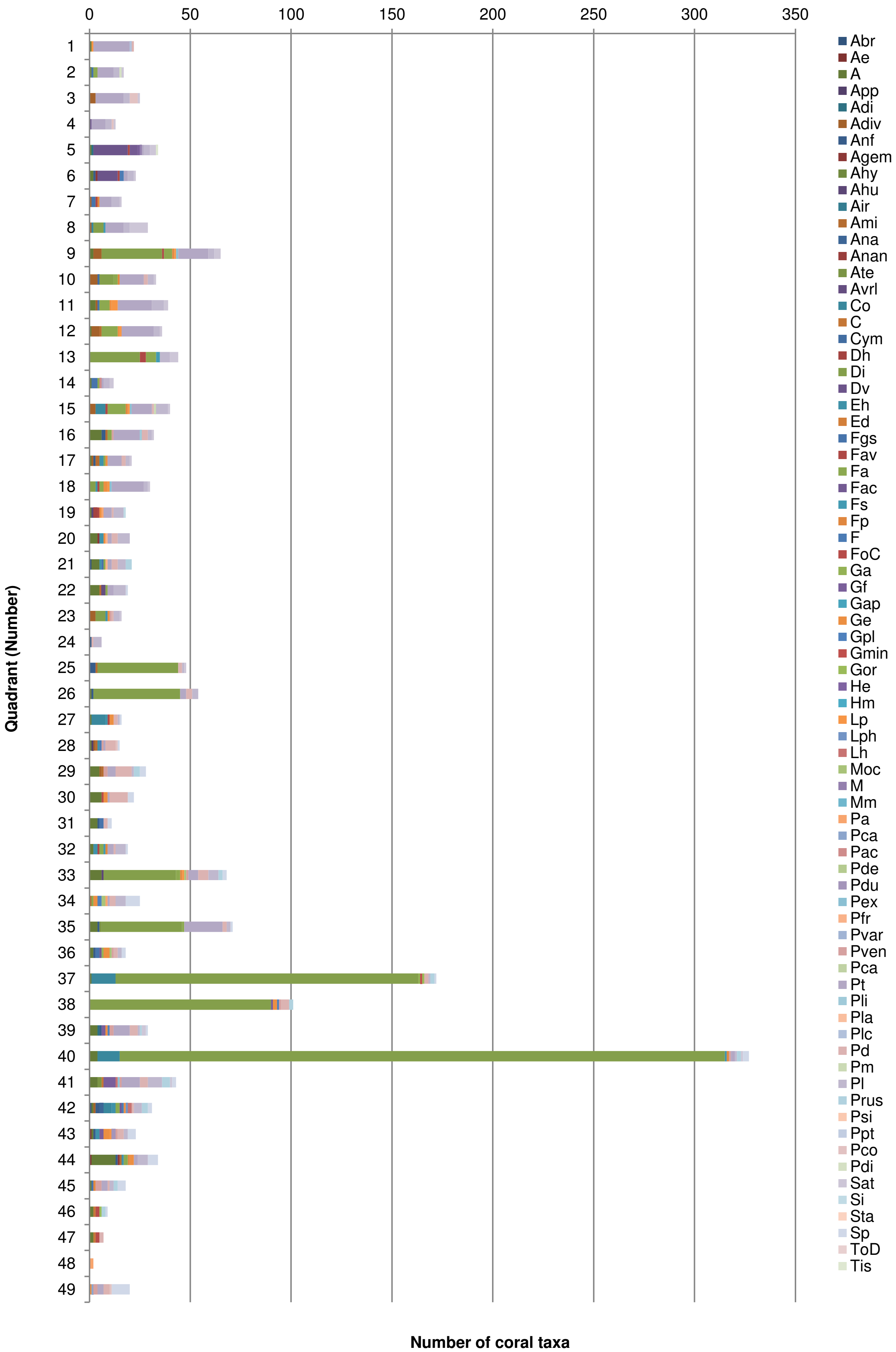


Fig. 43: Number of coral taxa and their abundance in quadrants 1-49 in the southern part of T9.

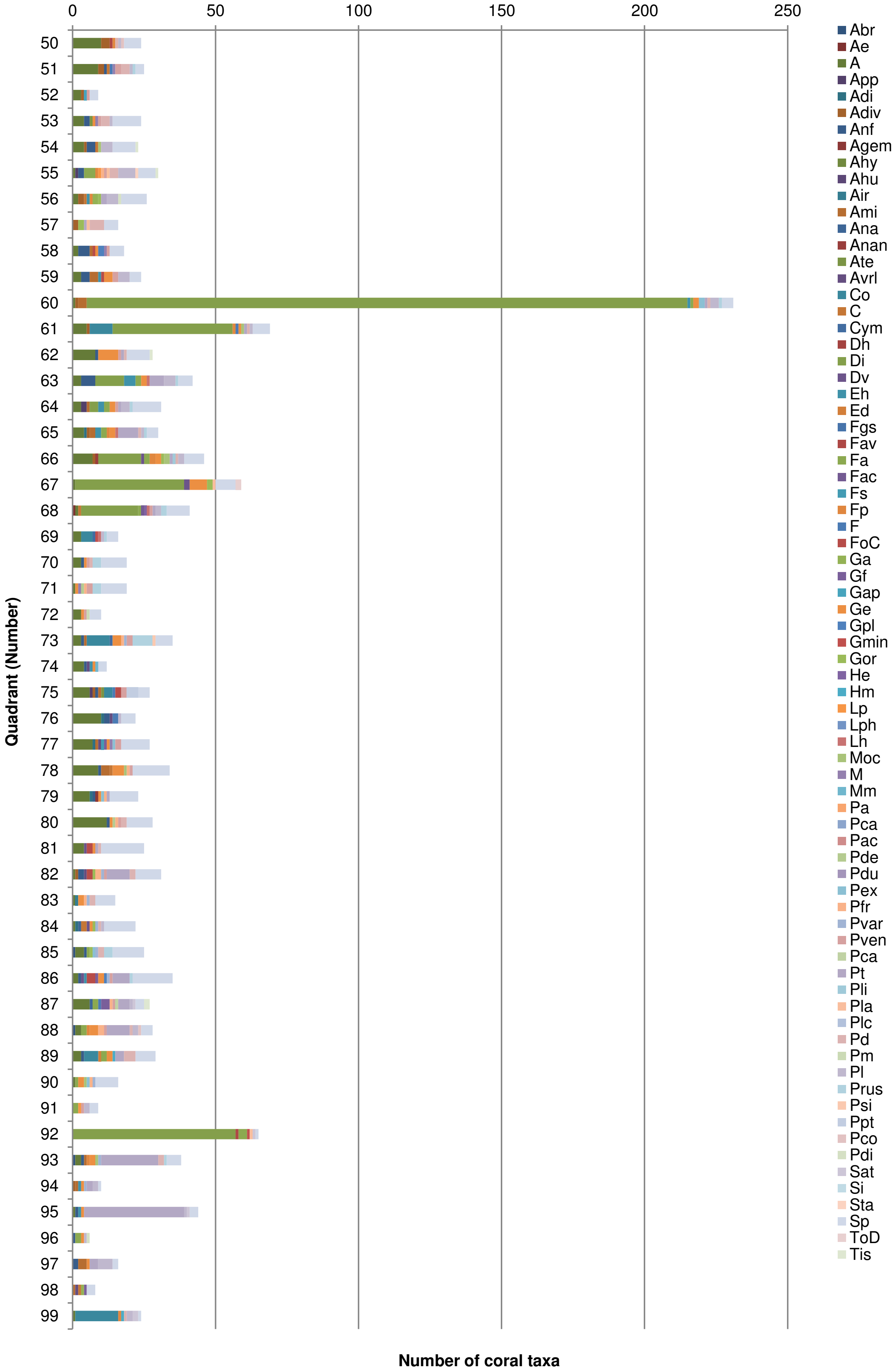


Fig. 44: Number of coral taxa and their abundance in quadrants 50-99 in the southern part of T9.

The distribution of coral taxa is shown in figure 43-45. The first part of the southern side (quadrant 1-50) is dominated by *Palythoa* cf. *tuberculosa* und *Discosoma* sp., whereas the abundance of *Discosoma* sp are also very high in the quadrants 61-68. The number colonies of *Palythoa* cf. *tuberculosa* increase from quadrant 86 on. The massive and extensive *Porites lutea* or *P. lobata* cover big parts of the transect exspecially in the first 25 quadrants. In the quadrants 50-90 the scleractinian corals *Acropora* sp. and *Stylophora pistillata* are frequently present. The number of colonies of *Goniastrea edwardsi* or *G. retiformis* increases from quadrant 59 on. The studied section exhibit a relative high and variable density of coral colonies due to their position in the reef. Most of the corals occur at the reef edge, where transect T9 is located. Figure xx show the number of coral taxa in the 99 quadrants of the southern part of T9 with a relatively steady running trend curve. In average there are 8.6 taxa per quadrant with a maximum of 15 taxa in two of the 99 quadrants.

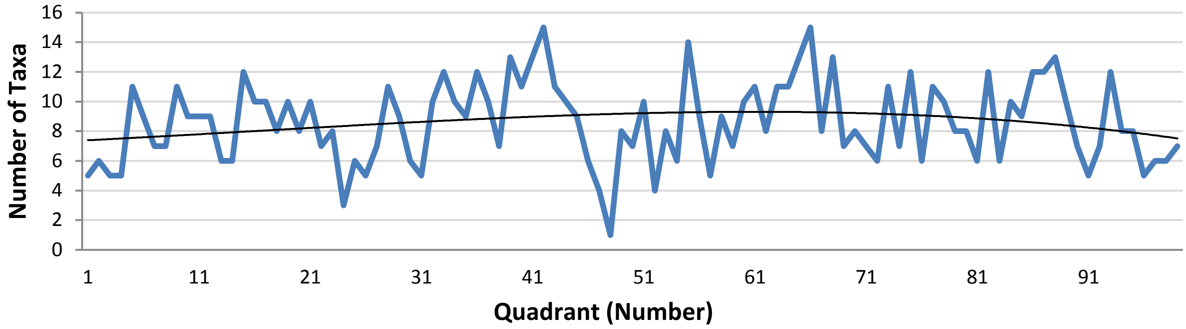


Fig. 45: Number coral taxa in the quadrants of the southern part of T9 with trend curve (black line).

3.2.3.6 Coral coverage in the southern part of T9

The living coral coverage per quadrant in the southern part of T9 is shown in figure 46. The number of coral colonies shed light on the abundance of coral taxa but not on the coral coverage, because the size of colonies was not considered. Only 39.2 m^2 of the analysed 99 m^2 are covered with living corals. The other 60.8% is covered with dead corals or other sediment. In figure 46 two high peaks with a living coral coverage of 84% and 96% are visible. The first peak is located in the quadrants 24 and 25 while the second peak exists in the quadrants 96-98. The first peak is attributed to some big and massive growing colonies of *Porites lutea* or *P. lobata* and the second peak is due to a comprehensive expansion of *Acropora* species. A dead field of *Acroproa* is located in the quadrants 46-48 where living coral coverage is rare (1-2%).

The number of dead corals and their distribution in the southern part of T9 is represented in figure 47. A total of 366 dead coral colonies with an average of 7 colonies per quadrant were estimated. The highest abundance of dead corals with 20 colonies and a percentage wit 5.5% is located in quadrant 30 followed by 14 colonies and a percentage of 3.8% (quadrant 43 and 57), 13 colonies with a percentage of 3.6%

(quadrant 28, 56 and 81) and 12 colonies (3.3%) in the quadrants 49, 58 and 62. There is no distinct correlation between the living and the dead coral coverage.

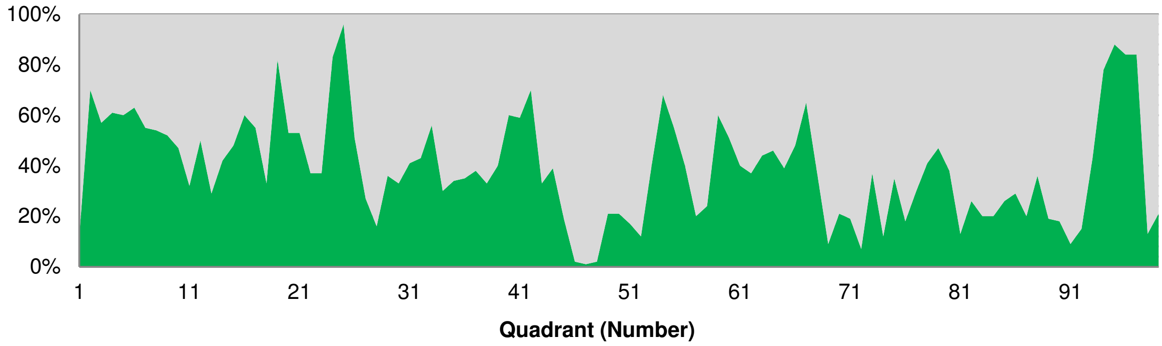


Fig. 46: Living coral coverage per quadrant in the southern part of T9.

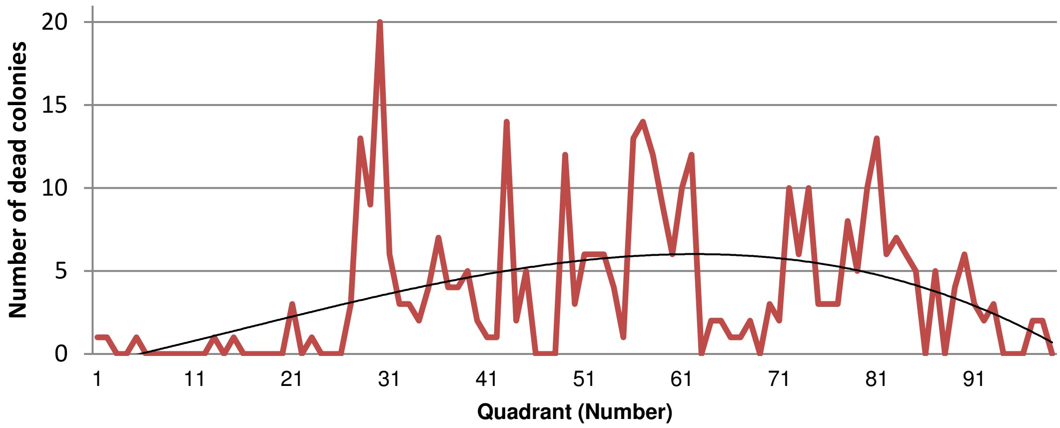


Fig. 47: Dead coral colonies per quadrant in the southern part of T9 with trend curve (black).

3.2.3.7 Coral recruitment in the southern part of transect 9

Observations of the abundance of coral recruits, their growth and their decrease could give some indication of the status of a reef.

In this section all recruits with a size of less than 10 cm were assumed as recruits. A total of 315 recruits (9 Taxa) were found in the southern part of T9. *Acropora* recruits are with 161 colonies the most common ones in this section (fig. 48). *Acropora* is the most species rich taxon as well as the most common and widespread taxon in the Indo-Pacific. *Acropora* is competitive and a fast growing coral species. *Stylophora* is with 92 colonies also well represented. Furthermore 25 *Pocillopora*-, 16 *Goniastrea*-, 9 *Favia*-, 8 *Favites*- and 2 *Pavona* recruits as well as 1 *Turbinaria* and 1 *Palythoa* recruit could be found in this section.

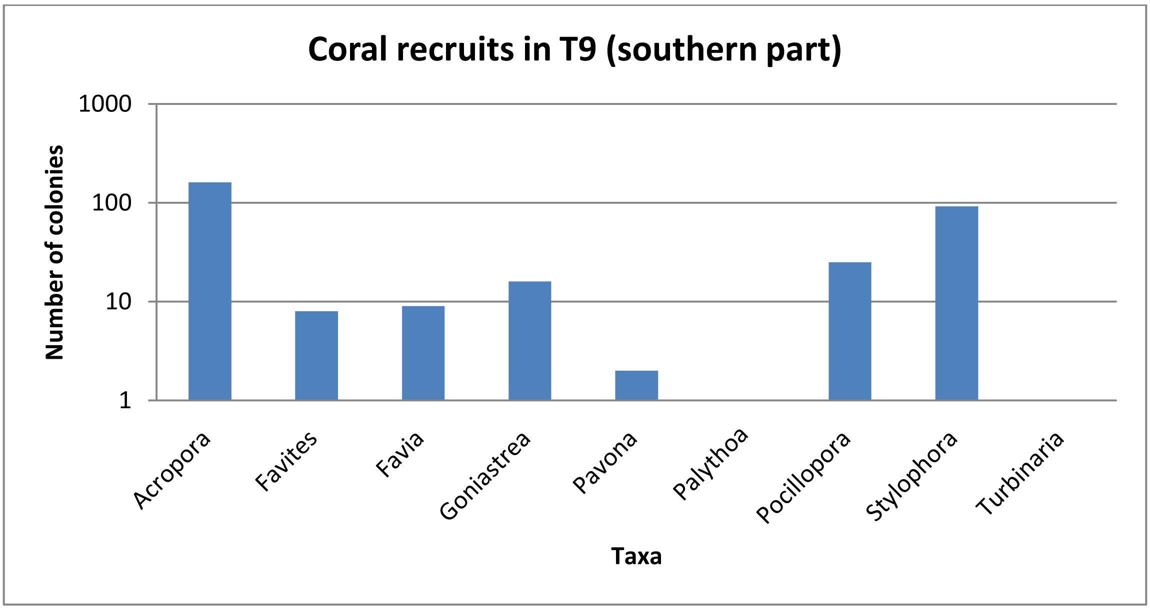


Fig. 48: Number of recruits in the southern part of T9.

Coral recruits are variable distributed in this section of T9 (fig. 49). At the beginning of the reef edge (quadrant 2-8) and at the end of T9 (quadrant 91-91, 94-98) as well as in the some areas of the middle part (quadrant 10, 15, 21-25 and 39) no recruits were recognized. The highest abundance of recruits was noticed in quadrant 50 with 12 recruits. In quadrant 34 and 45 11 recruits were sighted while in quadrant 63, 77 and 80 10 recruits were seen.

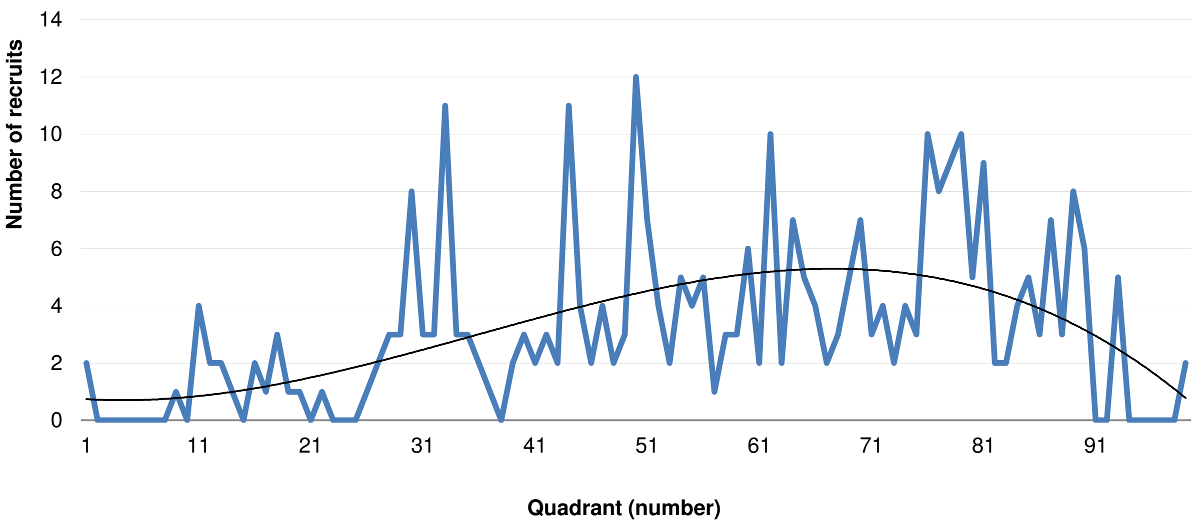


Fig. 49: Abundance and distribution of coral recruits in the southern part of T9 with trend curve (polynom 3. degree).

4 Catalogue of corals newly identified in 2013

The following descriptions are essentially based on Veron (2000). For morphological structures and skeletal elements, see Veron; the major growth forms, referred to in the subsequent text, are also explained in our 2011 report.

Acropora appressa (Ehrenberg, 1834)

Colonies are caespitose to corymbose upright bushes with conspicuous or conical axial corallites. Radial corallites are tubular with naiform openings and may form incipient axial corallites. Colonies are witish often with brown lower brunches and brown corallites. A. appressa is common in the western Indian Oceans and occurs in shallow rocky foreshored (fig. 50).

Fig. 50: *Acropora appressa* T3 185.1l. Left: growth form of a colony, right: detail.

Acropora cuneata or A. palifera

These taxa form solid plates and columns with no distinctive axial corallites (fig. 51).

Acropora cuneata (Dana, 1846)

Colonies are solid plates or form short flattened branches. Corallites are smooth, rounded and not very excert. Usually colonies do not have axial corallites. Colonies are colored cream or brown. A. cuneata is a sommos species and occur in all reef environments, especially upper reef slopes and reef flats (fig. 51).

Acropora palifera (Lamarck, 1816)

Colonies are encrusting plates or form thick columns or branches. The shape of the branches is determined by wave action. They are either upright or horizontal and irregular in shape. There are usually no axial corallites. Radial corallites are smooth, rounded and excert. Colonies are pale cream or brown and occurs in all reef environments (fig. 51).

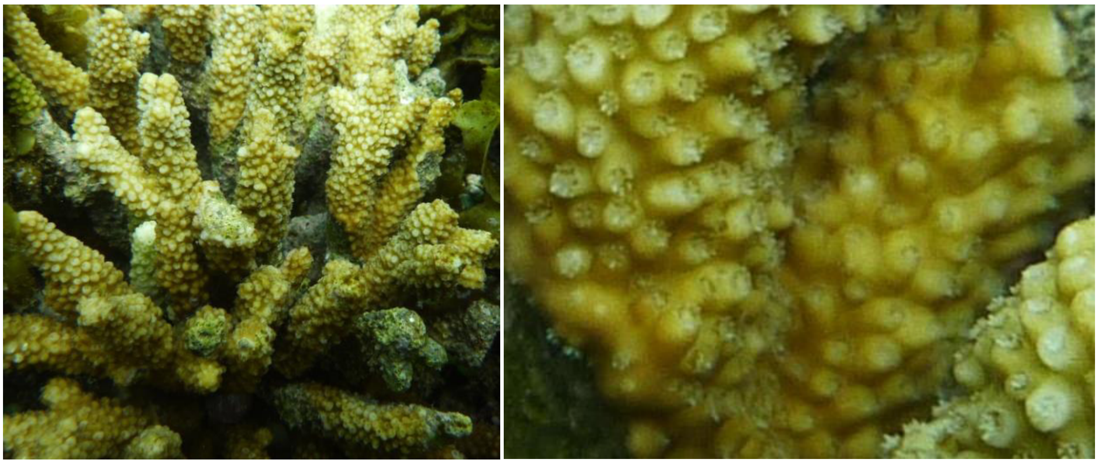


Fig. 51: *Acropora cuneata* or *A. palifera* T3 144l. Left: growth form of a colony, right: detail.

Acropora gemmifera (Brook, 1892)

Colonies are digitate. Branches are thick. Axial corallites are small. Radial corallites are of two sizes, usually arranged in rows. The larger ones increase in length towards branch bases. Here are incipient axial corallites common. Coloneis are usually purple, blue, cream or brown, with blue or white branch tips. In the western Indian Ocean the colonies are usually dark grey with white corallite rims and yellow axial corallites. *A. gemmifera* is common and occurs on exposed upper reef slopes and flats (fig. 52).

Fig. 52 *Acropora gemmifera* T9 44l. Left: growth form of a colony, right: detail.

Acropora humilis (Dana, 1846)

Colonies are digitate with thick branches and branchlets or incipient axial corallites at the base of the mane branches. Axial corallites are dome-shaped. Radial corallites are of two sizes. The larger ones are usually arranged in rows and increase only slightly down to the base of branches. Most of the colonies are cream, brown, purple or blue with blue or cream tips. *A. humilis* is common and occurs on exposed upper reef slopes and reef flats and (fig. 53).

Fig. 53: *Acropora humilis* T3 179r. Left: growth form of a colony, right: detail.

Acropora microphthalma (Verrill, 1859)

Colonies are arborescent and small. They usually form thickets. Branches are slender and straight. Sub-branches may occur at irregular intervals. Radial corallites are small, numerous and of similar size. Often colonies exceed 2 metres across and may form extensive single species stands. Colonies are pale grey, pale brown or cream. *A. micrphthalma* is common and occurs in shallow water where they may be a dominant species or on upper reef slopes, often in turbid water or sandy lagoons (fig. 54).

Fig. 54: *Acropora microphthalma* T8 145.1l Left: growth form of a colony, right: detail.

Acropora monticulosa (Brüggemann, 1879)

This taxon may form dome-shaped colonies over 3 metres across composed of isolated subcolonies which are shaped like upturned hands. Colonies are digitate with thick branches. Colonies exposed to strong wave action mya have pyramid-shaped branchlets. Axial corallites are small. Radial corallites are uniform in size and usually arranged in rows. Colonies are blue or cream, usually with pale branch tips of contrasting colours. *A. monticulosa* is usually uncommon and occurs on upper reef slopes (fig. 55).

Fig. 55: *Acropora monticulosa or A. gemmifera* T1 158l. Left: growth form of a colony, right: detail.

Acropora cf. *nana* (Studer, 1878)

Colonies are compact clumps of long, non-tapering, straight, equidistant branchlets. Branchlets radiate from a solid base. Axial corallites are tubular with rounded margins. Radial corallites are long, tubular and appressed. The whole colony is delicate and branchlets are easily broken. Colonies are cream, blue or purple, usually with purple branch tips. *A. nana* is common and occurs on reef flats where currents or wave action is strong (fig. 56).

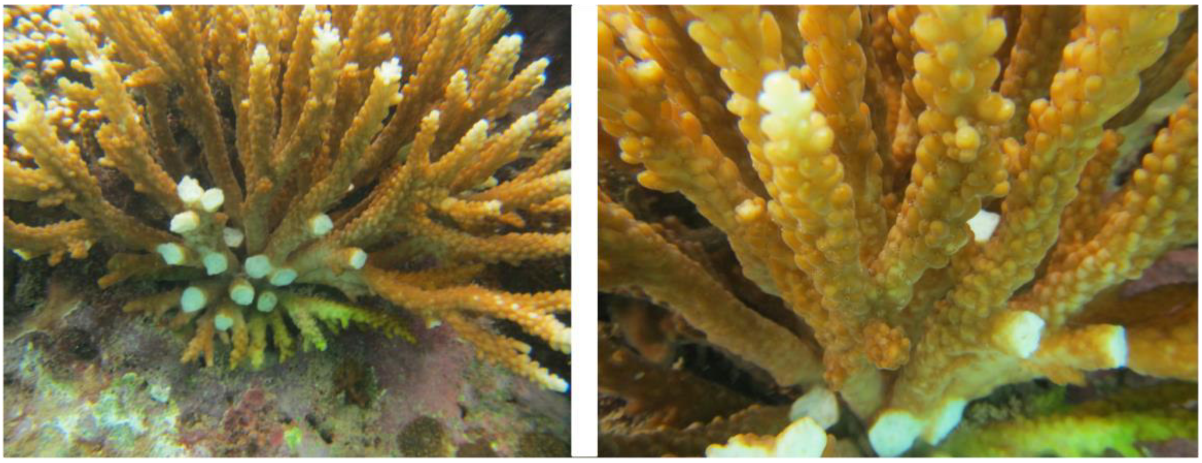


Fig. 56: *Acropora* cf. *nana* T9 66l Left: growth form of a colony, right: detail.

Acropora cf. *nasuta* (Dana, 1846)

Colonies are irregularly corymbose with elongate tapering branchlets. Axial corallites are tubular. Radial corallites are usually arranged in neat rows and are nariform in shape. Colonies are cream or pale brown with blue branch tips, cream with brown corallites or greenish-brown with purple or blue corallites. A. nasuta is common and occurs especially on upper reef slopes (fig. 57).

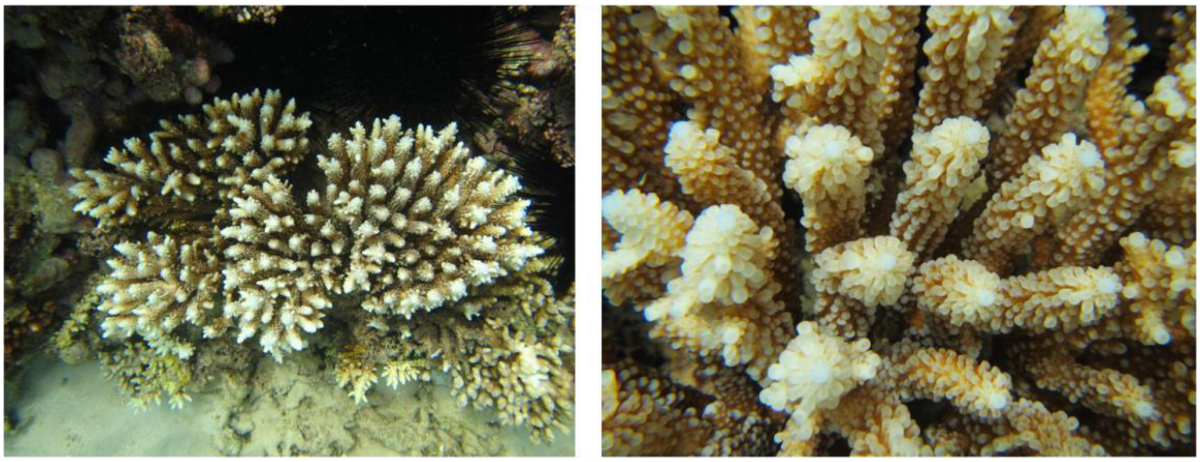


Fig. 57: *Acropora* cf. *nasuta* T9 66l Left: growth form of a colony, right: detail.

Acropora cf. *robusta* (Dana, 1846)

Colonies are irregular in shape. They have an encrusting base. Branhces are thick and conical at the centre and thinner and postrate with upturned ends at the periphery. These branches have completely dissimilar shapes. Radial corallites are of mixed sizes and shapes but are generally rasp-like. Colonies are bright green with deep pink branch tips or pinkish-brown, yellow-brown or cream. *A. robusta* is common in the central Indo-Pacific and occurs in shallow reef environments, especially reef margins exposed to strong wave action (fig. 58).

Fig. 58: *Acropora robusta* T3 155l. Left: growth form of a colony, right: detail.

Acropora verweyi (Veron and Wallace, 1984)

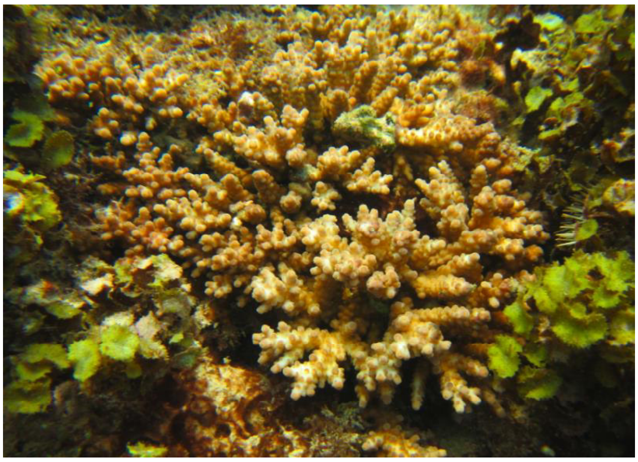
Colonies form encrusting plates with short branches, or are cushion-shaped, or form extensive corymbose bushes. Branches are 7-9 millimeters thick. They do not taper and have short branchlets towards their bases. Axial corallites are prominent. Radial corallites are rounded, tubular, appressed, and arranged in rows. Colonies are uniform creamy-brown with yellow axial corallites. *A. verweyi* is common especially in the western Indian Ocean and occurs on upper reef slopes particularly exposed to wave action or currents (fig. 59).

Acropora roasaria (Dana, 1846)

Colonies are upright bushes or cushion-like. Main branches have secondary and tertiary sub-branches. Axial corallites are large and dome-shaped but not elongate. Radial corallites are bead- or pocket-like. All corallites have thick walls.Colonies usually are cream or brown, sometimes bright blue or pink. *A. rosria* may be a common species and occurs in shallow reef environments (fig. 59).

Acropora loripes (Brook, 1892)

Colonies have a lot of growth forms varying from upright bushes to thick plates. There is a continuous range of shape and size between axial and radial corallites; both may be tubular to nearly spherical, with very thick walls. Tubular axial corallites often have no radial corallites on one side and pocket-like radial corallites on the other. All corallites are smooth and rounded. Coloneis usually are pale blue or brown. Axial corallites are usually whitish. *A. loripes* is common in the central Indo-Pacific and occurs in a wide range of environments especially on upper reef slopes (fig. 59).



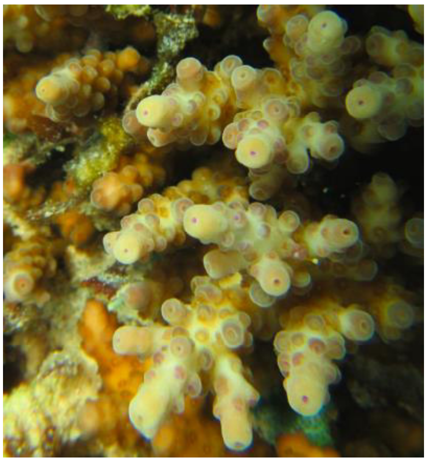


Fig. 59: *Acropora verweyi or A. Rosaria or A. loripes* T8 116l Left: growth form of a colony, right: detail.

Acropora vermiculata (Nemenzo, 1967)

Colonies are corymbose clumps or cushions. Cushions occur either singly or in groups. Main branches are short or absent while branchlets are of uniform length and spacing. Axial corallites are short and tubular. Radial corallites are scale-like and arranged in a neat rosette. Colonies are usuylly uniform grey-brown. *A. vermiculata* is common in the western Indian Ocean and occurs on upper reef slopes (fig. 60).

Acropora verweyi (Veron and Wallace, 1984)

Colonies form either encrusting plates with short branches or are cushion-shaped or form extensive corymbose bushes. Branches are 7-9 millimetres thick and do not taper. There are short branchlets towards their bases. Axial corallites are prominent. Radial corallites are rounded, tubular and appressed and arranged in rows. Colonies are uniform creamy-brown with yellow axial corallites. *A. verweyi* is common in the western Indian Ocean and occurs on upper reef slopes especially on those exposed to wave action (fig. 60).

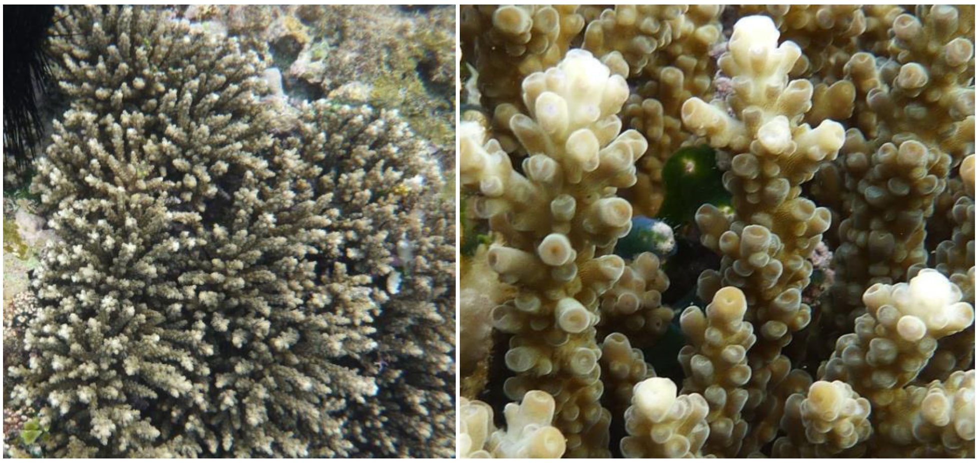


Fig. 60: *Acropora vermiculata or A. verweyi* T3 184.4l. Left: growth form of a colony, right: detail.

Alveopora daedalea (Forskål, 1775)

Colonies are encrusting or form thick plates. They can also form columns up to 1m high. Colonies have a smooth surface. Corallites have alternating long and short fine septal spines. Tips of polyp tentacles are truncated. That gives the colonies a squared appearance. Colonies are uniform pale or dark brown. A. dadalea are common in the western Indian Ocean and occurs on protected upper reef slopes (fig. 61).

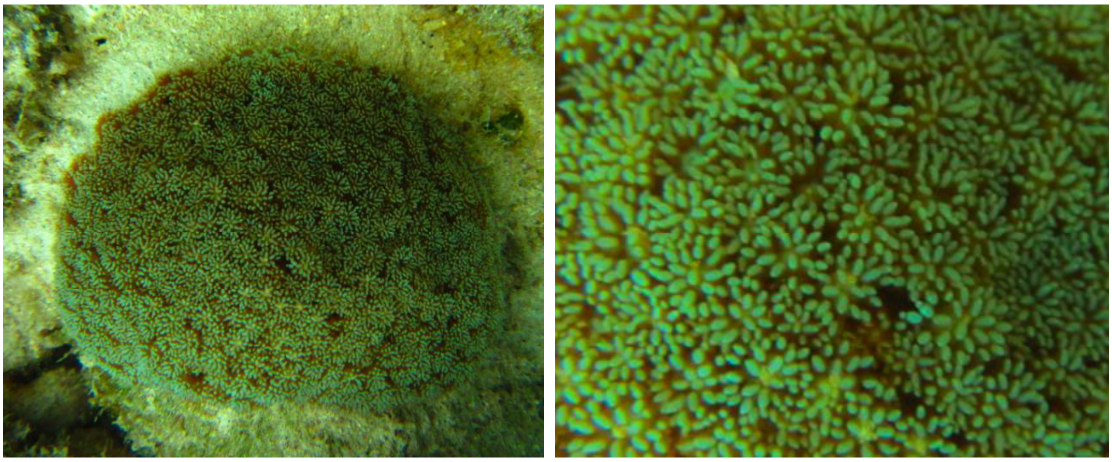


Fig. 61: *Alveopora daedalea* T8 142l Left: growth form of a colony, right: detail.

Astreopora listeri (Bernard, 1896)

Colonies are hemispherical, flattened or encrusting. Corallites are small, immersed and may be crowded. They have small rounded openings surrounded by spinules. The walls are slightly porous. Coenosteum papillae are fine. Tentacles are extended only at night. Colonies are cream, grey or brown. A. lister is usually uncommon and occurs in a wide range of environments, especially in shallow turbid water (fig. 62).

Fig. 62: *Astreopora listeri*T7 147r Left: growth form of a colony, right: detail.

Blastomussa

Colonies are phaceloid to subplocoid. Tentacles have fleshy mantles extended during the day and forming a continuous cover. Under water skeletal structures are hidden underneath the mantles. Tentacles are extended only at night.

Blastomussa cf. *merleti* (Wells, 1961)

B. merleti is the only species of this taxon that occur in the western Indian Ocean. The colonies of *B. merleti* are phaceloid to plocoid. Corallites are less than 7 millimeters in diameter. Colonies are commonly dark red, but they can also be pink, orange, brown or uniform dark grey with white margins and conspicuous green oral discs. *B. merleti* is uncommon and occurs especially in reef environments with turbid water (fig. 63).

Fig. 63: *Blastomussa* cf. *merleti* T2 159r. Left: growth form of a colony, right: detail.

Corallimorpharia gen. spp.

Corallimorpharia is quite closely related to the scleractinian corals. This taxon is found worldwide, but it is mostly tropical. A skeleton is completely lacking. That is one reason for the little knowledge about this taxon. Colonies consist of an oral disc with a central mouth and a tube-like body. Tentacles are short and arranged in rows radiating from the mouth. Corallimorpharia are secondary colonizers, which rapidly cover mainly dead rocky substrate on coral reefs. In the study area large parts of the reef edges are covered with Corallimorpharia. They have a high resistance against pollutants and are used as indicators for pollution of coastal areas caused by human activities. For the species presented here a name can't be given (fig. 64).

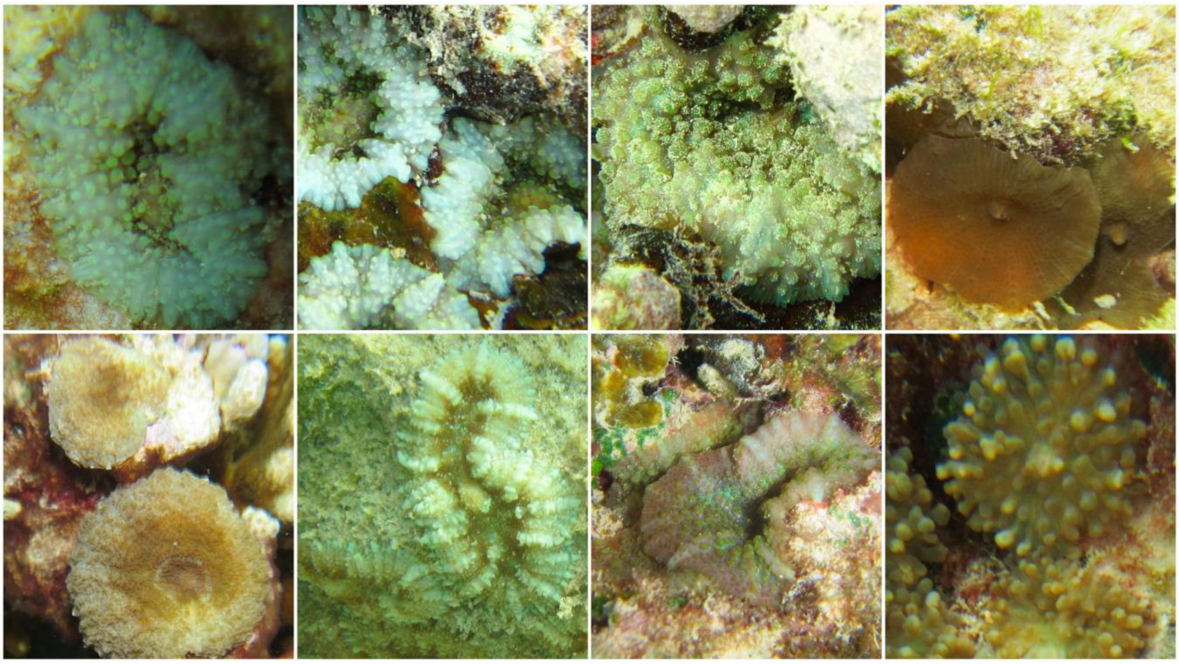


Fig. 64: A selection of Corallimorpharia gen. spp. In transect 9.

Diploastrea heliopora (Lamarck, 1816)

Colonies are dome-shaped with an even surface and may be several meters high and across. Corallites form low cones with small openings and very thick walls. Columellae are large. Coastae are distinct. Septa are equal and are thick at the wall and thin where joining the columellae. Tentacles are extended only at night. Colonies are usually uniform cream or grey, sometimes greenish. *D. heliopora* may be a dominant species and occurs in exposed as well as in protected reef environments (fig. 65).

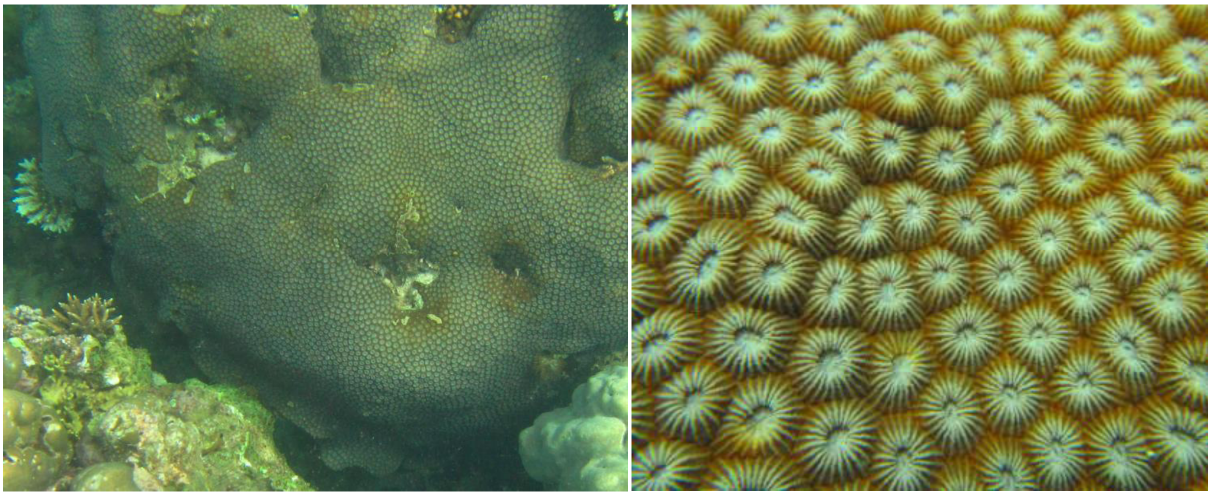


Fig. 65: *Diploastrea heliopora* T8 158l Left: growth form of a colony, right: detail.

Edwardsiidae (Andres, 1881)

Edwardsiidae (sand anemones) lives solitary on sand or debris (fig. 66). They have a wide basal disc attached to solid substrate. The oral disc is surrounded by banded, long, cylindrical tentacles with a pointed end. The tentacles catch plankton and particles floating in the water. During disturbances these anemones can retract rapidly into the substrate. Edwardsiidae are relative small in size (diameter of the oral disc 4-5 cm) and their coloration adapted to the surrounding, these anemones are easily overlooked (Erhard & Knopp, 2005).

Fig. 66: Edwardsiidae T9 89l. Growth form of a colony.

Favia pallida (Dana, 1846)

Colonies are massive. Corallites are circular. Corallites are closely compacted in shallow water, but more widely spaced in deeper water. Septa are widely spaced and characteristically irregular. Colonies are pale yellow, cream or green, with dark brown or green oral discs. *F. pallida* occurs in all reef environments and is often a dominant species of back reef margins (fig. 67).

Fig.67: *Favia pallida* T3 180.8r Left: growth form of a colony, right: detail.

Favites flexuosa (Dana, 1846)

Colonies are hemispherical or flat. Corallites are angular and deep. Septa are prominent with large teeth. Colonies are brightly colored, but usually with contrasting walls and oral discs. *F. flexuosa* is sometimes a common species and occur in a wide range of reef environments and rocky foreshores (fig. 68).

Fig. 68: *Favites flexuosa* T3 186r Left: growth form of a colony, right: detail.

Gardineroseis planulata (Dana, 1846)

Colonies are massive to encrusting. Corallites have poorly defined walls and are separated by acute ridges so that each corallite is at the bottom of a neatly rounded excavation. Septo-costae are fine and even. Columellae are present. Tentacles are rarely extended and only at night. Colonies are pale or dark brown and sometimes yellow or green. *G. planulata* is uncommon and usually occurs on walls or under overhangs in clear water (fig 69).

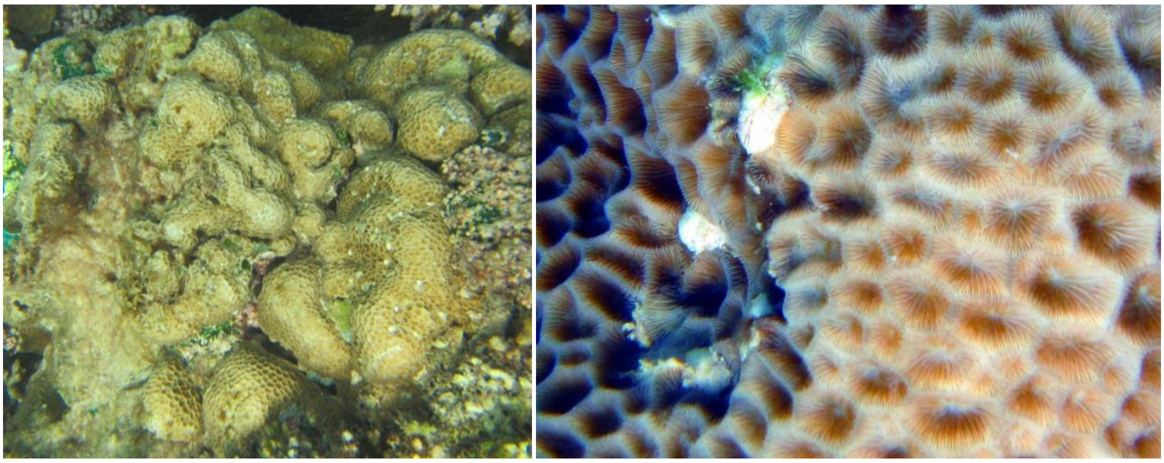


Fig. 69: *Gardineroseris planulata* T7 155r Left: growth form of a colony, right: detail.

Heliofungia actiniformis (Quoy and Gaimard, 1833)

Polyps are large and have a central mouth up to 30 mm wide. They are solitary, free-living and flat. Septa have large lobed teeth. Tentacles are extended day and night. They are long, similar to those of giant anemones. Colonies are pale or dark blue-green or grey tentacles with white or pink tips. The oral disc is striped. *H.*

actiniformis is common and occurs usually on flat soft or rubble substrates especially in reef lagoons or shallow turbid environments (fig. 70).

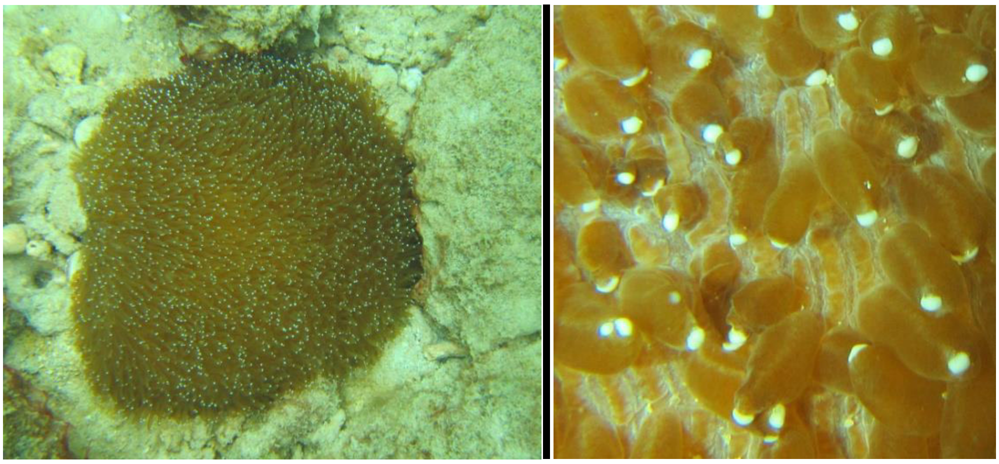


Fig.70: *Heliofungia actiniformis* T8 165l Left: growth form of a colony, right: detail.

Herpolitha limax (Houttuyn, 1772)

Colonies are usually elongate and generally have rounded ends. Mouths occur within the axial furrow which runs most of the length of the colony. But there are numerous of secondary mouths outside the furrow as well. Sometimes there are a few primary septo-costae which extend from the axial furrow to the perimeter. Some colonies develop forked axial furrows and become Y, T or X shaped. Tentacles are extended only at night. Colonies are pale or dark brown or greenish-brown. *H. limax* is common and occurs on reef slopes and lagoons where *Fungia* occurs (fig. 71)

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Fig. 71: Herpolitha limax T8 165l Left: growth form of a colony, right: detail.

Lobophyllia hemprichii (Ehrenberg, 1834)

Colonies are flat to hemispherical. Sometimes colonies either form extensive monospecific stands over several meters or various colonies (which may be different colours and have polyp mantles of different texture) may grow together to form a single composite stand. Colonies are phaceloid to flabello-meandroid. Flabello-meandroid colonies have irregularly dividing valleys. Septa Retracted polyps are thick and fleshy, with either smooth or rough mantles. Colonies are uniform in colour or with two or more colours concentric to mouths or valley walls. All corallites of the same colony have the same colours. *L. hemprichii* may be frequently a dominant species and occurs in upper reef slopes (fig. 72).

Fig. 72: *Lobophyllia hemprichii* T3 188r Left: growth form of a colony, right: detail.

Millepora sp.

Millepora (Fire corals) are colonial marine organisms and belong to Hydrozoa. Colonies are branching, plate-like or encrusting. Fire corals have a firm calcareous external skeleton perforated by innumerable pores where the polyps can extend into the open water. Some taxa can easily be mistaken for the blues coral (*Heliopora coerulea*). Fire corals have thin, longish polyps without a noticeable ring of tentacles like the blue coral. Colonies are golden-brown to pale and grayish-brown. They may form extensive stands often in parts of the reef where the tidal currents are strong but they are also abundant on upper reef slopes and in lagoons (fig. 73).

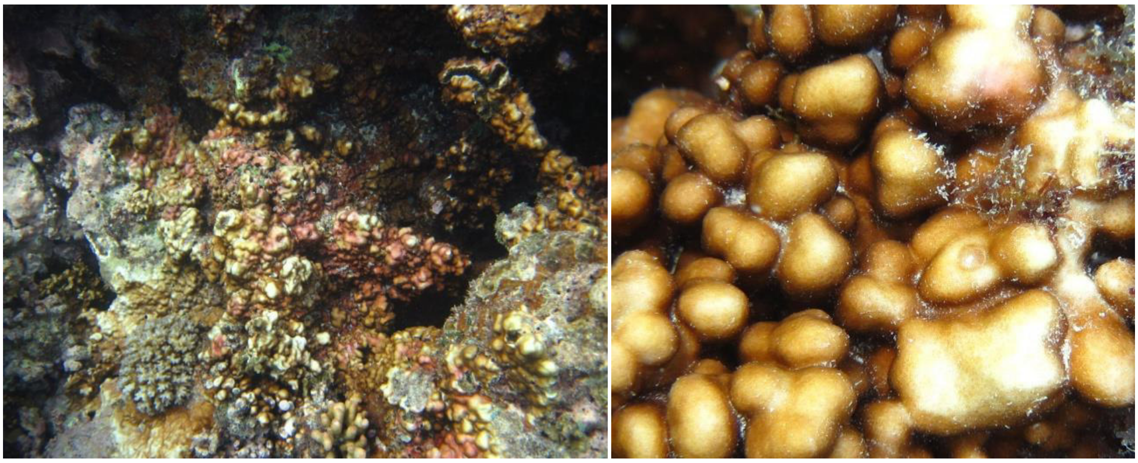

Fig. 73: *Millepora* sp. T2 l65.8l Left: growth form of a colony, right: detail.

Pavona cactus (Forskål, 1775)

Colonies are composed of thin, contorted, bifacial, upright fronds. Sometimes colonies have thickened branching bases. Corallites are fine and shallow. They are aligned in irregular rows parallel to frond margins. Colonies are pale brown or greenish-brown. The margins are often white. *P. cactus* is common and usually found in lagoons and on upper reef slopes in turbid water protected from wave action (fig. 74).

Fig. 74: *Pavona cactus* T9 49l.

Pavona clavus (Dana, 1846)

Colonies are columnar, club-shaped and/or laminar. They may form colonies several metres across or extensive single species stands. Columns divide but do not fuse. Corallites have thick walls and are well defined. Septo-costae are of two very distinct orders. Coloneis are uniform pale grey, cream or brown. *P. clavus* is common and occurs in habitats exposed to currents (fig. 75).

Fig. 75: *Pavona clavus* T9 49l Left: growth form of a colony, right: detail.

Pavona decussata (Dana, 1846)

Colonies are thick interconnecting bifacial upright plates or they are submassive, with or without lobed horizontal margins and upright plates. Corallites are irregular, deep seated, and are sometimes aligned parallel to margins or to radiating ridges. Colonies are brown, creamy-yellow or greenish. *P. decussata* is common and occurs in most reef environments (fig 76).

Fig. 76 *Pavona clavus* T9 14l Left: growth form of a colony, right: detail.

Plesiastrea versipora (Lamarck, 1816)

Colonies are flat and are frequently lobed. Corallites are 2-4 millimeters in diameter. Paliform lobes are present and form a neat circle around a small columellae. Tentacles are short and of two alternating sizes. Sometimes they are extended during the day. Colonies are yellow, cream, green or brown. *P. versipora* is seldom common and occurs in most reef environments but especially in shaded places such as under overhangs. Colonies also occurs on rocky foreshores of temperate locations protected from strong wave action (fig. 77).

Fig. 77: *Pavona decussata* T9 71l Left: growth form of a colony, right: detail.

Psammocora digitata (Milne Edwards and Haime, 1851)

Colonies are composed of plates and/or columns. Corallites are small and shallow. Septa are slightly exsert. Colonies are purple, grey or brown. *P. digitata* is uncommon and occurs in most reef environments (fig. 78).

Fig. 78: *Pavona decussata* T7 145l Left: growth form of a colony, middle: detail with tentacles extended, right: detail with tentacles contracted.

Styllocoeniella sp. (Yabe and Sugiyama, 1935)

Colonies are massive, columnar or encrusting. Corallites are immersed and circular. The coenosteum is covered either with fine spinules or with larger pointed coenosteum styles. These bulges are almost as numerous as the corallites. *Stylocoeniella* occurs particularly in shallow reef environments (fig. 79).

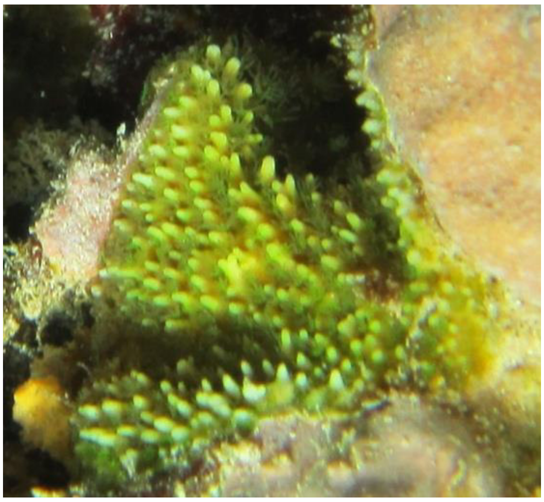

Fig. 79: *Stylocoeniella* sp. T2 l62.5l.

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