

The influence of a pollution gradient from a large urbanised area on coral reef fish population structure and coral reef resilience at Jakarta, Indonesia



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Summary of Thesis

Coral reefs are considered as the most complex and diverse marine ecosystems (Knowlton, 2001; Jackson et al., 2001). Coral reefs have a high degree of natural variability caused by large scale natural disturbances (Green et al., 1999). However, anthropogenic disturbances now threaten coral reefs as well. Most coral reef ecosystems are present near coasts, and are therefore also subjected to stressors associated with urbanization, including land-based pollution, agricultural runoff, deforestation, oil spills, coral mining, overfishing, untreated sewage, siltation, marine litter, nutrient overloads and resource extraction (Jackson et al., 2001; Green & Bellwood, 2009; Cleary et al., 2008).

Because of these human activities, the composition and functional characteristics of coral reefs change. Herbivorous reef fishes are known to be one of the determining factors whether coral reefs are likely to recover after disturbances. Herbivorous fishes play a crucial role in coral reef resilience by limiting the establishment and growth of algal communities that disturb coral recruitment (Hughes et al., 2007; Green & Bellwood, 2009). Consequently, functional groups of herbivores prevent the occurrence of coral-algae phase shifts (Hughes et al., 2007).

The total fish biomass and environmental parameters within reefs of the Pulau Seribu island complex, located near the coast of Jakarta, Indonesia, were measured in order to address the question 'How does the pollution gradient from a large urbanised area affect coral reef fish populations as an indicator for coral reef resilience against regime shifts from a coral dominated reef structure towards macroalgal communities in the Indonesia's Jakarta Bay – Pulau Seribu reef complex?'

Total biomass of all fish species, total biomass of herbivores and total biomass of the functional herbivorous group Grazers/Detrivores were all negatively influenced by urbanisation. Also, fish diversity was negatively affected by urbanisation.

Only two significant relations were found, focusing on the influence of herbivorous biomass on coral reef structure; between biomass browsers and sponges cover ($p=0,001$) and between biomass of scrapers/small excavators and algae cover ($P=0,032$); indicating a small influence of herbivorous biomass variation on the coral reef structure.

In terms of coral reef resilience, results suggest that the locations near the urbanised area of Jakarta experience low resilience, indicated by the low amount of herbivorous biomass, therefore increasing the chance of going from a coral dominated to an algae dominated system with increasing the human pressure. The influence of herbivorous reef fishes on coral reef resilience is limited. Still there seems to be a relation between coral reef fishes and coral reef resilience, as evidenced by the found relations between reef fish diversity and cover of coral, sponges, rubble and sand.

Preface

This research is the final part of the master Sustainable Development, with the specialization Global Change and Ecosystems (former Land-use, Environment and Biodiversity) from the University of Utrecht, located in Utrecht, the Netherlands. The research has been supervised by dr. Jerry van Dijk of the University of Utrecht, and was executed in 2011 on site in the Jakarta Bay- Pulau Seribu complex, which is located in Indonesia, under the supervision of dr. Nicole de Voogd from Naturalis Biodiversity Center, located in Leiden, the Netherlands. The whole research focused on the impact of urbanization on coral reef ecosystems, the research of this master thesis focused on the impact of urbanization on coral reef fish population structure.

I experienced the fieldwork as extremely instructive and enjoyable. Especially the scuba diving in coral reefs and the valuable discussions in the evenings with the research staff of Naturalis I will remember. The period after the fieldwork, from July 2011 till now, is characterized by ups and downs, mainly in physical health, which caused ups and downs in the progress of finishing the master thesis. Therefore I am very grateful that I have been able to finish this thesis with the support of my supervisors and the University.

Introduction

Coral reefs are considered as the most complex and diverse marine ecosystems, both in structure as in abundance of fish and invertebrate species that use them as their habitat (Knowlton, 2001; Jackson et al., 2001). More than one third of all the world's marine fish species live near or in close relation to coral reefs (Reaka-Kudla, 1996), even though only 0,1% of all marine ecosystems consists of coral reefs (Spalding et al., 2001). Coral reefs, therefore, play an important role in maintaining marine biodiversity (Hughes et al., 2003). Coral reefs consist of many different types of coverage, ranging from hard and soft corals to sand and sponges, and can take on many structurally complex forms like barrier reefs and fringing reefs (Spalding et al., 2001). Differences in the structure of coral reefs define the species of marine fish and invertebrates that use these reefs as their habitat.

Coral reefs do not only play a large role in the maintenance of marine biodiversity, but are also important as a provider of different ecosystem goods and services (Hughes et al., 2003). Almost 500 million people live within 100 km from a coral reef (Bryant et al., 1998), in more than 100 countries that have coastlines with coral reefs (Moberg and Folke, 1999). Coral reef fishes and invertebrates are used for consumption and thereby provide millions of people with much-needed proteins (Moberg and Folke, 1999). Moreover, coral reefs are exploited for tourism and other money-making purposes. Constanza et al. (1997) estimate the average global value of annual ecosystem services of coral reefs on US\$375 billion per year. In addition, coastlines with coral reefs depend on these reefs for shoreline protection. The reefs do not only reduce wave energy and thereby protect coasts from storms and erosion, but also supply carbonate material for the growth of coastal margins (Rees et al., 1999; Green & Bellwood, 2009).

Hence, coral reefs provide a large amount of merits, but are very vulnerable when it comes to disturbances in their surroundings. Large scale episodic disturbances, such as major storms, have a big impact on coral reefs, destroying notable portions of these reefs. Coral reefs, therefore, have a high degree of natural variability (Green et al., 1999). Even though it takes a long time for coral reefs to repair this damage, generally, reefs are able to recover from these natural disturbances in a few years to decades (Green & Bellwood, 2009). However, anthropogenic disturbances now threaten coral reefs as well. Disturbances related to human activities incorporate habitat destruction, climate change, pollution and the exploitation of living resources (for instance by overfishing), and negatively affect biodiversity and overall health of fifty-eight percent of the world's coral reefs (Jackson et al., 2001; Green & Bellwood, 2009).

Coral reef ecosystems are present at short distances from a coast, and are therefore in particular increasingly subjected to multiple, interacting stressors associated with human activities and urbanization. Stressors related to human activities include overexploitation of marine resources and destructive fishing practices (Rees et al., 1999; Jackson et al., 2001; Cleary et al., 2008; Green & Bellwood, 2009). Stressors related to urbanization include land-based pollution such as sedimentation, agricultural runoff, deforestation, oil spills, coral mining, overfishing, untreated sewage, siltation, eutrophication (the addition of harmful artificial substances like phosphate to aquatic systems), persistent organic pollutants, heavy metals, acidification, radioactive substances, marine litter, nutrient overloads, pesticide pollution and resource extraction (Jackson et al., 2001; Green & Bellwood, 2009; Cleary et al., 2008). Because of these human activities, the composition and functional characteristics of coral reefs change. Heavy metals and other toxic substances from industrial effluent can reduce fertility, cause deviations from normal growth patterns and interfere in symbiotic bonds between algae and

corals, in addition to making corals more susceptible to bleaching during storm events (Hughes et al., 2003; Cleary et al., 2008). Nutrient inputs can in turn alter species composition and multiply algal blooms, thereby disturbing the delicate phototropic coral reproduction and reducing the photic zone (Cleary et al., 2008).

These threats to the health and presence of coral reefs require urgent action. It is still largely unclear how marine environments will be affected by human population growth and urbanization. A first crucial step in understanding this is to study changes in the structure and composition of coral reefs through time and relate these to changes in the coastal urban environment. There is a lack of studies that directly assess how human settlement patterns have affected, and continue to affect, these diverse ecosystems. Understanding this influence will facilitate informed policy and management decisions that aim to protect the world's coral reefs.

Traditionally, to verify the necessity to protect a coral reef, or to evaluate the effectiveness of a current coral reef protection measure, data is collected by monitoring the status of coral communities (for instance coral cover) and populations like fish species in a coral reef (for example Graham et al., 2013). These data provide useful information on the current status of coral reef communities and can be applied in modern conservation strategies through efforts to preserve biodiversity (Cheal et al., 2013).

Nowadays, other parameters in data collection become more important, because researchers are focusing more on managing reef protection through the protection of reef resilience (Folke et al., 2004; Green & Bellwood, 2009). Walker et al. (2004) define resilience as "the capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity and feedbacks" (Walker et al., 2004, p. 2). Coral reef resilience is not only this ability to absorb recurring disturbances, but also, following coral mortality, the ability of these reefs to rebuild hard coral dominated systems rather than shifting to fleshy algal dominated systems (Bellwood et al., 2004; Green & Bellwood, 2009; Hughes et al., 2010).

While monitoring the status of coral communities and populations provides helpful information on the present condition of these communities, it does not provide information on the status of leading ecological processes that are crucial for maintaining coral reef resilience (Bellwood et al., 2004; Hughes et al., 2005; Worm et al., 2006). Therefore, it does not provide an indication of whether coral reefs are likely to recover after disturbances. Since, due to climate change, recurring and more severe disturbances will be an increasing problem in future, coral reef resilience will become more and more important (Green & Bellwood, 2009). There are several factors that are considered crucial for maintaining coral reef resilience. These are largely factors that aid coral recruitment and survivorship, including (but not limited to) good water quality, a stable, solidified substratum (basis), and the availability of coral larvae (as an indicator for the ability of a reef to establish new coral colonies and maintain a healthy reef system) (Green & Bellwood, 2009). Consequently, factors that negatively influence this coral recruitment and survivorship are poor water quality (mostly due to runoff of sediments and nutrients from poor land use practices), loose rubble and an unstable and non-solidified substratum, and the lack of coral larvae (Green & Bellwood, 2009). Also, the presence of thick algal mats, large stands of macroalgae or specific species of soft corals indicate a decline in coral reef resilience. Dense stands of macroalgae overgrow and kill coral colonies, and disturb coral recruitment by lowering coral fertility, settlement rates, and post settlement survival (Birrell et al., 2008). Therefore, maintaining reef resilience requires the control of algal communities by eliminating, or at least diminishing, the influence of negative factors on coral reefs, including the prevention of the establishment of dense stands of macroalgae (Green & Bellwood, 2009).

Cheal et al. (2013) suggest the study of functional roles of species that populate coral reefs. Current coral reef management strategies that take into account the abundance and distribution of species in light of their functional role in the reef might help conserve vulnerable marine ecosystems, but too little is known about which species has which functional role within an ecosystem and the way functional groups contribute to the ecosystems resilience (Cheal et al., 2013). Therefore, a study on the influence of various functional groups on coral reef resilience is urgently needed.

Herbivores play a crucial role in coral reef resilience by limiting the establishment and growth of algal communities that disturb coral recruitment (Hughes et al., 2007; Green & Bellwood, 2009). Consequently, herbivores prevent the occurrence of coral-algae phase shifts (Hughes et al., 2007). Fishes are the dominant group of herbivores on coral reefs in the Indo-Pacific Region (Green & Bellwood, 2009), and can therefore aid in maintaining coral reef resilience. The role of herbivorous reef fishes in promoting reef resilience depends upon their feeding preferences, and their numerical abundance and biomass relative to benthic (seabed) cover (Ledlie et al., 2007). Thus, herbivorous reef fishes do not constitute an ecologically uniform group (Choat, 1991), but consist of four functional groups that differ in terms of how they feed, what they consume, and their impact on the underlying substratum (Green & Bellwood, 2009). Each of these functional groups play an important role in preventing coral-algal phase shifts: scrapers/small excavators, large excavators/bioeroders, grazers/detritivores, and browsers (Green & Bellwood, 2009). Several studies have demonstrated how the loss of these herbivorous fishes can trigger coral-algal phase shifts on coral reefs. (Hughes et al., 2007; Bellwood et al., 2006).



Figure 1: Examples of species within the functional groups. Clockwise, starting at the upper left corner: a scraper, a school of large excavators/bioeroders, a school of browsers, and a grazer.

Although four functional groups exist, the broadest distinction between herbivores is between fishes which mostly graze on algal turfs and fishes which browse on fleshy macroalgae (Williams, 2013). However, overlaps occur in these feeding preferences. Scrapers and small excavators play similar roles in coral reef resilience by limiting the establishment and growth of macroalgae while intensely grazing epilithic algal turf, and providing areas of clean substratum for coral recruitment (Green & Bellwood, 2009). Large excavators/bioeroders play a different role in coral reef resilience by opening up new sites for colonization by coralline algae and corals (Green & Bellwood, 2009). Grazers/detritivores play an important role in coral reef resilience by intensely grazing epilithic algal turfs, which can limit the establishment and growth of macroalgae (Green & Bellwood, 2009). Browsers consistently feed on macroalgae, and therefore play an important role in reducing coral overgrowth and shading by macroalgae. (Green & Bellwood, 2009).

Given the critical role that coral reef resilience plays in sustaining coral reefs, and the role functional groups of herbivorous fishes play in the maintenance of this coral resilience, developing new metrics for monitoring coral reef resilience that are process-oriented is urgent for the improved management of coral reefs. Monitoring coral reef resilience will require a combined approach to monitor key ecological processes and functional groups that contribute to these processes. This approach should include coral population dynamics (size structure and patterns of recruitment), factors that influence coral recruitment and survivorship (particularly water quality, substratum consolidation, and benthic communities (particularly macroalgae)), and factors that influence the establishment and growth of macroalgal communities (particularly functional groups of herbivorous reef fishes). This research will aim to incorporate this combined approach to improve monitoring strategies.

Problem definition

Very few coral reefs are located close enough to large cities to study the influence of large urban populations on reef assemblages. An exception is the Thousand Islands (Pulau Seribu) reef complex to the north of Jakarta, the capital city of Indonesia, and one of the largest conurbations in the world (de Voogd & Cleary, 2008; Cleary et al., 2008). Despite harbouring among the most diverse marine environments in the world, relatively little is known about Indonesian coral reefs (Tomascik et al., 1997). Further research on Indonesian coral reefs is therefore needed. This study is part of a larger study, assessing the historical impact of urbanization on coral reef environments nearby the major city Jakarta, Indonesia in southeast Asia. The Thousand Island reef complex near Jakarta can be seen as a very fruitful research location, since earlier research found that the reef complex is under various levels of pressure from human activities, including unsustainable fishing, coral mining, oil exploration, uncontrolled tourism, sand dredging, anchor damage, resort construction and the discharge of industrial and domestic effluent (Rinawati et al., 2012; Rees et al., 1999; Rachello-Dolmen & Cleary, 2007). An analysis of data of 1995 of the Indonesia's Jakarta Bay, Pulau Seribu reef complex, showed pronounced on-to-offshore variation in relation to the city of Jakarta in variables like the cover of sand, fish abundance, and fish species richness (Cleary et al., 2008). Back then, the majority of reefs were in poor to very poor conditions (Cleary et al., 2008), and it is unknown how these reefs have developed after 1995. At the Thousand Islands reef complex, monitoring is still only focused on the status of coral communities (for example coral cover) and populations like fish species. As stated earlier, these measures provide useful information on the current status of these communities, but do not provide information on the status of key ecological processes that are essential for maintaining coral reef resilience (Bellwood et al., 2004; Hughes et al., 2005). Therefore, they do not provide an indication of whether coral reefs are likely to recover after disturbance. Unknown are the implications of monitoring on functional group level rather than species level. This research will be focussed on monitoring the current status of reef fish communities, but will also be one of the first studies to incorporate presence of key functional groups of herbivorous reef fishes as indicators of coral reef resilience. Therefore, it will propose a better way to assess coral reef health and resilience in future, which will contribute to better conservation strategies and to a better overall academic understanding of the workings of marine ecosystems.

Aim

The aim of this research is to analyse coral reef fish population structure along a pollution gradient from a large urbanised area as an indicator for coral reef resilience against regime shifts from coral dominated reef structure towards macroalgal communities in the coral reef system, by making a spatial comparison of reef fish communities in the area of the Thousand Islands and the Jakarta Bay.

Main Research Question

How does the pollution gradient from a large urbanised area affect coral reef fish populations as an indicator for coral reef resilience against regime shifts from a coral dominated reef structure towards macroalgal communities in the Indonesia's Jakarta Bay – Pulau Seribu reef complex?

Subquestions

1. Which changes in fish species composition can be observed with increasing distance from Jakarta?
2. Which changes in reef health indicators can be observed with increasing distance from Jakarta?
3. Which changes in fish species composition affect the changes in reef health indicators and therefore coral reef structure?

Hypothesis

Distance from the city of Jakarta will be used as a proxy for the pollution gradient from the large urbanised area, with sites closest to the city assumed to have the highest pollution, and sites at the outer end of the Pulau Seribu island complex expected to have the lowest pollution. This pollution is hypothesized to diminish going further away from the bay of Jakarta, therefore also fish population parameters and reef health indicators will be influenced less by pollution from the urbanised area at locations further away from Jakarta. Thus, linear positive relations are expected between distance from Jakarta and the fish population parameters and reef health indicators. Also a linear positive relation is hypothesized between distance from Jakarta and Shannon Wiener index number, because reef fish biodiversity is expected to have a positive influence on removing macro algae.

The factors that will be focused on in the coral reef resilience process in this research are a stable, consolidated substratum and coral recruitment and survivorship. Herbivorous fishes limit the establishment and growth of algal communities, which negatively influence coral recruitment, and therefore coral-algae phase shifts can be avoided. Consequently, health indicators which are very abundant in a resilient coral reef, like coral and sponges, are hypothesized to have a positive relation with the fish population parameters. Health indicators cover of Rock, Rubble, Sand, Algae, which are taken as indicators for the failure of coral recruitment and survivorship, will have a hypothesized negative relation with the fish population parameters. Algae can overgrow and kill coral colonies, and the other coverages are a sign that this process has already occurred, resulting in loose rubble or unconsolidated substratum.

Research framework

Fish species numbers and reef health indicator coverages were measured during fieldwork in the Jakarta Bay- Pulau Seribu complex. Then, out of the fish species data, biomass for each family was measured using known length-weight constants. Furthermore, distance from Jakarta and the total cover of the reef health indicators was calculated. Also, a biodiversity number and evenness number for each coral reef was calculated using the Shannon Wiener Diversity Index.

Next, biomass, coverages and Shannon Wiener index numbers were correlated to distance from Jakarta to answer subquestions one and two. Subsequently, fish biomass composition and reef health indicator coverage differences between measurement locations were analysed using Principle Correspondence Analysis. To answer subquestion three, fish biomass composition differences were correlated to reef health indicator differences, to analyse the impact of coral reef fish biomass changes on the cover of reef health indicators, and therefore coral reef structure.

Methods

Preparations

Before the fieldwork, the observer learned which fish species are present in the Indonesian Archipelago, and learned to recognize those fish species on family level.

As a starting point for fish family recognition, there was looked at older fish family data recorded in 1995 and 2005 in the same area, and the families which were counted then were trained to recognise. A total of 30 families were selected, namely Acanthuridae, Apogonidae, Balistidae, Blenniidae, Caesionidae, Canthigasteridae, Carangidae, Centriscidae, Chaetodontidae, Cirrhitidae, Dasyatidae, Diodontidae, Diploprionidae, Ephippidae, Fistulariidae, Gobiidae, Haemulidae, Holocentridae, Kyphosidae, Labridae, Lethrinidae, Lutjanidae, Microdesmidae, Monacanthidae, Mullidae, Nemipteridae, Ostracionidae, Parapercidae, Pempheridae, Platacidae, Plotosidae, Pomacanthidae, Pomacentridae, Priacanthidae, Pseudochromidae, Scaridae, Scolopsidae, Scorpaenidae, Serranidae, Siganidae, Synanceidae, Syngnathidae, Synodontidae, Tetraodontidae and Zaclidae. Especially there was focused on the most important fish families in line with the research question, namely the herbivorous fish families, which are Acanthuridae, Ephippidae, Kyphosidae, Labridae, Pomacanthidae, Scaridae, and Siganidae.

Second, length categories were determined: Fish categories of 2,5 cm were used for fish less than 10 cm in length, 5 cm categories were used for all larger fish, in accordance to the method proposed in Green & Bellwood, 2009.

Last, the observer learned how to estimate fish lengths, by printing a fish picture in different lengths, varying from 2,5 cm to 35 cm in steps of 5 and 10 cm, which correspond to the largest values of the length categories used.

Study site

Quantitative data was collected in the Jakarta Bay-Pulau Seribu reef complex, in Indonesia. This complex extends from Jakarta Bay to more than 80 km towards the northwest (Figure 2). These reefs are well studied (Cleary et al. 2006; Rachello-Dolmen & Cleary 2007) and one of the few examples of still relatively intact reefs in the proximity of a major conurbation. Jakarta is one of the largest urban environments in the world with more than 10 million people living in a 460 km² area. Several rivers transport sewage and storm water over a 2000 km² catchment area to the central sector of the bay (Rees et al., 1999). This central sector is defined by two flanking delta systems, both of which have a large sediment input (Rees et al., 1999). Data have been collected by Naturalis Biodiversity Centre in 1995 and 2005 in this area. Almost all transect locations of the 1995 and 2005 surveys (Cleary et al., 2006 and 2008) were revisited.

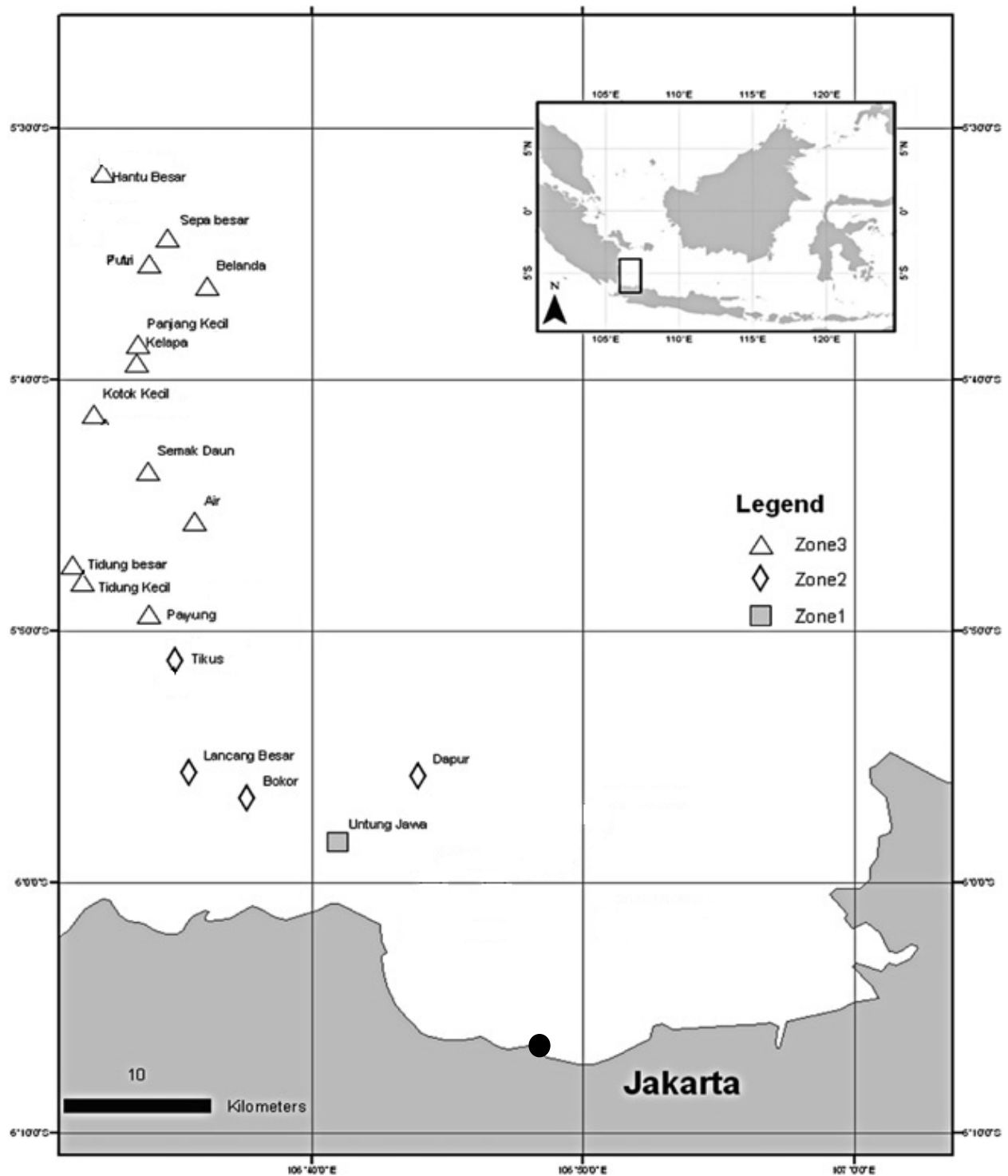


Figure 2: Map of research area, with triangles, squares and diamonds, indicating the 2011 sampling localities in the Thousand Islands archipelago. Zone 1: Inshore zone within 21 km of the port of Sunda Kelapa Jakarta, Zone 2: a midshore zone between 22 and 40 km from Jakarta, Zone 3: an offshore zone more than 40 km from Jakarta. The black spot is the harbour of Jakarta. (Modified version of the figure of Cleary et al., 2008)

Sampling

Sampling occurred from July 20 – August 20, 2011.

On every location, three replicate 50 m belt-transects were laid parallel to the reef crest at approximately 5 m depth, in order to count fishes on the reef flat and reef slope. All individuals observed within 5 m on either side of the 50 m transect were identified to taxonomic groups on family level, and species level where possible, and recorded, see figure 3. Each transect encompasses a total survey area of 500 m² per transect and 1500 m² per site. Both fish species abundance and size (total length in cm, TL) were monitored, since there is a strong negative relationship between biomass of herbivorous fishes and macroalgal cover (Mumby et al 2006), and therefore coral reef resilience (Green & Bellwood, 2009), see appendix 1. All individuals of species in the transect area from the reef substratum to the water surface were counted, and fish that had left and subsequently re-entered the transect area were not counted again (Hoey & Bellwood 2008, Dickens et al. 2011). All data were recorded directly onto pre-prepared data sheets of underwater paper, see figure 4.

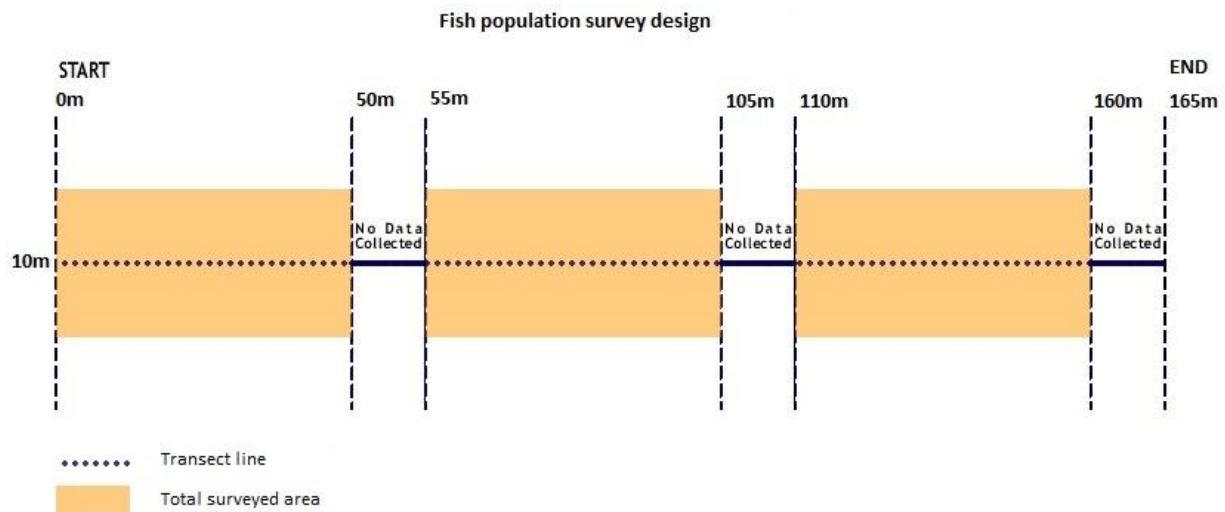


Figure 3: Fish population survey design

To minimize disturbance to the fish communities, the boat was not floating over the area prior to the survey, the observer was the first person to swim through the survey area, the observer was swimming very quietly while surveying, and waited for at least 5mins after laying down the transect line before starting the survey (Dickens et al. 2011). Also, all belt-transects were placed in the same direction (NW), and with a distance of 5-10 meter between each other.

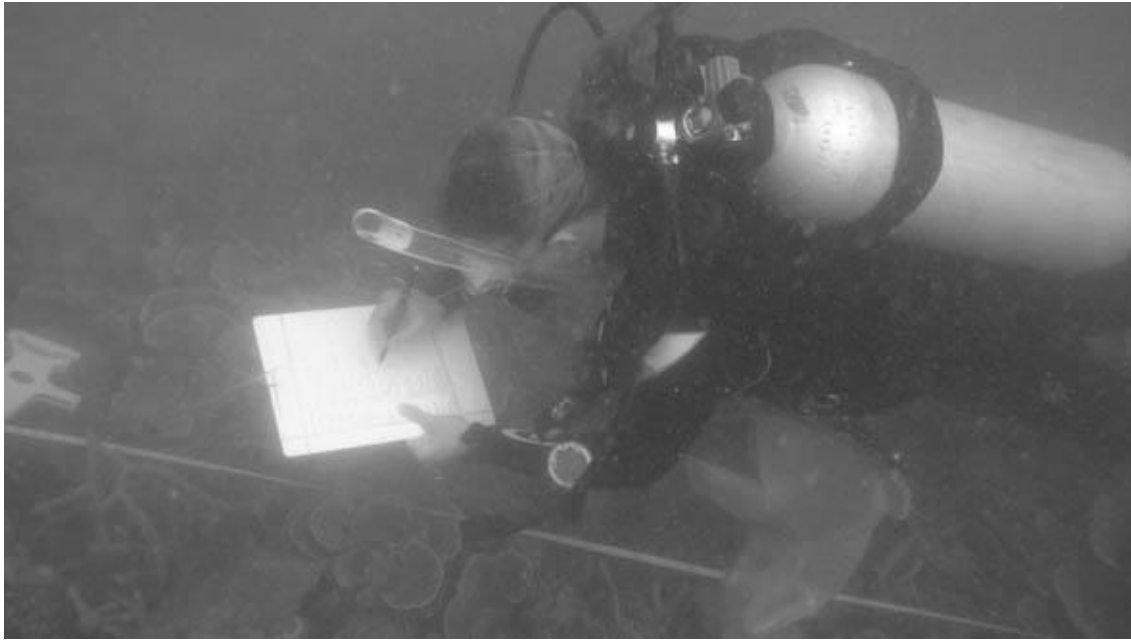


Figure 4: Surveying fishes along the transect line, writing species down on data sheets of underwater paper

Assessing Distance to Jakarta

In order to address the possible influence of the positioning of the measurement points in coral reef complex relative to Jakarta as part of the large urbanised area, for all measurement points, distance to the harbour of Jakarta was calculated, see table 1.

The 'haversine' formula to calculate the shortest distance over the earth's surface was used to determine the distance between the harbour of Jakarta and all measurement locations (<http://www.movable-type.co.uk/scripts/latlong.html>). The haversine formula consists of a couple of parameters: latitude (ϕ), longitude (λ) and earth's radius (R).

$$a = \sin^2(\Delta\phi/2) + \cos \phi_1 \cdot \cos \phi_2 \cdot \sin^2(\Delta\lambda/2)$$

$$c = 2 \cdot \text{atan2}(\sqrt{a}, \sqrt{1-a})$$

$$\text{distance (km)} = R \cdot c$$

Assessing Fish Family Biomass

For all fish families, total fish biomass was calculated, which is a measure of reef fish abundance (Graham et al. 2013). First, size estimates were converted to biomass using known length-weight relationships for each species using the formula $W = aL^b$ (Kulbicki et al. 2005), see appendix 2.1. Where: W = weight of the fish in grams (g); L = fork length (FL) of the fish in centimeter; and a and b are constants calculated for each species or genus. The biomass constants used for each family can be seen in table 1, those are obtained from Appendix 2 of Green & Bellwood, 2009.

Table 1: Fish families and their correspondent a and b constants, and their tail shape.

family	a	b	Rounded/square or fork tail
Acanthuridae	0.02562	3.0184	Fork
Apogonidae	0.01192	3.2622	Fork
Blenniidae	0,00858	3,4503	Square
Caesionidae	0,009	3,255	Fork
Centriscidae	0.0004	4.120	Round
Chaetodontidae	0,03743	2,9143	Square
Dasyatidae	0.0094	3.352	Square
Ephippidae	0.0443	2.951	Round
Fistulariidae	0.0004	3,1265	Round
Gobiidae	0,0163	2,8192	Square
Haemulidae	0,0207	2,9335	Square
Labridae	0,01411	3,054	Round
Lethrinidae	0,0212	2,9973	Fork
Lutjanidae	0,0159	3,0395	Square
Microdesmides	0.0091	3	Fork (Santavy et al. 2012)
Monacanthidae	0.0070	3.262	Round
Mullidae	0,01065	3,2155	Fork
Parapercidae	0.0133	2.943	Round
Pempheridae	0.0439	2.62	Fork (Santavy et al. 2012)
Pomacanthidae	0,06645	2,6475	Round
Pomacentridae	0,0257	3,0921	Fork
Priacanthidae	0.0294	2.807	Round
Scaridae	0,0228	2,9635	Fork
Scolopsidae	0.0157	3.054	Fork
Serranidae	0,01195	3,06975	Round
Siganidae	0.0145	3.122	Fork
Sphyrnaeidae	0.0058	3.013	Fork
Synodontidae	0,00847	3,055	Fork
Tetraodontidae	0,0391	2,837	Round
Zanclidae	0.0147	3.370	Fork

Because total length (TL) of the fish was estimated during the fieldwork, TL was converted into FL in order to use the formula for weight estimates. For species with rounded or square tails, FL and TL are the same (Green & Bellwood, 2009). However, for species with forked tails, FL is approximately 90% of TL for most species (Kulbicki et al. 2005). Additionally, because size categories were used, fish lengths used for biomass estimates should be the mid value for each size category (Green & Bellwood, 2009). All size categories used in this research are displayed in table 2, with their correspondent mid values for TL and converted FL.

Table 2: Used length categories and their corresponding TL and FL.

Length category	cm	Total length (TL)	Fork Length (FL)
I	< 2.5	1,25	1,125
II	2.5 - 5.0	3,75	3,375
III	5.0 - 7.5	6,25	5,625
IV	7.5 - 10.0	8,75	7,875
V small	10.0 - 15.0	12,5	11,25
VI small	15.0 - 20.0	17,5	15,75
VII medium	20.0 - 25.0	22,5	20,25
VIII medium	25.0 - 30.0	27,5	24,75
IX medium	30.0 - 35.0	32,5	29,25
X large	35.0 - 40.0	37,5	33,75
XI large	40.0 - 45.0	42,5	38,25
XII large	45.0 - 50.0	47,5	42,75
XIII large	> 50.0	52,5	47,25

The shape of the tail was determined for each fish family, and can be found in table 1. Then, either TL or FL values from table 2 were used, depending on the tail shape, and combined with the constants a and b of table 1 in the formula of W, giving the weight of the individual fishes for each fish family, see appendix 2.1. On each location, total weight W for each fish family was calculated by summing up the separate weights of each fish in each length category within a family.

In the next step, the total amount of biomass for each fish family was calculated using the formula: biomass (kg per ha) = [(biomass per sampling unit W ÷ 1000) ÷ area of the sampling unit in m²] x10,000. The total area that was covered within a sampling unit is 1500 m²: three belts of 50 meter long, which were surveyed 5 meters on each side. For the total biomass in each measurement location, the biomass values of all families present were summed up (see appendix 2.2).

Assessing Herbivorous Functional Groups

For the purposes of this research, all families are divided into functional groups, focused on their possible contribution on reef ecosystem resilience (table 3). Herbivorous fish families were divided based on their feeding patterns into the groups grazers/detritivores (GD), browsers (B), scrapers/small excavators (SS) and large excavators/bioeroders. The fish families which consist of carnivorous, zooplanktonous, planktonous or omnivorous fish species were put in the group 'Others'.

Table 3: Family names and their corresponding total number of counted fishes and functional group.

<i>Fish Family</i>	<i>Functional Group</i>	<i>Fish Family</i>	<i>Functional Group</i>
Acanthuridae	Grazers/detritivores	Monacanthidae	Other
Apogonidae	Other	Mullidae	Other
Blenniidae	Other	Parapercidae	Other
Caesionidae	Other	Pempheridae	Other
Centriscidae	Other	Pomacanthidae	Grazers/detritivores
Chaetodontidae	Other	Pomacentridae	Other
Dasyatidae	Other	Priacanthidae	Other
Ephippidae	Browsers	Scaridae	Scrapers/small excavators if <35cm Large excavators/bioeroders if >35cm
Fistulariidae	Other	Scolopsidae	Other
Gobiidae	Other	Serranidae	Other
Haemulidae	Other	Siganidae	Grazers/ detritivores
Labridae	Scrapers/small excavators	Sphyraenidae	Other
Lethrinidae	Other	Synodontidae	Other
Lutjanidae	Other	Tetraodontidae	Other
Microdesmidae	Other	Zanclidae	Other

Feeding habits for all families were collected from table 1 of Green & Bellwood, 2009 and www.fishbase.org, and the biomass of the individuals of the families with the same feeding patterns were counted together, see table 7. For the family Scaridae, all individuals had a length smaller than 35 cm, therefore the biomass values of this family were summed up in the functional group scrapers/small excavators.

All four functional groups summed up logically give the total biomass at a measurement location. The biomass values of the separate herbivores functional groups were combined into another variable, namely total biomass of all herbivores (the groups grazers/detritivores, browsers, scrapers/small excavators counted together), to have a clear vision of the changes in all herbivores fishes within a reef over distance.

Herbivorous fish population structures are also used as coral reef resilience indicators, because sites that include a high total biomass of herbivorous reef fishes, all herbivorous functional groups, and a high biomass of the functional group large excavators/bioeroders are likely to have high resilience (Green & Bellwood, 2009).

Assessing Shannon Wiener Diversity and Evenness numbers

Shannon Wiener Diversity

The Shannon Wiener index (Shannon, 1949) has been a popular diversity index in the ecological literature. Shannon Wiener Diversity index reflects how many different types (such as families) there are in a dataset, and simultaneously takes into account how evenly the basic entities (such as biomass) are distributed among those types (Okpiliya, 2012). The value of a diversity index increases both when the number of types increases and when evenness increases (Okpiliya, 2012). For a given number of types, the value of a diversity index is maximized when all types are equally abundant (Okpiliya, 2012).

The Shannon entropy quantifies the uncertainty in predicting the species identity of an individual that is taken at random from the dataset (Pal & Choudhury, 2014). The formula is as follows:

$$H = -\sum(P_i \ln[P_i])$$

Where H is the average uncertainty per species in an infinite community made up of 'S' species with known proportional biomass p_1 p_2 p_3 till p_s (Okpiliya, 2012). The first step is to calculate P_i , which is the biomass of a given fish family divided by the total biomass number of all fish families observed at a measurement location. Then this number is multiplied by the natural log (ln) of the number. The index is computed from the negative sum of these numbers.

The index runs from 0 if there is one family at a measurement location type of up to a maximum that is determined by the total number of families in the formula: $-\ln(1/\text{number of families})$, when all families are represented by the same biomass numbers at a measurement location. In this research the maximum Shannon Wiener diversity number is $-\ln(1/30) = 3.40$.

The loss of important fish families or functional groups, decreasing fish species diversity, has the potential to severely compromise ecosystem function (Bellwood & Hughes, 2001, Hughes 1994). Also Burkepile and Hay (2008) state that herbivore species diversity can be critical for maintaining function of coral reefs. Therefore, if an ecosystem has more species variety, it will be more resistant to external influences. All in all, a high species diversity may indicate a healthy environment and is therefore added as additional biomass variable to this research.

Shannon Wiener index number is also used as a coral reef resilience indicator, because decreasing fish species diversity, has the potential to severely compromise ecosystem resilience, and stability (Bellwood & Hughes, 2001), because for example two complementary herbivore species are more effective at mitigating algal blooms than a single species (Burkepile and Hay, 2008). because macroalgae were unable to effectively deter fishes with different feeding strategies Also Roff & Mumby, 2012 state that elevated herbivore diversity can potentially increase reef resilience by fostering greater niche diversification and creating functional redundancy.

Evenness

Evenness (E) refers to how the species abundance (for example, the family biomass) are distributed among the families. When all families in a sample are equally abundant, the evenness index has a maximum value of 1 and it decreases towards zero as the relative abundance of the families diverges away from evenness (Okpiliya, 2012). An evenness of 0 indicates that only one family is present, and there is no dispersion of abundance at the measurement location.

Using species richness per location or total biomass per location (S) and the Shannon Wiener index (H), you can calculate a measure of evenness. Shannon's evenness (E_H) can be calculated by dividing H by H_{\max} (here $H_{\max} = \ln S$).

$$E_H = H / H_{\max} = H / \ln S$$

If an assemblage in a reef is perturbed by chronic pollution, it can shift from one state in which species abundances are relatively evenly distributed to a second state which has fewer species and exhibits high dominance (low evenness) of certain species (Cleary et al., 2005, Nyström et al., 2000, Magurran and Dawn, 2001). Therefore, an ecosystem with higher evenness may indicate a healthy environment. Consequently, evenness is added as additional biomass variable to this research.

Assessing Coral Reef Health Indicators

In the fieldwork period, next to fish family data, also the following life forms were recorded: Acropora branching, Acropora digitata, Acropora tabular, Caulerpa and turfs, Coral branching, Coral encrusting, Coral foliose, Coral Massive, Coral submassive, Coral Tabular, Coralline algae, Dead coral with algae, Dead coral, Halimeda, Heliopora, Millepora, Mushroom corals, Other corals, Rock, Rubble, Sand, Soft corals, Sponges, and Turf algae. For the purpose of this research, those variables were simplified to 5 combined variables, representing the reef health indicators: Rock, Rubble, Sand, Algae, Coral and Sponges.

Two transects of 30 meters were placed at the same depth as the fish transects. Around both transects, the coverages of the different life forms were recorded. The coverages of the environmental parameters from the two transects were counted together to get the total coverage per measurement location.

Statistical Analysis

Regression Analyses

To answer subquestions one and two, regression analyses were performed to explore all possible relations of distance from Jakarta and fish family biomass/ herbivorous functional group biomass/ Shannon Wiener Diversity and Evenness index numbers/ coral reef health indicator coverages, with distance as an independent variable and the biomass data/ coral reef health indicator coverages as dependent variables.

To answer subquestion 3, regression analyses were performed to explore all possible relations of herbivorous functional group biomass/ Shannon Wiener Diversity index numbers and coral reef health indicator coverages, with herbivorous functional group biomass as independent variables and the coral reef health indicator coverages as dependent variables.

Ordination analyses

In order to see the variation in the whole biomass community composition of fish families per site, functional groups per site and reef health indicator coverage composition per site, a multidimensional scaling analysis, ordination analysis, , was performed in which the family/functional group biomass and the reef health indicator coverages increase or decrease can be seen along the islands (Graham et al. 2013). In this way, outlier locations can be observed, which have abnormal biomass compositions, just as clustered locations, which will have very similar biomass datasets.

Detrended Correspondence Analysis

Ordination can be based on the linear response model or an unimodal response model. In order to define whether to use an ordination method belonging to a linear response model (PCA, RDA) or a method belonging to an unimodal response model (CA, CCA), the variation in the dataset has to be determined by performing a Detrended Correspondence Analysis (DCA) to calculate the longest gradient length (Lepš & Šmilauer, 2003). If the longest gradient has a value larger than 3, the unimodal methods have to be used, since the data are too heterogeneous and too many species deviate from the assumed model of linear response (Lepš & Šmilauer, 2003). If the longest gradient is shorter than 3, the dataset is more homogenous, and the linear method is a better choice.

The Detrended Correspondence Analyses performed on the biomass data of all families, the biomass data of the functional groups grazers/detritivores (GD), browsers (B) and scrapers/small excavators (SS), and environmental dataset all show longest gradients smaller than 3. Therefore, all statistical methods used are based on the linear response model.

Principle Component Analysis

Principle Component Analyses are performed on the biomass data of all families, the biomass data of the functional groups grazers/detritivores (GD), browsers (B) and scrapers/small excavators (SS), and environmental dataset. A PCA displays the main part of the variability in the biomass data and environmental data composition in a multidimensional scaling plot, of which the maximal variation is displayed among ordination axis one, expressed as the cumulative percentage variance of species data in the PCA summary. The amount of the total variation that can be explained in these datasets is the same as the sum of all canonical eigenvalues. Then, a regression of the ordination axes on the measured environmental variables was calculated (the environmental variables were projected into the ordination diagram).

The connection between the environment variable and the biomass samples is calculated independently of the result of the PCA analysis (indirect method). The cumulative percentage variance of species-environment relation measures the strength of the relation between species and environment for a particular axis, which can further clarify the possible relations between distance and biomass or environmental parameters of subquestions one and two, and the possible relations between the biomass parameters and environmental parameters of subquestion 3 (Schmitt, 2006). It expresses the amount of variance explained by our axes as a fraction of the total explainable variance (Schmitt, 2006).

The multidimensional scaling plot displays the arrows of the parameters within the biomass datasets and reef indicator dataset, and the arrow representing distance in the case of subquestion one and two, and the arrows of the parameters within the reef indicator dataset and the arrows of the functional group biomass in case of subquestion 3. The arrows point in the direction of the largest increase in weighted averages in the biomass/coverage/km of the specific parameter. The length of the arrows indicates the degree of change in value of the parameter in the corresponding direction. Therefore, there can be analysed which parameters exhibit similarities: their corresponding arrows will have the same direction among the ordination plot.

Redundancy analysis

To answer subquestion 3, which involves multiple explanatory biomass variables for the reef health indicator coverage dataset, also a Redundancy Analysis (RDA) was performed. RDA is a form of constrained ordination, in which the gradients consist of combinations of independent, explanatory variables. In the direct ordination, the ordination axes are aggregates of the environmental variables that best explain the species data (Schmitt, 2006). By calculating a constrained ordination, the main part of the biological variability explained by the environmental variables will not be overlooked (Lepš & Šmilauer, 2003). In constrained ordinations, the relationships between species and the environment are maximized (Lepš & Šmilauer, 2003). Therefore, it will become clear which biomass variables can be combined in order to explain as much variation of the reef health indicator coverages possible. Finally, a Monte Carlo permutation test was performed in order to see if those combined explanatory variables can significantly explain the variation of the reef health indicator coverages.

Results

Observations

A couple of observations at the Jakarta Bay-Pulau Seribu reef complex are worth mentioning. The conditions inside all reefs seemed to be deteriorated. The nearest locations to Jakarta of the 1995 and 2005 surveys could not be revisited, due to the risk of health problems. At the nearest accessible measurement locations from Jakarta, the visibility was extremely low, just around 20 cm. Lonely territorial fish, defending the sparse anemones, were counted there, see figure 5. Furthermore, a clear boundary layer could be seen from the boat, around 20 km distance from Jakarta, where a clear division of green/brown waters and clearer blue waters could be seen.



Figure 5, a territorial nemo fish at location Jak 14.

According to Green & Bellwood, 2009, individuals which are placed into the categories V and VI are already considered small sized fishes. At the research location, most fishes counted were placed in even lower length categories, regularly category III, see appendix 1. Medium sized fishes, categories VII till IX, were seen less frequent, and large sized fishes were rare.

Jakarta Bay-Pulau Seribu reef complex

Total fish species numbers

At the coral reefs of the Jakarta Bay-Pulau Seribu reef complex, fish were counted in different locations which differed in distance to Jakarta. The total area that was covered during the survey is 24.000 m², which is 2.4 hectares (16 locations, 1500m² per location). A total of 5466 fish were counted during the 2011 survey (see appendix 1). The fish which were counted could be divided into 30 different families. Table 4 displays all families found in the total survey, including the amount of individuals counted. Numbers vary from 1 individual within the family of the Zaclidae, until 2135 individuals within the family of the Pomacentridae. Many families only have a few individuals present, which is very few in an area of 24.000m².

Table 4: Family names and their corresponding total number of counted fishes.

Fish Family	Total number of fishes	Fish Family	Total number of fishes
Acanthuridae	97	Monacanthidae	6
Apogonidae	1088	Mullidae	5
Blenniidae	6	Parapercidae	8
Caesionidae	540	Pempheridae	37
Centriscidae	23	Pomacanthidae	60
Chaetodontidae	242	Pomacentridae	2135
Dasyatidae	2	Priacanthidae	4
Ephippidae	13	Scaridae	94
Fistulariidae	4	Scolopsidae	124
Gobiidae	3	Serranidae	26
Haemulidae	2	Siganidae	98
Labridae	779	Sphyraenidae	31
Lethrinidae	11	Synodontidae	2
Lutjanidae	22	Tetraodontidae	2
Microdesmidae	1	Zaclidae	1

Table 5: Functional groups and their corresponding total number of counted fishes and families.

Functional Groups	Total number of fishes	Total number of families	Percentage
Total number	5464	30	100%
Grazers/detritivores	255	3	4,7%
Browsers	13	1	0,2%
Scrapers/small excavators	873	2	16,0%
Large excavators/bioeroders	0	0	0%
Other	4325	24	79,2%

Breaking down the total number of fishes by functional groups gives an insight in how the fish numbers are distributed among the functional groups. Under normal conditions, there are many more carnivore fish species in a reef than herbivores (McGinley, 2014). Evenso, in the researched reefs, the 'Other' group consists of the largest number of families, and largest number of fishes (see table 5). Out of the herbivorous groups, the group scrapers/small excavators consists of the most individual fishes counted over the whole research area, while the group grazers/detritivores consists of the most families.

At the Jakarta Bay-Pulau Seribu reef complex, a low contribution of 21% herbivores is seen compared to the functional group with all other feeding habits, group Other (figure 6). The group browsers has the smallest contribution of the herbivores on the total fish species number, and the group large excavators/bioeroders is not present at all. Of all herbivorous groups, the group scrapers/small excavators gives the greatest contribution on the total fish, 16%. The group of Other, has a contribution of 79% on the total fish species number.

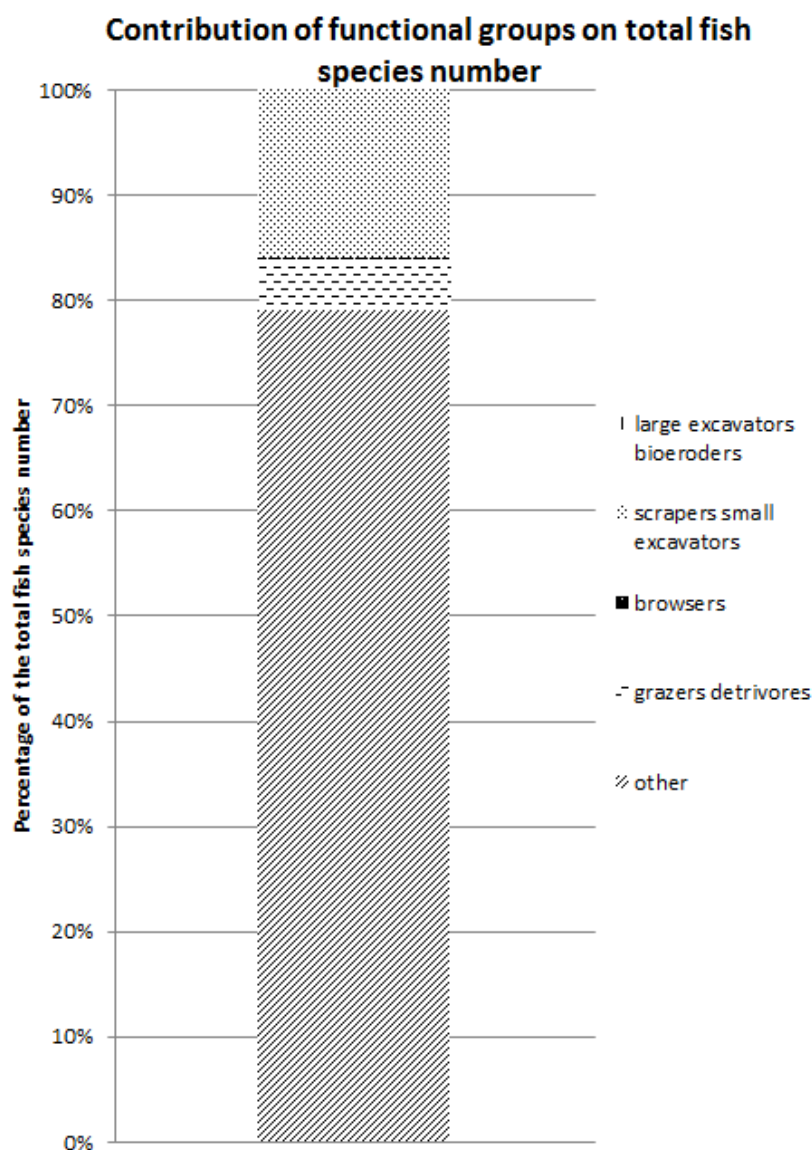


Figure 6: Cumulative bar graph, in which the contribution of herbivorous functional groups on the total species number is displayed.

Total biomass numbers

To investigate how the biomass among the different families was distributed, the weights of all individual fishes were counted together, and biomass (kg/ha) was calculated. The amount of biomass is displayed in table 6. In an area of one ha, biomass values range from 0,005 kg of the families Gobiidae and Microdesmides till 16,05 kg of the family Labridae. The family Pomacentridae, which has the most individuals present within the coral reefs of the Pulau Seribu complex, contributes only 6,53 kg to the total biomass, which is an average number. Also the biomass contribution of the family Centriscidae is very low compared to the amount of individuals.

The families Gobiidae and Microdesmides were only present with a couple of individuals, which clarifies the low biomass contribution. Also the families Blenniidae, Fistulariidae, Monacanthidae, Mullidae, Priacanthidae, Synodontidae, Tetraodontidae, and Zaclidae have a small contribution due to the small number of individuals present. On the other hand, the family Dasyatidae, which has only 2 individuals present, contributes a reasonable amount of 4,57 kg to the total biomass.

Table 6: Family names and their corresponding total biomass.

Family	Total family biomass (kg)	Family	Total family biomass (kg)
Acanthuridae	9,21	Monacanthidae	0,02
Apogonidae	6,52	Mullidae	0,03
Blenniidae	0,08	Parapercidae	0,05
Caesionidae	23,06	Pempheridae	0,40
Centriscidae	0,13	Pomacanthidae	1,37
Chaetodontidae	8,58	Pomacentridae	6,54
Dasyatidae	4,57	Priacanthidae	0,17
Ephippidae	3,98	Scaridae	4,15
Fistulariidae	0,10	Scolopsidae	0,63
Gobiidae	0,005	Serranidae	0,69
Haemulidae	0,38	Siganidae	0,56
Labridae	16,06	Sphyraenidae	0,48
Lethrinidae	1,95	Synodontidae	0,09
Lutjanidae	0,50	Tetraodontidae	0,17
Microdesmides	0,005	Zaclidae	0,07

Table 7: Functional groups and their corresponding total biomass.

Family	Total biomass	Percentage
Grazers/detritivores	11,15	12,3%
Browsers	3,98	4,4%
Scrapers/small excavators	20,21	22,3%
Large excavators/bioeroders	0	0%
Other	55,21	61,0%
total biomass herbivores	35,34	39,0%
total biomass per ha	90,55	100%

Also in terms of biomass weight, carnivorous fish should be more present than herbivores (McGinley, 2014). In the researched reefs, the 'other' group presents the largest biomass contribution (see table 7). Out of the herbivorous groups, the group scrapers/small excavators represents the most biomass, the group grazers/detritivores comes second and the functional group browsers has only a contribution of 3,9 kg. In total, the herbivorous groups contribute 35,3 kg on the total biomass of 90,54 kg/ha.

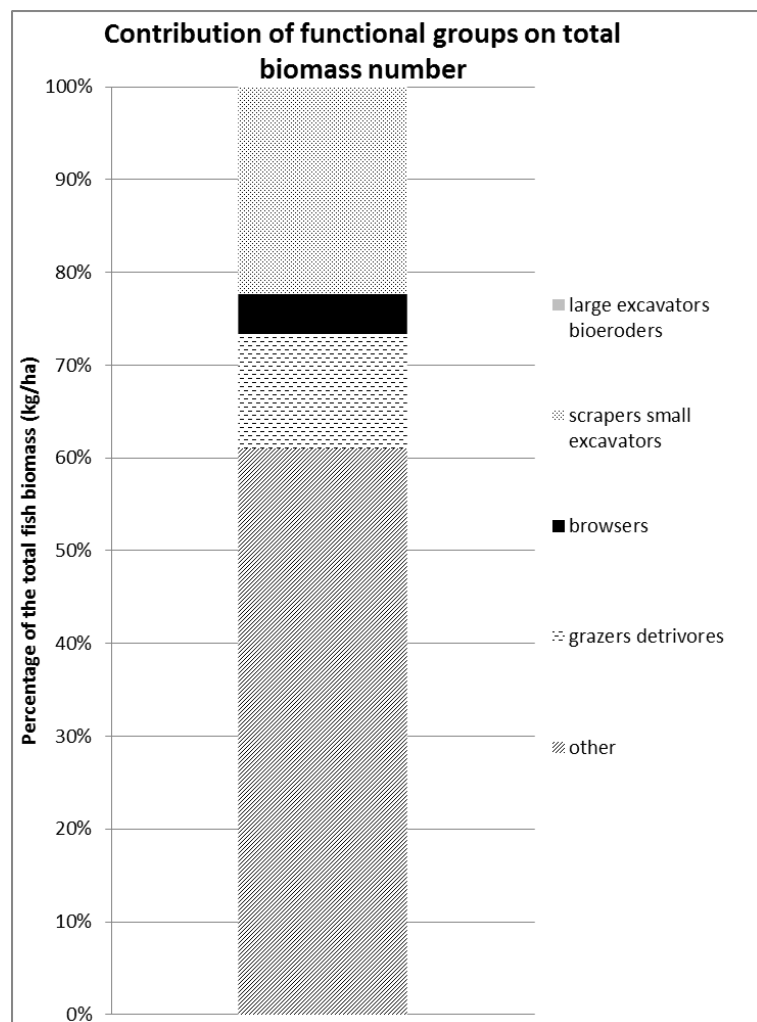


Figure 7: Cumulative bar graph, in which the contribution of herbivorous functional groups on the total species number is displayed.

At the Jakarta Bay-Pulau Seribu reef complex, herbivorous reef fishes are underrepresented compared to the total biomass (39%) (Figure 7), but this contribution is higher than the contribution on the total fish number. The group large excavators/bioeroders is not present at all. The group browsers has the smallest contribution of the herbivores, 4,4% on the total biomass number, but also this percentage is much higher than the percentage contribution on the total fish species number (table 5 versus table 7). Of all herbivorous functional groups, the group scrapers/small excavators gives the greatest contribution on the total biomass, 22%, which is also a higher contribution than on the total fish species number. The same applies to the functional group grazers/detritivores. Because of that, the functional group Other has a lower contribution to the total biomass number than to the total fish species number, but still gives the greatest contribution of 61%.

Distance

In order to address the possible influence of the measurement site location relative to Jakarta, on the amount of fish, families and functional group, for all measurement locations, distance to the harbour of Jakarta was calculated with the haversine formula, see table 8.

Table 8: All measurement points, with their coordinates and calculated distances to the harbour of Jakarta.

Distances for each measurement point				
	Topographical name	latitude	longitude	Distance to Jakarta Harbour (km)
	Jakarta Harbour	-6,106550	106,775882	-
jak 1	Pulau Air	-5,759762	106,578811	44.29
jak 2	Kotok Kecil	-5,687013	106,529469	54.03
jak 3	Semak Daun NW	-5,727880	106,565967	48.08
jak 5	Belanda NW	-5,604245	106,602424	59.06
jak 6	Tidung Kecil NW	-5,799501	106,517664	44.51
jak 8	Bokor	-5,942237	106,627573	24.55
jak 9	Lancang Besar	-5,924092	106,580825	29.61
jak 10	Pulau Kelapa	-5,655577	106,557626	55.65
jak 12	Tikus NW	-5,854972	106,575707	35.67
jak 13	Payung NW	-5,813539	106,547464	41.23
jak 14	Untung Jawa	-5,973957	106,703273	16.79
jak 15	Dapur	-5,923006	106,723062	21.23
jak 16	Panjang Kecil	-5,640012	106,555577	57.31
jak 17	Hantu Besar NW	-5,530535	106,538503	69.22
jak 18	Sepa NW	-5,575868	106,579505	62.88
jak 19	Putri Timor	-5,590931	106,56594	61.86

Distances vary from 16,79 km till 69,22 km to the harbour of Jakarta (table 3). Most measurement points are situated between 40 and 70 km away from Jakarta Harbour. Only the nearest location to Jakarta is positioned in zone one, the inshore zone within 21 km of the port of Sunda Kelapa Jakarta. Most locations are situated in zone three, the offshore zone more than 40 km away from Jakarta Harbour. The harbour Sunda Kelapa Jakarta is marked with a black spot on the map of figure 2.

Fish biomass

In order to answer sub question one and two (which changes in fish species composition/ reef health indicators can be observed with increasing distance from Jakarta), biomass data have been correlated to the previously calculated distances for each measurement location.

Families

Table 9 shows the rounded total amount of biomass (kg/ha) of each fish family at all measurement locations. The measurement locations of table 9 are put in sequence from the location closest to Jakarta, till the measurement location furthest away from Jakarta.

Table 9: Total biomass (kg/ha) within each location for all families sorted in such way that the location with the closest distance to Jakarta is displayed at the top, and the location with the longest distance is at the bottom.

family	Jak 14	Jak 15	Jak 8	Jak 9	Jak 12	Jak 13	Jak 1	Jak 6	Jak 3	Jak 2	Jak 10	Jak 16	Jak 5	Jak 19	Jak 18	Jak 17
Acanthuridae		4,55					1,50	30,5	19,9	7,97			22,9	8,24	38,0	13,9
Apogonidae		29,5		10,9	11,1	6,87	1,00		7,14	3,21	5,93		3,47	9,47	9,36	6,40
Blenniidae	0,10	0,10	1,00													
Caesionidae					9,58	4,99	36,6	62,8	72,7	20,0	24,0	14,1	19,8	33,4	31,8	39,2
Centriscidae	0,44			0,88											0,71	
Chaetodontidae		13,0	0,39	7,36	15,8	7,98	5,23	11,6	17,5	3,50	11,5	3,14	9,63	7,72	17,6	5,36
Dasyatidae		73,1														
Ephippidae							8,55	5,22		13,8			23,1			13,0
Fistulariidae									0,14	0,47		0,33	0,22		0,47	
Gobiidae						0,04										0,05
Haemulidae				6,06												
Labridae	0,42	9,22	2,94	11,6	15,0	6,82	14,2	23,9	55,3	15,1	24,6	15,6	21,5	16,7	5,60	18,5
Lethrinidae	2,12	7,75			17,1	2,12		2,12								
Lutjanidae					0,64				0,23	0,15			6,97			
Microdesmides											0,09					
Monacanthidae			0,11									0,22				
Mullidae		0,50								2,01						
Parapercidae	0,10					0,15			0,15	0,10		0,20	0,15			
Pempheridae		6,44														
Pomacanthidae		4,43			0,36	0,71	0,91			3,05	0,87		1,58	4,82	4,57	0,71
Pomacentridae	1,63	3,54	0,53	1,95	4,87	6,80	6,99	3,50	10,6	2,36	11,0	9,15	3,80	27,3	6,42	4,17
Priacanthidae							0,60					1,83			0,24	
Scaridae		3,18			3,79	5,15	15,9		8,54	2,74	10,3	6,12	0,20	0,74	3,00	6,77
Scolopsidae	0,14	0,88	0,02		0,06	0,21	1,61	0,17	0,86	0,45	0,34	2,63	1,14	0,11	1,30	0,12
Serranidae		0,74			0,37	0,19	2,17						1,04	2,69	0,56	3,33
Siganidae			0,30		1,29		2,32	3,36			0,12				1,08	0,55
Sphyraenidae											1,01				6,68	
Synodontidae					0,26								0,55			0,55
Tetraodontidae					0,88		1,79									
Zanclidae												1,06				
Total Biomass	4,96	157	5,30	38,8	81,2	42,0	99,5	143	193	72,8	89,7	54,4	116	111	127	113

Location jak 14 is positioned closest to Jakarta (table 9). Here, the biomasses of all families are the lowest. Also the total biomass at location jak 14 has the lowest value, only 4,96 kg per hectare (ha). Striking are the differences in biomass between locations jak 14/jak 8 and jak 15, where location jak 15 has a very high total biomass compared to the other two sites, while the differences in distances are small. One of the causes seems to be the appearance of the family Dasyatidae, which is a family of rays. The appearance of only one individual results in a very high amount of biomass, and location Jak 15 is the only one where rays were counted. Moreover, twice the amount of families were present at location Jak 15 compared to Jak 8/14, and combined they are also responsible for the high biomass number. Last, at location Jak 15, the amount of biomass from the family Apogonidae far exceeded the amounts from the other locations where the family is present.

The highest amount of total biomass was found at location jak 3 with 193 kg per ha, which is an island in the middle of the Pulau Serbu complex. At the outer locations, the amount of biomass was lower. At location jak 3, the families Caesionidae, Chaetodontidae and Labridae had a peak in their amount of biomass, leading to the large overall amount of biomass at location Jak 3.

Overall, only 2 fish families, the Labridae and Pomacentridae, were counted at all measurement locations. Nevertheless, the families Chaetodontidae and Scolopsidae were counted at all measurement locations except one. All other families are scattered present across the measurement locations.

Families which had the largest contribution on total biomass at the measurement locations are the families Caesionidae, Labridae, Acanthuridae and Chaetodontidae. Total biomass of those families for all locations counted together ranged from 137 kg till 368 kg. However, many other families only gave a small contribution to the total biomass of the whole island complex. The lowest contributions originate from the families Gobiidae and Microdesmides with only 0,086 kg/ha. Also the families of the Priacanthidae, Tetraodontidae, Mullidae, Centriscidae, Fistulariidae, Synodontidae, Blenniidae, Zaclidae, Parapercidae and Monacanthidae give low contributions, ranging from 0,33 kg till 2,66 kg. Those families are all only present at a couple of locations, and at those locations, the biomass numbers are very small, due to the small size of the fish species, or due to the reduced amount of counted individuals.

A regression analysis was performed to explore all possible relations with distance and family biomass, with distance as an independent variable and the biomass data as dependent variables. A Summary of those analyses are presented in table 10. The full regression results can be found in appendix 3.

Table 10: summary of regression analyses between biomass variables and distance from Jakarta

Distance independent variable, regression analysis with:	R ²	Sig
Total Biomass	0,169	0,114
Total Biomass without Dasyatidae*	0,340	0,018
Ephippidae	0,188	0,094
Fistulariidae	0,220	0,067
Pomacentridae	0,225	0,064
Serranidae	0,225	0,063
Acanthuridae	0,232	0,059
Caesionidae	0,292	0,031

* Without Dasyatidae, the biomass of location jak 15 went down from 157 kg/ha till 83,9 kg/ha

Looking at trend of the total biomass numbers over distance, no clear increasing or decreasing tendency can be noticed. Numbers are fluctuating over the whole island complex. However, when looking at figure 8, the locations closest to Jakarta seem to have a lower biomass number than the hindmost locations, with location Jak 15 and Jak 3 as clear outliers.

No significant positive relation between distance and total biomass was found (table 10), with only 16,9% of the variation of total biomass explained by distance, possibly due to surprisingly high biomass numbers at location Jak 15. The presence/absence of the family Dasyatidae seems to be part of the cause of the non-significance of this relation, due to the extremely patchy nature of the family, and thus high variance in biomass estimates between Jak 15 and all other measurement locations. When excluding the biomass calculations of the family Dasyatidae, the outlier jak 15 merged with the other data, (figure 8), and a highly significant positive relation between total biomass and distance to Jakarta is found ($p = 0,01$, table 10), with 34,0% of the total biomass variation explained by variation in the distance to Jakarta. Therefore, the hypothesized expectations of a clear positive relation between distance and total biomass cannot be rejected.

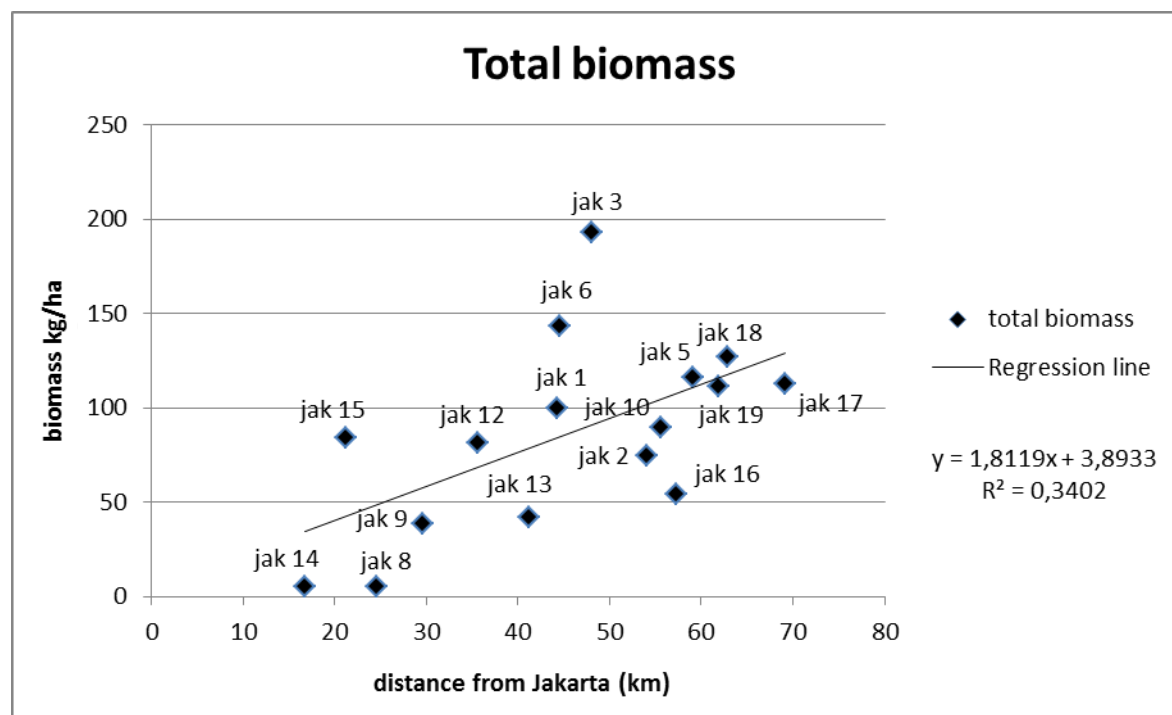


Figure 8: Total biomass versus distance from Jakarta, without biomass numbers of Dasyatidae

Observing the individual family biomass distributions against distance, first noticed is the occurrence of the family Blenniidae, which is only present at the three locations closest to Jakarta. Only one statistically significant positive relationship between distance from Jakarta and biomass of the family Caesionidae was found (table 10), in which 29,2% of the variation was explained by variation in the distance to Jakarta. The interactions between distance from Jakarta and biomass of the families Ehippidae, Fistulariidae, Pomacentridae, Serranidae and Acanthuridae were marginally significant (table 10). For all other families, no associations can be noticed correlated to the distance to Jakarta, mostly due to the patched distribution of the biomass numbers.

In order to compare all biomass data, one biomass dataset belonging to a particular location has to be equated with a set of biomass data belonging to another location. Therefore, an ordination analysis was performed. With this analysis, all locations are displayed in a graph based on the variation in biomass composition within the measurement locations. In this way, outlier locations can be observed, which have abnormal biomass compositions, just as clustered locations, which will have very similar biomass datasets.

De toevalsfactor wordt in je regressie meegenomen als de variatie om het gemiddelde (ruis). Als de toevalsfactor groter is dan het gemiddelde verband, is de uitkomst van je regressie niet significant.

Principle Component Analysis with families

A Principle Component Analysis (PCA) was performed on all biomass data. This analysis shows the following PCA summary:

Axes	1	2	3	4	Total variance
Eigenvalues:	0.954	0.025	0.008	0.005	1.000
Species-environment correlations :	0.253	0.424	0.218	0.007	
Cumulative percentage variance					
of species data:	95.4	97.9	98.7	99.2	
of species-environment relation:	92.2	99.0	99.6	99.6	
Sum of all eigenvalues					1.000
Sum of all canonical eigenvalues					0.066

Axis one has a high eigenvalue of 0,954, which signifies a great transition in family biomass composition between the measurement points, while the low eigenvalue of axis two implies slight variance in family biomass between the locations.

The summary shows for every axis the explained variance of the family biomass data among the measurement points: the cumulative percentage variance of species data. Axis one clarifies 95,4% of the total variance of the biomass dataset, and axis two adds 2,5% more to the explained variance. Thus, in total, axes one and two certify 97,9% of the total variance between the measurement locations in the biomass dataset.

The cumulative percentage variance of species-environment relation gives the total amount of variance in the dataset which is determined for each individual axis by environmental variables. It expresses the amount of variance explained by our axes as a fraction of the total explainable variance. Therefore for the family biomass dataset, 92,2% of the total variance could be explained by the environmental dataset of the variable distance in the first canonical axis. Furthermore, the first two axes taken together display 99% of the variation that *could* be explained by the variable distance. However, the interpretations of these statistics require some caution, because usually there is a large percentage of unexplained variance in ordination models of ecological communities (Schmitt, 2006). The amount of the total variation that we can explain in this biomass dataset is the same as the sum of all canonical (or constrained) eigenvalues. The sum of all canonical eigenvalues is a relative measure of the total explained variance. In this case, the total explained variance of the canonical axes is only 6,6%.

Figure 9 shows the projection of the measurement locations (circles) on a set of axes, in such a way that the maximal variation between the objects is projected along the x axis, and the maximum difference in remaining variation, excluding the variation explained by the x axis, is displayed in the y axis.

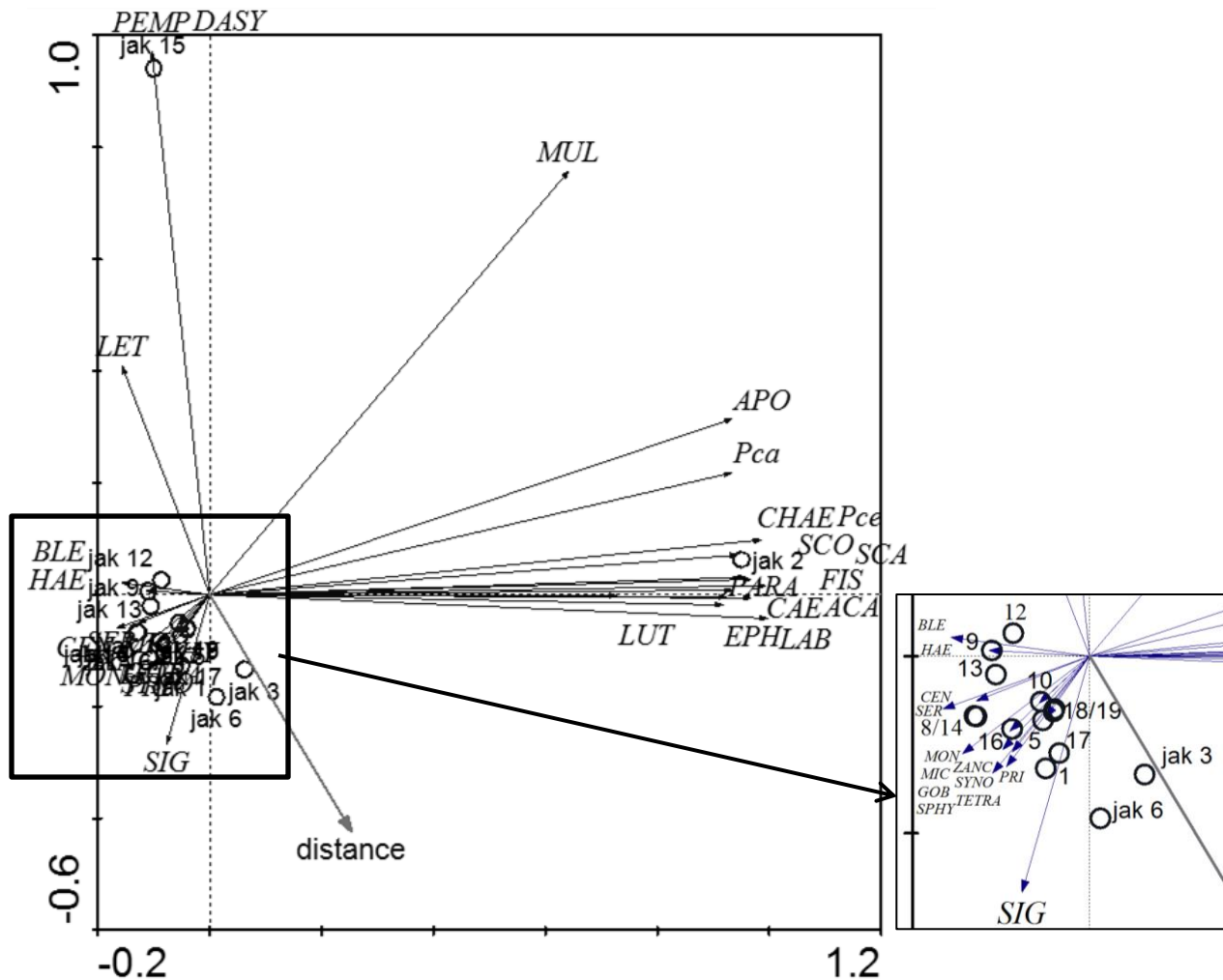


Figure 9: PCA ordination diagram of axis 1 and axis 2 with the biomass data of the measurement locations (circles), and nominal variables (arrows) of the absolute data, the functional groups. ACA= Acanthuridae, APO= Apogonidae, BLE= Blenniidae, CAE= Caesionidae, CHAE= Chaetodontidae, DASY= Dasyatidae, EPH= Ephippidae, FIS= Fistulariidae, HAE= Haemulidae, LAB= Labridae, LET= Lethrinidae, LUT= Lutjanidae, MUL= Mullidae, PARA= Parapercidae, Pca= Pomacanthidae, Pce= Pomacentridae, PEMP= Pempheridae, SCA= Scaridae, SCO= Scolopsidae, SIG= Siganidae.

Looking at figure 9, a couple of outliers can be seen, of which the outliers among the x axis are the locations with the most divergent species composition. At the right side of the graph, outlier jak 2 can be noticed. At the left side of the graph are situated measurement points jak 9, jak 12 and jak 13, who seem to have a very similar species composition, but are small outliers relative to the bulk of measurement points located in the oval on the graph. Therefore, jak 9, jak 12, jak 13 and jak 2 have deviations in their density composition compared to the other measurement points. Of those 4 locations, jak 2 seems to have the biggest modifications in species composition, positioned much further away from the oval than the other three locations.

The differences in biomass composition of these outlier locations can be correlated to the distribution of 15 out of 30 fish families, closely related to the first canonical correlation axis, which are the families Acanthuridae, Apogonidae, Blenniidae, Caesionidae, Chaetodontidae, Ehippidae, Fistulariidae, Haemulidae, Labridae, Lutjanidae, Parapercidae, Pomacanthidae, Pomacentridae, Scaridae and Scolopsidae. All arrows of those families are drawn in the same direction as the x axis, indicating that the explained variance along the first canonical axis is determined by the distribution of those families. Here, the arrow of the family Lutjanidae points in the same direction as the arrows of the other families, but the arrow is shorter, indicating a smaller degree of change. The distribution of the families Blenniidae and Haemulidae are opposite from the other families, indicating high values at locations jak 9, jak 12 and jak 13, and low values at location jak 2. All in all, the positions of the outliers jak 2, jak 9, jak 12 and jak 13 are closely related to changes in family biomass numbers of the families specified above, which are independent of the y axis.

Searching for the outlier locations of the second axis, which indicates a smaller transition, jak 15 was detected on the top side of the graph, Jak 3 and jak 6 can be observed as outliers at the bottom side of the graph. Out of the two, outlier jak 6 is more noticeable and has therefore a bigger deviation in its species composition than jak 3, but overall, jak 15 is the most pronounced outlier out of the three. The outliers are determined by deviating biomass numbers of the families Dasyatidae, Mullidae, Pempheridae, and Siganidae, whose arrows point in the same direction as the second canonical axis.

At the left side in the middle of the graph, which represents the average species composition, one clustered group of measurement points can be seen, the oval form, in which 9 of the 16 locations can be noted. Also, the biomass distributions of all other families are pointed this way, 10 out of 30 families, namely Centriscidae, Gobiidae, Microdesmides, Monacanthidae, Priacanthidae, Serranidae, Sphyraenidae, Synodontidae, Tetraodontidae and Zanclidae. All arrows are small, which means that the degree in biomass change is small. The arrow of family Siganidae has the same direction, but the arrow is larger, indicating a bigger degree of change and therefore more important to the positioning of the different measurement locations within the ordination plot.

The environmental variable distance, added as an additional input variable, is also displayed as an arrow in the ordination plot. This arrow points in the direction of the largest increase in weighted averages of the samples of this variable. The length of the arrow indicates the degree of change in value in the correspondent direction. The arrow of distance points in a different direction than all family arrows, indicating no clear relationships between the families and distance, and has also a smaller length compared to those of the families. The distance arrow is not closely related to one of the ordination axes.

Functional Groups

The locations in table 11 are already arranged in the order of the nearest location to Jakarta to the location farthest away.

Regression analyses were performed to explore all possible relations between distance and biomass variables, with distance as independent variable and the biomass data as dependent variables. A Summary of the analyses are presented in table 12. The full regression results can be found in appendix 4.

Table 11: Total biomass within each location for all functional groups sorted in such way that the location with the closest distance to Jakarta is on top, and the location with the longest distance is at the bottom.

Location	Distance	Total Biomass	Total Biomass Grazers/ detritivores	Total Biomass Browsers	Total Biomass Scrapers/ small excavators	Total Biomass of all herbivores	Total Biomass Other
jak 14	16.79	4,961808	0	0	0,421142	0,421142	4,540665684
jak 15	21.23	156,9574	8,980474	0	12,40251	21,38298	135,574374
jak 8	24.55	5,299001	0,303627	0	2,938141	3,241768	2,057232891
jak 9	29.61	38,81242	0	0	11,61874	11,61874	27,19367925
jak 12	35.67	81,1524	1,649613	0	18,81468	20,46429	60,68810312
jak 13	41.23	42,01567	0,7104	0	11,96395	12,67435	29,34132127
jak 1	44.29	99,46567	4,724034	8,54831	30,15699	43,42934	56,0363322
jak 6	44.51	143,1275	33,86103	5,221355	23,8632	62,94559	80,18193066
jak 3	48.08	192,99	19,88063	0	63,83655	83,71718	109,2728003
jak 2	54.03	74,81925	11,02662	13,76967	17,7944	42,59068	32,22856936
jak 10	55.65	89,6612	0,98711	0	34,8178	35,80491	53,85628916
jak 16	57.31	54,39589	0	0	21,73353	21,73353	32,66235734
jak 5	59.06	115,9161	24,42727	23,10431	21,64646	69,17805	46,73804151
jak 19	61.86	111,2225	13,05596	0	17,45336	30,50932	80,71318735
jak 18	62.88	127,3259	43,63137	0	8,600014	52,23138	75,09454399
jak 17	69.22	112,6367	15,15613	13,04003	25,28064	53,47681	59,15992761

Table 12: summary of regression analyses between herbivorous biomass variables and distance from Jakarta

Distance independent variable, regression analysis with:	R ²	Sig
Total Biomass without Dasyatidae*	0,365	0,013
Total Biomass Herbivores	0,404	0,008
Total Biomass Grazers/Detritivores	0,234	0,057
Total Biomass Browsers	0,188	0,094
Total Biomass Scrapers/Small excavators	0,163	0,121
Total Biomass Other	0,031	0,517

Focussing on the variable total biomass of all herbivorous functional groups together, it is noticed that those numbers are lower at almost all measurement locations compared to the total biomass numbers of the group Other, with biomass values ranging from 0,42 kg/ha till 83,7 kg per ha (table 11). This is logical because under normal conditions, there are many more carnivore fish species in a reef than herbivores. Carnivorous fishes make up from 41 - 68% of species on the reef, while only 10 – 25% of species on a Caribbean reef fishes are herbivores (McGinley, 2014). Only locations Jak 2, Jak 5 and Jak 8 deviate from this pattern, harbouring more herbivore fish biomass than carnivore/omnivore fish biomass, probably related to the presence of the functional group browsers at these locations, and fishery practices.

The lowest biomass of all herbivores is measured at location 14, which is closest to Jakarta (table 11, figure 10). However, the highest biomass value is not measured at the location farthest away from Jakarta, but at location jak 3, shown as a peak value in figure 10. Especially in the locations further away from Jakarta, high fluctuations in biomass numbers can be noticed, see for instance the difference between jak 3 and jak 16 over a relative small distance.

Therefore, the total herbivores biomass follows the same pattern as the variable total biomass: no clear increase or decrease can be noticed related to the distance to Jakarta. However, the regression line, showing a clear increase in biomass with increasing distance to Jakarta, explains 40% of the total variance in this dataset (r^2 , table 12 and figure 10), which is high. The high r^2 results in the positive relation between distance and total biomass herbivores being highly significant ($p=0,008$, table 12). Therefore, the hypothesized expectation of a clear positive relation between distance and total biomass herbivores is confirmed.

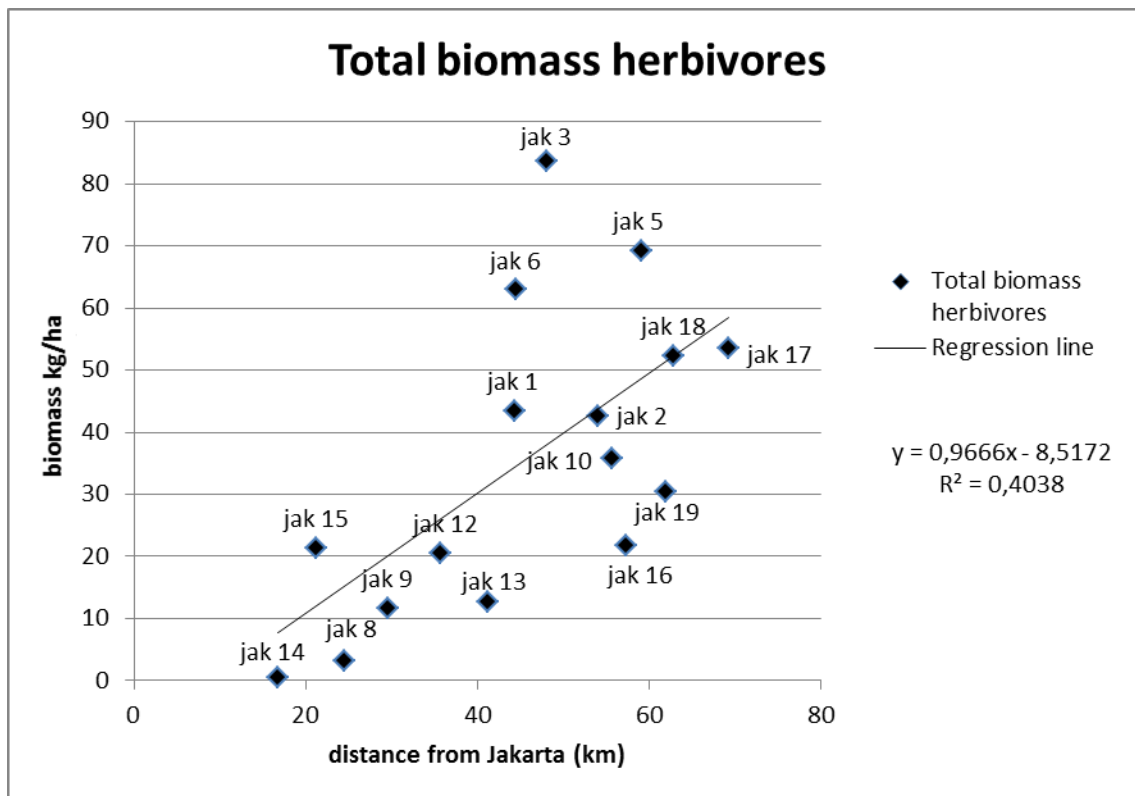


Figure 10: Total biomass herbivores versus distance from Jakarta

The group scrapers/small excavators contributes to the largest part of the total biomass for herbivorous reef fishes, having a biomass between 0,42 kg/ha at location Jak 14 and 63,8 kg per ha at location Jak 3 (table 11, figure 11). It is the only herbivorous group present at all measurement locations. Most biomass values at the measurement locations are between 0,42 and 34,8 kg/ha.

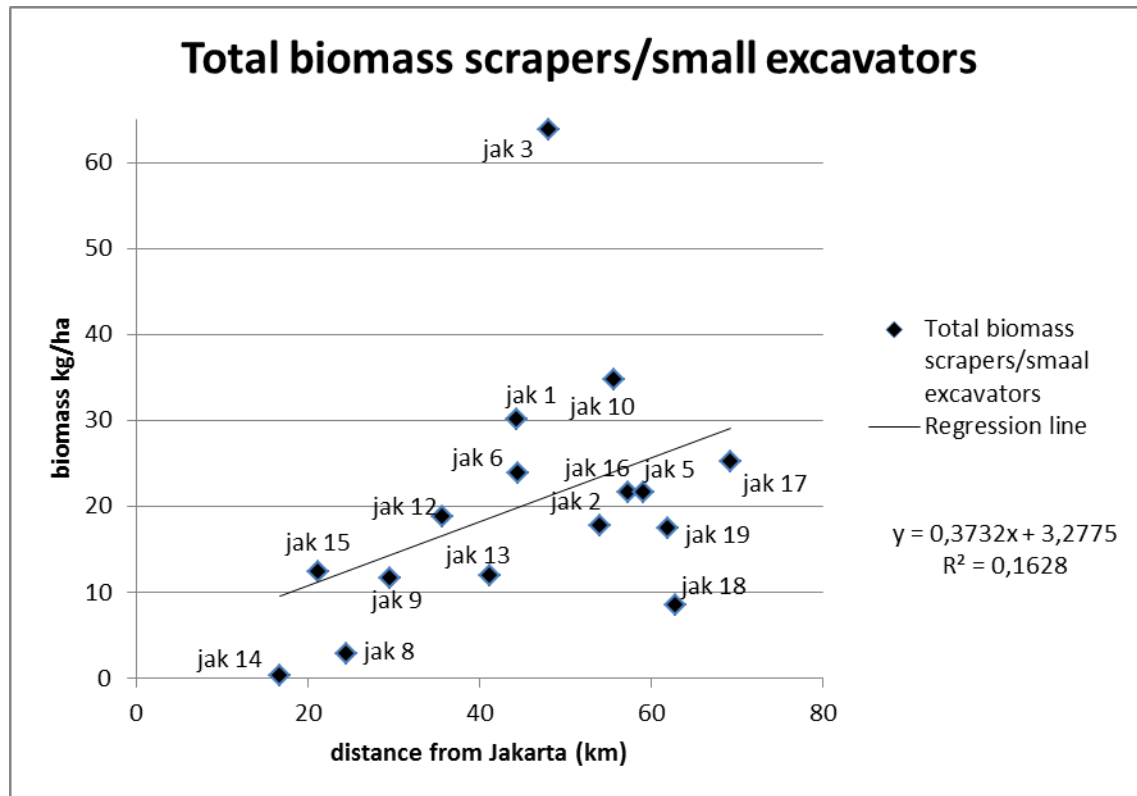


Figure 11: Total biomass scrapers/small excavators versus distance from Jakarta

In figure 11, jak 3 can be seen clearly as the only outlier. The other locations seem to have an increasing biomass value of scrapers/small excavators with distance, only that also those values exhibit the same fluctuating patterns as the total biomass of all herbivores. The increasing overall pattern is confirmed by the direction of the regression line, which indicates a positive relation between biomass of scrapers/small excavators and distance from Jakarta. The regression line explains 16,3% of the total variation between the measurement locations (table 12). This interaction is nearly significant ($P=0,12$). If only jak 3 would not have been such an outlier, this relationship would have been significant (28,9% explained variation, $P=0,039$). Therefore, the hypothesized expectations of a clear positive relation between distance and total biomass of scrapers/small excavators cannot be rejected wholeheartedly.

The functional group browsers contributes the least tot the total biomass of all herbivores, they are only present at 5 locations, and at those locations the biomass has a maximum of 23 kg per ha (table 11, figure 12). Jak 5, located in the middle of the island complex, has the highest biomass values for browsers. Untill 40 km away from Jakarta, no browsers were found. The functional group browsers has a very patchy distribution along the measurement locations positioned further away than 40 km, and therefore a highly fluctuating pattern can be observed in biomass values.

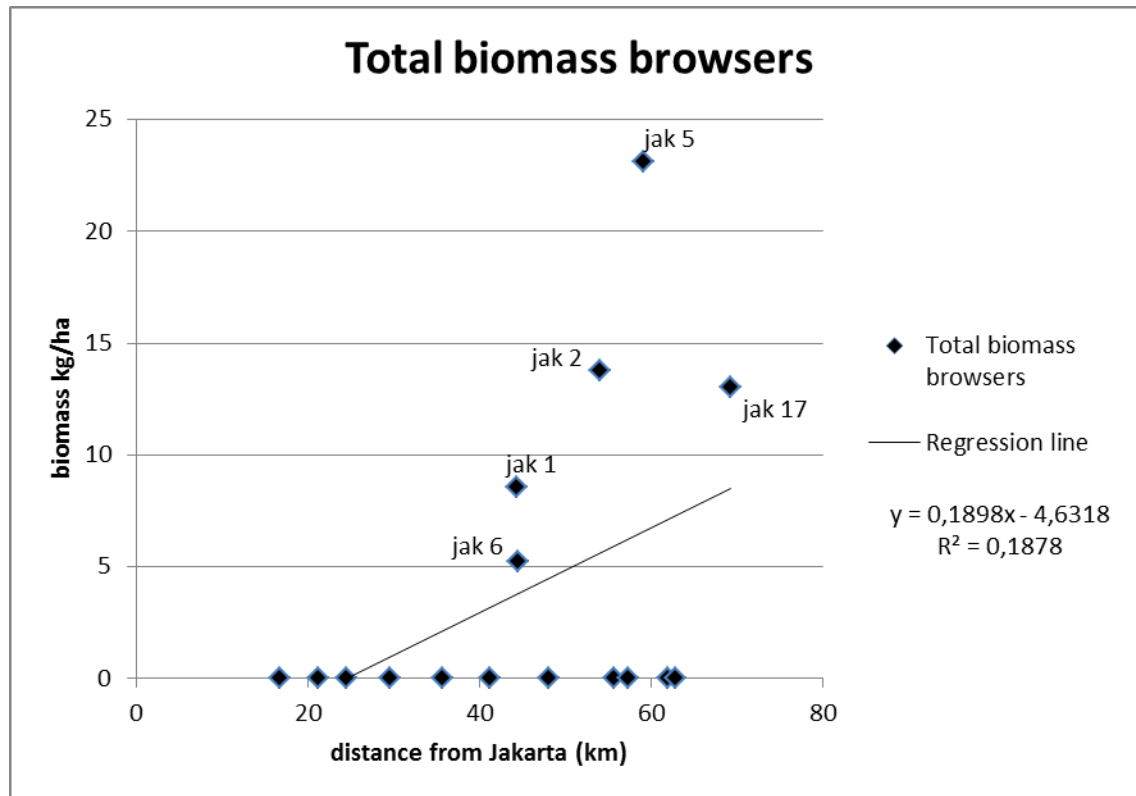


Figure 12: Total biomass browsers versus distance from Jakarta

No clear connection between increasing biomass value of browsers and distance can be seen. It looks more like a parabolic pattern, in which the measurement locations in the middle of the island complex seem to have higher biomass values than the locations at the outer end of the island complex. Surprisingly, when adding a linear regression line, 18,8% of the variance within the biomass dataset can be explained by the distance from Jakarta. This is a higher percentage than the linear regression line explained in the biomass data of the scrapers/small excavators (table 12). Also the p value is smaller, 0,09, which gives a nearly significant relation between the biomass of browsers and distance from Jakarta. On the other side, with these few biomass measurements, the probability of this found pattern has to be carefully evaluated. Therefore, the hypothesized expectations of a clear positive relation between distance and total biomass of browsers cannot be confirmed.

The group grazers/detritivores has biomass values between those of the scrapers/small excavators and browsers, except at location jak 5, jak 6 and jak 18, where this group has a higher biomass number than the scrapers/small excavators and browsers. The functional group grazers/detritivores has a very patchy distribution along the measurement locations, not being present at 3 locations. At locations where this group is present, biomass values range from 0 untill 43,6 kg/ha at jak 18; this measurement location can be seen as a peak value in figure 13.

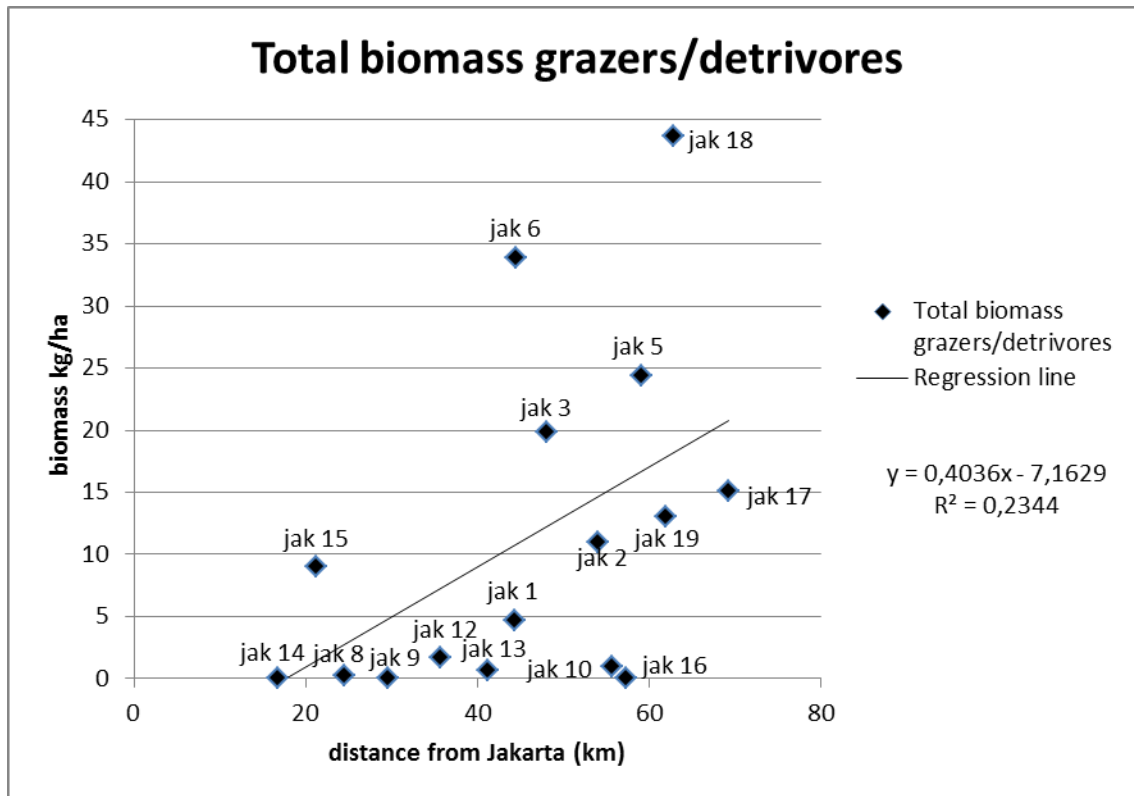


Figure 13: Total biomass grazers/detritivores versus distance from Jakarta

A clear increase of grazer/detritivores biomass values can be noticed related to the distance to Jakarta. This increase is confirmed by the regression line, having a positive direction through the biomass data with increasing distance to Jakarta. The regression line explains 23,4% of the total variance in this dataset (r^2 , see table 12), which is high. The high r^2 results in a statistically significant positive relationship between distance and total biomass grazers/detritivores ($p=0,008$, table 12). Therefore, the hypothesized expectation of a clear positive relation between distance and total biomass of grazers/detritivores is confirmed.

The variable total biomass of the functional group Other has values ranging from 2,08 kg/ha at location jak 8 till 135,5 kg/ha at location jak 15. Surprisingly, the lowest value is not found at the closest location to Jakarta, even though there, the biomass value is not high either (4,54 kg/ha). The high value of location Jak 15 is a peak in biomass values, as can be seen in figure 14. The family Dasyatidae is included in this functional group, which is the cause of this absurd high value for a location so close to Jakarta. Location Jak 3 gives also a peak in biomass value with 109 kg/ha. For all other locations, high fluctuations in biomass numbers between 20 and 90 kg/ha can be noticed over distance.

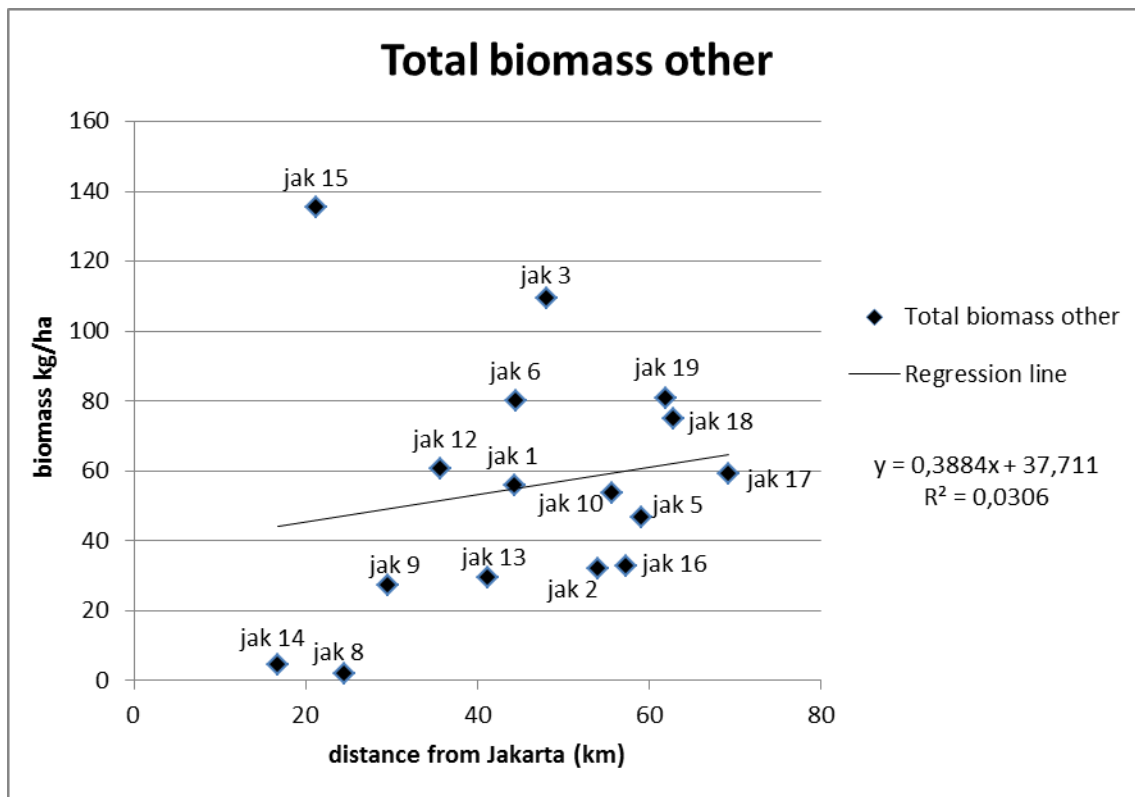


Figure 14: Total biomass other versus distance from Jakarta

No clear increasing or decreasing pattern of biomass values can be seen along the x axis, mostly because of the outlier jak 15. The regression line follows a small increasing pattern with increasing distance, but only 3% of the total variance in this dataset is explained by this line (table 12). This low r^2 results in a non significant slightly positive relation between distance and total biomass of the functional group other ($p=0,517$, table 12). Therefore, the hypothesized expectations of a clear positive relation between distance and total biomass Other is rejected.

In order to compare all functional group biomass data, one biomass dataset belonging to a particular location has to be equated with a set of biomass data belonging to another location. Therefore, a ordination analysis was performed. In this way, outlier locations can be observed, which have abnormal biomass compositions, even as clustered locations, which will have very similar biomass datasets.

PCA with functional groups

A Principle Component Analysis (PCA) was performed on all biomass data. The first principal component accounts for the maximum of variability in the dataset possible, and each following component clarifies as much of the remaining variability as possible. It is an unconstrained ordination, which displays the main part of the variability in functional group biomass composition. The functional group Other was not weighted in this analysis, just as the variable distance.

The analysis shows the following PCA summary:

**** Summary ****

Axes	1	2	3	4	Total variance
Eigenvalues:	0.541	0.362	0.097	0.000	1.000
Species-environment correlations :	0.564	0.215	0.237	0.000	
Cumulative percentage variance of species data:	54.1	90.3	100.0	0.0	
of species-environment relation:	88.6	97.2	100.0	0.0	
Sum of all eigenvalues					1.000
Sum of all canonical eigenvalues					0.194

Canonical axis one has an eigenvalue of 0,541, which signifies a quite large transition in functional group biomass composition between the measurement points along the x axis. The relative high eigenvalue of axis two implies an equally similar transition in family biomass along the y axis compared to the first axis.

The summary shows for every axis the explained variance of the biomass data of the functional groups among the measurement points: the cumulative percentage variance of species data. Axis one clarifies 54,1% of the total variance of the biomass dataset, and axis two adds 36,2% more to the explained variance. Thus, in total, axes one and two certify 90,3% of the total variance between the measurement locations in the biomass dataset.

The cumulative percentage variance of species-environment relation expresses the amount of variance explained by our axes as a fraction of the total explainable variance. Therefore for the functional group biomass dataset, 88,6% of the total variance could be explained by the environmental dataset of the variable distance in the first canonical axis. Furthermore, the first two axes taken together display 97,2% of the variation that *could* be explained by the variable distance. The amount of the total variation that we can explain in this biomass dataset is the same as the sum of all canonical eigenvalues. The sum of all canonical eigenvalues is a relative measurement of the total explained variance. In this case, the total explained variance of the canonical axes is only 19,4%.

Figure 15 shows the projection of the measurement locations (circles) on a set of axes, such that the maximal variation between the objects is projected along the x axis, and the maximum difference in remaining variation, excluding the variation explained by the x axis, is displayed in the y axis. Because the functional group Other was excluded from analysis, this group was added as a supplementary variable in the correlation matrix, like the environmental variable distance.

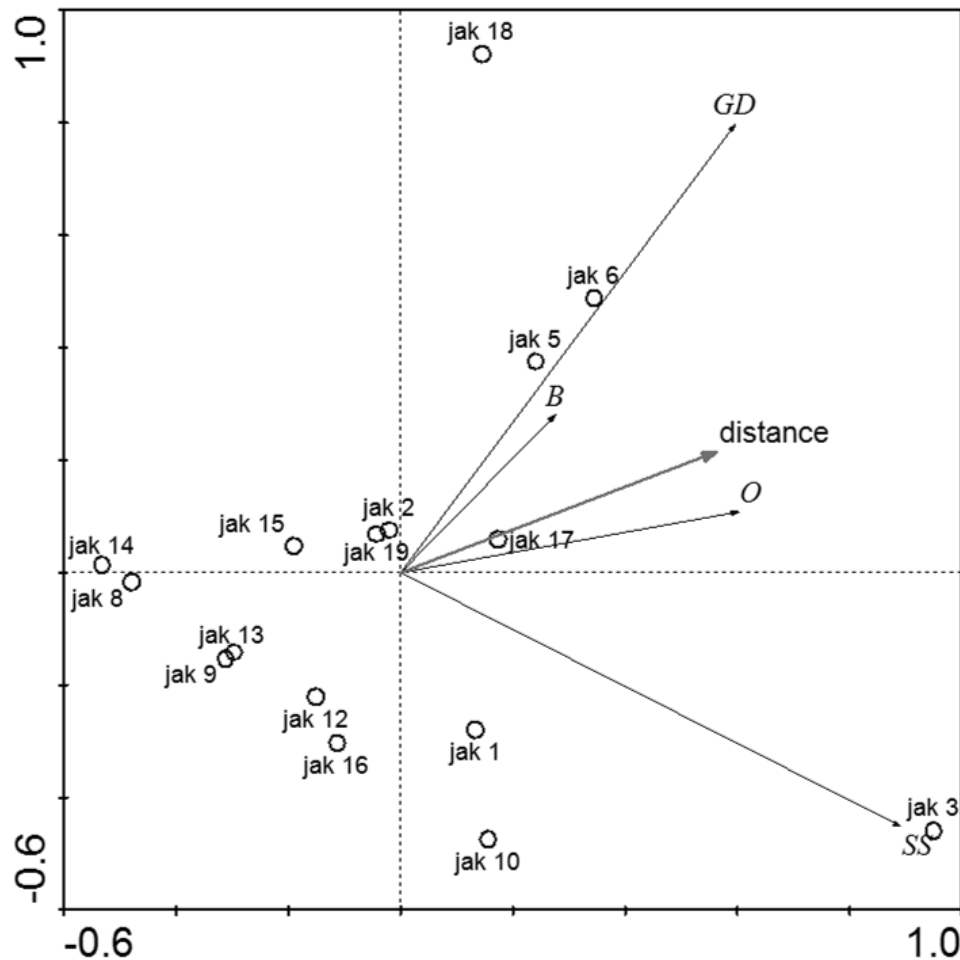


Figure 15: PCA ordination diagram of axis 1 and axis 2 with the biomass data of the measurement locations (circles), and nominal variables (arrows) of the absolute data, the functional groups. GD= grazers/detritivores, SS= scrapers/small excavators, B= browsers. O= other.

Looking at figure 15, a couple of outliers can be seen. At the right side of the graph, outlier jak 3 can be noticed, which seems to be closely correlated to the biomass distribution of the functional group SS, displayed as an arrow. Jak 3 seems to have a high biomass value of this group. Looking at figure 11, this high biomass value is confirmed. At the left side of the graph measurement points jak 8 and jak 14 are situated, who seem to have a very similar species composition. Observing the direction of all arrows of the functional groups, this biomass seems to be characterized by low biomass values of all three herbivores groups, which is confirmed by table 11. Jak 8 is positioned lower than jak 14 because of a higher value of the group SS.

Fixing on the variation along the y axis, outlier jak 18 is observed at the top of the graph. Its position seems to be closely correlated to the biomass distribution of the functional group GD, whose arrow has an upwards going direction. Location Jak 18 seems to have a high biomass value for this group. Looking at figure 13, this high biomass value is confirmed. On the bottom of the graph, outlier jak 10 is detected, which position seems to be linked to high values of the functional group SS, and low values of the functional group GD, judging by the direction of the arrows. Those biomass features are confirmed by the biomass values of the groups SS and GD, displayed in table 11.

No clear clustered group of measurement points can be seen, although jak 2 and 19 seem to have a similar species composition. Displayed in the middle of the ordination plot, those sites represent the average species composition. Jak 2 is located a little more to the right because of the presence of the group B. The bottom half of the diagram is dominated by the presence of the group SS in the biomass composition, while the top half of the diagram is dominated by the presence of the group GD, this group has a bigger arrow than group B, indicating a bigger degree of change and therefore more important to the positioning of the different measurement locations within the ordination plot.

Jak 1 has the same high biomass values for group SS as location jak 10, but has higher values of the groups SS and B, which explains its higher position on the ordination plot compared with location jak 10. Jak 5, 6 and 17 have high values of the group B and GD, and are therefore located in the right top part of the ordination plot. Out of those three locations, Jak 17 has the lowest biomass values of the group GD and the highest numbers of the group SS (table 11), which explains its lower position compared to the other two locations. Jak 9 and 13 are positioned closely together, indicating very similar biomass dataset, which is confirmed by table 11. Those locations are positioned at the bottom left of the ordination plot, because of the low values of the functional groups GD and B and higher biomass values of the group SS. Jak 12 and 16 are also located in this part of the ordination plot, but are positioned lower and more to the right compared to jak 9 and 16, due to the higher biomass values of the functional group SS.

The environmental variable distance, added as an additional input variable, is also displayed as an arrow in the ordination plot. This arrow points in the direction of the largest increase in weighted averages of the samples of this variable. The length of the arrow indicates the degree of change in value in the correspondent direction. The arrow of distance points in the same direction as the functional groups GD and B, indicating a similar variation distribution between those groups and distance. The distance arrow is not closely related to one of the ordination axes, although it seems closer related to the variation among the x axis than the y axis.

PCA with families within the functional herbivorous groups

In order to investigate the role of the functional groups within a coral reef more precisely, there was focussed on the families which shape the functional groups and their distribution among the measurement locations. In this way, the part of the hypothesis was explored in which was argued that within a very stressed coral reef, herbivores fish families could become extinct, and could possibly be replaced by other herbivore families who could fill the ecological gap, and so remaining the stability within the algae consuming community, and stabilizing the coral reef resilience.

Therefore, a principle component analysis (PCA) is performed on the family biomass data of the herbivorous fish families. The first principal component accounts for the maximum of variability in the dataset possible, and each following component clarifies as much of the remaining variability as possible. It is an unconstrained ordination, which displays the main part of the variability in the biomass composition of the herbivorous families.

The analysis shows the following PCA summary:

****** Summary ******

Axes	1	2	3	4	Total variance
Eigenvalues:	0.968	0.022	0.006	0.003	1.000
Species-environment correlations :	0.244	0.262	0.124	0.060	
Cumulative percentage variance					
of species data:	96.8	99.0	99.6	99.9	
of species-environment relation:	97.4	99.8	100.0	100.0	
Sum of all eigenvalues					1.000
Sum of all canonical eigenvalues					0.059

Canonical axis one has an eigenvalue of 0,968, which signifies a large transition in herbivore family biomass composition between the measurement points along the x axis. The low eigenvalue of axis two implies slight variance in herbivorous family biomass between the locations.

The summary shows for every axis the explained variance of the biomass data of the herbivorous families among the measurement points: the cumulative percentage variance of species data. Axis one clarifies 96,8% of the total variance of the biomass dataset, and axis two adds 2,2% more to the explained variance. Therefore, in total, axes one and two certify 99,0% of the total variance between the measurement locations in the herbivorous family biomass dataset.

Furthermore, 97,4% of the total variance in the biomass dataset could be explained by the environmental dataset of the variable distance in the first canonical axis. Additionally, the first two axes taken together display 99,8% of the variation that *could* be explained by the variable distance. The amount of the total variation that we can explain in this biomass dataset is the same as the sum of all canonical eigenvalues. In this case, the total explained variance of the canonical axes is only 5,9%.

Figure 16 shows the projection of the measurement locations (circles) on a set of axes, such that the maximal variation between the objects is projected along the x axis, and the maximum difference in remaining variation, excluding the variation explained by the x axis, is displayed in the y axis. The environmental variable distance was added as a supplementary variable in the correlation matrix.

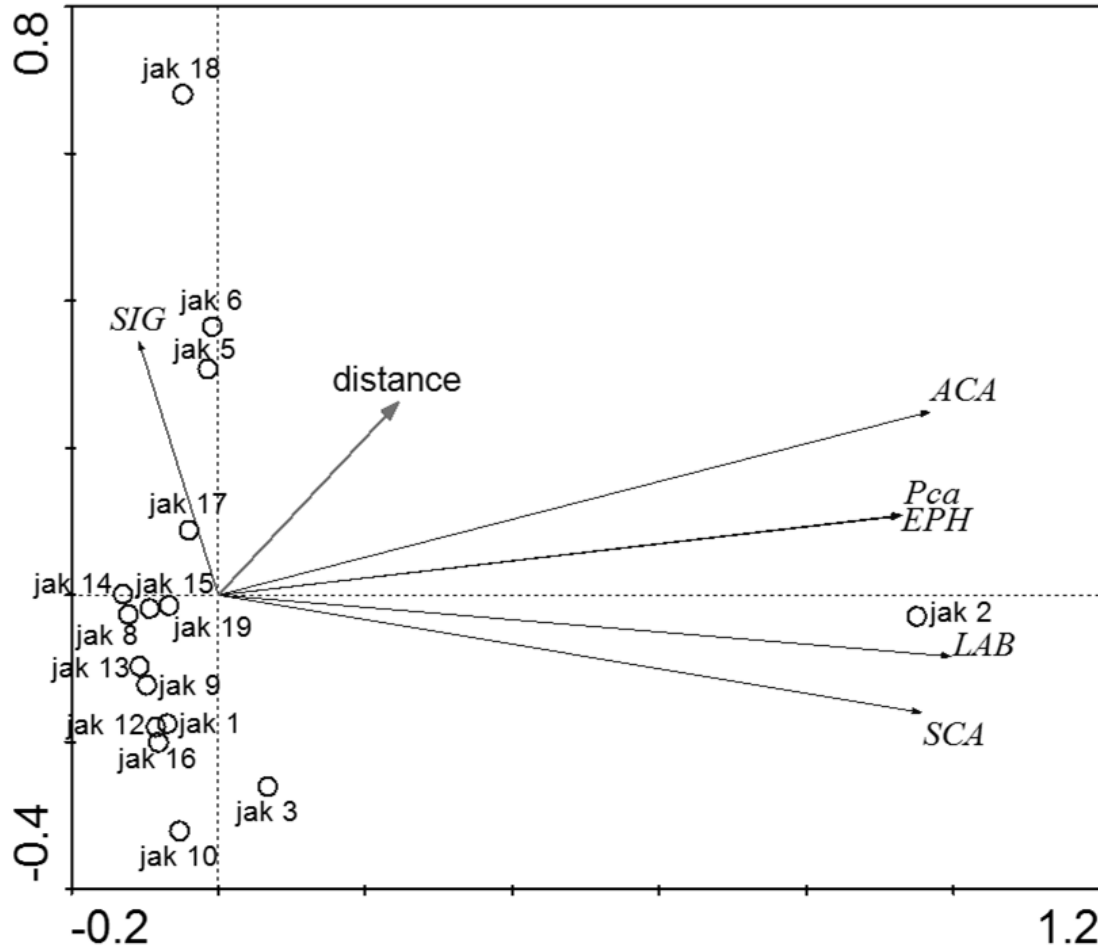


Figure 16: PCA ordination diagram of axis 1 and axis 2 with the biomass data of the measurement locations (circles), and nominal variables (arrows) of the absolute data, the functional groups. ACA= Acanthuridae, EPH= Ehippidae, LAB= Labridae, Pca= Pomacanthidae, SCA= Scaridae, SIG= Siganidae.

Looking at the arrows of the fish families in figure 16, the large transition along the x axis is caused by the variation in biomass numbers of the families Acanthuridae, Ehippidae, Pomacanthidae, Labridae and Scaridae. The small transition on the second axis is caused by biomass variation of the family Siganidae. Some outliers can be seen which are already noticed in figure 15. Along the y axis, the outliers jak 10 at the bottom of the ordination plot and jak 18 at the top are noticed. These locations seem to differ in their biomass values of the family Siganidae, this is confirmed by table 4. Furthermore, Jak 18 has high biomass values for the families Acanthuridae and Pomacanthidae, while jak 10 has high biomass numbers for the families Labridae and Scaridae, which defines the location on the plot also.

At the left side of the graph, outliers jak 8/14 can be noticed, although they are not as pronounced as in the ordination plot of figure 15. Jak 3, which is a very noticeable outlier in figure 15, has disappeared in figure 16, and location Jak 2 is the new outlier in the right side of the graph. Compared to Jak 3, location Jak 2 has very high biomass numbers of the families Ehippidae and Pomacanthidae (table 4).

The position of the location Jak 5, 6 and 17 at the top left part of the ordination plot seems to be associated with high biomass numbers of the families Ehippidae and Siganiidae, which is confirmed by table 4. Jak 1, 8, 10 and 12 also have higher values of the family Siganiidae, but they have even higher numbers for the families Labridae and Scaridae, which places them at the bottom left part of the ordination plot. In this area, a clustered group of measurement points can be noticed, their positions seem to be related to low values of the families Siganiidae, Acanthuridae, Ehippidae and Pomacanthidae, and high values of Labridae and Scaridae.

The environmental variable distance, added as an additional input variable, is again displayed as an arrow in the ordination plot. The arrow of distance points in the same direction as the families Acanthuridae, Ehippidae and Pomacanthidae, indicating a similar variation distribution between those groups and distance, the family arrow of the Acanthuridae seems to have the most corresponding direction. The distance arrow is not closely related to one of the ordination axes, although it seems closer related to the variation among the x axis than the y axis.

Striking is the difference of the arrow of the family Siganiidae, which has a very different direction than the arrows of the other families. This family belongs to the functional group grazers, but clearly has a very different distribution among the measurement locations than the other two families belonging to this group; Acanthuridae and Pomacanthidae. In terms of coral reef resilience, this family does not seem easy replaceable by one of the other two families. On the other hand, the arrows of the families Acanthuridae and Pomacanthidae have a very similar direction, which may mean that one can replace the other if stress at the coral reef causes one to disappear. The arrows of the families Pomacanthidae and Ehippidae follow the same direction most, but they are part of two different functional groups. Concentrating on the functional group scrapers/small excavators, the arrows of the families forming the group, Labridae and Scaridae, have a very similar direction, which may mean that one can occupy the niche of the other if stress at the coral reef causes one to vanish.

Biodiversity

Biodiversity numbers provide more information about community composition than simply species richness or biomass numbers, they also take the relative abundances or contributions of different species into account (Okpiliya,2012). For a given number of types, the value of diversity index is maximized when all types are equally abundant or contributing (Rosenzweig, 1995).

Shannon Wiener index

The higher the value of the index, the smaller the chance that, when looking at a measurement location, the following observed fish family will be the same fish family as the previous noticed family. A higher index value may occur because there are many fish families present, but can also be influenced by the number distribution of the species themselves. If the species have more evenly biomass numbers, then the uncertainty is greater and therefore the value of the index is also higher. If one family is very dominant, then it is likely that this family will be observed in the following sample. The value of the index is then low.

All calculated Shannon Wiener Diversity numbers (H) are placed in table 13. The locations are sorted in such a way, that the location closest to Jakarta harbour is placed at the top of the table, and the location with the longest distance to Jakarta is placed at the bottom.

Table 13: Shannon Wiener Diversity numbers for each location sorted in such way that the location with the closest distance to Jakarta is on top, and the location with the longest distance is at the bottom.

Location	Distance	Shannon Wiener based on fish family biomass data
jak 14	16.79	1,416798
jak 15	21.23	1,767905
jak 8	24.55	1,33139
jak 9	29.61	1,559675
jak 12	35.67	2,020575
jak 13	41.23	2,008324
jak 1	44.29	1,985202
jak 6	44.51	1,563816
jak 3	48.08	1,639456
jak 2	54.03	2,045719
jak 10	55.65	1,787985
jak 16	57.31	1,830034
jak 5	59.06	2,051524
jak 19	61.86	1,844886
jak 18	62.88	1,994972
jak 17	69.22	1,969932

Shannon Wiener Diversity numbers range from 1,33 at location jak 8, till 2,05 at location jak 5. These diversity numbers are all very low, and consequently give the impression that all coral reefs in the Pulau Seribu island complex are in poor condition. Although measurement location jak 8 is not the location closest to Jakarta, and jak 5 is not the location furthest away from Jakarta, there seems to be an increasing trend noticeable moving from the locations closest to Jakarta to the locations farthest away. This increasing trend is also observed in figure 17, the regression line shows an increasing pattern. This regression line explains 40,2% of the total variance in this dataset, which is high, and logically a highly statistical significant positive relationship between Shannon Wiener Diversity number and distance from Jakarta is measured ($p=0,008$, see Appendix 5 for the complete regression analysis). This was also predicted in the hypothesis. Therefore, the already poor conditions within all coral reefs deteriorate even more moving closer to Jakarta. This could be because less families are present, or the biomass distribution along the families present is not even.

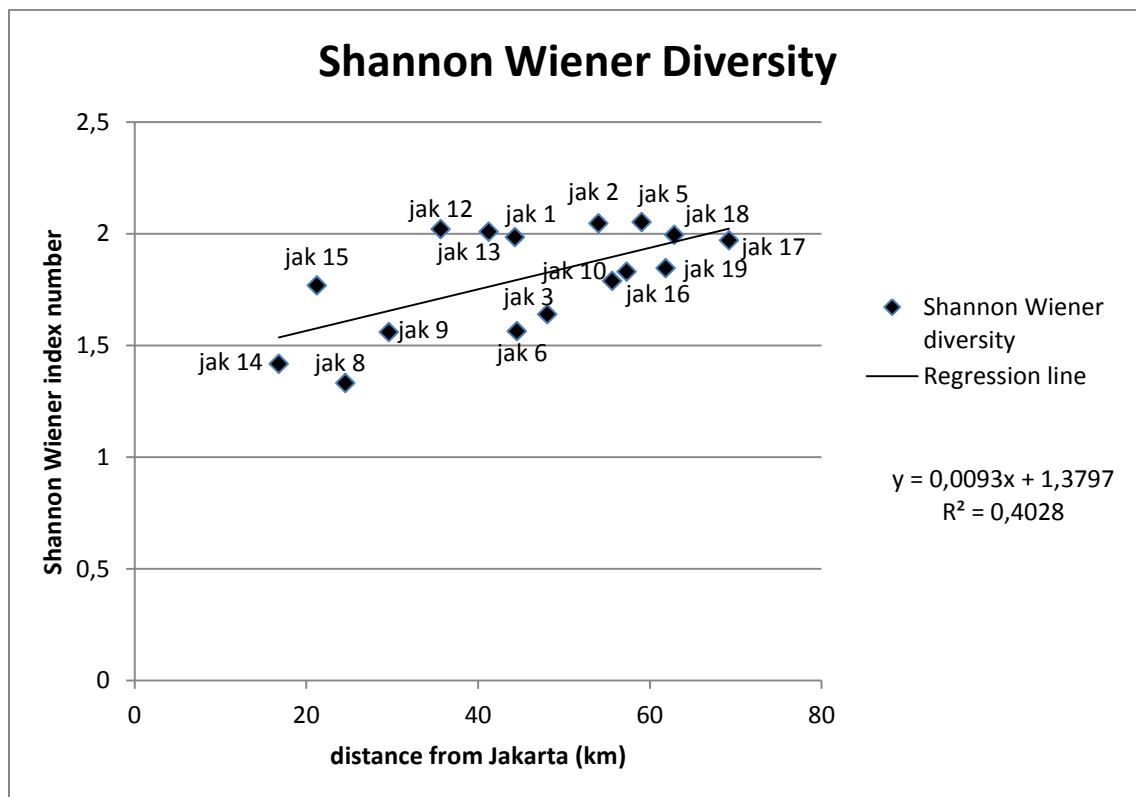


Figure 17: Shannon Wiener index numbers versus distance from Jakarta

Evenness

Evenness (E) refers to how the species abundance (or example, the number of individuals, biomass, cover etc) are distributed among the species. When all species in a sample are equally abundant, the evenness index is 1 and it decreases towards zero as the relative abundance of the specie diverges away from evenness (Okpiliya,2012). An evenness of 0 indicates that only one specie is present, and there is no dispersion of abundance at the measurement location.

Evenness numbers are calculated for all measurement locations by dividing the Shannon Wiener Index numbers by the maximum Shannon Wiener index numbers possible for that particular location, using maximum biomass measured. Numbers are displayed in table 14.

Table 14: Evenness numbers for each location sorted in such way that the location with the closest distance to Jakarta is on top, and the location with the longest distance is at the bottom.

Location	Distance	Evenness based on fish family biomass data
jak 14	16.79	0,88452
jak 15	21.23	0,349667
jak 8	24.55	0,798426
jak 9	29.61	0,426287
jak 12	35.67	0,459605
jak 13	41.23	0,537266
jak 1	44.29	0,431583
jak 6	44.51	0,315048
jak 3	48.08	0,311527
jak 2	54.03	0,477097
jak 10	55.65	0,39768
jak 16	57.31	0,457933
jak 5	59.06	0,431639
jak 19	61.86	0,391568
jak 18	62.88	0,411161
jak 17	69.22	0,41699

Evenness index numbers range from 0,311 at jak 6 till 0,88 at jak 14 (table 14). Therefore, the coral reefs in the island group range from having an even distribution till having a very deviating abundance. Strikingly, looking at figure 18, the regression line shows a decreasing trend. This therefore means that at the locations closest to Jakarta, the biomass is more evenly distributed among the families which are present, while going to the locations further away from Jakarta, the biomass distribution becomes more irregular, which was not predicted in the hypothesis. The regression line explains 29,2% of the total variance in this dataset, which is quite high, and logically a statistical significant negative relationship between Evenness number and distance from Jakarta is measured ($p=0,031$, see Appendix 5 for the complete regression analysis).

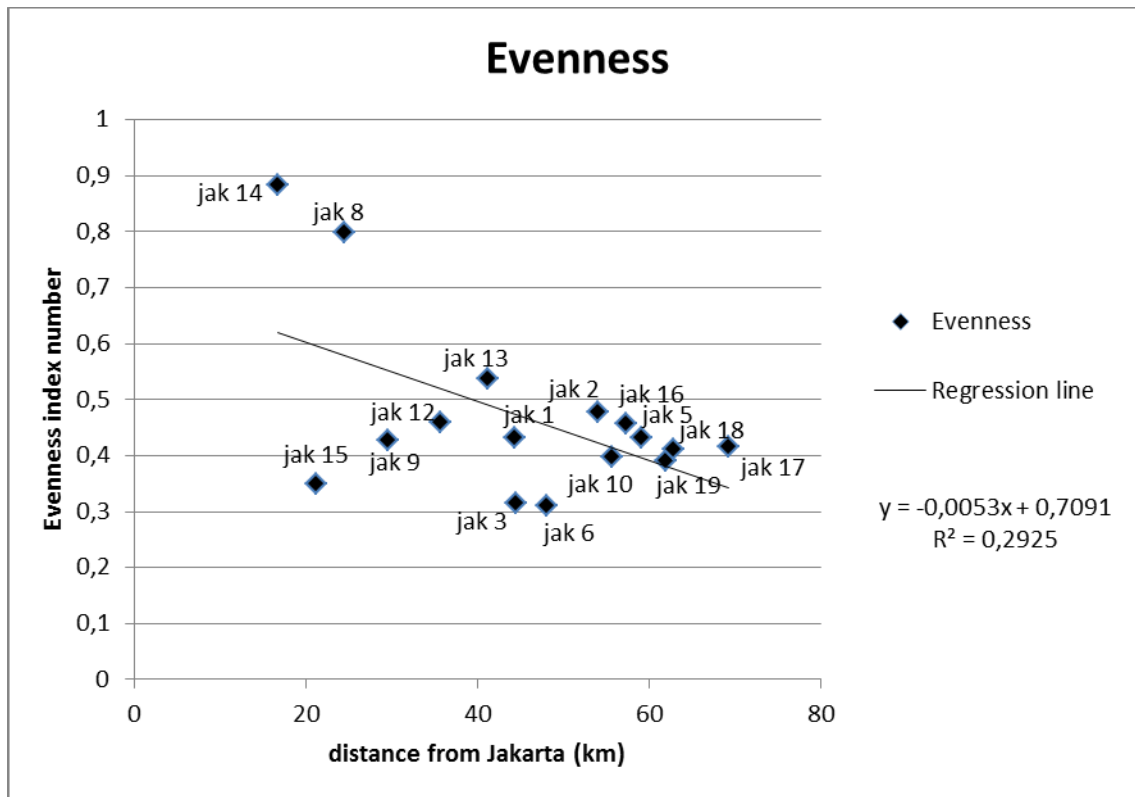


Figure 18: Evenness index numbers versus distance from Jakarta

This negative relationship is caused by the relative high evenness numbers of jak 8 and 14 (see figure 18). Because there is only looked at the biomass distribution among the families which are present at these locations, it can be a coincidence that the few families found there, have very similar biomasses. When removing those locations, a horizontal cloud of measurement locations remains in figure 18, in which the regression line has an nearly horizontal direction, thus still an absence of the predicted positive relation between evenness and distance from Jakarta.

Biotic environment

In this part of the results there is attempted to link variations in the composition of the herbivorous fish population to the indicators for coral reef health which can be influenced by herbivore fishes, which are coral recruitment and survivorship. Cover of Coral, and Sponges were taken as positive factors for coral recruitment and survivorship, because they form a stable, consolidated substratum. Cover of Rock, Rubble, Sand, Algae, were taken as indicators for the failure of coral recruitment and survivorship. Algae can overgrow and kill coral colonies, and the other coverages are a sign that this process has already occurred, resulting in loose rubble or unconsolidated substratum.

First, there is focussed on possible related changes of the cover of those indicators within the measured coral reefs with distance from Jakarta. Second, the indicators will be correlated to the different functional group biomass parameters used in previous sections, to see if the biomass variations have an influence on the cover of the indicators for coral reef health. In this way, finally there can be focused on the importance of the herbivorous fish population structure for coral reef resilience.

From the raw environmental data, presented in appendix 6, 6 combined environmental parameters were derived, namely rock, rubble, sand, algae, coral and sponges. The cover values (m) of those environmental parameters are displayed in table 15, sorted in such way that the location with the closest distance to Jakarta is on top, and the location with the longest distance is at the bottom.

Table 15: Environmental parameters and their total coverage (m) per location, sorted in such way that the location with the closest distance to Jakarta is on top, and the location with the longest distance is at the bottom.

Environmental parameters								
Location		Rock (m)	Rubble (m)	Sand (m)	Algae (m)	Coral (m)	Sponges (m)	Distance to Jakarta (km)
jak 14	Untung Jawa	0,68	11,5	13,81	20,72	12,92	0,37	16,79
jak 15	Dapur	6,4	9,66	9,78	5,64	28,4	0,12	21,23
jak 8	Bokor	0	50,72	1,2	1,8	6,28	0	24,55
jak 9	Lancang Besar	0	22,17	0	14,88	22,9	0,05	29,61
jak 12	Tikus NW	2,02	3,12	0,39	13,93	39,64	0,48	35,67
jak 13	Payung NW	0	1,01	0,06	14,66	44,27	0	41,23
jak 1	Pulau Air	8,04	5,77	0,25	19,46	25,97	0,51	44,29
jak 6	Tidung Kecil NW	0	16,9	6,1	13,2	23,8	0	44,51
jak 3	Semak Daun NW	0,42	11,67	0,1	25,46	22,09	0,21	48,08
jak 2	Kotok Kecil	1,55	13,65	0,13	8,46	34,26	1,49	54,03
jak 10	Pulau Kelapa	0	6,67	0,2	21,64	31,26	0,23	55,65
jak 16	Panjang Kecil	0	19,08	9,3	19,68	11,94	0	57,31
jak 5	Belanda NW	4,07	26,71	1,98	8,9	17,39	0,95	59,06
jak 19	Putri Timor	0	12,28	1,04	21,29	24,06	0,13	61,86
jak 18	Sepa NW	0	19,66	3,38	11,31	26,2	0,65	62,88
jak 17	Hantu Besar NW	0,52	25,1	0	8,9	24,55	0,93	69,22

Regression analyses were performed to explore all possible relations between distance and the environmental parameters, with distance as independent variable and the environmental data as dependent variables. A Summary of the analyses are presented in table 16. The full regression analysis results can be found in appendix 7.

Table 16: Table 10: summary of regression analyses between environmental parameters and distance from Jakarta

Distance independent variable, regression analysis with environmental parameters:	R ²	Sig
Rock	0,039	0,462
Rubble	0,001	0,933
Sand	0,181	0,10
Algae	0,025	0,556
Coral	0,020	0,602
Sponges	0,186	0,095

Environmental parameters versus distance from Jakarta

The parameter Rock has a very patchy distribution, not being present at 8 locations out of 16 (see table 16). These 8 locations are spread among the whole island complex, so no clear connection to the distance from Jakarta can be noticed. The lowest value of the rock cover, 0,42 meter, is found at location jak 3, which is located in the middle of the Pulau Seribu island complex. The highest value of rock cover is found at location jak 1, namely 8,04 meter, but this location is also situated in the middle of the island complex. Most locations have a rock cover number between 0 and 1 meter, as can also be seen in figure 19.

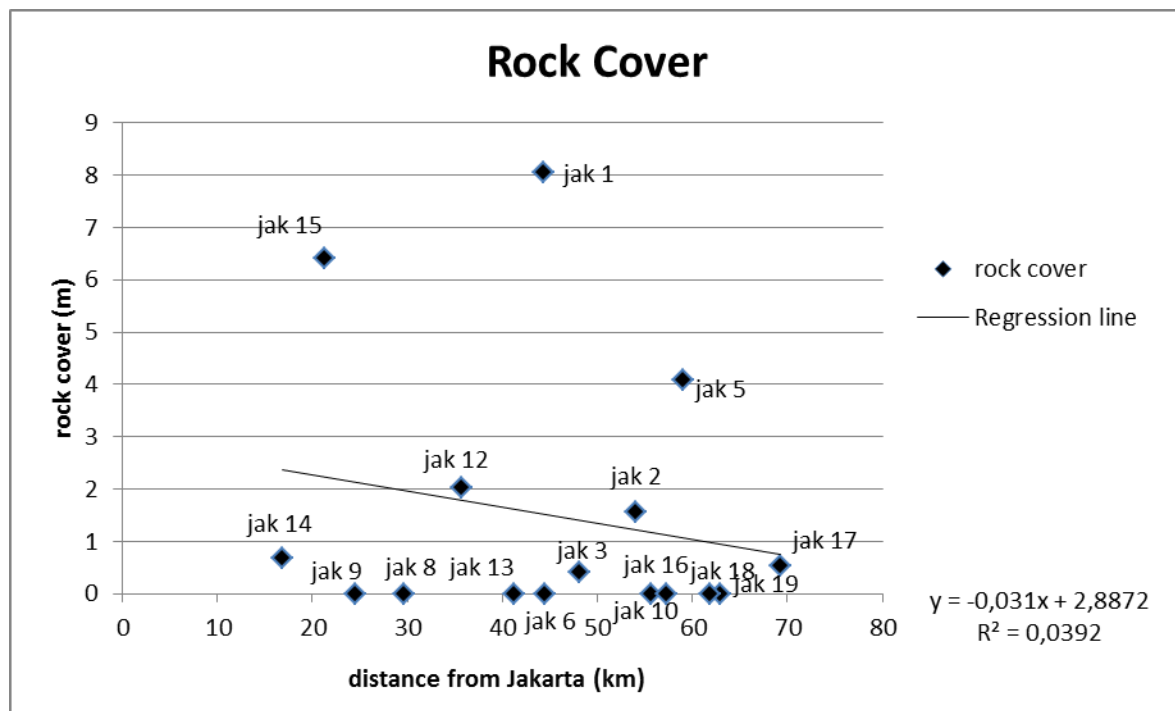


Figure 19: Total rock cover versus distance from Jakarta

Figure 19 clearly displays some high outliers, namely jak 1, 5 and 15. Rock cover values seem to be higher at the locations closer to Jakarta and lower at locations far away from Jakarta, even though rock cover values follow a fluctuating pattern. A decreasing trend of rock cover with distance from Jakarta can be noticed. This assumption is confirmed by the direction of the regression line, which indicates a negative relation between rock cover and distance from Jakarta. Unfortunately, the regression line explains only 3,9% of the total variation between the measurement locations (table 16). This interaction is consequently not significant ($P=0,462$). Therefore, the hypothesized expectations of a clear negative relation between distance and rock cover can be rejected.

The parameter Sand has also a very patchy distribution. The highest value, 13,81 meter, is found at location jak 14, which is the closest location to Jakarta (see table 15). There are two locations where no sand cover was measured, which are locations jak 9 and jak 17, which is the location farthest away from Jakarta. Over distance, sand cover values follow a fluctuating pattern, which can be seen in figure 20.

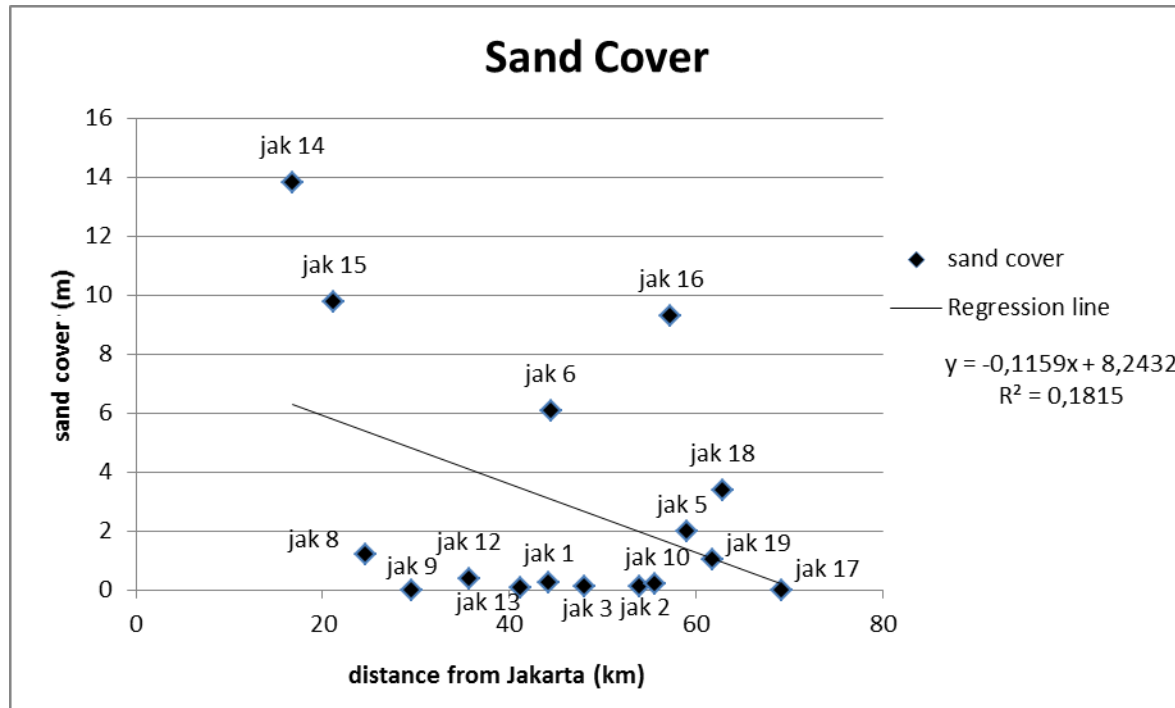


Figure 20: Total sand cover versus distance from Jakarta

Figure 20 clearly displays a couple of outliers, of which location jak 14 is the most recognizable. Most sand cover values range between 0 and 2 meter. Because of the decreasing sand cover numbers of locations jak 14,15, 6, 16 and 18/17, the assumption arises of a decreasing trend of sand cover with distance from Jakarta. This assumption is confirmed by the direction of the regression line, which indicates a negative relation between sand cover and distance from Jakarta. The regression line explains 18,1% of the total variation between the measurement locations (table 16). This interaction is nearly significant ($P=0,10$). Therefore, the hypothesized expectations of a clear negative relation between distance and sand cover cannot be rejected unquestionably.

Moreover, the parameter Sponges has a very patchy distribution, not present at all at 4 locations. The highest value, only 1,49 meter, is found at location jak 2, which is located in the middle of the Pulau Seribu island complex (see table 15). Over distance, sponges cover values follow a fluctuating pattern, which can be seen in figure 21.

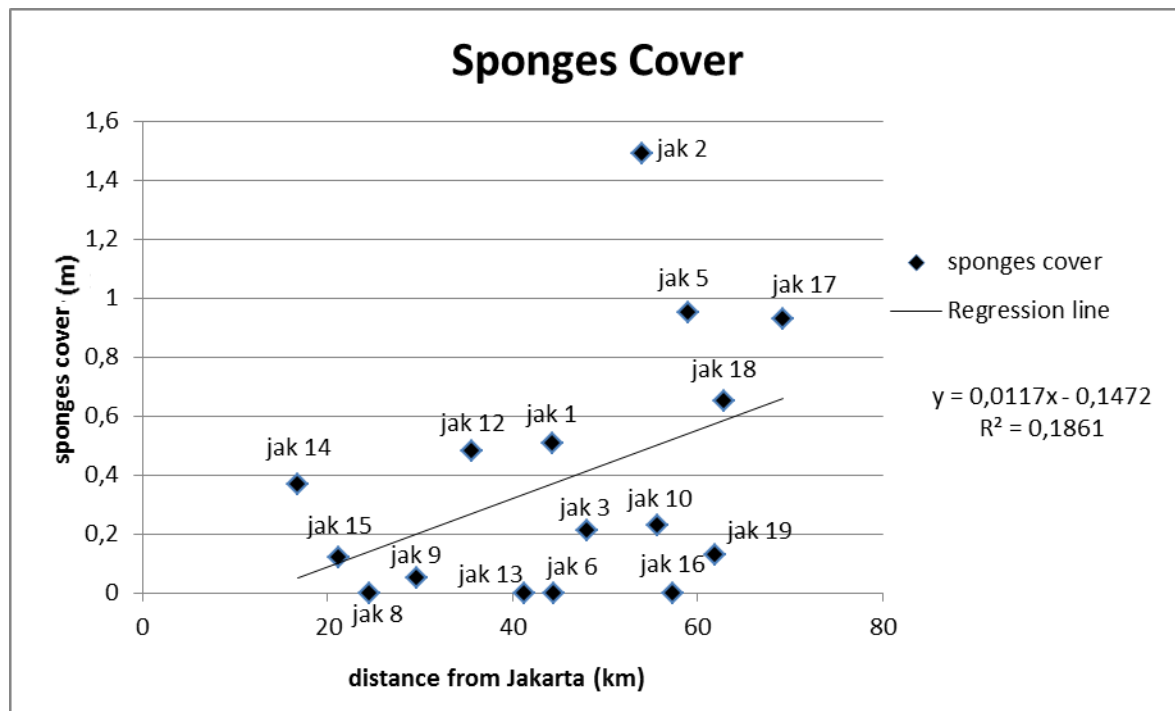


Figure 21: Total sponges cover versus distance from Jakarta

Figure 21 clearly displays outlier jak 2. Sponges cover values seem lower at the locations closer to Jakarta and higher at locations far away from Jakarta. An increasing trend of sponges cover with distance from Jakarta can be noticed. This assumption is confirmed by the direction of the regression line, which indicates a positive relation between sponges cover and distance from Jakarta. The regression line explains 18,6% of the total variation between the measurement locations (table 16). This interaction is nearly significant ($P=0,095$). Therefore, the hypothesized expectations of a clear positive relation between distance and sponges cover cannot be rejected undeniably.

The environmental parameter Coral is one of the parameters with the highest coverage numbers, which can implicate a healthy reef condition. At every location, cover of coral is found, see table 15. Coral cover numbers are ranging from 6,28 meter at location jak 8 (one of the closest locations to Jakarta) and 44,27 meter at location jak 13 (which is located in the middle of the Pulau Seribu island complex). Over distance, coral cover numbers seem to increase till location Jak 13, and to decrease going to locations positioned further away from Jakarta than Jak 13 (figure 22).

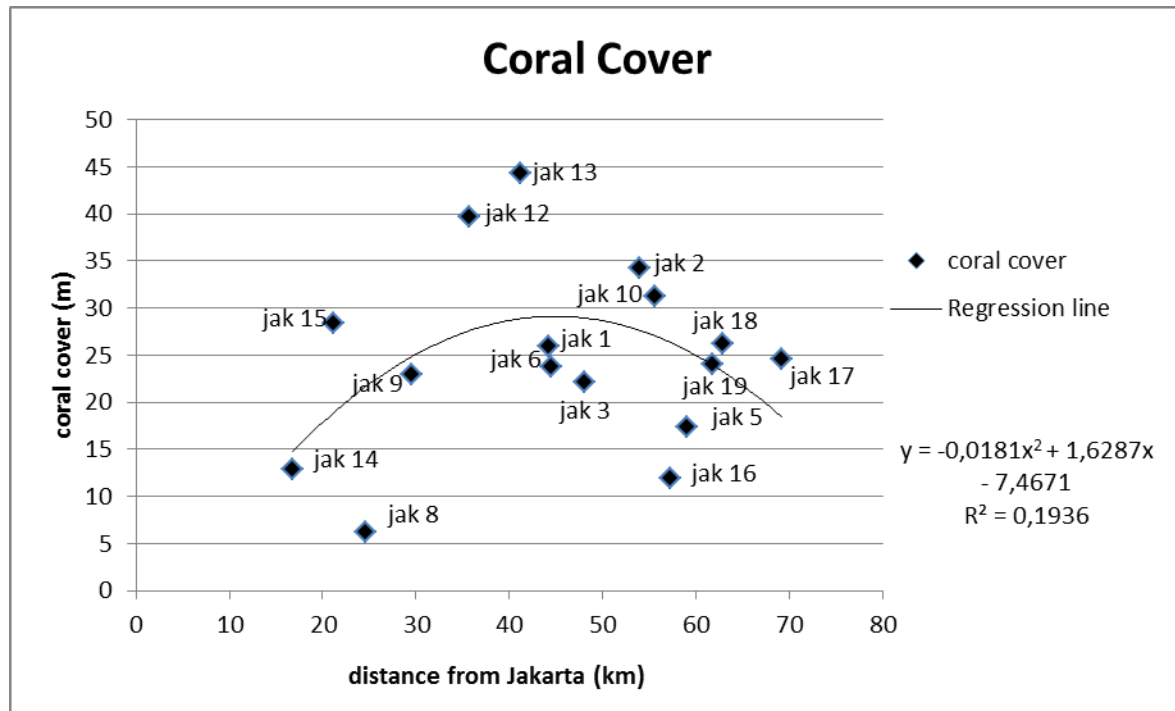


Figure 22: Total coral cover versus distance from Jakarta

Figure 22 clearly displays outlier jak 13. Coral cover values seem to follow a parabolic pattern over distance from Jakarta, therefore no clear linear pattern can be noticed. This is confirmed when adding a linear regression line, which only explains 2% of the total variation between the measurement locations (table 16). Therefore, the hypothesized positive relation between distance and coral cover is rejected.

Adding a regression line of a polynomial form, displayed in figure 22, the suspected parabolic relationship between distance and coral cover is confirmed. This parabolic regression line explains 19,3% of the total variation between the measurement locations. The parabolic relation is not significant, but it is the relation which has the lowest p-value ($p=0,247$). It is therefore stated that there is a positive relation between coral cover and distance from Jakarta till around 40 km away, but at the outer end of the island complex, coral cover is declining again. This declining can be caused by other phenomena's than the presence of a major city near the coral reef complex.

Also the environmental parameter Rubble is one of the parameters with the highest coverage numbers, which is a feature of deteriorated coral reefs. At every location, cover of rubble is found, see table 15. Rubble cover numbers are ranging from 1,01 meter at location jak 13 (which is located in the middle of the Pulau Seribu island complex) and 50,72 meter at location jak 8 (one of the closest locations to Jakarta). Therefore, the cover numbers of rubble deviate the most out of all environmental parameters between the measurement locations. Over distance, rubble cover numbers seem to decrease till location Jak 13, and to increase going to locations positioned further away from Jakarta than Jak 13 (figure 23). For that reason, rubble cover seems to follow the reverse pattern of coral cover.

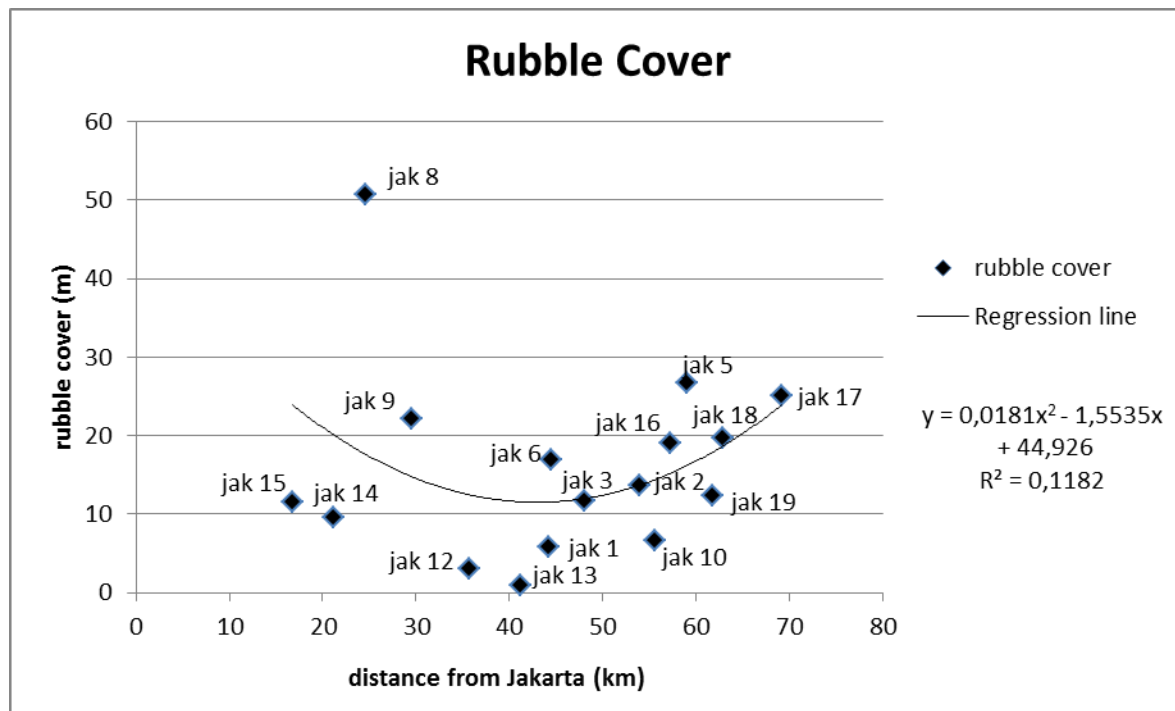


Figure 23: Total rubble cover versus distance from Jakarta

Figure 23 clearly displays outlier jak 8. Rubble cover values seem to follow an inverse parabolic pattern over distance from Jakarta, therefore no clear linear pattern can be noticed. This is confirmed when adding a linear regression line, which only explains 0,1% of the total variation between the measurement locations (table 16). Therefore, the hypothesized negative relation between distance and rubble cover is rejected.

Adding a regression line of a polynomial form, displayed in figure 23, the suspected inverse parabolic relationship between distance and rubble cover is confirmed. This parabolic regression line explains 11,8% of the total variation between the measurement locations. The parabolic relation is not significant, but it is the relation which has the lowest p-value ($p=0,442$). It is therefore stated that there is a negative relation between rubble cover and distance from Jakarta till around 40 km away, but at the outer end of the island complex, rubble cover is growing again. This progression can be caused by other phenomena's than the presence of a mayor city near the coral reef complex, maybe the same one that causes coral cover to decline.

Also the environmental parameter Algae has high coverage numbers in all measured coral reefs (table 15), which is a feature of deteriorated coral reef system. Algae cover numbers are ranging from 1,8 meter at location jak 8 (one of the closest locations to Jakarta) and 25,46 meter at location jak 3 (which is located in the middle of the Pulau Seribu island complex. No clear increase or decrease in cover values with distance can be noticed looking at figure 23. Location jak 14, which is also located close to Jakarta, has very high cover number of 20,72. Looking at the locations farthest away from Jakarta, cover values range from 8,9 meter at location jak 17 and 21,29 meter at location jak 19.

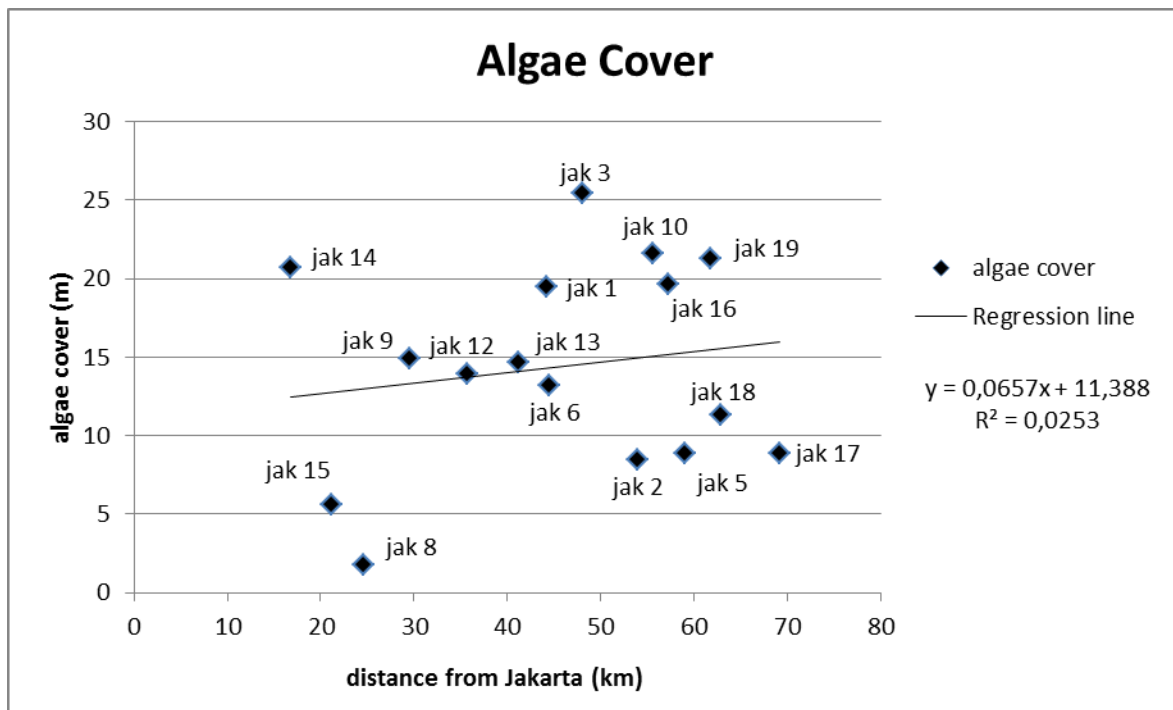


Figure 24: Total algae cover versus distance from Jakarta

The highest cover value jak 3 can be seen in figure 24, but not as pronounced as the outliers in figures 19 till 23. The algae cover values seem to be evenly distributed among the measurement locations displayed against distance. This assumption is confirmed by the direction of the regression line, which directs in a slightly positive direction over distance from Jakarta. Nevertheless, the regression line explains only 2,5% of the total variation between the measurement locations (table 16). This interaction is not significant ($P=0,556$). Therefore, the hypothesized expectations of a clear negative relation between distance and algae cover can be rejected.

In order to compare all environmental data, one environmental dataset belonging to a particular location has to be equated with a set of environmental data belonging to another location. Therefore, an ordination analysis was performed. In this way, outlier locations can be observed, which have abnormal environmental data compositions, even as clustered locations, which will have very similar environmental datasets.

PCA

A Principle Component Analysis (PCA) is performed on the environmental data. The first principal component accounts for the maximum of variability in the dataset possible, and each following component clarifies as much of the remaining variability as possible. It is an unconstrained ordination, which displays the main part of the variability in the environmental data composition along the measurement locations. The variable distance was not weighted in this analysis.

The analysis shows the following PCA summary:

**** Summary ****

Axes	1	2	3	4	Total variance
Eigenvalues:	0.708	0.199	0.071	0.021	1.000
Species-environment correlations:	0.089	0.084	0.460	0.004	
Cumulative percentage variance					
of species data:	70.8	90.7	97.8	99.9	
of species-environment relation:	25.1	31.4	99.5	99.5	
Sum of all eigenvalues					1.000
Sum of all canonical eigenvalues					0.022

Canonical axis one has an eigenvalue of 0,708, which signifies a quite large transition in environmental data composition between the measurement points along the x axis. The eigenvalue of axis two implies a significant variance in environmental data between the locations on the y axis, even though it is not as large as the transition on the x axis.

The summary shows for every axis the explained variance of environmental data among the measurement points: the cumulative percentage variance of species data. Axis one clarifies 70,8% of the total variance of the environmental dataset, and axis two adds 19,9% more to the explained variance. Thus, in total, axes one and two certify 90,7% of the total variance between the measurement locations in the environmental dataset.

The cumulative percentage variance of species-environment relation expresses the amount of variance explained by our axes as a fraction of the total explainable variance. Therefore for the environmental dataset, 25,1% of the total variance could be explained by the variable distance in the first canonical axis. Furthermore, the first two axes taken together only display 31,4% of the variation that *could* be explained by the variable distance. The amount of the total variation that we can explain in this environmental dataset is the same as the sum of all canonical eigenvalues. The sum of all canonical eigenvalues is a relative measure of the total explained variance. In this case, the total explained variance of the canonical axes is only 2,2%, which is very low.

Figure 25 shows the projection of the measurement locations (circles) on a set of axes, such that the maximal variation between the objects is projected along the x axis, and the maximum difference in remaining variation, excluding the variation explained by the x axis, is displayed in the y axis. The environmental variable distance was added as a supplementary variable in the correlation matrix.

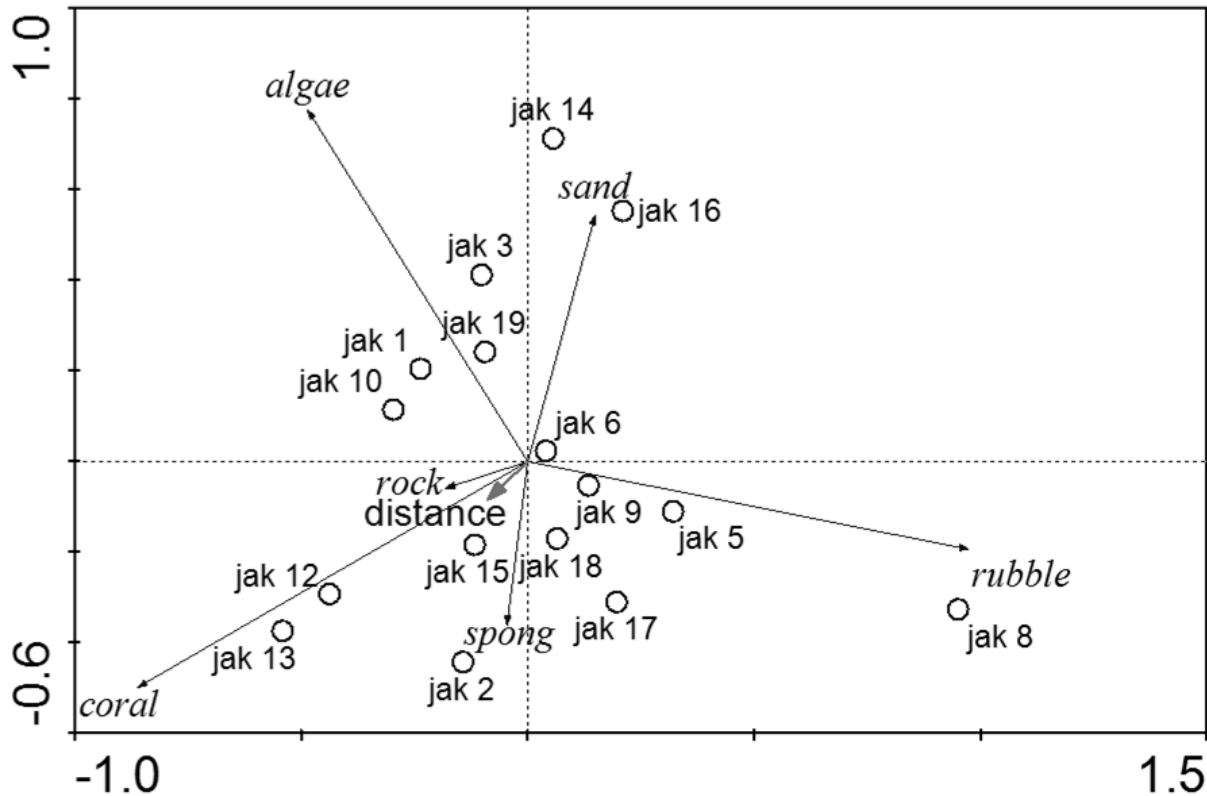


Figure 25: PCA ordination diagram of axis 1 and axis 2 with the environmental data of the measurement locations (circles), and nominal variables (arrows) of the absolute data, the environmental parameters. rock = Rock (m), rubble = Rubble (m), sand = Sand (m), algae = Algae (m), coral = Coral (m), and spong = Sponges (m).

Looking at figure 25, a couple of outliers can be seen along the x axis. At the right side of the graph, outlier jak 12 and 13 can be noticed, whose location seems to be closely correlated to the covering distribution of coral, displayed as an arrow. Jak 3 seems to have a high value of this group. Looking at figure 22, the high value for coral on those locations is confirmed. At the left side of the graph measurement point jak 8 is situated. Observing the direction of all arrows of the environmental parameters, this environmental dataset seems to be characterized by high values of rubble and low value of cover of algae, coral, rock and sponges, which is confirmed by table 15.

Fixing on the variation along the y axis, outlier jak 14 is observed at the top of the graph. Its position seems to be closely correlated to the coverage distribution of algae and sand, whose arrows have an upwards going direction. Location Jak 14 seems to have a high value for these parameters. Looking at table 15, these high values are confirmed. On the bottom of the graph, outlier jak 2 is detected, which position seems to be linked to high coverage values of sponges and coral, and low values of algae and sand, judging by the direction of the arrows. These coverage numbers are confirmed by the values of those environmental parameters, displayed in table 15.

Two clear clustered groups of measurement points can be seen, one in the upper part of the graph and one in the bottom part of the graph. The separation of the two groups is caused by deviations in the environmental dataset along the y axis, which relates to differences in cover of algae, sand and sponges. The group on the top half of the diagram is dominated by the presence of the parameters algae and sand, of which parameter algae has a longer arrow, indicating a bigger degree of change and is therefore more important to the positioning of the different measurement locations within the ordination plot. The group in the bottom half of the diagram is more scattered along the x axis than the group in the upper part, caused by stronger deviations along the measurement points in the cover of coral and rubble. Displayed in the middle of the ordination plot, jak 6 represents the average environmental data composition.

The environmental variable distance, added as an additional input variable, is also displayed as an arrow in the ordination plot. This arrow points in the direction of the largest increase in weighted averages of the samples of this variable. The length of the arrow indicates the degree of change in value in the correspondent direction. The arrow of distance points in the same direction as the environmental parameters rock, coral, and sponges, indicating a similar variation distribution between those groups and distance. The arrow points in the opposite direction of the parameter sand, indicating an inverse correlation between those two variables. The distance arrow is not closely related to one of the ordination axes. The arrow is very small, indicating that the degree of change is not very large, which is confirmed by the low cumulative percentage variance of species-environment relation in the PCA summary. This is probably why there is only found a positive significant relationship between distance and sponges, and no significant positive relations between distance and coral/rock.

Influence of fish biomass distribution on environmental parameters

In this part of the results the indicators will be correlated to the different functional group biomass parameters used in previous sections, to see if the biomass variations have an influence on the cover of the indicators for coral reef health. In this way, finally there can be focussed on the importance of the herbivorous fish population structure for coral reef resilience. Cover of Coral, and Sponges were taken as positive factors for coral recruitment and survivorship, because they form a stable, consolidated substratum. Cover of Rock, Rubble, Sand, Algae, were taken as indicators for the failure of coral recruitment and survivorship. The outcomes of the regression analysis were placed in table 17. The complete regression analyses of the possible relations with a P value lower than 0,20 were placed in Appendix 8.

Table 17: summary of regression analyses between environmental variables and herbivorous biomass variables

Environmental variables (m)	Total Biomass		Total Biomass Grazers/ detritivores		Total Biomass Browsers		Total Biomass Scrapers/ small excavators		Total Biomass of all herbivores	
	R ²	P	R ²	P	R ²	P	R ²	P	R ²	P
Rock	0,076	0,300	0,004	0,811	0,133	0,164	0,004	0,808	0,012	0,686
Rubble tot.	0,069	0,326	0,015	0,648	0,040	0,457	0,081	0,286	0,002	0,862
Sand	0,017	0,626	0,001	0,925	0,056	0,380	0,141	0,152	0,096	0,242
Algae	0,018	0,624	0,022	0,586	0,120	0,189	0,289	0,032	0,022	0,588
Coral	0,046	0,425	0,000	0,955	0,001	0,899	0,016	0,641	0,003	0,830
Sponges	0,015	0,652	0,077	0,297	0,572	0,001	0,001	0,915	0,151	0,138

Looking at table 17, it becomes clear that many investigated linear relationships are not significant, and also a small percentage of total variance is explained by the calculated regression line. The positive relations between biomass of browsers and rock cover, biomass of scrapers/small excavators and sand, and biomass of all herbivores and sponges are nearly significant with P values around 0,15.

In terms of coral reef system resilience, the found positive relation between biomass of browsers and rock cover was not expected, because rock is an indicator of failure of coral recruitment and survivorship, while the presence of browsers seems to be a positive influence on coral reef resilience. The probability of this found pattern has to be carefully evaluated, because there are only a few browser biomass measurements, and also few rock cover measurements. The found positive relation of biomass of scrapers/small excavators and sand was also not expected ($p=0,152$), because sand is an indicator of failure of coral recruitment and survivorship, while the presence of scrapers/small excavators seems to be a positive influence on coral reef resilience. The role of sponges is not mentioned in the mechanism of coral reef resilience, but they seem to promote the general health of a coral reef ecosystem (De Goeij et al., 2013). Therefore the positive relation between biomass of all herbivores and sponges seems probable.

The negative relation between biomass of browsers and algae is also nearly significant ($P=0,189$). Evaluating the probability of this relation, the few biomass measurements of the functional group browsers must be taken into account. Yet this relation seems more likely than the relation between biomass of browsers and rock cover, because the algae cover is more evenly distributed among all measurement sites.

Only two significant relations were found. First, the relation between biomass browsers and sponges cover is highly significant ($p=0,001$) The two variables are plotted against each other in figure 26, with the correspondent positive linear regression line. Evaluating the probability of this relation, again the few biomass measurements of the functional group browsers must be taken into account. Nevertheless, the found positive relation of biomass of browsers and sponges cover fits into the picture of coral reef resilience, both being positive factors for coral reef health.

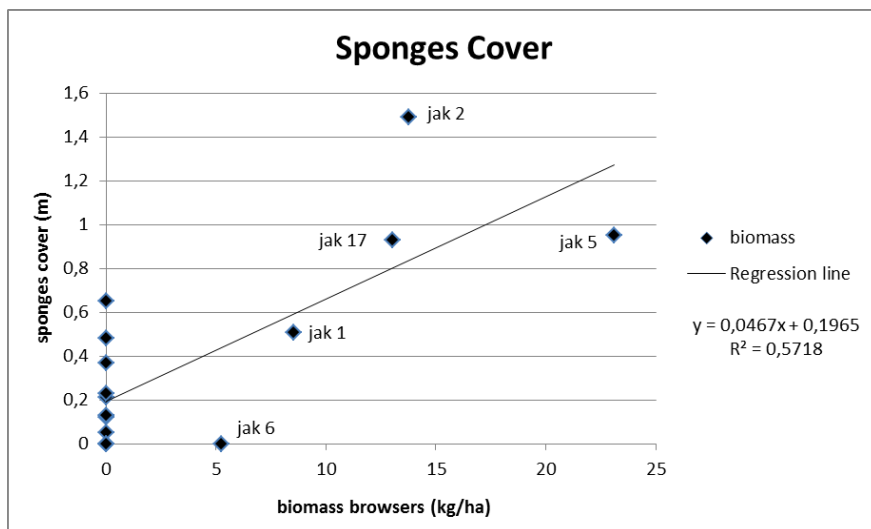


Figure 26: Total sponges cover versus total biomass browsers.

Second, the relation between biomass of scrapers/small excavators and algae cover is significant ($P=0,032$). The two variables are plotted against each other in figure 27, with the correspondent positive linear regression line. In terms of coral reef system resilience, the found positive relation between biomass of scrapers/small excavators and algae cover was not hypothesized, because algae cover is an indicator of failure of coral recruitment and survivorship, while the presence of scrapers/small excavators seems to be a positive influence on coral reef resilience. Outlier Jak 3 seems to be the cause of the positive direction of the regression line, but removing jak 3 still gives a positive regression line, even though in that case the relation is no longer significant.

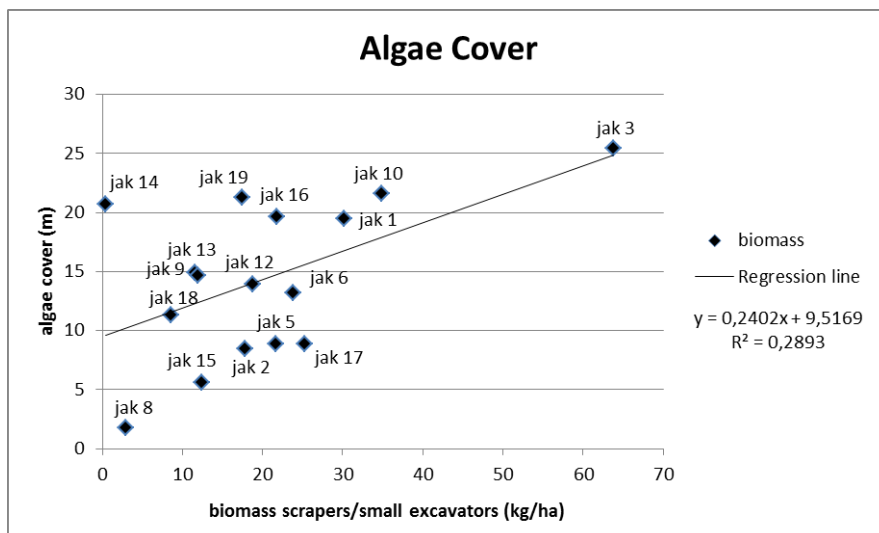


Figure 27: Total algae cover versus total biomass scrapers/small excavators.

In order to compare all environmental data, and link the variation of the environmental data to the variation in fish biomass data, one environmental dataset belonging to a particular location has to be equated with a set of environmental data belonging to another location. Therefore, an ordination analysis was performed. In this way, outlier locations can be observed, which have abnormal environmental data compositions, even as clustered locations, which will have very similar environmental datasets, and the spread of the locations can be linked to biomass parameters.

Having both environmental data and data on species composition, first an unconstrained ordination was calculated, and then a regression of the ordination axes on the measured environmental variables was calculated (i.e. to project the environmental variables into the ordination diagram). After this step, a constrained ordination, RDA, was calculated. According to Lepš & Šmilauer, 2003, the two approaches are complementary and both should be used. By calculating the unconstrained ordination first, the main part of the variability in species composition will not be missed, but that part of the variability that is related to the measured environmental variables can be missed (Lepš & Šmilauer, 2003). By calculating a constrained ordination, the main part of the biological variability explained by the environmental variables will not be overlooked, but the main part of the variability that is not related to the measured environmental variables can be overlooked (Lepš & Šmilauer, 2003).

PCA

First, a principle component analysis (PCA) is performed on the environmental data. The variable distance was not weighted in this analysis.

The analysis shows the following PCA summary:

**** Summary ****

Axes	1	2	3	4	Total variance
Eigenvalues:	0.708	0.199	0.071	0.021	1.000
Species-environment correlations :	0.363	0.427	0.522	0.574	
Cumulative percentage					
variance of species data:	70.8	90.7	97.8	99.9	
of species-environment relation:	59.7	83.0	95.3	99.8	
Sum of all eigenvalues					1.000
Sum of all canonical eigenvalues					0.156

The eigenvalues of axes one and 2, which are values for the transitions along the first and second canonical axis, remain the same as calculated in the previous section, because the environmental dataset has not changed. Therefore, also the explained variance of environmental data among the measurement points: the cumulative percentage variance of species data is not changed. Thus, in total, axes one and two still certify 90,7% of the total variance between the measurement locations in the environmental dataset.

The cumulative percentage variance of species-environment relation expresses the amount of variance explained by our axes as a fraction of the total explainable variance. Therefore for the environmental dataset, 59,7% of the total variance could be explained by the variations in the functional group biomass dataset in the first canonical axis. Furthermore, the first two axes taken together only display 83,0% of the variation that *could* be explained by the biomass variables. The amount of the total variation that we can explain in this environmental dataset is the same as the sum of all canonical eigenvalues. The sum of all canonical eigenvalues is a relative measure of the total explained variance. In this case, the total explained variance of the canonical axes is 15,6%.

Figure 28 shows the projection of the measurement locations (circles) on a set of axes, such that the maximum variation between the objects is projected along the x axis, and the maximum difference in remaining variation, excluding the variation explained by the x axis, is displayed in the y axis. The functional biomass variables were added as a supplementary variables in the correlation matrix.

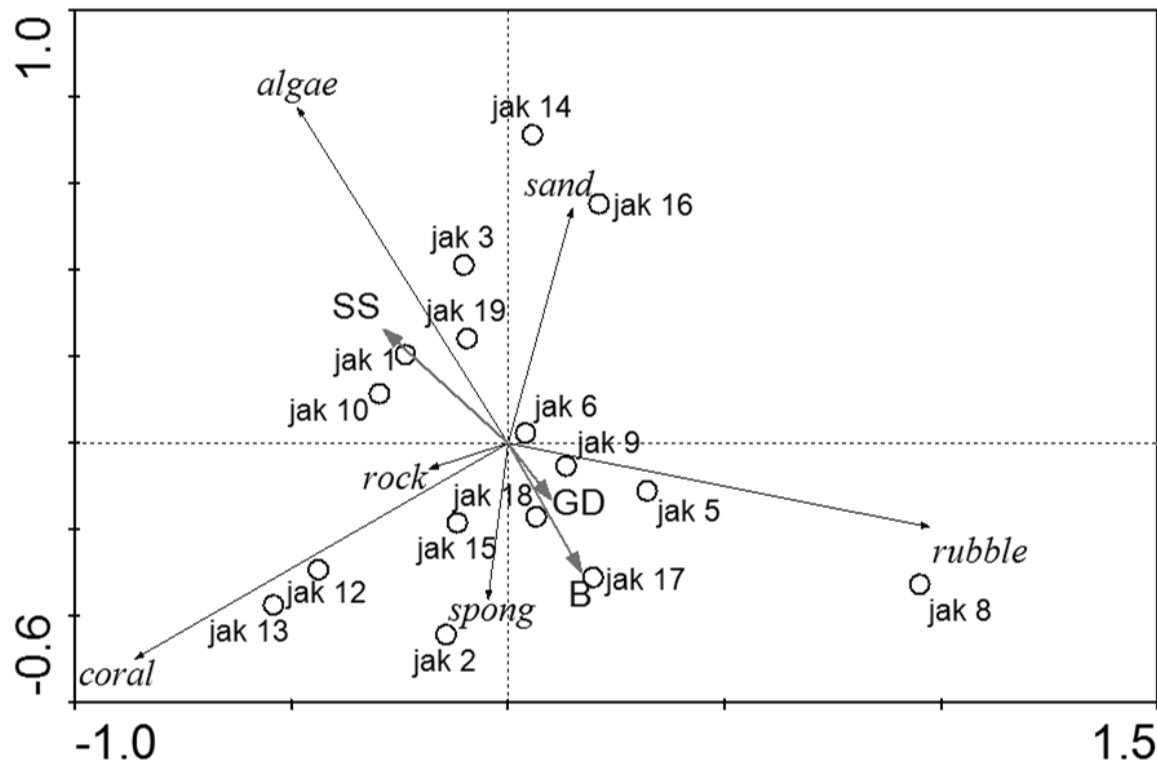


Figure 28: PCA ordination diagram of axis 1 and axis 2 with the environmental data of the measurement locations (circles), and nominal variables (arrows) of the absolute data, the environmental parameters and biomass variables. rock = Rock (m), rubble = Rubble (m), sand = Sand (m), algae = Algae (m), coral = Coral (m), and spong = Sponges (m). GD= grazers/detritivores, SS= scrapers/small excavators, B= browsers.

Looking at figure 28, the same outliers can be seen as in ordination plot of figure 25, which is logical because it represents the same data plot. Logically, the arrows of the environmental parameters have the same direction, since they determine the placement of the points.

The functional group biomass variables, added as additional input variables, is also displayed as an arrow in the ordination plot. This arrow points in the direction of the largest increase in weighted averages of the samples of this variable. The length of the arrow indicates the degree of change in value in the correspondent direction. The arrow of scrapers/small excavators points in the opposite direction compared to the arrows of browsers and grazers/detritivores. The arrow of scrapers/small excavators points in the same direction as the environmental parameter algae, indicating a similar variation distribution between this parameter and biomass of scrapers/small excavators. This relation is confirmed by the regression analysis of table 17.

The arrow of grazers/detritivores does not point in the same direction as one of the arrows of the environmental parameters, indicating no similar variation distribution between the environmental parameters and biomass of grazers/detritivores. The non-existence of relations is confirmed by the regression analysis of table 16. The arrow of grazers/detritivores points in the opposite direction of the parameter algae, indicating an inverse correlation between those two variables. Still, looking in table 17, this relation is not significant. This is probably caused by the big difference in length of the arrows of algae and grazers/detritivores.

The arrow of browsers points somewhat in the same direction as the environmental parameter sponges, indicating a similar variation distribution between sponges cover and biomass of browsers. This relation is confirmed by the regression analysis of table 17. The arrow of browsers points in the opposite direction of the parameter algae, indicating an inverse correlation between those two variables. This relation is nearly significant, according to table 17.

Comparing figure 25 and 28, the arrows of the functional groups are longer than the arrow of distance, indicating that the degree of change is somewhat bigger, which is confirmed by the higher cumulative percentage variance of species-environment relation in the PCA summary.

Two clear clustered groups of measurement points can be seen, one in the upper part of the graph and one in the bottom part of the graph. The separation of the two groups is caused by deviations in the environmental dataset along the y axis, which relates to differences in cover of algae, sand and sponges. But regarding the arrows of the functional group biomass parameters, the separation can also be caused by the difference in biomass distribution of the group scrapers/small excavators, dominating the upper half of the ordination plot, and distribution of the groups browsers and grazers/detritivores, dominating the bottom half of the ordination plot.

RDA

A Redundancy analysis (RDA) is performed on the environmental data. The first principal component accounts for the maximum of explained variability in the environmental dataset possible by the biomass variables, and each following component clarifies as much of the remaining explainable variability as possible. It is a constrained ordination, which displays the main part of the explained variability in the environmental data composition by the biomass variables.

The analysis shows the following RDA summary:

****** Summary ******

Axes	1	2	3	4	Total variance
Eigenvalues:	0.143	0.012	0.001	0.623	1.000
Species-environment correlations:	0.526	0.419	0.113	0.000	
Cumulative percentage variance					
of species data:	14.3	15.5	15.6	78.0	
of species-environment relation:	91.4	99.4	100.0	0.0	
Sum of all eigenvalues					1.000
Sum of all canonical eigenvalues					0.156

The eigenvalues of axes one and two are values for the transitions along the first and second canonical axis of the explained variance of the environmental dataset by the biomass variables. Canonical axis one has an eigenvalue of 0,143, which signifies a quite small transition in the explained variance of the environmental data composition between the measurement points along the x axis. The eigenvalue of axis two implies an even smaller transition in explained variance in environmental data between the locations on the y axis.

Therefore, also the explained variance of environmental data by the biomass variables among the measurement points, the cumulative percentage variance of species data, is small. In total, axes one and two certify 15,5% of the total explained variance between the measurement locations in the environmental dataset. Axis four represents 78% of the total variance, this is the variance which is not explained by the functional group biomass variables.

The cumulative percentage variance of species-environment relation expresses the amount of variance explained by the axes as a fraction of the total explainable variance. Therefore for canonical axis one, 14,3% of the total variance of the environmental dataset could be explained by the variations in the functional group biomass dataset, which is 91,4% of the total variance which can be explained by the biomass variables. Furthermore, the first two axes taken together display 99,4% of the variation that *could* be explained by the biomass variables. The amount of the total variation that we can explain in this environmental dataset is the same as the sum of all canonical eigenvalues. The sum of all canonical eigenvalues is a relative measure of the total explained variance. In this case, the total explained variance of the canonical axes by the biomass variables is 15,6%.

Figure 29 shows the projection of the measurement locations (circles) on a set of axes, such that the maximal explained variation between the objects is projected along the x axis, and the maximum difference in remaining explained variation is displayed in the y axis. The functional biomass variables were added as explanatory variables in the correlation matrix.

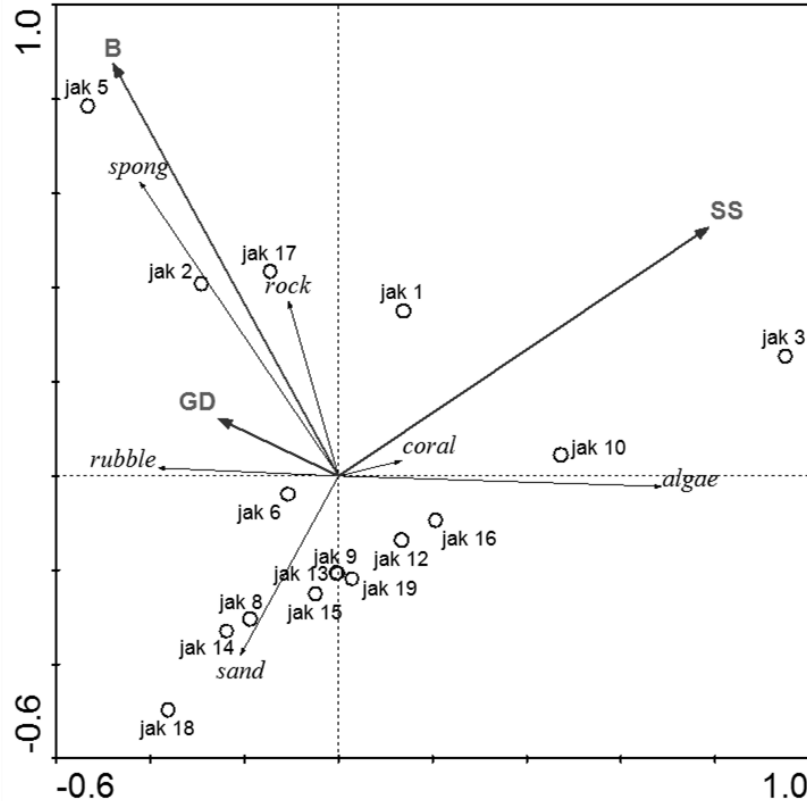


Figure 29: RDA ordination diagram of axis 1 and axis 2 with the environmental data of the measurement locations (circles), and nominal variables (arrows) of the absolute data, the environmental parameters and biomass variables. rock = Rock (m), rubble = Rubble (m), sand = Sand (m), algae = Algae (m), coral = Coral (m), and spong = Sponges (m). GD= grazers/detritivores, SS= scrapers/small excavators, B= browsers.

Looking at figure 29, it becomes evident that the biomass distribution of scrapers/small excavators has a reverse direction through the explained variance of the environmental dataset opposed to the biomass distributions of browsers and grazers/detritivores. A couple of outliers can be seen in the ordination plot, all located in the top half of the graph. At the left side of the upper part of the graph, outliers jak 5, 2 and 17 can be noticed, whose explained variations seem to be closely correlated to the biomass distribution of browsers, displayed as an red arrow. Looking at table 11, the high value for browsers at those locations is confirmed. Location Jak 5 has the highest biomass value of the functional group browsers, therefore is placed highest in the graph. Jak 17 has a higher value of the functional group scrapers/small excavators than jak 2, and is therefore situated more to the right.

At the right side of the upper part of the graph, outliers jak 3, 10 and 1 can be noticed, whose explained variations seem to be closely correlated to the biomass distribution of scrapers/small excavators, displayed as an red arrow. Looking at table 11, the high value for scrapers/small excavators at those locations is confirmed. Jak 1 is located more to the right of the ordination plot, because of the high biomass values of browsers.

Displayed in the middle of the ordination plot, jak 6 represents the average explained environmental data variance. One long clustered group of measurement points can be seen in the bottom half of the ordination plot. The shape of this clustered group is caused by differences in biomass values of scrapers/small excavators between the measurement locations within the clustered group. Location jak 18, located at the bottom end of the group, has a very low biomass value of scrapers/small excavators, while jak 16, located at the upper end of the clustered group, has a high biomass value of scrapers/small excavators (table 11).

The arrow of scrapers/small excavators points somewhat in the same direction as the environmental parameter algae, indicating a similar variation distribution between this parameter and biomass of scrapers/small excavators. This relation is confirmed by the regression analysis of table 17. The arrow of scrapers/small excavators points also in the same direction of the parameter coral, indicating a similar correlation between those two variables. Still, looking in table 17, this relation is not significant. This is probably caused by the difference in length of the arrows of coral and scrapers/small excavators. The arrow of scrapers/small excavators points in the opposite direction of the parameter sand, indicating an inverse correlation between those two variables. This relation is nearly significant, according to table 17.

The arrow of grazers/detritivores, which is the smallest arrow, does not point in the same direction as one of the arrows of the environmental parameters, indicating no similar variation distribution between the environmental parameters and biomass of grazers/detritivores. The non-existence of relations is confirmed by the regression analysis of table 17. The arrow of grazers/detritivores points in the opposite direction of the parameter algae, indicating an inverse correlation between those two variables. Still, looking in table 17, this relation is not significant. This is probably caused by the big difference in length of the arrows of algae and grazers/detritivores.

The arrow of browsers points in the same direction as the environmental parameter sponges, indicating a similar variation distribution between sponges cover and biomass of browsers. This relation is confirmed by the regression analysis of table 17. The arrow of browsers points also in the same direction of the parameter rock, indicating a similar correlation between those two variables. This relation is nearly significant, according to table 17. The arrow of browsers points in the opposite direction of the parameter algae, indicating an inverse correlation between those two variables. This relation is nearly significant, according to table 17.

Monte Carlo permutation test.

After performing the Monte Carlo Permutation test, the following summary appeared:

*** Unrestricted permutation ***

Seeds: 23239 945

**** Summary of Monte Carlo test ****

Test of significance of first canonical axis: eigenvalue = 0.143

F-ratio = 2.002

P-value = 0.5000

Test of significance of all canonical axes : Trace = 0.156

F-ratio = 0.742

P-value = 0.6220

(499 permutations under reduced model)

Testing the significance of both the first canonical axis and all canonical axes, a p value emerges of 0,50-0,62, and therefore the combinations of the functional group biomass variables do not significant explain the variation in the environmental variables

Influence of fish biodiversity distribution on environmental parameters

The attempt to link variations in the composition of the herbivorous fish population to the indicators for coral reef health which can be influenced by herbivores fishes; coral recruitment and survivorship, has not given clear results. In order to distinguish some kind of relationship between reef fish composition and the indicators for coral reef health, there is looked in a broader perspective to a coral reef system. In this part of the results, there is concentrated on the possible influence of total reef fish biodiversity on the composition of the researched reefs. The Shannon Wiener numbers calculated before are a good variable to focus on, because the reef fish diversity in terms of biomass contribution are central in this Index.

Cover of Coral, and Sponges were taken as positive factors for coral recruitment and survivorship, because they form a stable, consolidated substratum. Cover of Rock, Rubble, Sand, Algae, were taken as indicators for the failure of coral recruitment and survivorship. The outcomes of the regression analysis were placed in table 18. The complete regression analyses of the possible relations with a P value lower than 0,20 were placed in Appendix 9.

Table 18: summary of the different regression analyses performed, Shannon Wiener index as independent variable

Shannon Wiener number independent variable, regression analysis with environmental variables:	R ²	Sig
Rock	0,105	0,220
Rubble	0,199	0,083
Sand	0,153	0,134
Algae	0,002	0,880
Coral	0,399	0,009
Sponges	0,343	0,017

Out of the six regression analysis, 2 highly significant relations were found, and 2 relations which were not significant but had a low p value. Therefore, overall some kind of relationship between reef fish composition and the indicators for coral reef health seems to exist. Total reef fish biodiversity has a negative influence on the cover of rubble and sand, and a positive influence on the cover of coral and sponges. All four found relations fit into the picture of coral reef resilience, in which system fish biodiversity has a positive influence on the promoters of coral recruitment and survivorship, which are coral and sponges cover.

Two not significant relations were found with low p values. First, the relation between Shannon Wiener index and rubble cover is not significant ($p=0,083$). The two variables are plotted against each other in figure 30, with the correspondent negative linear regression line. Decreasing rubble cover values can be noticed with increasing Shannon Wiener index numbers. The found negative relation of Shannon Wiener index and rubble cover fits into the picture of coral reef resilience, Shannon Wiener being a positive factor for coral reef health, and rubble cover being a negative factor for coral reef health.

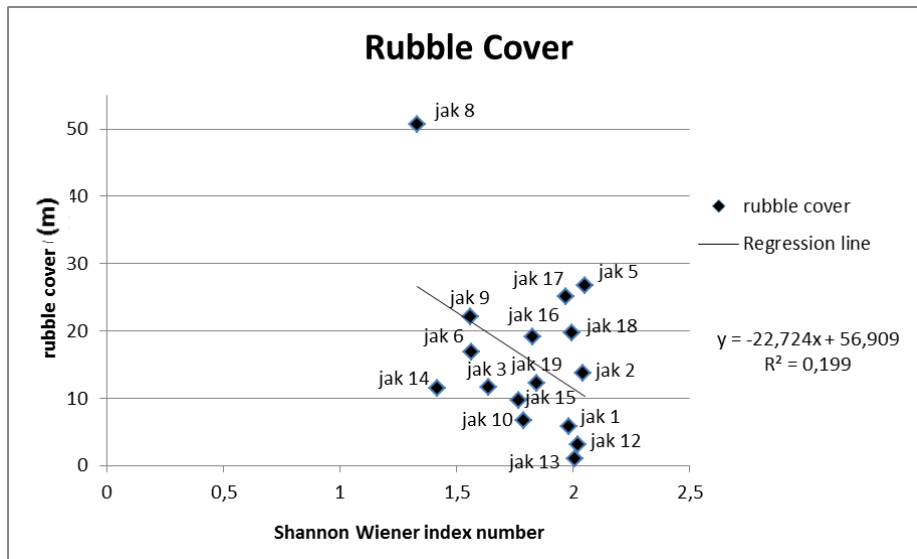


Figure 30: Rubble cover versus Shannon Wiener index numbers

Second, the relation between Shannon Wiener index and sand cover is not significant ($P=0,134$). The two variables are plotted against each other in figure 31, with the correspondent negative linear regression line. Decreasing sand cover values can be noticed with increasing Shannon Wiener index numbers. In terms of coral reef system resilience, the found negative relation between Shannon Wiener index and sand cover was hypothesized, Shannon Wiener being a positive factor for coral reef health, and sand cover being a negative factor for coral reef health.

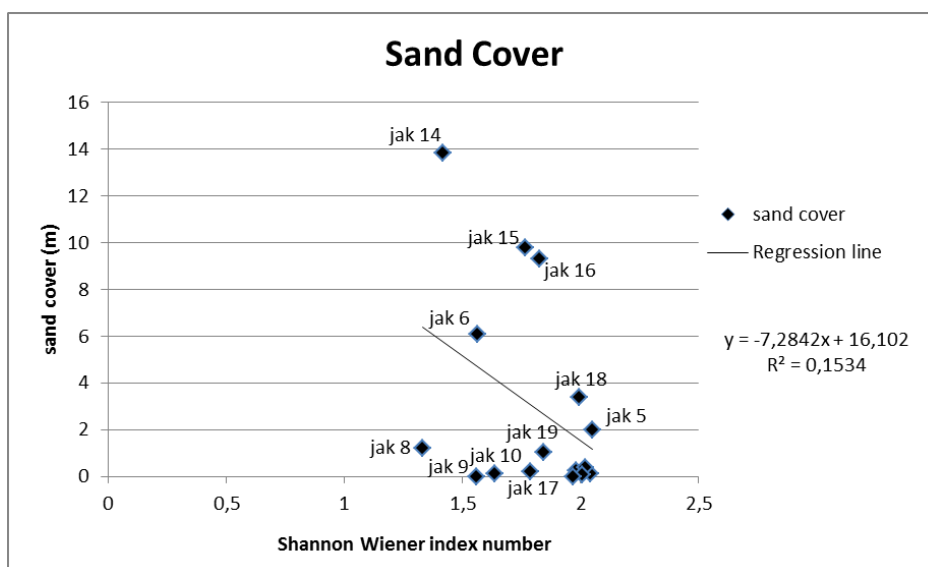


Figure 31: Sand cover versus Shannon Wiener index numbers

Two highly significant relations were found. First, the relation between Shannon Wiener index and coral cover is highly significant ($p=0,009$) The two variables are plotted against each other in figure 32, with the correspondent positive linear regression line. Increasing coral cover values can be noticed with increasing Shannon Wiener index numbers. The found positive relation of coral cover and Shannon Wiener index fits into the picture of coral reef resilience, Shannon Wiener index and coral cover both being positive factors for coral reef health.

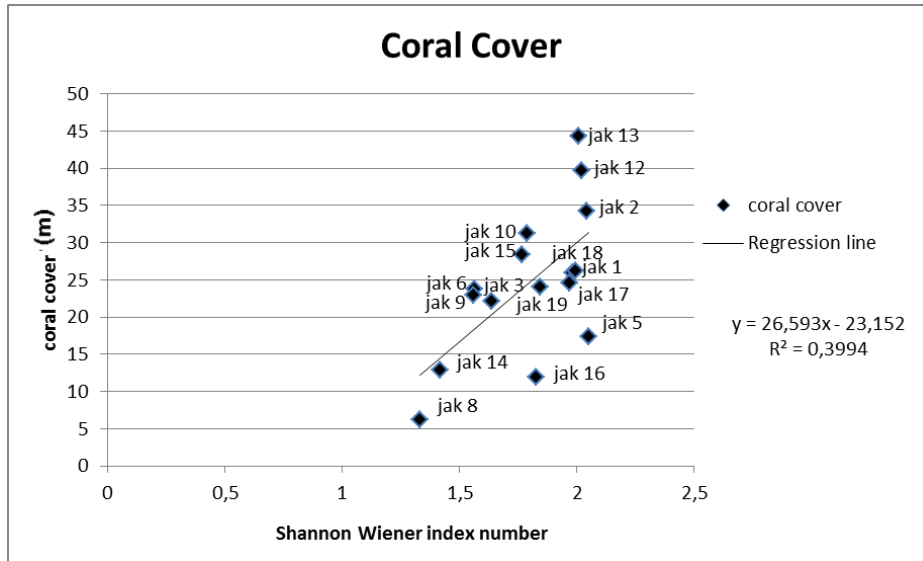


Figure 32: Coral cover versus Shannon Wiener index numbers

Second, the relation between Shannon Wiener index and sponges cover is highly significant ($P=0,017$). The two variables are plotted against each other in figure 33, with the correspondent positive linear regression line. Increasing sponges cover values can be noticed with increasing Shannon Wiener index numbers. In terms of coral reef system resilience, the found positive relation between Shannon Wiener index and sponges cover was hypothesized, Shannon Wiener index and sponges cover both being positive factors for coral reef health.

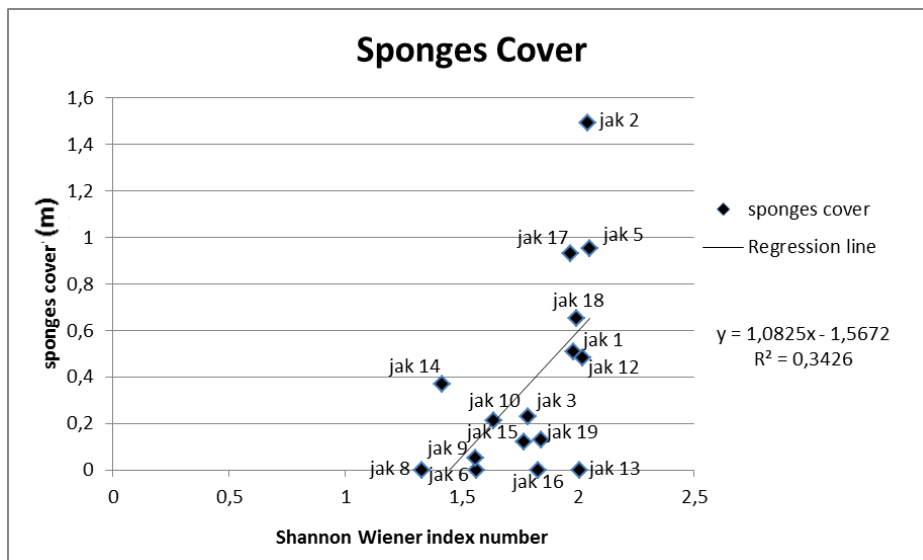


Figure 33: Sponges cover versus Shannon Wiener index numbers

Discussion

The urbanised area

The population of Indonesia amounts 253,609,643 (Cia World Factbook, July 2014), of which 98% occupies 5 main islands, namely 60% in Java (143,000,000 residents, BPS 2013), 20% in Sumatra, 7% in Sulawesi, 5% in Kalimantan, and 1% in West Papua. More than 200 million people are living highly concentrated on a single island which is Java. In 2005, a total of 23 million people lived in the metropolis around Jakarta (Jabotabek, see figure 34): about 8.7 million in the city of Jakarta; 5.6 million in the cities of Bogor, Depok, Tangerang and Bekasi; and 9.1 million in the three regencies (Bekasi, Tangerang and Bogor) (BPS, 2005). Nowadays, the number of inhabitants for this area is increased to 26 million, with 10 million residents in Jakarta (BPS, 2013). Estimates claim that the population in the city of Jakarta will increase to about 11 million people in 2025 (BPS). On the Pulau Seribu Islands more than 22,700 people live on 7,200 square kilometers. (The Center of Indonesia- Statistic, 2009).

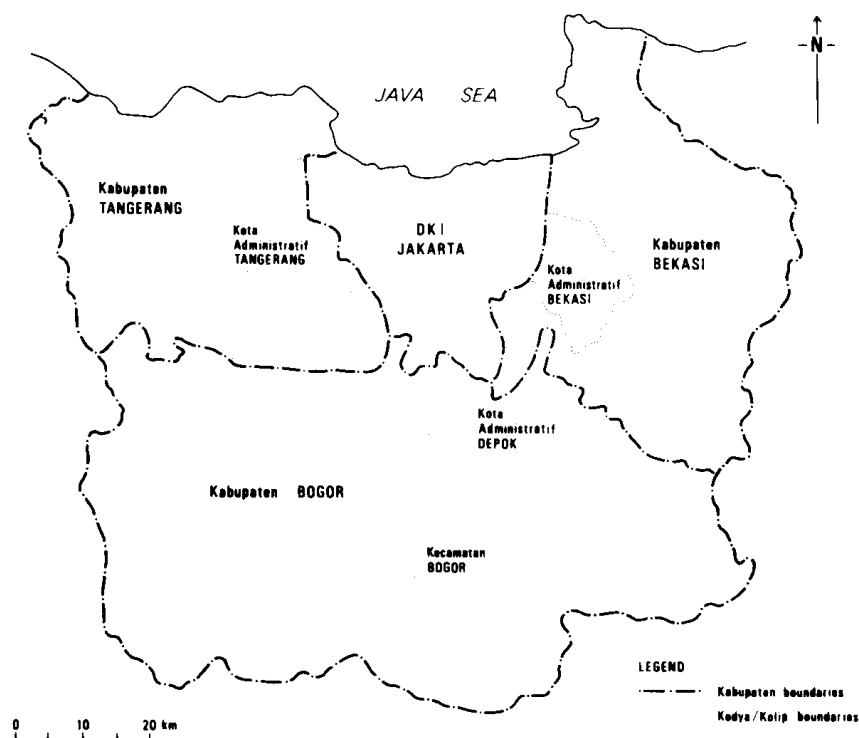


Figure 34: Regencies of Jabotabek; the mainland area close to the Pulau Seribu islands.
source: <http://archive.unu.edu/unupress/unupbooks/uu11ee/uu11ee15.htm>

A pollution gradient from a large urbanised area of Jakarta linked to distance from Jakarta.

These population numbers of the urbanised area give huge pressure on the Jakarta Bay and the measured reefs near the coast of Jakarta. All reefs are under various levels of pressure from a number of human activities including unsustainable fishing, coral mining, oil exploration, uncontrolled tourist developments, sand dredging, anchor damage, resort construction and the discharge of industrial and domestic effluent (Rinawati et al. 2012, Rees et al. 1999; Rachello-Dolmen & Cleary 2007).

Distance from the city Jakarta was used as a proxy for the pollution of an urbanised area, with sites closest to the village assumed to have the highest pollution. However, for example the research of Vincent et al., 2011, uses the same variable distance from the coast, but here, this variable is only linked to fishing pressure, influenced by the linear increased time needed for fishers to reach fishing grounds on distant reefs. Therefore one must be cautious in concluding that certain found relations between distance and fish biomass variables or environmental variables are due to some type of pollution.

In an Urbanised area there are a combination of many human induced activities. Stressors related to urbanization include land-based pollution such as sedimentation, agricultural runoff, deforestation, coral mining, overfishing, untreated sewage, siltation, eutrophication, persistent organic pollutants, heavy metals, acidification, radioactive substances, marine litter, nutrient overloads, pesticide pollution and resource extraction (Jackson et al., 2001, Green & Bellwood, 2009, Cleary et al 2008).

For the area of Pulau Seribu, the pollution of the water of Jakarta bay is the most important to the reasoning behind the choice of choosing the parameter distance to Jakarta as indicator for a pollution gradient. Several rivers transport sewage and storm water over a 2000 km² catchment area to the central sector of the bay (Rees et al., 1999). Studies in the western part of the bay of Jakarta have revealed that the degradation of water quality was due to household waste, whereas the studies in the eastern part of the bay revealed that water pollution was caused by hydrocarbons and heavy metals (Van der Meij et al., 2010). Also domestic sewage, industrial effluent, and urban runoff from big cities in the north part of Java are transported through runoff waters into the Jakarta Bay, threatening the water quality. Based on data from Regional Environment Agency BPLHD Jakarta, thirteen rivers flowing south-north to Jakarta Bay bring at least 14,000 cubic meters of mostly household garbage each day, or about half of the total of 28,435 cu m of garbage that pollutes the sea. The flow of pollution water into the Java Sea performs a linear decreasing relation with distance from the Bay.

A couple of other urbanisation stressors are weakening the chance of finding possible linear relations between fish biomass composition parameters/ environmental parameters and the pollution gradient over distance to Jakarta.

The Jakarta Bay is defined by two flanking delta systems, both of which rivers have a large sediment input (Rees et al., 1999). Those are located at another place along the Java coast, and therefore distance to Jakarta is not applicable here, although also this source is becoming less pronounced going away from the coast (see figure 35). Also, ocean currents can deviate the hypothesized linear pattern of urbanisation pollution. For example, floating litter can be carried for distances by currents and can pollute areas away from the source (Uneputty & Evans, 1997), and is therefore an unpredictable pollution source with no clear linear effect.

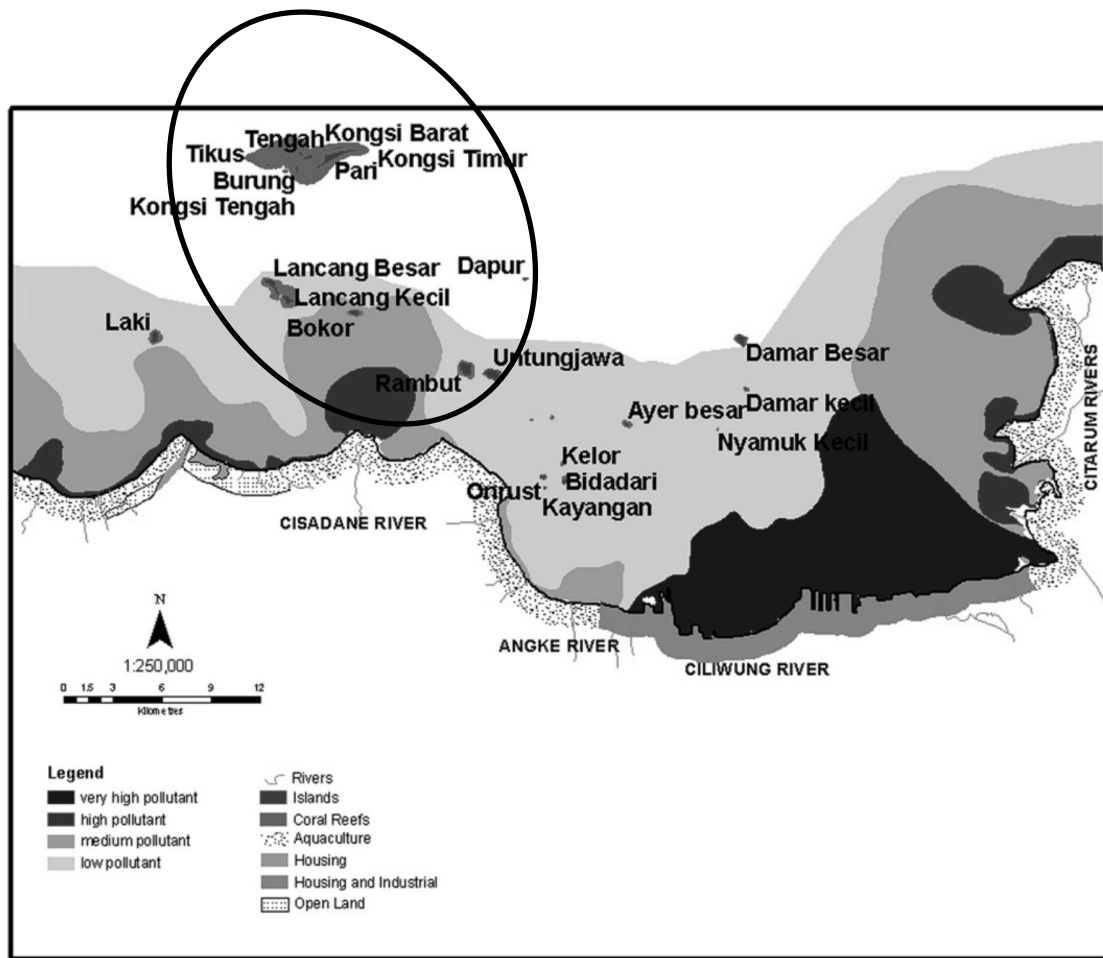


Figure 35: Pollution map. The oval represents the area of the measurement sites. Source: Farhan & Lim, 2012

Furthermore, some human induced pollution are not coming from the coast, they are coming from the ocean. There is oil exploration and extraction to the northwest of the outer end of the Pulau Seribu complex, which will affect the islands at the outer ends more, and the degree of pollution will fade going towards the coast of Jakarta. This urbanisation effect shows the reverse behavior compared to water pollution from Jakarta. Also, tourism and (dynamite) fishing on some islands within the complex can cause huge local deviations in the spreading of pollution through the island complex.

Overall, the most urbanisation induced pollution seems to come from the coast of Java, which performs a linear decreasing relation with distance from the Jakarta Bay. Distance from Jakarta can therefore be used as a proxy for urbanisation pressure, even though maybe distance to the coast would have been a better choice, including the pollution out of the rivers more.

Fish Community

Fish Biomass

Total biomass number

The highest total biomass number is found at location jak 3 with 193 kg per ha, which is an island in the middle of the Pulau Seribu complex. At the outer locations, located 50-70 km away from Jakarta, the biomass numbers are somewhat lower, but not as low as the biomass numbers measured at the locations nearest to Jakarta. The low biomass numbers at the nearest locations to Jakarta are probably caused by high influences of the stressors of an urbanised area mentioned above, of which reduced visibility caused by suspended terrigenous sediments, phytoplankton blooms due to increased nutrient concentrations in the Jakarta Bay and organic contaminants such as oils and hydrocarbons are the key nearshore stress factors which seem to be the most important, even as the destruction of coral reefs for building material (Rees et al., 1999, Farhan & Lim, 2012, De Vantier et al., 1998). The noticed fluctuations of total biomass across the whole island complex are probably caused by local pollution variations, due to deviations of ocean currents, fluctuations in fishery practices (dense populated islands versus inhabited islands within the pulau seribu complex), and local accumulations of plastics (Rees et al. 1999, Jackson et al., 2001, Cleary et al 2008, Green & Bellwood, 2009).

Location Jak 3, the island of Semak Daun, is a smaller island, which is located on its own large reef with an area of 750ha. Semak Daun is an ecosystem protection island. It contains an aquaculture which is part of a fish farming district government program managed by Keb Seribu PKSPL-IPB (pulauseribu-indonesia.com). In the shallow waters of the island complex, sea bass is cultivated, managed by PT Nusa Keramba. The fact that this area is a conservation area can explain the high biomass numbers found. This assumptions is probably the explanation for the highest total biomass numbers of the region.

Overall, the biomass numbers show an increasing trend going further away from Jakarta. Including all biomass data, no significant positive relation between distance and total biomass was found ($p=0,114$), with only 16,9% of the variation of total biomass explained by distance. This is mainly due to surprisingly high biomass numbers at location Jak 15 compared to Jak 8/14, the 3 locations positioned closest to Jakarta. The presence/absence of the family Dasyatidae seems to be part of the cause of the non-significance of this relation. Found from the intertidal zone to a depth of 30 m, this family is common throughout the tropical Indian Oceans in coral reef-associated habitats (Fishbase, Atmosphaera, Encyclopedia of Life, 2014). The species which is counted, *Taeniura lymma*, the bluespotted ribbontail ray, is one of the most abundant stingrays inhabiting Indo-Pacific reefs, generally spends the day hidden alone inside caves or under coral ledges, often with only its tail showing (Fishbase, Atmosphaera, Encyclopedia of Life, 2014). The assumption can therefore be made that this family is listed on other measurement sites, but it is not counted because the rays hide in daytime. It is therefore a coincidence that this family was only counted at location Jak 15, and these biomass numbers can be excluded.

When eliminating the biomass calculations of the family Dasyatidae, the outlier jak 15 merged better with the other data, going from a biomass number of 157 kg/ha to a biomass number of 83,9 kg/ha, and a highly significant positive relation between total biomass and distance to Jakarta is found ($p = 0,01$), with 36,5% of the total biomass variation explained by variation in the distance to Jakarta. Therefore, there is a clear connection between the total biomass of the reef fish population and distance from Jakarta.

Herbivorous biomass

Herbivores biomass numbers show the same fluctuations as the total biomass numbers, described above: lowest biomass numbers at the location nearest to Jakarta, highest biomass number found at location Jak 3, and somewhat lower biomass numbers found at the reefs at the outer end of the Pulau Seribu island complex. Probably the same human induced factors are causing these variations. Also in this case, the protection program of location Jak 3 seems to be the cause of the highest herbivore biomass numbers present.

Overall, a clear increase of herbivores biomass numbers can be noticed related to the distance to Jakarta. The regression line, which follows the increase in biomass with increasing distance to Jakarta, explains 40% of the total variance in this dataset, which is high. The positive relation between distance and total biomass herbivores is highly significant ($p=0,008$).

In the research of Vincent et al., 2011, focusing on fishing effects on herbivore biomass, overall herbivore biomass also increased with distance from shore. He attributed this relation to the increased time needed for fishers to reach fishing grounds on distant reefs, which is the same linear effect as the effect of the stressors of urbanisation.

Therefore, there is a clear connection between the total biomass of the reef fish population and distance from Jakarta.

Herbivorous functional group biomass

Grazers/detritivores

The group grazers/detritivores has biomass values between those of the functional groups scrapers/small excavators and browsers. The functional group grazers/detritivores is not present at 3 locations, but a clear increase of grazer/detritivores biomass values can be noticed related to the distance to Jakarta. This increase is confirmed by the regression line, which explains 23,4% of the total variance in this dataset. A highly significant positive relationship between distance and total biomass grazers/detritivores is found. Therefore, the hypothesized expectation of a clear positive relation between distance and total biomass of grazers/detritivores is confirmed. Consequently, there is a clear connection between the biomass numbers of the grazers/detritivores and distance from Jakarta.

This finding is supported by the research of Vincent et al., 2011, where the biomass of the family Acanthuridae, divided into the functional group of grazers/detritivores, increased significantly with distance from the village, which is attributable to the increased time needed for fishers to reach fishing grounds on distant reefs.

There was also stated that the biomass of Siganids decreased with increased distance from the village, while the family Siganidae is also part of the functional group grazers (Vincent et al., 2011). Surprisingly, also this contradicting finding was done in the Pulau Seribu complex, where the PCA of functional groups with distance showed different variation distributions of Siganidae and Acanthuridae among the island complex, indicating differences in behavior to distance from Jakarta of those two species, while they have the same feeding preferences (figure 16).

Scrapers/small excavators

The group scrapers/small excavators contributes the largest part of the total biomass for herbivorous reef fishes. It is the only herbivorous group present at all measurement locations. Apart from location Jak 3, the other locations seem to have an increasing biomass value of scrapers/small excavators with distance. The increasing overall pattern is confirmed by the direction of the regression line, which explains 16,3% of the total variation between the measurement locations. This interaction is not significant ($P=0,12$). If only Jak 3 would not have been such an outlier, this relationship would have been significant (28,9% explained variation, $P=0,039$).

Because of this last finding, the suspicion arises that the biomass number in Jak 3 is the only number that is high compared to all other locations, because it is a conservation area so possibly fishing pressure is under restriction or not present at all. It is likely that there is a positive relationship between the biomass of scrapers/small excavators and distance from Jakarta, but in the Pulau Seribu complex, this relation is modified by fishing pressure differences. The lack of presence of large fishes forces humans to catch smaller fishes, and because scrapers/small excavators have the largest biomass numbers among the complex, they are more likely to get caught. This assumption is strengthened by research done throughout the Pulau Seribu area in 1998, which already described the absence of large reef fishes (Devantier et al., 1998).

Browsers

The functional group browsers contributes the least to the total biomass of all herbivores, they are only present at 5 locations, and at those locations the biomass has a low contribution to the total herbivore biomass. A similar result was found by Heenan & Williams, 2013. In their research, the biomass of browsers was also notably low relative to other functional groups across all islands. Until 40 km away from Jakarta, no browsers were found. A possible explanation for the low biomass numbers is that only one out of two families which form the functional group browsers is present in the Pulau Seribu Complex. This is Ehippidae, the family of batfishes which are observed to be very vulnerable for diving measurement techniques. A highly fluctuating pattern of biomass values can be observed along the measurement locations positioned further away than 40 km. Proceeding a regression analysis, 18,8% of the variance within the biomass data set can be explained by the distance from Jakarta, indicating a positive relation between biomass of browsers and distance from Jakarta, but this relation is not significant ($p=0,09$). Because the species is only present at locations more than 40 km away from Jakarta, there seems to be a same pattern appearing as with the other two functional groups, but this can not be substantiated because of the lack of measurement points.

Variation of herbivorous group biomass over the whole island complex

In the research of Heenan and Williams, 2013, the dominant herbivore functional group was grazers/detritivores, followed by scrapers/small excavators, which is the reverse outcome compared to this research. But the research of Heenan and Williams, 2013 was performed on a Mesoamerican reef. According to Steneck 1988, the dominant herbivores on many Indo-Pacific reefs are the family Acanthuridae, part of the functional group grazers. This statement is in line with our research results.

Based on the principle component analysis, the total explained variance of the canonical axes is 19,4%. Out of this explainable variance, distance explained 88,6% of the total variance in the first canonical axis, up to 97,2% of the variation of the first two axes taken together. Therefore, distance is a very important factor which explains a sufficient part of the variation among the functional group biomass in the Pulau Seribu complex.

In the ordination plot of the PCA, the bottom half of the diagram is dominated by the presence of the group SS in the biomass composition, while the top half of the diagram is dominated by the presence of the groups GD and B, indicating differences in behavior to distance from Jakarta of those two functional groups.

Fish Diversity

Shannon Wiener

Shannon Wiener is used to determine the species diversity on a measurement location. The fish species diversity of the area is expressed as a number between 0 (only one species) and 5. The loss of important families or functional groups, decreasing fish species diversity, has the potential to severely compromise ecosystem function (Bellwood & Hughes, 2001). Global warming, coral bleaching, and overfishing are all capable of changing reef biodiversity and reducing the quality of reefs over large areas (Bellwood & Hughes, 2001, Hughes 1994). Also Burkepile and Hay (2008) state that herbivore species diversity can be critical for maintaining function of coral reefs. Complementary feeding by herbivorous fishes drove the herbivore richness effects, because macroalgae were unable to effectively deter fishes with different feeding strategies (Burkepile and Hay, 2008). Therefore, if an ecosystem has more species variety, it will be more resistant to external influences. All in all, a high species diversity may indicate a healthy environment.

Shannon Wiener Diversity numbers range from 1,33 at location jak 8, till 2,05 at location jak 5. These diversity numbers are all very low, and consequently give the impression that all coral reefs in the Pulau Seribu island complex are in poor condition. There is an increasing trend noticeable moving from the locations closest to Jakarta to the locations farthest away, which is explained by the regression line, explaining 40,2% of the total variance. A highly statistical significant positive relationship between Shannon Wiener Diversity number and distance from Jakarta is measured ($p=0,008$). Therefore, the already poor conditions within all coral reefs deteriorate even more moving closer to Jakarta. The research of Claery et al. 2005 found a different variation of Shannon Wiener among distance. Shannon's H' varied unimodally with the distance offshore and was highest at intermediate distances. Nevertheless, they also conclude that biodiversity is influenced by urbanisation. Concluding, there is a clear connection between the Shannon Wiener Diversity numbers and distance from Jakarta.

Evenness

Evenness is a measure of the relative abundance of the different species making up the richness of an area. Evenness refers to how the species abundance (in this research total biomass) are distributed among the species (Okpiliya, 2012). All species will have an almost equal abundance when $E=1$, but when $E=0$, species deviate in biomass, giving an uneven distribution with pronounced dominance. If an assemblage in a reef is perturbed by chronic pollution, it can shift from one state in which species abundances are relatively evenly distributed to a second state which has fewer species and exhibits high dominance (low evenness) of certain species (Cleary et al., 2005, Nyström et al., 2000, Magurran and Dawn, 2001). Wilsey and Potvin, 2000 found that biomass increased linearly with increasing levels of evenness, indicating that healthy reefs with high biomass numbers have high evenness numbers.

Evenness index numbers range from 0,311 at jak 6 till 0,88 at jak 14 (table 14). Therefore, the coral reefs in the island group range from having an even distribution till having a very deviating biomass. Strikingly, the regression line, explaining 29,2% of the total variance, shows a decreasing trend. A statistical significant negative relationship between Evenness number and distance from Jakarta is measured ($p=0,031$). This negative relationship is caused by the relative high evenness numbers of jak 8 and 14. This therefore means that at the locations closest to Jakarta, which are more polluted, the biomass is more evenly distributed among the families which are present, while going to the locations further away from Jakarta, which are relatively healthy, the biomass distribution becomes more irregular.

Also the Spermonde shelf did not have the positive relation between evenness and distance from the coast (Cleary et al., 2005). In de Spermonde area, evenness did not vary significantly with the distance offshore, although also in this area the coral reefs at the coast contained degraded assemblages (Cleary et al., 2005).

In this dataset, one explanation of this relation can be that many fish species families have disappeared from the locations closest to Jakarta, increasing the chance that the biomass is evenly distributed among the families still present. Shannon Wiener numbers, which are a combination of species richness number in the form of biomass and evenness of the biomass distribution, exhibits a natural pattern of increasing fish diversity, even though the part of evenness does not. Species richness and evenness can act independently from each other. For example, the fact that diversity is changing due to pollution, can alter the relative abundance of species without changing species richness (Cleary et al., 2005). Therefore, in the measured reefs, the fish richness seems to be extra important, because they counteract the variation in abundance of species in such way that the Shannon Wiener numbers exhibit the opposite relation with distance. Concludingly, for this reef complex, fish species richness in terms of total biomass is more important than the relative contribution of the fish species on total fish biomass.

Reef Community Structures

The dominant cover of all reefs were coral, algae and rubble (table 16). Algae distribution shows no clear association with distance from Jakarta, this is also found by Cleary et al., 2008. Because the coral reef system of the Pulau Seribu complex is highly degraded, all coral reefs are possible at the maximum cover of algae. Coral distribution exhibits a parabolic distribution with distance, therefore highest coverage numbers can be found in the middle of the Pulau Seribu complex, while lowest coverage numbers can be found at the locations with the smallest and . Rubble distributions displays the inverse pattern, indicating opposite reactions to distance from Jakarta compared to coral cover which is logical, because rubble is degraded coral structure.

Despite the fact that the parabolic relation between coral cover and distance from Jakarta is not significant ($p=0,247$), this relation is confirmed by other literature. In the same area in the year 1985, still a linear relation existed between coral cover and distance from Jakarta, with very low cover in the Jakarta Bay and the highest cover was in the outlying reefs of zone 3 (Cleary et al, 2006). In 1995, this relation had changed: then, live coral cover was higher in midshore sites than either in- or offshore sites (Cleary et al. 2008). They think that this major shift in reef structure and composition between 1985 and 1995 is caused by the changes in cover of acroporids, which were largely restricted to midshore and a few offshore sites in 2005 (Cleary et al., 2008). This coral family is less resilient to environmental stress than many other corals, indicating an increase in environmental stress in the period between 1985 and 1995 (Cleary et al., 2008, Bellwood & Hughes, 2001). Also in the Spermonde archipelago, Indonesia, this parabolic relation was found with distance from the city of Makassar (Cleary et al., 2005).

Coral cover seems to be more affected by human induced influences affecting the outer measurement points of the pulau Seribu complex than herbivorous fish population, giving no clear significant linear relation between coral cover and distance from Jakarta. These differences in distribution of herbivorous reef species versus coral cover can be explained by literature. Cleary et al., 2008, states that despite relatively low live coral cover, offshore sites still maintained a complex habitat structure largely composed of dead coral skeleton that provide refuge for fish species, in contrast to the less complex sand dominated environments near the coast of Jakarta. The coral declining can be caused by other human induced phenomena's than the presence of a mayor city near the coral reef complex, like human pressure related contaminations directed from the ocean, including overexploitation of marine resources (oil mining), and destructive fishing practices (blast fishing) (Rees et al. 1999, Jackson et al., 2001, Cleary et al 2008, Green & Bellwood, 2009, Farhan & Lim, 2012, De Vantier et al., 1998). The locations farthest away from Jakarta are also influenced by the outbreak of crown-of-thorns-starfish since 1995, limiting coral growth (Farhan & Lim, 2012).

The reefs the closest to Jakarta have high sand cover numbers, while location Jak 17, located farthest away from Jakarta, has no sand cover. This signifies a linear relation between sand cover and distance from Jakarta, but this relation is not significant ($p=0,10$), due to a highly fluctuating distribution. All in all, this relation is one of the two strongest relation between an environmental variable and distance from Jakarta found in this research. Cleary et al., 2008, found a significant negative relation between sand cover and distance from Jakarta, indicating that sand cover is indeed positively influenced by distance from Jakarta, but probably this linear relation is not significant because of other sources along the coast for sand accumulation, like river sediment discharge.

The other strong relation found between an environmental variable and distance from Jakarta in this research is between cover of sponges and distance to Jakarta. Sponges cover values are lower at the locations closer to Jakarta and higher at locations far away from Jakarta. Therefore, an increasing trend of sponges cover with distance from Jakarta can be noticed. This relation is also not significant ($p=0,095$), but also this relation is found in other literature. Cleary et al., 2008, and De Voogd & Cleary, 2008, found a significant positive relation between sponges cover and distance from Jakarta, caused by the very high turbidity and low live coral cover of the inshore environment, and also Cleary et al., 2005, found a positive relation between sponges cover and distance from the city of Makassar in the Spermonde archipelago. This indicates that sponges cover is indeed negatively influenced by stressors correlated to distance from Jakarta.

Variation of environmental variables over the whole island complex

Based on the principle component analysis, the total explained variance of the canonical axes is only 2,2%. Out of this explainable variance, distance explained 25,1% of the total variance in the first canonical axis, up to 31,4% of the variation of the first two axes taken together. Therefore, distance is not an important factor in the changes of the environmental variables, explaining only a small part of the variation in the Pulau Seribu complex.

In the ordination plot of the PCA, the top half of the diagram is dominated by the presence of the environmental parameters algae and sand. The bottom half of the diagram is dominated by the presence of the variables coral, rock, sponges and rubble. The converse behavior of rubble and coral determine the explained variance of the ordination plot the most, going in opposite directions among the x axis, while sponge and distance are strongly related to the y axis, just as algae and sand, going in the opposite direction.

Coral Reef Resilience

Herbivores fishes play a critical role in coral reef resilience by limiting the establishment and growth of algal communities that impede coral recruitment (Hughes et al. 2007, Green & Bellwood, 2009) and thereby avoiding coral-algae phase shifts. Several key factors are critical for maintaining coral reef resilience, which facilitate coral recruitment and survivorship, and a consolidated substratum (Green & Bellwood, 2009). According to Hughes et al. 2007, Green & Bellwood, 2009, herbivorous fishes play a critical role in coral reef resilience by limiting the establishment and growth of algal communities that impede coral recruitment and thereby avoiding coral-algae phase shifts. The role of herbivorous reef fishes in promoting reef resilience depends upon their feeding preferences, and their numerical abundance and biomass relative to benthic cover (Ledlie et al 2007).

The loss of important families or functional groups, decreasing fish species diversity, has the potential to severely compromise ecosystem function, resilience, and stability (Bellwood & Hughes, 2001). The influence of fish diversity on the overall status of the reef is confirmed by Burkepile and Hay, 2008, who state that herbivore species diversity can be critical for maintaining the structure and function of coral reefs, based on their observation that two complementary herbivore species were more effective at mitigating algal blooms than was a single species. Elevated herbivore diversity can potentially increase reef resilience by fostering greater niche diversification and creating functional redundancy (Roff & Mumby, 2012). For example, complementary feeding by herbivorous fishes drove the herbivore richness effects, because macroalgae were unable to effectively deter fishes with different feeding strategies (Burkepile and Hay, 2008).

Resilience determined by the herbivorous fish biomass

Green & Bellwood, 2009, state that measurement sites can be ranked in terms of their relative resilience to identify sites that are likely to have high, moderate or low resilience in terms of herbivorous reef fishes. Sites that include a high total biomass of herbivorous reef fishes, all functional groups, and a high biomass of large parrotfishes are likely to have high resilience, sites that contain a low total biomass of herbivorous reef fishes, only one or two functional groups of herbivores, and a low biomass of large parrotfishes (Scaridae), are likely to have low resilience; and sites that comprise moderate levels of all three characteristics are likely to have moderate resilience (Green & Bellwood, 2009).

Table 19: schematic overview of relative resilience versus distance from Jakarta

Measurement Locations	Distance from Jakarta	Total biomass herbivores	Number of functional groups	Biomass of large Labridae	Relative Resilience
jak 14	16.79	0,421142	1	0	Very low
jak 15	21.23	21,38298	2	0	Low
jak 8	24.55	3,241768	2	0	Very low
jak 9	29.61	11,61874	1	0	Very low
jak 12	35.67	20,46429	2	0	Low
jak 13	41.23	12,67435	2	0	Low
jak 1	44.29	43,42934	3	0	Medium
jak 6	44.51	62,94559	3	0	Medium
jak 3	48.08	83,71718	2	0	Medium
jak 2	54.03	42,59068	3	0	Medium
jak 10	55.65	35,80491	2	0	Low
jak 16	57.31	21,73353	1	0	Very low
jak 5	59.06	69,17805	3	0	Medium
jak 19	61.86	30,50932	2	0	Low
jak 18	62.88	52,23138	2	0	Medium
jak 17	69.22	53,47681	3	0	Medium

At all measurement locations in the Pulau Seribu complex, no large parrotfishes (Scaridae) are present. Research of 1998 already described the absence of large reef fishes throughout the Pulau Seribu Complex (De-Vantier et al., 1998). Even Harger, 1988 already described the transition which was going on in the Pulau seribu complex, in which a macrobenthic coral reef community was changed into a micropelagic community based principally on plankton and small fish. Because of this transition, also one functional group (large excavators/bioeroders) is absent in the whole island complex, which contains normally all large sized fishes. Therefore, looking at the criteria of Green & Bellwood 2009, not one location can be described as resilient in terms of herbivorous reef fish assemblages. Looking at table sites are ranked relative of each other, relative resilience ranging from medium to very low. Medium resilient sites have 2 or 3 functional groups present, combined with high total herbivorous biomass numbers ranging from 40 kg/ha till 83 kg/ha. Those sites are found in the middle of the Pulau Seribu complex and at the outer end. Low resilient sites have 2 functional groups, combined with herbivorous biomass numbers ranging from 12 kg/ha till 35 kg/ha. Very low resilient sites only have one functional group, combined with a herbivorous biomass number from 0,42 kg/ha till 11 kg/ha. Those sites can be found close to Jakarta.

When there is only one herbivorous group present on a reef which consumes algae, this group is less likely to control and limit the establishment and growth of algal communities, space occupied by algae overwhelms the ability of grazing fishes to crop it down, and those algae communities are going to impede coral recruitment. When this coral reef becomes pressurized by influences from the outside, like hurricanes or human induced impacts like urbanisation, coral-algae phase shifts are less expected to be avoided. This effect is supported by the research of Burkepile and Hay, 2008, who demonstrated that two complementary herbivore species were more effective at mitigating algal blooms than one single species.

A process which can also influence the resilience in terms of herbivorous reef fishes, is niche occupation. Within a coral reef, every fish species is occupying this own niche, with its correspondent feeding behaviors, environmental limitations and habitat preferences. Each herbivorous fish family occupies its own niche. When a reef is under pressure, one of the herbivorous reef families can possibly become extinct. Relevant for the resilience of a coral reef is whether this herbivorous fish family can be replaced with the population growth of another herbivorous fish family, which will occupy the vacant niche, and remain the same grazing pressure on algae, reducing the chance the coral reef will shift from a coral dominated system to an algae dominated system.

In the area of the Pulau Seribu complex, 3 functional groups exist, which consist of a total of 6 herbivorous fish families. According to Green & Bellwood, 2009, it is possible that a coral reef system of the Indo-Pacific can house a total of 9 herbivorous fish families (Choat 1991). The total amount of herbivorous fish families present in the Pulau Seribu complex is average. Therefore, the chance of possible replacement of one family by the growth of another family becomes smaller.

Focusing on the PCA which displays the direction of the herbivorous fish families through the total variance present in the measured coral reefs (figure 16), it becomes clear that the family Siganidae cannot be replaced by another family if it becomes extinct, because this family has a very different variation distribution among the Pulau Seribu complex. Luckily, the family Siganidae has the same feeding influences on a coral reef as the families Acanthuridae and Pomacanthidae, all part of the grazer/detritivores functional group. The arrows of those two families are pointing in the same direction in the PC ordination plot, which indicates that those two families can probably replace each other if one vanishes. This will limit the chance that the whole functional group will disappear if the measured coral reefs have to deal with increased pressure. The families within the functional group scrapers/small excavators, Labridae and Scaridae, have a very similar variation direction, which increases the chance one can occupy the niche of the other if stress at the coral reef causes one to disappear. A high risk functional group are the browsers, only consisting of one family inside the measured reefs. If this group becomes extinct, all reefs will have one functional group less, increasing the chances of algae overgrowth.

All in all, there are very limited amount of herbivores families present, decreasing the possible resilience of the measured coral reefs. On the other hand, the families in 2 out of 3 functional groups can easily replace one another, increasing the possible resilience when a reef is facing pressure.

Resilience determined by the interactions of herbivorous biomass on the reef community structures

The reef health indicators were correlated to the different functional group biomass parameters, to see if the biomass variations have an impact on the cover of the indicators for coral reef health. The importance of the herbivorous fish population structure for coral reef resilience will be highlighted.

Many linear relationships between the biomass parameters and environmental parameters are not significant, indicating the lack of influence of herbivores biomass on the reef substratum. Herbivory is possibly only one of several factors that influence coral-algal dynamics (Heenan and Williams, 2013).

Also, all mentioned stressors of a large urbanised area could have caused such stress on the coral reefs, that normal predator-prey (in this case herbivorous fishes-algae) fluctuations are deviated. Even under normal conditions, predator-prey cycles can take a couple of years. For example, the cycle between snowshoe hares and the lynx are observed at roughly 8-10 year intervals, and the lynx population decline follows the snowshoe hare population crash after a lag of one to two years (Hewitt, 1921). Therefore, at the period of measuring, the prey-predator cycle of algae and herbivorous fishes could not have been in an equilibrium state. Also, many disturbances of coral reefs do not result in immediate loss of habitat structure; they kill corals but their skeletons may remain intact for years, maintaining abundant and diverse fish assemblages while other conditions are deteriorating (Lindahl et al. 2001).

One other cause of the lack of relations can be caused because the researched Pulau Seribu island complex is not a closed system. The coral Triangle between Indonesia, Malaysia and the Philippines, which our researched area is part of, depends for its diversity and resilience on coral and fish larvae swept in from the South China Sea and Solomon Islands (Kool et al., 2011). Therefore, the hypothesized relations between fish biomass and coral cover are influenced by the replenishment of both variables from other locations.

Out of all relations, only two relations were significant. Three other relations are worth discussing, because their P value was around 0,15.

Sponges

The role of sponges is not mentioned in the mechanism of coral reef resilience, but they seem to promote the general health of a coral reef ecosystem (De Goeij et al., 2013). Sponges make food sources out of the waste products of coral and algae, which can be used by other reef inhabitants (De Goeij et al, 2013). Therefore, sponges ensure that energy and nutrients remain retained within a coral reef (De Goeij et al, 2013). Consequently, the found positive relation between **biomass of all herbivores and sponges** seems probable but not significant ($p=0,138$). On the other hand, the positive relation between **biomass browsers and sponges** cover is highly significant ($p=0,001$). The found positive relation of biomass of browsers and sponges cover fits into the picture of coral reef resilience, both being positive factors for coral reef health.

Rock

No significant relations are found between herbivorous biomass variables and rock cover. The found positive relation between **biomass of browsers and rock cover** is worth mentioning because it has a relative low p value ($p=0,164$) but it is not significant. In terms of coral reef system resilience, the found relation was not expected and is not probable, because rock is an indicator of failure of coral recruitment and survivorship, while the presence of browsers seems to be a positive influence on coral reef resilience. There are only a few browser biomass measurements, and also few rock cover measurements, which gives even more doubt on the relationship found, and no literature can support this found relation.

Sand

Although Cleary et al. (2008) found that decreasing fish species number was significantly explained by an increase in sand cover, no significant relations between herbivorous biomass variables and reef health indicators are found. Worth mentioning is the found relation of biomass of **scrapers/small excavators and sand** because it has a relative low p value ($p=0,152$) but it is not significant. In terms of coral reef system resilience, the found positive relation was not expected and is not probable, because sand is an indicator of failure of coral recruitment and survivorship, while the presence of scrapers/small excavators seems to be a positive influence on coral reef resilience.

Coral

No significant relations are found with coral cover and the herbivorous variables. This is in contrast to Cleary et al., 2008, who found that the fish species variation was significantly explained by coral cover. Also Jones et al. 2004 found a decline in fish biodiversity with a decline in coral cover. Furthermore, variation in cover was best explained by the biomass of specific herbivorous functional groups rather than by all herbivores combined (Heenan and Williams, 2013). Also an increase in grazers/detritivores biomass with increased hard coral cover was found.

On the contrary, herbivory is stated to be only one of several factors that influence coral-algal dynamics. For example, coral community composition is influenced by sedimentation load and the density of coral juveniles is higher in sheltered compared to exposed reefs (Heenan and Williams, 2013). The research of Carassou et al., 2013, found no evidence of herbivorous fish species enhancing coral reef resilience through the influence on coral covers. Furthermore, Wilson et al. 2006 found only an effect of coral loss on the coral feeding fishes and not the herbivorous fishes.

Research is divided whether fish biomass increase is related to coral cover decrease. This research

Algae

It is a commonly-held belief that grazing fish maintain algal turfs (Nystrom and Folke 2001; Bellwood et al. 2004) and, in a natural system, a greater cover of algal turf should support a greater biomass of grazers (Graham et al. 2008).

The relation between biomass of **scrapers/small excavators and algae** cover is significant ($P=0,032$). In terms of coral reef system resilience, the found positive relation between biomass of scrapers/small excavators and algae cover was not hypothesized, because algae cover is an indicator of failure of coral recruitment and survivorship, while the presence of scrapers/small excavators seems to be a positive influence on coral reef resilience. Maybe the biomass of scrapers/small excavators is still large enough in this polluted system to control algae growth, and is a greater cover of algae supporting a greater biomass of scrapers/small excavators (Graham et al. 2008). Scrapers/small excavators are the most mobil herbivorous reef group, which can enhance the control on algae cover (Cheal et al., 2012). It is also a positive sign that herbivorous biomass indeed influences the coral reef resilience in the Pulau Seribu island complex by limiting the algal growth on a reef.

No other significant relations between algae cover and the herbivorous variables are found. Worth mentioning is the found negative relation between **biomass of browsers and algae** because it has a relative low p value ($p=0,189$) but it is not significant. In terms of coral reef system resilience, the relation between biomass of browsers and algae is reversed from the found relation between biomass of **scrapers/small excavators and algae** cover and seems more likely because in a polluted system, a high algae cover is weakening the coral reefs, which can therefore harbor less reef fishes. Therefore, in this reef complex, the biomass of browsers is not sufficient to control the algal cover, which is confirmed by the patchy distribution of browsers and the low biomasses. Also Heenan & Williams found that the herbivorous functional group of browsers was not the strongest predictor for macroalgal cover.

The research of Vincent et al. 2011 supports herbivorous functional groups having different relations with algae cover within a reef complex, by finding increased turf algae on sites displayed lower scrapers/small excavators biomass, while Grazers/Detritivores biomass increased as turf algae increased.

Types of algae cover seem to play a role, supported by Heenan & Williams, 2013, who found that macroalgal and turf algal cover decreased with increasing biomass of grazers/detritivores and cover of encrusting algae increased with increasing biomass of grazers/detritivores.

Other studies have also failed to find evidence of an increase in herbivorous fish biomass or abundance with increasing algae cover. Cleary et al found no relationships between fish species variation and turf algae cover, macroalgal cover and dead coral cover. Also the researches of Carassou et al. (2013) and Mumby et al. (2006) found no evidence of herbivorous fish species enhancing coral reef resilience through the influence on alga covers. Furthermore, the research of Vincent et al., 2011, detected no increase in the herbivorous fish biomass with increased algal turf cover.

All in all, herbivory is only one of several factors that influence coral-algal dynamics. For example, macroalgal cover increases with decreasing water quality, and macroalgal cover is increased in areas exposed to wave impacts (Heenan and Williams, 2013).

Resilience determined by the interactions of fish biodiversity on the reef community structures

In order to distinguish some kind of relationship between reef fish composition and the indicators for coral reef health, there is looked in a broader perspective to a coral reef system.

In the researched reefs, 2 highly significant relations were found, and 2 relations which were not significant but had low P values. The first highly positive significant relation found is between Shannon Wiener number and coral ($p=0,009$). Also Burkepile and Hay, 2008 found that mixed-herbivore treatments compared with single-herbivore treatments increased coral cover by 22%. This relation is also confirmed the other way around: coral loss typically resulted in a decline in species richness of fish communities (Wilson et al., 2006, Jones et al., 2004, Graham et al., 2007). Overall, the fish species which depend the most on living coral as juvenile recruitment sites, declined the most in abundance (Jones et al, 2004).

The second significant relation found is between Shannon Wiener number and sponges ($p=0,017$). The relations with a low p value are those between Shannon Wiener and rubble ($p=0,083$) and sand (0,134). Therefore, some kind of relationship between reef fish composition and the indicators for coral reef health seems to exist. Total reef fish diversity has a negative influence on the cover of rubble and sand, and a positive influence on the cover of coral and sponges.

Those four found relations fit into the picture of coral reef resilience, in which ecological system, fish biodiversity has a positive influence on the promoters of coral recruitment and survivorship, which are coral and sponges cover.

Coral Reef Health Indicators

Reef health indicators are found for coral reef management in the Mesoamerican region (MAR), and are compared with the results out of this research to distinguish the present overall status of the reefs in the Pulau Seribu complex. Those health indicators can be found at <http://www.healthyreefs.org/>. A target value, a benchmark value and a red flag value are given for certain reef health indicators. The critical boundary of a reef health indicator is indicated by the benchmark value. In order to call a coral reef healthy, the target values must be reached. The red flag value represents a reef in poor health conditions.

Compared to Mesoamerican Reefs, the reefs of the Indo-Pacific have many more species and higher mean biomass numbers (Roff & Mumby, 2012). Indo-Pacific coral reefs are home to 4000-5000 species of reef fishes (Roff & Mumby 2012, Veron 2000, Lieske and Myers 2001). It is therefore plausible that the red flag criteria, which are the values of the reef health indicators which represent a reef in very poor health, have lower values than the boundary values the Indo-Pacific reefs would have, because the mean species and biomass values are higher.

The same applies to the red flag values of the biomass of herbivores. The abundance and biomass of herbivorous fish is much higher in the Indo-Pacific region than in the Mesoamerican region. The Indo-Pacific region has 70 species and six genera of parrotfish, while the Caribbean only has 13 species and two genera of the fish (Roff & Mumby, 2012).

Total fish biomass number

Healthy reefs can produce up to 35 tons of fish per square kilometer each year, but damaged reefs produce much less (McClellan & Bruno, 2008). For total fish biomass, a promising sign of Benchmark reef recovery would be a MAR-wide average biomass of 5000 g/100m² (figure 36).

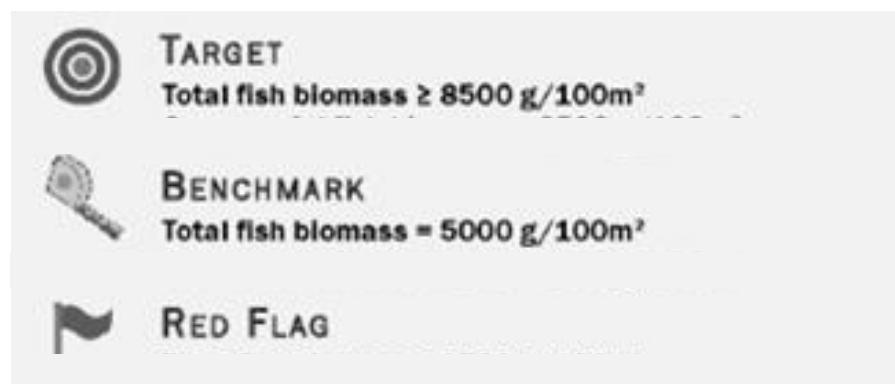


Figure 36: MAR wide averages for red flag, benchmark and target values of total fish biomass.

In the area of the Pulau Seribu complex, an average coral reef would have a total fish biomass number of 90,55 kg/ha (see table 15). This is converted to gr/100m², which leads to a number of 905,5 gr/100m². This number is very concerning, because it reaches far beneath the red flag number set for the Mesoamerican reefs, which already have a lower mean biomass number compared to the Indo-Pacific reefs. Therefore, urgent action is needed to protect the fish stock still left in the Pulau Seribu complex.

Total herbivorous biomass number

A promising sign of Benchmark reef recovery would be a regional biomass of 2500 g/m² for parrotfish and surgeonfish combined.



Figure 37: MAR wide averages for red flag, benchmark and target values of parrotfish (scaridae) and surgeonfish (acanthuridae) biomass.

In the area of the Pulau Seribu complex, an average coral reef would have a total fish biomass number of 35,34 kg/ha (see table 15). This is converted to gr/100m², which leads to a number of 353,4 gr/100m². This number is very concerning, because it reaches far beneath the red flag number set for the Mesoamerican reefs, which already have a lower mean biomass number compared to the Indo-Pacific reefs. Also, the biomass number of 353,4 gr/100m² represents the biomass of all herbivorous fish species in the Pulau Seribu island complex, and thus not only the biomass numbers of parrotfishes (scaridae) and surgeon fishes (acanthuridae). Altogether, the biomass number would even be lower. Therefore, urgent action is needed to protect the herbivorous fish stocks still left in the Pulau Seribu complex.

Coral Cover

Indo-Pacific reefs are typically characterized by high coral cover and low macroalgal cover, whereas Caribbean reefs have typically lower coral cover and higher macroalgal cover (Roff & Mumby, 2012). Indo-Pacific coral reefs are home to over 600 species of hard corals (Figure 38 Veron 2000, Lieske and Myers 2001).

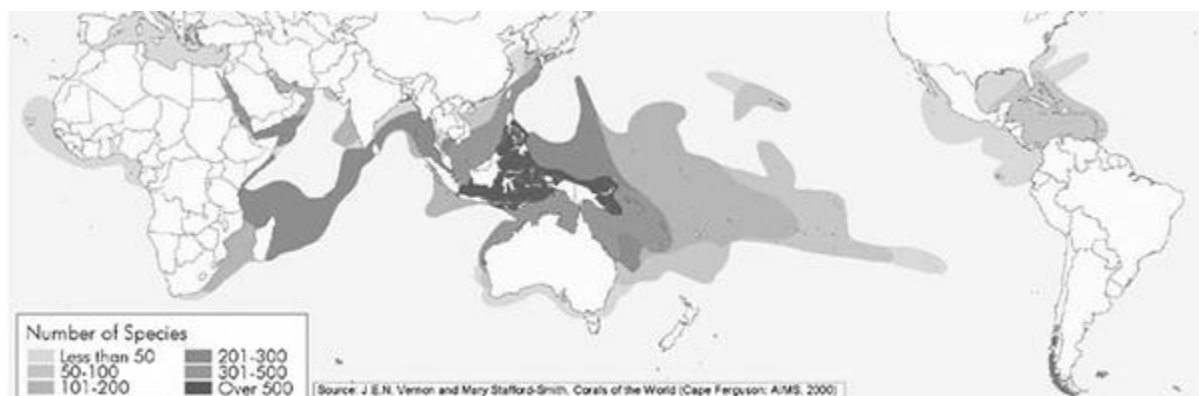


Figure 38: Number of coral species within a coral reef over the world.

source: Vernon, J.E.N., Stafford-Smith, M., 2000, Corals of the world, Cape Ferguson, AIMS.

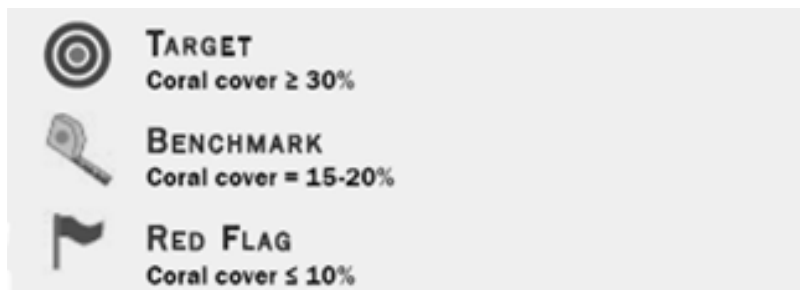


Figure 39: MAR wide averages for red flag, benchmark and target values of coral cover.

A good sign of Benchmark reef recovery would be a Mesoamerican reef-wide average of 15-20% live coral cover.

Mean coral cover for the Pulau Seribu area was calculated from the coral cover values of table 16. Out of 60 meters of measured cover, an average of 24,75 meter was coral cover. Therefore, at an average location in the Pulau Seribu complex, 41,24% of the reef composition consisted of live coral cover. Looking at figure 39 this percentage is higher than the target number set for the Mesoamerican reefs. However, the coral cover is naturally higher in a Indo-pacific reef, causing the numbers of figure 39 to be higher looking at an Indo-pacific reef. According to Cleary et al., 2008, a poor condition within a measurement site is characterized by coral cover numbers ranging between 10.0 and 39.3%. A location with a coral cover between 29.6 and 53.2% is classified as fair to good (Cleary et al., 2008). Summarized, the overall coral cover number lays around the benchmark number for Indo Pacific reefs.

Method implications/limitations and resulting avenues for further research

Diving

Diver-based Underwater Visual Censuses (UVCs), particularly transect-based surveys, are key tools in the study of coral reef fish ecology (Dickens et al., 2011). Those techniques are also used in this research, but there are some problems that make it difficult to collect accurate numerical data. One of these problems is the diver effect, which is the reaction of a fish species on the diver who is measuring them. Dickens et al., 2011 tried to quantify how much fish individuals were not counted with divers present in the water. Overall, the diver effect resulted in a 52% decrease in the mean number of individuals recorded, with declines of up to 70% in individual families (Dickens et al., 2011). This number is very high, but certain adaptations to the research methods can be done which will influence the level of the error significantly.

In the research of the Pulau Seribu complex, the diver effect was taken into account, and therefore the diver waited for 5 minutes after laying down the transect line in order to give the fish species the chance to get back to their original position before diver disturbance. The results of this research method are displayed in figure 40. There can be seen that this method had less error, resulting in only a 27% decrease in the mean number of individuals recorded, with declines only going up to 46% in individual families. Consequently, fish species numbers did recover to some extent after a 5 minute waiting period. Still, this error is of that big of a size that it can cause the missing out on possible relations within a highly environmentally disturbed environment.

Therefore, for next research, there is proposed to refine the research method in such way that the exposure of fishes to divers will be minimized even further. Suggested is to use tapes or lines deployed by a second diver, which appears to maximise fish counts and minimise diver effects (Dickens et al., 2011).

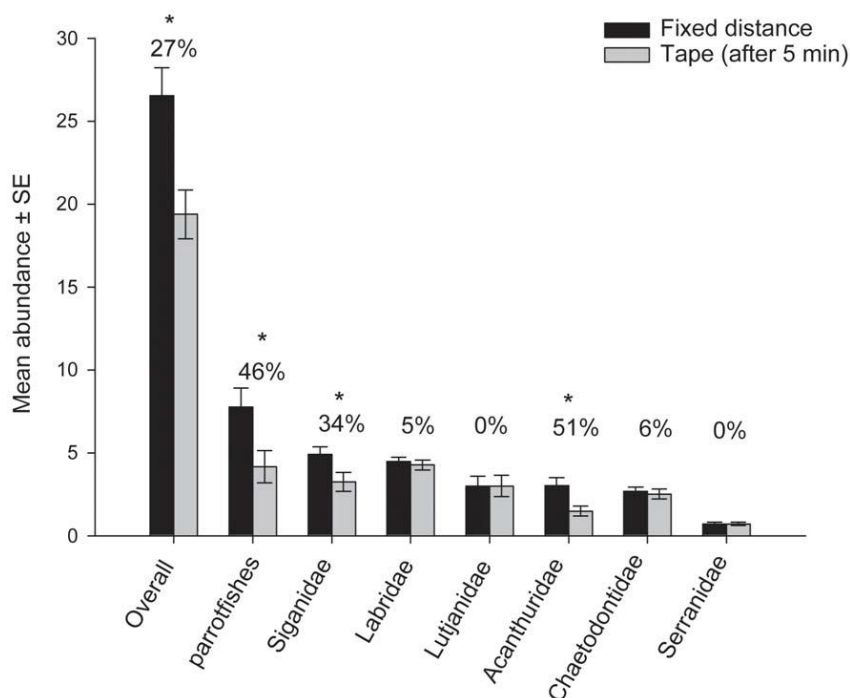


Figure 40: Relative diver effects – fixed distance and 5 minute waiting period. Relative diver effects on estimated reef fish densities comparing counts over a fixed distance 50 m transect and counts after a 5 minute waiting period.

Also, to effectively monitor all of the species listed in table 1, it will be necessary to combine the transects with a long swim method that will provide more precise estimates of the abundance, biomass and size structure of large (>35cm TL), highly mobile species, that tend to be rare, patchy or clumped in distribution (Green & Bellwood, 2009). In this research, long swims were not conducted, and consequently, the biomass of large individuals were probably underestimated. Proposed is to perform these long swims next time to measure fish biomass more accurately, by consecutive swims along the same transect or by one observer counting larger fish and another counting the smaller fish.

Role Pomacentridae

Pomacanthidae, or damselfishes were excluded from this research, based on the advice of Green and Belwood (2008). They argue that damselfishes are small, and hard to identify. They also comprise a wide variety of diets (herbivores, detritivores, algae grazers and planktivores), and it is a complex and difficult task to assign them to functional groups (Green & Bellwood 2009). Furthermore they argue that the herbivorous damselfish species also tend to be small and contribute less in terms of ecosystem resilience, because they are territorial and farm algae for their own consumption.

Other researchers argue that pomacentrids have a limited ability to reduce algal biomass and fall under the “Non-denuding” herbivore functional group (Steneck 1988, Hixon 1997). Most pomacentrids within the non-denuding herbivore group are territorial grazers that maintain and defend their territories; algae gardens or lawns, against other herbivores thereby reducing the grazing impact of scrapers (excavators) and grazers inside and in close proximity to their territories, and therefore they are only able to significantly impact algal assemblages at high population densities (Steneck 1988, Hixon 1997).

Pomacentridae is one of the most representative families of herbivorous fishes inhabiting both tropical and temperate reefs, with 29 genera and more than 350 species. Despite the high abundances of the pomacentrids in temperate waters of Western Australia, and their likely importance in removing algae from reefs in the region, there is a lack of information on their diet and their impact on the reef algal community (Vitelli, 2013). His research showed that total algal biomass was significantly lower while species richness was higher inside compared to outside territories, and therefore provides the evidence to refute the theory that temperate Pomacentridae have a low impact on the temperate reefs.

Also, the abundance of pomacentridae can indicate the presence of human induced pressure on coral reefs. Edwards CB et al. 2014 shows that in reefs which are exposed to fishing, the structure of the herbivore community is altered by disproportionately reducing biomass of large-bodied functional groups (scraper/excavators, browsers, grazer/detritivores), while increasing biomass and abundance of territorial algal-farming damselfishes (Pomacentridae). Also the role of the smaller species within the family of the pomacentridae was investigated. Although the larger, previously well-studied species had the most visible effect on the benthic community in their territories, all the smaller species also significantly affected the algal composition, normally with an increase of palatable algae (Ceccarelli, 2007).

All in all, for the Pulau Seribu area, recommended is next time to incorporate damselfishes to the herbivorous fish population analysis as an additional functional group ‘Non Denuding’, because they are fish family with the largest total fish number on these reefs and can therefore probably contribute significantly in the herbivorous fish biomass variations (table 10). Also, in the research of Vincent et al., 2011, focusing on fishing effects on herbivore biomass, total biomass of pomacentridae increased with distance from shore, indicating that this species is sensitive to human disturbances.

Reef geomorphology

Reef geomorphology was not measured at this research in de Pulau Seribu complex, while according to some researches, the position on the continental shelf, the reef type, and the structural complexity of coral reefs are important for the reef fish biomass distribution among reefs (Cheal et al., 2012, Lindahl et al., 2001, Wilson et al., 2006, Nadon et al., 2007).

Research of Cheal et al., 2012 found that diversity and abundance of the herbivorous families Acanthuridae, Labridae and Siganidae were strongly associated with position on the continental shelf. The inshore environments had a reduced herbivore assemblage compared to the offshore environments, both dominated with different families and functional groups (Cheal et al., 2012). Furthermore, Hoey and Bellwood, 2012, found different feeding habit variation of Labridae across the continental shelf. While Labridae is responsible for erosion and predation of corals on the outer shelves of the reef, in contrast on inner shelves, they were responsible for grazing and reworking of sediment. Consequently, the biomass numbers were different: low biomass numbers of Labridae were present at the inner shelf, outer-shelf reefs were characterized by high biomass of Labridae (Hoey and Bellwood, 2012). They concluded that each part of the shelf system has its own processes influencing the reef fishes biomass distribution.

Having an inshore-offshore system at the Pulau Seribu complex, advised is that next time the coral reefs located at different positions on the continental shelf have to be investigated separately to look for possible differences in herbivores fish feeding habits and biomass distributions.

Nadon et al., 2007, differentiated 3 reef types: patch reefs, fringing reefs and barrier reefs. Fish abundance and diversity, just as coral cover, were higher on patch reefs than the other two reef types. On the other hand, Vincent et al., 2011, did not found any relations between reef type and biomass numbers. Still, it would be interesting to incorporate the different types of reefs into a research at the Pulau Seribu Complex, to investigate if this variable is causing variation among biomass and reef health covers.

Studies have suggested that the three-dimensional complexity of reefs with high hard coral cover favours large and diverse populations of herbivorous fish (Graham et al. 2008, Graham et al. 2007). If reef structure is maintained after a disturbance, abundant and diverse fish populations can house those reefs (Lindahl et al., 2001). However, when those skeletons are reduced to rubble, fish abundance and diversity decrease markedly (Graham et al. 2007, Sano et al. 1987). Graham et al. (2007) found that a loss of structural complexity due to skeletons erosion posed one of the biggest threats to fish communities in the Seychelles. All in all, it seems that disturbances that result in an immediate loss of habitat complexity, have a greater impact on fishes, compared with disturbances that kill corals, but leave the reef framework intact. (Wilson et al., 2006)

It would be interesting to measure 3d complexity of the coral reefs too in the next research at the Pulau Seribu area, because of the pollution gradient present. In this way, there can be focussed at the influence of pollution in 3d structure of the coral reef, related with fish biomass distribution. A research like Rachello-Dolmen and Cleary, 2007, can be performed, who had the goal to relate species traits (colony shape, colony form, corallite size) to environmental variables.

Algae

In this research, algae were indicated as one environmental variable, ignoring the different algae types present within a reef. There is advised to remain all algae types in the follow up studies, because algae type seems to be important for the distribution of herbivorous reef fishes. Looking at the different functional groups, immediately there can be made a differentiation between functional groups only eating turf algae and micro algae (the groups of the grazers and scrapers/small excavators) and eating macro algae only (browsers). These two algae types have to be incorporated. Also, one variable in this research was described as 'dead coral with algae', see appendix 6. In the follow up research, differentiations have to be made which algae type is on dead coral. The importance of distinguishing the different algae types is confirmed by the research of Heenan and Williams, 2013, who found strong relations between biomass of grazers/detritivores and macroalgae and turf algae, and between encrusting algae and biomass of grazers/ detritivores and browsers.

Oceanographical and Chemical variables

In this research, no chemical and oceanic variables were available. This was difficult, because pollution from the urbanization area becomes visible with turbidity, pH, temperature and chemical data of the water column. Distance to Jakarta is an indirect and global measure of urbanisation pressure, while chemical data can indicate local environmental differences between measurement sites, increasing the chances of finding possible explanations for certain found relations. Because of large river water input in the Jakarta bay, (Rees et al., 1999), which is nutrient rich and contains a large sediment load, it is important to investigate to which extent this water influences the Pulau Seribu Complex, and this can be accomplished by measuring chemical content.

The research done in 1995 in the Pulau Seribu complex found that the fish species variation was significantly explained by heavy metal concentrations in seawater, physical variables Ph, turbidity, Ca, M, Sn, Mo and Th in sediment, and Zn, Cd en Cr in seawater (Cleary et al., 2008), indicating the need for chemical data to relate with biomass variation.

To construct the oceanographic condition in the region, tidal, bathymetry, and wind data is needed (Farhan, Lim, 2012). In a nearby area, the Spermonde Archipelago, sponge and coral diversity variation were related to distance offshore, depth and exposure to oceanic currents, indicating a strong influence of oceanographic condition on species assemblages (Cleary et al., 2005).

Heenan and Williams, 2013, also found strong relations between reef community structure and chemical and oceanographical variables. For example, macroalgal cover increases with decreasing water quality, coral community composition is influenced by sedimentation load and macroalgal cover is increased in areas exposed to wave impacts (Heenan and Williams, 2013).

All in all, it is advised that in a follow up research, chemical data and oceanographical data have to be collected, because species assemblages within a reef, including fish biomass variables, can possibly be explained by those.

Theoretical implications

Theoretical implications were derived from the methodological limitations and the knowledge gaps still left after the result analysis of the discussion.

Urbanisation

Never before, total fish biomass numbers were attempted to link to urbanisation pressure. Looking at the few studies done on the influence of urbanisation related to fish population structure, most of the researches (for example Cleary et al, 2008, Carassou et al., 2013) focuss on the total fish species number/fish species richness rather than on the biomass numbers. Studies focused on the influence of urbanisation on coral reefs, focuss on coral reef assemblages as coral cover variations rather than fish species variations (Hughes et al 2003, Cleary et al., 2006, 2008, Rachello-Dolmen and Cleary, 2007, Green et al., 1999, Van der Meij et al., 2010) Only at one research, herbivorous biomass numbers were linked to a human induced perturbation, namely fishery (Vincent et all, 2011,)

Coral Reef resilience

Most researches focus on the herbivorous fish species numbers relative to changing coral reef assemblages, mostly the change in hard coral cover, some in order to address coral reef resilience through algal eating fishes (Bellwood et all, 2004, 2006, Hughes et al 2003, 2005, 2007, 2010, Green & Bellwood, 2009, Ledlie et al., 2007, Cheal et al., 2013, Folke et all., 2004, Carassou et al., 2013) A couple of studies focus on the herbivorous fish biomass numbers relative to changing coral reef assemblages, mostly the change in hard coral cover (Heenan & Williams, 2013, Green & Muljadi, 2009)

All in all, this is the first research which combines the effect of urbanisation on coral reef fish biomass structure with the effects these biomass changes have on coral reef assemblages, focused on the resilience of coral reefs.

Managerial or policy implications

In order to try to reduce the degradation of herbivore fish biomass and the coral reef structure in the Pulau Seribu island complex, some recommendations can be done.

Protection of herbivorous reef fishes by creating Marine Reserve no take areas.

Already, a Marine National Park was created in the Pulau Seribu area, but for almost three decades, the implementation and regulation has been lagging, as well as the boundary of Marine National Park has not been reformed (Farhan & Lim, 2012). The Indonesia government's focus is rather on the land-based development, despite the consequence of the negligence in the coastal management in which Indonesia already lost four islands associated with Seribu Islands by 1999 (Farhan & Lim, 2012).

This is a missed opportunity, because for example Mumby et al. 2006 and Hughes et al., 2007 found a greater biomass of parrotfishes and less macroalgae inside a no-take reserve when testing the potential importance of marine no-take areas for safeguarding herbivorous reef fishes and their ability to control blooms of algae. Therefore, a no-take reserve is enhancing coral reef resilience on local level. Also Jones et al., 2004 indicates that marine reserves can be an effective management strategy for protecting marine biodiversity.

However, marine reserves can protect fish from exploitation, and coral reefs from being destroyed for building material, but they cannot protect fish biodiversity in degrading environments (Jones et al., 2004). Therefore, marine reserve areas cannot protect reefs from large-scale pollution or global warming (Graham et al., 2013). As a result, although marine reserves are necessary to control the local impact of human predation, they must be combined with management strategies that fundamentally address large scale processes which will cause more coral reef and reef fish extinction. (Jones et al. 2004).

Cleaning of sewage and river water coming into the Jakarta Bay- Pulau Seribu complex

Therefore, the marine Park no-take areas have to be combined with plans to decrease pollution flowing from the Jakarta Bay into the Pulau Seribu island complex. Also Farhan & Lim, 2012 state that management plans have to focus on decreasing the pollution flowing into Seribu Islands, in which the two central governments of Jakarta and Banten Province must collaborate with the local government of the Pulau Seribu area. Until now, no appropriate actions were taken from the governments to prevent or process the pollutant flowing from the rivers the Ciliwung and the Angke, which contribute to the high pollution of the Jakarta Bay area (Cheal et al. 2013). They therefore state that river pollution will be worsening if no urgent cleaning strategies are implemented.

In terms of the overall health of the Pulau Seribu Complex, the percent cover of live coral at Central part of Indonesia are : 7.09 % excellent, 22.70 % good, 33.33 % fair, and 36.88 % poor (De Vantier et al., 1998). De Vantier et al., 1998 estimates that coral covers will be reduced by approximately 70% within 40 years if management strategies are not implemented soon.

Conclusions

The total fish biomass and environmental parameters within reefs of the Pulau Seribu island complex, located near the coast of Jakarta, were measured in order to address the question 'How does the pollution gradient from a large urbanised area affect coral reef fish populations as an indicator for coral reef resilience against regime shifts from a coral dominated reef structure towards macroalgal communities in the Indonesia's Jakarta Bay – Pulau Seribu reef complex?'

Distance from the city Jakarta was used as a proxy for the pollution gradient, in order to distinguish the effect of the urbanised area on fish population variance among the Pulau Seribu Island complex. Total biomass of all fish species, total biomass of herbivores and total biomass of the functional herbivorous group Grazers/Detrivores were all negatively influenced by urbanisation. Also, fish diversity was negatively affected by urbanisation. Similarly, there seem to be relations between the distance from Jakarta and sponges and sand cover, although these relations are not significant. These relations were also found during the 1995 survey in the same area. Worth mentioning is also the found parabolic relation between distance from Jakarta and coral cover. Even though this relation is not significant, this relation was also found during the 1995 survey in the same area.

Looking at the influence of herbivorous biomass variation on coral reef structure, only two significant relations were found between biomass browsers and sponges cover ($p=0,001$) and between biomass of scrapers/small excavators and algae cover ($P=0,032$). This indicates a small influence of herbivorous biomass variation on the coral reef structure. The relations between sponge cover and herbivorous biomass parameters seem to be the strongest, while the relations between the two determining reef health indicators for the function of herbivores reef fishes into coral reef resilience, coral cover and algae cover, are weak.

In terms of coral reef resilience, our results suggest that the locations near the urbanised area of Jakarta experience low resilience, indicated by the low amount of herbivorous biomass, therefore increasing the change of the transition from a coral dominated system to an algae dominated system when the human pressure is even further increased. In terms of herbivorous reef fishes contributing to the coral reef resilience, the relations between the two determining reef health indicators for the function of herbivores reef fishes into coral reef resilience, coral cover and algae cover, are weak, limiting the influence of herbivorous reef fishes on coral reef resilience.

Still there seems to be some kind of relation between coral reef fishes and coral reef resilience, as evidenced by the found relations between reef fish diversity and cover of coral, sponges, rubble and sand.

The reefs were compared to benchmarks developed for the Mesoamerican reefs, which makes quite clear that the coral reefs of the Pulau Seribu Complex are highly deteriorated.

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Appendices

Appendix 1.1: Explanation raw data

To provide guidance in finding the right raw data, the table underneath lists the pagenumbers on which you can find the raw data corresponding to the research locations above the column.

Locations and transect numbers 				
	JAK1 JAK2 JAK3 JAK5	JAK6 JAK8 JAK9 JAK10	JAK12 JAK13 JAK14 JAK15	JAK16 JAK17 JAK18 JAK19
Family names and size categories 	121	126	131	136
	122	127	132	137
	123	128	133	138
	124	129	134	139
	125	130	135	140

Appendix 1.2: Raw Data

Locations	Length	Total	JAK1			JAK2			JAK3			JAK5		
Transects			1	2	3	1	2	3	1	2	3	1	2	3
Acanthuridae	V	3					1	2						
	VI	44				4		2	6	9	3	1	4	3
	VII	26			1	1		1	2		1	4	2	
	VIII	18								1		1	2	
	IX	6												
Apogonidae	III	56				4		10			2			
	IV	798		15		1	6	30		20		32	20	
	V	234						2		27				
Blenniidae	IV	5												
	V	2												
Caesionidae	V	24				4			20					
	VI	320	2		5	5	17	3		20		5		5
	VII	146	2		6	3	2	2	11	20	25	14		
	VIII	19	1	8	3									
	IX	5												
Centriscidae	III	0												
	V	23												
Chaetodontidae	IV	15				1	7	4	3					
	V	173	2	4	2	2			9	5	5	8	2	9
	VI	36		2				1		2	3			
	VII	10							2				1	
	VIII	2												
Dasyatidae	XIII	2												

Ephippidae	IV	0												
	V	0												
	VI	0												
	VII	8										8		
	VIII	2				1								
	IX	2		1		1								
	X	1												
Fistulariidae	IX	1									1			
	X	1												1
	XI	1												
	XII	2						1						
Gobiidae	II	0												
	III	2												
	IV	1												
	V	0												
Haemulidae	V	0												
	VI	0												
	VII	0												
	VIII	1												
	IX	1												
Labridae	III	0												
	IV	25				12		3						
	V	607	12	15	23	4	5	11	29	13	16	12	16	7
	VI	120	2			1		7	14	2	10	4	7	
	VII	30	1	1		1		3	1	8		3		3
	VIII	8							7					

Lethrinidae	VII	0												
	VIII	8												
	IX	1												
	X	2												
Lutjanidae	III	0												
	IV	2				1		1						
	V	12								1		11		
	VI	8										7		
Microdesmides	III	0												
	IV	0												
	V	1												
	VI	0												
Monacanthidae	II	0												
	III	0												
	IV	6												
	V	0												
Mullidae	IV	0												
	V	0												
	VI	5				2		2						
	VII	0												
Parapercidae	II	0												
	III	0												
	IV	5				2								
	V	4									1		1	
Pempheridae	III	8												
	IV	14												
	V	3												

	VI	12												
Pomacanthidae	II	0												
	III	0												
	IV	18		2	2	1	3	3						
	V	33	1			1							1	1
	VI	9					2							1
Pomacentridae	I	3												
	II	513		80		53	5	11	50		20			
	III	1289	47	48	43	7	15	10	40	40	20	26		35
	IV	255			3		5	2	20	35		3		10
	V	60			1						3	1		
	VI	15			1									
Priacanthidae	IV	0												
	V	1												
	VI	2			1									
	VII	1												
Scaridae	V	29		1		1	2			3	1	1		
	VI	37	6	1	2		4			6				
	VII	27		1	5				4					
	VIII	5		1	1									
Scolopsidae	II	2				1								
	III	52				2	2	1	3	2	1	10	2	5
	IV	42	1		1	5		1	2		2	3		2
	V	22	2		4				1	1	1	1	1	1
	VI	6			1									
Serranidae	III	0												
	IV	0												

	V	13												
	VI	8		2									2	
	VII	4		1										
Siganidae	II	30												
	III	0												
	IV	48												
	V	17												
	VI	1												
	VII	2		2										
Sphyraenidae	VI	0												
	VII	20												
	VIII	0												
	IX	1												
Synodontidae	IV	0												
	V	0												
	VI	1												
	VII	2											1	
Tetraodontidae	IV	0												
	V	0												
	VI	1												
	VII	1		1										
Zanclidae	IV	0												
	V	0												
	VI	1												
Total		5466	79	186	105	121	76	113	224	215	115	155	62	83

Locations	Length	Total	JAK6			JAK8			JAK9			JAK10		
Transects			1	2	3	1	2	3	1	2	3	1	2	3
Acanthuridae	V	3												
	VI	44	4	3	3									
	VII	26	6	3	3									
	VIII	18	1	1										
	IX	6												
Apogonidae	III	56											15	
	IV	798							32	10	58	30	17	37
	V	234							10		10			
Blenniidae	IV	5				1	1	1						
	V	2					1	1						
Caesionidae	V	24												
	VI	320	45	29	20								17	2
	VII	146		17										14
	VIII	19												
	IX	5												
Centriscidae	IV	0												
	V	23									10			
Chaetodontidae	IV	15												
	V	173	5	7	7		1			1	4	11		2
	VI	36	1		3						1	1	2	1
	VII	10								2				1
	VIII	2												
Dasyatidae	XI	0												
	XII	0												
	XIII	2												

Ephippidae	IV	0												
	V	0												
	VI	0												
	VII	8												
	VIII	2			1									
	IX	2												
	X	1												
Fistulariidae	IX	1												
	X	1												
	XI	1												
	XII	2												
Gobiidae	II	0												
	III	2												
	IV	1												
	V	0												
Haemulidae	V	0												
	VI	0												
	VII	0												
	VIII	1								1				
	IX	1									1			
Labridae	III	0												
	IV	25				6		4						
	V	607	43	24	10	2	1	2	7	20	17	37	12	10
	VI	120	7	6			2		4			2	7	3
	VII	30											4	
	VIII	8												

Lethrinidae	VII	0												
	VIII	8		1										
	IX	1												
	X	2												
Lutjanidae	III	0												
	IV	2												
	V	12												
	VI	8												
Microdesmides	III	0												
	IV	0												
	V	1										1		
	VI	0												
Monacanthidae	II	0												
	III	0												
	IV	6					2							
	V	0												
Mullidae	IV	0												
	V	0												
	VI	5												
	VII	0												
Parapercidae	II	0												
	III	0												
	IV	5												
	V	4												
Pempheridae	III	8												
	IV	14												
	V	3												

	VI	12												
Pomacanthidae	II	0												
	III	0												
	IV	18												
	V	33												
	VI	9										1		
Pomacentridae	I	3				3								
	II	513						9					10	
	III	1289	75	41	9		11	2	15	5	12	69	22	73
	IV	255	3	10						5	3	29	9	
	V	60										2	2	
	VI	15												
Priacanthidae	IV	0												
	V	1												
	VI	2												
	VII	1												
Scaridae	V	29										1		
	VI	37										3	1	
	VII	27										1	4	2
	VIII	5												
Scolopsidae	II	2												
	III	52				1								
	IV	42	2	1									1	2
	V	22												1
	VI	6												
Serranidae	III	0												
	IV	0												

	V	13												
	VI	8												
	VII	4												
Siganidae	II	30			30									
	III	0												
	IV	48	21	10	10		5					2		
	V	17	1	1	2									
	VI	1												
	VII	2												
Sphyraenidae	VI	0												
	VII	20												
	VIII	0												
	IX	1												1
Synodontidae	IV	0												
	V	0												
	VI	1												
	VII	2												
Tetraodontidae	IV	0												
	V	0												
	VI	1												
	VII	1												
Zanclidae	IV	0												
	V	0												
	VI	1												
Total		5466	214	154	98	13	24	19	68	44	116	190	123	149

Locations	Length	Total	JAK12			JAK13			JAK14			JAK15		
Transects			1	2	3	1	2	3	1	2	3	1	2	3
Acanthuridae	V	3												
	VI	44												
	VII	26												
	VIII	18												
	IX	6											1	
Apogonidae	III	56												
	IV	798	57	27	35	55						25	17	
	V	234		15		15								125
Blenniidae	IV	5								1		1		
	V	2												
Caesionidae	V	24												
	VI	320		2	5		6							
	VII	146	2				2							
	VIII	19			2									
	IX	5												
Centriscidae	IV	0												
	V	23								5				
Chaetodontidae	IV	15												
	V	173	5	7	2	1	3	3					2	5
	VI	36	2		2	1	4						3	1
	VII	10		1									1	
	VIII	2			1								1	
Dasyatidae	XI	0												
	XII	0												
	XIII	2										2		

Ephippidae	IV	0												
	V	0												
	VI	0												
	VII	8												
	VIII	2												
	IX	2												
	X	1												
Fistulariidae	IX	1												
	X	1												
	XI	1												
	XII	2												
Gobiidae	II	0												
	III	2						2						
	IV	1												
	V	0												
Haemulidae	V	0												
	VI	0												
	VII	0												
	VIII	1												
	IX	1												
Labridae	III	0												
	IV	25												
	V	607	13	14	22	19	2	3	2			16	16	9
	VI	120		4	4		3					1		
	VII	30												
	VIII	8												

Lethrinidae	VII	0											
	VIII	8	1	1	1	1			1			2	
	IX	1										1	
	X	2			2								
Lutjanidae	III	0											
	IV	2											
	V	12											
	VI	8	1										
Microdesmides	III	0											
	IV	0											
	V	1											
	VI	0											
Monacanthidae	II	0											
	III	0											
	IV	6											
	V	0											
Mullidae	IV	0											
	V	0											
	VI	5											1
	VII	0											
Parapercidae	II	0											
	III	0											
	IV	5									2		
	V	4					1						
Pempheridae	III	8											8
	IV	14										4	6
	V	3											3

	VI	12												12
Pomacanthidae	II	0												
	III	0												
	IV	18										3		
	V	33	1				2					2	2	
	VI	9												3
Pomacentridae	I	3												
	II	513				10	20						15	
	III	1289	36	45	24	8	16	4	6	11	3	20	10	12
	IV	255	2	7	2	26	5		5	1	3			2
	V	60					5	3						
	VI	15											2	
Priacanthidae	IV	0												
	V	1												
	VI	2												
	VII	1												
Scaridae	V	29	2	3		1								
	VI	37		1			4	1						
	VII	27		2			1	1				1		
	VIII	5												1
Scolopsidae	II	2												
	III	52	3				2		5		2	1	2	
	IV	42										3		
	V	22					1						1	
	VI	6										1		
Serranidae	III	0												
	IV	0												

	V	13	1	1			1						2	2
	VI	8												
	VII	4												
Siganidae	II	30												
	III	0												
	IV	48												
	V	17	1	2	4									
	VI	1												
	VII	2												
Sphyraenidae	VI	0												
	VII	20												
	VIII	0												
	IX	1												
Synodontidae	IV	0												
	V	0												
	VI	1		1										
	VII	2												
Tetraodontidae	IV	0												
	V	0												
	VI	1			1									
	VII	1												
Zanclidae	IV	0												
	V	0												
	VI	1												
Total		5466	127	133	107	137	78	17	19	18	10	83	82	187

Locations	Length	Total	JAK16			JAK17			JAK18			JAK19		
Transects			1	2	3	1	2	3	1	2	3	1	2	3
Acanthuridae	V	3												
	VI	44						2						
	VII	26				1			1					
	VIII	18					2	2			5	3		
	IX	6								3	2			
Apogonidae	III	56								25				
	IV	798							50	32	50	100	42	
	V	234				30								
Blenniidae	IV	5												
	V	2												
Caesionidae	V	24												
	VI	320		2	3	30	19	2		35	9		5	27
	VII	146	1			3					5			17
	VIII	19					2	2			1			
	IX	5		3				1	1					
Centriscidae	IV	0												
	V	23									8			
Chaetodontidae	IV	15												
	V	173	2	4	2	2	4	5	6	8	9	7	6	4
	VI	36					1		1	2	1	1		
	VII	10							2					
	VIII	2												
Dasyatidae	XI	0												
	XII	0												
	XIII	2												

Ephippidae	IV	0												
	V	0												
	VI	0												
	VII	8												
	VIII	2												
	IX	2												
	X	1				1								
Fistulariidae	IX	1												
	X	1												
	XI	1		1										
	XII	2									1			
Gobiidae	II	0												
	III	2												
	IV	1						1						
	V	0												
Haemulidae	V	0												
	VI	0												
	VII	0												
	VIII	1												
	IX	1												
Labridae	III	0												
	IV	25												
	V	607	5	14	10	12	19	23		5	10	17	14	14
	VI	120	3	4	7	2		4		1	1	2		6
	VII	30			1			1	1				1	1
	VIII	8					1							

Lethrinidae	VII	0												
	VIII	8												
	IX	1												
	X	2												
Lutjanidae	III	0												
	IV	2												
	V	12												
	VI	8												
Microdesmides	III	0												
	IV	0												
	V	1												
	VI	0												
Monacanthidae	II	0												
	III	0												
	IV	6	2	2										
	V	0												
Mullidae	IV	0												
	V	0												
	VI	5												
	VII	0												
Parapercidae	II	0												
	III	0												
	IV	5		1										
	V	4			1									
Pempheridae	III	8												
	IV	14												
	V	3												

	VI	12												
Pomacanthidae	II	0												
	III	0												
	IV	18											1	3
	V	33						2		7	1	2	6	4
	VI	9									2			
Pomacentridae	I	3												
	II	513				100				25		50	55	
	III	1289	46	34	23	16	15	51	15	10	30	31	57	101
	IV	255	20	9	5	2	3		4			3	6	13
	V	60			1				4	3		4	20	11
	VI	15		2					2			8		
Priacanthidae	IV	0												
	V	1									1			
	VI	2			1									
	VII	1		1										
Scaridae	V	29	3	3	1	1	2	1		1				1
	VI	37	2	1	2			1			1	1		
	VII	27				1	1	1			2			
	VIII	5			1			1						
Scolopsidae	II	2					1							
	III	52	6	2										
	IV	42	3	3	1		1	1	2		3		2	
	V	22			1				1	4	1			
	VI	6	2	2										
Serranidae	III	0												
	IV	0												

	V	13					1	2	1	2				
	VI	8						1					1	2
	VII	4				1	1							1
Siganidae	II	30												
	III	0												
	IV	48												
	V	17				1		2	2	1				
	VI	1								1				
	VII	2												
Sphyraenidae	VI	0												
	VII	20									20			
	VIII	0												
	IX	1												
Synodontidae	IV	0												
	V	0												
	VI	1												
	VII	2						1						
Tetraodontidae	IV	0												
	V	0												
	VI	1												
	VII	1												
Zanclidae	IV	0												
	V	0												
	VI	1		1										
Total		5466	95	89	60	203	73	107	93	165	163	229	216	205

Appendix 2: Raw Biomass Data

2.1: weight (gr) W = aL^b for each family per location (1500m²)

family	Total weight	JAK1	JAK2	JAK3	JAK5	JAK6	JAK8	JAK9	JAK10	JAK12	JAK13	JAK14	JAK15	JAK16	JAK17	JAK18	JAK19
Acanthuridae	22104,19873	224,8498	1195,951	2982,094	3427,682	4575,345							682,2341		2083,648	5696,254	1236,14
Apogonidae	15658,6962	150,0086	480,7648	1071,075	520,0297			1640,346	890,0996	1670,285	1030,248		4421,83		960,4334	1403,495	1420,081
Blenniidae	180,8419031						150,3118					15,26503	15,26503				
Caesionidae	55333,35659	5495,819	2997,118	1090,7,99	2963,335	9411,964			3602,53	1437,554	748,0039			2114,143	5874,672	4771,601	5008,622
Centriscidae	304,1284727							132,2298				66,11489				105,7838	
Chaetodontidae	20585,73163	784,9469	524,5788	2618,958	1445,162	1746,524	58,87687	1104,354	1719,765	2364,601	1196,968		1952,463	471,0149	804,6115	2635,035	1157,873
Dasyatidae	10968,11093												10968,11				
Ephippidae	9552,551763	1282,247	2065,45		3465,647	783,2033									1956,005		
Fistulariidae	243,7585662		69,86225	21,32865	33,36328									49,34214		69,86225	
Gobiidae	13,09158101										5,714294				7,377287		
Haemulidae	909,0864373							909,0864									
Labridae	38541,49141	2136,101	2257,797	8294,742	3217,251	3579,481	440,7211	1742,811	3683,271	2253,78	1022,837	63,17135	1383,273	2341,777	2776,29	840,454	2507,734
Lethrinidae	4689,416623					318,6389				2570,502	318,6389	318,6389	1162,998				
Lutjanidae	1198,272369		23,20922	34,31272	1045,337					95,41382							
Microdesmides	12,95683594								12,95684								
Monacanthidae	49,66833016						16,55611							33,11222			

Mullidae	75,415 03677		301, 4847										75,3 7117				
Parapercidae	129,34 28845		15,7 4749	22,4 9354	22,4 9354						22,4 9354	15,7 4749		30,3 6728			
Pempheridae	966,16 17428												966, 1617				
Pomacanthidae	3299,9 0152	136, 1737	458, 0417		236, 4089				129, 8489	53,2 8	106, 56		664, 8369		106, 56	685, 9378	722, 2537
Pomacentridae	15692, 21562	1049 ,166	354, 1105	1585 ,641	570, 1782	524, 4481	79,7 7269	293, 036	1650 ,245	730, 0518	1019 ,685	243, 8616	531, 0346	1373 ,028	626, 1493	962, 269	4099 ,538
Priacanthidae	400,26 71951	90,6 8911												274, 3107		35,2 6742	
Scaridae	9959,8 26102	2387 ,448	411, 3628	1280 ,741	29,7 1839				1539 ,398	568, 4216	771, 7557		477, 1034	918, 2527	1015 ,807	449, 5481	110, 2703
Scolopsidae	1508,3 64219	241, 1805	67,4 0972	129, 1158	171, 4289	25,7 1403	3,06 7424		51,1 8934	9,20 2273	31,6 1016	21,4 7197	131, 5776	394, 758	17,7 8722	195, 7086	17,1 4269
Serranidae	1663,9 70515	325, 5255			156, 3918					55,6 7208	27,8 3604		111, 3442		499, 9714	83,5 0811	403, 7214
Siganidae	1355,0 40485	347, 5817				503, 8096	45,5 4411		18,2 1765	194, 162					83,2 1228	162, 5131	
Sphyraenidae	1153,3 09359								151, 658							1001 ,651	
Synodontidae	204,48 48667				82,9 8734					38,5 1018					82,9 8734		
Tetraodontidae	399,53 77342	268, 1134								131, 4243							
Zanclidae	159,27 69078													159, 2769			
Total Weight	217312 ,4726	1491 9,85	1092 1,45	2894 8,5	1738 7,41	2146 9,13	794, 8501	5821 ,863	1344 9,18	1217 2,86	6302 ,351	744, 2712	2354 3,6	8159 ,383	1689 5,51	1909 8,89	1668 3,38

2.2: biomass (kg/ha) = [(biomass per sampling unit W ÷ 1000) ÷ area of the sampling unit in m2] x10,000, for each family per location

family	Total biomass	JAK1	JAK2	JAK3	JAK5	JAK6	JAK8	JAK9	JAK10	JAK12	JAK13	JAK14	JAK15	JAK16	JAK17	JAK18	JAK19
Acanthuridae	147,3613	1,49 8998	7,97 3009	19,8 8063	22,8 5122	30,5 023							4,54 8228		13,8 9098	37,9 7503	8,24 0935
Apogonidae	104,3913	1,00 0057	3,20 5099	7,14 05	3,46 6865			10,9 3564	5,93 3997	11,1 3523	6,86 8321		29,4 7887		6,40 289	9,35 6631	9,46 7208
Blenniidae	1,205613		0				1,00 2079					0,10 1767	0,10 1767				
Caesionidae	368,889	36,6 388	19,9 8079	72,7 1996	19,7 5557	62,7 4643			24,0 1686	9,58 3695	4,98 6693			14,0 9429	39,1 6448	31,8 1067	33,3 9081
Centriscidae	2,027523		0					0,88 1532				0,44 0766				0,70 5225	
Chaetodontidae	137,2382	5,23 298	3,49 7192	17,4 5972	9,63 4414	11,6 435	0,39 2512	7,36 2357	11,4 651	15,7 64	7,97 9787		13,0 1642	3,14 0099	5,36 4077	17,5 669	7,71 9151
Dasyatidae	73,12074		0										73,1 2074				
Ephippidae	63,68368	8,54 831	13,7 6967		23,1 0431	5,22 1355									13,0 4003		
Fistulariidae	1,625057		0,46 5748	0,14 2191	0,22 2422									0,32 8948		0,46 5748	
Gobiidae	0,087277		0								0,03 8095				0,04 9182		
Haemulidae	6,060576		0					6,06 0576									
Labridae	256,9433	14,2 4067	15,0 5198	55,2 9828	21,4 4834	23,8 632	2,93 8141	11,6 1874	24,5 5514	15,0 252	6,81 8914	0,42 1142	9,22 182	15,6 1184	18,5 086	5,60 3026	16,7 1823
Lethrinidae	31,26278		0			2,12 4259				17,1 3668	2,12 4259	2,12 4259	7,75 3322				
Lutjanidae	7,988482		0,15 4728	0,22 8751	6,96 8911					0,63 6092							
Microdesmides	0,086379		0						0,08 6379								
Monacanthidae	0,331122		0				0,11 0374							0,22 0748			
Mullidae	2,512372		2,00 9898										0,50 2474				

Paraperidae	0,862286		0,10 4983	0,14 9957	0,14 9957						0,14 9957	0,10 4983		0,20 2449			
Pempheridae	6,441078		0										6,44 1078				
Pomacanthidae	21,99934	0,90 7824	3,05 3611		1,57 6059				0,86 5659	0,35 52	0,71 04		4,43 2246		0,71 04	4,57 2919	4,81 5025
Pomacentridae	104,6148	6,99 4442	2,36 0737	10,5 7094	3,80 1188	3,49 6321	0,53 1818	1,95 3573	11,0 0163	4,86 7012	6,79 79	1,62 5744	3,54 0231	9,15 352	4,17 4329	6,41 5126	27,3 3025
Priacanthidae	2,668448	0,60 4594	0											1,82 8738		0,23 5116	
Scaridae	66,39884	15,9 1632	2,74 2419	8,53 827	0,19 8123				10,2 6265	3,78 9478	5,14 5038		3,18 0689	6,12 1685	6,77 2044	2,99 6987	0,73 5135
Scolopsidae	10,05576	1,60 787	0,44 9398	0,86 0772	1,14 2859	0,17 1427	0,02 0449		0,34 1262	0,06 1348	0,21 0734	0,14 3146	0,87 7184	2,63 172	0,11 8581	1,30 4724	0,11 4285
Serranidae	11,09314	2,17 017	0		1,04 2612					0,37 1147	0,18 5574		0,74 2294		3,33 3143	0,55 6721	2,69 1476
Siganidae	9,033603	2,31 7211	0			3,35 8731	0,30 3627		0,12 1451	1,29 4413					0,55 4749	1,08 3421	
Sphyraenidae	7,688729		0						1,01 1053							6,67 7676	
Synodontidae	1,363232		0		0,55 3249					0,25 6735					0,55 3249		
Tetraodontidae	2,663585	1,78 7423	0							0,87 6162							
Zanclidae	1,061846		0											1,06 1846			
Total Biomass	1448,75	99,4 6567	72,8 0965	192, 99	115, 9161	143, 1275	5,29 9001	38,8 1242	89,6 612	81,1 524	42,0 1567	4,96 1808	156, 9574	54,3 9589	112, 6367	127, 3259	111, 2225

Appendix 3: Regression analysis: distance independent, family biomass dependent

Total Biomass

Variables Entered/Removed^a

Model	Variables Entered	Variables Removed	Method
1	Distance ^b	.	Enter

a. Dependent Variable: TotBiomass

b. All requested variables entered.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,411 ^a	,169	,110	49,88646

a. Predictors: (Constant), Distance

ANOVA^a

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	7086,502	1	7086,502	2,848	,114 ^b
	Residual	34841,228	14	2488,659		
	Total	41927,730	15			

a. Dependent Variable: TotBiomass

b. Predictors: (Constant), Distance

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	29,193	38,508		,758	,461
	Distance	1,355	,803	,411	1,687	,114

a. Dependent Variable: TotBiomass

Total biomass minus the family Dasyatidae

Variables Entered/Removed^a

Model	Variables Entered	Variables Removed	Method
1	Distance ^b	.	Enter

a. Dependent Variable: TotBiomass

b. All requested variables entered.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,583 ^a	,340	,293	41,89607

a. Predictors: (Constant), Distance

ANOVA^a

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	12672,390	1	12672,390	7,220	,018 ^b
	Residual	24573,927	14	1755,281		
	Total	37246,317	15			

a. Dependent Variable: TotBiomass

b. Predictors: (Constant), Distance

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	3,893	32,340		,120	,906
	Distance	1,812	,674	,583	2,687	,018

a. Dependent Variable: TotBiomass

Ephippidae

Variables Entered/Removed^a

Model	Variables Entered	Variables Removed	Method
1	Distance ^b	.	Enter

a. Dependent Variable: Ephippidae

b. All requested variables entered.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,433 ^a	,188	,129	6,55342

a. Predictors: (Constant), Distance

ANOVA^a

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	138,771	1	138,771	3,231	,094 ^b
	Residual	601,263	14	42,947		
	Total	740,034	15			

a. Dependent Variable: Ephippidae

b. Predictors: (Constant), Distance

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-4,624	5,059		-,914	,376
	Distance	,190	,105	,433	1,798	,094

a. Dependent Variable: Ephippidae

Fistulariidae

Variables Entered/Removed^a

Model	Variables Entered	Variables Removed	Method
1	Distance ^b	.	Enter

a. Dependent Variable: Fistulariidae

b. All requested variables entered.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,470 ^a	,220	,165	,15876

a. Predictors: (Constant), Distance

ANOVA^a

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	,100	1	,100	3,959	,067 ^b
	Residual	,353	14	,025		
	Total	,453	15			

a. Dependent Variable: Fistulariidae

b. Predictors: (Constant), Distance

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-,129	,123		-1,051	,311
	Distance	,005	,003	,470	1,990	,067

a. Dependent Variable: Fistulariidae

Pomacentridae

Variables Entered/Removed^a

Model	Variables Entered	Variables Removed	Method
1	Distance ^b	.	Enter

a. Dependent Variable: Pomacentridae

b. All requested variables entered.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,474 ^a	,225	,169	5,80035

a. Predictors: (Constant), Distance

ANOVA^a

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	136,356	1	136,356	4,053	,064 ^b
	Residual	471,017	14	33,644		
	Total	607,373	15			

a. Dependent Variable: Pomacentridae

b. Predictors: (Constant), Distance

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-1,990	4,477		-,444	,664
	Distance	,188	,093	,474	2,013	,064

a. Dependent Variable: Pomacentridae

Serranidae

Variables Entered/Removed^a

Model	Variables Entered	Variables Removed	Method
1	Distance ^b	.	Enter

a. Dependent Variable: Serranidae

b. All requested variables entered.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,475 ^a	,225	,170	,98308

a. Predictors: (Constant), Distance

ANOVA^a

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	3,933	1	3,933	4,069	,063 ^b
	Residual	13,530	14	,966		
	Total	17,463	15			

a. Dependent Variable: Serranidae

b. Predictors: (Constant), Distance

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-,755	,759		-,995	,337
	Distance	,032	,016	,475	2,017	,063

a. Dependent Variable: Serranidae

Acanthuridae

Variables Entered/Removed^a

Model	Variables Entered	Variables Removed	Method
1	Distance ^b	.	Enter

a. Dependent Variable: Acanthuridae

b. All requested variables entered.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,482 ^a	,232	,178	11,18878

a. Predictors: (Constant), Distance

ANOVA^a

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	530,580	1	530,580	4,238	,059 ^b
	Residual	1752,643	14	125,189		
	Total	2283,223	15			

a. Dependent Variable: Acanthuridae

b. Predictors: (Constant), Distance

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-7,606	8,637		-,881	,393
	Distance	,371	,180	,482	2,059	,059

a. Dependent Variable: Acanthuridae

Caesionidae

Variables Entered/Removed^a

Model	Variables Entered	Variables Removed	Method
1	Distance ^b	.	Enter

a. Dependent Variable: Caesionidae

b. All requested variables entered.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,541 ^a	,292	,242	19,35068

a. Predictors: (Constant), Distance

ANOVA^a

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	2164,696	1	2164,696	5,781	,031 ^b
	Residual	5242,281	14	374,449		
	Total	7406,978	15			

a. Dependent Variable: Caesionidae

b. Predictors: (Constant), Distance

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-10,918	14,937		-,731	,477
	Distance	,749	,311	,541	2,404	,031

a. Dependent Variable: Caesionidae

Appendix 4: Regression analysis: distance independent, functional group biomass dependent

Total Biomass Herbivores

Variables Entered/Removed^a

Model	Variables Entered	Variables Removed	Method
1	Distance ^b	.	Enter

a. Dependent Variable: HerbBiomass

b. All requested variables entered.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,635 ^a	,404	,361	19,50177

a. Predictors: (Constant), Distance

ANOVA^a

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	3606,065	1	3606,065	9,482	,008 ^b
	Residual	5324,467	14	380,319		
	Total	8930,532	15			

a. Dependent Variable: HerbBiomass

b. Predictors: (Constant), Distance

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-8,517	15,054		-,566	,580
	Distance	,967	,314	,635	3,079	,008

a. Dependent Variable: HerbBiomass

Total Biomass Grazers/Detrivores

Variables Entered/Removed^a

Model	Variables Entered	Variables Removed	Method
1	Distance ^b	.	Enter

a. Dependent Variable: BiomGrazersDetrivores

b. All requested variables entered.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,484 ^a	,234	,180	12,11089

a. Predictors: (Constant), Distance

ANOVA^a

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	628,743	1	628,743	4,287	,057 ^b
	Residual	2053,432	14	146,674		
	Total	2682,175	15			

a. Dependent Variable: BiomGrazersDetrivores

b. Predictors: (Constant), Distance

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-7,163	9,349		-,766	,456
	Distance	,404	,195	,484	2,070	,057

a. Dependent Variable: BiomGrazersDetrivores

Total Biomass Browsers

Variables Entered/Removed^a

Model	Variables Entered	Variables Removed	Method
1	Distance ^b	.	Enter

a. Dependent Variable: BiomBrowsers

b. All requested variables entered.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,433 ^a	,188	,130	6,55340

a. Predictors: (Constant), Distance

ANOVA^a

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	139,056	1	139,056	3,238	,094 ^b
	Residual	601,259	14	42,947		
	Total	740,316	15			

a. Dependent Variable: BiomBrowsers

b. Predictors: (Constant), Distance

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-4,632	5,059		-,916	,375
	Distance	,190	,105	,433	1,799	,094

a. Dependent Variable: BiomBrowsers

Total Biomass Scrapers/Small Excavators

Variables Entered/Removed^a

Model	Variables Entered	Variables Removed	Method
1	Distance ^b	.	Enter

a. Dependent Variable: BiomScrapers

b. All requested variables entered.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,403 ^a	,163	,103	14,05201

a. Predictors: (Constant), Distance

ANOVA^a

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	537,476	1	537,476	2,722	,121 ^b
	Residual	2764,425	14	197,459		
	Total	3301,901	15			

a. Dependent Variable: BiomScrapers

b. Predictors: (Constant), Distance

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	3,278	10,847		,302	,767
	Distance	,373	,226	,403	1,650	,121

a. Dependent Variable: BiomScrapers

Total Biomass Scrapers/Small Excavators minus Jak 3

Variables Entered/Removed^a

Model	Variables Entered	Variables Removed	Method
1	Distance ^b	.	Enter

a. Dependent Variable: BiomGrazersDetrivores

b. All requested variables entered.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,537 ^a	,289	,234	12,07432

a. Predictors: (Constant), Distance

ANOVA^a

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	769,793	1	769,793	5,280	,039 ^b
	Residual	1895,260	13	145,789		
	Total	2665,053	14			

a. Dependent Variable: BiomGrazersDetrivores

b. Predictors: (Constant), Distance

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-9,320	9,328		-,999	,336
	Distance	,447	,195	,537	2,298	,039

a. Dependent Variable: BiomGrazersDetrivores

Total Biomass Other

Variables Entered/Removed^a

Model	Variables Entered	Variables Removed	Method
1	Distance ^b	.	Enter

a. Dependent Variable: BiomOther

b. All requested variables entered.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,175 ^a	,031	-,039	36,32318

a. Predictors: (Constant), Distance

ANOVA^a

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	582,300	1	582,300	,441	,517 ^b
	Residual	18471,224	14	1319,373		
	Total	19053,523	15			

a. Dependent Variable: BiomOther

b. Predictors: (Constant), Distance

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	37,711	28,039		1,345	,200
	Distance	,388	,585	,175	,664	,517

a. Dependent Variable: BiomOther

Appendix 5: Regression analysis: distance independent, Shannon Wiener/ Evenness dependent

Shannon Wiener

Variables Entered/Removed^a

Model	Variables Entered	Variables Removed	Method
1	Distance ^b	.	Enter

a. Dependent Variable: ShannonWiener

b. All requested variables entered.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,635 ^a	,403	,360	,18780

a. Predictors: (Constant), Distance

ANOVA^a

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	,333	1	,333	9,441	,008 ^b
	Residual	,494	14	,035		
	Total	,827	15			

a. Dependent Variable: ShannonWiener

b. Predictors: (Constant), Distance

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	1,380	,145		9,518	,000
	Distance	,009	,003	,635	3,073	,008

a. Dependent Variable: ShannonWiener

Evenness

Variables Entered/Removed^a

Model	Variables Entered	Variables Removed	Method
1	Distance ^b	.	Enter

a. Dependent Variable: Evenness

b. All requested variables entered.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,541 ^a	,293	,242	,13684

a. Predictors: (Constant), Distance

ANOVA^a

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	,108	1	,108	5,789	,031 ^b
	Residual	,262	14	,019		
	Total	,371	15			

a. Dependent Variable: Evenness

b. Predictors: (Constant), Distance

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	,709	,106		6,713	,000
	Distance	-,005	,002	-,541	-2,406	,031

a. Dependent Variable: Evenness

Appendix 6: Raw environmental data

Raw Environmental Parameters

Environmental Parameters (m)																								
	ACB	ACD	ACT	AA	CB	CE	CF	CM	CS	CT	CA	DCA	DC	HA	CHL	CME	CMR	OT	RCK	R	S	SC	SP	TA
jak 1	0,95	0,46	0	0,73	1,86	3,81	4,61	10,1	1,05	0,39	2,23	16,2	0	0,31	0,54	0,61	0,86	0,33	8,04	5,77	0,25	0,42	0,51	0
jak 2	14,54	0	0,64	0	2,92	2,2	0,72	9,2	1,05	0,63	0	8,4	0,47	0	0	0,07	0,25	0,24	1,55	13,2	0,13	1,8	1,49	0,06
jak 3	2,81	0	2,35	5,59	1,23	0,91	2,01	6,93	0,84	0,54	0	18,0	0,02	0	0,43	0,24	1,04	0,12	0,42	11,7	0,1	2,64	0,21	1,91
jak 5	0,83	0	0,41	0,05	2,77	3,54	1,76	3,51	1,77	0	0	8,85	0	0	0,23	0	2,46	0,01	4,07	26,7	1,98	0,1	0,95	0
jak 6	2,6	0	1,06	4,1	11,9	1,12	1,42	5,24	0	0	0	8,42	0	0	0	0	0,3	0,16	0	16,9	6,1	0	0	0,68
jak 8	0,47	0	0	0	0,2	0,25	0	1,09	0,06	0	0	1,8	0	0	0	0	0	0	0	50,7	1,2	4,21	0	0
jak 9	8,81	0	0	0	2,33	2,29	7,65	1,14	0,58	0	0	14,9	0	0	0	0	0,1	0	0	22,2	0	0	0,05	0
jak 10	6,54	0	1,03	0	3,96	1,3	4,54	8,71	1,42	0,1	0	21,4	0	0	0	0,98	0,98	0	0	6,67	0,2	1,7	0,23	0,26
jak 12	11,49	0,4	1,52	0	3,58	3,18	13,2	2,43	0,35	0,48	0,05	12,2	0	0,32	0	0	0,69	0	2,02	3,12	0,39	2,32	0,48	1,34
jak 13	3,23	0	0,23	0,53	38,6	0,33	0,68	0,94	0	0	0,2	13,9	1,01	0	0	0	0,27	0	0	0	0,06	0	0	0
jak 14	1,38	0	0	0	0,18	2,29	0,09	2,04	0	0	0,85	11	0	1,16	0	0	0	0,09	0,68	11,5	13,8	6,85	0,37	7,71
jak 15	6,46	0	5,42	0,4	2,26	4,2	3,82	2,66	0,96	0,14	0	5,24	0,3	0	0	0	0	0	6,4	9,36	9,78	2,48	0,12	0
jak 16	0,8	0	0	1,03	0,37	1,9	0,04	4,66	1,03	0	0	15,2	0	2,32	0,04	1,13	0	0,24	0	19,1	9,3	1,73	0	1,12

jak 17	6,84	0	0	0	2,05	3,35	3,49	1,76	6,57	0	0,21	8,57	0,06	0	0	0	0,39	0,1	0,52	25,0	0	0	0,93	0,12
jak 18	3,81	0	0	0	1,59	3,37	9,95	0,97	0,24	0	0	11,3	0,19	0	0	6,07	0,2	0	0	19,5	3,38	0	0,65	0
jak 19	13,93				0,48	0,51	1,95	1,01	0,46			20,7				5,57	0,15			12,3	1,04		0,13	0,6

Used combined health indicators					
Rock	Rubble	Sand	Algae	Coral	Sponges
"Rock" "RCK"	"Rubble" "R"	"Sand" "S"	"Caulerpa and turfs" "AA"	"Acropora branching" "ACB"	"Sponges" "SP"
	"Dead coral" "DC"		"Coraline algae" "CA"	"Acropora digitata" "ACD"	
			"Dead coral with algae" "DCA"	"Acropora tabular" "ACT"	
			"Halimeda" "HA"	"Coral branching" "CB"	
			"Turf algae" "TA"	"Coral encrusting" "CE"	
				"Coral foliose" "CF"	
				"Coral Massive" "CM"	
				"Coral submassive" "CS"	
				"Coral Tabular" "CT"	
				"Heliopora" "CHL"	
				"Millepora" "CME"	
				"Mushroom corals" "CMR"	
				"Other corals" "OT"	
				"Soft corals" "SC"	

Appendix 7: Regression analysis: distance independent, biotic variables dependent

Rock

Variables Entered/Removed^a

Model	Variables Entered	Variables Removed	Method
1	Distance ^b	.	Enter

a. Dependent Variable: Rock

b. All requested variables entered.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,198 ^a	,039	-,029	2,54596

a. Predictors: (Constant), Distance

ANOVA^a

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	3,706	1	3,706	,572	,462 ^b
	Residual	90,747	14	6,482		
	Total	94,453	15			

a. Dependent Variable: Rock

b. Predictors: (Constant), Distance

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	2,887	1,965		1,469	,164
	Distance	-,031	,041	-,198	-,756	,462

a. Dependent Variable: Rock

Rubble

Variables Entered/Removed^a

Model	Variables Entered	Variables Removed	Method
1	Distance ^b	.	Enter

a. Dependent Variable: RubbleTotal

b. All requested variables entered.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,023 ^a	,001	-,071	12,37645

a. Predictors: (Constant), Distance

ANOVA^a

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1,129	1	1,129	,007	,933 ^b
	Residual	2144,470	14	153,176		
	Total	2145,598	15			

a. Dependent Variable: RubbleTotal

b. Predictors: (Constant), Distance

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	16,755	9,554		1,754	,101
	Distance	-,017	,199	-,023	-,086	,933

a. Dependent Variable: RubbleTotal

Sand

Variables Entered/Removed^a

Model	Variables Entered	Variables Removed	Method
1	Distance ^b	.	Enter

a. Dependent Variable: Sand

b. All requested variables entered.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,426 ^a	,181	,123	4,08834

a. Predictors: (Constant), Distance

ANOVA^a

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	51,887	1	51,887	3,104	,100 ^b
	Residual	234,004	14	16,715		
	Total	285,891	15			

a. Dependent Variable: Sand

b. Predictors: (Constant), Distance

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	8,243	3,156		2,612	,020
	Distance	-,116	,066	-,426	-1,762	,100

a. Dependent Variable: Sand

Algae

Variables Entered/Removed^a

Model	Variables Entered	Variables Removed	Method
1	Distance ^b	.	Enter

a. Dependent Variable: Algae

b. All requested variables entered.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,159 ^a	,025	-,044	6,77040

a. Predictors: (Constant), Distance

ANOVA^a

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	16,675	1	16,675	,364	,556 ^b
	Residual	641,737	14	45,838		
	Total	658,412	15			

a. Dependent Variable: Algae

b. Predictors: (Constant), Distance

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	11,388	5,226		2,179	,047
	Distance	,066	,109	,159	,603	,556

a. Dependent Variable: Algae

Coral

Variables Entered/Removed^a

Model	Variables Entered	Variables Removed	Method
1	Distance ^b	.	Enter

a. Dependent Variable: Coral

b. All requested variables entered.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,141 ^a	,020	-,050	10,12274

a. Predictors: (Constant), Distance

ANOVA^a

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	29,170	1	29,170	,285	,602 ^b
	Residual	1434,578	14	102,470		
	Total	1463,748	15			

a. Dependent Variable: Coral

b. Predictors: (Constant), Distance

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	20,801	7,814		2,662	,019
	Distance	,087	,163	,141	,534	,602

a. Dependent Variable: Coral

Sponges

Variables Entered/Removed^a

Model	Variables Entered	Variables Removed	Method
1	Distance ^b	.	Enter

a. Dependent Variable: Sponges

b. All requested variables entered.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,431 ^a	,186	,128	,40543

a. Predictors: (Constant), Distance

ANOVA^a

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	,526	1	,526	3,201	,095 ^b
	Residual	2,301	14	,164		
	Total	2,827	15			

a. Dependent Variable: Sponges

b. Predictors: (Constant), Distance

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-,147	,313		-,470	,645
	Distance	,012	,007	,431	1,789	,095

a. Dependent Variable: Sponges

Appendix 8: Regression analysis: biomass variables independent, biotic variables dependent

Total Biomass Browsers and Rock

Variables Entered/Removed^a

Model	Variables Entered	Variables Removed	Method
1	BiomBrowsers ^b	.	Enter

a. Dependent Variable: Rock

b. All requested variables entered.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,365 ^a	,133	,071	2,41808

a. Predictors: (Constant), BiomBrowsers

ANOVA^a

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	12,593	1	12,593	2,154	,164 ^b
	Residual	81,860	14	5,847		
	Total	94,453	15			

a. Dependent Variable: Rock

b. Predictors: (Constant), BiomBrowsers

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	,962	,700		1,374	,191
	BiomBrowsers	,130	,089	,365	1,468	,164

a. Dependent Variable: Rock

Total Biomass Browsers and Algae

Variables Entered/Removed^a

Model	Variables Entered	Variables Removed	Method
1	BiomBrowsers ^b	.	Enter

a. Dependent Variable: Algae

b. All requested variables entered.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,346 ^a	,120	,057	6,43364

a. Predictors: (Constant), BiomBrowsers

ANOVA^a

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	78,928	1	78,928	1,907	,189 ^b
	Residual	579,484	14	41,392		
	Total	658,412	15			

a. Dependent Variable: Algae

b. Predictors: (Constant), BiomBrowsers

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	15,670	1,864		8,409	,000
	BiomBrowsers	-,327	,236	-,346	-1,381	,189

a. Dependent Variable: Algae

Total Biomass Browsers and Sponges

Variables Entered/Removed^a

Model	Variables Entered	Variables Removed	Method
1	BiomBrowsers ^b	.	Enter

a. Dependent Variable: Sponges

b. All requested variables entered.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,756 ^a	,572	,541	,29408

a. Predictors: (Constant), BiomBrowsers

ANOVA^a

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1,617	1	1,617	18,691	,001 ^b
	Residual	1,211	14	,086		
	Total	2,827	15			

a. Dependent Variable: Sponges

b. Predictors: (Constant), BiomBrowsers

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	,197	,085		2,307	,037
	BiomBrowsers	,047	,011	,756	4,323	,001

a. Dependent Variable: Sponges

Total Biomass Scrapers/small excavators and Sand

Variables Entered/Removed^a

Model	Variables Entered	Variables Removed	Method
1	BiomScrapers ^b	.	Enter

a. Dependent Variable: Sand

b. All requested variables entered.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,375 ^a	,141	,080	4,18849

a. Predictors: (Constant), BiomScrapers

ANOVA^a

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	40,283	1	40,283	2,296	,152 ^b
	Residual	245,608	14	17,543		
	Total	285,891	15			

a. Dependent Variable: Sand

b. Predictors: (Constant), BiomScrapers

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	5,215	1,807		2,885	,012
	BiomScrapers	-,110	,073	-,375	-1,515	,152

a. Dependent Variable: Sand

Total Biomass Scrapers/small excavators and Algae

Variables Entered/Removed^a

Model	Variables Entered	Variables Removed	Method
1	BiomScrapers ^b	.	Enter

a. Dependent Variable: Algae

b. All requested variables entered.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,538 ^a	,289	,239	5,78137

a. Predictors: (Constant), BiomScrapers

ANOVA^a

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	190,472	1	190,472	5,699	,032 ^b
	Residual	467,940	14	33,424		
	Total	658,412	15			

a. Dependent Variable: Algae

b. Predictors: (Constant), BiomScrapers

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	9,517	2,495		3,815	,002
	BiomScrapers	,240	,101	,538	2,387	,032

a. Dependent Variable: Algae

Total Biomass Herbivores and Sponges

Variables Entered/Removed^a

Model	Variables Entered	Variables Removed	Method
1	HerbBiomass ^b	.	Enter

a. Dependent Variable: Sponges

b. All requested variables entered.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,388 ^a	,151	,090	,41419

a. Predictors: (Constant), HerbBiomass

ANOVA^a

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	,426	1	,426	2,480	,138 ^b
	Residual	2,402	14	,172		
	Total	2,827	15			

a. Dependent Variable: Sponges

b. Predictors: (Constant), HerbBiomass

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	,139	,186		,744	,469
	HerbBiomass	,007	,004	,388	1,575	,138

a. Dependent Variable: Sponges

Appendix 9: Regression analysis: Shannon Wiener independent, biotic variables dependent

Rock

Variables Entered/Removed^a

Model	Variables Entered	Variables Removed	Method
1	ShannonWiener ^b	.	Enter

a. Dependent Variable: Rock

b. All requested variables entered.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,324 ^a	,105	,041	2,45690

a. Predictors: (Constant), ShannonWiener

ANOVA^a

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	9,944	1	9,944	1,647	,220 ^b
	Residual	84,509	14	6,036		
	Total	94,453	15			

a. Dependent Variable: Rock

b. Predictors: (Constant), ShannonWiener

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-4,765	4,906		-,971	,348
	ShannonWiener	3,468	2,702	,324	1,283	,220

a. Dependent Variable: Rock

Rubble

Variables Entered/Removed^a

Model	Variables Entered	Variables Removed	Method
1	ShannonWiener ^b	.	Enter

a. Dependent Variable: RubbleTotal

b. All requested variables entered.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,446 ^a	,199	,142	11,07986

a. Predictors: (Constant), ShannonWiener

ANOVA^a

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	426,914	1	426,914	3,478	,083 ^b
	Residual	1718,685	14	122,763		
	Total	2145,598	15			

a. Dependent Variable: RubbleTotal

b. Predictors: (Constant), ShannonWiener

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	56,909	22,123		2,572	,022
	ShannonWiener	-22,724	12,186	-,446	-1,865	,083

a. Dependent Variable: RubbleTotal

Sand

Variables Entered/Removed^a

Model	Variables Entered	Variables Removed	Method
1	ShannonWiener ^b	.	Enter

a. Dependent Variable: Sand

b. All requested variables entered.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,392 ^a	,153	,093	4,15784

a. Predictors: (Constant), ShannonWiener

ANOVA^a

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	43,865	1	43,865	2,537	,134 ^b
	Residual	242,027	14	17,288		
	Total	285,891	15			

a. Dependent Variable: Sand

b. Predictors: (Constant), ShannonWiener

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	16,102	8,302		1,940	,073
	ShannonWiener	-7,284	4,573	-,392	-1,593	,134

a. Dependent Variable: Sand

Algae

Variables Entered/Removed^a

Model	Variables Entered	Variables Removed	Method
1	ShannonWiener ^b	.	Enter

a. Dependent Variable: Algae

b. All requested variables entered.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,041 ^a	,002	-,070	6,85206

a. Predictors: (Constant), ShannonWiener

ANOVA^a

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1,103	1	1,103	,023	,880 ^b
	Residual	657,309	14	46,951		
	Total	658,412	15			

a. Dependent Variable: Algae

b. Predictors: (Constant), ShannonWiener

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	16,451	13,681		1,202	,249
	ShannonWiener	-1,155	7,536	-,041	-,153	,880

a. Dependent Variable: Algae

Coral

Variables Entered/Removed^a

Model	Variables Entered	Variables Removed	Method
1	ShannonWiener ^b	.	Enter

a. Dependent Variable: Coral

b. All requested variables entered.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,632 ^a	,399	,357	7,92424

a. Predictors: (Constant), ShannonWiener

ANOVA^a

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	584,637	1	584,637	9,310	,009 ^b
	Residual	879,111	14	62,794		
	Total	1463,748	15			

a. Dependent Variable: Coral

b. Predictors: (Constant), ShannonWiener

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-23,152	15,822		-1,463	,165
	ShannonWiener	26,593	8,715	,632	3,051	,009

a. Dependent Variable: Coral

Sponges

Variables Entered/Removed^a

Model	Variables Entered	Variables Removed	Method
1	ShannonWiener ^b	.	Enter

a. Dependent Variable: Sponges

b. All requested variables entered.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,585 ^a	,343	,296	,36435

a. Predictors: (Constant), ShannonWiener

ANOVA^a

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	,969	1	,969	7,297	,017 ^b
	Residual	1,859	14	,133		
	Total	2,827	15			

a. Dependent Variable: Sponges

b. Predictors: (Constant), ShannonWiener

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-1,567	,727		-2,154	,049
	ShannonWiener	1,083	,401	,585	2,701	,017

a. Dependent Variable: Sponges