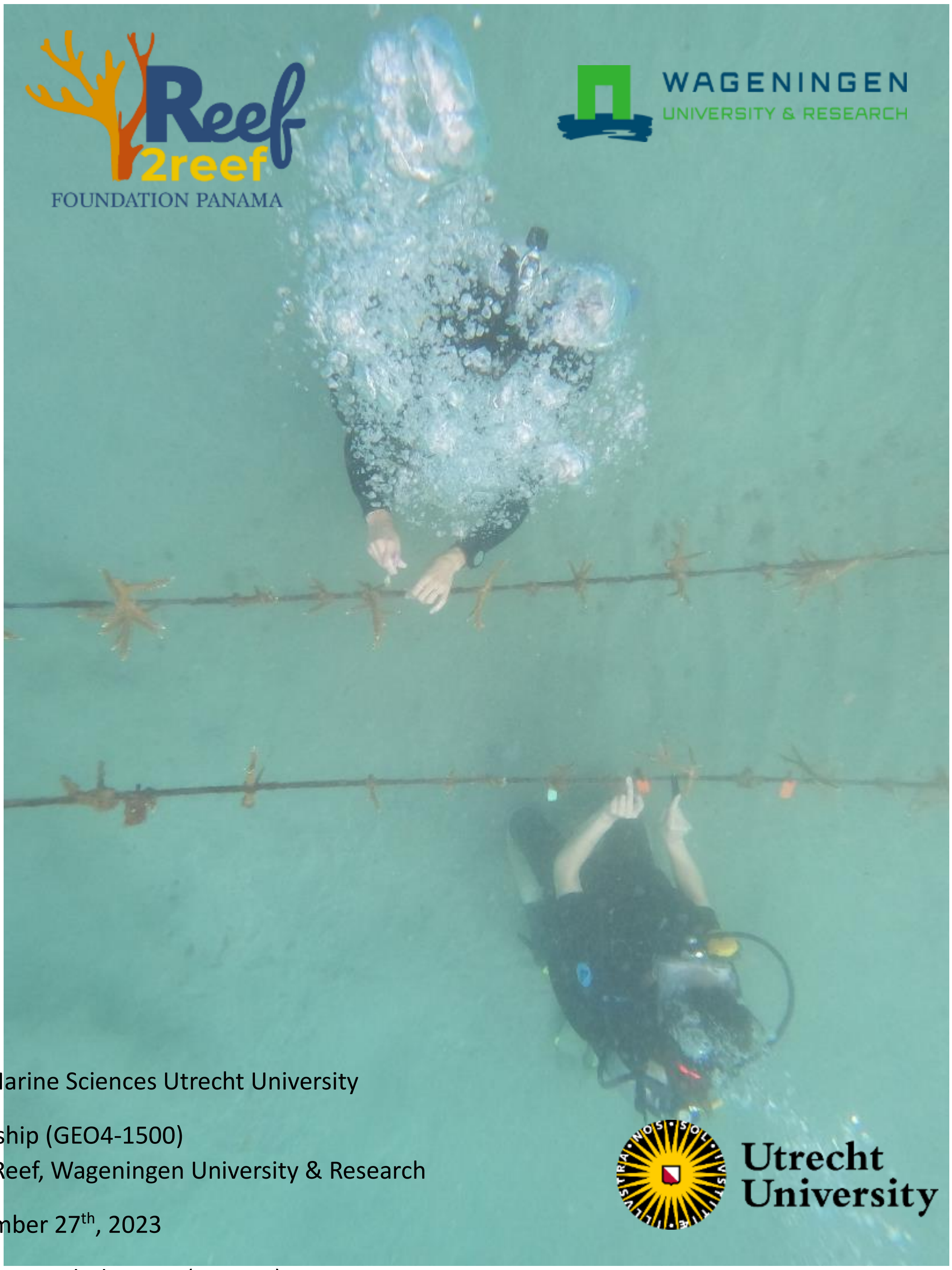
The potential for coral reef restoration in Portobelo, Panama

An assessment of ecological status, public awareness and perception



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Abstract

Coral reefs, vital components of marine ecosystems, are confronting severe degradation, necessitating prompt restorative interventions to enhance resilience against increasing local and global stressors. This baseline study, conducted at the coral reef restoration project Reef2Reef in Portobelo, Panama, aimed to achieve a comprehensive understanding of the ecological condition of the reefs and to gain insights into the public's perception and awareness regarding the state of the reefs and restoration activities. The ecological assessments entail underwater evaluations at eight dive sites, revealing variations in coral health. Live hard coral coverage ranges between 21% and 48%, and macroalgae between 20% and 44%. Distinct ecological compositions and species diversities prevail across sites, highlighting ecological hotspots. Simultaneously, surveys explore awareness and perception among local residents and visitors. A noticeable knowledge gap concerning coral reefs exists, yet, there is a consistent recognition of their significance. Threat assessment reveals coral health issues due to predation and diseases, and the indirect consequences of the invasive Lionfish. Visitors often mentioned more general and global threats, like climate change, whereas the inhabitants of Portobelo were more aware of local threats such as garbage and boats. Drake Island, Buenaventura La Piscina, and Homereef Scuba have been identified as strategic sites for out-planting of the *Acropora* fragments. Interviews within the local community and visitors reveal a lack of awareness with regard to coral reef restoration, but also positive sentiments towards restoration activities, indicating substantial social support. Recommendations emphasize conservation education, citizen science, and collaboration with local experts. Future research should encompass additional ecological parameters and methodological refinements for comprehensive monitoring. Positioned at the nexus of tourism, conservation, and science, Reef2Reef is well-positioned to maintain a harmonious balance between these sectors.

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Picture of the *Acropora cervicornis* fragments hanging on the clotheslines in the coral garden.

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1. Introduction

Coral reefs are among the most diverse, productive and complex marine ecosystems on our planet, supporting more than a quarter of all marine species, yet occupying just 0.1% of ocean area (Heron et al., 2017; Reaka-Kudla, 1997; Moberg & Folke, 1999). They provide ecosystem goods and services to millions of people around the world, among others food security, income generated by tourism and coastal protection by reducing wave energy (Obura et al., 2017; Ferrario et al., 2014).

Like many ecosystems around the world, coral reefs have survived years of natural variation, but they might not survive the rapid changes Earth is experiencing nowadays. Continuously occurring local stressors include overexploitation of fish populations, coastal development, surface runoff resulting in sediments and excess nutrients, but also diseases, invasive species and tourists trampling the corals (Frade et al., 2019; Bak et al., 2005). Such local stressors weaken the coral reefs and decrease their resilience to increasing global threats, like sea surface temperature rise, ocean acidification and sea level rise (de Bakker et al., 2019).

Coral reef degradation in the Caribbean started in the seventies when the white-band disease (WBD) killed nearly 90% of the dominant reef-building corals of the genus *Acropora* (elkhorn and staghorn corals) (Bak et al., 1984; Steneck, 2005; Guzmán et al. 1991). In the 1980s *Diadema antillarum* sea urchins, the most important herbivore, experienced a significant population decline due to an unidentified pathogen, which began a few km from the Caribbean entrance of the Panama Canal (Lessios et al., 1984; Hughes, 1994; Jackson et al., 2014). This ecological extinction (Bak et al. 1984), and overfishing (Jackson et al. 2014) has led to a decrease in grazing pressure on fleshy macroalgae (de Bakker et al., 2017; Mumby et al. 2006) which often results in a shift from coral-dominated reefs to algae-dominated reefs, negatively affecting the productivity and biodiversity of the reef (Wiener et al., 2011). Bleaching during the 1982/82 El Niño event affected about 32% of live coral cover, primarily *Agaricia spp*. and *Montastraea/Orbicella annularis* species, resulting in 53% mortality rate in *Agaricia* cover (Guzman, 2003; Lasker et al. 1984). In the 1990's lionfish, an invasive species, native to the Pacific and Indian Oceans, has been introduced to the Caribbean through the aquarium trade and poses a threat to the reefs, by preying on native herbivory fish species. Increases in sea water temperature, hurricanes and other threats further decreased Caribbean coral cover to below 20% in 2014 (Gardner et al., 2003; Jackson et al., 2014; Hylkema et al., 2021). Worldwide, the decrease of reef fish is an issue, but the relatively low species richness of Caribbean coral reefs makes these reefs even less resilient and more vulnerable to degradation compared to their Indo-pacific counterparts (Bellwood et al., 2004). The status of the coral reefs in the Caribbean combined with the increasing threats makes these reefs practically unable to recover naturally (Goreau and Hilbertz, 2005; Mumby and Steneck, 2008).

Panama, connecting the Atlantic and Pacific Ocean via the famous Panama Canal, has 1295 km of coastline on the Caribbean side. From Punta Cabo Tiburón on the border with Colombia to Punta Boca del Drago, 27 km from Costa Rica, coral reefs, mostly fringing reefs, are present along almost all of this coast, covering a total estimated area of 754 km^2 (Guzman, 2003). A study by Bryant and colleagues conducted in 1998 found that more than 80% of the coral reefs in Panama are at risk because of environmental pressures. A more detailed analysis shows that in the province of Colón, where Portobelo is located, 100% of the reefs are at high-risk (Guzman, 2003; Bryant et al. 1998). This percentage was estimated based on a combination of four threat factors: inland pollution and erosion, overexploitation, marine pollution and coastal development (Guzman, 2003).

1.1 Coral reef restoration

The worldwide decline of coral reefs has drawn attention to mitigation activities, such as coral reef restoration, which aims to return deteriorating coral reefs, as close as possible, to their original state (Clark & Edwards, 1995; Yap, 2000; Edwards, 1998). By restoring coral reefs and identifying and combatting local stressors, these ecosystems get more resilient to global stressors. As reef restoration can be an expensive effort, it is important to conduct profound research to assess both present and past conditions, as well as potential obstacles that might impede the success of the restoration initiatives. Box 1 provides background information on corals.

Box 1 ***Additional information about corals.***

Corals are marine invertebrates that belong to the phylum Cnidaria, they are composed of tiny, individual organisms called polyps. Coral reefs are underwater ecosystems that are formed by the calcium carbonate skeletons of coral polyps, which are tiny, soft-bodied animals that live in colonies. The calcium carbonate is extracted from the seawater and used to create a hard exoskeleton that protects the soft tissue. Corals obtain their energy and nutrients through a symbiotic relationship with unicellular dinoflagellates, from the family Symbiodiniaceae (Goulet et al. 2019), referred to as algal symbionts whereas previously referred to as zooxanthellae. These algae live inside the coral's tissue and produce food through photosynthesis. In turn, the coral provides the algae with a protected environment and the nutrients they need to survive (Leal et al., 2017; Wiener et al., 2011). A distinction can be made between "soft" (Octocorallia) and "hard" or Scleractinian corals, the first being flexible organisms, whereas the latter are also called hermatypic, and are known to build the reef because of the hard skeleton they create. The calcium carbonate exoskeletons provide a hard substrate for the younger coral polyps to live on and to add their exoskeleton to the existing coral structure. Over time, this is how a coral reef gradually grows and forms a complex framework, providing a three-dimensional habitat for marine life to live. Corals reproduce both sexually and asexually. Sexual reproduction occurs when coral polyps release eggs into the water, which can then fertilize and form new coral larvae. Asexual reproduction occurs when the coral polyp divides into two or more smaller polyps, also referred to as fragmentation. The branching *Acropora* corals are for example more prone to physical breakage due to their growth form, making fragmentation the predominant natural dispersal method (Wallace, 1985).

Most corals only grow in shallow areas with clear water, due to their need for sunlight for photosynthesis. The colours of the corals are caused by the algal symbionts and when they become stressed, the algae can leave the polyp, leaving the white skeleton behind. This is referred to as bleaching, a process that mainly occurs when the seawater temperature becomes too high. The algal symbionts might return when the temperature decreases again, but the coral dies if that is not the case. A narrow window of ecological conditions, consisting of depth, temperature and salinity, determines coral growth and survival (Wiener et al., 2011). Generally, a healthy coral reef is dominated by a variety of reef-building corals and crustose coralline algae, accompanied by a diverse community of fish, molluscs, crustaceans and other marine life (Wiener et al., 2011).

A well-known restoration strategy is based on the forest silviculture principles, often referred to as "coral gardening", where corals are being farmed in nurseries and out-planted on degraded sites, to kick-start the recovery of those reefs (Epstein et al., 2003). This strategy is often combined with the use of Artificial Reefs (AR), which can be defined as "submerged structures deliberately placed on the seabed to mimic some functions of a natural reef" (Hylkema et al. 2020; Baine 2001). These structures provide a hard substrate for the corals to settle on and habitat complexity for other organisms to live in and around. The corals from the nurseries can be out planted on such hard structures, or these structures themselves can be used as nurseries. These two restoration practices are considered active restoration, which is generally more expensive than passive restoration, which entails conservation practices, such as the implementation of Marine Protected Areas (MPAs) (Baine 2001).

The coral gardening methodology has proven to be a successful approach at different scales in the Caribbean (O'Donnell et al. 2017; Young et al. 2012; Lirman et al. 2010; Bowden-Kerby, 2001). The species *Acropora cervicornis* (staghorn coral) is used most commonly due to its natural propensity to fragmentation and rapid growth rate (Shafir et al. 2006; Bowden-Kerby, 2001). In the 1980s in the Caribbean, *Acropora cervicornis* and *palmata* (elkhorn and staghorn corals) formed dense, three-dimensional patches between 5 and 20 meters depth, significantly contributing to reef formation (Jackson, 1992; Shinn 1966; Bruckner 2002), but currently they are on the United States Endangered Species List (Jackson et al., 2014).

1.2 Reef2Reef

The coral reef restoration project and Non-Governmental Organisation (NGO) Reef2Reef was established in 2018 and is located in Portobelo National Park. It is a public-private partnership between the Maritime University of Panama and the dive centre ScubaPanama. Reef2Reef's mission is to advance environmental and biodiversity goals through restoration and conservation practices, involving and educating the local community and visitors and contributing to and utilizing science, thereby creating a society aware of and committed to caring for our ocean.

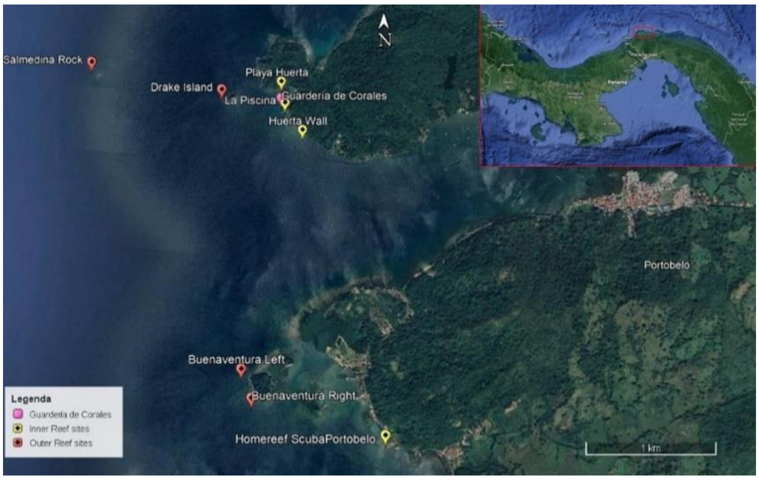


Figure 1 Portobelo Bay, with the coral garden (Guardería de Corales) and the Inner (yellow) and Outer (red) dive sites.

In 2018, the first reef restoration structures were built and placed on a sandy area what is now called the coral garden, within the national park, near Playa Huerta (Fig.1). *Acropora cervicornis* fragments were obtained by extracting 10% of three coral colonies located on both sides of the bay of Portobelo and placed on the coral nurseries and artificial reefs. Currently, they have 10 clothesline nurseries with 551 fragments of 12 different genotypes of staghorn coral in development and 164 colonies ready for replanting. In addition, there are 12 artificial reef structures, consisting of 4 different designs, each design having three replicates in the water. Designs include traditional rebar minidomes, Endless Reef modules, developed by Boskalis and two concrete structures, MOSES, developed by ReefSystems and Reef balls (Fig.2). These artificial structures were placed in the coral garden area as part of the Panama pilot project from Boskalis, which aimed to compare the performance of four different artificial reef types under the same conditions in the same environment.

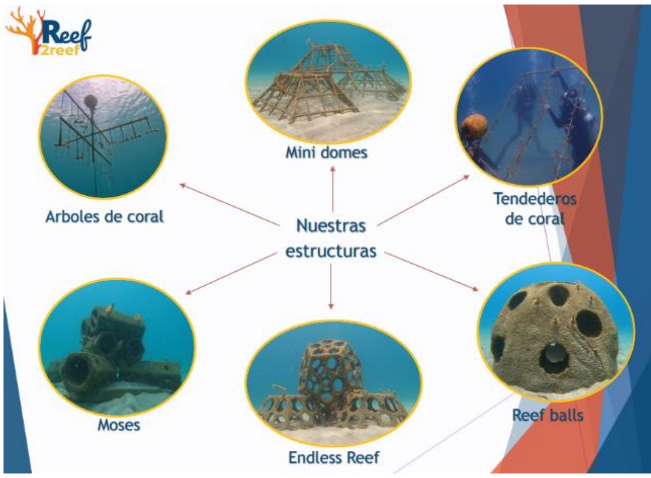


Figure 2 Nurseries and AR designs deployed by Reef2Reef.

1.3 Objectives & Research Questions

The state of the ecosystem is decisive in which combination of conservation or restoration strategies to apply. When the natural recovery of the reefs is insufficient, and ecological conditions of the area offer promise, restoration practices should be initiated (Hein et al., 2019). To ascertain the potential success of restoration practices, the causes of coral reef degradation need to be understood and mitigated (Edwards, 2010). Community engagement plays a vital role across all project stages and the utilization of local knowledge is emphasized in land- and watershed-based restoration projects (e.g. McGinnis et al., 1999; Dhillion et al., 2004) and has been shown to boost acceptance of conservation efforts and fasten the implementation of management strategies (Danielsen et al., 2010; Guzman, 2003). Enhancing awareness and involvement holds the potential to foster greater environmental stewardship, subsequently leading to more sustainable utilization of the ecosystem and long-term community support, as demonstrated by the insights provided by Kittinger et al. (2016). As socio-economic and ecological parameters are often closely linked, it is recommended to monitor both in the same place and at the same time (Hill and Wilkinson, 2004).

This study aims to achieve an understanding of the ecological status of the reefs, by assessing the community composition of the reef, and to provide a baseline study on the public's perception and awareness regarding the status of and threats to the reefs and coral reef restoration. This research topic is influenced by and extends a study by Bernal et al. (2023), which emphasizes the necessity for further investigations along the coastline of Portobelo National Park to enhance our understanding of the coral reef ecosystems within this region and suitable nursery and outplant locations. They also mention the importance of environmental education to increase awareness, as there have been problems with damaged structures due to a lack of knowledge about the purpose of those structures.

In summary, the aim of this internship was to gain valuable insights into the current status of and threats to the coral reefs, identify suitable outplant locations, and assess the social support from both the local community and visitors, by addressing the following research questions:

Ecological Status

- What is the current state of the coral reefs in the Portobelo area?
  - What is the benthic composition of the reefs?
  - What is the coral species richness and diversity of the reefs?
- What are the main threats to the coral reefs in the Portobelo area?
- Which sites in Portobelo are considered most suitable for restoration efforts?

Awareness & Perception

- To what extent are inhabitants of Portobelo and visitors aware of the status of the reefs in this area?
- To what extent are inhabitants and visitors aware of threats to the reefs in this area?
- What are inhabitants' and visitors' perceptions towards coral reef restoration?

2. Material & Methods

2.1 Site Description

2.1.1 Portobelo

Reef2Reef is located at ScubaPortobelo, a dive school and hotel near the town of Portobelo. Portobelo is a small harbour town located on the Caribbean coast of Panama in the province of Colon, approximately 80 km northwest of Panama City (Fig.1). Christopher Columbus arrived here in 1502 and called the place “Puerto Bello”, meaning “Beautiful Port”. During the colonial era, Portobelo was a crucial trade hub for the Spanish Empire, through which silver and other valuable goods from South America were transported to Europe. An abundance of coral reefs in the coastal region of Portobelo made corals an accessible and practical building material in the construction of fortifications to fend off pirate attacks. In 1980, the fortifications were declared World Cultural Heritage by UNESCO (Gúzman, 2003).

The district of Portobelo counts about 10.000 inhabitants, whereas the town inhibits about 5000 inhabitants, according to the population census from March 2010 (Abel Díaz, Ofice du Turismo Portobelo). The average annual income is 1515 balboas/dollars, 60.5% of the population in this area receives less income than the basic family income baseline. There has been a perception and often a reality of unequal development and support between the Caribbean coast and the Pacific coast in Panama. Historically, the Pacific side of Panama has received more infrastructure investment, economic development, and governmental attention compared to the Caribbean coast (Sigler, 2014).

Portobelo experiences a tropical climate, characterized by high temperatures and humidity throughout the year. The average annual temperature ranges from 24°C in higher areas to 27°C in coastal and lowland regions. The region has distinct wet and dry seasons, with the rainy season lasting from May to December, bringing an estimated 250-700 mm of rainfall. The area’s climate variability is influenced by factors like the El Niño Southern Oscillation, sea surface temperatures, and tropical cyclones. Portobelo's topography is characterized by irregularities, featuring hills and slopes with gradients exceeding 45º. The region's geological features consist of volcanic-origin rocks, including tuffs and lavas with andesitic and basaltic compositions (Guzman, 2003). Upwelling does not affect the Caribbean waters in this area but strong runoff from rivers and rainfall causes nutrients to enter the ocean (Cubit et al. 1989).

2.1.2 Portobelo National Park

Panama boasts a vast marine area spanning 331.318 km2, delineated by its exclusive economic zone (EEZ). Within this expansive territory, 21% has been designated for protection from fishing activities (Marine Protection Atlas, accessed January 2023, Fig.3). The Portobelo National Park was established on December 22, 1976, and in 2004 its limits were defined, covering 35,929 hectares, of which 22.4% is marine area. Tropical rainforests, islands and coastal ecosystems, consisting of mangroves, seagrass fields and fringing reefs, with 53 coral species occurring over 70km of reef area, extending 2,000 m seaward, fall within the boundaries of the park (Guzman, 2003; Bernal et al., 2023).

Marine Protected Areas (MPAs) around the world and in Panama have frequently earned the label of so-called “paper parks”, implying that their establishment is often more symbolic on paper than effective in practice (Gissi & Chapman, 2014). Overcoming the “paper park” syndrome requires a holistic approach involving community participation, effective monitoring, proper funding, capacity building and strong legal frameworks (Wood et al., 2008).

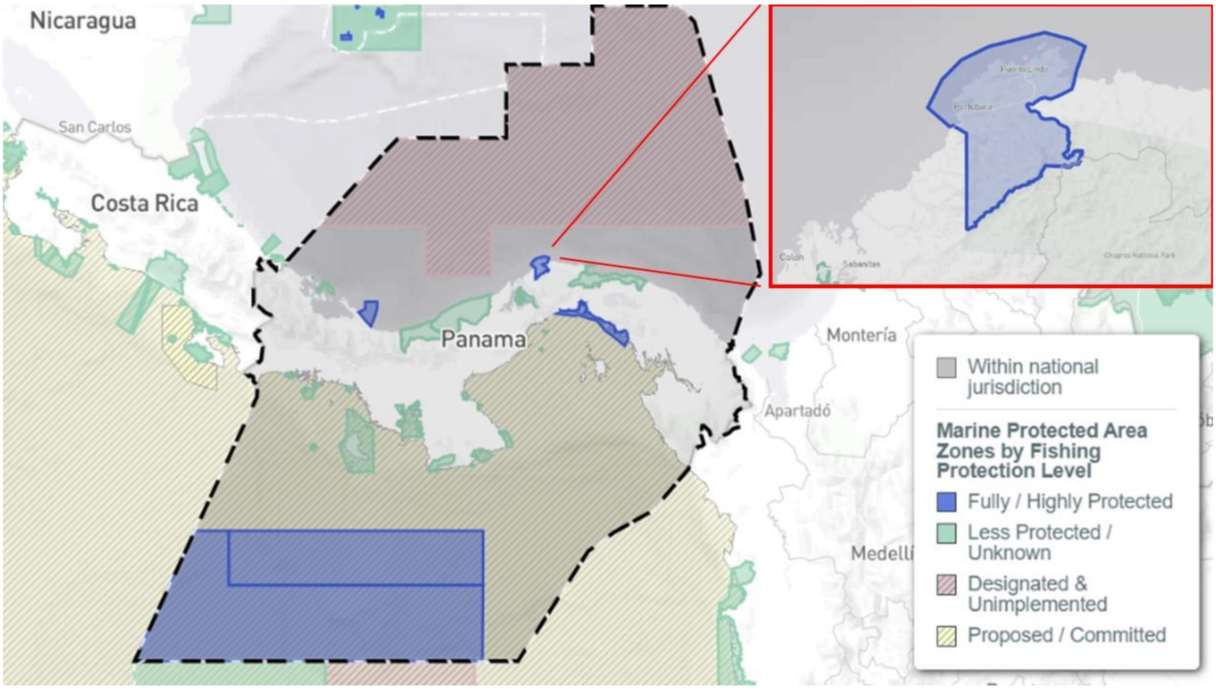


Figure 3 Marine Protected Areas of Panama, zoomed in on the Portobelo National Park. Source: Marine Protection Atlas

2.2 Public Awareness & Perception

The social research was conducted in February and March 2023. Questionnaires were designed to gain insights in the awareness and perception of both the local community and visitors regarding the current status of the reefs and coral reef restoration practices. In the context of this study, the term 'awareness' is defined by the following dictionary reference: "knowledge that something exists, or understanding of a situation or subject at present based on information or experience" (Cambridge Dictionary, 2019). Similarly, the definition of 'perception' is elucidated as " a belief or opinion, often held by many people and based on how things seem " (Cambridge Dictionary, 2019).

Two interview questionnaires, containing a mix of open and closed questions, were employed as the data collection method. The open-ended questions allowed people to express their points of view in their own words (McLafferty, 2003). These questionnaires were available in Spanish and English (Appendix A) and were based on a similar study conducted for the coral reef restoration project REEFolution in Kenya and Indonesia (Rokhmah, 2022; Bartholomeus, 2019). Two versions of the questionnaires were prepared: one for visitors and another for the local residents of Portobelo. To ensure consistency and comprehensibility, the questionnaires underwent testing, making slight adjustments based on feedback received from individuals at ScubaPortobelo (Groves et al., 2011). Visitors were given the option to complete the questionnaire on their phones or fill it out collaboratively. The inhabitants of Portobelo were interviewed, with their responses recorded via an online form.

The sampling strategy employed a combination of convenience and snowball sampling, involving engaging random individuals in public areas and following up on contacts suggested by participants (McLafferty, 2003). Abel Díaz from the Tourism Office provided invaluable assistance as a guide through town and as a translator. Each interview lasted approximately 15 minutes. Participants were assured that their identities would remain entirely confidential during the analysis and communication of the collected data. Each completed questionnaire was assigned a unique code, incorporating the interviewee's number, date, and location. Throughout the process, respondents were given the freedom to share as much as they wished, and it was emphasized that there were no right or wrong answers.

Questions concerned ecosystem services acquired from coral reef ecosystems, threats to coral reefs and the importance of the reefs and coral reef restoration. The latter is about attitudes and opinions, for which the Likert scale has been used as a fixed-response format. An odd number of responses, in this case five, presents two extreme responses in opposing positions and the middle value represents a neutral opinion (Groves et al., 2011).

To enhance visibility and participation, informative posters containing a QR code linking to the online questionnaire form were placed at various tourist sites in Portobelo, including ScubaPortobelo, El Castillo, El Bongo, Casa Congo, Casa Vela, Rico Rico, Morgan's Cave, Hostel Portobelo, souvenir shops, and a local Chinese restaurant. Additionally, the questionnaire link was distributed to the Reef2Reef VIP volunteer group and shared through ScubaPanama. To engage younger locals, the questionnaire was shared with Escuelita del Ritmo, and a visit, combined with an educational presentation to the high school, was planned.

In total, the research included 56 interviews with the inhabitants of Portobelo and 59 with visitors. The questionnaire results are available in Appendix B and summarized in 3Results – Public Awareness & Perception. The responses have been presented descriptively using percentages to illustrate the distribution of answers. Statistical analyses were not applied due to the specific nature of the study and the research objectives.

2.3 Ecological status

2.3.1 Field data collection

The ecological research was conducted from January to March 2023. To gather information about the status of the reefs, eight dive sites, of which four can be categorized as inner reefs and four as outer reefs, have been monitored (Fig.1). The term inner reef refers to fringing reefs that grow out from the shore or those that are separated from the shore by a shallow lagoon. These reefs are often parallel to the coastline and are mostly very shallow. With low tide, they (nearly) reach the water's surface. The outer reefs are located further offshore from the coastline, often at the edge of a continental shelf or in deeper waters, where the ocean depth increases significantly from the coastline. The outer reefs tend to have a steeper slope and deeper depths compared to the inner reef and are usually exposed to stronger ocean currents, waves, and open-sea conditions (Allen Coral Atlas' geomorphic map accessed: January 2023). The inner reef provides information on the conditions where the coral nursery and the Panama pilot are located. The outer reefs represent the areas where the natural *Acropora* colonies are located (Fig.1). A comparative assessment of a series of sites was executed to provide information on which areas are most suitable for out planting of the coral fragments. The general condition of the reefs was assessed, by looking into the benthic composition, live hard coral cover, species richness and Shannon Diversity Index (SDI).

At each dive site, six point intercept transects of 10 meters with an interval of 20 cm were conducted. Additionally, picture quadrats were used, capturing 50 images of a 20 cm by 20 cm PVS quadrat per transect. These pictures served as a backup and enabled post-dive analysis thus reducing the required bottom time. Along each transect, the benthos type at every 20 cm interval beneath the measurement tape was identified. This resulted in 300 point intercepts per dive site. Transects were placed parallel to the shore at the depth range that was available or most suitable at that specific site. In general, as this research aimed to identify suitable coral restoration outplant locations, the depth ranges between 3 to 10 meters. A GoPro 7 and GoPro 9 were used to obtain the images. This methodology is based on and adapts similar techniques used in other studies (Newman et al., 2006

Knoester et al. 2023, Guzman, 1991) and recommended by the Global Coral Reef Monitoring Network (GCRMN).

During the transect surveys and afterwards, during the analysis of the photographs, a rough and preliminary assessment of the coral colonies' overall health was conducted. The presence of any signs of diseases, as well as observations of other marine invertebrates including predatory organisms, were recorded. Additionally, coral recruitment was quantified by counting coral colonies smaller than 4cm, to exclude the possibility that colonies were derived from fragments through fragmentation (Bak and Engel, 1979).

2.3.2 Organism and substratum identification

Organisms and inorganic substrata encountered every 20 cm beneath the transect line were classified into functional groups, including hard corals, soft corals, sponges, macroalgae, crustose coralline algae (CCA), and 'other' (encompassing rubble, bare substrate, mud or sand and tunicates). Fleshy macroalgae primarily comprised *Lobophora spp*. and *Dictyota spp*. The identification of live hard (Scleractinian) corals extended to the genus level and when the distinction between species within a genus was possible, corals were visually identified to both genus and species levels. The Atlantic and Gulf Rapid Reef Assessment (AGRRA) protocol (Lang et al., 2015) facilitated hard coral species identification. Fire corals, *Millepora alcicornis* and *Millepora complanata* were grouped under hard corals. In the case that the point intercept would fall on soft coral plumes, fish or motile invertebrates (like sea cucumbers), these were not quantified but rather the substratum beneath them. When groups would overgrow each other, only the overgrowing group was scored.

2.3.3 Data Analysis

The percentage cover of each benthic group was computed by dividing the number of points falling on that organism type by the total number of points per transect (300 points). Pie charts provide a visual representation of the distribution per benthic group per site. 95% confidence limits have been calculated for the percentage hard coral cover per site. Analysis of Variance (ANOVA) and a post hoc test (Tukey HSD) was performed on the percentage hard coral cover data to identify significant differences among sites. Data processing and statistical analyses were conducted using the R programming environment v4.2.0 with the *vegan* package. Shannon-Weaver Diversity and Species Richness indices were computed across all identified hard coral species. Species richness provides information about the number of different species present at each site. For species richness, a saturation curve was plotted to visualise how increased sampling effort correlates with the discovery of additional species (Gotelli & Colwell, 2001). The addition of the Shannon Diversity Index allows for a more nuanced comparison, as it considers both species richness and evenness, which is the relative abundance of each species, taking into account how evenly or unevenly the species are distributed. This helps to identify sites with distinct ecological characteristics and potential restoration and conservation priorities. High Shannon Diversity indicates a more balanced community where no species dominates, while low diversity may suggest dominance by a few species. The minimum value is 0, indicating a completely homogenous community. The maximum value is not precisely defined, but rarely exceeds a value of around 4 to 5 for natural communities (Jost, 2006; Gotelli & Colwell 2001; Magurran, 2004; Krebs, 2014).

2.3.4 Fish biomass

Within this study, it was intended to include a fish biomass assessment per study site. Assessments were done through Underwater Visual Censuses (UVCs), using a modification of the stationary point count (Bohnsack and Bannerot 1986). Due to initial camera absence, limited bottom time and challenging conditions such as poor visibility caused by high turbidity, UVCs were conducted only on a few sites. Additionally, some of the recorded data went missing. Consequently, it was decided to exclude fish biomass assessment from this research. Nevertheless, the limited data collected will be made available as supplementary material. Future research is strongly encouraged to incorporate fish biomass assessment and monitoring to gain a more comprehensive and holistic understanding of the reef's status.

SCUBA divers performed the surveys, one recording the fish data on a slate, while the other documented the survey for future reference. During each UVC, the divers approached the plot horizontally, recording fish as soon as the reef was within 5 meters. A virtual cylindrical column, extending 1 m sideways from the plot and 2 meters upward from the bottom, encompassed all fish included in the survey. All fish were counted and identified to species level and categorized based on visual estimation of total fork length. For smaller fish (less than 20 cm), size classes of 5 cm intervals were used, while larger individuals were grouped into 10 cm size classes. Each UVC lasted for 2 minutes, after which the reef was examined to record all fish residing within its internal spaces. Surveys were conducted during daylight, at least 2 hours after sunrise and 2 hours before sunset (Hylkema et al., 2021; Hill & Wilkinson, 2004). To account for the dynamic nature of moving fish and ensure comprehensive data collection, the objective was to conduct 10 UVCs per site, distributed over the three-month data collection period.

2.3.5 Suitable out-plant sites

A specific set of conditions, consisting of both biotic (living) and abiotic (non-living) factors, is needed for corals to thrive in the Caribbean. Biotic (living) factors include for example a sufficient supply of sunlight for photosynthesis, the availability of food sources such as zooplankton, and the presence of symbiotic algae. Abiotic (non-living) factors include a suitable temperature range, typically between 22 and 29 degrees Celsius, a pH level between 8.1 and 8.4, and a salinity level between 33 and 37 parts per thousand. In addition, low levels of suspended sediments, pollutants and pathogens are favourable for coral growth (Hill & Wilkinson, 2004). Additionally, to select a suitable site to out-plant corals that have been grown in nurseries, some other factors should be considered to ensure the long-term survival of the transplanted corals.

Out-plant requirements for Acropora cervicornis

First of all, the chosen site should have a healthy and suitable substrate, like rock, or coral skeletons, for the coral to attach to. Another option is to apply artificial reefs in areas that are dominated by sand (Bostrom-Einarasson et al., 2020), whereas substrate stabilization could be used in areas with a lot of coral rubble (Hein et al., 2019). In addition, algae removal can create a more suitable substrate for the coral to attach to (Bostrom-Einarasson et al., 2020). The selected site has to be within the preferred depth range for the coral species. For *Acropora cervicornis*, shallow areas between 3 and 10 meters are recommended, where they receive sufficient light for photosynthesis. Ideally, a site that is less susceptible to human disturbances is recommended. The genetic diversity of the staghorn population should be considered to enhance resilience against environmental stressors. It is important to comply with local laws, regulations and permits related to coral restoration in the area. Accessibility to the site is another factor, as regular monitoring of the out-planted corals should take place and the transfer from the nursery to the outplant sites should not exceed 30 minutes (Mercado et al. 2015). The absence of signs of diseases and predation should also be considered (Link et al., 2015).

The requirements for out-plant sites, combined with the information obtained about the different sites, are being structured and visualised in a table to provide an overview and recommendations for suitable out-plant sites. The terms 'low', 'moderate', and 'high' were assigned to each site based on a qualitative comparison relative to one another.

3. Results – Public Awareness & Perception

This research encompassed a total of 115 participants, comprising 56 inhabitants and 59 visitors, who were interviewed to obtain insights into their awareness regarding the status of coral reefs and their perceptions of coral reef restoration.

3.1 Respondent's social profile

The initial segment of the questionnaire aimed to gather demographic information to provide a comprehensive background of the interviewees.

3.1.1 Inhabitants of Portobelo

Among the interviewed inhabitants, 46% identified as female, while 54% identified as male. The age distribution revealed that the majority (64%) fell within the 20 to 40 age range, followed by 27% in the 40 to 60 range. A small percentage (5.5%) was aged 60 and above, with an even lower percentage (3.6%) below 20. The schools had holidays during the first period of this research. Notably, due to unforeseen circumstances, the planned educational activity related to coral reef restoration involving school students was cancelled. The questionnaire and presentation materials remain available, presenting an opportunity for future engagement and achieving a more balanced respondent social profile. Regarding the place of birth, 55.6% of the interviewees were born in Portobelo, while 22.2% had recently moved to the area. The remaining participants had been residing in the town for durations ranging from 5 to 20 years. In terms of educational attainment, 60% had completed high school, 27.3% held a bachelor's degree, and one respondent reported having a master's degree. The predominant occupational categories included hospitality and tourism (48.2%), boat drivers (25%), individuals with public functions (14.3%), fishermen (8.9%), unemployed (10.7%), and those engaged in construction (7.1%) (Appendix B: Section A).

3.1.2 Visitors

Among the interviewed visitors, 61% were male, and 39% were female. The age distribution indicated that 57.6% fell within the 20 to 40 age range, followed by 32.2% in the 40 to 60 range, and 10.2% above the age of 60. The majority of visitors originated from within Panama (47.5%), while 32.2% came from Europe, 11.9% from North America, and 5% from South America. In terms of the duration of stay, 34% of the visitors remained in the area for a few days, another 34% for over a week, and 22% were day visitors. The primary motivations for visiting Portobelo were diving and snorkelling (34%), followed by beaches (22%), sailing (12.6%), and cultural exploration (14%). The majority (45.8%) held a bachelor's degree as their highest level of education, while 32.2% had a master's degree, 11.9% had completed high school, and 5% possessed a PhD. The prominent occupational groups included hospitality and tourism (12.7%), science and education (12.7%), construction (12.7%), health care (8%), finances (8%), students (6.4%), and legal services (6.4%) (Appendix B: Section A).

3.2 Awareness of coral reefs and their status

The second section of the questionnaire consisted of people their self-reported knowledge about coral reefs followed by a more detailed characterization of awareness, where they were actually 'tested' on their knowledge.

3.2.1 Inhabitants of Portobelo

A large majority (80.4%) of the interviewees had seen the reefs in the area of Portobelo. Among those who had seen the reefs, most of them (60.9%) reported seeing them from a boat, followed by 39.1% who had seen corals as building materials in the old buildings and fords around town. A notable proportion (56.5%) had observed the reefs while swimming and snorkelling, while a smaller fraction (15.2%) had experienced them through Scuba diving. It's important to note that respondents were allowed to select multiple answers, meaning that their experiences may overlap.

Respondents who had seen the live reefs were asked to rate the status of the reef, based on colour, marine life, absence and presence of algae, on a scale from 1 to 5, ranging from 'very bad' to 'very good'. Pictures were shown with this question as a visual aid to present distinct stages or conditions of coral reefs, facilitating interviewees' comparative assessment of their personal experiences with these reef states. 9.1% of the interviewees rated the condition of the reefs as 'very bad', followed by 6.8% as 'bad', 31.8% as 'neutral', 22.7% as 'good' and 29.5% as 'very good' (Fig.4A).

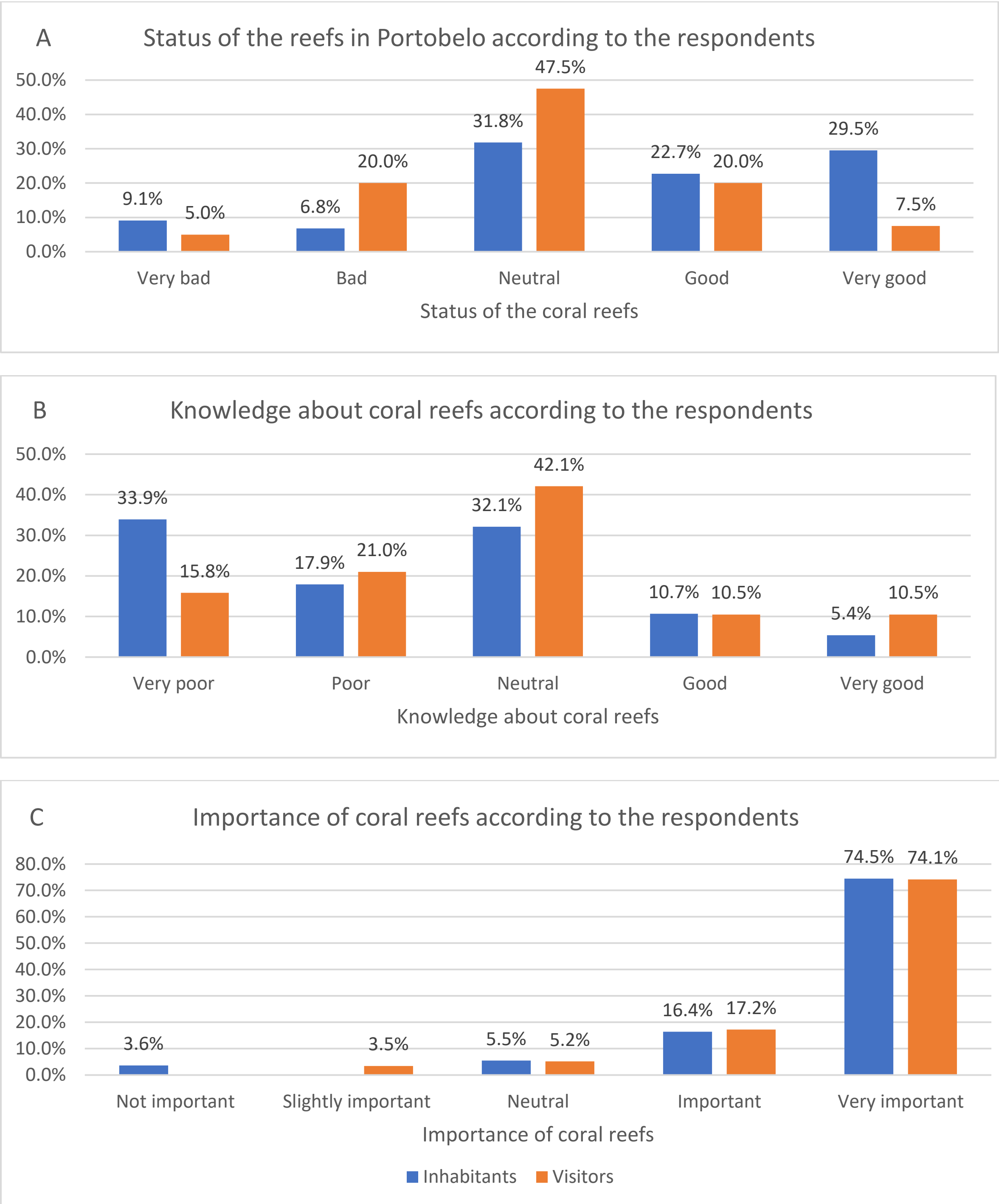


Figure 4 A: Status of the reefs in Portobelo according to inhabitants and visitors. B: Self-assumed knowledge about coral reefs according to inhabitants and visitors. C: Importance of coral reefs according to inhabitants and visitors.

Participants were also asked to rate their knowledge of corals, with responses distributed as follows (Fig.4B): 'very poor' (33.9%), 'poor' (17.9%), 'neutral' (32.1%), 'good' (10.7%), and 'very good' (5.4%). When asked to define what a coral is, the majority (62.5%) incorrectly identified it as a rock, while 19.6% described it as a plant, and 16.1% recognized it as an animal, with 16.1% indicating uncertainty. Despite the misconceptions regarding the nature of corals, approximately three-quarters of the interviewees (74.5%) deemed coral reefs 'very important', 16.4% as 'important', 5.5% as 'neutral', and only 3.6% as 'not important' (Fig.4C). Interesting observations during the interviews underscored the need for increased ecological awareness. For instance, one interviewee, a chef in a Portobelo restaurant, paradoxically deemed coral reefs as 'not important' while preparing octopus, a dish made possible by the reefs. Additionally, another respondent, seemingly indifferent to the significance of coral reefs, casually discarded a Coke can into the natural environment during the interview.

The subsequent questions were open-ended to avoid influencing responses, with answers categorized thereafter. The primary reasons cited for the importance of coral reefs included 'Marine life' (39.7%), encompassing responses such as 'refuge for marine species', 'nursery grounds for fish', and 'essential for marine life'. Approximately 20.6% of participants did not specify a reason, while 10.3% highlighted the role of reefs as integral components of the ecosystem. Aesthetic aspects of coral reefs were mentioned by 8.8% of respondents, while 7.4% emphasized coastal protection. Additional reasons included tourism (5.9%), the significance of reefs as a food source (5.9%), and 1.5% associating the importance with cultural benefits (Fig.5A).

Another open-ended question aimed to assess awareness of threats to coral reefs in the Portobelo area (Fig.5B). 32.9% of the participants reported to have no knowledge of any threats. The most frequently mentioned threats were garbage, particularly plastic waste (15.8%), and pollution encompassing sewage, chemicals, and oil spills (13.2%). Other threats identified included boat-related factors, such as fuel and anchoring (9.2%), varied fishing practices, including illegal fishing, fishing nets, aquarium fisheries, coral extraction, and octopus fishing (9.2%). Tourism (6.6%) and climate change (3.9%), particularly in terms of rising sea temperatures, were also cited as threats, as well as the presence of invasive species such as lionfish (3.9%). The remaining responses, constituting 5.3%, included soil erosion, construction, lack of maintenance and dredging (Fig.5B).

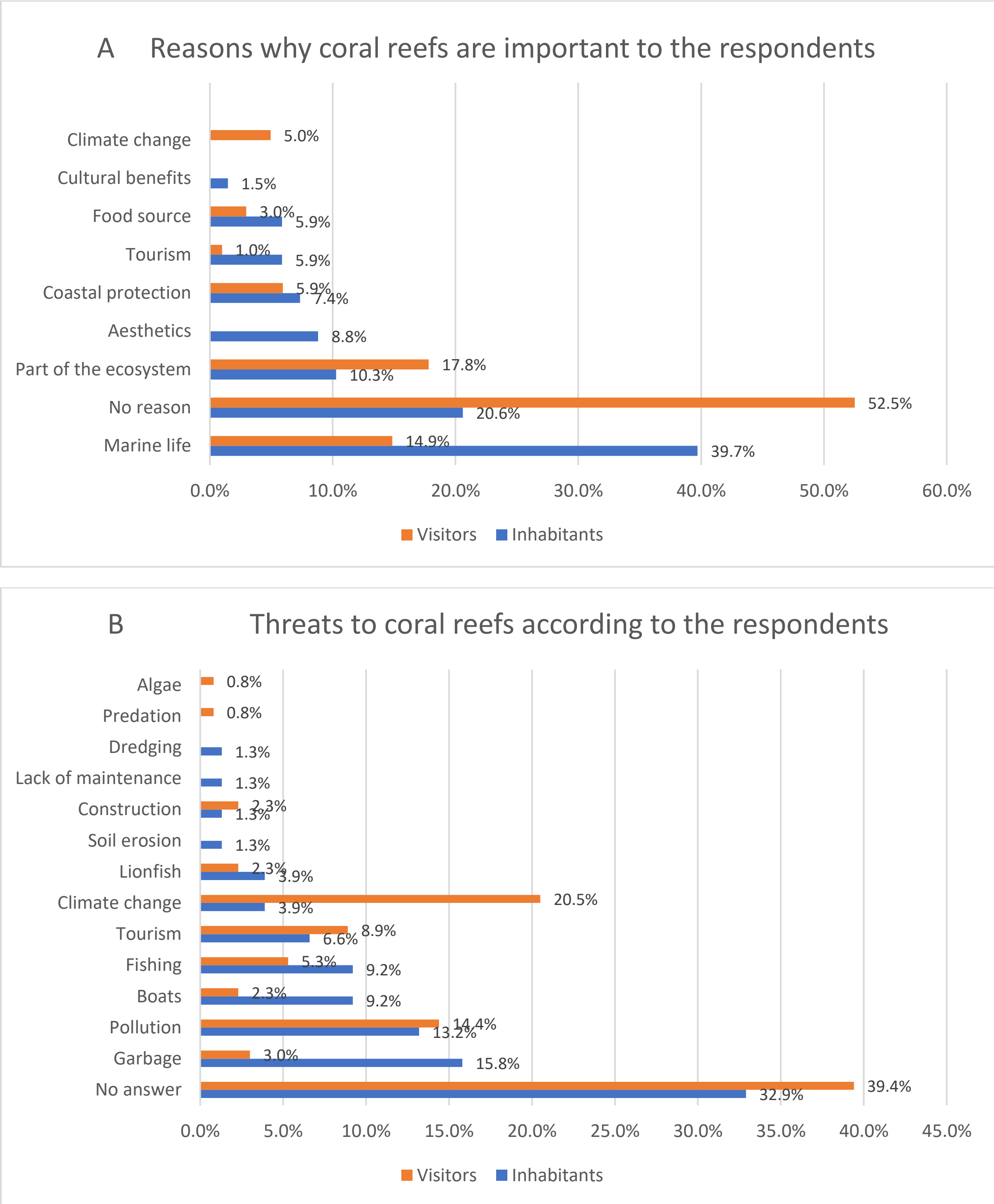


Figure 5A: Reasons why coral reefs are important to the respondents. B: Threats to coral reefs mentioned by respondents.

3.2.2 Visitors

Among the interviewed visitors, a significant proportion (70.7%) reported having observed the reefs in the study area. Of these, 46.3% experienced the reefs through scuba diving, 28.4% via snorkelling, 10.5% from photographs, and the remainder from different perspectives such as boats, use of coral as a building material, and fishing. When asked to evaluate the state of the reefs in the area, 5% indicated ‘very bad’, 20% ‘bad’, 47.5% of the respondents expressed a 'neutral' opinion, 20% ‘good’ and 7.5% ‘very good’(Fig.4A).

Among the divers, 31.6% reported diving over 20 times in the area, 26.3% over 10 times, 26.3% fewer than 5 times, and 13.2% only once. When respondents recalled dive site names, Salmedina Rock and Drake Island were most frequently ranked as 'good' and 'very good', each accounting for 40% of the votes. Conversely, Playa Huerta, Huerta Wall, and Home Reef Scuba were commonly rated as 'bad', with percentages of 18.2%, 16.7%, and 31.2%, respectively (Fig.6).

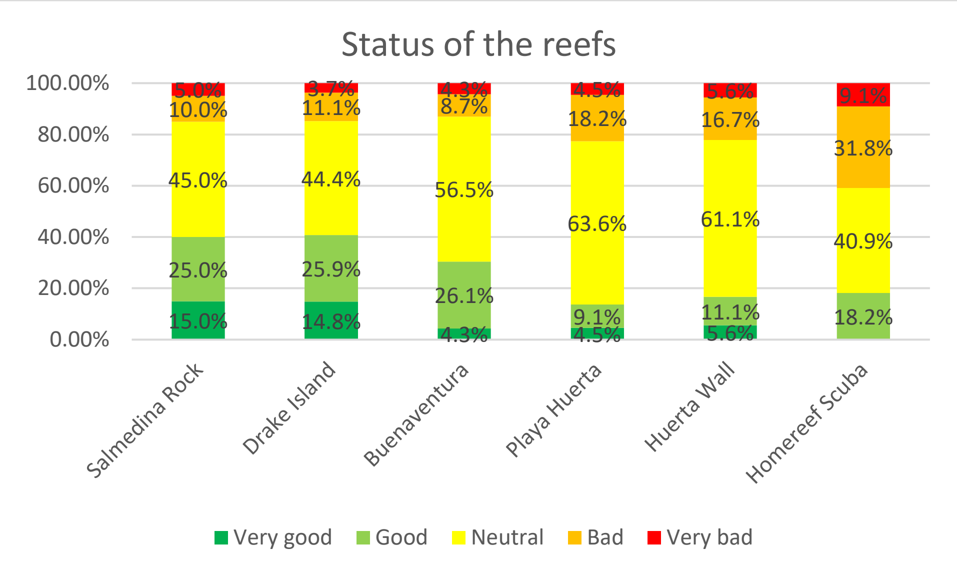


Figure 6 The status of the reefs at different dive sites according to visitors.

Regarding coral knowledge, 15.8% of the visitors assessed their understanding as ‘very poor’, 21% as ‘poor’, 42.1% as 'neutral', 10.5% as 'good' and 10.5% as 'very good' (Fig.4B). A notable majority (60.3%) correctly identified corals as animals, while 24.1% believed they were plants, 12% thought they were rocks, and 3.5% were uncertain (Appendix B, section B).

Approximately three-quarters of respondents (74.1%) considered coral reefs to be 'very important', 17.2% as 'important', 5.2% as 'neutral', and 3.5% as 'a little important'. Notably, a significant portion (49.5%) did not provide a reason for the perceived importance. Among those who did, the most common rationale was that coral reefs are integral components of the ecosystem (17.8%), followed by the importance of reefs for marine life (14.9%) and coastal protection (5.9%). Other reasons mentioned included combatting climate change (5%), which also consisted of answers regarding coral reefs producing oxygen and acting as carbon sinks, which is a misconception as reefs are net producers of CO_2 and contribute to acidify the ocean (Frankignoulle et al., 1994; Ware et al., 1992). Coral reefs being a food source made up 3% of the answers, and the value of coral reefs for tourism 1% (Fig.5A).

Furthermore, 39.4% of the interviewees indicated a lack of awareness regarding threats to coral reefs in the area. Among those who identified threats, climate change was mentioned by 20.45%, followed by pollution (13.8%), and tourism impacts (8.9%). Additional threats mentioned included fishing practices, garbage, lionfish, boats, construction work, predation, and algae (Fig.5B).

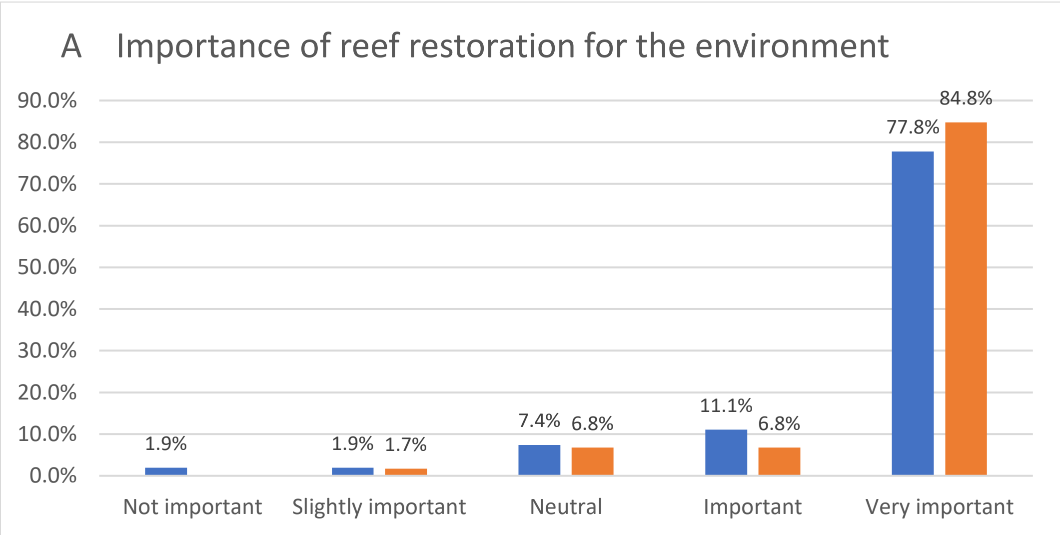
3.3 Perception of coral reef restoration

In general, both among inhabitants and visitors, there exists a positive perception of coral reef restoration efforts.

3.3.1 Inhabitants of Portobelo

The open-ended question aimed at understanding people's knowledge of coral reef restoration resulted in a majority (80.5%) of participants providing no response or expressing uncertainty. A much smaller proportion of the participants (6.1%) mentioned the restoration project at ScubaPortobelo. Another 6.1% expressed the view that coral reef restoration is beneficial for both the environment and society. A few respondents (4.8%) indicated that they believed restoration efforts were challenging and time-consuming, and one individual (2.4%) stated that such a project does not exist in the area (Appendix B, fig.11).

Participants were also asked to rate the importance of coral reef restoration for the environment on a scale from 1 (not important) to 5 (very important). A majority (77.8%) considered coral reef restoration 'very important' for the environment (Fig.7A). A similar question was posed regarding the importance of restoration for the community, with 75.9% of the interviewees rating it as 'very important' (Fig.7B).



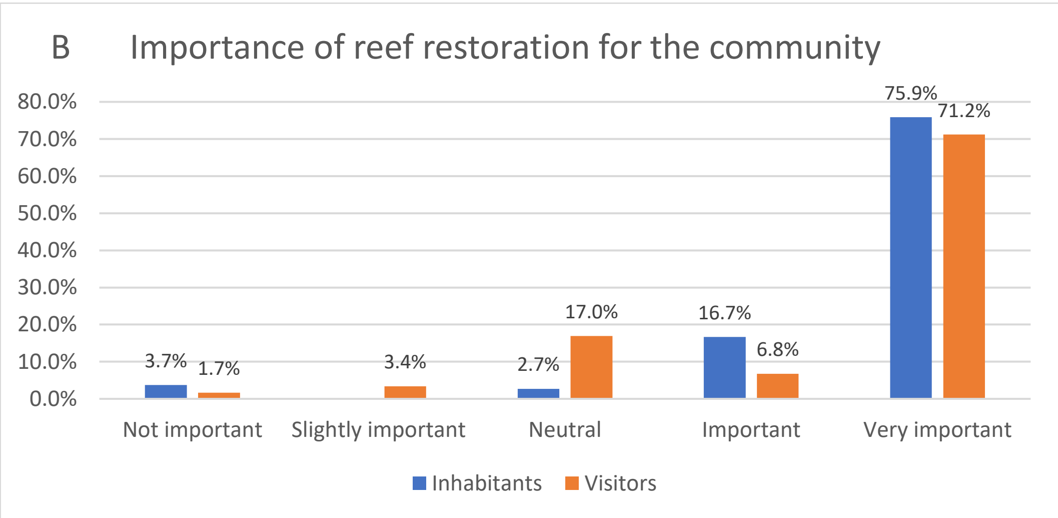


Figure 7A: Importance of coral reef restoration for the environment according to the respondents. B: importance for the community according to the respondents.

To gauge support for the coral reef restoration project in the village, interviewees were asked if they would be willing to assist in reef restoration efforts. A majority (62.5%) answered 'yes', 33.9%

responded 'maybe', and 3.6% answered 'no' (Fig.8A). Concerning awareness of the ongoing coral reef restoration project "Reef2Reef," 23.3% of the respondents had heard of it (Fig.8B).

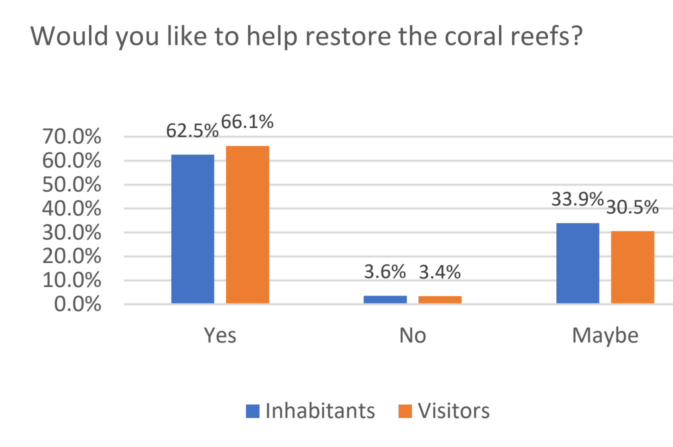
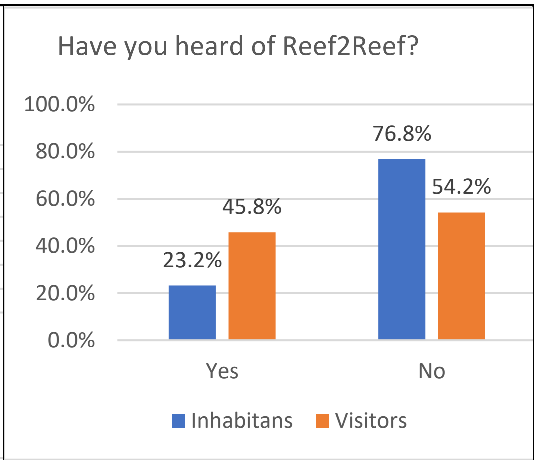


Figure 8A: Responses regarding willingness to contribute to coral reef restoration.



8B: responses regarding awareness about the coral reef restoration project Reef2Reef.

After a brief explanation of this research and the work of Reef2Reef, the final open-ended question invited respondents to share their thoughts on this research and Reef2Reef. Among the 42 respondents who provided input, 54% emphasized the importance of the project in the area, with expressions of gratitude and encouragement. An additional 18.9% highlighted the significance of involvement and awareness, while another 13.5% mentioned the potential positive impact on tourism. An equal proportion (13.5%) expressed expectations of town development as a result of the project (Appendix B, fig.13).

3.3.2 Visitors

Among the interviewed visitors, one-third (33.3%) reported having no knowledge of coral reef restoration. Another 23.3% claimed to know 'a little bit' about it, while 10% described the work being done by Reef2Reef. Additional responses mentioned the importance of restoration, the use of artificial reefs, fragmentation, nurseries, and out planting (Appendix B, Section C, fig.12). Coral reef restoration was perceived as highly important for both the environment (84.8%, fig.7A) and the community (71.2%, fig.7B). A significant portion (66.1%) expressed a willingness to help restore the reefs, while 30.5% responded with 'maybe' (Fig.8A). Almost half of the interviewees (45.8%) had heard of Reef2Reef (Fig.8B). Comments related to this research project often highlighted the importance of involvement (52.6% of 19 answers), with individuals leaving their contact details and emphasizing the significance of the project and research (Appendix B, section C, fig.13).

4. Ecological Results

4.1 Benthic group composition

The four inner reef sites, Playa Huerta, La Piscina, Huerta Wall and Homereef Scuba all had relatively high average hard coral covers ranging from 44 to 48%. This is in contrast to the four outer reef sites, Salmedina Rock, Drake Island, and Buenaventura left & right, where hard coral cover was more variable (21% to 43%). On average, the outer reefs had more sponge cover, 15% versus 4% on the inner reef and a higher occurrence of soft coral, 6% versus 0.17% on the inner reef. Drake Island and Salmedina Rock showed the highest sponge covers, respectively 18% and 26.3%. The outer reefs had on average 5% more macroalgae on the reef compared to the inner reefs (Fig.8). Inner reef Huerta Wall has the highest percentage of macroalgae cover (44%). Crustose Coralline Algae were found most often at Salmedina Rock (13.7%) (Fig.8).

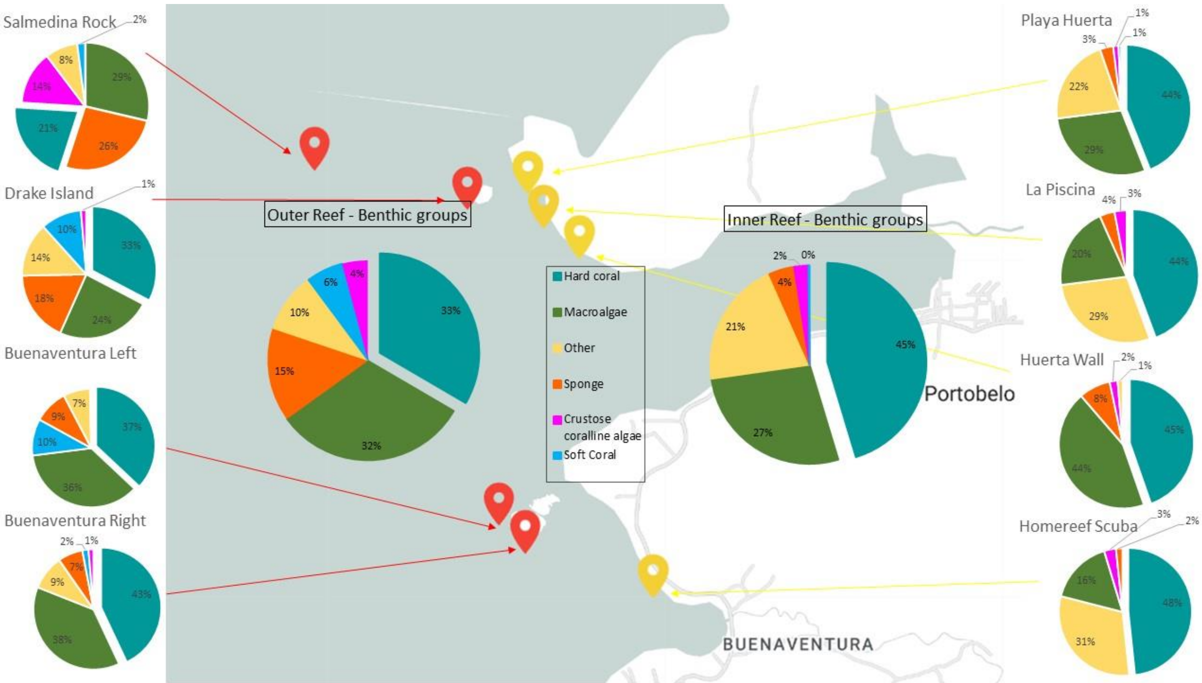


Figure 8 Benthic composition at the 4 inner and outer dive sites.

The hard coral cover per site has been compared among the eight different sites, showing that the coral cover at Salmedina Rock significantly differs from Buenaventura left, Buenaventura right, Homereef Scuba, Huerta Wall, La Piscina and Playa Huerta ($p<0.05$) (Fig.9; Appendix C, table 1 & 2). Drake Island had a significantly lower coral cover than Homereef Scuba ($p<0.05$) (Fig.9; Appendix C, table 1&2), which showed the highest hard coral cover. Hard coral cover alone is not sufficient to assess the status of the reefs, therefore in the next section hard coral genus composition and hard coral species richness and diversity are also looked at.

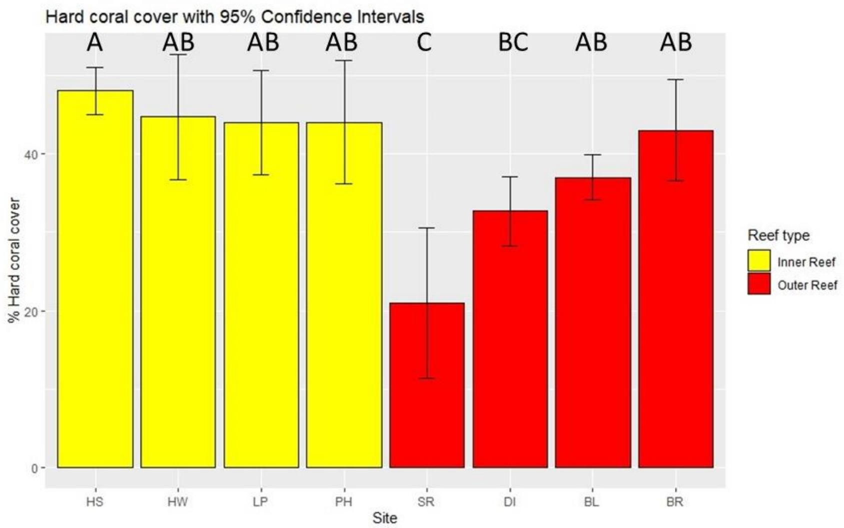


Figure 9 Hard coral cover with 95% confidence intervals for the 8 dive sites, yellow: inner reef, red: outer reef.

4.2 Hard coral composition

Agaricia tenuifolia, the lettuce coral, is the dominant hard coral species on both the inner and outer reefs, making up 44% and 54% of the coral cover, respectively. Salmedina Rock and Homereef Scuba are exceptions to this. At Salmedina Rock, *Millepora spp.,* the fire coral, is dominant (44.4%), whereas at Homereef Scuba *Siderastrea siderea* occurs the most often (36.8%), after which fire coral is the second most abundant genus (22.2%)(Fig.10). At Drake Island and Huerta Wall, the *Agaricia tenuifolia* colonies outnumber the other hard coral species on these reefs with, 86.73% and 79.85% respectively (Fig.10).

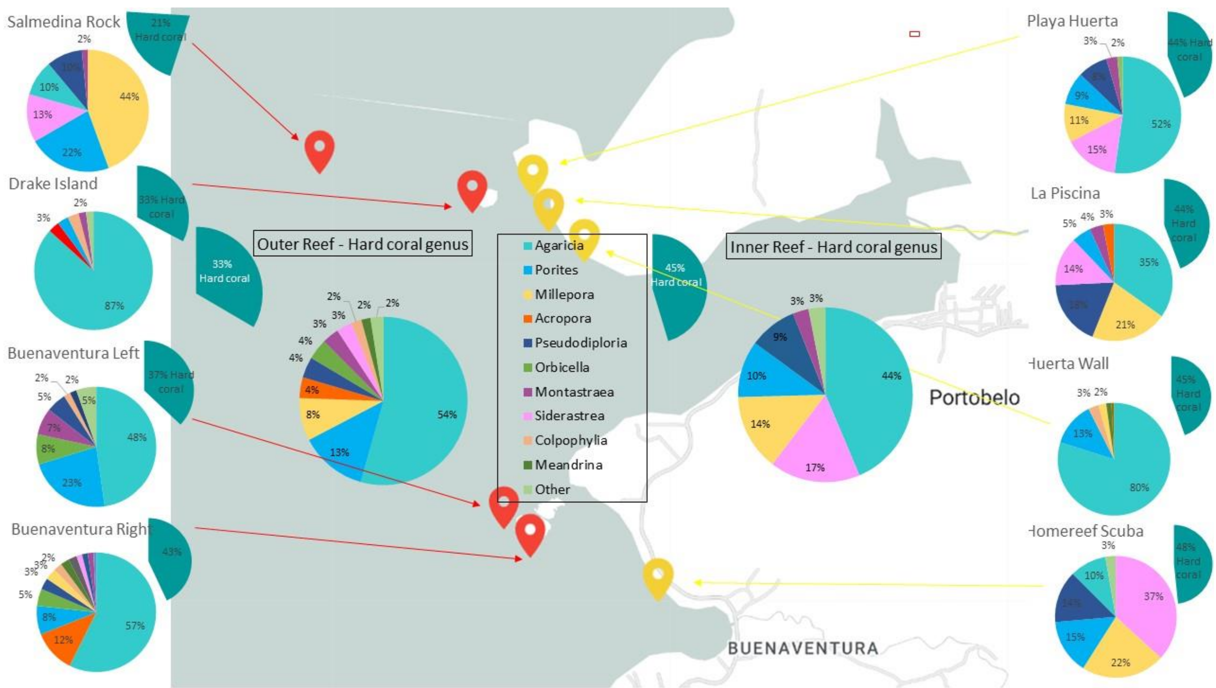


Figure 10 Hard coral composition at the inner and outer reef sites.

4.3 Hard coral species richness & diversity

Table 2 provides an overview of the Scleractinian and hydrocoral (*Millepora*) coral species observed during this fieldwork, totalling 25 different coral species.

Table 1 Overview of the Scleractinian and hydrocoral coral species observed within this study.

Acropora cervicornis *Acropora palmata*
Agaricia agaricities *Agaricia humilis* *Agricia tenuifolia*
Colpophylia natans
Diploria labyrinthiformis
Eusmilia fastigiate
Favia fragum
Meandrina jacksoni *Meandrina meandrites*
Millepora alcicornis *Millepora complanata*
Montastraee cavernosa
Musa angulosa
Mycetophylia ferox
Orbicella faveolata *Orbicella franksi*
Porites astreoides *Porites furcata*
Pseudodiploria clivosa *Pseudodiploria strigosa*
Siderastrea siderea *Siderastrea radians*
Stephanocoenia intersepta

In Buenaventura, a notable diversity of hard coral species was observed on both the left (15 species) and right (20 species) sides (Table 2). The Homereef, situated in front of Scuba, exhibited 12 distinct coral species, boasting the highest Shannon Diversity Index (SDI) of 1.97. La Piscina had 10 species, with an SDI of 1.82, while the remaining sites did not surpass 10 different coral species (Table 2). Huerta Wall (HW) and Drake Island (DI) showed relatively lower species richness, with 7 and 8 species, respectively, and correspondingly lower Shannon Diversity values of 0.92 and 0.62 (Table 2).

The sample size of this study was determined based on a comprehensive review of existing literature, as well as considerations of time constraints, budget limitations, and the availability of required materials and resources. As this study serves as a baseline investigation for this area, a species richness saturation curve was plotted to assess species richness comprehensively and to provide insights into the optimal number of transects necessary to adequately capture the diversity of species present in the area (Fig.11). At four sites, Buenaventura left, Homereef Scuba, La Piscina and Drake Island, the number of coral species stabilizes at the last two transects, whereas for the other sites the number keeps increasing from transect 5 to 6 (Fig.11).

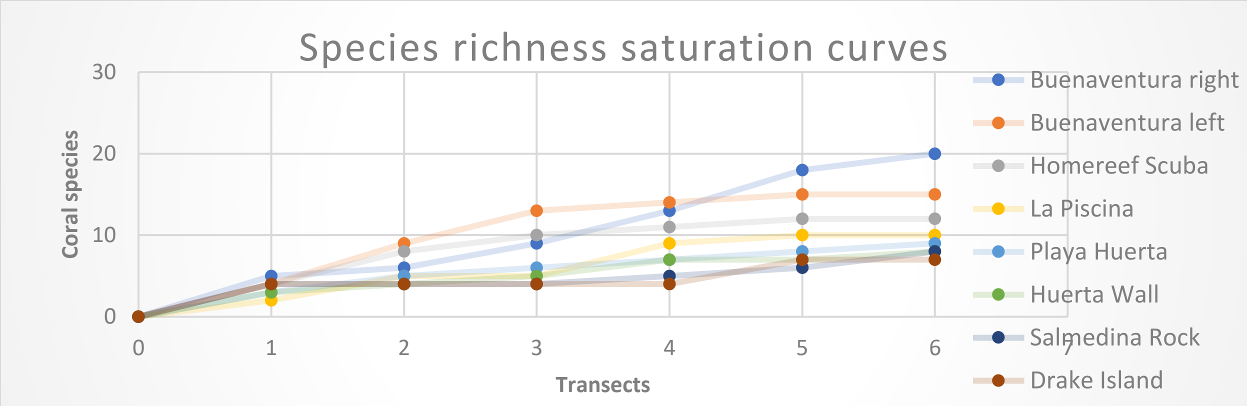


Figure 11 Species richness saturation curves for each study site.

4.4 Suitable Outplant Sites

'Appendix D – Individual Site Descriptions' provides more detailed information about each study site, including reef characteristics, monitoring depths, environmental conditions, observations during data collection, observed threats, coral recruitment and coral colony health status. This section provides a summarized overview of that information (Table 2), combined with the requirements for out-plant sites (2.3.5) to provide recommendations for suitable outplant sites.

Site	Depth range (m)	CCA (%)	Habitat integrity **	Human disturbances	Diseases/ predation	(Historical) presence Acropora	Species Richness	SDI	Recruits
Homereef Scuba	0.5-2.5	3.0	Moderate	High	High		12	1.97	50
Huerta Wall	5-8.5	2.0	Low	Moderate	Moderate		8	0.92	-
La Piscina	1-3	3.0	Moderate	Moderate	Absent	Present	10	1.82	26
Playa Huerta	2.5-5	1.33	Moderate	High	Moderate		9	1.52	-
Salmedina Rock	5-10	13.67	High	Low	Absent	Present (*Palmata*)	8	1.56	7
Drake Island	6.5-11	1.33*	High	Low	Moderate	Present	7	0.62	X*
Buenaventura left	6.5-10	0.33	High	Low	Absent		15	1.79	-
Buenaventura right	5-7	1.33	High	Low	Moderate	Present	20	1.88	-

Table 2 Outplant requirements overview for each study site.

*During an exploratory dive, a significantly higher abundance of CCA was observed. The same goes for the coral recruits observed in this area, they were not counted as part of the transects, but they were present in relatively high numbers.
**Habitat integrity assesses the overall integrity of the area, considering factors like substrate availability and reef structure.

During the exploratory dive conducted at Drake Island, a substantial expanse of rocky terrain was observed, with several coral recruits, which might serve as an ideal natural hard substrate to out-plant the coral fragments onto. Furthermore, both Drake Island and Buenaventura feature sandy regions that could potentially accommodate the placement of artificial structures, thereby facilitating the process of coral reef restoration. This table can be expanded to include additional factors that may not have been monitored in the scope of this study. As all sites are located within the Portobelo National Park, local laws and regulations related to coral restoration and marine conservation are similar for each site. Monitoring and management capacity, as all reef sites are within a 10-15 min boat drive away from the coral garden and ScubaPortobelo, is not a criterion that is discussed separately.

5. Discussion & Recommendations

The results reveal coral reef restoration's role at the community scale and the importance of socio-ecological system analysis. The answers to the research questions will be addressed, whereafter the most important findings, recommendations and limitations of the results are discussed.

The current condition of the coral reefs in the area of Portobelo has been assessed by looking into the benthic composition, hard coral composition and cover, Shannon Diversity and species richness. Live coral coverage is relatively high, although the presence of substantial macroalgae, due to excessive nutrient levels and a decrease in grazing pressure, might be concerning. CCA is particularly high at the outer reef site, Salmedina Rock, but also present in lower amounts at the other reef sites. At six of the eight studied sites, *Agaricia Tenuifolia* is the dominant coral species and at four sites isolated patches of *Acropora cervicornis* and *palmata* were observed. Species diversity and richness fluctuate across sites, with the highest values at Homereef Scuba and Buenaventura (left and right). With regard to the awareness and perception of the status of the reefs, the outcomes indicate a knowledge gap about coral reefs among both the local community and visitors. However, a consistent perception of the importance of coral reefs was measured.

The main threats to the coral reefs observed in the Portobelo area include coral health issues, suggesting signs of White Pox Disease and Aspergillosis, predators like fire and feather worms, corallivorous snails and vermetid snails, as well as the indirect effects of the invasive Red Lionfish. A substantial portion of respondents (39.4% of visitors and 32.9% of inhabitants) did not provide answers regarding threats to the coral reefs. Among those who did, visitors most often expressed concerns about 'climate change', while inhabitants mentioned more often 'garbage', 'boats', 'fishing' and 'tourism' as threats.

Based upon this preliminary assessment, the most suitable outplant locations for the *Acropora* fragments are Drake Island and Buenaventura as outer reef sites and La Piscina and Homereef Scuba as Inner reef sites.

The local interviews revealed a knowledge gap regarding coral reef restoration and the existence of Reef2Reef. Despite these outcomes, there exists a positive perception of coral reef restoration within the community and among visitors, suggesting social support for the project.

5.1 Current conditions of the reefs

5.1.1 Benthic composition

Macroalgae

The Caribbean region is renowned for its comparatively modest live coral coverage, often falling below 40%, accompanied by substantial levels of algae coverage (Jackson et al., 2014). In the context of this study, the live coral coverage is relatively elevated, yet concurrently, the algae coverage remains substantial. Dead sections of the reef are often covered by macroalgae and encrusting sponges, which hampers the settlement of new coral colonies as also observed by Diaz-Pulido & McCook (2004). In general, the occurrence of macroalgae may vary widely across a reef, influenced by local nutrient fluxes, associated with heavy rainfalls and temperature fluctuations. Increases in macroalgae can however also be an indication for a decreased grazing pressure from herbivorous fish or sea urchins or nutrient increases caused by surface runoff consisting of agricultural fertilizers or sewage (Burkepile & Hay, 2008; Hughes et al., 2000). This area is influenced by the significant population decline of the keystone species, *Diadema antillarum* sea urchin in the 1980s, which decreased grazing pressure on fleshy macroalgae (Bak et al. 1984; de Bakker et al., 2017), as well as the decline in fish biomass due to overfishing and other factors (Paddack, et al., 2009; Hawkins &

Roberts, 2004). In addition, deforestation for agriculture in the Portobelo area has resulted in higher sedimentation and nutrient levels (Guzman, 1991). The absence of sewage infrastructure in the area might be another contributor to the elevated nutrient levels and thus macroalgae cover in this area. Box 2 provides additional information on the turbidity in the area.

Box 2 ***Additional information about the turbidity in the area.***

The Allen Coral Atlas charts and monitors coral reefs across the globe, gathering essential data on potential threats to provide actionable data (Allen Coral Atlas, accessed June 2023). One of the reef threats monitored by the Allen Coral Atlas in the area of this study is turbidity, the suspended particles in the water column (Fig.12). Turbidity can be caused by both human-induced events (sewage) as well as natural events (rainfall, river runoff) (Allen Coral Atlas). As can be seen in the figures below, the turbidity increased from mainly low and moderate levels to high and even severe levels in the first quarter of 2023, when this research was carried out. This change in turbidity could possibly relate to the increase in precipitation from mid-October to April (Visualcrossing, accessed September 2023).

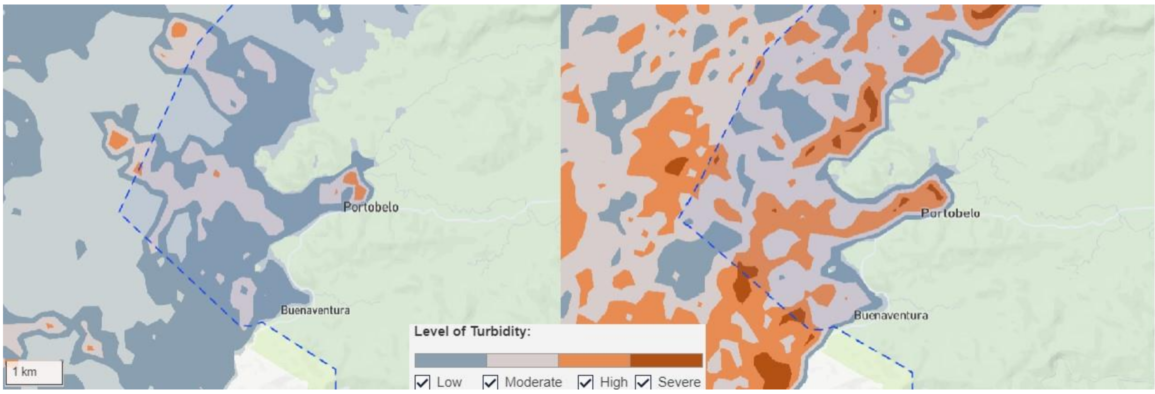


Figure 12 The study area, the blue dotted line is the limit of the MPA. The left figure shows the turbidity in the last quarter of 2022. The right figure shows the first quarter of 2023.

Crustose Coralline Algae

The availability of a suitable substrate, characterized by the absence of sand and the presence of CCA, is vital for coral settlement. CCA contain a settlement cue which is necessary for the coral larvae to proceed to metamorphosis, after which the larvae can settle and grow on most bare substrates (Petersen et al. 2021). This underscores the crucial role of CCA in coral settlement and highlights the importance of optimal substrate conditions for the establishment of healthy coral communities.

While the presence of CCA was notably high at outer reef sites like Salmedina Rock and Drake Island, its cover remained generally below 3% at the other locations. Interestingly, this lower CCA cover aligns with studies on Bonaire by De Bakker and colleagues (2017), showing a decline from 6.4% to 1% across various sites and depths from 1973 to 2014. Kendrik (1991) and Harrington et al. (2005) note a negative correlation between CCA and sedimentation, potentially explaining its higher prevalence in outer reef areas. Research from the Great Barrier Reef revealed a decline in CCA cover from 30% in low-sedimentation habitats to as low as 1% in regions experiencing high sedimentation (Fabricius and Death, 2001).

The outer reef site, Salmedina Rock, showed the highest CCA coverage, but a relatively lower number of coral recruits. This might be explained by the fact that the higher wave energy and physical disturbance at this site makes it challenging for coral larvae to settle and survive. Salmedina Rock had, compared to the other sites, the lowest hard coral coverage (21%), of which the fire coral was the most abundant (44%). The supply of coral larvae plays a crucial role in the presence of coral recruits, which could be limited at this site, because the coral recruits found were mostly *Siderastrea* species. Additionally, the composition of CCA species can have different effects on coral recruits, varying from enhancing coral settlement, survival and growth, while others may have neutral or even negative impacts (Jorrison et al. 2020).

Live coral cover

As observed in this study and described by Guzman (2003) in the area's characterization, the fringing reefs maintain a depth not exceeding 15 meters. This depth constraint is influenced by persistent ocean waves and northeast trade winds throughout the year. The relatively high percentages of hard coral cover in this study could be attributed to the fact that only dive sites within an MPA have been monitored, thus specifically targeting the more pristine coral reefs, instead of taking an average over a larger area. Over time, live coral cover has shown some variation in the reefs of Portobelo and Isla Grande. Guzman and colleagues (1991) monitored this area as a control site in a study on the effects of the major oil spill in 1986. In 1985, some reefs showed an average cover of approximately 25%, which declined to 10% in 1992, caused by anthropogenic and natural disturbances (Guzman et al., 1991; Guzman, 2003). These findings, though the solely available dataset for comparison, should be contextualized as they stem from a slightly distinct area north of Portobelo Bay, and used a different methodology (1m2 quadrats divided into 10x10cm cells versus line intercept points deployed in this study). More information about the current benthic cover in the area is given in Box 3.

Box 3 ***Additional information about the benthic cover in the area.***

The Allen Coral Atlas provides information on the benthic cover, distinguishing benthic habitat map classes developed by Roelfsema et al. 2013, combined with input from other reef benthic classifications. Remote sensing data is used to distinguish six different classes, namely coral habitat (coral/algae), sand, unknown, rubble, rock, seagrass, and microalgal mat. The class of coral habitat does not distinguish between corals and seaweeds/algae, as these are spectrally similar due to their photosynthetic nature. Therefore this class refers to a hard underlying framework, either limestone or non-carbonate) with a benthic cover of coral, both hard and soft corals and/or seaweeds, including turf and macroalgae. As can be seen in Figure 13, the study sites consist mainly of rock, coral/algae and in some places seagrass and sand. The benthic composition has not been accurately been displayed for Salmedina Rock, Drake Island (DI), La Piscina (LP) and Huerta Wall (HW), which could be attributed to the limitations of the use of remote sensing data, combined with the lack of field validation in this area. For both Buenaventura left and right (BL & BR), Playa Huerta (PH) as well as the Homereef Scuba (HS), this study confirms that coral and algae make up for 60-80% of the studied area. The sandy area at Buenaventura was observed during this study and is displayed on the map (Fig.13).

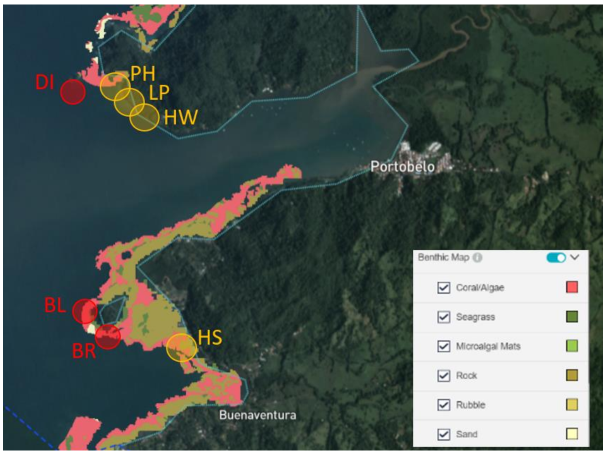


Figure 13 Allen Coral Atlas Benthic habitat map with the study sites on top.

5.1.2 Coral composition

The composition of coral species at the different sites can provide insights into the dynamics of the ecosystem and the ecological conditions. At six out of the eight sites monitored within this study, *Agaricia tenuifolia* was the dominant species on the reefs. After *Agaricia*, *Porites*, *Millepora*, *Siderastrea* and *Pseudodiploria* make up the largest part of the hard coral cover. According to literature about the whole Caribbean region (Frade et al., 2019; Bak et al., 2005), *Agaricia* is the dominant coral genus in deep reefs, whereas in this study this also applies to shallow reefs. Which is in line with findings of Guzman (2003), where he states that the shallow reefs in the Portobelo area (down to 2m) consisted mainly of *Agaricia tenuifolia, Pseudoiploria clivosa*, and *Millepora complanata*. Going deeper by a relatively short slope, *Siderastrea siderea, Pseudodiploria strigosa* and *Colpophyllia spp*. compose the reefs (Guzman, 2003). The only differences with the data of Guzman are the higher occurrence of *Porites* at our sites and the relatively lower occurrence of *Colphophyllia* at our transects.

Opportunistic Agaricia

Agaricia tenuifolia dominating 6 out of the 8 studied reefs could be attributed to their opportunistic or "weedy" behaviour, as they are known to thrive under certain conditions, thereby outcompeting other coral species. Their fast growth rates allow quick colonization of available substrates on the reef. They can tolerate larger stress, such as suboptimal water quality and temperature fluctuations, compared to other hard coral species, giving them a competitive advantage. The asexual reproduction of *Agaricia* enables this species to form large colonies and occupy space efficiently (Aronson et al., 2002). Findings from Aronson and colleagues (1998) about a study in Belize, indicate that the change in dominant coral species from *Acropora* to *Agaricia* in areas from 3 to 15 meters deep was driven by external factors, such as disease outbreaks (White Band disease). Cramer et al. (2021) also mention that the *Acropora* losses in the 1960s in the Caribbean caused weedy and stress-tolerant Scleractinian corals and the competitive fire coral to increase in occurrence. The dominance of a single species, especially an opportunistic one, can have several implications for the reef ecosystem. The structural complexity of the reef reduces, which affects the availability of breeding grounds, hiding places and overall reef resilience (Nelson et al., 2016). This emphasizes the importance of maintaining diverse coral communities for the overall health and resilience of the reef ecosystems and underlines the importance of coral reef restoration.

Salmedina Rock & Homereef Scuba

On the other two sites, Salmedina Rock and Homereef Scuba, *Agaricia* was not the dominant genus. Salmedina rock was dominated by fire coral, after which *Porites* and *Siderastrea*, *Agaricia* and *Pseudodiplora* made up the largest parts of the cover. The fire coral *Millepora spp*. is a type of hydrozoan, which resembles coral but is not a true coral species. This species can rapidly colonize and grow in damaged areas, thus their high presence in this area may be indicative of a relatively unstable environment (Lewis, 2006). Salmedina rock does indeed experience frequent disturbances like high wave energy, due to its location further offshore.

In contrast, the primary coral presence within the Homereef adjacent to ScubaPortobelo is characterized by the dominance of *Siderastrea*, a coral genus renowned for its preferential occurrence in less turbulent environments, such as back-reef zones and lagoons (Bernal-Sotelo & Acosta, 2012). The diminished influence of water currents and wave energy in this location suggests a more sheltered and safeguarded habitat, aligning aptly with the characteristics exhibited by the reef in front of ScubaPortobelo.

Acropora

As observed within this study, small and isolated patches of *Acropora cervicornis* and *palmata* were observed at the outer reef (Drake Island, Buenaventura, Samedina Rock) and one single *palmata* colony at La Piscina. Guzman (2003) described the occurrence of *Acropora palmata* in the area between Isla Grande and near Portobelo, where this genus once constituted extensive fringing reefs running parallel to the coastline (Macintyre and Glynn 1976). The outer reef sites are more prone to optimal light conditions, experiencing lesser influences from surface runoff and sedimentation. These factors provide favourable conditions for *Acropora* growth in these regions. Similarly, nutrient levels tend to be higher on inner reef sites due to terrestrial activities, while *Acropora* corals thrive in oligotrophic (low-nutrient) environments. In addition, their branching and plating growth forms dissipate wave energy and allow survival in areas with higher wave energy (Ruiz-Diaz et al., 2022; Griffin et al., 2012).

5.1.3 Diversity & Richness

In this study, 25 different coral species were found along the transects. Guzman (2003) mentions the diversity of both hard and soft corals to be 70, of which 77% occurs in the central region of Panama, which concerns our study area. The richness of Scleractinian corals in the area of Isla Grande-Portobelo has previously been estimated at 54 species (Jackson et al., 2014; Guzman, 2003). The observed prevalence of nearly half the species in this investigation can be attributed to the methodological approach employed for data collection.

The species richness saturation curve has been plotted to assess whether a representative portion of the species present in the ecosystem has been captured. The pattern that the number of species continues to increase at four of the eight sites, suggests that increasing the number of samples would likely lead to the discovery of additional species (Gotelli & Colwell, 2001).

The values of the Shannon-Wiener Diversity Index (SDI) are comparable to those of Guzman and colleagues (1991), who assessed SDI of coral colonies in the same region and similar depth ranges (0.5-6m), showing fluctuations around a SDI of 1. Another study by Guzman and colleagues (2004) on the largest MPA of Pacific Panama (Coiba island), showed that higher live coral covers were found in areas of high coral species richness, which aligns with our findings, with the exception of Huerta Wall, where low species richness (8) coupled with high coral cover (45%) (Table 2).

In considering suitable outplant locations for *Acropora* fragments, it is essential to draw insights from recent research on the effect of species richness and diversity on ecosystem recovery. Clements and Hay (2021) emphasize that biodiversity has a positive but saturating effect on coral reefs, demonstrating that coral performance tends to improve in mixed species assemblages, with peak performance occurring at intermediate species richness levels. Their findings suggest that harnessing the positive interactions of species diversity can be pivotal in ecosystem conservation and restoration. Similarly, Williams et al. (2017) underscore the importance of species diversity in marine ecosystem restoration, showing that in a seagrass restoration experiment within the Coral Triangle, plant survival and coverage increased with the number of species transplanted. These studies highlight the potential benefits of considering species richness and diversity when selecting outplant locations for *Acropora* fragments.

5.1.4 Respondents' awareness & perception of the current status of the reefs

Respondents' self-perceived knowledge, as well their general knowledge about coral reefs, indicates a knowledge gap. Approximately twice as many inhabitants reported having a very poor understanding of coral reefs compared to visitors (33.9% vs. 15.8%), whereas half of the visitors (52.2%) could not come up with a reason why coral reefs are exactly important, compared to 20.6% of the inhabitants.

This might be explained by the fact that the inhabitants are in a different way connected to the reefs, as they are more directly depending on them (Diedrich, 2007). Only 1% of the visitors mentioned 'tourism' as a reason of importance, compared to 5.9% of the inhabitants, who largely depend on tourism as this is the major source of income for most of them (48.2% work in hospitality and tourism, and 25% are boat drivers). This is in line with a study by Trialfhianty & Suadi (2017), where they found that the level of community participation is influenced by the relation between their work and coral reefs.

Interestingly, despite the identified knowledge gap, which presents an opportune area for intervention through educational programs aligned with the objectives of Reef2Reef, this research highlights a consistent perception of the importance of coral reefs among respondents. About three-quarters of the respondents, both visitors and inhabitants, affirmed that they consider coral reefs to be very important, suggesting there may be factors beyond individual knowledge that influence the perceived importance of coral reefs. Existing literature, drawing upon community participation studies (Hein et al., 2019; Ryan and Hamin, 2008), emphasizes the subjectivity and context-specific nature of awareness and perception. Thus, it is highly recommended for subsequent research to explore the variations and correlations in perception and awareness across different locations and respondent groups, such as diverse professions and age cohorts.

Respondents who had seen the live reefs were asked to rate the status of the reef, based on colour, marine life, and the presence or absence of algae. It should however be noted that it is unknown if and what kind of reefs the respondents had seen elsewhere, thus to what standards they compare their experiences in Portobelo. Concurrently, the ecological research functions as a baseline study and lacks appropriate data for direct comparisons. Therefore, it is somewhat subjective to make definitive claims about the 'current status of the reefs in Portobelo'. The majority of respondents, comprising 31.8% of inhabitants and 47.5% of visitors, characterized the reefs as 'neutral' – neither significantly degraded nor in excellent health. Inhabitants and visitors expressed varied opinions, with 22.7% of inhabitants and 20% of visitors describing the reefs status as 'good' and 29.5% of inhabitants rating it as 'very good', compared to only 7.5% of visitors. This divergence in perception may be attributed to visitors' potential exposure to more pristine reefs in other locations, whereas inhabitants may have primarily experienced the reefs in Portobelo. However, this hypothesis warrants further exploration in subsequent research. Studies within the field of environmental psychology and reef ecology (Trialfhianty & Saudi, 2017; Losciale et al., 2022) suggest that perceptions of reef health may be influenced by subjective factors, including past experiences.

Moreover, when visitors were asked to rate specific dive spots they had encountered, Salmedina Rock (SR) and Drake Island (DI) were often assessed as 'good' to 'very good' by 40% of respondents. In contrast, Homereef Scuba (HS) received similar assessments of 'bad' to 'very bad' from 40%. This contradicts our ecological research findings, which indicate that HS boasts a higher live coral cover, greater Shannon Diversity Index, and increased species richness compared to SR and DI. Overall, these results underscore the importance of considering both ecological data and subjective assessments in understanding how individuals perceive and value coral reef ecosystems.

5.2 Threats to the coral reefs of Portobelo

5.2.1 Coral Diseases

There were several observations of coral health issues within the studied coral species, of which an analysis is provided below.

Siderastrea siderea – White Dots

The presence of white dots on *Siderastrea siderea* colonies, mainly at the Homereef, may indicate parrotfish bites or the occurrence of White Pox Disease (WPD). Considering the characteristics of the dots, they are likely whitepox disease, also known as Puntos Blancos. This ailment is recognized by circular lesions on coral colonies and is primarily associated with *Acropora palmata*, attributed to the pathogen *Serratia marcescens* (Patterson et al. 2002; Sutherland et al. 2004). Nonetheless, observations have illuminated the susceptibility of *Siderastrea siderea* to this disease as well (Mantilla Galindo, 2015). The presence of symmetrical white dots, measuring 2 to 3 cm in diameter, raises the possibility that the pathogens affecting *Siderastrea siderea* may differ from *Serratia marcescens* (Mantilla Galindo, 2015). WPD has been linked to poor water quality, increased nutrient levels and sewage pollution (Sutherland et al., 2010). A study by Zaneveld and colleagues (2016) highlights how corals are affected on microbial scales by the interaction of nutrient pollution, overfishing and temperature and more specifically that nutrients promote bacterial opportunism and mortality among corals that have been grazed upon by parrotfish. A readily attainable step to enhance water quality in the vicinity of coral reefs is to prioritise the establishment and maintenance of appropriate sewage infrastructure.

Siderastrea siderea – Red Dots

The presence of red dots and purplish rings on *Siderastrea siderea* also observed at the Homereef, might be indicative of *Aspergillosis*, a coral disease caused by the fungal pathogen *Aspergillus sydowii*. This disease leads to tissue recession, exposing the coral's axial (internal) tissue, which can potentially cause mortality in affected colonies (Sheridan et al., 2013). The purplish rings suggest that the hyphae of the fungus penetrate the tissue, and on occasion, the coral may exhibit tumour-like growth as a defensive response (Mantilla Galindo, 2015). This disease often thrives in warm waters with high levels of organic matter and nutrients, similar to WPD as mentioned above, and is in line with the prevailing conditions at the Home reef.

Acropora – White Bulbs

The appearance of white bulbs on *Acropora* coral branches might indicate several possibilities, including coral bleaching, physical damage, disease, or even natural growth. It's crucial to differentiate between these possibilities to accurately assess the health of the coral. Bleaching, caused by environmental stress, leads to the loss of the coral's vibrant colour, and affected areas may turn white. Physical damage, predation, and disease can also cause localized tissue loss, resulting in white patches that are different from bleached patches, because bleached patches still exhibit the transparent live coral tissue. Rapid Tissue Loss (RTS), White Pox and White Band Disease could be potential diseases affecting the *Acropora* colonies (Bright et al., 2016; Rogers & Muller, 2012).

Pseudodiploria strigosa – White Edge

The presence of a white edge on *Pseudodiploria strigosa*, formerly known as *Diploria strigosa*, can indicate various possibilities related to the health and condition of the coral colony. It may be a sign of bleaching, attributed to stress, or a consequence of predation. Although diseases affecting *Pseudodiploria* are generally less common, it could still be an option as well (Mantilla Galindo, 2015).

For all of the above descriptions, goes that on-site examination by coral (-disease) experts or marine biologists, thorough assessments, and samples for laboratory analysis, are essential to identify the precise cause and implement appropriate conservation measures to protect the coral.

5.2.2 Predators

Incidental observations of fire worms, feather worms, and the potential threat of corallivorous and vermetid snails on the coral ecosystems are discussed below.

Fire worms

Fire worms, belonging to the family Amphinomidae, characterized by their bristly appearance, were occasionally observed during the transects. These voracious grazers can harm corals, particularly through their feeding habits, which can lead to localized damage to coral colonies. In the Caribbean, two species occur, *Hermodice caraculata* and *Eurythoe complanata*. They are carnivorous, feeding on a variety of organic materials, including small invertebrates, algae, and detritus, but they have also been observed feeding on coral tissue. This particularly happens when corals are weakened by disease, stress or bleaching (Wolf et al., 2014).

Feather worms

Feather worms were incidentally encountered on the reefs, they belong to the family Sabellidae and Sabellariidae and are filter feeders. By filtering and recycling nutrients they play an essential role in the reef ecosystem. Notably, recent research (Hoeksema et al. 2022) showed that the Caribbean split-crown feather duster worm (*Anamobaea sp*.) has a close ecological relationship with 27 stony coral species and that it can cause distinct injuries in most host coral species and induce morphological deformities in a select few.

Corallivorous snails

Additionally, although not directly observed during the transects, but found in the nursery, the potential impact of corallivorous snails cannot be overlooked. These belong to the family Coralliophila and are small, hard-to-spot snails that have a notorious reputation for damaging coral colonies by feeding on their living tissue, targetting both hard and soft corals. The most common corallivorous snail species in the Caribbean is *Coralliophila abbreviate*, also known as the "short-spined corallivorous snail", often associated with stony corals and found in varying abundances across different reef habitats. Some natural predators, such as certain fish species, can help control corallivorous snail populations. Also, initiatives to restore damaged coral reefs can help mitigate the impact of corallivorous snails, as healthy coral colonies increase the chances of survival (Miller, 2001). Their absence from the observed transects doesn't rule out their presence. The occurrence of observed coral colony damage on the *Acropora* colonies raises questions about the potential role of these corallivorous snails.

Vermetid snails

The presence of vermetid snails, particularly *Dendropoma maximum*, has not been observed during the transects, but has been encountered at other times at Buenaventura and Playa Huerta. These sessile snails employ a feeding strategy that involves extrusion of a mucous net, which, as previous observational studies (Colgan 1985; Zvuloni et al., 2008) suggest, can have adverse effects on coral growth, survival and morphology of some coral species, reducing growth and survival by as much as 80% (Shima et al., 2010). The impact of vermetids is particularly pronounced for branching corals like *Pocillopora cf. verrucosa*, which frequently co-occur with vermetids on *Porites* reefs (Stier et al., 2010).

5.2.3 Lionfish

The Red Lionfish (*Pterois volitans)*, a species of venomous fish, native to the Pacific Ocean but an invasive species in the Caribbean, has also been observed in the region. Their rapid spread, as they have few natural predators in this area and can reproduce rapidly, poses a significant threat to local marine biodiversity (Arias-González et al., 2011). Lionfish outcompete native species for food and habitat, they are known to prey on small fish and other reef organisms, potentially disrupting the delicate balance of the coral reef ecosystem. Understanding the extent of their presence in the area and their interactions with native species is crucial for coral reef management. Lionfish hunting and consumption are promoted in the Caribbean region as a way to control the population (de León et al., 2013).

5.2.4 Respondents' awareness of threats

To assess threats to Portobelo's reefs, respondents were asked to identify them. Natural disturbances in Panama affecting coral reefs, primarily consist of sea warming and diseases affecting reef-related organisms and corals (Guzman, 2003; Shulman and Robertson 1996). While 39.4% of visitors and 32.9% of inhabitants did not provide an answer, a more general and global threat, 'climate change' was a common concern for visitors (20.5%), while inhabitants mentioned more local threats such as 'garbage' (15.8%), followed by 'pollution' (13.2%), 'boats' (9.2), 'fishing' (9.2%) and 'tourism' (6.6%). These findings align with Losciale et al. (2022) and support the perception that people are aware of reef vulnerability (Hein et al., 2019; Goldberg et al., 2016). Coral diseases were not recognized by the respondents as a threat to the reefs.

Tourism's impact, including coral trampling which was also observed at our study sites, was mentioned by both inhabitants and visitors, consistent with Guzman's (2003) assessment that coastal development and increasing tourism are the most important risk factors. However, coastal development, referred to as construction, was mentioned by only 2.3% of visitors and 1.3% of inhabitants.

Unlike Losciale et al. (2022), our respondents did not mention 'runoff' and 'direct damage' as threats, even though these are significant concerns in the region. In the Isla Grande-Portobelo region, the impact of sedimentation was even worse compared to the central Caribbean coast of Panama (Guzmán et al. 1991), as a result of deforestation and the increase in tourism (Guzman, 2003). It has also occurred that tree trunks were carried by the rivers into the ocean, destroying shallow reef habitats (Guzman, 2003; Kilar and Norris 1988).

Nearly 40% of Portobelo's residents reported seeing coral used in buildings, compared to only 4.48% of visitors. Historical records reveal that coral mining began over 500 years ago during the Spanish conquest, with massive extraction continuing for about two centuries. Coral species like *Montastrea*, *Colpophyllia*, and *Siderastrea* are found in the town's fortresses and buildings (Guzman, 2003). Archival records from the Archivo General de Indias (AGI) detail the extensive extraction, with over 70,000 cubic meters of coral mined in a short period (Guzman, 2003). The town's buildings and ruins, a UNESCO World Heritage site since 1980, have been measured on-site, revealing that 12,923 cubic meters of the total 15,387 cubic meters were corals (Guzman, 2003). In the early 1990s, Spanish architects obtained permission to extract coral for restoring historic buildings like the Customs House. Despite reports indicating low live coral cover (less than 10%) in Portobelo National Park since 1985 (Guzman et al., 1991), extraction continued into 1997, the International Year of the Reef. The local media reported that "technical assistance was offered to train more than 30 Portobelo residents in restoration work with coral" (Guzman, 2003), quite the opposite of the coral reef restoration work being carried out in Portobelo by Reef2Reef nowadays.

5.3 Suitable Outplant locations

Among the outer reef locations of the eight studied sites, Salmedina Rock, Drake Island, and Buenaventura (left)—emerged as the most promising candidates for serving as suitable out-plant sites for the Acropora fragments. It is noteworthy, however, that while Salmedina Rock demonstrates highly favourable conditions, its offshore positioning raises accessibility concerns, particularly in adverse weather conditions. The rocky surface at Drake Island could function as an ideal location to outplant fragments on natural bare substrate, whereas the sandy area at Buenaventura could potentially serve as an outer reef site to place artificial reef structures. One limitation of Buenaventura is the low cover of CCA, which could potentially be stimulated through interventions at this site. Additionally, the inner reef site La Piscina, which currently houses the coral nursery and artificial reefs, has also emerged as a suitable location for out-planting. This reaffirms that this location is well-suited for its current purpose. The pilot project involving artificial reefs conducted here could be extended or redone with a more rigorous monitoring approach and interventions to mitigate the impact of fireworms, which caused substantial damage and mortality during the previous pilot. Homereef Scuba has also demonstrated potential, although it faces notable challenges such as human disturbances and signs of diseases and predation. Nevertheless, if ScubaPortobelo were to implement specific measures (e.g. sewage installation and preventing tourists from stepping on the reef), it has the potential to become an excellent location, particularly due to its direct accessibility from ScubaPortobelo. This accessibility could enhance public awareness and conservation initiatives.

5.4 Awareness & perception of coral reef restoration & Reef2Reef

The results of the local interviews reveal a significant knowledge gap concerning coral reef restoration, with the majority of respondents (80.5%) indicating a lack of familiarity with these practices. Interestingly, among the tourist population, only one-third were uninformed about such efforts, underscoring the need for more comprehensive and engaging educational initiatives within Portobelo. This outcome illustrates how the reefs and the restoration activities are linked to scuba-diving tourism and restricted to the underwater environment.

In terms of awareness of the Reef2Reef project, approximately 25.8% of Portobelo's inhabitants and 43.3% of the visitors were aware of its existence. These findings, combined with a substantial willingness among both visitors and residents to contribute to the restoration efforts (with two-thirds indicating definite willingness and another one-third considering participation), indicate strong social support for the project.

5.5 Recommendations

While certain recommendations have been briefly alluded to earlier, this section provides a concise summary of those points and introduces several additional considerations.

Ecological status

It is important to note that interpreting benthic and coral composition, diversity and richness alone provides limited information about the status and resilience of a reef ecosystem. As mentioned before, other factors and physical parameters, such as water quality, temperature, salinity, water current velocity, light penetration, and fish biomass should also be considered to gain a comprehensive understanding of the ecological status of the reefs. Enhancements in the methodology could encompass the establishment of permanent markers to monitor change over time, as advocated by literature (Rogers et al., 1994) and Smithsonian researchers. However, due to constraints encompassing time, budget, and the study's baseline focus, this initiative was not realized herein. With the advancement of continuous research integrated into the coral reef restoration project by Reef2Reef, it is strongly advisable to establish a dedicated data repository, providing accessibility to research outcomes and findings. Due to the low amount of tunicates observed during the transects, these were grouped under "other". However, for further analysis of the pictures, it is recommended to divide the group "other" into "other biota" and "abiotic substrate". To optimize operational efficiency and secure comprehensive data for potential future analysis, capturing transect information through photography was chosen. Water clarity however profoundly affects the image quality and organisms beneath coral plates or rock ledges are not visible, besides, precise identification may require on-site observation. It is therefore recommended to conduct the surveys with two people, where on-site examination is combined with photography.

Citizen science & reef rangers

To cultivate increased awareness and positive attitudes, it is advisable to integrate conservation education and stewardship through hands-on experiences, as suggested by Hungerford and Volk (1990). Citizen science programs emerge as a potent remedy for addressing community awareness gaps and fostering involvement (Losciale et al., 2022). Past studies have demonstrated the effectiveness of citizen science, ranging from assessing marine reserve efficacy to identifying sources of marine debris and securing restoration funding (Cigliano et al., 2015; Dean et al., 2018). These programs engage non-professionals in scientific research, including environmental monitoring and supervising the MPA, a key aspect of environmental management (Dean et al., 2018). Essential preparatory seminars and training, including swimming, snorkelling, or scuba diving lessons, should be part of the program, to train so-called "reef rangers". Collaborative efforts with local experts possessing traditional and local knowledge can yield valuable educational materials, potentially involving institutions like Smithsonian and local schools.

Tourism & environmental conservation

Reef2Reef is intricately linked to the tourism industry through its involvement in scuba diving tourism. Situated in an area experiencing significant tourism growth—anticipated to escalate further with the construction of a new road connecting Panama City to Portobelo—there is a need to address the delicate equilibrium between the advantages and costs of tourism. The interview outcomes underscored tourism's dual role: both a reason for recognizing the importance of coral reefs and a threat. During the World Conservation Union's World Commission on Protected Areas congress in 2003, the ecological costs associated with tourism were acknowledged and it was recommended to "design tourism in and around protected areas as a vehicle for conservation .." (Diedrich, 2007). Reef2Reef is actively implementing initiatives to raise awareness, which serve the dual purpose of conservation and engaging tourists in marine conservation efforts. Positioned at the nexus of tourism, conservation, and science, Reef2Reef is well-positioned to maintain a harmonious balance between these sectors.

Reliability of the results

The relatively small sample size (N=56 inhabitants & N=59 visitors) presents challenges in drawing comprehensive conclusions. De Vaus (2001) asserts that a case study lacks the capacity to yield generalizations applicable to larger populations beyond the specific case. The conclusions derived remain specific to the case at hand. Nevertheless, the description of the process could serve as a guide for others to replicate and follow. Furthermore, the findings could contribute to understanding analogous situations in Panama or along the Caribbean Coast. The alignment of some outcomes from this study with other research implies that certain conclusions might also hold relevance and applicability to other (coral reef) restoration projects.

6. Conclusion

Globally, coral reefs are facing relentless degradation, threatening marine ecosystems. In the quest to rejuvenate these ecosystems and increase their resilience against local and global stressors, coral reef restoration emerges as a potent remedy. This research internship was conducted at the coral reef restoration NGO Reef2Reef, located near the Caribbean town of Portobelo, Panama. Reef2Reef operates a coral nursery, cultivating *Acropora* fragments and deploys artificial reef structures. Their mission encompasses to contribute to the health of marine ecosystems by means of coral reef conservation and restoration, scientific research, educational outreach and community engagement.

The primary objective of this study was to gain insight into the current status of the coral reefs, by assessing the benthic composition, species richness and diversity, threats to the reefs and identify suitable outplant locations. Simultaneously, the awareness and perception of coral reefs and restoration practices among the local community and visitors, thereby assessing the level of social support, was investigated. To address these aims, underwater assessments were combined with social surveys.

The ecological investigations were conducted at eight dive sites, comprising four inner reef sites proximate to the mainland and four outer reef sites situated farther offshore. At each site, six 10-meter point intercept transects were deployed, after which the organisms and inorganic substrata encountered every 20 cm beneath the transect line were classified into functional groups. The social assessment consisted of questionnaires with closed and open questions, which were filled in by the respondents or were conducted as semi-structured interviews.

The results reveal high live coral coverage (inner 45% and outer 33%), as it concerns all dive sites within a Marine Protected Area (MPA), but also the substantial presence of macroalgae (inner 27% and outer 32%), which can be attributed to the elevated nutrient levels and declined grazing pressure. Crustose Coralline Algae (CCA) was notably high at the outer reef site Salmedina Rock (14%), but also present in lower amounts at the other reef sites. Six of the eight sites exhibited *Agaricia tenuifolia* as the dominant coral species, patches of *Acropora cervicornis* and *palmata* were observed at four sites. Variability in species diversity and richness was evident, with peak values at Homereef Scuba and Buenaventura (left and right), signifying ecological hotspots.

In parallel, the exploration of awareness and perception revealed a knowledge gap regarding coral reefs among both the local community and visitors. Nonetheless, a consistent recognition of the importance of coral reefs resonated in the responses. The main threats to the coral reefs observed in the Portobelo area include coral health issues, suggesting signs of White Pox Disease and Aspergillosis, predators like fire and feather worms, corallivorous and vermetid snails, as well as the indirect effects of the invasive Red Lionfish. A substantial portion of respondents (39.4% of visitors and 32.9% of inhabitants) did not provide answers regarding threats to the coral reefs. Among those who did, visitors most often expressed more general and global threats, like climate change, whereas inhabitants mentioned more often garbage, boats and fishing as threats. The findings align with the perception that people are aware of reef vulnerability, but other significant threats like runoff, direct damage and diseases were not mentioned, despite their relevance to the region.

Based upon this preliminary assessment, the most suitable outplant locations for *Acropora* fragments are the outer reef sites Drake Island and Buenaventura and the inner reef sites La Piscina and Homereef Scuba. The interviews also revealed a knowledge gap regarding coral reef restoration and the existence of Reef2Reef. Despite these outcomes, there exists a positive perception of coral reef restoration within the community and among visitors, suggesting social support for the project.

To catalyse Reef2Reef's mission, it is recommended to implement conservation education, citizen science programs to engage community members in coral monitoring and increase collaboration with local experts to use traditional knowledge. To gain a more comprehensive assessment of the status of the reefs, it is highly recommended to include other factors such as fish biomass and physical parameters. Methodological enhancements, including the incorporation of permanent markers and the establishment of a centralized data repository, should underpin long-term monitoring efforts.

This study aimed to holistically assess the social and ecological facets of coral reef restoration feasibility in the Portobelo area. The findings illuminate Reef2Reef's promising trajectory, poised for expansion both on land and in the water. Positioned at the nexus of tourism, conservation, and science, Reef2Reef is well-positioned to maintain a harmonious balance between these sectors.

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Appendix A – Questionnaires

Questionnaire for inhabitants of Portobelo (English)

Dear participant,

Thank you for participating in my research. This questionnaire is created to get insights in the perception of communities towards the coral reefs around Portobelo. Your input will be vital for this research and your time investment is greatly appreciated. The questionnaire consists of 19 open-ended and closed questions and it will take about 7 minutes to complete. Your identity will be kept completely confidential during the analysis and communication of the data obtained from this interview. The results will be discussed in a report which can be provided to you on request. If you have any questions or concerns, please contact Rosanne (r.s.j.p.bartholomeus@students.uu.nl)

Section A: Respondent social profile

1.What is your gender?

- Female
- Male
- Other / prefer not to say

2.How old are you?

- Under 20
- 20-40
- 40-60
- 60+

3. How long do you live here? ..... years

4. What is your highest level of education?

- Primary school
- High school
- Bachelor's
- degree Master's
- degree PhD
- Prefer not to say
- Anders: ______________________

5. What is your workfield? Multiple answers possible.

- Finances
- Health Care
- Fishery
- Hospitality / Tourism
- Agriculture
- Science / Education
- Legal services
- Construction
- Student
- Public function
- Boat driver

Unemployed
Retired
☐ Prefer not to say
☐ Other: ________________

Section B: Coral reefs and its status

6.Have you seen the coral reefs here? If not, please continue with question9.

◯ Yes ◯ No

7.If yes, how have you seen the reefs? Multiple answers possible. **If not, continue with question 9.**
Multiple answers possible.

Scuba diving
☐ Snorkelling
☐ Swimming
☐ Fishing
☐ From the boat
☐ Pictures
☐ In buildings, as building material
☐ Other: ________________

8.If yes, how do they look? **'Very bad' implying no corals, or bleached corals or overgrown by algae and no marine* life, no fish around, whereas 'very good' implies many different corals, a lot of color and marine life.

1. Very bad 2. Bad 3. Neutral 4. Good 5. Very Good

9.How is your knowledge of corals?

1. Very poor 2. Poor 3. Neutral 4. Good 5. Very Good

10. What are corals?

- Rocks
- Plants
- Animals
- I don't know

11. How important are coral reefs to you?

1. Not important 2. Slightly important 3. Neutral 4. Important 5. Very important

12. Why are coral reefs (not) important to you?

13. Do you know what are threats to coral reefs in this area? If yes, please list them below

Section C: Coral reef restoration

14. What do you know about coral reef restoration?

15. How important do you think coral reef restoration is for **the environment**?

1. Not important 2. Slightly important 3. Neutral 4. Important 5. Very important

16. How important do you think coral reef restoration is for **the community**?

1. Not important 2. Slightly important 3. Neutral 4. Important 5. Very important

17. Would you like to help restore the reefs?

- Yes
- No
- Maybe

18. Have you heard of Reef2Reef?

- Yes
- No

19. Is there anything else you would like to share with me regarding this research? In case you'd like to get involved, you can leave your contact details here and we might get back to you.

Thank you!

Thank you very much for your time. You have given me some valuable insights. Please do not hesitate to contact me if you have any questions or further observations regarding my research.

Questionnaire for visitors (English)

Dear participant,

Thank you for participating in my research. This questionnaire is created to get insights in the perception of communities towards the coral reefs around Portobelo. Your input will be vital for this research and your time investment is greatly appreciated. The questionnaire consists of 24 open-ended and closed questions and it will take about 7 minutes to complete. Your identity will be kept completely confidential during the analysis and communication of the data obtained from this interview. The results will be discussed in a report which can be provided to you on request. If you have any questions or concerns, please contact Rosanne (r.s.j.p.bartholomeus@students.uu.nl)

Section A: Respondent social profile

1.What is your gender?

- Female
- Male
- Other / prefer not to say

2.How old are you?

- Under 20
- 20-40
- 40-60
- 60+

3. Where are you from? Multiple answers possible

- Panama
- Mexico
- Colombia
- Argentina
- Costa Rica
- United States
- Canada
- Italy
- Spain
- Germany
- Netherlands
- France
- Denmark
- Sweden
- England
- Switzerland
- Other: ______________________

4. How long do you stay here?

- Just for the day
- A couple of days
- A week
- Over a week
- Other: ______________________

5. What is the reason for your visit? Several answers possible.

- [ ] Culture
- [ ] History Art
- [ ] Beaches
- [ ] Diving / Snorkkeling
- [ ] Sailing
- [ ] Business
- [ ] Other: ______________________

6. What is your highest level of education?

- ( ) Primary school
- ( ) High school
- ( ) Bachelor's
- ( ) degree Master's
- ( ) degree PhD
- ( ) Prefer not to say
- ( ) Anders: ______________________

7. What is your workfield? Multiple answers possible

- [ ] Finances
- [ ] Health Care
- [ ] Fishery
- [ ] Hospitality Tourism
- [ ] Agriculture
- [ ] Science Education
- [ ] Legal services
- [ ] Construction
- [ ] Student
- [ ] Retired
- [ ] Unemployed
- [ ] Prefer not to say
- [ ] Other: ______________________

Section B: Coral reefs and its status

8. Have you seen the coral reefs here? **If not**, continue with question 14.

- ( ) Yes
- ( ) No

9. If yes, how have you seen the reefs? Multiple answers possible

- [ ] Scuba diving
- [ ] Snorkelling
- [ ]
- [ ]

- Swimming
- Fishing
- From the boat
- ☐ Pictures
- ☐ In buildings, as building material
- ☐ Anders: ____________________

10. **If yes**, how do they look?

*’Very bad’ implying no corals, or bleached corals or overgrown by algae and no marine life, no fish around, whereas ‘very good’ implies many different corals, a lot of color and marine life.

1. Very bad   2. Bad   3. Neutral   4. Good   5. Very Good

In case you have been **diving and/or snorkelling** in this area, please answer the following questions. If not, please continue with question 14.

11. How many times have you been diving / snorkelling in Portobelo?

- Only once
- Less than 5 times
- Less than 10 times
- 10+ times
- 20+ times

12. How many times did you dive / snorkel in your life?

- Less than 10 times
- 10-20 times
- 20-30 times
- 30-40 times
- 50+

13. If you have visited more dive/snorkel sites here in Portobelo and you remember the reef's name and status (ranging from very poor to very good), please provide your information in the table below.

Status Dive site	*Very bad*	*Bad*	*Neutral*	*Good*	*Very good*	*NA*
Playa Huerta						
Homereef Scuba						
Huerta Wall						
Drake Island						
Buenaventura						
Salmedina Rock						

14. How is your knowledge of corals?

1. Very poor   2. Poor   3. Neutral   4. Good   5. Very Good

15. What are corals?

- ☐ Rocks
- ☐ Plants
- ☐ Animal
- ☐ No idea

16. How important are coral reefs to you?

1. Not important 2. Slightly important 3. Neutral 4. Important 5. Very important

17. Why are coral reefs (not) important to you?

18. Do you know what are threats to coral reefs in this area? If yes, please list them below

Section C: Coral reef restoration

19. What do you know about coral reef restoration?

20. How important do you think coral reef restoration is for **the environment**?

1. Not important 2. Slightly important 3. Neutral 4. Important 5. Very important

21. How important do you think coral reef restoration is for **the community**?

1. Not important 2. Slightly important 3. Neutral 4. Important 5. Very important

22.Would you like to help restore the reefs?

Yes No Maybe

23. Have you heard of Reef2Reef?

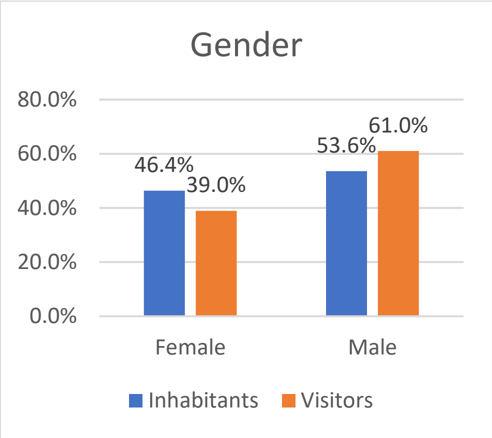
Yes No

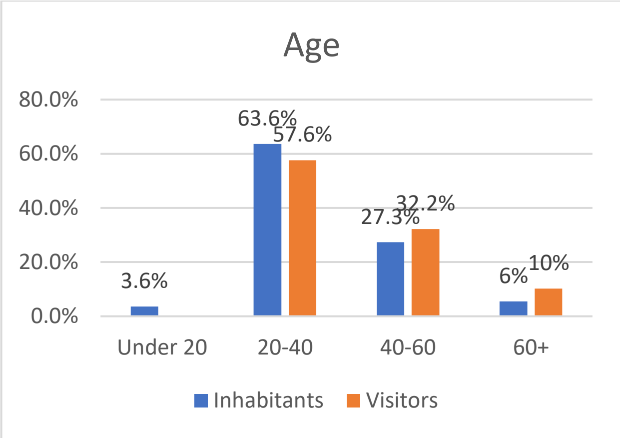
24. Is there anything else you would like to share with me regarding this research? In case you'd like to get involved, you can leave your contact details here and we might get back to you.

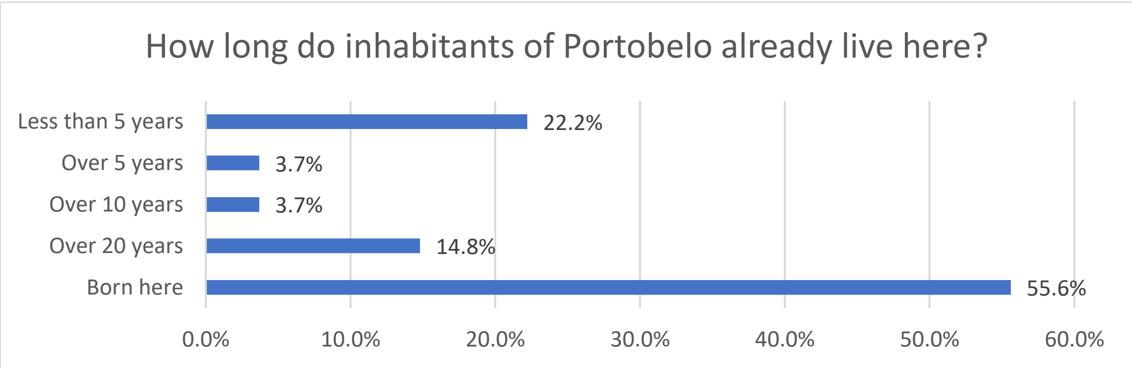
Thank you!

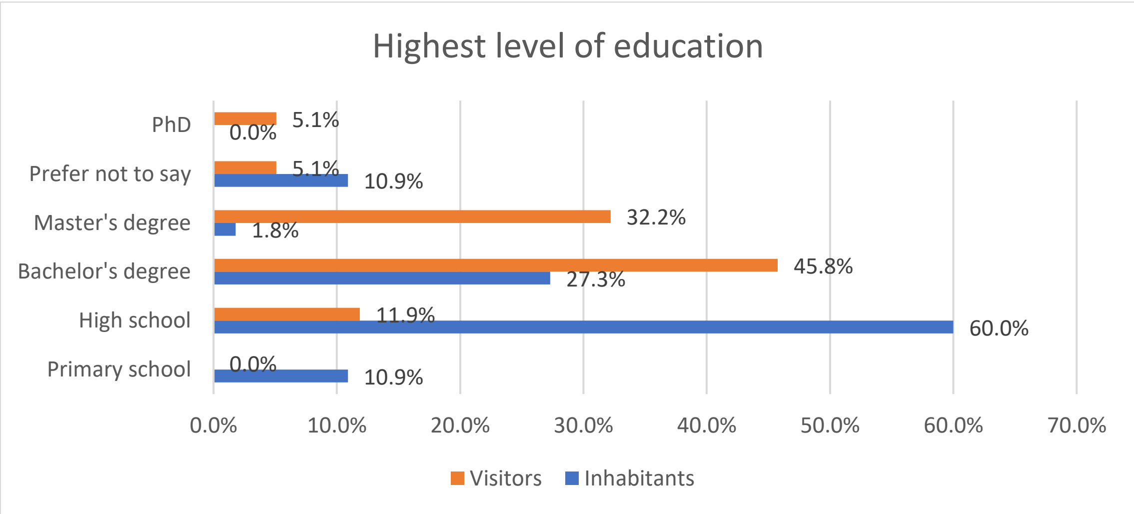
Appendix B – Questionnaire output

Section A : Respondent's social profile









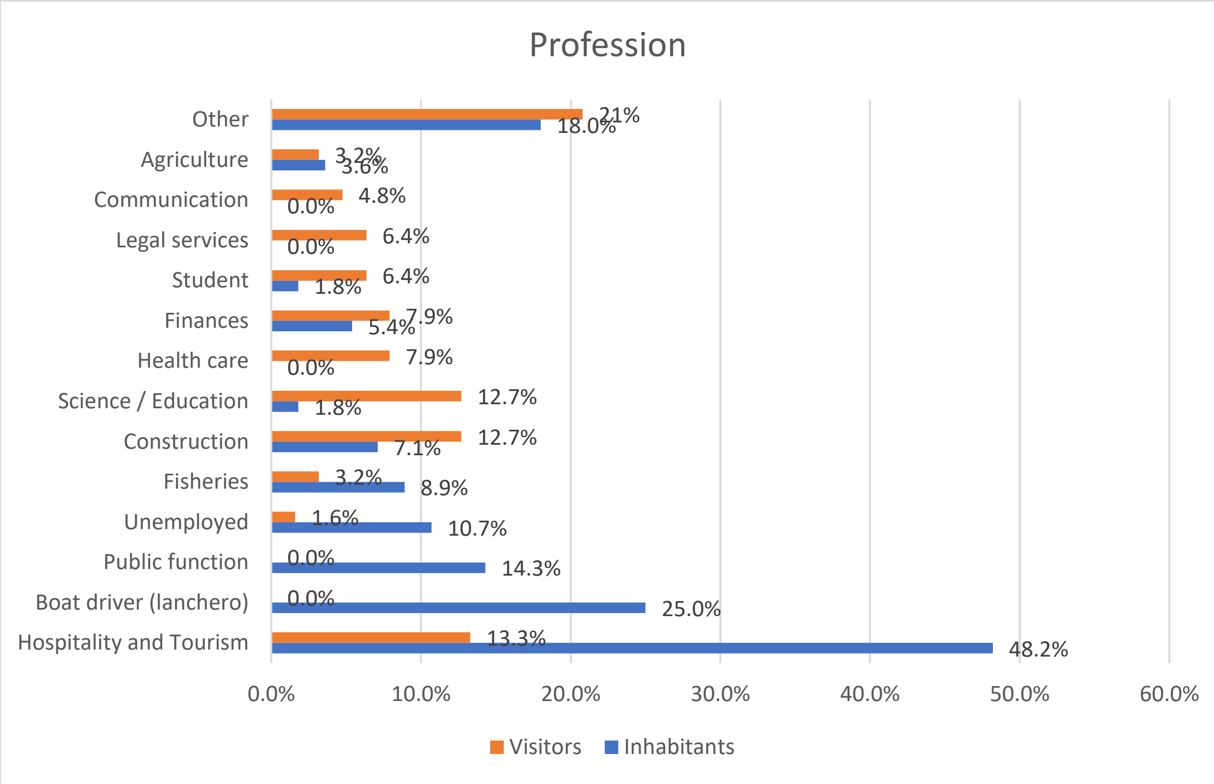
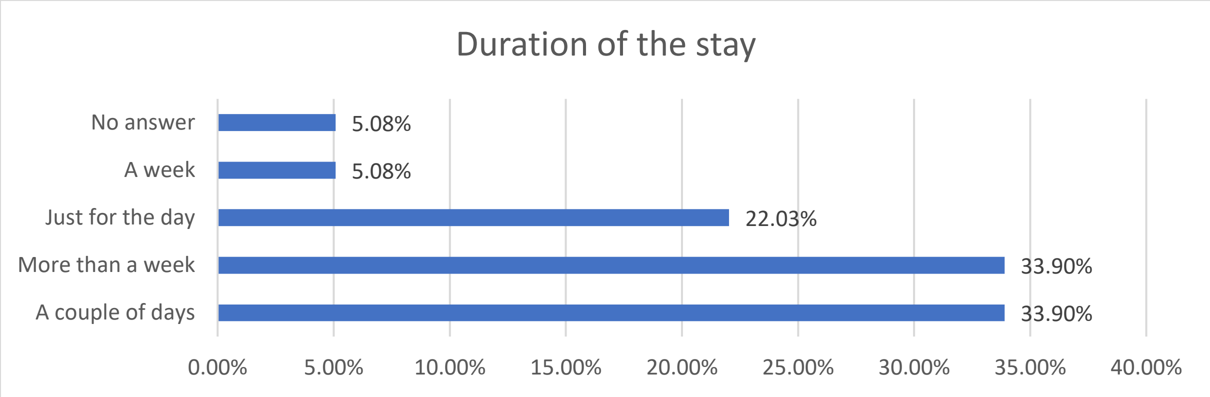
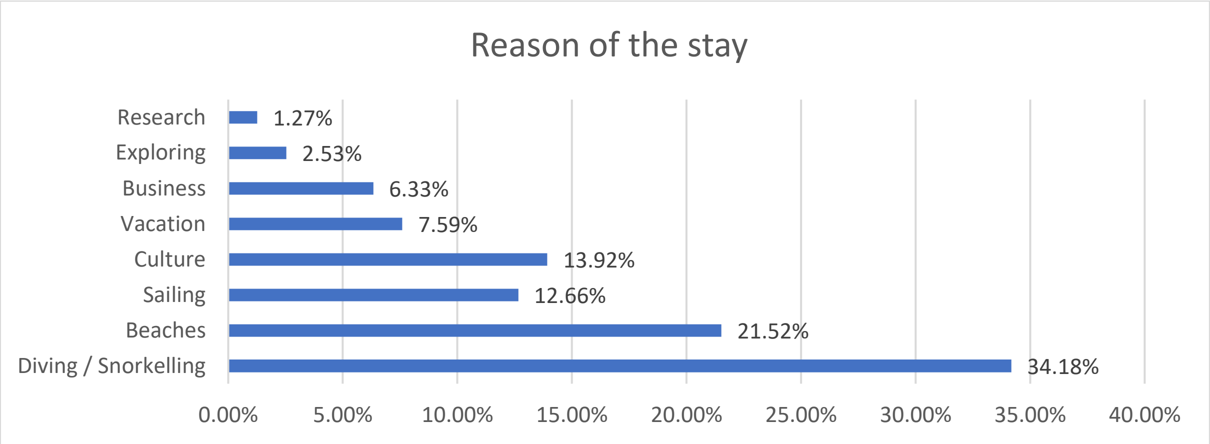


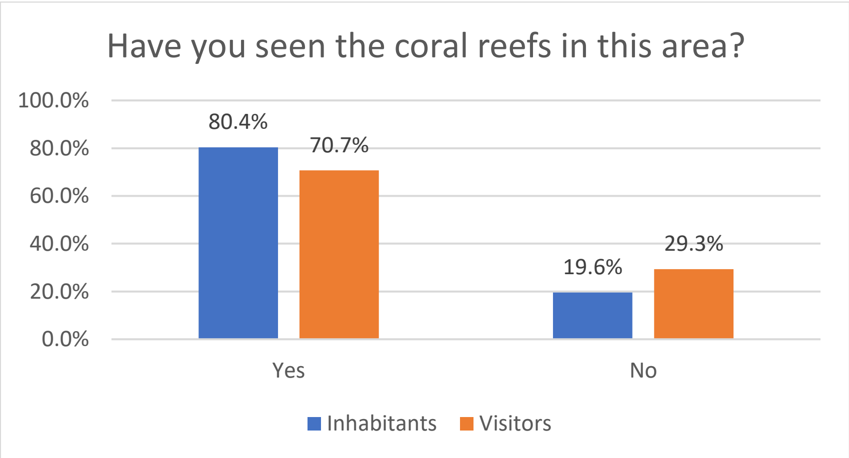
Table 14: Home country of the visitors.

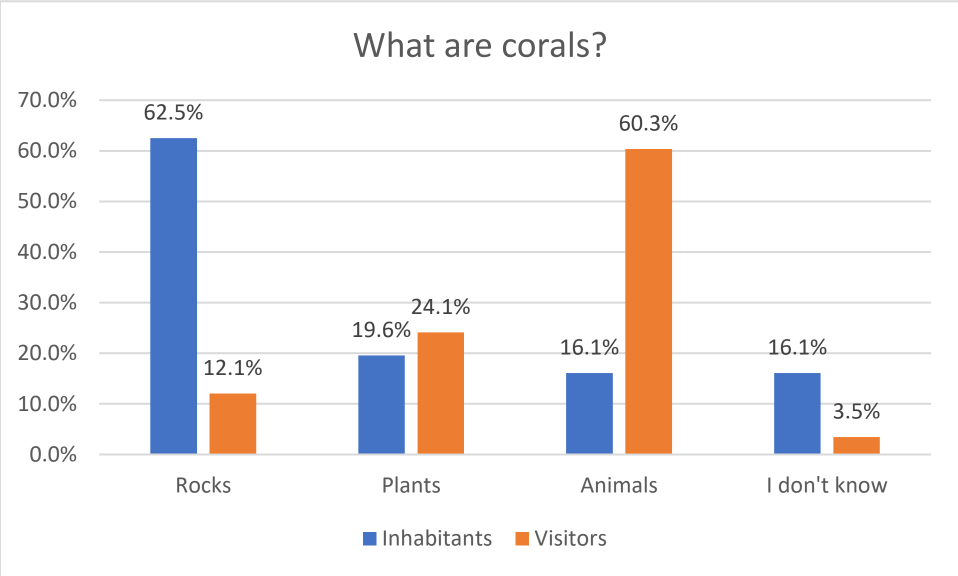
Country	Percentage
Panama	47.46%
United States	10.16%
Netherlands	8.47%
Spain	5.08%
Poland	5.08%
France	5.08%
Germany	3.39%
Italy	3.39%
Canada	1.69%
Venezuela	1.69%
Mexico	1.69%
Switzerland	1.69%
Colombia	1.69%
Israel	1.69%
Costa Rica	1.69%
Brazil	1.69%

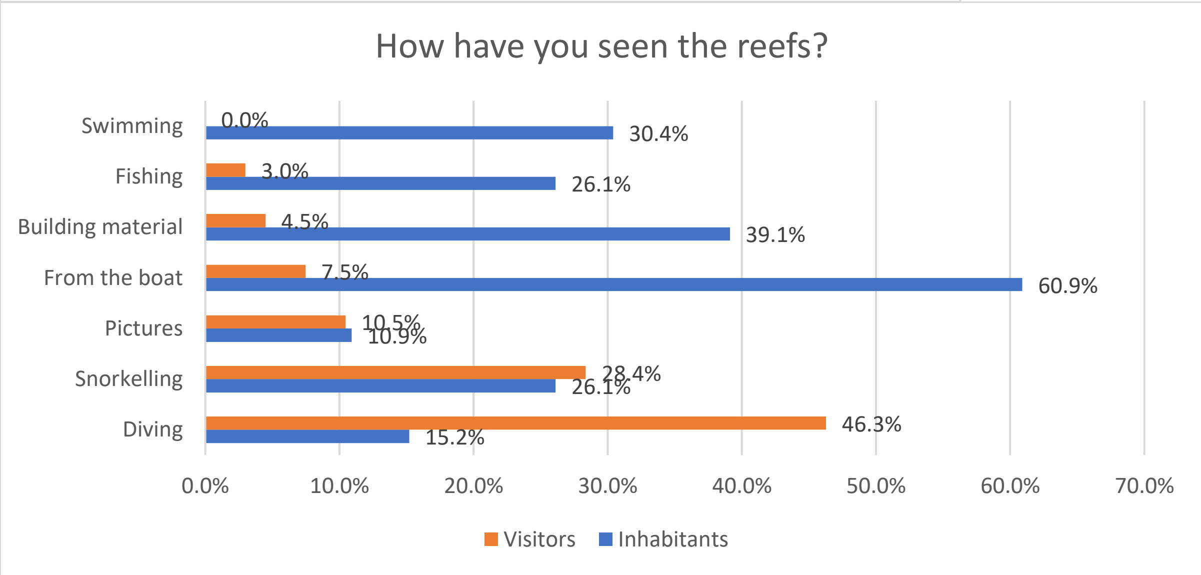


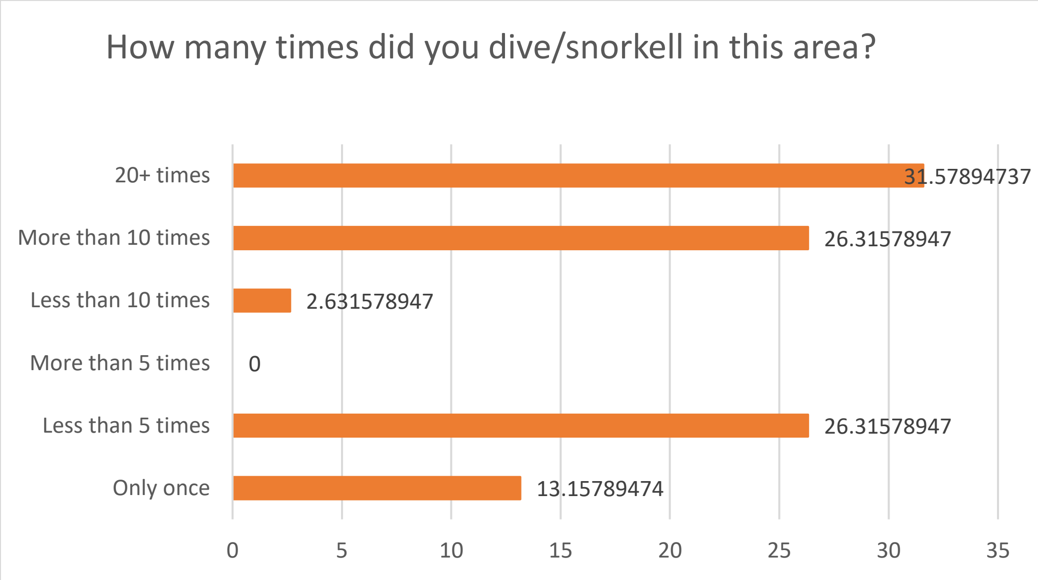


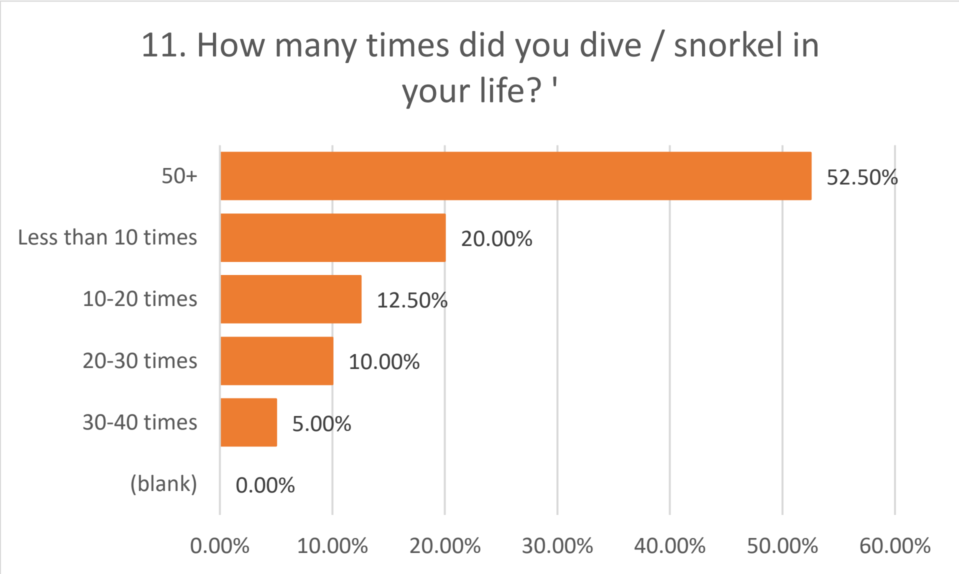
Section B : Awareness about coral reefs and its status



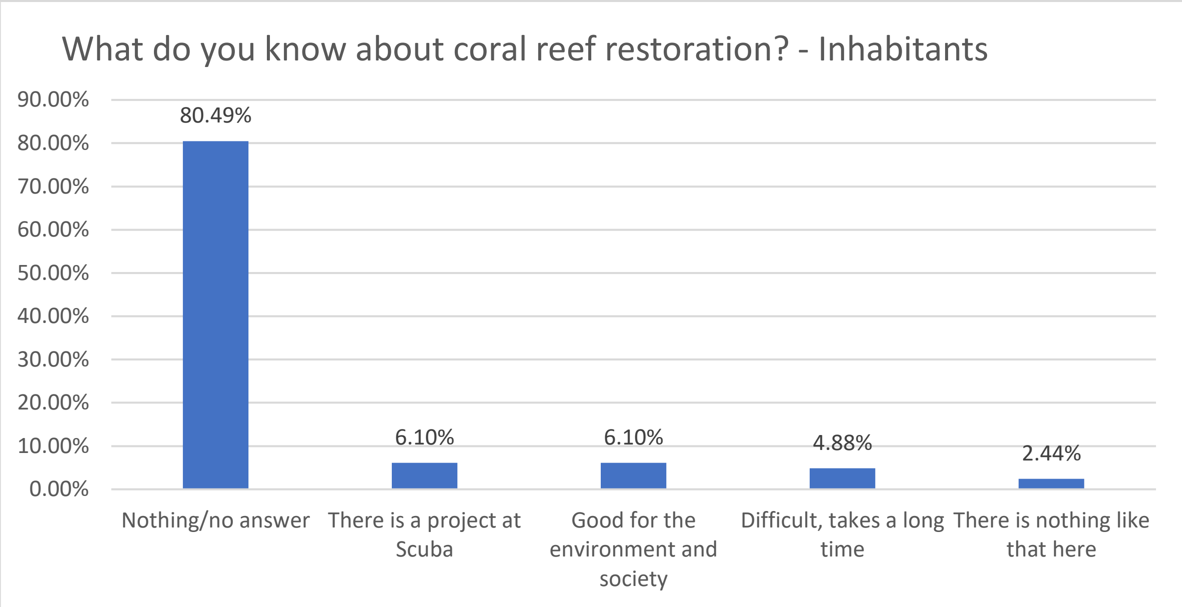

What are corals?
70.0%
60.0%
50.0%
40.0%
30.0%
20.0%
10.0%
0.0%
62.5%
12.1%
19.6%
24.1%
16.1%
60.3%
16.1%
3.5%
Rocks
Plants
Animals
I don't know
Inhabitants
Visitors

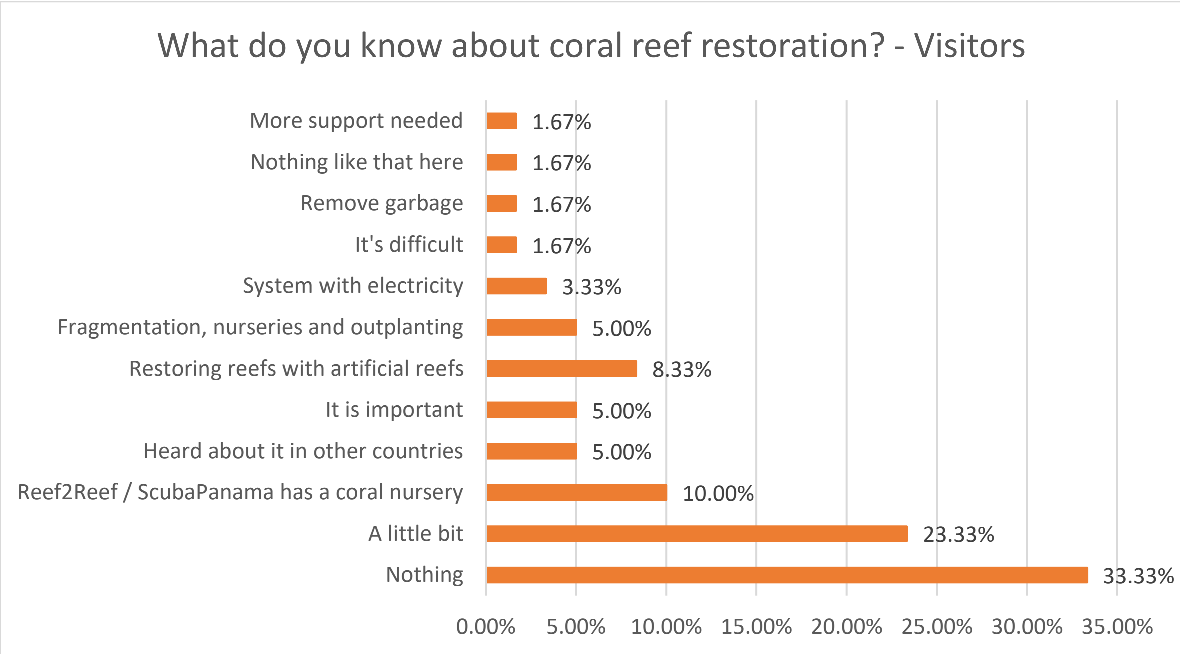

How have you seen the reefs?
Swimming
Fishing
Building material
From the boat
Pictures
Snorkelling
Diving
0.0%
30.4%
3.0%
26.1%
4.5%
39.1%
7.5%
60.9%
10.5%
10.9%
28.4%
26.1%
46.3%
15.2%
0.0%
10.0%
20.0%
30.0%
40.0%
50.0%
60.0%
70.0%
Visitors
Inhabitants


How many times did you dive/snorkell in this area?
20+ times
More than 10 times
Less than 10 times
More than 5 times
Less than 5 times
Only once
31.57894737
26.31578947
2.631578947
0
26.31578947
13.15789474
0
5
10
15
20
25
30
35


11. How many times did you dive / snorkel in your life? '
50+
Less than 10 times
10-20 times
20-30 times
30-40 times
(blank)
52.50%
20.00%
12.50%
10.00%
5.00%
0.00%
0.00%
10.00%
20.00%
30.00%
40.00%
50.00%
60.00%

Section C: Perception of coral reef restoration





Appendix C – Statistical Analysis test output Ecological Status

Table 1: Analysis of Variance (ANOVA) showing there are significant differences between the sites.

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Site	7	3279	468.5	7.064	**1.7e-05** ***
Residuals	40	2653	66.3		

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Table 2: p-values retrieved from TukeyHSD test, multiple comparisons of means, 95% family-wise confidence level, for significance difference in coral cover among sites.

Sites	diff	lwr	upr	p adj
BR-BL	6.00E+00	-9.0288448	21.0288448	0.9022656
DI-BL	-4.33E+00	-19.3621781	10.6955115	0.9820956
HS-BL	1.10E+01	-4.0288448	26.0288448	0.29848
HW-BL	7.67E+00	-7.3621781	22.6955115	0.7294337
LP-BL	7.00E+00	-8.0288448	22.0288448	0.808672
PH-BL	7.00E+00	-8.0288448	22.0288448	0.808672
SR-BL	-1.60E+01	-31.0288448	-0.9711552	**0.0298568** *
DI-BR	-1.03E+01	-25.3621781	4.6955115	0.3745965
HS-BR	5.00E+00	-10.0288448	20.0288448	0.9607003
HW-BR	1.67E+00	-13.3621781	16.6955115	0.9999599
LP-BR	1.00E+00	-14.0288448	16.0288448	0.9999988
PH-BR	1.00E+00	-14.0288448	16.0288448	0.9999988
SR-BR	-2.20E+01	-37.0288448	-6.9711552	**0.0007912** *
HS-DI	1.53E+01	0.3044885	30.3621781	**0.0426608** *
HW-DI	1.20E+01	-3.0288448	27.0288448	0.2038641
LP-DI	1.13E+01	-3.6955115	26.3621781	0.2642369
PH-DI	1.13E+01	-3.6955115	26.3621781	0.2642369
SR-DI	-1.17E+01	-26.6955115	3.3621781	0.232689
HW-HS	-3.33E+00	-18.3621781	11.6955115	0.9962434
LP-HS	-4.00E+00	-19.0288448	11.0288448	0.9887185
PH-HS	-4.00E+00	-19.0288448	11.0288448	0.9887185
SR-HS	-2.70E+01	-42.0288448	-11.9711552	**0.0000281** *
LP-HW	-6.67E-01	-15.6955115	14.3621781	0.9999999
PH-HW	-6.67E-01	-15.6955115	14.3621781	0.9999999
SR-HW	-2.37E+01	-38.6955115	-8.6378219	**0.0002648** *
PH-LP	2.13E-14	-15.0288448	15.0288448	1
SR-LP	-2.30E+01	-38.0288448	-7.9711552	**0.0004114** *
SR-PH	-2.30E+01	-38.0288448	-7.9711552	**0.0004114** *

Appendix D – Individual Site Description

This section provides essential information about each study site, including reef characteristics, monitoring depths, environmental conditions, observations during data collection, observed threats, coral recruitment and coral colony health status. The temperature refers to the water temperature at the depth range of the data collection. Efforts were made to accurately represent the locations of the transects with red marks on the picture; however, it should be noted that these representations serve as approximations. The transects were randomly deployed underwater.

Inner Reef

Homereef ScubaPortobelo

Coordinates: 9°32'10.21"N 79°40'23.94"W **Date:** 13/02/23 **Depth range:** 0.5-2.5m
Temperature: 29 °C

Figure - 1 Homereef Scuba, Benthic cover and coral species.

This site features a fringing reef, separated from the shore by a shallow lagoon, which is covered by macroalgae, followed by seagrass fields before reaching the homereef. The reef is patchy and shallow (Fig.2), ranging from 0.5 to 5 meters in depth. During the data collection two lionfishes (*Pterois volitans*), five sea urchins (*Diadema antillarum*) and a bearded fireworm (*Hermodice carunculate*) were observed (Fig.3). Sewage from the nearby hotels and the river runoff from Rio Buenaventura, especially during heavy rainfall, contribute to water turbidity and potential water quality issues. A layer of suspended particles is observed on top of sand, rocks, corals and algae in some places (Fig.4). from the nearby hotels and the river runoff from Rio Buenaventura, especially during heavy rainfall, contribute to water turbidity and potential water quality issues. A layer of suspended particles is observed on top of sand, rocks, corals and algae in some places (Fig.4). Coral recruits were observed on the concrete structures and rocky substrate in this shallow lagoon and on the reefs that were monitored (Fig.5). Approximately 47 coral recruits of *Siderastrea* and 3 of *Favia fragum* were observed, resulting in a high density of coral recruits (4.2 recruits per m2) at this site.

18 points out of the 53 points with *Siderastrea Siderea* showed colonies that were covered in white dots (Fig.6), suggesting parrot fish bites or White Pox Disease (WPC).

A coral colony of *Pseudodiplora strigosa* shows a different, bleached colour on the edges (Fig.7). Siderastrea colonies were also observed covered in red/purple stains (Fig.8), which might suggest signs of Aspergillosis (ASP). Additionally, *Siderastrea* colonies were overgrown by algae, possibly as a consequence of one of the abovementioned diseases (Fig.9).

Figure - 2 Distribution of coral patches in front of ScubaPortobelo.

Figure - 3 Sea urchin (Diadema antillarum) and a bearded fireworm (Hermodice carunculate) on fire coral.

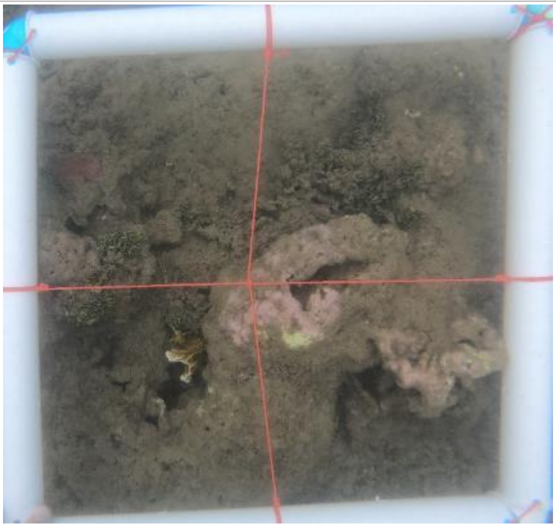


Figure - 4 Suspended matter covering algae and other substratum.

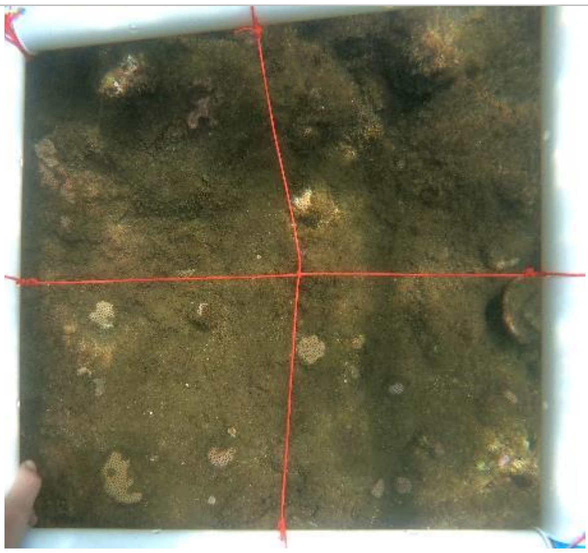


Figure - 5 Coral recruits of Siderastrea.

Figure - 6 White dots on Siderastrea.

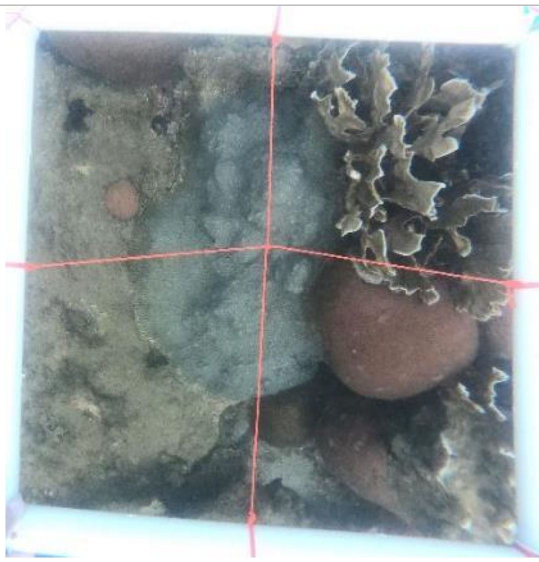


Figure - 7 Bleached edges of (Pseudo)Diploria strigosa.

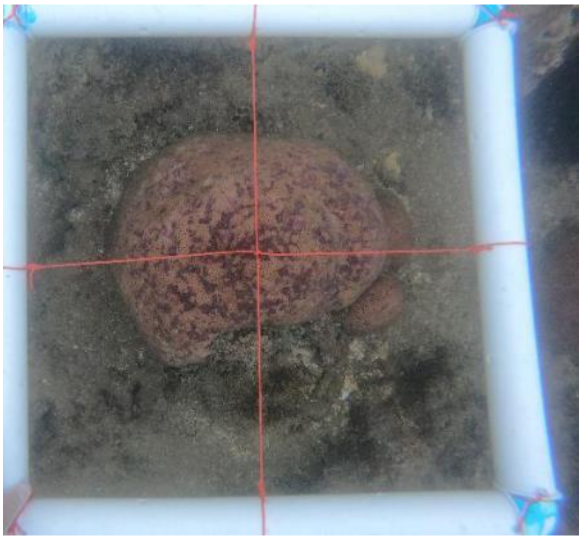


Figure - 8 Red/purple lesions on Siderastrea.

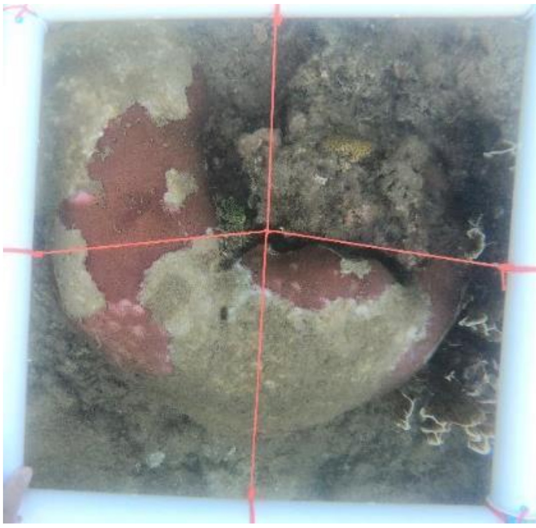


Figure - 9 Siderastrea partly overgrown by algae.

Huerta Wall

Coordinates: 9°33'30.12"N 79°40'45.54"W Date: 18/01/23 & 08/02/23 Depth range: 5-8.5m Temperature: 27 °C

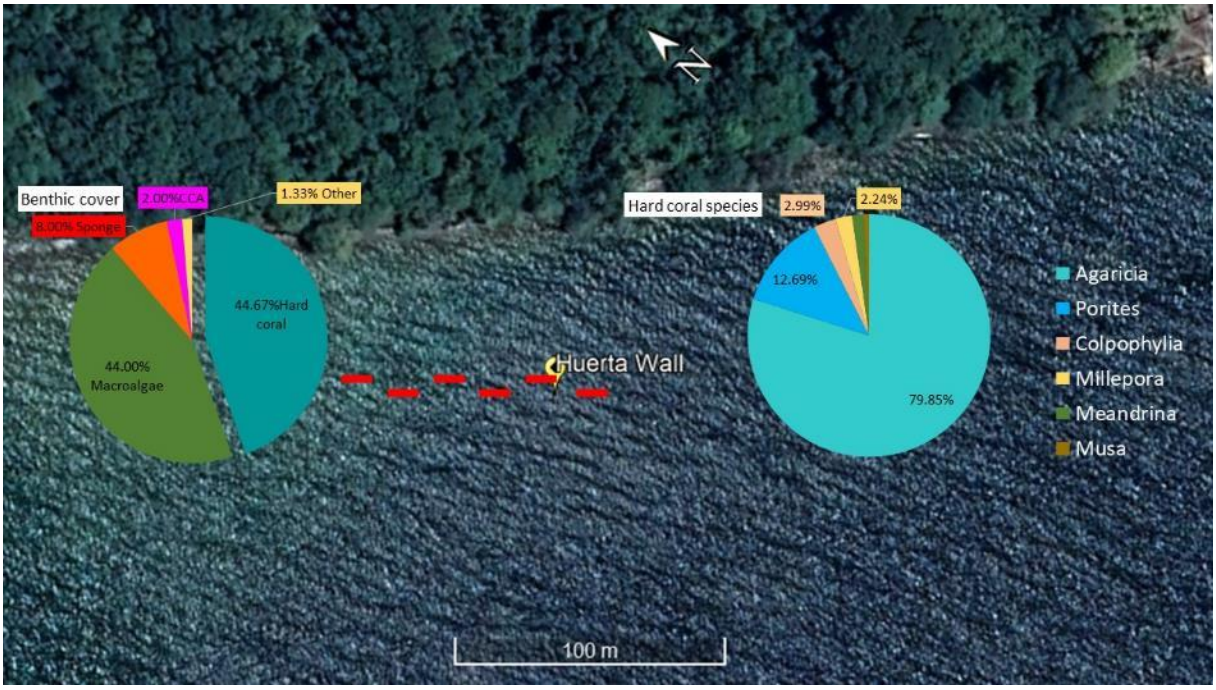


Figure - 10 Huerta Wall, benthic composition and coral species.

Huerta Wall is characterized by a steep coral wall, starting at shallow depths (0.5m) and extending to approximately 15 meters in depth. The shallow reef consists of rocks, bare substrate and some boulder corals, as well as *Acropora palmata* skeletons (Fig.11). The mainland consists of vegetation and no buildings, however, the proximity of Portobelo town and the river outflow of Rio Cascaja into the bay of Portobelo could potentially affect visibility and water quality at this site. Macroalgae, mainly *Dictyota* spp. make up a large part of the reef, together with *Agaricia tenuifolia* being the dominant coral species on this reef (Fig.10). Figure 12 shows the patchy appearance of Porites colonies on this reef.

Figure - 11 Acropora palmata coral skeleton in the distance and showing the slope of Huerta Wall.

Figure - 12 Patches of porites.

La Piscina

<u>Coordinates: 9°33'37.74"N 79°40'50.34"W Date: 17/01/23 & 15/02/23 Depth range: 1-3m</u>
<u>Temperature: 29 °C</u>

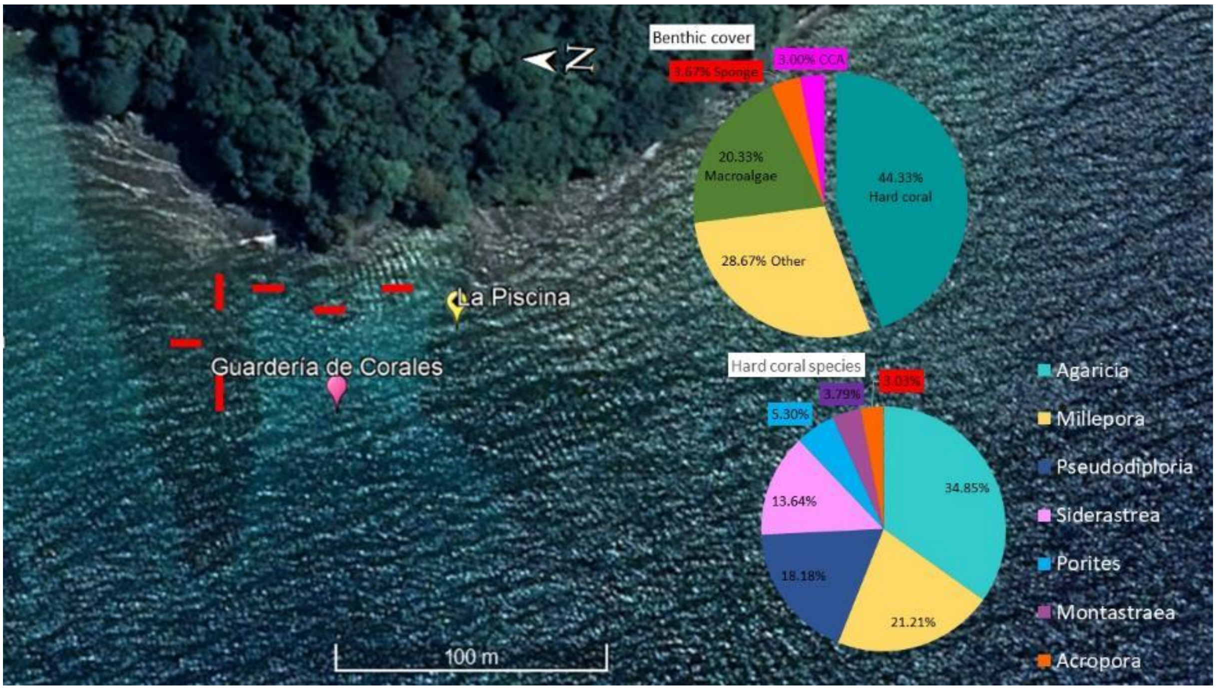


Figure - 13 La Piscina, Benthic composition and coral species.

La Piscina consists of a shallow patchy reef (0.5-1.5m) near the coast, with corals, alternated by rocks and sand. The patchy distribution of the reef causes there to be a lot of 'other' (26.7%), sandy areas in between the coral colonies, as depicted in figure 13. A total of 26 coral recruits were counted within the transect quadrats (12m2), along with 2 sea urchins. A channel-shaped reef extends from the mainland towards the open ocean (Fig.14). This reef formation is about 28 meters wide in the middle, consisting of patchy reefs, some small canyons in between, varying from 1.5-3.5m in depth. The reefs near the shore and this reef formation going from the coast into the open ocean, surround a sandy plane where the coral nursery and artificial structures are located. One *Acropora cervicornis* was found on a rocky surface on the reef near the coast, this is likely one of the fragments from the coral nursery that was detached from the nursery and found a new place to settle. Two *Acropora palmata* skeletons were encountered in this area (Fig.15), which might also be suitable for out-planting on a natural substrate. A live *Acropora palmata* was also found on the rocks (Fig.16). Due to the shallow nature of the site, random quadrant pictures have been taken in combination with swimming along some transect lines.

Figure - 14 Reef formation.

Figure - 15 Acropora Palmata skeleton

Figure - 16 Acropora Palmata

Playa Huerta

<u>Coordinates: 9°33'43.71"N 79°40'51.41"W Date: 08/02/23 Depth range: 2.5-5m Temperature: 27 °C</u>

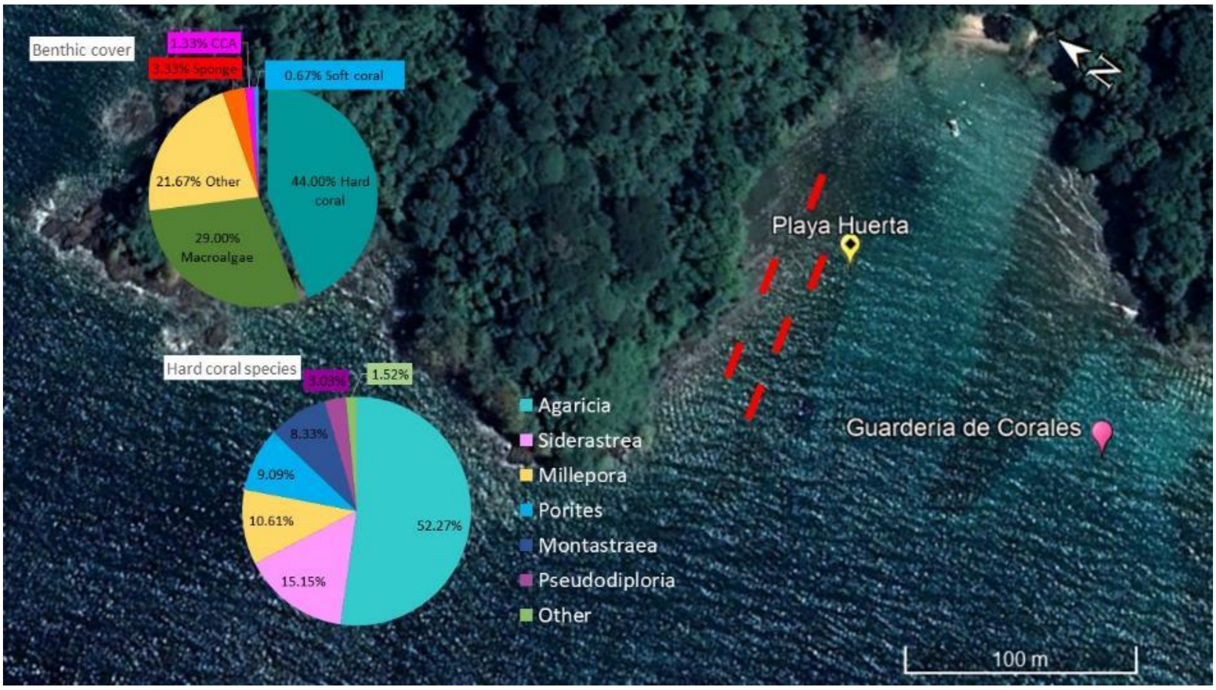


Figure - 17 Playa Huerta Benthic compositio and coral species.

This site, located next to La Piscina, also features a channel-shaped reef parallel to the coast. The patchy distribution of the reef explains the high percentage of 'other' (21.7%) at this site (Fig.17). It is a popular destination for diving, snorkelling, and beach tourism, leading to occasional littering issues. The beach clean-ups organized by Reef2Reef are often held at this beach. Access to the beach is primarily by boat, with a small hiking trail available as well.

Siderastrea siderea showed similar white dots as observed at the Homereef (Fig.18), *Siderastrea* was also observed being overgrown by algae, including crustose coralline algae (Fig.19).

Figure - 18 Siderastrea white dots.

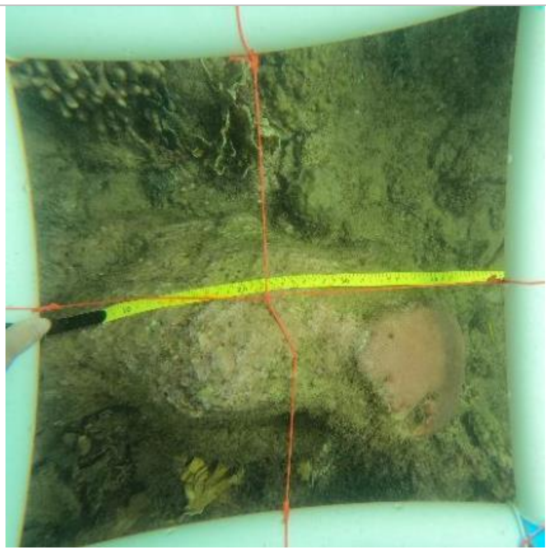


Figure - 19 Siderastrea overgrown by coralline algae.

Outer reef

Salmedina Rock

Coordinates: 9°33.825'N 79°41.727'W Date: 09/03/23 Depth range: 5-10m
Temperature: 26 °C

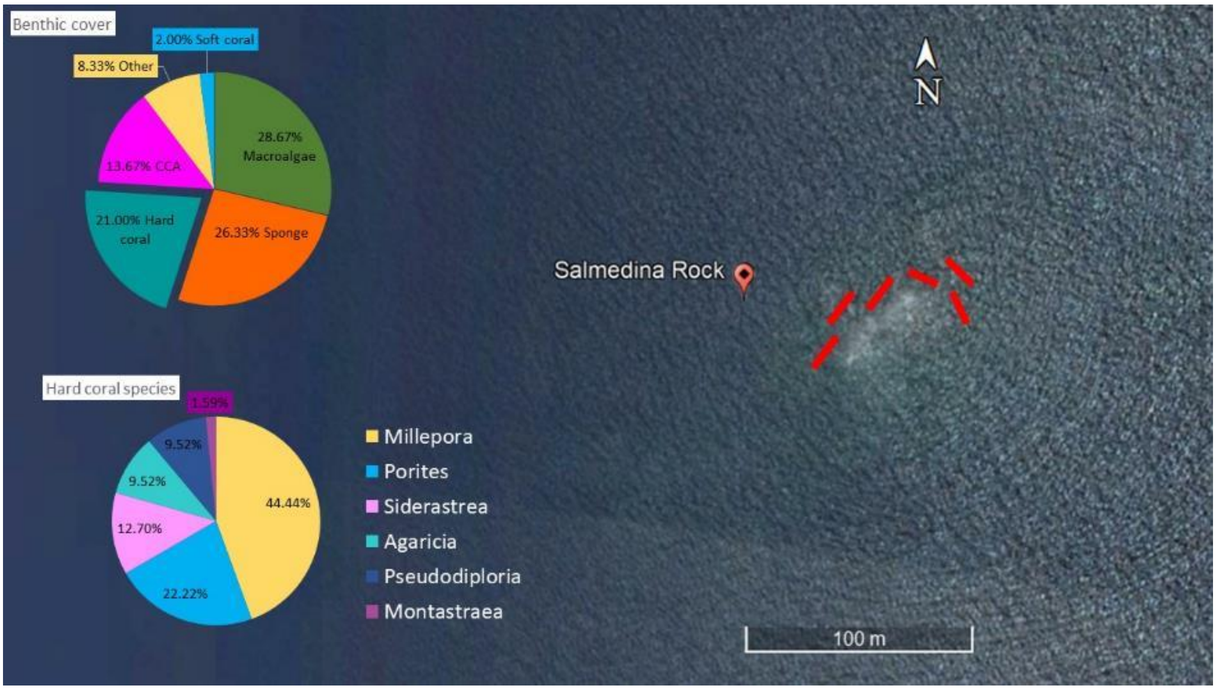


Figure - 20 Salmedina Rock benthic composition and coral species.

Salmedina Rock is situated further offshore, where weather conditions are decisive for the accessibility of the dive site and the visibility underwater (Fig.20). The reef primarily comprises rocky formations interspersed with occasional coral colonies and sandy areas. Notably, the hard substrate of the rock formations consistently exhibited frequent encrustation by crustose coralline algae (CCA) (Fig.20,21). Dominating the benthic cover at this site are macroalgae (28.7%) and sponges (26.3%). In contrast, hard coral contributes only 21% of the benthic cover. The hard coral observed in this location is predominantly composed of fire coral (*Millepora*, 44.4%), followed by *Porites* (22.2%), *Siderastrea* (12.7%), and *Agaricia* and *Psuedodiploria* (9.5%). 7 coral recruits of *Siderastrea* were observed at this site and one sea urchin.

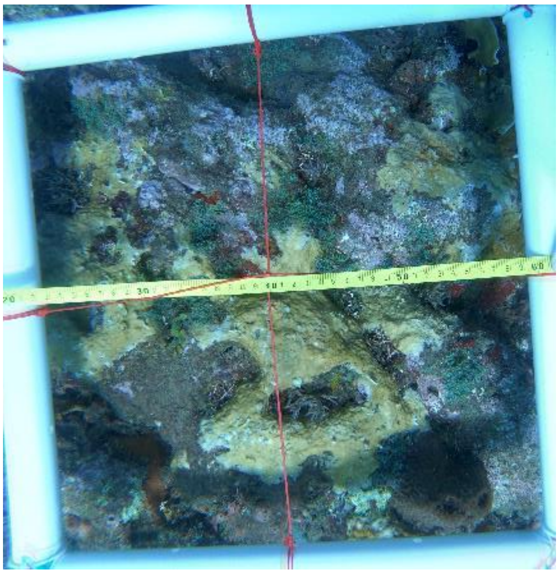


Figure - 21 CCA and fire coral.

Drake Island

<u>Coordinates: 9°33'41.58"N 79°41'7.68"W Date:12/01/23 & 17/01/23 Depth range: 6.5-11m Temperature: 27°C</u>

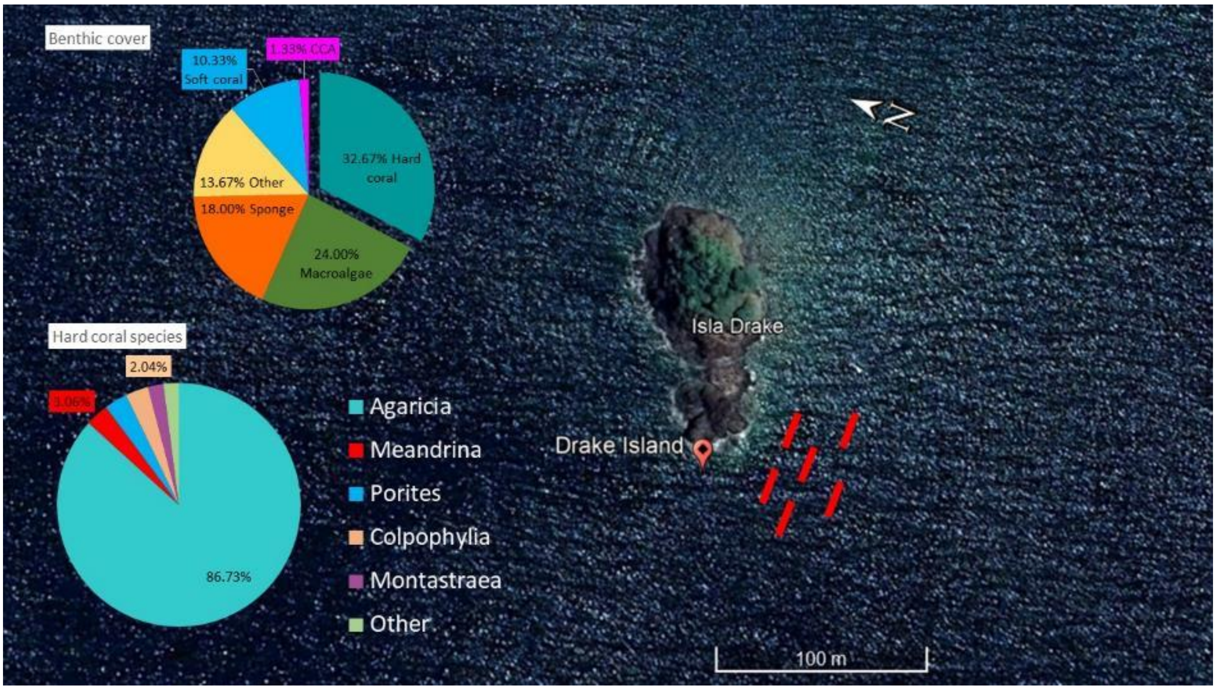


Figure - 22 Drake Island benthic composition and coral species.

Drake Island is a small, uninhabited rocky island characterized by sparse vegetation (Fig.22). The reef commences at a depth of approximately 10 meters, transitioning from a sandy bottom to form a plateau at 6-7 meters, where the transects have been conducted. Notably, on the right side of the island, facing the mainland, a 4 by 4 meter rocky area with bare substrate exhibited a substantial presence of coral recruits, suggesting its suitability as a potential site for coral out-planting on natural substrates. Additionally, during the surveys, one feather worm was observed. The area monitored at Drake Island showed the lowest values for both Shannon-Weaver Diversity and species richness, with 86.7% of the hard coral cover consisting of *Agaricia tenuifolia* (Fig.22).

During an exploratory dive (24/01/23), 3 healthy colonies of *Acropora palmata* were found in this area (Fig.23). As can be seen in the pictures, rocks are covered in CCA and surrounded by fire coral (*Millepora*). These findings are very different compared to the outcomes achieved from the transects, therefore it is worth mentioning that extra surveys in the area around Drake Island are recommended to obtain a more complete picture of the ecological status of those reefs.

Figure - 23 Acropora Palmata colonies.

Buenaventura Left

Coordinates: 9°32'27.9"N 79°41'04.1"W **Date: 18/01/23** **Depth range: 6.5-10m**
Temperature: 27 °C

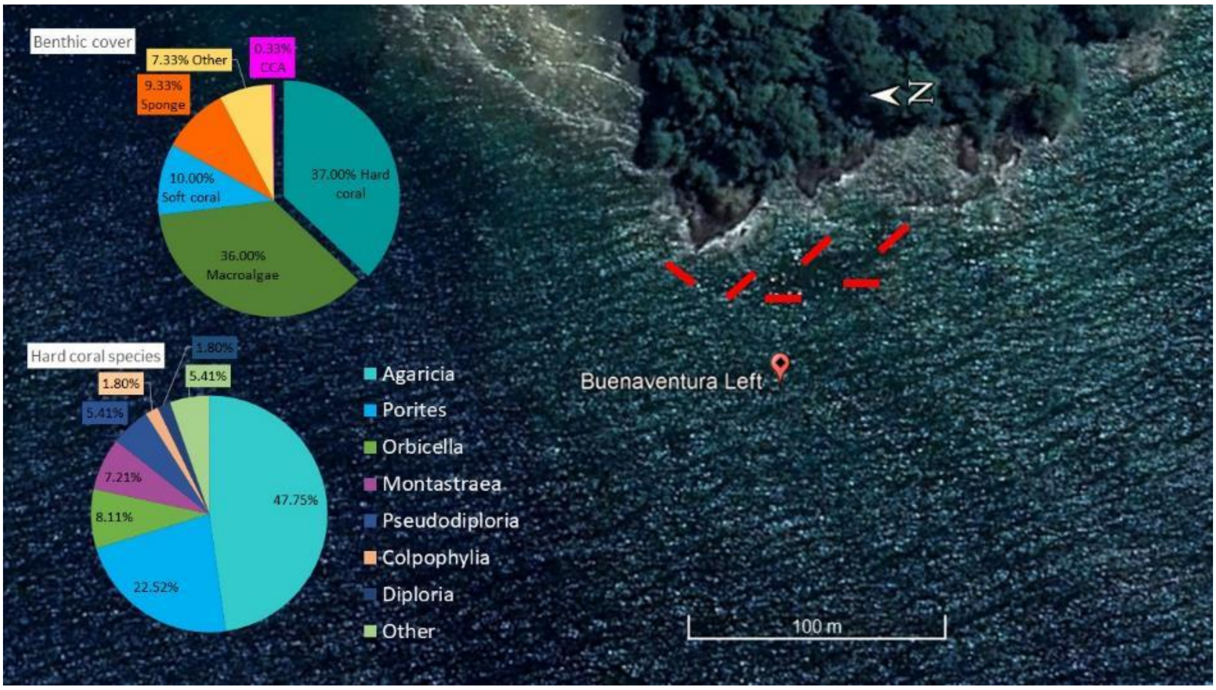


Figure - 24 Buenaventura left benthic composition and coral species.

This area is located near Isla Mangote, a small island close to the mainland, divided into two parts (Fig.24). The side closer to the coast features a private beach owned by ScubaPortobelo, with seagrass and mangroves, while the side facing the open ocean is more exposed to wave energy, this is the site being examined here. Underwater, sandy areas are interspersed with channel-shaped reefs, displaying the patchy distribution of reef plateaus and almost vertical reef walls (Fig.25).

Figure - 25 Reef wall at Buenaventura Left.

Buenaventura Right

Coordinates: 9°32'19.48"N 79°40'58.11"W   Date: 10/01/23 & 24/01/23   Depth range: 5-7m
Temperature: 27 °C

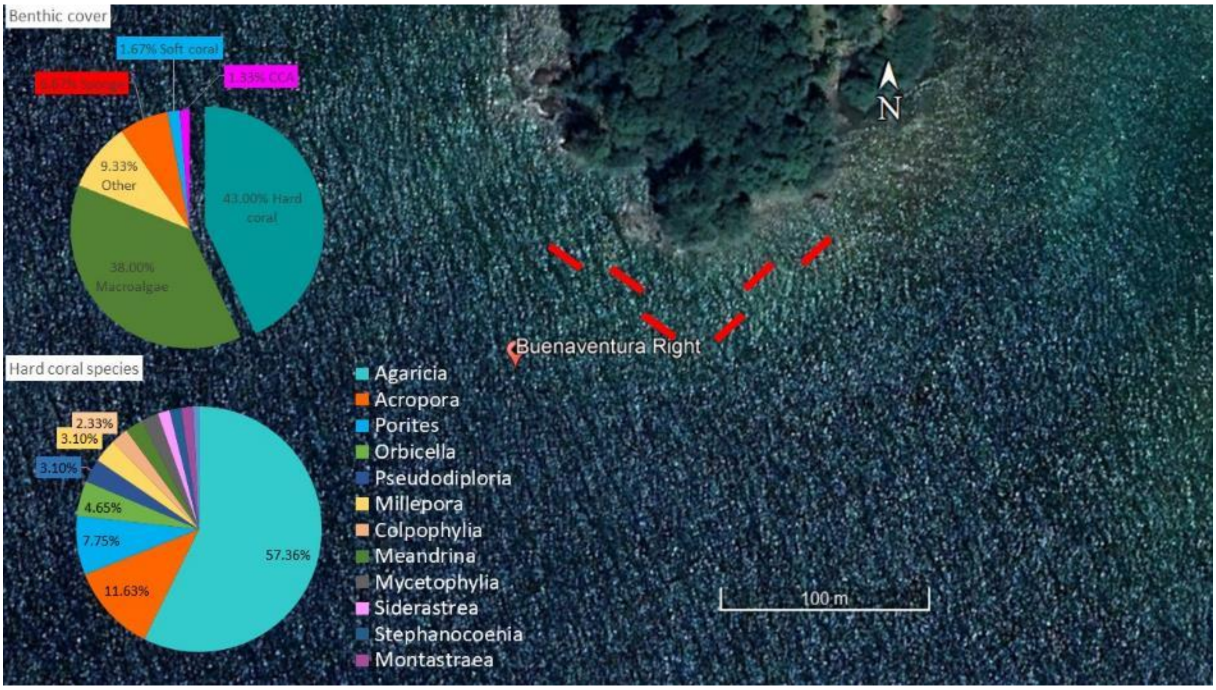


Figure - 26 Buenaventura Right benthic composition and coral species.

This reef exhibits similar reef characteristics as the one described above (Buenaventura Left). However, the species richness and diversity at this site are higher, accompanied by the presence of *Acropora cervicornis* and *palmata*. The status of the *Acropora* colonies found here is debatable, as some of the *cervicornis* branches were either covered in algae, bleached or showed white bulbs (Fig.27), and the *palmata* colony showed also these white bulbs (Fig.28). Three feather worms and one sea urchin were found along the transects.

Figure - 27 Acropora cervicornis white branches.

Figure - 28 Acropora Palmata white bulbs.