Linnæus University
Sweden

Bachelor's thesis

The Ecological and Anthropogenic Impacts of fishing gear in a tropical system

- How the size of Spotted Rose Snapper (*Lutjanus guttatus*) and the ratio of target catch, is influenced by approved fishing gear within a marine area of responsible fishing in the South-Western Gulf of Nicoya, Costa Rica.

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Abstract

The oceans are essential for humanity, yet these systems continue to be degraded and suffer from pollution, habitat destruction and overexploitation. The Costa Rican Gulf of Nicoya is a productive gulf that is fished by both large-scale industrial fisheries and small-scale artisanal fishermen. However, the gulf is profoundly overfished and there has been a shift in both the type of species and size of fishes being targeted, which has had devastating economic and ecological effects in the region. To improve their livelihoods, artisanal fishermen have together with governmental agencies instituted partially protected marine protected areas, known as AMPRs which are intended to give artisanal fishermen exclusive fishing rights and to better the health of the ecosystems. However, these AMPRs can vary greatly within and between each other in aspects such as what types of fishing gear is allowed. To investigate how fishing techniques impact the health of the fish stocks and the wellbeing of fishermen within an AMPR, the size of a target fish, Spotted Rose Snapper (*Lutjanus guttatus*) and the number of undesired fish caught, was compared based on the number of approved fishing methods such as nets, longlines and commercial scuba diving, between different zones. This was conducted by identifying and measuring catch in collaboration with the National University of Costa Rica, who contributed with databases and field assistance, and artisanal dead bait longline fishermen (bottom long line) in the Paquera-Tambor AMPR. The results showed that in areas where fishing gear is more restricted, the mean weight of Spotted Rose Snapper was higher, but the relative proportion bycatch was not different. Furthermore, there was no difference in legal capture or breeding lengths between areas with high and low restriction of fishing gear. This indicates that the effects of overfishing are less predominant in zones where fewer fishing methods are permitted. The restriction of fishing methods could increase biodiversity and size in fish by exploiting less cohorts of populations. The preservation of size in fish species is very important regarding reproductive success, and it is therefore paramount that larger individuals are protected. This could be accomplished by for example, restricting the amount of allowed fishing gear or introducing maximum catch sizes. However, an improvement of the fish stocks, and therefore human wellbeing cannot be achieved in the Gulf of Nicoya without a revision of the strategies of two influential governmental bodies, the Costa Rican coast guard and the Costa Rican Institute of Fisheries and Aquaculture.

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Introduction

Small-scale artisanal fishing in Gulf of Nicoya, Costa Rica

The state of marine systems

Humans are dependent on the oceans. It provides many essential ecosystem functions and has plenty of economic incentives that we as a species rely on (Alms & Wolff 2019). Fish and other types of seafood serve as the primary source of protein for over one billion people and accounts for 25% of the total animal protein consumption globally (Gutiérrez *et. al*. 2011). Additionally, fish offers consumers essential fatty acids and minerals, which may be difficult to obtain from other sources (Phang *et. al.* 2019). However, the oceans face many different threats such as global warming, overexploitation, and eutrophication which all can be linked to human activity (Garcia *et. al.* 2003). It has been made clear in recent years that even in productive systems, the abundance of marine resources is finite. Human impact and mismanagement of fish and invertebrate populations has had a severe impact on both the aquatic systems and the humans that depend on them (Garcia *et. al.* 2003). As much as, 60% of ecosystems are degraded and the majority of fish stocks are either fully exploited or exhausted to the point of which they have collapsed and need to be restored (Palumbi *et. Al.* 2009; Gutiérrez *et. Al.* 2011).

The Gulf of Nicoya is situated off the north-western Pacific Coast of Costa Rica (Figure 1). Its estuarine water covers 1500km^2 and is regarded as one of the most productive marine environments in the world, having a net primary production of 610g C/m^2/year compared to the coastal global average of 100g C/m^2/year (Kappelle 2016). This highly productive system is bottom up controlled and supports both a large-scale and a small-scale fishing industry (Kappelle 2016; Alms & Wolff 2019). However, this productivity does not make the gulf immune to overfishing and it has like the majority of marine systems been overexploited (Kappelle 2016; Alms & Wolff 2019; Palumbi *et. Al.* 2009; Gutiérrez *et. Al.* 2011).

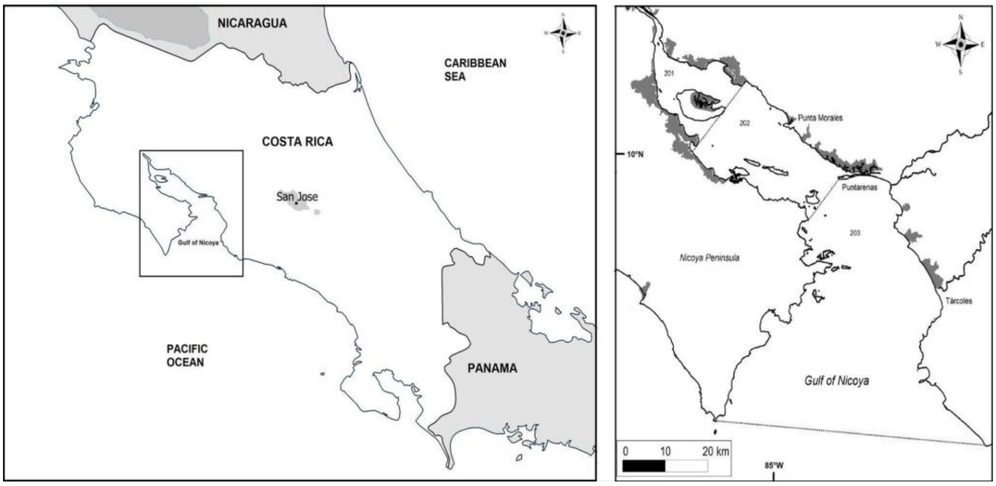

Figure 1: *Illustration of the Gulf of Nicoya, Costa Rica* ©Alms & Wolff (2019)

Target catch & bycatch

The total biodiversity from the pacific mainland of Costa Rica to the island; Isla del coco, is made up of 4,745 species, where over 800 of these species are fish (Dumont *et. Al.* 2009). Of these 800 species, only a few species are targeted by the fishermen for their commercial importance. The artisanal fishermen of the Tambor region encountered in the field, primarily targeted the Spotted Rose Snapper, *Lutjanus guttatus*, with dead bait longline (bottom longline). This species is important for the coastal artisanal fisheries in the Costa Rican Gulf of Nicoya, due to their high commercial value (Soto-Rojas *et. Al.* 2018; Pollnac 1979). In the gulf, this species reaches sexual maturity at 30 cm in total length, with a maximum size of 65 cm and has a minimum legal catch size of 34 cm (Soto-Rojas *et. Al.* 2018; Pérez 2020). The Spotted Rose Snapper has two main reproductive seasons; one from May to August and a second from October to November (Soto-Rojas *et. Al.* 2018). The species inhabit coastal zones with rocky bottoms and feed off an assortment of crustaceans and other fish (Soto-Rojas *et. Al.* 2018; Mongeon, *et. Al.* 2013).

On the contrary to target species, there are certain species that the fishermen usually try to avoid. These include members of the sea catfish family *Ariidae*, but some species of certain sizes would still be kept. These unwanted and subsequently discarded fish would be considered bycatch species (NOAA Fisheries 2017; NOAA Fisheries 2018). Bycatch is defined as any animal unwillingly caught that cannot be sold, kept or otherwise is unwanted by the fishermen (NOAA Fisheries 2018). Bottom longline fishing has a strong link to overfishing since species that are considered bycatch, and are returned to the ocean, in some cases show poor survival rate (Dapp *et. al.* 2013). An example is when sea turtles or rays are caught on the hooks (Dapp *et. al.* 2013). They experience a high mortality rate and turtles have been in decline in Costa Rica due to the continued use of this fishing method (Dapp *et. al.* 2013).

Fishing gear

In the Costa Rican Gulf of Nicoya, small-scale fishermen employ many different methods like dead bait longline (Linea planera), live bait longline (Linea Taiwanesa), nets (trasmallo) and handline (cuerdas de mano) to capture fishes. Most of the fishermen use small motorboats (panga) that can be modified to the needs of the artisanal fishermen (Pollnac 1979). These boats are usually operated by a captain and up to three crew members (Pollnac 1979). They do not use any navigational equipment and they keep track of their lines or nets with small floating flags (Pollnac 1979). Some fishermen use a pipe to listen in the water and locate aggregations of croaking weakfish (*Sciaenidae*) and then steer the boat in the right direction (Baltz & Campos 1996). The small-scale fishermen usually only fish a few times a week when the conditions are optimal. The tides, the wind, the moon, and the season are some factors that influence when they decide to go fishing (Baltz & Campos 1996).

The number of different fishing methods and the type of fishing gear can impact what is caught (Campbell, *et. al.* 2013; Blyth-Skryme *et. al.* 2006). Different fishing methods target different sizes and species, which can influence the size and abundance of the fishes (Campbell, *et. al.* 2013; Blyth-Skryme *et. al.* 2006). For example, handlines and creels target larger sizes and have a greater impact on the structure of the ecosystem than nets (Campbell, *et. al.* 2013).

A common fishing technique for the small-scale fishermen in the Gulf of Nicoya is longline fishing (Watson & Kerstetter 2006). This method is used all over the world but mainly in the Pacific Ocean and Costa Rica and is predominantly performed by artisanal fishermen (Watson & Kerstetter 2006; Herrera-Ulloa *et. al.* 2011). This fishing technique consists of a thick main line where several hooks (baited or un-baited) are attached, with branch lines at regular intervals (Gilman *et. al.* 2007). Long line fishing is a diverse technique and can be modified in several ways to fit the needs of the fishermen (Gilman *et. al.* 2007). For example, if the fishermen use dead bait, they do not use floats to keep the line suspended in the water as they do with live bait. The total number of hooks, how long the longline is and the depth at which it is deployed depends on personal preference and what species is being targeted (Watson & Kerstetter 2006).

By changing the hook size and hook type on the bottom longline, it is possible to influence what is caught. For instance, increasing J-hook size from #8 to #6 can reduce the amount of bycatch (Mongeon *et. al.* 2013). However, this also decreases the number of the target fish, while also increasing the size of the target catch (Mongeon *et. al.* 2013). Conversely, the number of target catch can be increased by reducing the hook size from #8 to #10 but this also increases bycatch while not affecting the size of Spotted Rose Snapper (Mongeon *et. al.* 2013). Regarding hook type, circle hooks can profoundly decrease mortality of most target and bycatch species by hooking the fish more externally (Pacheco *et. al.* 2011; Reinhardt *et. al.* 2017). The type of hook can also impact the relative catch of bycatch species, where for example, turtle bycatch decreases while shark bycatch increases (Reinhardt *et. al.* 2017).

The catch can be sold to local collection centres which, contrary to most fishermen, have the monetary means to distribute the fish to markets and other buyers further away from the catch sites (Chavez Carrillo *et. al.* 2019). These collection centres also work akin to a bank, lending fishermen resources and capital to start up and sustain their operations, which can involve contracts which ties them to a specific centre (Chavez Carrillo *et. al.* 2019). The current challenges of the small-scale sector have led some fishermen to transition away from fishing to tourism and aquaculture projects (Chavez Carrillo *et. al.* 2019).

Exploitation and preservation of marine resources

Ecosystem services & over-exploitation

The communities of artisanal fishermen that live along the Gulf of Nicoya have a long tradition of fishing and the area is therefore of both high economic and social importance (Alms & Wolff 2019). The fishermen together with large-scale fishing fleets have caused this highly productive gulf to become overexploited (Alms & Wolff 2019; Kappelle 2016). Overexploitation can be defined as when the number of fish caught from a particular population exceeds the amount that can be replaced through reproduction (Shakouri *et. al.* 2010). This activity can result in the reduction of fish populations and have adverse effects on both the environment, the health of the fish stocks and the economy (Shakouri *et. al.* 2010; Berkeley *et. al.* 2004). This has been done to such an extent that the Gulf of Nicoya today is labelled as one of the most overfished marine areas in all of Central America (Alms & Wolff 2019).

According to a study from Berkeley and colleagues (2004), when large individuals in a population are targeted, it will result in a human induced selection pressure favouring early maturing, slow growing individuals rather than fish that are fast growing and late maturing. Fishing in this manner will therefore change the population over time and negatively alter productivity. This phenomenon is known as fishing induced genetic change or fisheries induced selection (Alms & Wolff 2019; Heino *et. al.* 2015; Berkeley *et. al.* 2004) This effect can be attributed to how the fecundity of an individual fish changes throughout its lifetime. As a fish matures, it will increase in weight and body length, which are two influential aspects that have a positive effect on reproductive success (Berkeley *et. al.* 2004; Kamler 2005; Lambert 2008). This can be explained by two factors; firstly, a larger female can simply have more and larger eggs than a smaller female and secondly, a mature fish can allocate more resources on reproduction than a growing fish. For example, in terms of egg production, a 80 cm Bocaccio rockfish (*Sebastes paucispinis*) can produce nearly ten times more eggs than a female of 40 cm (Berkeley *et. al.* 2004). Therefore, by removing the late maturing fish, the productivity and profitability of the system will be impacted (Alms & Wolff 2019; Heino *et. al.* 2015; Berkeley *et. al.* 2004).

Furthermore, size and age has been proven to have an overall positive effect on the viability and survival of spawn (Berkeley *et. al.* 2004; Kamler, E. 2005; Lambert, 2008). In Black rockfish (*Sebastes melanops*), fry from mature females grew three times faster and survived starvation two and a half times longer than conspecific fry from younger females (Berkeley *et. al.* 2004). In the fry stage they are the most vulnerable, and by growing faster and surviving without food longer, they are more likely to reach adulthood. Therefore, to prevent fish populations from decaying in quality from fishing malpractices, Berkeley and colleagues (2004) have proposed three methods that can be employed; introducing both maximum and minimum catch sizes, exploiting the population less or introducing marine protected areas where fishing is prohibited.

Target species like Spotted Rose Snapper and members of the weakfish family are regarded as overexploited in the Gulf of Nicoya (Soto-Rojas *et. al.* 2018; Alms & Wolff 2019; Pollnac 1979). They are highly profitable and therefore sought after by artisanal and industrial fishermen alike (Soto-Rojas *et. al.* 2018; Alms & Wolff 2019; Pollnac 1979). The decline of previous target species has caused a shift to new target species and from large and medium to smaller species and juveniles (Alms & Wolff 2019). From 1993 to 2013 the target species and the economic output of the fisheries have changed drastically (Alms & Wolff 2019). There has been an increase in both the gross efficiency and the overall catch by around 20% each (Alms & Wolff 2019). However, there has been an overall decrease in the total economic output from the fisheries by 48% (Alms & Wolff 2019).

Overfishing of certain species can influence the relative abundance of other species, through trophic cascades. The Gulf of Nicoya is recognized as a bottom-up controlled system, meaning that planktivorous groups such as coastal shrimps (*Litopenaeus spp.*) and small pelagic fish are important for the transfer of energy upwards in the trophic levels (Alms & Wolff 2019). These ecologically and economically valuable groups have declined due to overfishing which also negatively impacts the already struggling fish populations (Alms & Wolff 2019). However, even though a system is mostly bottom-up controlled, it can still be influenced by top-down cascades (Scheffer *et. al.* 2005). It has been proposed that these types of trophic interactions operate in the Gulf of Nicoya, where the heavy fishing pressures of predatory fishes has led to an increase of benthic invertebrates like crabs and lobsters (Alms & Wolff 2019).

Protection of marine environments

Ecosystems containing a biodiverse community of organisms are more resistant to change and more productive than systems that only have a few species (Purvis & Hector 2000). When the biodiversity of a system is high, there are many species with overlapping niches meaning that if one were to go extinct, there are other species that could take advantage of those resources (Palumbi *et. al.* 2009). This high niche complementarity in marine ecosystems is common due to niche partitioning, where different species avoid competition by utilizing the same resources in a different manner, ultimately making the system more resilient (Palumbi *et. al.* 2009). Overfishing of target species can lead to a shift in species abundance, where less overfished species fills the vacant niches of overexploited species (Molfese *et. al.* 2014; Pauly *et. al.* 1998). Overfishing together with pollution has been declared as the main threat to biodiversity in marine ecosystems (Costello *et. al.* 2010). Through the overexploitation of target species, bycatch species decrease in abundance as well, which alters the composition, and the dynamics of a food web (Costello *et. al.* 2010).

To protect species and to promote ecosystem health, an area can be designated in which the harvesting of marine resources is prohibited or limited (Sala & Giakoumi 2017; Purvis & Hector 2000; Palumbi *et. al.* 2009). These areas are known as marine protected areas (MPA) and are usually intended to maintain and/or restore the marine biodiversity of a region (Sala & Giakoumi 2017). There are different varieties of MPAs ranging from marine reserves where extraction of resources is prohibited to partially protected MPAs where fishing is permitted to a certain extent (Sala & Giakoumi 2017). In the Gulf of Nicoya, there are several partially protected MPAs such as such as Área Marina de Pesca Responsable Paquera-Tambor (AMPR-Paquera-Tambor) known as Marine Areas of Responsible Fishing (AMPRs; Figure 2; Chavez Carrillo *et. al.* 2019). These areas are intended to give small-scale fishermen exclusive management and fishing rights but also protect the ecosystems (Chavez Carrillo *et. al.* 2019; SINAC 2014).

For an AMPR to be instituted, the communities need to come up with a collective management plan that should include the location of the AMPR, the social and ecological importance of the area and the rules that should apply (Chavez Carrillo *et. al.* 2019). The AMPRs are requested to and administered by the Institute of Fisheries and Aquaculture (INCOPESCA) but enforced by the national coast guard. However, the coast guard does not have the means nor the time to reinforce the rules and choose to prioritize national security and drug trafficking (Chavez Carrillo *et. al.* 2019). This lack of government supervision and enforcement has led some fishermen to disregard the AMPR rules (Chavez Carrillo *et. al.* 2019). Furthermore, many fishermen come from poor social situations and find it difficult to follow the safety and equipment requirements set by INCOPESCA when they need to provide for themselves and their families (Chavez Carrillo *et. al.* 2019).

Figure 2: A: *Location of some of the AMPRs in the Gulf of Nicoya*. B: *Location in Costa Rica* ©Chavez Carrillo *et. al.* 2019.

The Paquera-Tambor AMPR consists of three sectors: Paquera, Playa Blanca and Tambor, with 14 zones distributed among them, which have different rules and regulations (Chavez Carrillo *et. al.* 2019; Ramírez 2014). Within the AMPR, there are certain zones that are more protected than others (Figure 3; Ramírez 2014). This includes locations such as Tortuga Island (Isla Tortuga), Negritos Islands (Reserva Biológica Islas Negritos) and Cerdos Island (Reserva Biológica Guayabo; Figure 3) (SINAC 2014; Ramírez 2014). These are not no-take zones, however certain fishing regulations apply, such as limitations of what fishing gear can be used (Figure 3).

Zone	Allowed fishing techniques and activities
1	- Handline with size #6 and #7 hooks
2 3	- Bottom longline with a maximum of 500 size #7 hooks - Gillnets with minimum mesh size of 3 ½"
4	- Handline with size #7 hooks - Gillnets with minimum mesh size of 5 ⅛" - Commercial scuba diving
5	- Gillnets with minimum mesh size of 3 ½" - Handline with size #7 hooks - Commercial scuba diving
6	- No commercial fishing allowed
7	- Handline with size #7 hooks - Bottom longline with a maximum of 500 size #7 hooks - Creels - Commercial scuba diving - Sportfishing - recreational diving
8 9	- Handline with size #6 and #7 hooks
10	- No commercial fishing allowed - Recreational activities, tourism and investigation
11	- Bottom longline with a maximum of 500 size #7 hooks - Handline with size #6 and #7 hooks from 6am to 6pm - Recreational activities and tourism from 6am to 6pm
12	- Bottom longline with a maximum of 500 size #7 hooks - Handline with size #7 hooks - Commercial scuba diving
13	- Bottom longline with a maximum of 500 size #7 hooks - Handline with size #7 hooks - Gillnets with minimum mesh size of 5 ⅛" - Creels - Commercial scuba diving
14	- Bottom longline with 500 size #7 hooks - fishing lines with a maximum of 20 size #12/0 circle hooks

Figure 3: *Map of Paquera-Tambor AMPR. The numbers on the map correspond to the numbers in the table of allowed fishing techniques.* ©Ramírez 2014

Partially protected areas can vary a lot regarding what type of extraction is allowed and therefore it can be difficult to assess their ecological impact (Lester & Halpern 2008). According to a meta-analysis from Sala & Giakoumi (2017) no-take MPAs on average have a 670% increased biomass than surrounding non-protected environments. This compared to 183% in partially protected MPAs of which the Costa Rican AMPRs would be included. Furthermore, no-take marine reserves cause an increase in the number of species, the size, and the number of predators, which makes the ecosystem more resilient through more complex trophic interactions (Sala *et. al.* 2013; Purvis & Hector 2000). They can also improve the fishing grounds in nearby unprotected areas by working as a nursery for fish that then disperse from the marine reserve (Lester & Halpern 2008). However, even though no-take MPAs are superior in regard to species abundance and richness than partially protected ones, they still have their advantages (Lester & Halpern 2008). No-Take MPAs can be difficult to establish due to opposition from fishermen and cooperations, who would lose fishing grounds and in the short term obtain less catch (Lester & Halpern 2008). Therefore, partially protected MPAs can be an attractive tool to reach compromises between disagreeing parties (Lester & Halpern 2008).

Purpose & Research question

Dead bait longlines are widely used by artisanal fishermen in Costa Rica and cause problems with overfishing (Herrera-Ulloa *et. al.* 2011; Molfese *et. al.* 2014; Alms & Wolff 2019). Based on observations in the field, undesired fish are often killed or already dead before they are returned to the sea, which could pose an ecological problem for the ecosystems and the people who depend on them (J. A. Espinoza personal communication 2023-03-03).

The positive effects of protected areas on the overall condition of fish stocks is a well-studied subject (Sala *et. al.* 2013; Purvis & Hector 2000; Lester & Halpern 2008; Sala & Giakoumi 2017; Alms & Wolff 2019). However, most studies on bycatch focus on species like cetaceans, seabirds, or turtles, that are of high conservation status (Dapp *et. al* 2013; Herrera-Ulloa *et. al.* 2011; Pacheco *et. al.* 2011; Reinhardt *et. al.* 2017; Read *et. al.* 2006 Gilman *et. al.* 2007). Furthermore, studies on marine protected areas usually compare non protected ones to protected ones rather than exploring differences within one such marine protected area (Sala & Giakoumi 2017; Purvis & Hector 2000; Palumbi *et. al.* 2009; Chavez Carrillo *et. al.* 2019; Sala *et. al.* 2013; Purvis & Hector 2000; Lester & Halpern 2008).

Therefore, it is relevant to discern how effective different degrees of protection within a marine protected area are at maintaining good ecological status and therefore good fishing grounds. This was conducted by measuring two aspects related to the quality of the fish stocks; the size of Spotted Rose Snapper and the relative fish-bycatch based on different protection levels. The size was based on two aspects: mean weight of snappers by the protection level and the count of individuals below or at the legal capture length (34 cm) and breeding size (30 cm) by protection level.

To investigate if the level of protection influenced size distribution and target catch ratio, the following research questions were formulated; Does a high protection level reduce the amount of relative bycatch and is the mean weight of Spotted Rose Snapper greater in areas with high protection than areas with low protection? The first part of the question aims to discern if target catch relative to bycatch can be affected by protection level. The relative bycatch will act as a proxy for the economic wellbeing of the small-scale fishermen (Molfese *et. al.* 2014; Pauly *et. al.* 1998). The second part aims to discern how effective more protected areas are at promoting the weight of Rose Spotted Snapper, which is an important factor for reproduction (Soto-Rojas *et. al.* 2018; Berkeley *et. al.* 2004).

This was performed by compiling fishing data from different locations in the Paquera-Tambor AMPR, into two levels of protection: High and low based on the number of allowed fishing methods. Additionally, the locations where the data was collected were compared to each other. In total, six collection sites of Spotted Rose Snapper and five locations of bycatch within the Paquera-Tambor AMPR, was considered in this study. The data obtained in the field was complimented by data provided by the National University of Costa Rica.

Methods

Execution of field study

Ethical aspects

This project involved the handling and euthanizing of live fishes which was done in a respectful manner that minimised pain and suffering. The number of fish euthanized was based on the requirement that sufficient data had to be obtained to provide representative information on relative bycatch and the weight distribution of Spotted Rose Snapper (Bennett *et. al.* 2016). The research permits required to perform research on fishes were provided by the University of Costa Rica (UNA).

Preparations

Approximately 10 kg of bait fish from the genus *Opisthonema* was prepared. First, they were descaled by scraping the spine of a knife against the scales, going from the head towards the tail of the fish. The bait was then gutted by first making a cut a few cm behind the eyes, measuring ¾ of the head deep. A second but vertical cut was then made from the end of the first cut, removing the bottom ¼ of the ventral part of the fish. The fish was then filleted and cut into small chunks approximately 2x2x1 cm.

The longline was made up of a braided mainline which was estimated to be 2 km in length and approximately 2 mm thick. From the mainline, several 1 mm thick braided filament branch lines were tied, with an interval of 2 metres apart. In total about 600 size #7 and 200 size #8 circle hooks were tied on to the mainline through a loop. At one end of the longline an anchor was attached with a rope, but no other weights were used. The longline was stored in a large cylindrical plastic basket, where the hooks of the branch lines were hung around its edge. The hooks were then baited by piercing the skin-side of the bait once, and then hung back around the plastic rim.

Start of field study

At 8 pm, to the north of Negritos islands (9°50'05.2"N 84°52'13.0"W), on the 3rd of March 2023, the longline was set. This was performed by first releasing the anchor and then securing it by manoeuvring the boat until the anchor got fixed into place. The boat was then driven forward which pulled the line outward. Each individual branch line had to be handled and thrown in separately while simultaneously steering the boat. When the end of the longline was reached, it was tied to the boat and left until 4 am. The longline was harvested by first untying the longline from the boat and then dragging it into the boat by hand. When two branch lines had been pulled up (one per person) the catch was evaluated and depending on what was caught it was either kept or thrown back. Target catch was kept, uneaten bait was thrown back, and bycatch was depending on species either kept for the fishermen's own consumption or thrown back dead or alive. After the branch lines had been harvested, the mainline was put back into the basket and the branch lines were hung back against the rim of the basket. When the end of the line was reached, the anchor was pulled up and stored in the boat. All the catch was identified in the field and the kept catch was weighed, measured, and had their gonads and stomachs collected.

Post field study

Spotted Rose Snapper

The weight and number of Spotted Rose Snapper (*Lutjanus guttatus*) obtained in the field was compiled into an excel sheet containing similar data from June 2015 to April 2017, provided by the National University of Costa Rica. Locations within the provided dataset were chosen based on available data and their degree of protection. Only Spotted Rose Snappers caught with size #8 and #7 hooks were used, but the effective fishing time differed between 5 and 10 hours and the number of hooks varied from 300 and 1400 between efforts. In total, 398 specimens of Spotted Rose Snapper from six coastal locations in the western internal Gulf of Nicoya data were used (Table 1). Each collection point used was assigned to a zone according to visual analysis of Figure 3 and are represented in Table 1.

Table 1: *Locations, approved fishing gear, protection level, number of specimens and efforts of Spotted Rose Snapper data. New and previous data from North Negritos was combined.*

Location	Approved fishing gear	Protection level (high, low)	Number of specimens	Number of efforts
North of Negritos	handlines	High	97	7
Tortuga Island	handlines, bottom longlines, tourism	High	66	5
The lighthouse of Negritos	handlines	High	28	6
In front of Curú	handlines, longlines, creels, commercial scuba diving, sportfishing and recreational scuba diving	Low	38	1
In front of Órganos	handlines, longlines, creels, commercial scuba diving, sportfishing and recreational scuba diving	Low	97	4
Órganos	handlines, longlines, creels, commercial scuba diving, sportfishing and recreational scuba diving	Low	72	2

To meet the assumptions of the statistical test, the weight was transformed with square root transformations (Appendix 1) and the number of efforts, mean weights, coefficient of variation and the number of individuals from each category were calculated. The total number of Spotted Rose Snapper below the legal catch size of 34 cm and below breeding size of 30 cm was summarised for all locations. To determine if the locations differed in Spotted Rose Snapper weight, a one-way analysis of variance (ANOVA) followed by a Multiple Comparisons of Means test (Tukey test) was used. Visual interpretation of diagnostic plots justified the use of these tests.

To investigate if the level of protection had an influence on snapper weight, a Welch two sample t-test was used. The square root weight (Appendix 2) of Spotted Rose Snappers from each location was assigned to a protection category and was then statistically compared (Table 1). Of the 398 Rose Spotted Snappers that were used, 191 were from high protection and 207 were from locations with low protection.

Proportion bycatch

The number of bycatch and target catch obtained in the field, was compiled into an excel sheet containing similar data from April 2015 to April 2017, provided by the National University of Costa Rica. Locations within the dataset were chosen based on available data and their degree of protection. Only fish species caught with size #8 and #7 hooks were used, but the effective fishing time differed between 6.5 and 10 hours and the number of hooks varied from 100 and 500 between efforts. Data was taken of 403 specimens of various fish species, from five coastal locations in the western internal Gulf of Nicoya (Table 2). Each collection point used was assigned to a zone according to visual analysis of Figure 3 and are represented in Table 2.

Table 2: *Locations, approved fishing gear, protection level, number of specimens, target catch and efforts of proportion bycatch data. North Negritos was split into new and old collection data.*

Location	Approved fishing gear	Protection level (high, low)	Number of specimens	Number of target catch	Number of efforts
North of $Negritos_{new}$	handlines	High	83	19	1
Tortuga Island	handlines, bottom longlines, tourism	High	145	15	3
North of $Negritos_{old}$	handlines	High	40	4	2
In front of Órganos	handlines, longlines, creels, commercial scuba diving, sportfishing and recreational scuba diving	Low	47	11	2
The river mouth of Tiburón	handlines, longlines, creels, commercial scuba diving, sportfishing and recreational scuba diving	Low	88	8	3

All species caught were divided into two categories; Target catch, which included all sellable species and bycatch, which contained species where no profit could be made. In this study, bycatch was entirely based on species and factors such as legal catch size were disregarded. The categorization was based on field observations of artisanal fishermen and complemented by scientific studies (Soto-Rojas *et. al.* 2018; Alms & Wolff 2019; Pollnac 1979).

To determine if the proportion of bycatch differed by locations, Pearson's chi-squared test was used. All locations were compared to each other in separate tests. To investigate if the level of protection had an influence on the relative target catch, Pearson's chi-squared test was used. The number of target species and bycatch species from each location were assigned to a protection category of either high or low protection (Table 2). Of the 403 fish species used, 268 were from high protection while 135 were from low protection.

Results

Spotted Rose Snapper

Weight distribution by protection level

The Welch Two Sample t-test of Spotted Rose Snapper weight by protection level differed significantly between high and low protection (p-value = 0.0000014). Mean weight of Spotted Rose Snapper was on average greater in areas with high protection compared to areas with low protection (t-value = 4.92, df = 322). Spotted Rose Snappers caught in areas of high protection had a mean weight of 549g, compared to 413g in collection points of low protection (Figure 4).

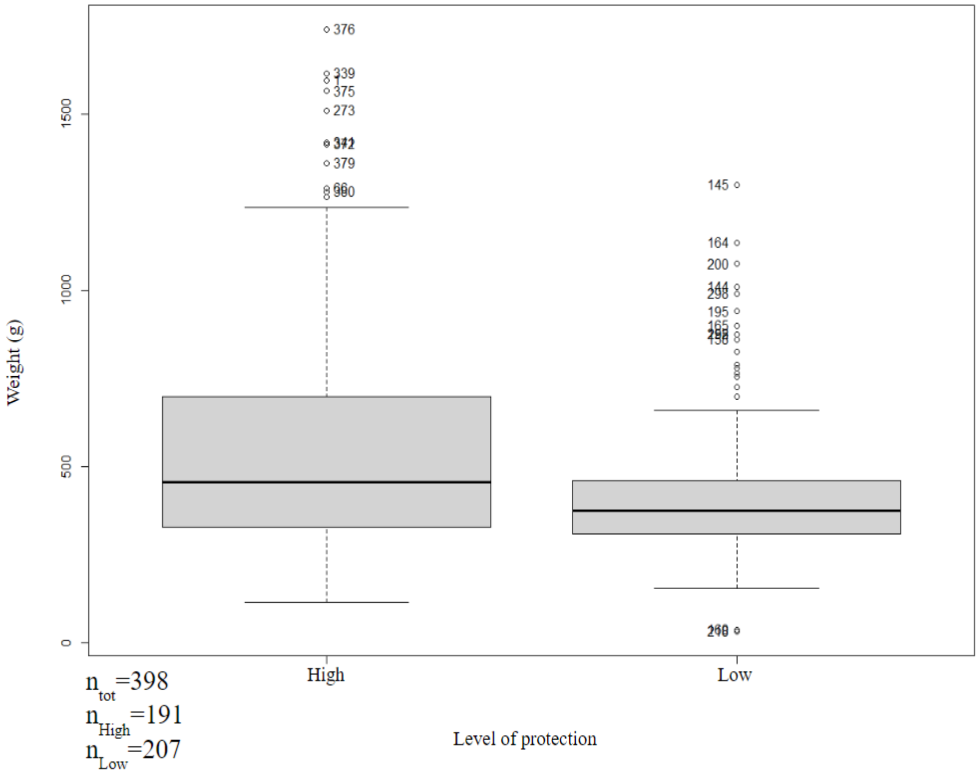

Figure 4: *Boxplots illustrating Spotted Rose Snapper weight (g) by protection level. Weight is presented on the Y-axis and nature protection level is on the X-axis. "Low" indicates locations with lower protection and "high" are locations with higher protection.*

Weight distribution by location

A one-way analysis of means test (ANOVA) of Spotted Rose Snapper showed that the weight differed significantly by location (F-value = 7.28, df = 136 and p-value = 0.0000045). A Multiple Comparisons of Means test (Tukey test) showed that Tortuga Island was the only location that differed significantly from the others and had the highest mean weight of 666g (Figure 5). The lowest mean weight came from in front of Curú, which had an average weight of 396g (Figure 5). North Negritos and the lighthouse of Negritos had mean weights of 485g and 493g respectively, while Órganos averaged 418g and in front of Òrganos had a mean of 416g (Figure 5).

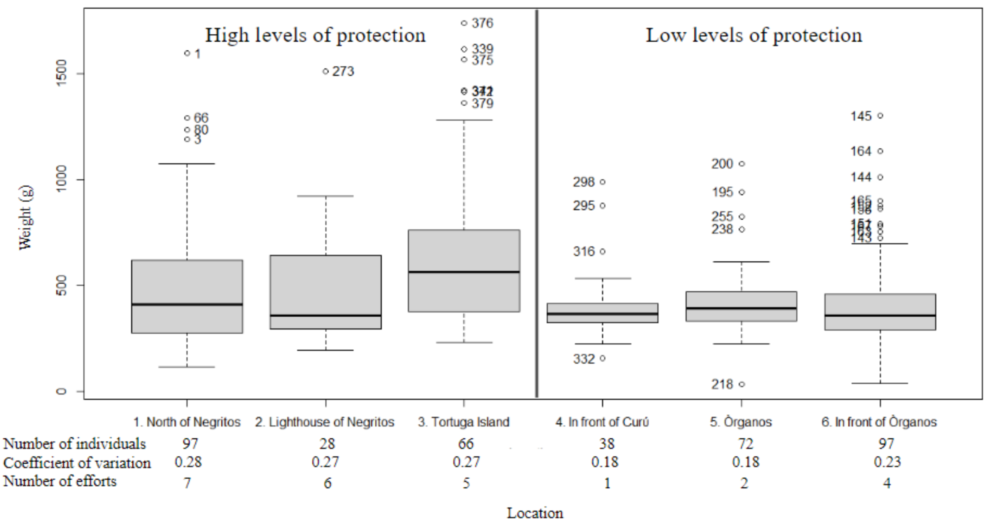

Figure 5: *Boxplots of Spotted Rose Snapper square root weight (g) by location, where weight is on the Y-axis and location on the X-axis. The number of individuals, the coefficient of variation and the number of efforts is displayed for each location.*

Length distribution by protection level

Pearson’s chi-squared test of Spotted Rose Snapper below 30 and 34 cm did not differ significantly with protection level (p-value = 0.2). In high protection, 28% were below 30 cm and 51% were below 34 cm, while 32% were below 30 cm and 75% were below 34 cm, in low protection (X-squared = 1.67, df = 1). In total, 30% of all Spotted Rose Snappers were below 30 cm and 64% were below 34 cm.

Bycatch

Proportion by location

Pearson's chi-squared test of bycatch proportion by location, showed that some locations differed from each other (Table 3). All locations differed in relative target catch to at least one other location (Table 3). The river mouth of Tiburón was statistically different from both in front of Òrganos (p-value = 0.023) and North of Negritos$_{new}$ (p-value = 0.013; Table 3). Tortuga island was also different from in front of Òrganos (p-value = 0.023) and North of Negritos$_{new}$ (p-value = 0.011; Table 3). North Negritos$_{old}$ was statistically different from in front of Órganos (Table 3). The relative proportions of target catch from the locations varied from 9% at the river mouth of Tiburón to 23% at in front of Órganos (Table 4). The average relative target catch of all locations combined was 17% and the relative bycatch was 83% (Table 4).

Table 3: *Pearson's chi-squared tests of bycatch proportions compared by each location. Significant values are indicated with red text.*

	North of Negritos$_{old}$	**In front of Òrganos**	**North of Negritos$_{new}$**	**Tortuga Island**
In front of Òrganos	x-squared: 2.72 p-value: 0.01			
North of Negritos$_{new}$	x-squared: 2.95 p-value: 0.086	x-squared: 0.0044 p-value: 0.95		
Tortuga Island	x-squared: 0.0041 p-value: 0.95	x-squared: 5.17 p-value: 0.023	x-squared: 6.55 p-value: 0.011	
The river mouth of Tiburón	x-squared: 2.95 p-value: 0.086	x-squared: 5.19 p-value: 0.023	x-squared: 6.12 p-value: 0.013	x-squared: 0.097 p-value: 0.76

Table 4: *Relative target catch from each location.*

Location	**Relative amount of target catch**
In front of Òrganos	23%
North of Negritos$_{old}$	10%
North of Negritos$_{new}$	22%
Tortuga Island	10%
The river mouth of Tiburón	9%

Proportion by protection level

A Pearson's chi-squared test of bycatch proportion by protection level, determined that the proportion of bycatch did not in general differ between areas of high protection and areas with low protection (p-value = 0.977). The relative number of target catch from both high and low protection was 17%. The chi-squared test produced a X-squared value of 0.000816 with 1 degree of freedom.

Discussion

Spotted Rose Snapper

The results indicate that the weight of Spotted Rose Snapper (*Lutjanus guttatus*) differed between locations and protection status. High protection status did have an impact on the weight of Spotted Rose Snapper, which implies a healthier population that produces more profitable fish. When the weight was compared with location, only Tortuga Island was statistically significant from the other locations in the Paquera-Tambor AMPR. However, the mean weight values and the coefficients of variance were higher for all locations with high protection compared to areas with low protection, which alludes to a possible significance if more data would have been collected.

The greater coefficient of variance in high protection can be traced to a higher proportion of heavier individuals rather than an equal increase of both smaller and larger individuals around the median. This implies that high protection locations have a higher proportion of large spawning individuals. This could be a consequence of the higher protection status of these areas or alternatively that the habitats differed in quality. However, no apparent difference or pattern could be observed between the habitats in the field, but it should be noted that no detailed mapping of the habitats were conducted. Alternatively, the discrepancy in variance could be a consequence of the lower number of efforts in the low protection group, even though the groups had a comparable number of individuals. More efforts over more days, gives a more complete picture of the population. However, since other aspects such as, effective time in water, number and size hooks also differed, it was not justifiable to standardize the number of efforts.

The median lengths of Spotted Rose Snapper from all locations except Tortuga Island were below the 34 cm threshold for legal capture size (Pérez 2020). Furthermore, 30% of the catch in this study were below breeding size and 64% was below legal capture size. However, there was not a difference in lengths below breeding and legal capture size between high and low protection. Nonetheless, the high catch percentage below legal catch and breeding size, alludes to overexploitation which is consistent with the findings of Soto-Rojas and colleagues (2018). This is a serious problem since many fishermen disregard the rules and regulations and sell fish below legal limits, which leads to a fishing induced genetic change that favours small individuals that reproduce early (Berkeley *et. al.* 2004; Chavez Carrillo *et. al.* 2019). This is related to the mismanagement of the AMPRs by governmental bodies which are supposed to enforce the rules, conduct surveillance, and communicate sustainable fishing practices to the fishermen.

The discrepancy in mean weight and variance between locations, illustrates that the Paquera-Tambor AMPR is a heterogeneous partially protected MPA that varies greatly in the quality of the fish stocks. Within the category of high protection, it is permitted to use handlines and longlines while a plethora of fishing practices are allowed in low protection. With the presumption that these habitats are of equal quality and get fished to the same degree, it can be argued that some fishing methods are worse than others for maintaining a higher weight quality in the Spotted Rose Snapper populations. Alternatively, the combination of several different fishing techniques may be the culprit of lower weights in the low protection category (Campbell, *et. al.* 2013; Blyth-Skryme *et. al.* 2006). A variety of methods might target different cohorts of the snapper population depending on factors such as behaviour and size. This is supported by other studies that have found that restricting fishing methods can over time, increase the size of fishes caught (Campbell, *et. al.* 2013; Blyth-Skryme *et. al.* 2006). This is also evident when changing parameters within a fishing method, such as changing the type of hook or the size of the hook in bottom long lines (Mongeon *et. al.* 2013; Reinhardt *et. al.* 2017).

However, the effectiveness of preserving the viability of the fish stocks in the partially protected MPAs can be discussed. According to Sala and Giakoumi (2017), these types of MPAs are not as effective at increasing biomass and biodiversity as no-take MPAs. The reason why the Gulf of Nicoya does not have any of these MPAs could be a consequence of a conflict of interest. The main objective of the zones of the Paquera-Tambor AMPR is to benefit the fishermen first and reduce overexploitation second. Since the fishermen are allowed to collectively vote and choose what rules are implemented, it is not unreasonable to assume that they will produce rules that would benefit themselves. This can lead to short term gains that in the long term can be disastrous for both the fishermen and the ecosystems that they depend on. One such example is that none of the zones of the AMPR has any regulations on maximum catch size of Spotted Rose Snapper (Pérez 2020). The largest fish fetch the highest price and therefore the fishermen are incentivized to keep them, which removes important breeders from the population. This is also evident in the decreased profitability of the fisheries in the Gulf even though total catches and efficiency has increased (Alms & Wolff 2019).

With all things considered, the results of this study suggest that partially protected MPAs do increase both the mean weights and the weight variation of Spotted Rose Snapper, in the Paquera-Tambor AMPR. When the mean weight of Spotted Rose Snapper was compared between protection levels, fish from high protection weigh 549g, compared to 413g in low protection, a difference of 33%. This is a profound contrast, especially when considering that both these categories are within the same AMPR. Furthermore, the weight increase was greater than the average size increase (28%) of all marine organisms in marine reserves (Sala *et. al.* 2013).

The findings of this study are consistent with other studies, which have shown that both no-take and partially protected MPAs increase the quality of life for both the fishes and the fishermen in the long term (Sala *et. al.* 2013; Sala & Giakoumi 2017). Marine reserves can effectively compensate for their cost in five years, with the added benefit of a more durable and productive ecosystem which appeals to tourists (Sala & Giakoumi 2017). The size and the biomass increase that no-take and partially protected MPAs offer, translates to an increase in more, larger, and older fishes, with higher fecundity, which results in a spillover effect of larvae and adults into neighbouring systems (Sala *et. al.* 2013; Sala & Giakoumi 2017; Berkeley *et. al.* 2004; Kamler 2005; Lambert 2008). This makes the introduction of MPAs an appealing tool in combating and reversing the effects of overfishing.

Bycatch

The results indicate that relative bycatch differed between location but not protection status. Overfishing does not just affect the target species; the abundance of bycatch species can decrease as well (Costello *et. al.* 2010). This has a negative effect on biodiversity and can alter the dynamics of the food web which ultimately would impact the target catch and therefore the fishermen (Costello *et. al.* 2010). In this study, it was proven that more protected areas have a higher mean weight of Spotted Rose Snapper. It is not unreasonable to assume that similar weight distributions would apply to bycatch. Since bycatch by definition includes unsellable target species, it can be the case that the increase in mean weight of Spotted Rose Snapper in the high protection category, decreases the number of undesirable fish (NOAA Fisheries 2018). Therefore, it can be argued that bycatch is reduced to some degree in more protected areas. However, size was not considered in this study since fishermen regarded fish below legal capture lengths as target species, even though they would be considered illegal to capture (J. A. Espinoza personal communication 2023-03-03).

Bycatch can be considered a proxy for overfishing due to niche partitioning, where less desirable or different animals presume the roles of more desirable fish (Molfese *et. al.* 2014; Pauly *et. al.* 1998). Overfishing usually affects the top-consumers first due to their higher profit, which leads to a shift in what species are available (Molfese *et. al.* 2014). This can cause their prey items to increase in abundance due to trophic cascades (Alms & Wolff 2019). For the fishermen, this means that catch that previously were considered bycatch or less desirable, now is regarded as target catch. This is evident in the Gulf of Nicoya, where the target species have shifted from large profitable fish to juveniles and small pelagic fish (Alms & Wolff 2019).

Based on personal observations of the field, fishermen like J. A. Espinoza (personal communication 2023-03-03) held a very negative attitude to bycatch, and it was not uncommon to witness them going out of their way to cull them. This was particularly the case for sea catfish (*Ariidae*) which was a common bycatch species in the field. This attitude of needlessly killing bycatch could negatively impact the biodiversity of the ecosystem. Even if the species of fish is not desirable, it can still contribute to the food web and therefore this behaviour could be counterproductive.

As stated previously, the main difference between areas with high protection and low protection, are the allowed fishing methods. Since the relative bycatch did not vary significantly with protection status, it could be argued that the use of multiple different fishing methods does not have an effect. However, less bycatch should in theory be caught in areas with less protection since more non-discriminating fishing methods like net fishing are allowed there, which would remove more bycatch from the population (Campbell, *et. al.* 2013; Blyth-Skryme *et. al.* 2006; Mongeon *et. al.* 2013; Reinhardt *et. al.* 2017). This is also supported by the personal observations that indicate that bycatch experience poor survival rate due to how fishermen handle them (J. A. Espinoza personal communication 2023-03-03). However, an argument can still be made that, more non-discriminating fishing methods proportionally removes more target catch relative to bycatch since the slim survival odds of bycatch are still greater than the ones for target catch. On the contrary, it can also be the case that the bycatch species that are caught with dead bait longline are unrelated to the bycatch species caught with other fishing methods, which would explain why there is no difference between the categories. This could be discerned by comparing relative bycatch between multiple fishing methods such as net fishing or live-bait longline fishing over protection status.

Bycatch is a problem for artisanal bottom longline fishermen, who struggle when less target catch is caught. Overall, the average relative target catch of all locations was 17% meaning that 83% of all catch was of no monetary benefit for the fishermen. This problem deserves to be highlighted, due to its implication for the fisheries and the ecosystems. Bycatch species do contribute to the food web and biodiversity which in turn increases target catch and tourism (Costello *et. al.* 2010; Sala & Giakoumi 2017; Purvis & Hector 2000; Alms & Wolff 2019). Most other studies on bycatch focus on bycatch species that are of high conservation status such as cetaceans, seabirds, or turtles (Dapp *et. al.* 2013; Herrera-Ulloa *et. al.* 2011; Pacheco *et. al.* 2011; Reinhardt *et. al.* 2017; Read *et. al.* 2006 Gilman *et. al.* 2007). However, the findings of this study shows that low status bycatch species need attention too if overfishing is to be combated.

Solutions to overexploitation

There are several ways in which the level of overexploitation in the Gulf of Nicoya could be decreased. Overfishing of Spotted Rose Snapper can be overcome by exploiting the population less which can be achieved by implementing and enforcing rules. According to the findings of this study, it would be advisable to increase the protection level by limiting the allowed fishing techniques. Both increased size and total length has a positive effect on fecundity (Berkeley *et. al* 2004). Therefore, it is imperative to protect larger spawning Spotted Rose Snapper females who produce the most fry of the highest quality. This is not only true for Spotted Rose Snappers inside the Paquera-Tambor AMPR, but the same can be said for other species in other waters (Berkeley *et. al.* 2004; Heino *et. al.* 2015). By protecting large females, it would mitigate fishing induced genetic change, resulting in smaller, less valuable fishes (Alms & Wolff 2019; Berkeley *et. al* 2004; Chavez Carrillo *et. al.* 2019; Heino *et. al.* 2015).

Other studies have proposed other countermeasures such as introducing no-take marine reserves which are ecologically better than AMPRs or implementing maximum catch sizes which both have been proven to be successful (Berkeley *et. al.* 2004; Sala & Giakoumi 2017). In the Paquera-Tambor AMPR, marine reserves could for instance be instituted in important breeding grounds or locations such as Tortuga Island where many large breeder females congregate. This could result in a spillover effect for neighbouring locations and improve the quality of those fishing grounds as well (Berkeley *et. al.* 2004). A similar result could be achieved if large spawning fish were protected within the AMPR. Furthermore, shrimps (*Litopenaeus spp.*) and small pelagic fish are important prey items for many target species and by limiting the industrial and artisanal exploitation of these trophically important animals, it would provide more prey for the target fish (Alms & Wolff 2019).

Regarding bycatch in this study, it is unclear if the ratio of target catch could be improved by creating more protected areas. However, other studies have found that overfishing causes a decrease in desirable species, therefore, by implementing more sustainable fishing practices, bycatch could be limited (Alms & Wolff 2019; Molfese *et. al.* 2014; Pauly *et. al.* 1998; Costello *et. al.* 2010). This would include the implementation of marine reserves which as discussed before, which also would benefit the population of Spotted Rose Snapper. However, bycatch can be limited in other ways too. For example, by increasing J-hook size in longline artisanal fisheries of the AMPR, less bycatch is caught at the disadvantage of less overall target catch (Mongeon *et. al.* 2013). Increased J-hook size also increases the size of the Spotted Rose Snappers caught which would not be beneficial for the population (Mongeon *et. al.* 2013). However, larger hooks do not always equal larger fish and less bycatch, and it is important to evaluate how hooks affect catch rates on a species-specific basis (Bacheler & Buckel 2004; Gilman *et. al.* 2017; Piovano *et. al.* 2010; Reinhardt *et. al.* 2017). Furthermore, the implementation of circle hooks has also been proven an effective option in reducing mortality of bycatch in other pacific systems, which would lower the ecological impact of the fisheries (Reinhardt *et. al.* 2017). The type of hook and the size of hook are therefore two important factors in governing the relative bycatch and the size of the catch and should therefore be considered when implementing fishing restrictions.

These proposed solutions are only possible with collective action from the fishermen and proper management from authorities which as of the writing of this report, the Gulf of Nicoya lacks. The Costa Rican coast guard is underfunded and lacks the resources to educate employees on the rules, let alone enforce them (Chavez Carrillo *et. al.* 2019). INCOPESCA on the other hand, fails to properly monitor the Paquera-Tambor AMPR which removes the incentive for fishermen to cooperate (Chavez Carrillo *et. al.* 2019). If there is no consequence to breaking the rules, fishermen will likely continue to break them. Furthermore, poverty has stricken many fishermen due to loans with distribution centres and lower quality target catch due to overfishing (Chavez Carrillo *et. al.* 2019). This leaves them little choice but to continue to fish and disregard the rules to survive. It would be naive to introduce new rules and expect fishermen to follow them when they do not abide by the current rules. Therefore, both the surveillance and the enforcement of current AMPR rules, need to be addressed before new rules are implemented.

It should be noted that the datasets provided by the National University of Costa Rica, was not intended for this study and this impacted the results. The number of efforts, effective fishing time, time of year, length of lines, number and size of hooks differed between locations and protection level. Even though measures were taken to standardise the data as much as possible, this would undoubtably have impacted the results of this study.

In summary, overfishing and its symptoms need to be addressed in the Paquera-Tambor AMPR as well as in many other marine environments across the globe, for the wellbeing of the ecosystems, the fishermen and the people that depend on them. There is no lack of solutions to overfishing but rather a lack of governmental involvement and foresight within this marine protected area.

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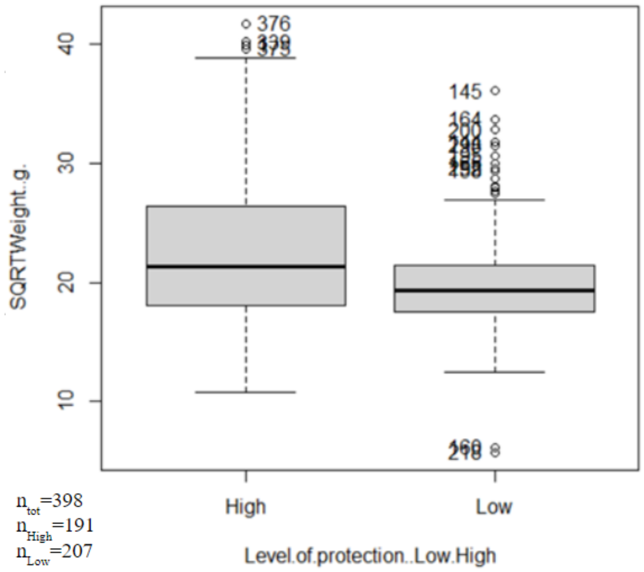
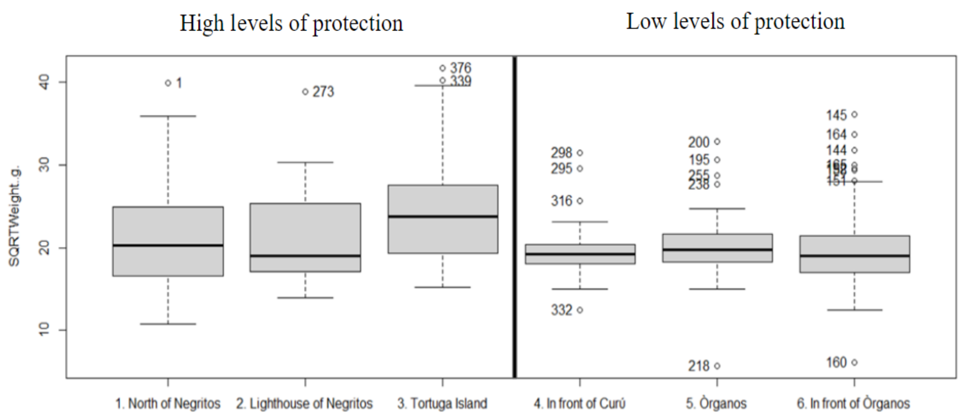
Appendix



Appendix 1: B*oxplots illustrating square root transformed Spotted Rose Snapper weight (g) by protection level. Square root weight is presented on the Y-axis and nature protection level is on the X-axis. "Low" indicates locations with lower protection and "high" are locations with higher protection. Within the low category were three locations: Órganos, in front of Órganos and in front of Curú. The high category included three locations: Tortuga Island, North Negritos, and the lighthouse of Negritos Negritos.*



	1. North of Negritos	2. Lighthouse of Negritos	3. Tortuga Island	4. In front of Curú	5. Òrganos	6. In front of Òrganos
Number of individuals	97	28	66	38	72	97
Coefficient of variation	0.275529841	0.268809896	0.265428127	0.181357363	0.184479236	0.231548275
Number of efforts	7	6	5	1	2	4

Appendix 2: *Boxplots of Spotted Rose Snapper square root weight (g) by location, where weight is on the Y-axis and location on the X-axis. The number of individuals, the coefficient of variation and the number of efforts is displayed for each location.*