Status and trends reef fish and coastal fisheries Bonaire (Caribbean Netherlands): report card 2014-2015

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Contents

Executive summary

Caribbean coral reefs have been declining for decades due to a combination of anthropogenic drivers and natural phenomena like hurricanes. The degradation of coral reefs is characterised by, among others, a decline in coral cover, a decline in apex predators (e.g. sharks, large groupers and snappers), a decline in invertebrates (*Diadema*), and an increase in macro-algal cover. In the past 40 years large-scale shifts from coral-dominated to macro-algal-dominated reef communities have occurred throughout the Caribbean.

Healthy coral reef ecosystems and sustainable coastal fisheries are of utmost importance for the small island economies of Bonaire, Saba and St Eustatius. Bonaire (288 km^2) is located in the southern Caribbean and is surrounded by the Bonaire National Marine Park (BNMP) which was established in 1979. The BNMP starts at the high-water mark and extends to 60m depth, covering an area of 27 km^2. In 2008 two fish reserves (no fishing allowed) and two dive reserves (no diving or snorkelling allowed) were established. In this report we document the 2014-2015 status of the coral reef fish stocks, the coral reef fisheries and the coastal pelagic fisheries. Where possible the current status and trends will be discussed in a historical and wider geographical (Caribbean) perspective.

KEY FINDINGS

The total estimated annual landing of the Bonairian coastal fishery in 2014 was ca. 102 t with a value of ca. 0.7-1 million USD. The landings of shore fishers, small boat fishers and big boat fishers were ca. 12, 30 and 60 t, respectively. The catch composition consisted predominantly of large pelagic species (85%) such as wahoo and tuna species. Below the status of the fisheries, fish stocks and the health of the coral reef ecosystem are given.

<u>*Shore-based fishery:*</u> The mean daily effort, catch and catch rate of the shore-based fishery along the West coast was 64 hr, 32 kg and 0.5 kg/hr respectively. Reef fish contributed nearly 90% in number and 60% in weight to the total catch of ca. 12 t. The most commonly landed fish species (in number) were yellowfin mojarra (*Gerres cinereus*), French grunt (*Haemulon flavolineatum*), graysby (*Cephalopholis cruentata*), coney (*Cephalopholis fulva*) and yellowtail snapper (*Ocyurus chrysurus*). Effort and catches appeared modest and similar to the few values reported for other shore-based coral reef fisheries. The characteristics of the shore-based, predominantly recreational fishery do not appear to give any reason for major concern. Furthermore, with the possible exception of discarded fishing line, the direct physical impact of shore-based fishers on benthic reef organisms seems minimal. Due to a complete lack of historical records of the shore-based fishery it is, however, impossible to quantify any positive or negative trends related to changes that may have occurred over time in catch, effort and species composition.

<u>*Boat-based fishery:*</u> The number of fishers, boats and daily boat activity has been constant since the early 1900s. Major technological changes have been the transition from sail boats to motorised boats in the 1950s and the introduction of GPS and fish finders on most big boats since the 1990s. Fishing gears and methods have changed little, trolling lines are used to target large pelagic fish and handlines are used to catch demersal reef fish. In 2014, 84 small boats and 26 big boats were recorded on average during the monthly frame surveys. The average daily boat activity coefficient was 14% for the small boats, and 23% for the big boats. The observed daily boat activity was similar to values reported in the late 1960s and 1980s. The mean duration of a big boat fishing trip (9.5 hours) was nearly twice as long as that of a small boat (5.5 hours). Both small boats (100%) and big boats (85%) conducted most of their fishing trips near to the shore (<400 m). Overall catch rate was 7.4 kg/trip for small boats and 28.1 kg/trip for big boats. The mean daily effort of the small boats fleet was 11 trips resulting in a mean daily catch of 82 kg of mainly large pelagic fish (ca. 85%). The most commonly landed species by the small boats were wahoo (23%) and blackfin tuna (20%). The mean daily effort of the big boat fleet was 6 trips resulting in a mean daily catch of 162 kg of mainly large pelagic fish (ca. 90%). The most commonly landed species were wahoo (60%), barracuda (10%) and blackfin tuna (8%). The total annual effort and

catch of the small boats was estimated at ca. 4000 trips and ca. 30 000 kg, respectively. The total annual effort and catch of the big boats was estimated at ca. 2100 trips and ca. 60 000 kg, respectively.

The perceived reductions in catch rate of large pelagic species as reported by Johnson & Jackson (2015) based on interviews with fishers, could, however, neither be supported nor dismissed by the limited amount of available fisheries statistics. Comparison of the 2014 catch rates with the few available historical catch rates may indicate possible overall decline over time but the uncertainty is high. Furthermore, individual big boat fishers in 2014 achieved daily catch rates similar to the daily catch rates recorded for the 1970s and 1980s. Potential reasons for concern are the high fishing pressure on barracuda (both small boats and large boats) and graysby (small boats only) based on the outcomes of a length based assessment model and the high harvest rate of the standing stock, and the near absence of dolphinfish in the 2014 landings. Whether the observed increase in barracuda and decrease in dolphinfish is incidental or structural can only be determined if a basic fisheries monitoring is continued. Since 2010 the harvest of sharks and rays is prohibited, in 2014 sharks were rarely observed in the landings (<1% in biomass) of the boat-based fishery. A directed shark fishery does not exist on Bonaire, however, sharks are occasionally caught as by-catch in the boat-based fishery.

Coral reef fishery: Reef fish were landed by both the shore-based and boat-based fisheries. In total ca. 13 t of reef fish was harvested from the sheltered leeward side of Bonaire by shore fishers (ca. 50%), small boats (ca. 35%) and big boats (ca. 15%). The yield (2.1 t/km^2/year) was similar to values reported for other coral reef ecosystems and indicated that the status of the reef fish fisheries can be considered as fully exploited. The overall harvest of reef fish was ca. 5% of the standing stock, which appears moderate but differed significantly between fish families. Around 18% of the grouper standing stock on the sheltered leeward side of Bonaire was harvested, indicating a high fishing pressure. The length based assessment model indicated overharvesting of graysby, a small grouper species. A second reason for concern was the considerable contribution of barracuda to the reef fish catch of especially the big boats compared to historical catch composition data. More than 90% of the biomass of landed reef fish by the big boats consisted of barracuda. The overall contribution of reef fish to the landings of boat-based fishers appeared to have declined since the early 1900s in favour of large, pelagic fish species.

Reef fish stocks: On the sheltered West Coast and the exposed East Coast the average biomass of the fish assemblage was 10.3 and 8 kg/100m^2 respectively and differed significantly between habitat zones, fish biomass increased from shallow to deeper waters. Due to the clear differences in reef fish measures (e.g. biomass, abundance, trophic structure) between zones across the reef, care has to be taken when comparing fish assemblage characteristics with other areas in the Wider Caribbean Region. Fish biomass along the deeper reef zones appeared relatively high compared to other Caribbean sites. The fish biomass in the shallow areas, on the other hand, is only average compared to other Caribbean reef systems, most likely due to poor structural complexity of the habitat, especially in the No Fishing zones. In general, the effect of habitat zone on reef fish assemblages along Bonaire's sheltered West coast was significantly more pronounced than the effect of management zone.

The grouper species composition is characteristic for highly fished areas with little management. Biomass of commercial fish (especially snapper) was higher than average for the Wider Caribbean Region, but the low biomass of grouper and particularly the low contribution of large grouper biomass to total grouper biomass are undesirable. No sharks were observed. Herbivorous fish play an important role in controlling macro-algae. At present the herbivorous biomass is higher than the mean biomass observed in the wider Caribbean Region. Both parrotfishes and surgeonfishes only form a minor part of the reef fish catch. The status of key herbivorous fish (parrotfish and surgeonfish) biomass is good.

Health coral reef ecosystem: Coral cover continues to decline gradually but macro-algae do not yet dominate benthic cover. While the status of the water quality is unclear due to a lack of data, the high prevalence of dermal parasites on reef fish, the presence of deep-water cyanobacteria mats and reported high concentrations of nutrients in the water column are reasons for concern. Due to a decline in coral cover, increase in macroalgal cover and decline in biomass of commercial fish species, the Reef Health Index for the reefs of Bonaire has declined from "very good" in the 2000s to only "fair" in 2014-2015.

Overall, the current evaluation of status and trends of Bonaire's coastal fish and fisheries was hampered by the lack of regular, standardized historical surveys and a management plan with quantifiable objectives.

RECOMMENDATIONS

Based on the results of the study we recommend to:

a) develop a management plan with clearly defined indicator and quantifiable objectives, targets and reference points with regards to coral reef health, elasmobranchs and sustainable fisheries,

b) continue standardised monitoring of coral reef health, elasmobranch and fisheries indicators; develop and implement a standardised monitoring of water quality,

c) report results regularly to evaluate the performance of implemented management by comparing the status of the indicators against the quantified targets, objectives and reference points to facilitate adaptive management,

d) address water quality to ensure the highest water quality possible (e.g. water treatment, minimize erosion) to enhance the recovery of stony coral cover and reduce macro-algae cover and,

e) enhance the recovery of structural complexity to the shallow reef areas affected by the die-off of frame-work coral species such as elkhorn coral (*Acropora palmata*) and staghorn coral (*Acropora cervicornis*) by coral restoration and (temporary) artificial reefs to improve reef fish biomass.

Furthermore, it is desirable to implement adaptive legislation and regulations to:

a) improve water quality to prevent a further decline of the health of the reef,

b) reduce fishing mortality of large grouper and snapper species to as close to zero as possible to enhance the recovery of these apex predators,

c) reduce fishing pressure on small grouper species and barracuda if high fishing pressure persists and,

d) prevent an increase in fishing effort on the coral reef ecosystem.

1. Introduction

Overall the health of Caribbean coral reefs has been declining for decades due to a combination of anthropogenic drivers such as unsustainable fishing practices, pollution, erosion and coastal development, and natural phenomena like hurricanes (Jackson et al., 2014 and references therein). Outbreaks of coral diseases (e.g. decimated *Acropora* species) and the dramatic decline of the long-spined sea urchin (*Diadema antillarum*) due to an unknown pathogen in the early 1980s have had detrimental effects on the health of coral reefs in the Caribbean. The degradation of coral reef ecosystems is characterised by, among others, an increase in macro-algal cover, and a sharp decline in coral cover, number of large parrotfish, sharks and other apex predators. . It is, however, not always straightforward to link anthropogenic factors of reef degradation to their measurable effects. Despite the overall negative trend in the status of Caribbean coral reefs, there are regional differences in the condition of reef ecosystems. Although the causes for these regional differences are not fully understood, the healthier coral reefs are often found in areas with (a combination of) well-developed conservation and fisheries management, regulation and compliance, little pollution, erosion, and (coastal) development, and/or lower occurrences of disease outbreaks, coral bleaching events and hurricanes (Jackson et al., 2014 and references therein).

Healthy coral reef ecosystems and sustainable coastal fisheries are of utmost importance for the economy (nature tourism) of Bonaire. In the Netherlands, fisheries <0.1%) and tourism (<0.1%) only contribute marginally to gross domestic product, however, on Bonaire incoming tourism accounted for a direct contribution to Bonaire's (GDP) of approximately 16.4 percent in 2012 (www.cbs.nl). The coral reefs are the most important commodity for Bonaire and the health of the coral reef ecosystem and its fisheries is vital for the economy. Unfortunately Bonaire's reef coral cover is declining and macro-algae cover is increasing (Bak et al., 2005; Steneck et al., 2015; Meesters pers. comm.). Fish stocks also appear to be declining since 2000s (Johnson & Jackson 2015) according to the perception of local fishers. For the marine protected areas surrounding the islands of the Caribbean Netherlands the following main threats were identified in its Nature Policy Plan: invasive fauna, nutrient enrichment, coastal development, traditional fishery, pollution, recreational fishery, sedimentation, coral bleaching, diving/snorkelling and poaching.

Management of the valuable natural resources requires: a) a management plan with clearly defined quantifiable objectives, targets and reference points of fisheries and coral reef health indicators (e.g. coral, fish, water quality), b) a continuous robust and standardised monitoring of fisheries and coral reef health indicators, and c) a transparent decision framework with respect to conservation, coastal development, environmental and fisheries management strategies with active participation of all relevant stakeholders.

Table 1.1: *Overview of international treaties and conventions and reporting obligations for Bonaire with regards to pelagic fisheries, coral reef fisheries and coral reef ecosystems.*

Treaty, Convention, Organisation	Species/habitats
Food and Agricultural Organisation (FAO)	Status and trends landings pelagic fish, mixed reef fish, spiny lobster and conch; status and trend fishing effort
Convention on international trade in endangered species of wild fauna and flora (CITES)	International trade in Queen conch; status and trends conch population and its fishery to determine quota (non-detriment finding)
Specially Protected Areas and Wildlife (SPAW) (Multilateral Environmental Agreement, a Protocol under the Convention for the Protection and Development of the Marine Environment in the Wider Caribbean Region (WCR) or Cartagena Convention	status and trends whales, dolphins (and sea turtles); status and quality coral reef ecosystem; queen conch and spiny lobster Annex III SPAW protocol
Inter-American Convention for the protection of Sea Turtles (IAC)	Status and trends of sea turtles, and their interaction with fisheries
Convention on the Conservation of Migratory Species of wild animals (CMS)	Status and trends population and distribution sharks
International Coral Reef Initiative (ICRI) and its Global Coral Reef Monitoring Network (GCRMN)	Status and trends of coral reefs
International Commission for the Conservation of Atlantic Tunas (ICCAT)*	Status and trends catch and effort ICCAT listed fish species (e.g. tuna's, marlin, sharks)

**The Netherlands (the Caribbean Netherlands, i.c. Bonaire) is not a member of ICCAT but membership is currently under review.*

In the current form of government the Caribbean Netherlands (Bonaire, Saba, St Eustatius) fall directly under the Dutch State and hence the Minister of Economic Affairs is responsible for the realisation and implementation of international treaties and conventions regarding the management of fish stocks, biodiversity and coral reef habitats in the territorial waters and exclusive economic zone of the three islands. The Kingdom of the Netherlands has ratified international treaties and conventions (Table 1.1) and made national laws for the protection of nature and biodiversity on the islands of the Caribbean Netherlands.

These treaties request reporting on status and trends of fisheries, biodiversity, coral reef ecosystems and threatened species (Table 1.1). Good local indicators of the health of coral reefs and its fisheries is important for local management to maintain or regain healthy coral reef ecosystems. Good indicators also help gaining insight in the processes impacting coral reef ecosystems in the Wider Caribbean Region. Simplifying and standardizing monitoring and ensuring regular data collection will facilitate adaptive management by the responsible authorities in the Caribbean Netherlands. Since 2012 WAGENINGEN MARINE RESEARCH has been working with local organizations on marine resource studies and the development and implementation of robust, efficient and (internationally) standardized monitoring programs of coral reef health indicators in the Caribbean Netherlands on request by the Dutch Ministry of Economic Affairs.

Bonaire is the largest (290 km^2) islands of the Caribbean Netherlands and is located in the Southern Caribbean ca. 100km north of Venezuela and 12' north of the equator. The Bonaire National Marine Park (BNMP) was established in 1979. The Park starts at the high water mark and extends to 200 ft (60 meters) of depth and it covers an area of 27 km^2. The Timeline Table below provides a brief overview of events impacting fish, fisheries and marine biodiversity on Bonaire (modified from Bak et al., 2014).

Timeline	
1950s	Synthetic fish lines introduced
1961	Minimum catch size for lobster & regulation protecting sea turtles (incl. eggs and nesting sites)
1963	Regulation on the use of dragging nets
1971	Spearfishing banned
1975	Harvesting of corals banned
1979	Bonaire Marine Park established
1983	Mass mortality *Acropora cervicornis* species (staghorn coral) due to White Band Disease
1983	Mass mortality *Diadema antillarum* (sea urchin)
1988	Tropical storm Joan
1999	Hurricane Lenny (Category 3) hits sheltered SW coast
2008	Establishment two Fish Protection Areas and two No-Diving Zones; Hurricane Omar causes localized effect
2009	First invasive Lionfish detected
2010:	Harvesting of Parrotfish banned; harvesting of all sharks, manta ray, southern stingray and spotted eagle ray banned fish trap licenses phased out; new permit system for nets; 10-20% corals bleached; Tropical storm Thomas
2015	“Yarari” Shark and Whale sanctuary established in Bonaire’s territorial and EEZ waters

In this report we document the 2014-2015 status of the coral reef fish stocks, the coral reef fisheries and coastal pelagic fisheries. Where possible the current status and trends will be discussed in a historical and/or wider geographical (Caribbean) perspective.

2. Materials and Methods

2.1 Study area

Bonaire (288 km^2) is located in the southern Caribbean and is surrounded by the Bonaire National Marine Park (BNMP) which was established in 1979. The BNMP starts at the high-water mark and extends to 60m of depth, covering an area of 27 km^2. In 2008 two “No fishing” zones (no fishing allowed) and two “No diving“ zones (no diving or snorkelling allowed) were established (Fig. 2.1).

Fig. 2.1 *The location of the two “No Diving” (left) and “No fishing” (right) zones on the sheltered West Coast of Bonaire (Source: STINAPA).*

In the “No Fishing” zone it is forbidden to fish with the only exception of collecting baitfish, belonging to the following categories: Masbangu (bigeye scad, *Selar crumenopthalmus*), larger than 8 cm total length; Boka Largu (balao halfbeak, *Hemiramphus balao*), large than 20 cm total length; Oulo (round scad, *Decapterus punctatus*) larger than 15 cm total length.

2.1 Fisheries survey

2.1.1 Coastal fisheries, shore-based

Fig. 2.2 *Map of the Bonaire showing the two routes within the survey area and the six different fishing areas on Bonaire (Source: STINAPA).*

Fishing effort (fishing hours per day) of the shore-based coastal fishery was estimated using a progressive count method, recording the number and location of shore fishers (Hoenig et al., 1993). This was done in “tours” consisting of two loops (Fig. 2.2). A full tour of the survey area consisted of a southern section (ca. 45km) and a northern section (ca. 35km). A tour took three hours to complete (Fig. 2.3). The number and location of shore fishers was recorded during each tour. The starting time of a tour was randomized in whole hours (7:00 to 18:00) to ensure that starting times had an equal probability to be selected. If the starting time was so late that a circuit could not be completed before 19:00, the rest of the circuit had to be completed from 7:00 onwards. This was done either on the same or the next day. The advantage of splitting the tour is that it is then not necessary to randomize the starting point (Hoenig et al., 1993). The direction (clockwise) of the northern section of the route was fixed because a large section of the northern coastal road is a one-way road. The direction of the southern section (clockwise or anti-clock wise) was randomly assigned. The 3-hour tours were conducted at least twice on random days and times on weekdays (Monday-Friday) and twice on weekends (Saturday-Sunday). No sampling occurred at night time and on most of the east coast of Bonaire because of logistical constraints. Most fishing activity was expected during the day-light hours on the sheltered West coast.

Fishers encountered during the tour were briefly interviewed to determine trip duration, gear type and number and species and length composition of the catch. Estimates of catch rates (kg/hour) were calculated for each season and these catch rates were multiplied by the effort estimated from shore counts for that season to estimate seasonal total catch. Variances were calculated for catch rate, effort, and catch for each season, explicitly taking into account differences in catch rates among days within each season.

Seasons: Data were pooled by four-month seasons instead of on a monthly basis, due to the small sample size. Seasons were based on fish availability/catch composition (Table 2.1). The survey began on 3 October 2013 (catch interviews from 17 October) and ran until 24 December 2014, with slightly higher coverage during the middle of the year.

Table 2.1 *The three seasons used in the analysis of coastal, shore-based fisheries.*

Season	Months	Number of days	Days sampled		Notes
			Effort	Catch	
1	NOV, DEC, JAN, FEB	120	23	14	wahoo (mula; *Acanthocybium solandri*)
2	MAR, APR, MAY, JUN	122	38	20	dolphinfish (dradu; *Coryphaena hippurus*)
3	JUL, AUG, SEP, OCT	123	54	43	deepwater snapper (kora; *Lutjanidae*)

Gears: The survey focused on catches of finfish, hence lobster and mollusc observations were excluded. Since seine net (SNET) fisheries target different species (e.g. baitfish and small pelagics) and have different catch rates compared to other shore fishing methods, these were also excluded. The remaining gear types were: handline (HL), fishing rod (ROD), snorkel and line (SN), fishing pot (FP), gillnet (GNET), cast net (TNET), lift-net (KN), undefined net (NET), and mixed gear (MG). These gear types were analysed collectively.

Fishing areas: Six fishing areas were distinguished (Fig. 2.2), the inland salt pans and five coastal areas using the marked dive sites along the shore line: North-West (no. 9-26), West (no. 27-35), South-West (no. 36-49), South (no. 50-61), East (from no. 61 to no. 62). *T*he main urban area (Kralendijk) is located in fishing area "West".

Effort estimation

Effort was estimated by first estimating daily effort, then combining these estimates for multiple-day periods (seasons), taking account of the variance in daily estimates. The methods described in Lockwood *et al.* (1999) were followed. Within each season, the estimated number of fishers on sampling day *d* was estimated from daily counts (one per day). It is assumed that the mean fishing trip lasted 3 hours. Therefore the number of fishing hours for day *d* (E_d) is calculated as

$$E_d = 3 \times f_d \times \frac{12}{L_d} \qquad \text{Eq. (1)}$$

where f_d is the number of fishers counted on sampling day *d*, 12 is the number of fishable hours on day *d* (07:00 – 19:00), and L_d is the duration (hours) of interval count *j* on sampling day *d*.

Daily estimates of effort are combined over the seasons (*s*) for the total number of fishing hours for each season (E_S) using the equation

$$E_s = \frac{D_s}{m_s} \sum_{d=1}^{m_s} E_d \qquad \text{Eq. (2)}$$

where D_s is number of fishing days per season *s* (D_1=120, D_2=122, D_3=123) and m_s is number of sampled days in season *s* (m_1=23, m_2=38, m_3=54).

Since only one count per sample day is made, the variance is calculated by accounting for the variance between daily estimates and the temporal coverage (number of days of the season sampled). This is determined using the following equation:

$$\widehat{\text{var}}(E_s) = \left(\frac{D_s}{m_s}\right)^2 \left[\frac{\sum_{d=1}^{m_s} E_d^2 - \frac{\left(\sum_{d=1}^{m_s} E_d\right)^2}{m_s}}{m_s(m_s-1)}\right] \qquad \text{Eq. (3)}$$

Confidence intervals were calculated by determining the standard deviation ($SD = \sqrt{Var}$) and then calculating the standard error from this accounting for the sample size ($SE = SD/\sqrt{n}$). The 95% confidence intervals ($CI_{5/95}$) were calculated as $\pm 1.96 \times SE$.

Catch rates

The minimum fishing trip data collected from an interview was information on fishing gear (type and number), duration of the fishing trip and weight of the catch. When possible the complete catch of a fisherman was identified to the lowest taxonomical level possible and measured to the nearest cm (fork) length. Short fishing trips (<30min) were omitted from the catch rate (kg/hour) analysis (Hoenig et al. 1993; Veiga et al. 2010).

The design of the effort survey was subject to one of the four commonly made errors when applying the progressive count method as stated by Hoenig et al. (1993); "*having the survey agent in progressive schemes interrupt the counting for appreciable amounts of time in order to interview anglers and thus not travelling at a constant speed."* However, this possible bias was made negligible by speeding up after interviews to predetermined check points to return back to the (ca. 3 hour) time schedule for the effort survey (Wade et al., 1991; Hoening et al., 1993).

For completed fishing interviews, the total daily catch rate (= catch per unit of effort, CPUE) (R_d) is calculated as the catch (kg) per fishing hour

$$R_d = \frac{c_d}{h_d}, \qquad \text{Eq. (4)}$$

where c_d is the total catch on day d, and h_d is the total fishing hours on day d.

Total fishing hours (h_d) is the total recorded hours fished for a given interview i.e. number of fishers multiplied by the trip length for that fishing party (e.g. for two fishers fishing for three hours, h_d=2×3=6 hours). The seasonal mean catch rate R_s is then the mean of the sampled days:

$$R_s = \frac{\sum_{d=1}^{j_s} R_d}{j_s}, \qquad \text{Eq. (5)}$$

where j_s is number of days with interviews in season s (j_1=*14*, j_2=*20*, j_3=43). The estimated variance between days of a season is then calculated using

$$\widehat{\mathrm{var}}(R_s) = \frac{\sum_{d=1}^{j_s} R_d^2 - \frac{\left(\sum_{d=1}^{j_s} R_d\right)^2}{j_s}}{(m_s - 1)}. \qquad \text{Eq. (6)}$$

Confidence intervals were computed from variance estimates as for effort (i.e. $CI_{5/95} = \pm 1.96 \times \sqrt{Var}/\sqrt{n}$).

Catch

Estimated catch is the product of the seasonal catch rate (R_s, *in kg/hour*, eq. [6]) and fishing effort (E_s, in hours, eq. [3]). Estimates are normally calculated separately for each fishing gear and then summed to provide total estimates. However, for Bonaire total catch across all gears was used due to limited sample numbers of certain gear types. The estimated seasonal catch is:

$$C_s = E_s \times R_s. \qquad \text{Eq. (7)}$$

The estimated variance takes account of both variance in estimated effort and estimated catch rates:

$$V\hat{a}r(C_s) = R_s^2 V\hat{a}r(E_s) + E_s^2 V\hat{a}r(R_s) - V\hat{a}r(E_s)V\hat{a}r(R_s). \qquad \text{Eq. (8)}$$

Confidence intervals (95%) were computed from these variance estimates as $CI_{5/95} = \pm 1.96 \times \sqrt{Var}/\sqrt{n}$).

Catch composition

Data from the catch interviews (species compositions and length frequencies) were used to estimate the mean weight of landed fish species. These data were used to construct catch compositions by species, family and broader groupings (e.g. sharks; deepwater snappers; reef fish, e.g. snappers, groupers, barracuda; large pelagic fish, e.g. wahoo, dolphinfish, tuna, jacks; small pelagic fish).

2.1.2 Coastal fisheries, boat-based

A sample-based fishery survey (Stamatopoulos, 2002) was implemented in October 2013 - January 2015 to collect basic data on catch, effort, species composition and length frequency of the fishery on Bonaire (Fig. 2.3). Rather than directly counting all catches, the total catch for each of the two boat categories (Small Boats (SB): <7m, open boats, no engine or outboard engine; Big Boats (BB): >7m, decked, inboard engine) was estimated by using data on the number and type of boats (frame survey), the activity level of the boats (boat activity and active days surveys) and the mean catches per boat per day (landings survey).

The generic formula for estimating catch is:

Catch = CPUE x [BAC x F x A]

Where:
CPUE is estimated from a Landings Survey
BAC is estimated from a Boat Activity Survey
F is provided by a Frame Survey
A is determined by an Active Days Survey

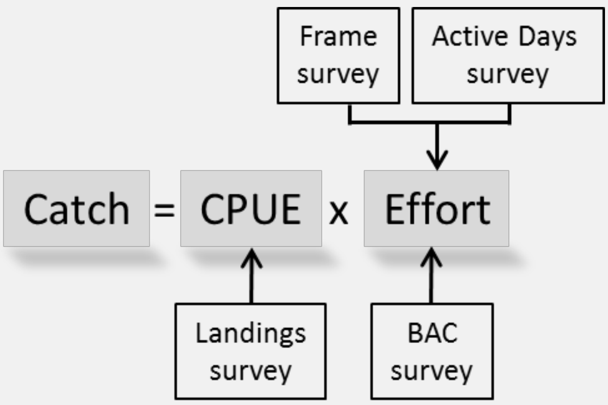


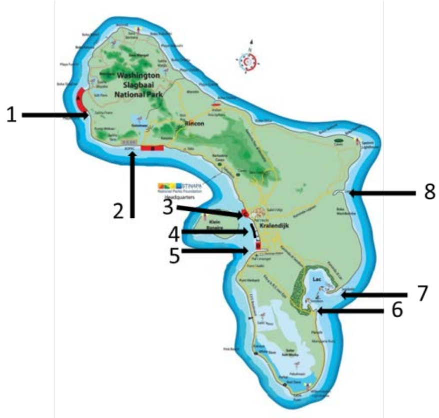
Fig. 2.3 *Schematic representation of the fisheries survey design.*

Frame Survey: A frame survey is a census-based approach to collate a list of homeports and boat/gear categories which is used as the basis for the Active Days, Boat Activity and Landings surveys (Fig 2.3). Frame surveys were conducted at the start of each year and were updated monthly throughout the year. They were conducted to determine the number of small (SB) and big (BB) fishing boats in the various harbours around the island, essentially measuring the total fishing capacity for the island and each harbour. New boats entered the fishery and old boats left it during the study period, so the total capacity varied over time. Eight harbours had small boats, and four harbours contained big boats.

Boat Activity Survey: Boat Activity Surveys were conducted at homeports (Table 2.2) for both boat categories to determine how many boats were active on a given day. For BB all 4 homeports were sampled every survey day, while for SB homeports were randomly sampled. Homeports of the SB category were weighted based on the number of fishing boats.

Table 2.2 *Overview of the distribution of Small Boats and Big Boats over the different homeports on Bonaire. Number include all boats observed during the study. Note that boats come and go, so that the total is more than the most observed in any given month (128).*

Harbour	# big boats	# small boats	Total
1 BOPEC	0	5	5
2 Playa Frans	0	13	13
3 Harbor Village	3	4	7
4 Playa Pabou	14	52	66
5 Plaza Resort	4	10	14
6 Sorobon	8	3	11
7 Cai	0	12	12
8 Lagun	0	4	4
Total*	**46**	**123**	**169**



Active Days Survey: Active Day Surveys are conducted at the end of each month to determine the number of active fishing days for each strata in the survey design (e.g. home port, boat/gear category). In the current survey active days were simply defined as the number of days in a months.

Landings Survey: Landings Surveys were conducted to collect data on catch, effort, species composition and length frequency by season and boat category. Homeports (Table 2.2) were selected randomly for landing surveys. Data from different homeports were weighted based on the number of fishing boats. In addition to the standard landings data, information was collected on the observations of whales and dolphins by fishermen. The results of these observations are published in Scheidat et al. (2015).

Data analysis: The analysis in this report is limited to the fishery on large pelagic fish and mixed reef fish. The same analyses were applied to both the SB and BB categories.

Total catch is estimated from estimates of effort and catch rate.

Effort estimation

Effort was estimated in boat days i.e. the number of days on which boats went fishing, not accounting for variability in the time (hours) spent fishing. For each month, boat days were calculated by estimating the proportion of boats fishing (Boat Activity Coefficients ;BACs) from each harbour each day, multiplying this proportion by the total number of boats in each harbour, and summing up across harbours.

The Boat Activity Coefficients (BACs) were calculated for each month of the study. BACs represent the probability that a fishing boat will be active on a given day in the month. On each sampling day the total number of boats that were active (i.e. not moored at the harbour) at each harbour were recorded. This total number is then divided by the total number of boats indicated for that harbour by the Frame Survey. For the big boat category, all harbours with big boats were combined since they were all surveyed on each trip. The BAC for each harbour for each month is the average of the daily activity estimates in that month,

$$BAC_{h,m} = \frac{\sum_{d=1}^{D_m} \frac{A_{h,d}}{F_{h,m}}}{D_m}, \quad \text{Eq. (9)}$$

where $F_{h,m}$ is the total number of boats estimated by the frame survey in harbour h in month m, $A_{h,d}$ is the number of active boats on day d in harbour h, and D_m is the number of days in month m.

The effort for each month and harbour ($E_{h,m}$) was calculated using the equation:

$$E_{h,m} = F_{h,m} \times BAC_{h,m} \times D_m \quad \text{Eq. (10)}$$

Seasonal effort (E_s) estimates were obtained by summing up the monthly effort values for each month in the season. No estimates of variance were made in the effort calculations.

Catch rate estimation

The mean catch rates, in weight, per boat per day (R_s) were calculated from the sampled data from each season:

$$R_s = \frac{\sum_{t=1}^{T_s} C_t}{T_s}, \quad \text{(Eq. 11)}$$

where C_t is the catch per boat trip t, and T_s is the number of boat trips sampled in season s. The estimated variance between trips in a season was then calculated using:

$$V\hat{a}r(R_s) = \frac{\sum_{t=1}^{T_s} C_t^2 - \frac{\left(\sum_{t=1}^{T_s} C_t\right)^2}{T_s}}{(T_s - 1)} \quad \text{Eq. (12)}$$

Confidence intervals were computed from variance estimates as for effort (i.e. $CI_{5/95} = \pm 1.96 \times \sqrt{Var}/\sqrt{n}$).

Total catch

Finally, the total catch was calculated as the product of effort and catch rate estimates for each season

$$C_s = E_s \times R_s \quad \text{Eq. (13)}$$

Since no variance estimates for effort were available, the variance of the catch was simply the variance in the CPUE ($V\hat{a}r(R_s)$) scaled up to the total catch:

$$V\hat{a}r(C_s) = E_s \times V\hat{a}r(R_s) \quad \text{Eq. (14)}$$

2.1.3 Length-based assessment model

We applied a simple length-based assessment method developed for the assessment of status and exploitation levels of tropical reef fish stocks. This method was previously successfully applied to Florida and Puerto Rico reef fish (Ault et al. 2008, 2014). This method only uses length-frequency data, which are relatively easy to collect and its outcomes. can be used directly to develop management actions. In the case of the Dutch Caribbean, where no quantitative assessment of the resource is available, implementing this method presents the first step towards the elaboration of scientific advice for fisheries management.

2.2 Coral reef fish survey

2.2.1 Study sites, management zones and habitat zones

Fish communities were surveyed in different management zones along the shoreline of Bonaire (Table 2.3; Fig. 2.4) between July and December 2014. On the sheltered (leeward) West Coast the 54 study sites were randomly selected within the management zones. Study sites on the rougher (windward) East Coast were selected opportunistically due to logistical challenges (e.g. difficult entry and exit, rough weather conditions, strong currents).

Table 2.3 *Overview of the number of study sites and transects across the management zones on the sheltered West Coast and exposed East Coast of Bonaire.*

	Code	Shore line	Study sites	Transects	
		(km)	(#)	(#)	(m^2)
Sheltered West Coast (WC)					
General Use zone (West Coast)	GU	34.3	28	213	10650
General Use Zone (Klein Bonaire)	KL	10.8	12	96	4800
No Fishing Zone	NF	3.5	8	60	3000
No Diving Zone	ND	4.6	6	48	2400
Exposed East Coast (EC)					
General Use Zone		50.5	8	45	2250
Total		103.7	62	462	23100

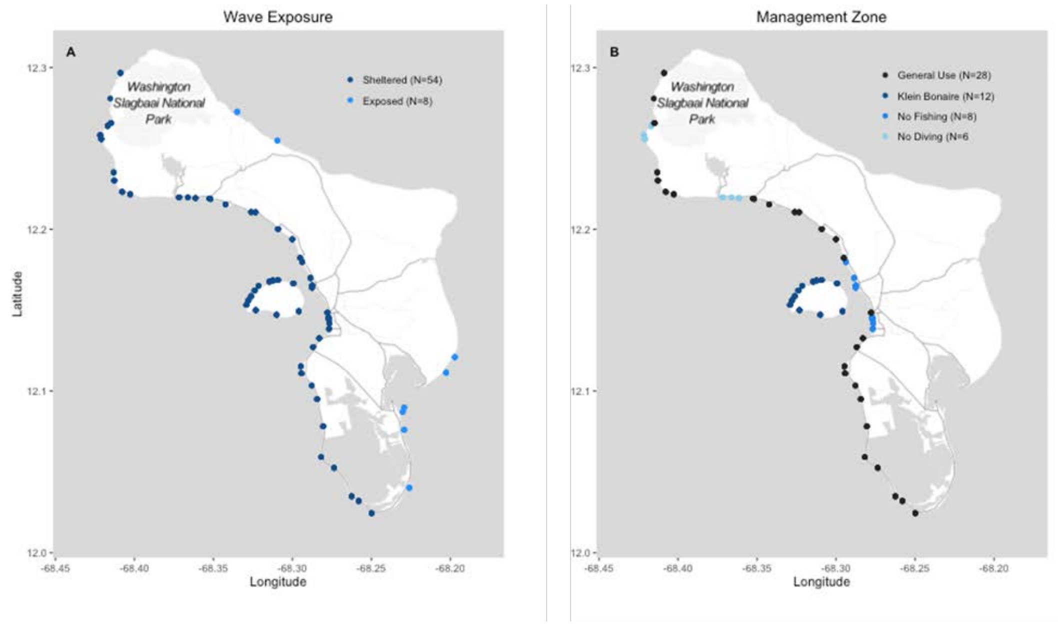
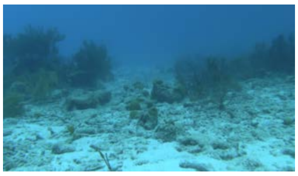


Fig. 2.4. *Overview of the distribution of the study sites on the sheltered West Coast and exposed East Coast (left) and across the different management zones on the sheltered West Coast (right).*

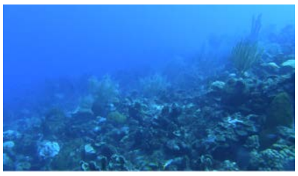
Within each management zone on the West Coast, four habitat zones were discerned (Bak 1977):

1. **Shallow-barren zone (0-4 meter depth):** This zone is characterised by rubble formations, small coral gardens, fire corals (family *Milleporidae*) and dispersed elkhorn and staghorn coral colonies (*Acropora palmata* and *Acropora cervicornis*).



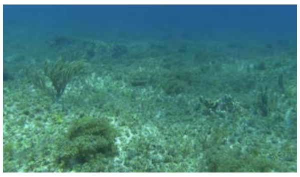
2. **Mixed reef zone (5-8 meter depth):** This zone connects the shallow zone to the start of the reef system and is characterised by large rubble fields and small stony coral gardens. Deeper in the zone soft corals (order Alcyonacea) are more frequently encountered.

3. **Drop-off zone (9-12 meter depth):** This zone is the start of the reef system, coral densities are high and more large stony corals (order Scleractinia) are found in this zone like the star corals (family Montastraeidae), brain corals (family Mussidae) cactus coral and lettuce coral (both family Agariciidae).



4. **Reef slope (upper) zone (13-20 meter depth):** This zone is characterised by the gentle slope of the reef at an angle of ca. 45°, this zone resembles habitat 3 zone in terms of stony coral species and coral abundance. This lower reef slope zone often continues to depths of up to 40 meter but coral densities drop because of lowered light intensity. At 40-50 m depth the coral reef makes way for sandy slopes.

The reef system on the exposed East Coast did not have the same depth-habitat zoning as described by Bak (1977) and Scatterday (1974) for the sheltered West Coast. The following three reef zones were distinguished for the East Coast reef system:



5. **Shallow zone (4-7 meter depth):** This zone is characterised by rubble layers covered with algae, high wave impact and strong surge, and few stony coral or sponge species.

6. **Mixed reef zone (8-16 meter depth):** At these depths the influence of wave action is reduced, but still important as this zone is characterised by large sea fans (order: *Alcyonacea*) moving with the surge. Coral abundance and diversity is higher than in the shallow zone.

7. **Reef slope zone (17-20 meter depth):** In this zone more stony corals are found, the zone marks the start of the reef. Wave action is reduced to a minimum at greater depths.

2.2.2 Stereo Diver Operated Video (sDOV)

At each study site fish surveys were conducted using stereo Diver Operated Video (sDOV) along transects. A sDOV consisted of two high-definition video cameras (Canon Legria HFG10) mounted on a metal base bar. The cameras were separated 0.7 m from each other and angled inward by 8 degrees to achieve maximum field of view (Harvey and Shortis, 2001).

For each transect habitat complexity was estimated from screen shots using Polunin's 6-point scale (Polunin & Roberts, 1993): 0 = bare substratum, 1 = low and sparse relief, 2 = low but widespread relief, 3 = moderate complexity, 4 = high complexity and 5 = extreme complexity (Fig. 2.5).

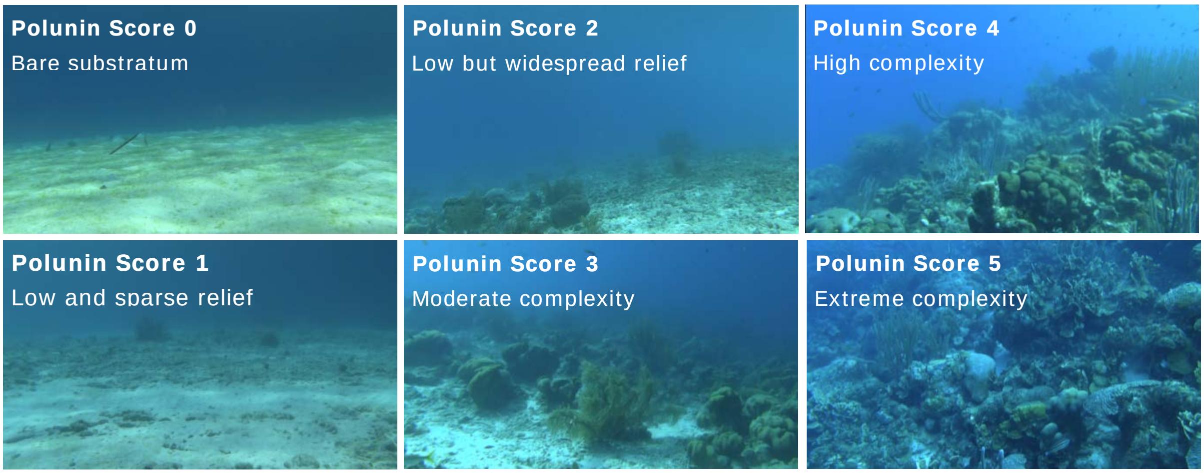


Fig. 2.5 *Examples of the different habitat categories following Polunin's 6-point scale (Polunin & Roberts, 1993).*

At the start of a transect a synchronizing diode was positioned within both cameras' field of view, to facilitate synchronization of camera frames during the video analysis process. Stereo-DOV transects were conducted by two SCUBA divers. The first diver operated the video system, the second diver measured swimming distance with a tape measure. Divers swam at a slow speed (5 min per transect) at 0.5-1m above the substrate with the video unit facing slightly downward. Transects were filmed so that the top of the reef always was filmed as the horizontal plane. Transects were filmed at consistent depths and in straight lines parallel to the shore. On the West Coast, eight 25m-transects were filmed during each dive, two in each of the four different habitat zones (if present). On the exposed East Coast, transects were conducted more opportunistically across the three habitat zones due to logistical constraints. If during a transect divers or snorkelers were encountered, transects were repeated.

2.2.3 Data analysis

Length-frequency distributions per fish species were produced through video analysis using SeaGIS EventMeasure software (SeaGIS-Pty.-Ltd., 2014b). Only fish that were located within the transect width of 2 meter and within 7 meter range from the DOV camera setup were included in the analysis. Fish were identified to species level and measured to the nearest mm total length or fork length. Small (< 5 cm) and cryptic species (i.e. Gobiidae, Blennidae) were excluded from the analysis, since the sDOV technique is not suitable for such species (Langlois et al., 2010; Watson et al., 2010). One Southern Stingray (*Dasyatis americana*) was encountered, for which disc width was measured, as is common practice for rays and skates (Smith & Merriner, 1987).

Accuracy and precision measures were produced to exclude erroneous length measurements. (SeaGIS-Pty.-Ltd. 2013b). Individual weight was calculated with the length-weight relationship $W = a \cdot L^b$ (Bohnsack et al. 1988), with the parameters a and b retrieved from FishBase, www.fishbase.org (Froese and Pauly 2016). Unmeasured individuals were assigned a weight in a step-wise process, only going to a next step when data was lacking: 1) mean weight per species per transect; 2) mean weight per species per habitat; 3) mean weight per species; 4) mean weight per genus. This left 21 individual fish without a calculated weight, these fish were manually assigned a length of $^2/_3$ their maximum length obtained from Reef Fish Identification: Florida, Caribbean, Bahamas (Humann and DeLoach 2002).

Fish-assemblage variables (total number and biomass, trophic group composition, and key ecological families) were analysed for their relationship with wave exposure, management zones, and habitat zones. Fish species were allocated to one of six trophic groups: planktivorous fish, herbivorous fish, invertivorous fish, omnivorous fish, piscivorous fish and apex predators (Appendix G: Species list in Houtepen 2016). The four key ecological families used were: parrotfishes (*Scaridae*), surgeonfishes (*Acanturidae*), snappers (*Lutjanidae*), and groupers (*Serranidae* belonging to the genera: *Cephalopholis, Dermatolepis, Epinephelus and Mycteroperca*). Species diversity was calculated from the Shannon-Weaver Diversity Index (Ludwig and Reynolds 1988): $H' = \sum (p_i \ln p_i)$, where pi is the proportion of all individuals counted that were of species i.

The effects of the explanatory factors habitat, habitat complexity, and management zone on fish-assemblage variables were analysed using bootstrapped means with Bonferroni-corrected confidence intervals. No data-transformations were used in the analyses. All statistical analyses were performed in an R-environment (R-Core-Team 2015).

3. Results

3.1 Fisheries survey

3.1.1 Coastal fishery; shore-based

Fishing gear, area and time

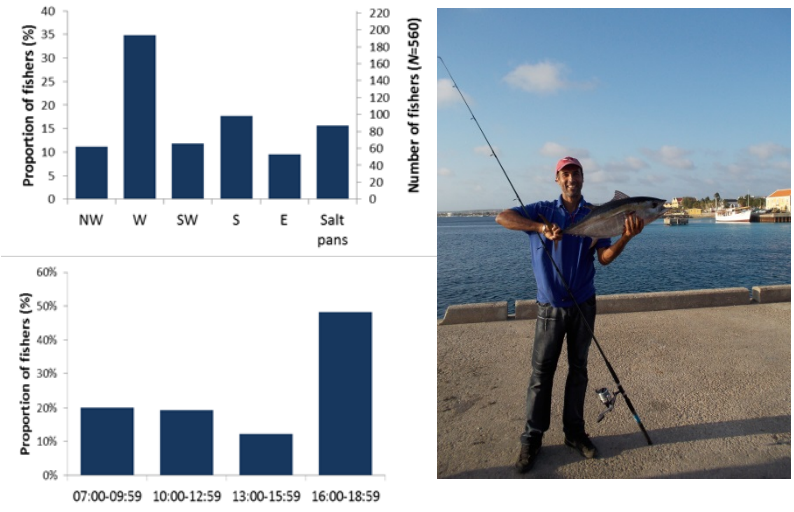


Fig. 3.1 *Spatial and temporal distribution of fishing effort by shore fishers within the survey area.*

Most fishing effort was allocated to the West area (Fig. 3.1), especially at the town pier in Kralendijk (see Fig. 2.2). Within the boundaries of the shore-based fishery survey, most fishing activity (ca. 50%) along the shoreline was observed in the late afternoon between 16:00 and 19:00. The most common fishing gears (Fig. 3.2) used by the shore-based fishers were handlines (ca. 75%) and fishing rods (ca. 15%).

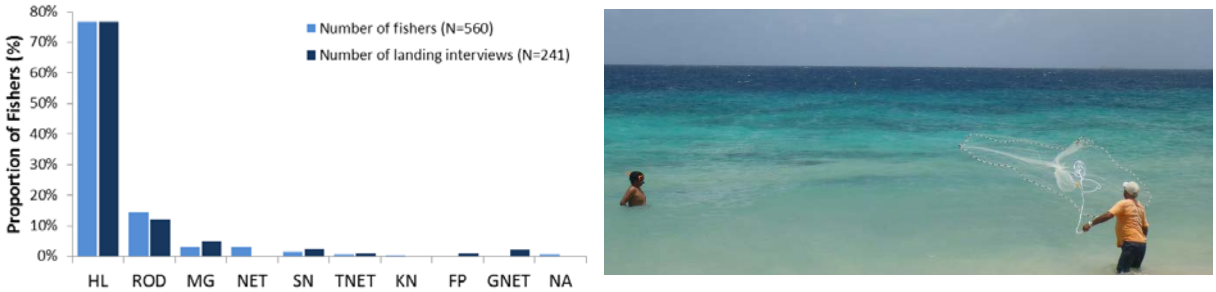


Fig. 3.2 *Distribution of fishing gears observed among shore-based fishers on Bonaire (HL = handline, ROD, = fishing rod, MG = mixed gear, NET = unspecified net, SN = snorkling + handline, KN = dropnet, FP = fish pot, GNET = gill net, NA = unknown.*

Catch rate, effort and total catch

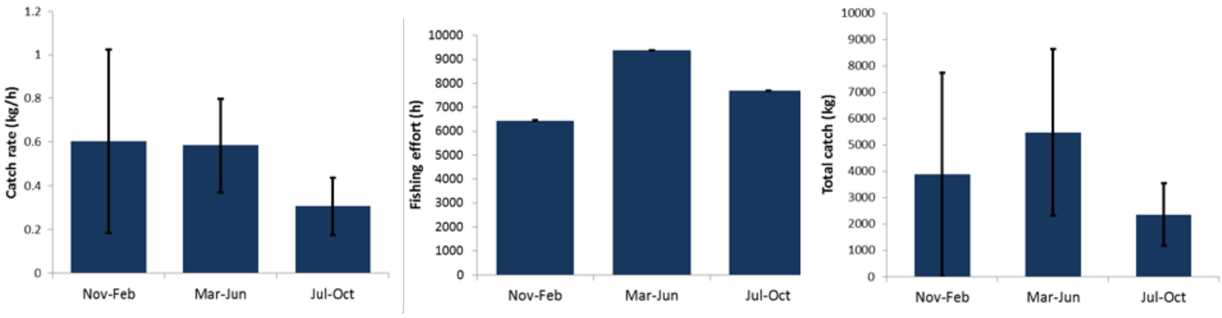


Fig. 3.3 *Mean catch rate (kg/hr), total effort (hr) and total catch (kg) of the shore-based fishery per season. Error bars are 95% confidence intervals.*

Overall catch rate of shore-based fishers was 0.5 kg/hr ranging between mean values of 0.3 and 0.6 kg/hr across the three seasons (Fig.3.3, Table 3.1). Total fishing effort was highest in Mar-Jun (ca. 9000 hrs) and lowest in Nov-Feb (ca. 6000 hrs). The mean daily effort of the shore-based fishery was 64 hr resulting in a mean daily catch of 32 kg from the shore area stretching from BOPEC to Sorobon between 7:00 and 19:00. The total annual effort and catch was estimated at ca.23 000 hr and 11 725 kg, respectively (Table 3.1).

Table 3.1 *Overview of catch rate, effort and total catch of the shore-based coastal fishery operating between BOPEC and Sorobon between 7:00-19:00.*

	Season 1 NOV-FEB 120 days		Season 2 MAR-JUN 122 days		Season 3 JUL-OCT 123 days		Year	
	Value	CI	Value	CI	Value	CI	Value	CI
Mean catch rate (kg/hr)	0.60	0.42	0.58	0.21	0.31	0.13	0.50	0.25
Total Effort (hr)	6442	13	9373	10	7684	4	23499	27
Total Catch (kg)	3888	3860	5476	3152	2361	1183	11725	8196
Mean daily effort (hr)	*54*		*77*		*63*		*64*	
Mean daily catch (kg)	*32*		*45*		*19*		*32*	

Catch composition

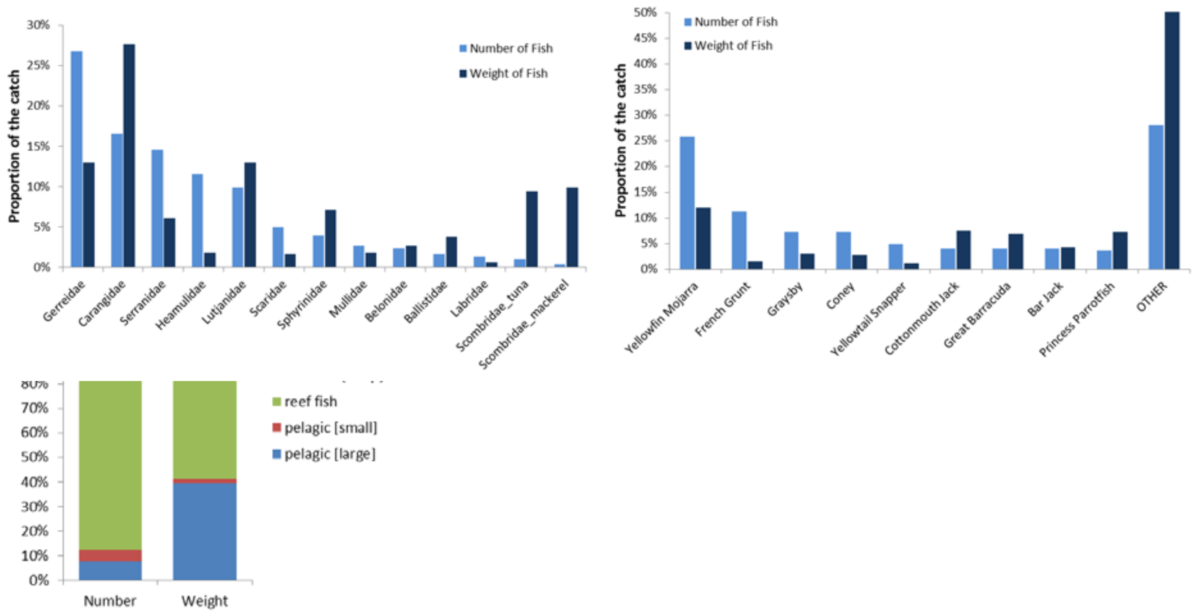


Fig. 3.4 *Species composition of the shore-based coastal fishery in number and weight across families (top left), common species (more than 10 fish observed and recorded in >5% of the monitored catches) (top right), and major habitat-associated groups (bottom, left).*

Interviews were conducted to determine length and species composition of the shore-fishery. Nearly 300 fish (ca. 136kg) were identified to species level and most fish were measured to the nearest cm fork length or total length (species without a forked tail). A broad range of predominantly reef fish was landed (Fig. 3.4). The most important contributors to the catch in number were Gerridae, Carangidae, Serranidae, Heamulidae and Lutjanidae. The most important contributors in weight were Carangidae, Lutjanidae, Gerranidae and Scombridae (tuna and mackerel). The contribution of Scombridae (both tuna and mackerel) resulted from few (<4), but large individuals observed during the shore-based fishery survey. The most commonly landed fish species (in number) were yellowfin mojarra (*Gerres cinereus*), French grunt (*Haemulon flavolineatum*), graysby (*Cephalopholis cruentata*), coney (*Cephalopholis fulva*) and yellowtail snapper (*Ocyurus chrysurus*). Overall, reef fish contributed nearly 90% in number and 60% in weight to the total catch of the shore-based coastal fishery.

3.1.2 Coastal fishery: boat-based

Fishing gear, distance to shore and trip duration

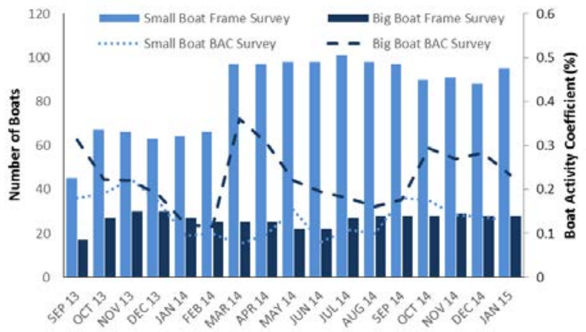


Fig. 3.5 *Overview of monthly changes in the number of small and big boats (Frame Survey) and Boat Activity Coefficients (BAC Survey) in the boat-based coastal fishery.*

A mean of 84 small boats and 26 big boats were recorded during the monthly frame surveys with mean daily boat activity coefficients of 14% and 23% respectively (Fig. 3.5).

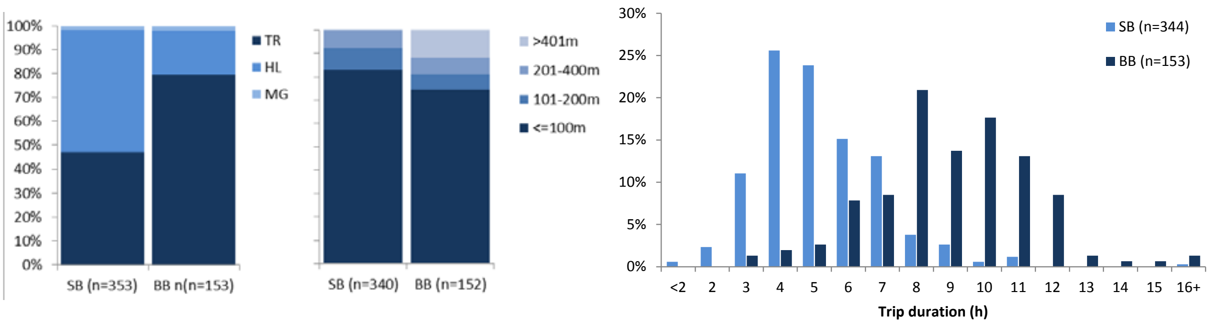


Fig. 3.6 *Distribution of fishing gears (TR = trolling, HL = handline, MG = mixed gears) [left graph], distance to the shore [middle graph], and duration of fishing trips [right graph] by small boats (SB) and big boats (BB).*

SB were observed using handlines for reef fish and trolling lines for pelagic fish in roughly equal numbers, while BB mainly (80%) trolled lines for large pelagic fish (Fig. 3.6). Both SB (100%) and BB (85%) conducted most of their effort near to the shore (<400m), only some of the BB were observed fishing further offshore (1-100 km). The mean duration of a BB fishing trip (9.5 hours) was nearly twice as long as the duration of a SB fishing trip (5.5 hours).

Catch rate, effort and total catch

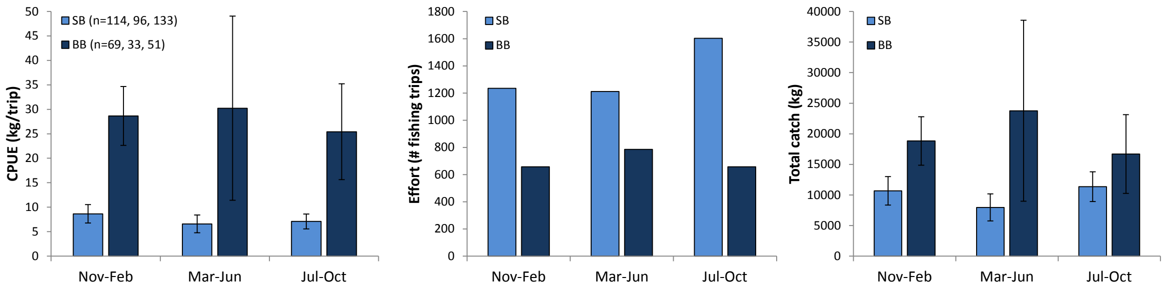


***Fig. 3.7** Mean CPUE (kg/hr), total effort (# trips) and mean catch (kg) of the coastal fishery with small and big boats per season. Error bars are 95% confidence intervals.*

Overall catch rate (kg/trip) was 7.4 kg/trip (6.6-8.6 kg/trip across the three seasons) for SB and 28.1 kg/trip (25.4-30.2 kg/trip across the three seasons) for Big Boats. Little seasonal variation in effort or catch was observed for both the SB and BB fishery (Fig. 3.7, Tables 3.2-3.3). The mean daily effort of the SB was 11 trips resulting in a mean daily catch of 82 kg of reef and pelagic fish (see *Fig. 3.8*). The mean daily effort of the BB was 6 trips resulting in a mean daily catch of 162 kg of pelagic fish (*see Fig. 3.8*).The total annual effort and catch of the Small Boat coastal fishery was estimated at ca. 4000 trips and ca. 30 000 kg, respectively (Table 3.2). The total annual effort and catch of the BB coastal fishery was estimated at ca. 2100 trips and ca. 60 000 kg, respectively (Table 3.3).

***Table 3.2** Overview of catch rate, effort and total catch of the **Small Boat** in the boat-based coastal fishery.*

	Season 1 NOV-FEB 120 days		Season 2 MAR-JUN 122 days		Season 3 JUL-OCT 123 days		Year	
	Value	CI	Value	CI	Value	CI	Value	CI
Mean CPUE (kg/trip)	8.6	1.9	6.6	1.8	7.1	1.5	7.4	1.74
Total Effort (# trips)	1235		1211		1603		4049	
Total Catch (kg)	10670	2328	7968	2201	11349	2429	29988	6958
Mean daily effort (# trips)	*10*		*10*		*13*		*11*	
Mean daily catch (kg)	*89*		*65*		*92*		*82*	

***Table 3.3** Overview of catch rate, effort and total catch of the **Big Boats** in the boat-based coastal fishery.*

	Season 1 NOV-FEB 120 days		Season 2 MAR-JUN 122 days		Season 3 JUL-OCT 123 days		Year	
	Value	CI	Value	CI	Value	CI	Value	CI
Mean catch rate (kg/trip)	28.7	6.0	30.2	18.8	25.4	9.8	28.1	11.6
Total Effort (# trips)	657		786		657		2100	
Total Catch (kg)	18826	3962	23765	14799	16702	6440	59292	25201
Mean daily effort (# trips)	*5*		*6*		*5*		*6*	
Mean daily catch (kg)	*157*		*195*		*136*		*162*	

Catch composition

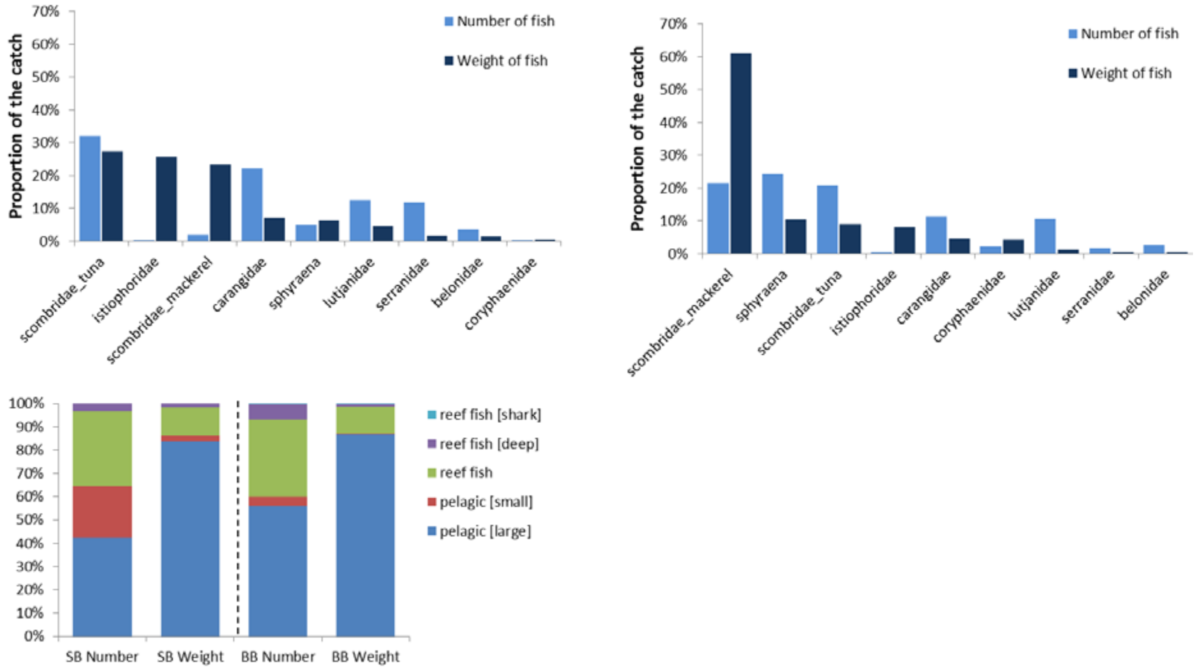


Fig. 3.8 *Species composition at family level in number and weight of small boats [top left] and big boats [top right]. Species composition in major habitat-associated groups of small boats and big boats in number and weight.*

Interviews were conducted to determine length and species composition of the boat-based coastal fishery. Nearly 2000 fish (small boats) and 1100 fish (big boats) were identified to species level and most fish were measured to the nearest cm fork length or total length (species without a forked tail).

A range of pelagic and reef fish were landed by the small boats (Fig. 3.8). The most important contributors to the catch in number were Scombridae (tuna), Carangidae, Serranidae, and Lutjanidae. The most important contributors in catch weight were Scombridae (both tuna and mackerel) and Istiophoridae. The big boats landed predominantly pelagic fish with Scombridae (both tuna and mackerel) and Sphyraenidae, being the most important contributors to the catch in both number and weight.

The most commonly landed species by the small boats were blackfin tuna (22% number, 20% weight), wahoo (2% number, 23% weight), graysby (11% number, 1 % weight) and blue marlin (<1% number, 18% weight). Within the big boat fishery the most commonly landed species were barracuda (24% number, 10% weight), wahoo (21% number, 60% weight), blackfin tuna (19% number, 8% weight) and blue marlin (<1% number, 8% weight). Overall, large pelagic fish species contributed more than >80% in weight to the total catch of both small and big boats of the boat-based coastal fishery.

3.1.3 Length-based assessment model

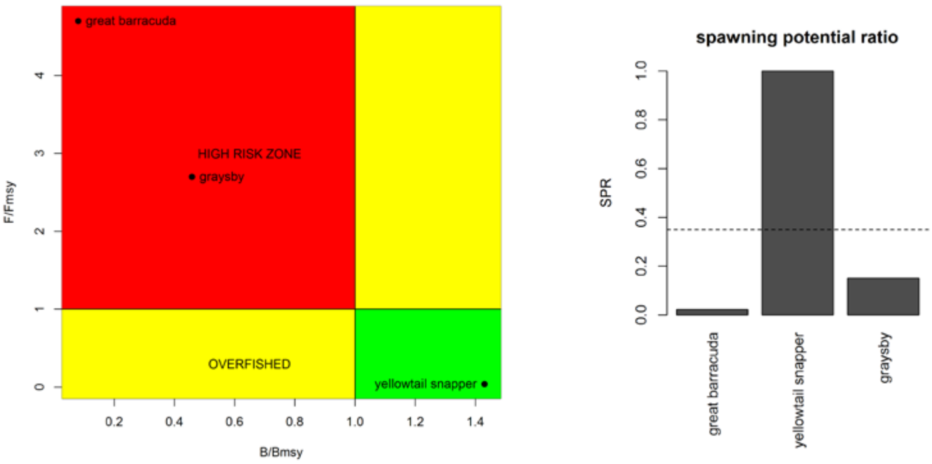


Figure 3.9 *Phase plot of preliminary estimates of stock status and fishing mortality relative to B_{msy} and F_{msy} for some reef fish stocks of Bonaire. Stocks are considered in a good state when B/B_{msy} >=1, and are considered overfished when B/B_{msy} is below the limit threshold (<1). Overfishing is defined by F/F_{msy} > 1 (left). Estimates of spawning potential ratio (current stock size compared to pristine state) for reef fish stocks of Bonaire. The horizontal line represents SPR = 35%, a proxy for the MSY state.*

The preliminary estimates of the status of three exploited reef fish stocks as estimated by the length based assessment model is presented in Fig. 3.9. Two species, great barracuda and graysby appeared to be at high risk: the stock biomass indicator was estimated to be low while fishing pressure was high. Meanwhile, yellowtail snapper was estimated to be in a good shape and being close to pristine state. Unfortunately not enough length data were collected for other exploited reef fish. The results of the length-based assessment model needs to interpreted with care, as rigorous sensitivity analyses of the model remain to be done to determine the robustness of the model and its outcomes.

3.2 Coral reef fish survey

3.2.1 Habitat complexity

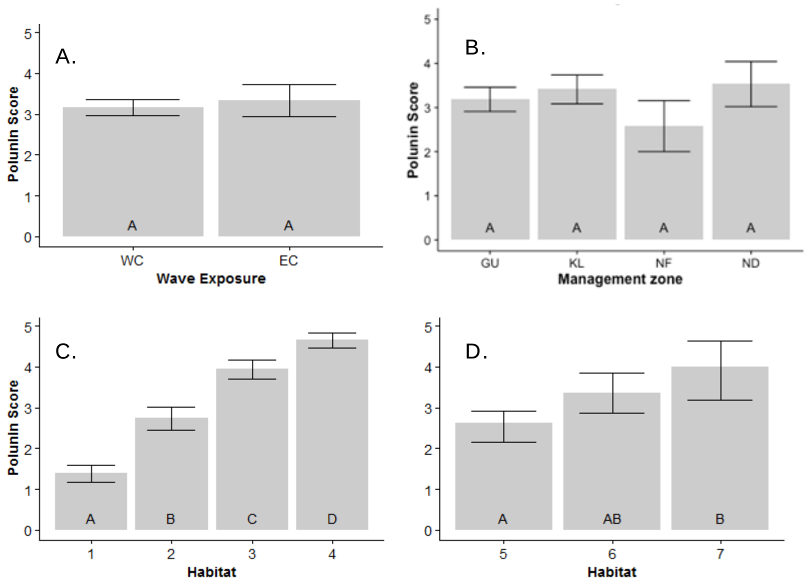


Fig. 3.10 *Habitat complexity (Polunin scale) of A) the sheltered West Coast (WC)and exposed East Coast (EC); B) per management zone for the sheltered West Coast; C) per habitat zone for the sheltered west coast; D) per habitat type for the exposed east coast. Error bars are 95% confidence intervals. Different letters indicate statistically significant differences between groups (p<0.05; Bonferroni-corrected bootstrapped values).*

Habitat complexity (management and habitat zones pooled) did not differ significantly between the West Coast and the exposed East Coast (Fig. 3.10a). Differences in habitat complexity between management zones on the sheltered West Coast were not significant (Fig. 3.10b).On both the West Coast and East Coast habitat complexity increased significantly across the different habitat zone Fig. 3.10b,c) from shallow to deeper water.

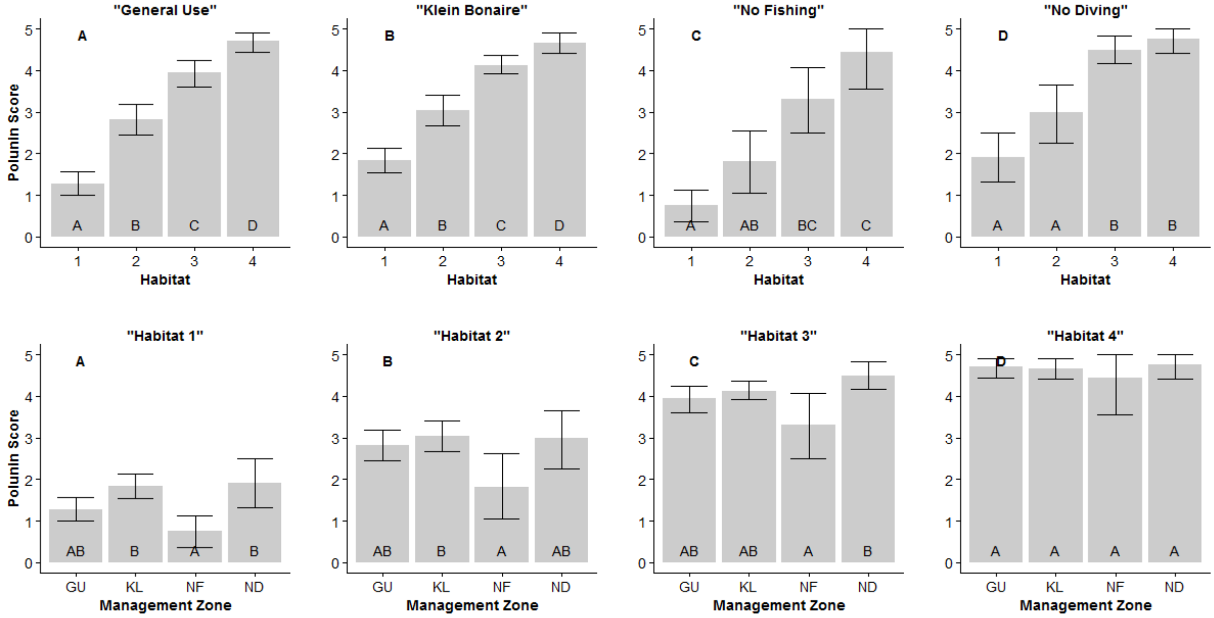


Fig. 3.11 *Habitat complexity (Polunin scale) on the West Coast per habitat zone for different management zones (top graphs) and per management zone for the different habitat zones (bottom graphs). Error bars represent 95% confidence intervals. Different letters indicate significant differences between groups (p<0.05; Bonferroni corrected bootstrapped values).*

On the sheltered West Coast habitat complexity increased significantly across habitat zones within each different management zone (Fig. 3.11a-d, top graphs). Within each habitat zone, habitat complexity did differ significantly among management zones. Most notably, habitat complexity in the “No fishing” zone was lower in habitat zones 1, 2, and 3 (Fig. 3.11a-d, bottom graphs).

3.2.2 Coral reef fish abundance, biomass and diversity

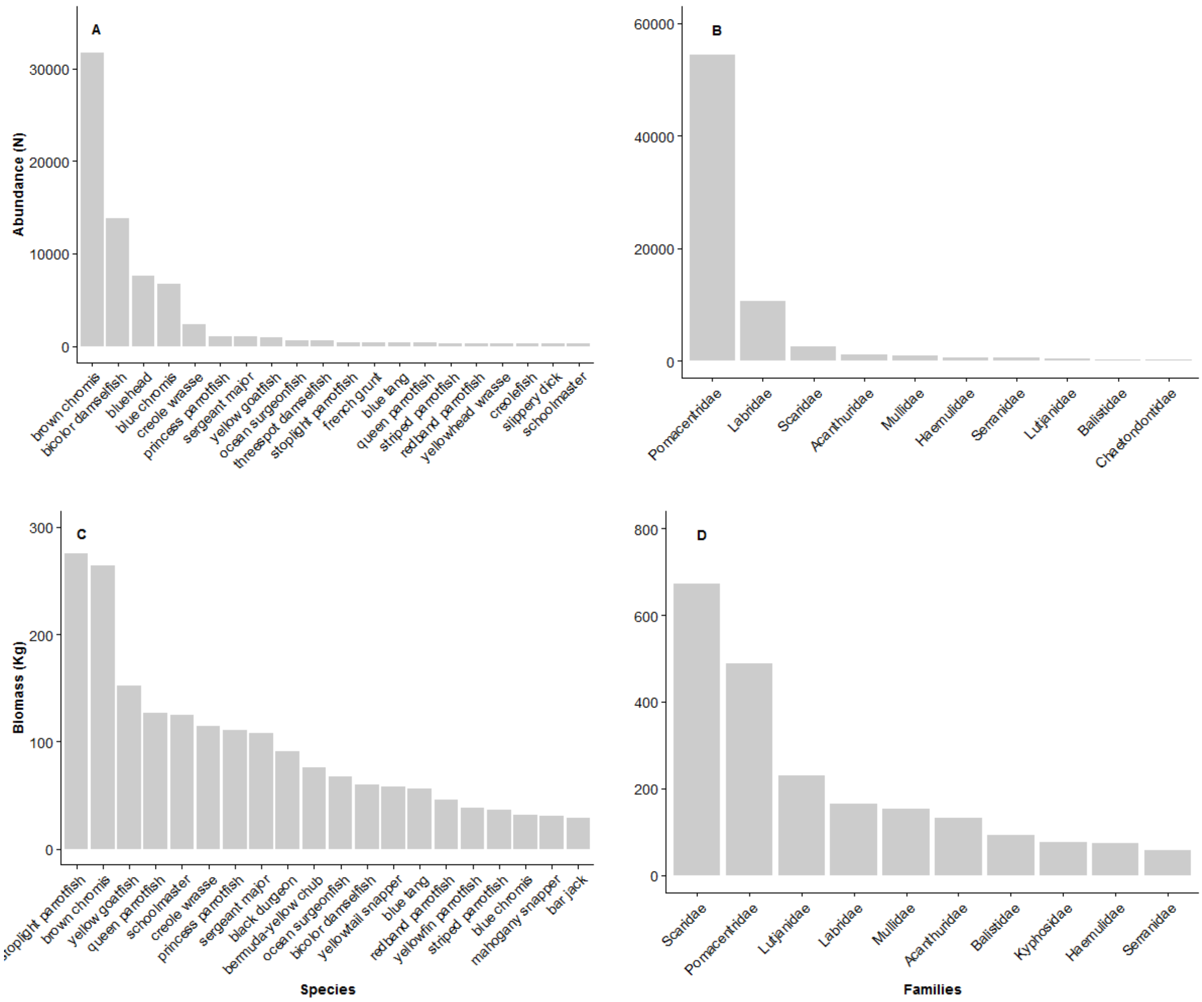


Fig. 3.12 *Overview of common families and species in abundance (top graphs) and biomass (bottom graphs).*

In total 73 378 fish were observed belonging to 109 species from 30 families in 462 transects, with an estimated total weight of 2688 kg (Fig. 3.12; Table 3.4). The five most common species in numbers were the brown chromis (*Chromis multilineata*) followed by bicolor damselfish (*Stegastes partitus*), bluehead wrasse (*Thalassoma bifasciatum*), blue chromis (*Chromis cyanea*) and creole wrasse (*Clepticus parrae*). The three most common families in number were damselfishes (*Pomacentridae*) followed by wrasses (*Labridae*) and parrotfishes (*Scaridae*). The five most common species in biomass were stoplight parrotfish (*Sparrisoma viride*) followed by brown chromis (*Chromis multilineata*), yellow goatfish (*Mulloidichthys martinicus*), queen parrotfish (*Scarus vetula*) and schoolmaster (*Lutjanus apodus*). The three most common families in biomass were parrotfishes (*Scaridae*) followed by damselfishes (*Pomacentridae*) and snappers (*Lutjanidae*).

Table 3.4 provides an overview of the most common species on the sheltered West Coast and exposed East Coast observed during the sDOV survey. On both the West Coast and East Coast of Bonaire the same four small-sized species (brown chromis, blue chromis, bicolor damselfish (Pomacentridae) and bluehead wrasse (Labridae)) made up ca. 80% of the observed fish in numbers. On the East Coast the black durgeon (Balistidae) appeared to be more common both in number and biomass, while on the West Coast the schoolmaster (Lutjanidae), Bermuda/yellow chub (Kyphosidae) and sergeant-major (Pomacentridae) formed a more dominant part of the fish assemblage, especially in biomass.

Table 3.4 *Overview of the contribution of the 10 most common species to the species assemblage on the sheltered West Coast and exposed East Coast of Bonaire.*

NUMBER	**Sheltered**			**Exposed**		
Rank	**Common Name**	**Rel**	**Rel. Cum**	**Common Name**	**Rel**	**Rel. Cum**
1	brown chromis	45.4%	45.4%	bicolor damselfish	28.2%	28.2%
2	bicolor damselfish	18.3%	63.8%	bluehead wrasse	21.1%	49.2%
3	bluehead wrasse	9.6%	73.3%	brown chromis	18.9%	68.2%
4	blue chromis	9.1%	82.4%	blue chromis	11.4%	79.6%
5	creole wrasse	3.3%	85.8%	ocean surgeonfish	2.7%	82.3%
6	sergeant major	1.6%	87.3%	creole wrasse	2.2%	84.5%
7	princess parrotfish	1.5%	88.8%	striped parrotfish	2.0%	86.5%
8	yellow goatfish	1.3%	90.2%	black durgeon	1.9%	88.4%
9	threespot damselfish	0.8%	91.0%	princess parrotfish	1.3%	89.7%
10	ocean surgeonfish	0.7%	91.7%	creolefish	1.0%	90.7%

BIOMASS	**Sheltered**			**Exposed**		
Rank	**Common Name**	**Rel.**	**Rel. Cum.**	**Common Name**	**Rel.**	**Rel. Cum.**
1	brown chromis	12.0%	12.0%	black durgeon	16.3%	16.3%
2	stoplight parrotfish	12.0%	23.9%	stoplight parrotfish	10.2%	26.5%
3	yellow goatfish	6.8%	30.7%	ocean surgeonfish	8.1%	34.6%
4	queen parrotfish	5.6%	36.3%	princess parrotfish	4.2%	38.8%
5	schoolmaster	5.6%	41.9%	striped parrotfish	4.1%	42.9%
6	creole wrasse	5.0%	46.9%	yellow goatfish	3.9%	46.8%
7	sergeant major	4.9%	51.8%	brown chromis	3.8%	50.6%
8	princess parrotfish	4.8%	56.6%	creole wrasse	3.8%	54.3%
9	bermuda-yellow chub	3.3%	59.9%	queen parrotfish	3.6%	57.9%
10	black durgeon	2.9%	62.8%	yellowfin parrotfish	3.6%	61.5%

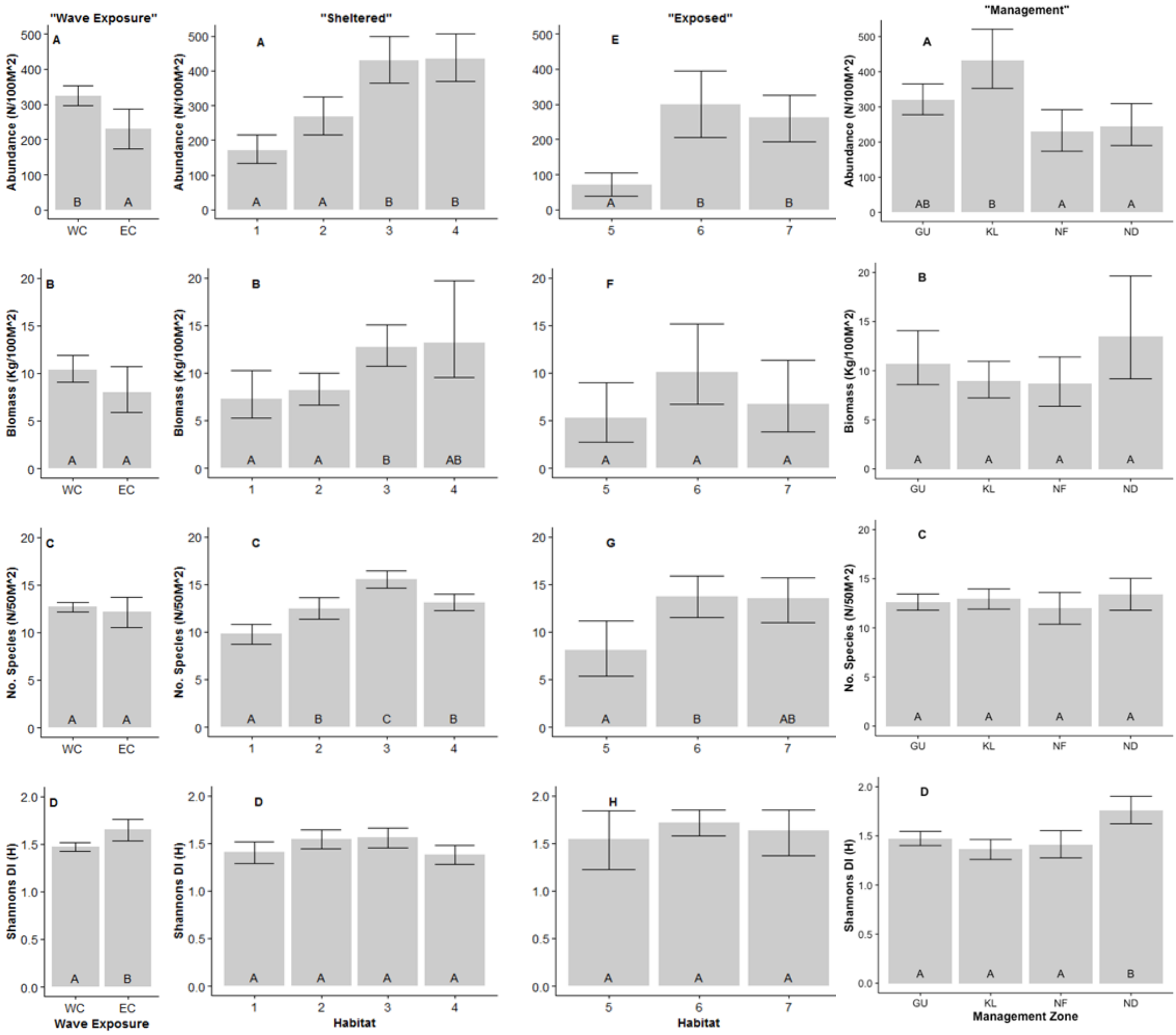
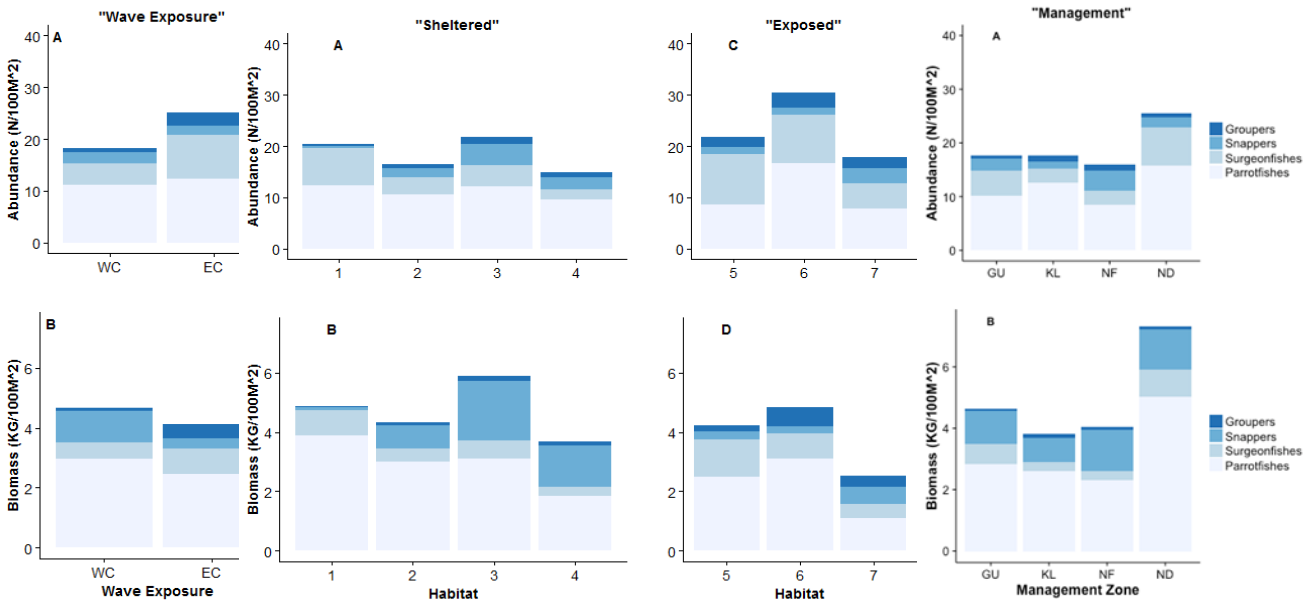


Fig. 3.13 *Abundance (n/100 m²), biomass (kg/100m²), species richness (no species/50 m²) and Shannon's Diversity Index of the sheltered West Coast and exposed East Coast (left graphs a-d,) per habitat (reef) zone for the sheltered West Coast (middle graphs a-d) and exposed East Coast (middle graphs e-h) and per management zone on the sheltered West Coast (right graphs a-d). Error bars represent 95% confidence intervals. Different letters indicate significant differences between groups (p<0.05; Bonferroni-corrected bootstrapped values).*

Overall, fish abundance both in number and biomass appeared to be higher on the sheltered West Coast (Fig. 3.13). Species richness was similar while Shannon's diversity index was higher on the exposed East Coast. On both the West Coast and East Coast fish abundance both in number and biomass differed among habitat zones, although this effect was more pronounced on the West Coast. Species richness also differed among habitat zones and peaked in zone 3 (drop-off) on the West Coast. Shannon's diversity index was similar among the habitat zones on both sides of the island. Fish biomass and species richness were similar across the management zones on the sheltered West Coast. "Klein Bonaire" had a higher number of fish and "No Diving" demonstrated a higher species diversity compared to the other management zones. Overall the effect of habitat zone on the fish assemblage was more pronounced than the effect of management zone.

3.2.3 Key ecological families

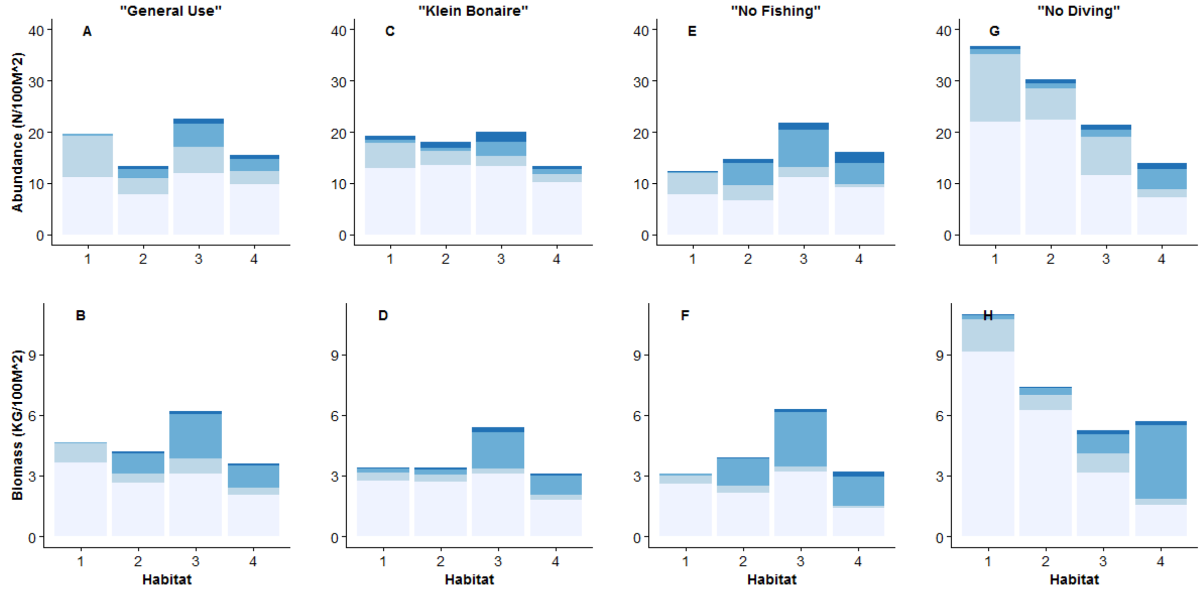
Biomass and abundance



Abundance	Wave Exposure			Habitat									Management			
	WC	EC		1	2	3	4		5	6	7		GU	KL	NF	ND
Groupers	A	**B**		A	AB	**B**	**B**		A	A	A		A	A	A	A
Snappers	A	A		A	**B**	**B**	**B**		A	A	A		A	A	A	A
Surgeonfishes	A	**B**		**B**	A	AB	A		A	A	A		AB	A	A	**B**
Parrotfishes	A	A		A	A	A	A		A	**B**	A		AB	AB	A	**B**
Biomass	Wave Exposure			Habitat									Management			
	WC	EC		1	2	3	4		5	6	7		GU	KL	NF	ND
Groupers	A	**B**		A	AB	**B**	**B**		A	A	A		A	A	A	A
Snappers	**B**	A		A	**B**	**B**	**B**		A	A	A		A	A	A	A
Surgeonfishes	A	A		**B**	AB	AB	A		**B**	AB	A		AB	A	A	**B**
Parrotfishes	A	A		**B**	AB	**B**	A		A	A	A		AB	AB	A	**B**

Fig. 3.14 *Abundance and biomass of key ecological fish families on sheltered West Coast (left graphs a-b) and the exposed East Coast, across the habitat zones on the West Coast and East Coast (middle graphs a-d) and across management zones on the sheltered West Coast (right graphs 1-b). Different letters indicate significant differences between groups (p<0.05; Bonferroni corrected bootstrapped values).*

On the exposed East Coast groupers and surgeonfishes were more commonly observed compared to the sheltered West Coast (Fig. 3.14). The biomass of snappers on the other hand was significantly higher on the West Coast. Distribution patterns of the four ecological key families differed across the habitat zones of the west coast, with the herbivorous surgeonfishes and parrotfishes having a lower biomass towards the drop-off and the slope, while piscivorous snappers and groupers were more abundant there. On the East Coast these patterns were less pronounced with only surgeonfishes having a lower occurrence in the deeper habitat types towards the reef slope. No differences were observed in the occurrence of groupers and snappers across management zones on the West Coast. Parrotfishes and surgeonfishes appeared to be least common in the “No Fishing” zone while the highest densities were found in the “No Diving” zone.



Abundance	General Use				Klein Bonaire				No Fishing				No Diving			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Groupers	A	AB	**B**	**B**	A	A	A	A	A	A	A	A	A	A	A	A
Snappers	A	**B**	**B**	**B**	A	A	A	A	A	AB	**B**	**B**	A	A	A	A
Surgeonfishes	**B**	A	AB	A	A	A	A	A	**B**	AB	AB	A	**B**	**B**	AB	A
Parrotfishes	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Biomass	General Use				Klein Bonaire				No Fishing				No Diving			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Groupers	A	AB	**B**	**B**	A	A	A	A	A	A	A	A	A	A	A	A
Snappers	A	**B**	**B**	**B**	A	AB	**B**	AB	A	AB	**B**	**B**	A	A	A	A
Surgeonfishes	**B**	AB	AB	A	A	A	A	A	A	A	A	A	**B**	AB	AB	A
Parrotfishes	A	A	A	A	A	A	A	A	A	A	A	A	**B**	**B**	AB	A

Fig. 3.15 *Abundance and biomass of key ecological fish families across habitat zones for each management zone on the sheltered West Coast of Bonaire. Different letters indicate significant differences between groups ($p<0.05$; Bonferroni corrected bootstrapped values).*

The overall pattern of decreasing herbivorous surgeonfishes and parrotfishes and increasing snappers and groupers across habitat zones of increasing depth was also observed in each of the management zones on the sheltered West Coast (Fig. 3.15). The patterns were most obvious in the “General Use” and “No Diving” zones. No differences were observed in the biomass of the four key fish families across the different management zones for any of the habitat zones (*see* Appendix 8.1). Only the abundance of parrotfishes was higher in habitat 2 in the “No Diving” zone compared to the other management zones.

Overall the effect of habitat zone on the distribution and abundance of the four key families was significantly more pronounced than the effect of management zone.

__Length__

Fig 3.16 *Mean length of key ecological families on the sheltered West Coast and Exposed East Coast of Bonaire. Error bars represent 95% confidence intervals. Different letters indicate significant differences between groups (p<0.05; Bonferroni-corrected bootstrapped values).*

The mean length of parrotfishes (Scaridae) and surgeonfishes (Acanthuridae) was slightly larger at the West Coast than at the East Coast (Fig. 3.16). The mean length of groupers (genera: *Cephalopholis, Dermatolepis, Epinephelus* and *Mycteroperca)* was slightly larger on the East Coast while for snappers (Lutjanidae) no significant difference was observed.

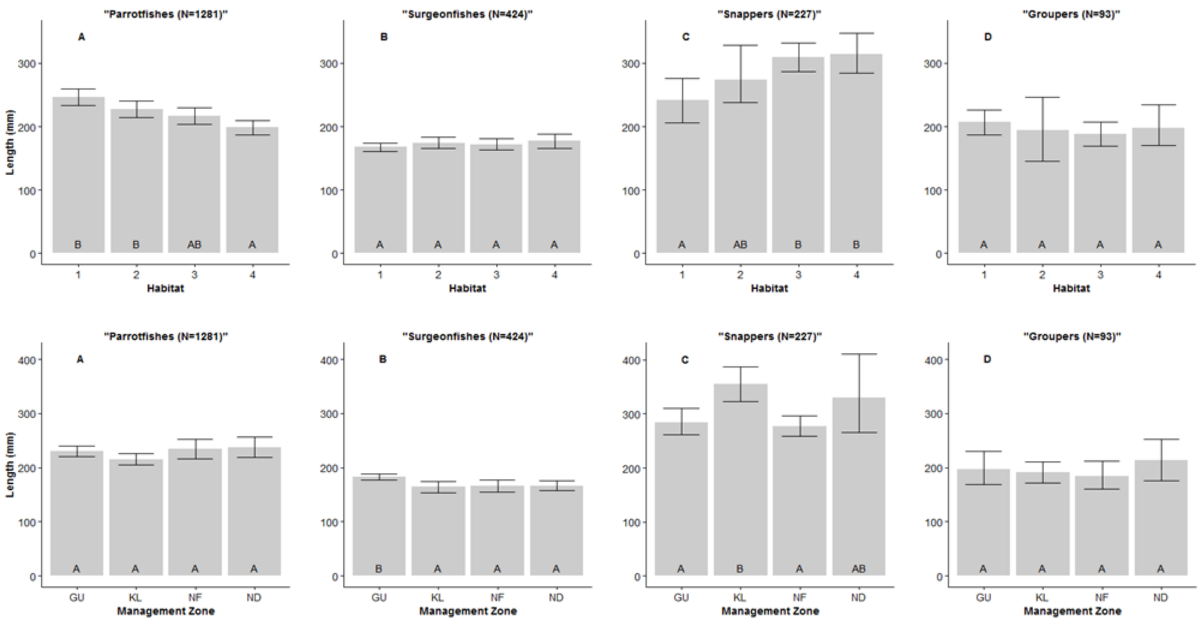
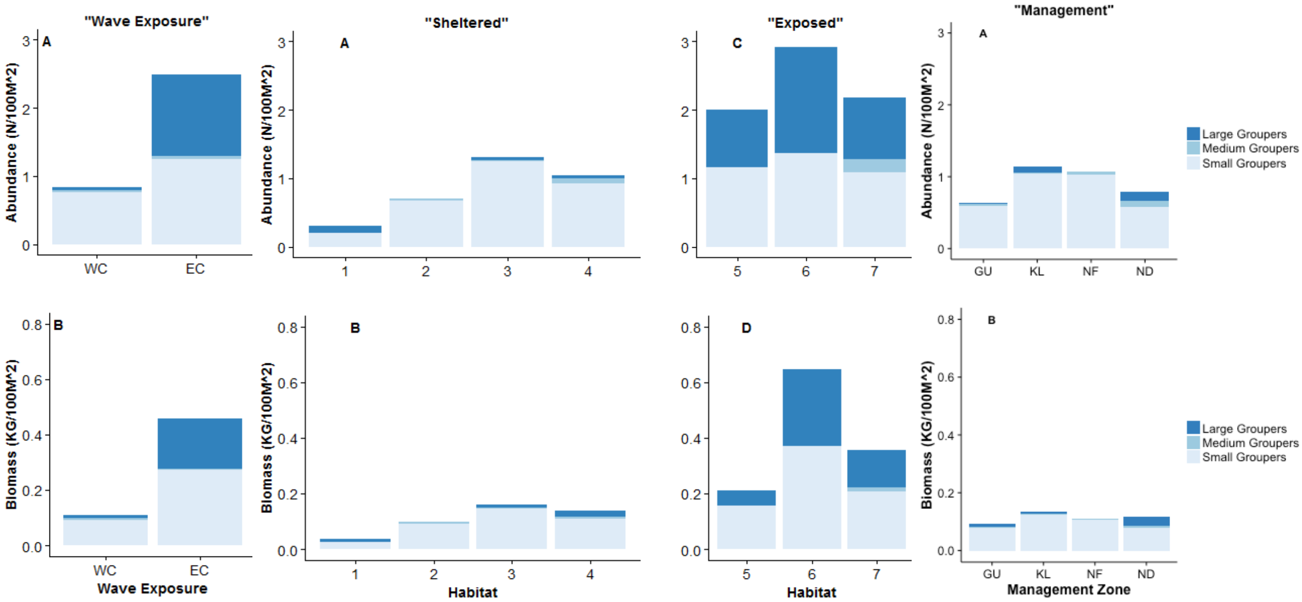


Fig. 3.17 *Mean length of key ecological fish families across habitat zone (top graphs) and across management zones (bottom graphs) on the sheltered West Coast of Bonaire. Error bars represent 95% confidence intervals. Different letters indicate significant differences between groups (p<0.05; Bonferroni-corrected bootstrapped values).*

On the sheltered West Coast of Bonaire, the mean length of parrotfishes differed between habitat zones but not across management zones (Fig. 3.17). No significant differences were observed in the mean length of surgeonfishes and groupers across both habitat zones and management zones. The mean length of snappers differed significantly between habitat zones, with larger fish observed along the deeper habitat zones. Larger snappers also tended to occur in the “Klein Bonaire” and “No Diving” management zones.

Groupers



Abundance	Wave Exposure			Habitat									Management			
	WC	EC		1	2	3	4		5	6	7		GU	KL	NF	ND
Large	A	**B**		A	A	A	A		A	A	A		A	A	A	A
Medium	A	A		A	A	A	A		A	A	A		A	A	A	A
Small	A	A		A	AB	**B**	**B**		A	A	A		A	A	A	A
Biomass	Wave Exposure			Habitat									Management			
	WC	EC														
Large	A	**B**		A	A	A	A		A	A	A		A	A	A	A
Medium	A	A		A	A	A	A		A	A	A		A	A	A	A
Small	A	**B**		A	AB	**B**	**B**		A	A	A		A	A	A	A

Fig. 3.18 *Abundance and biomass of groupers on sheltered West Coast and the exposed East Coast (left graphs A-B), across the habitat (reef zones) on the West Coast and East Coast (middle graphs A-D) and across manageement zones on the West Coast (right graphs A-B). In the Table different letters indicate significant differences between groups (p<0.05; Bonferroni corrected bootstrapped values).*

Medium-sized grouper species (red hind, rock hind; 40-60cm) were rarely observed on either coastline of Bonaire (Fig. 3.18). Both large groupers (e.g. tiger grouper, Nassau grouper, yellowmouth grouper; >60cm) and small groupers (coney, grasby <40 cm) were more commonly observed on the exposed East Coast. On the sheltered West Coast, only small groupers differed significantly across habitat zones but no patterns were observed across habitat zones for any of the grouper categories on the East Coast. Small, medium and large groupers did not differ significantly in abundance across management zones.

3.2.4 Trophic groups

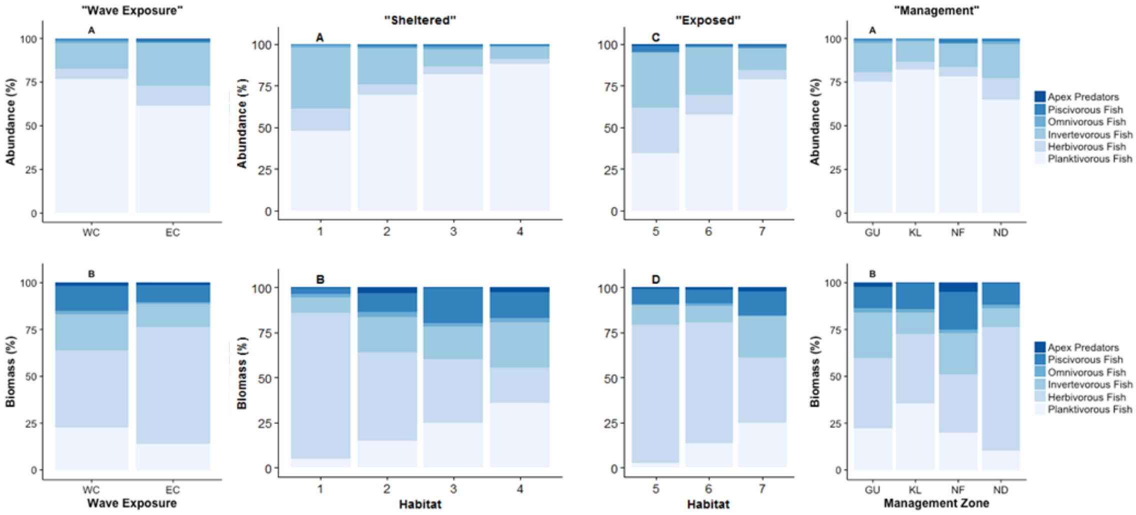


Fig. 3.19 *Relative biomass and abundance of trophic groups on the sheltered West Coast and the exposed East Coast of Bonaire (top left graphs), across management zones on the West Coast (top right graphs) and across the different habitat zones on the sheltered West Coast and the exposed East Coast of Bonaire.*

On the exposed East Coast and sheltered West Coast roughly the same patterns were observed in the abundance and biomass of the different trophic groups in relation to the habitat zones (Fig. 3.19). Apex predators were uncommon and nearly exclusively observed at the deeper habitat zones in the "No Fishing" zone (*see* Appendix 8.2). Nearly 40-50% biomass consisted of herbivorous fish followed by planktivores (ca. 20-25%), omnivores (ca. 15-20%) and piscivores (ca. 10-20%).

Clear differences in the trophic composition of the fish assemblages were observed across the habitat zones on both the west and east coasts. Planktivores and carnivores (apex, piscivores, omnivores, and invertivores) increased from the reef flat (habitat zones 1, 2 and 5) to the reef edge and reef slope (habitat zones 3, 4, 6 & 7). In contrast herbivores decreased from the shallow to the deeper habitat zones. Patterns across management zones were less clear, although herbivores appeared more common in the "No Diving" zone while carnivores seemed more abundant in the "No Fishing" zone.

4. Discussion and conclusions

4.1 Status and trends fisheries

4.1.1 Coastal fisheries: shore-based

The shore-based fishery on Bonaire can best be described as a predominantly recreational, subsistence fishery. Entry into the fishery is easy and does not require a significant investment in fishing gear or fishing licences. Shore-based fishing is an important cultural and social activity with one third of the Bonairian households participating at least one or twice a month in recreational fishing (Lacle et al. 2012).

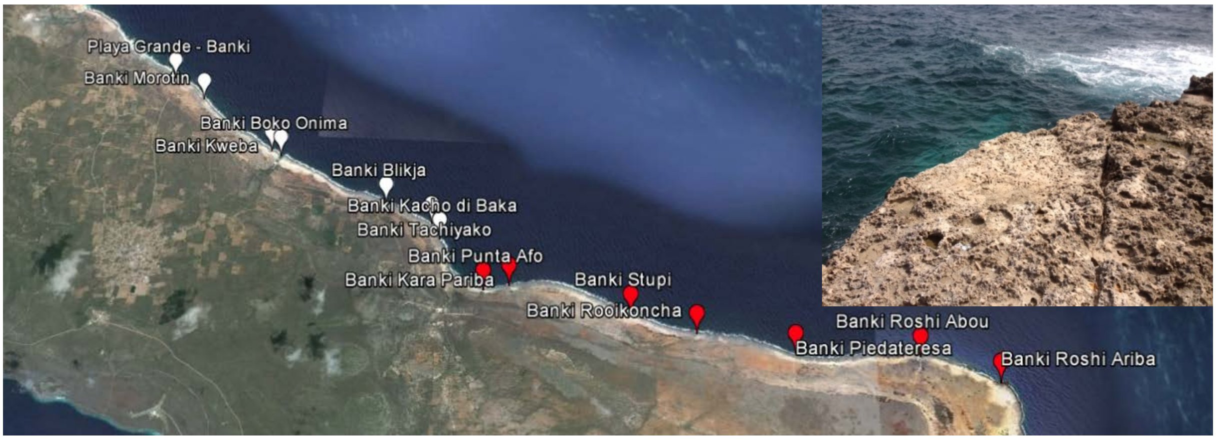


Fig. 4.1 *Overview of the locations of historical shore fishing location or* "banki's" *(see insert) along the cliffs on the exposed north-eastern coast of Bonaire.*

Shore-based subsistence fishing has a long history as demonstrated by the presence of so-called "*banki's*" along the exposed east coast of the island (Fig. 4.1). *"Banki's"* are small areas where the sharp lime-stone (coral) rock has been smoothened, forming platforms that can be used for fishing from the steep cliffs. These traditional fishing sites most likely date back for several decades or even centuries. During this study the location of 14 *"banki's"* was mapped with the help of local fishers. Due to the inaccessibility of most of these *"banki's"* along the exposed east coast, these historical shore fishing sites were not included in the current shore-based fishery survey.

Despite the cultural and social importance of subsistence, small-scale coral reef fisheries, basic catch and effort statistics are rarely collected and reported. This is because logistical challenges of monitoring the widely dispersed fisheries. Also management authorities traditionally have given emphasis to commercial fisheries. Incomplete catch estimates and the lack of historical trends are a reason for concern given the potential impact of fisheries on the health of coral reef ecosystems in the Caribbean (Jackson et al., 2014). The current study provides the first sample-based assessment of catch and effort of the shore-based subsistence fishery for Bonaire. Simple handlines are the most commonly used gear. Fishing effort is concentrated around the West fishing area where main town (Kralendijk) is located and occurs mainly at the end of the day. Catches did not show significant seasonal patterns and the overall CPUE (ca. 0.5 kg/hr) was similar to CPUEs reported for American Samoa by Ponwith (1991) and Craig et al (2008) for shore-based handline (0.5 and 1.3 kg/hr) and rod & line (1.3 and 1.5 kg/hr) fisheries on Tutuila Island (main island) and Ofu & Olosega (outer islands). The shore-based fishery landed mainly reef fish with Carangidae (jacks), Lutjanidae (snappers), Gerranidae (surf perch), Sphyraenidae (barracude) and Serranidae (groupers) being the most important contributors in catch weight.

It is impossible to determine the trends of Bonaire's shore-based fishery due to the complete lack of regular, standardized historical surveys on Bonaire. The additional absence of shore-based fishery statistics from other areas in the wider Caribbean region further prohibits comparisons with the results of the current survey to attempt to place the characteristics of the Bonairian shore-based fishery in a broader geographical perspective. The status of the coral reef fisheries (shore-based and boat-based combined) is described in *Section 4.1.3*. Despite introducing a ban on harvesting parrotfish in 2010, parrotfish were still regularly observed in the catches of shore-based fishers albeit in modest amounts (<10% of the total catch weight; ca. 200 kg or ca. 0.15% of the standing stock; see Table 4.4 and Houtepen 2016). The survey has provided a solid baseline to determine trends and to evaluate the effectiveness of future management on shore-based fisheries. Due to the inaccessibility of the "*banki's*" along the east coast and the north-western shore area of Washington Slagbaai Park and the year-round sun set at ca. 19:00, we assumed that most shore fishing occurred within the boundaries of the survey design. If a shore-based fishery survey is repeated in the future it might be worthwhile to include a pilot survey of the "*banki*" fishery on the exposed east coast and shore surveys after 19:00 along the west coast.

Current status: The characteristics of the shore-based recreational, subsistence fishery on the sheltered west coast of Bonaire does not appear to give any reason for major concern. Overall, effort and catches appeared modest and similar to the few values reported for other shore-based coral reef fisheries. Only the fishing pressure on groupers (e.g. graysby) appeared to be high and these species could be considered overfished. Furthermore, parrotfish were still observed occasionally in the landings of shore-based fishers despite the introduction of a complete ban on the harvest of parrotfish in 2010.

Trends: Due to a complete lack of historical records of the shore-based fishery it is impossible to quantify any positive or negative trends related to changes that may have occurred over time in catch, effort and species composition.

4.1.2 Coastal fisheries: boat-based

Reconstructing trends in Bonaire's coastal fisheries was hampered by the lack of a systematic record of fisheries statistics. Based on the limited availability of information in the literature an attempt was made to describe major trends in effort, catch, CPUE and species composition of Bonaire's boat-based coastal fisheries.

Effort (number of boats and fishers)

Table 4.1 *Overview of number of fishing vessel and fishers on Bonaire (see also Appendix 8.3).*

Year	Fishing boats		Fishers		Reference
	Small (<7m)	Large (>7m)	Full-time	Part-time	
1903			93	275*	
1904	60	25	105	305*	Zaneveld, 1961 and references therein
1959	90**		40	60	Zaneveld, 1961 and references therein
1979	100	18	-	-	Archive LVV Bonaire
1985	170	23	52	-	Leendertse & Verbeek, 1987
2004	64	25	53	-	Dilrosun, 2004
2007	99	32	-	-	Steneck et al., 2007
2010	-	-	78***		Johnson, 2011
2014	78-98	27-31	-	-	this study

in 1903 and 1904 all person registered as "seaman" were included under part-time fishermen. **no information on boat type, probably a mixture of small rowboats and large sailboats; * no information on fisher type, a mixture of full-time and part-time fishermen.*

An overview of the historical changes in the number of fishing boats and fishers is given in Table 4.1. In 1904 there were 25 large vessels of which 20 were reported to mainly fish near the Roques Islands. The remaining five big boats and the 60 canoes (small sailing or rowing vessels) were used for the coastal fishery and on Lac Bay, a shallow natural lagoon on the East coast. Trolling and bottom handlining were the most common fishing methods. Zaneveld (1961) reported that in 1959 the boat types were basically the same as in 1905: wooden rowboats, and sailing vessels, either ‘canoes’ (pointed stern), or ‘sailboats’ (flat stern, usually open). In contrast to 1905 there were also motorboats with inboard engines (1-5 reg. tons). Some canoes and sailboats had auxiliary 15-20 HP outboard engines. However, overall little technological development was observed in fishing vessels between 1905 and 1959.

In the early 1980s, 23 big boats with inboard engines and 170 small fishing vessels were registered. Most were powered by 6-10 hp outboard engines (Leendertse & Verbeek, 1987). Van Buurt (1984) reported that the fishery on Bonaire was primarily a pelagic fishery using small (4-5.5m) open boats driven by outboard engines (6-25 hp) and larger (7-10m), round-bottomed trolling vessels with cabins powered by inboard diesel engine (70-120 hp).

In 2004, 64 small boats and 25 big boats were reported by Dilrosun (2004). The 53 full-time fishermen (100-200 fishing days) were mainly operating coastal trollers (40 fishermen) with a smaller number of full-time (13) reef fishers. Dilrosun (2004) was not able to quantify the number of part-time fishermen (defined as <100 fishing days per year) during the brief inventory of the fishery.

Overall, the number of big boats predominantly used by full-time fishermen has remained surprisingly consistent of the last century. Major technological changes were the shift from sailboats to motorised boats since the 1950s and the advancement of electronical equipment like GPS and fish finders. Whether these technological changes have actually influenced the catchability of large pelagic fish is uncertain as the main fish techniques of trolling several handlines close to shore has not changed since the early 1900s. The small boats are a mixture of full-time, part-time and recreational fishermen with no obvious changes in fishing gear and techniques over the past century.

Effort (daily boat activity)

During the 2014 survey, on average 84 small boats and 26 big boats were recorded during the monthly frame surveys with an average daily boat activity coefficient of 14% and 23% respectively. The observed daily boat activity appear similar to values reported in the late 1960s and 1980s. Leenderste & Verbeek (1987) reported an average daily boat activity coefficient of 16% for small boats in 1986. In 1968 UNDP/FAO (1972) reported a daily boat activity of 15%, although it is unclear if this percentage refers to the whole fleet or only the small boats. Like the number of fishing boats and fishers, the daily boat activity appeared also rather conservative and consistent over the last half century.

Effort (trip duration)

The mean duration of a big boat fishing trip (9.5 hours) was nearly twice as long as the duration of a small boat fishing trip (5.5 hours). No historical data on trip duration are available for the Bonairian boat-based coastal fishery. The boat-based coastal fishery on the nearby island of Curacao is similar to the Bonairian boat-based fishery with respect to boat types, gears and techniques. For Curacao’s coastal fishery, both LVV (2003) and Leenstra (2005) reported trip durations for small boats and big boats of 5-6 and 9-10 hours respectively, which is similar to the results from the current survey of Bonaire’s fishery.

Annual Catch

Table 4.2 *Overview estimated catches of fish on Bonaire.*

Period	Total Annual Catch (t)	Boat-based fishery		Shore-based fishery	Method	Reference
		Large boats	Small boats			
1908	110 t*	110 t*		-	12 month survey	in Zaneveld (1961)
1956	140 t	140 t		-	survey?	in Zaneveld (1961)
1968	100 t	100 t		-	extrapolation 3 month survey	in Palm, 1985
1978	160 t	160 t		-	survey?	in Palm, 1985
1984	80 t	80 t		-	survey?	van Buurt, 1984
1973-1985	200 t	200 t	-	-	extrapolation 1 fishing boat	Leendertse & Verbeek, 1987
2010	160 t	160 t			literature	Lindop et al, 2015
2014	102 t	60 t	30 t	12 t	12 month survey	this study

**catch in numbers converted to biomass assuming small pelagics 0.1 kg, deepwater snappers and reef fish 2 kg; large pelagics 10 kg, sharks 20 kg.*

An overview of historical estimates of total landings of Bonaire's coastal fisheries is presented in Table 4.2. Over the past centuries estimated landings of Bonaire's coastal fisheries have fluctuated between 100-200 t per year. Lindop et al. (2015) attempted to reconstruct the landings of the artisanal, recreational and subsistence fishery on Bonaire and the other islands of the Dutch Caribbean for the period 1950-2010 based on the available literature and concluded that "*the lack of nuance in the reconstructions reflects our limited ability to accurately piece together historical fishing in the Netherlands Antilles, as no systematic records have ever been kept*".

It is often unclear what the estimated landings are actually based on (1956, 1978, 1984). The 1968 and 1973-1985 estimates are at risk of being severely biased as each estimate is large based on extrapolation of a limited survey. The 1968 estimate is based on just a three month survey and hence susceptible to bias as Bonaire's fishery can be highly seasonal in CPUE (Fig. 4.2) and species composition (Fig. 4.4). The 1973-1985 estimates on the other hand, are based on extrapolation of the landings of just one fishing vessel over the **whole** fleet of big boats and hence susceptible to bias as annual landings are usually variable between fishing boats.

The most complete historical survey was conducted in 1908 by Fishery Advisor Dr P.J. van Breemen who collected landings of fresh fish for a period of 12 months on Bonaire (Zaneveld, 1961). However, for 1908 only the landings (in number) were reported in Zaneveld (1961), unfortunately without any details on effort (type of boat, type of gear, duration of fishing trip) or length and/or weight of landed fish.

Catch rate

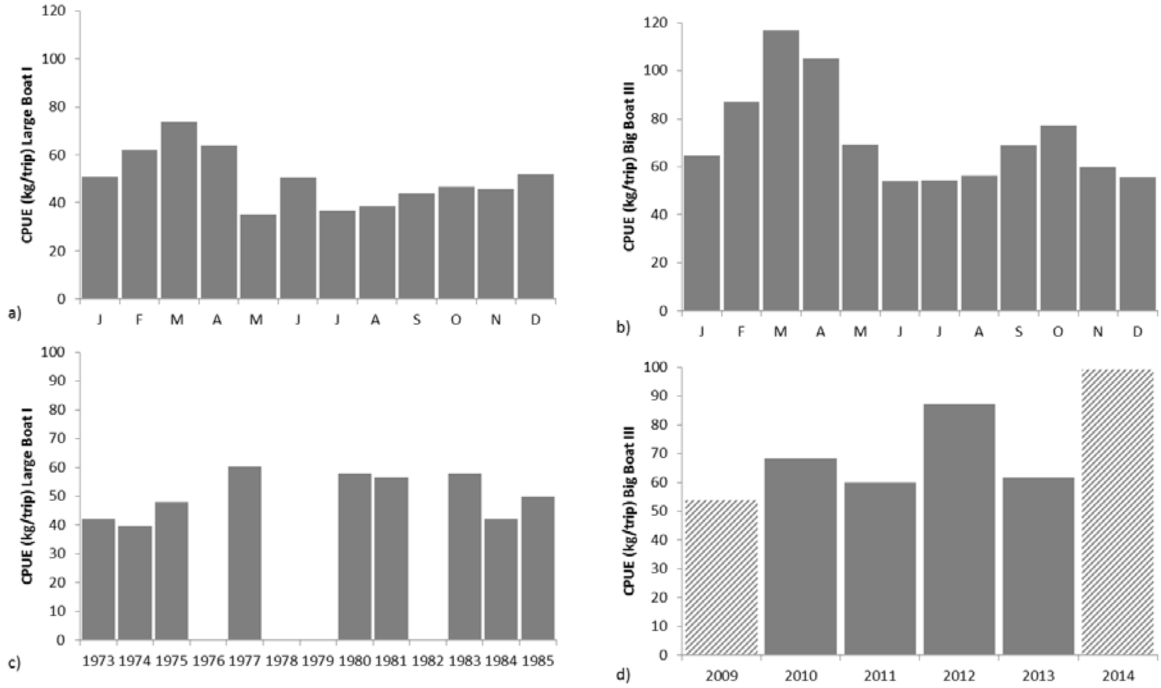


Fig. 4.2. *Seasonal (a, b) and annual changes (c, d) in CPUE of one big boat in the period 1973-1985 (Leendertse & Verbeek, 1987) and one big boat in the period 2009-2014 (this study, note that for 2009 (Jun-Dec, low season) and 2014 (Jan-Jun, high season) only 6 months of data was available).*

For the periods 1973-1985 (Leendertse & Verbeek, 1987) and 2009-2014, historical CPUE data were available but restricted to only one fishing vessel (big boat) in each period (Fig. 4.2). Seasonal patterns in CPUE were similar in both periods, with the highest CPUE in the months January to April. In both periods, the seasonal variation in catches appeared larger than the inter-annual variation. CPUE remained relatively stable within each period, with no clear declining or increasing trend. Leendertse & Verbeek (1987) reported a CPUE of 60 kg per trip for a second boat in 1983, similar to the CPUE of the big boat in Fig 4.2c in that year. For the years 2009 (Jun-Dec, low season) and 2014 (Jan-Jun, high season) data were only available for part of the year.

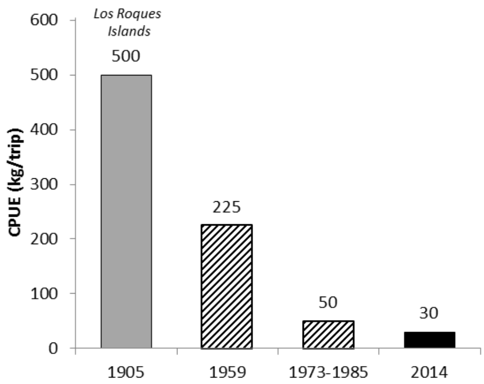


Fig. 4.3 *Rough estimates of changes in CPUE (kg of fish per trip) for the large, trolling vessels in Bonaire's coastal waters. Sources: 2014, this study; 1972-1985, Leendertse & Verbeek (1987) based on records of one fishermen; 1959, Zaneveld (1991) p. 150 (15-30 fish per boat per day assuming a mean weight of 10 kg per fish); 1905 Bonairian fishermen at Los Roques, Boeke (1907) p. 85 (500-700 large fish in 1-3 week trips; assuming 80% large pelagics (10 kg per fish) and 20% demersal fish (2 kg per fish).*

Between 1959 and 2014, CPUE appeared to have declined in Bonaire's (pelagic) coastal fishery (Fig. 4.3). However, care has to be taken with the interpretation of these CPUE data. The 1959 CPUE data are based on just one comment "15-30 fish per boat per day" on page 150 of Zaneveld (1961) and the 1973-1985 CPUE data are based on the catches of a single big boat while the 2014 CPUE is based on the mean of the whole fleet (20+ big boats) after a 12 month survey. Significant variation in CPUE between fishing vessels is not uncommon as even in recent years some boats maintained an average CPUE of ca. 70 kg per trip, similar to the big boat in 1973-1985 (Fig. 4.2).

No historical CPUE data were available for small boats. Leendertse & Verbeek (1987) only mentioned a figure of ca. 20 kg per trip for small boats but this value was not based on a survey or records of a fish merchant. Assuming that the reported figure is roughly correct then the CPUE of small boats may also have declined between 1973-1985 and 2014 (ca. 7.5 kg / trip, see Table 3.2).

The Bonairian catch per trip for small boats (ca. 7.5 kg) and big boats (ca. 30 kg) were in the same order of magnitude as the daily catches reported for Curacao's coastal fishery. In 2002 a daily catch of ca. 7 kg for small boats and ca. 23 kg for big boats was reported (LVV, 2003). In 2004-2005 Leenstra (2005) recorded daily catch rates for small boats between 8 kg (handline) and 13 kg (trolling) and for big boats between 24 kg (handline) and 30 kg (trolling). Schulting & Lindenberg (2006) reported a daily catch per trip (small and big boats pooled) of ca.18 kg for trolling and ca. 7 kg for handlining during a 4-month survey (Feb-May) in 2006.

For the Indian Ocean, Laroche and Ramananarivo (1995 and references therein) reported daily catches of line fishing for artisanal reef fisheries ("small boats") in the late 1980s; 4.8 kg Tulear (Madagascar), 4.6 kg Mauritius, 7.3 kg Comores, 9.1 kg Seychelles, 10.5 kg Kenya. At the time the Tulear, Comores, Seychelles and Kenya where considered at full exploitation and Mauritius overfished. Craig et al. (2008) reported a CPUE of 1.1 kg/hr for line fishing from boats on the outer reefs of American Samoa.

It is difficult to quantify trends in catch rates of the boat-based fishery due to the lack of regular historical fisheries statistics. The few available historical catch rates may appear to show a possible overall decline over time but the uncertainty is high. Furthermore, individual big-boat fishers in 2014 appeared to achieve catch rates similar to the catch rates recorded for the 1970s and 1980s (Leedertse and Verbeek, 1987).

Johnson and Jackson (2015) explored the perceptions of fishers on (reef) fish populations through interviews of part-time and full-time fishers on Bonaire and Curacao. Most fishers perceived catching fewer and smaller fish than previous generations. Bonairian fishers (Johnson 2011) mentioned a reduction in catches of large pelagic fish (i.e., tunas, wahoo, dolphinfish) and reef fish (i.e. coneys, groupers (especially Nassau groupers, yellowtail snappers).

Species composition (major groups)

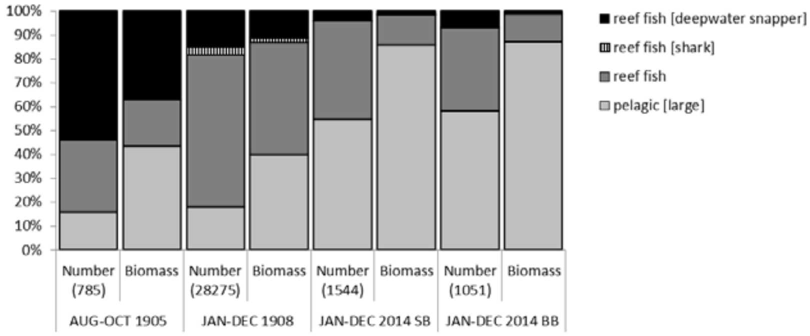


Fig. 4.4. *Temporal changes in the species composition in number and biomass of the landings in major groups (sharks; deepwater snappers; reef fish, e.g. snappers, groupers, barracuda; large pelagic fish, e.g. wahoo, dolphinfish, tuna, jacks). For 1905 (Boeke, 1907)) and 1908 (Zaneveld 1961)) data numbers were converted to weight assuming sharks 20 kg, deepwater snappers 2 kg, large pelagics 10 kg, reef fish 2 kg. Small pelagics were excluded. SB = small boat, BB = big boat.*

In 1905 statistics were kept of the fish landed in the bay of Kralendijk by Bonairian fishers during the months August through October (Boeke, 1907). During this period small pelagic fish (so-called "*masbangu*" in Papiamentu) caught with beach seines were the most commonly landed fish both in number and weight. Most of these small pelagic fish were exported to Curacao. The high contribution of deep-water snapper to the landed catch in 1905 (Fig. 4.4) is most likely an artefact of the season (AUG-OCT) in which the survey was conducted. Seasonal patterns in landed species were observed in 1973-1985 and 2009-2014, with the months JUL-OCT characterised as deep-water snapper season (Fig. 4.5). In his 1908 survey, Dr P.J. van Breemen Found that, similar to 1905 the landings were dominated in number by small pelagic fish. Bonaire's coastal fishery appears to have targeted large pelagic fish species at least since the beginning of the 20th century. In 1905 and 1908 already roughly a third of the catch (excluding small pelagics) consisted of large pelagic fish. The contribution of reef fish to the landings appears, however, to have declined since the early 1900s. At the beginning of the 20th century reef fish contributed roughly one third to the landings in biomass (excluding small pelagics). In the landings of the big boats in 1973-1985 and 2009-2014, reef fish contributed <5% to the catch weight. The 2014 survey demonstrated that only a minor part (<15% catch weight) of the landings of both small boats and big boats consisted of reef fish (Fig. 4.4).

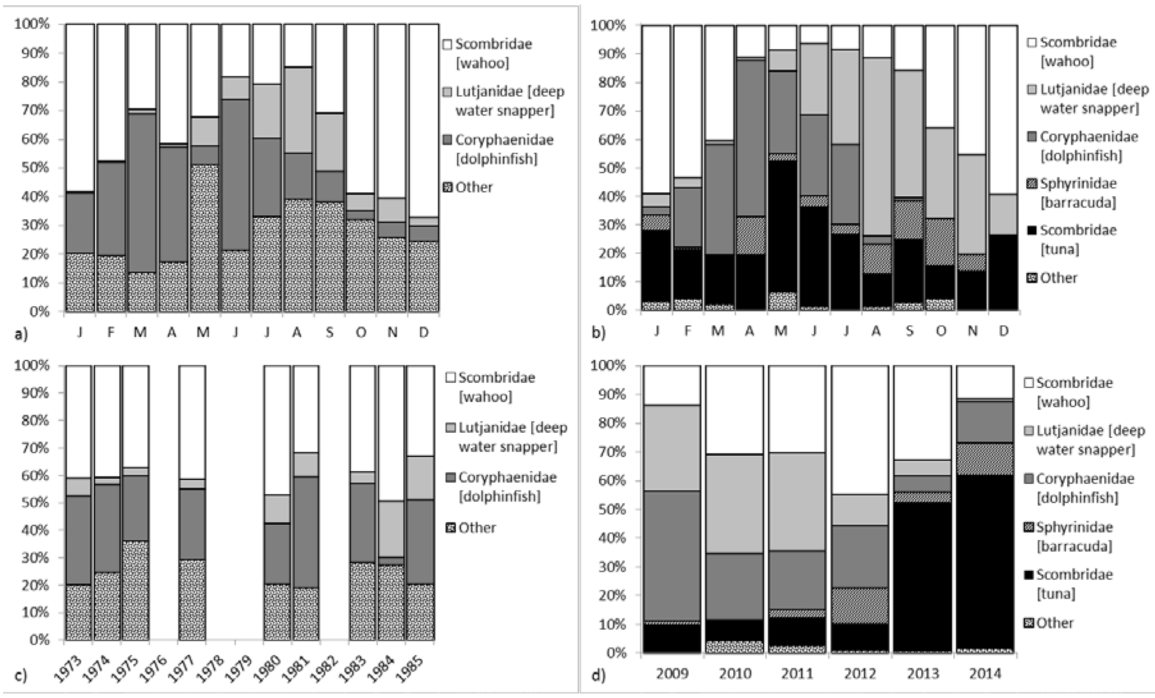


Fig. 4.5 *Seasonal and annual changes in species composition (biomass) of one big boat (a,c) in the period 1973-1985 (Leendertse & Verbeek, 1987) and one big boat (b,d) in the period 2009-2014 (note that for 2009 and 2014 only 6 months of data was available).*

In 1973-1985 and 2009-2014, the big boat catches were dominated by large pelagic fish species with deep-water snappers being the only significant group of demersal fish species being landed (Fig. 4.5). The species composition of the catch changed significantly over the seasons. Seasonal patterns appeared highly conservative and did not seem to differ between 1973-1985 and 2009-2014. Wahoo was most commonly observed in the months NOV-FEB, dolphinfish in MAR-JUN and deep water snapper in JUL-OCT. In the period 2009-2014, the big boat caught tuna species throughout the year without a clear seasonal pattern.

During 1973-1985 the species composition did not appear to change markedly across years. Wahoo (~40%) and dolphinfish (~30%) being the most important landed species each year (Fig. 4.5). Based on the 1983 species composition of second big boat (Fig. 4.6), tuna's most liked contributed two thirds to the "other" category of big boat (Fig. 4.5a,c) in 1973-1985. Between 2009 and 2014 the species composition of the one big boat appeared to have changed significantly, with a decrease in dolphinfish and an increase in especially tuna species and to a lesser extend an increase in the contribution of barracuda to the catches in later years (Fig. 4.5d).

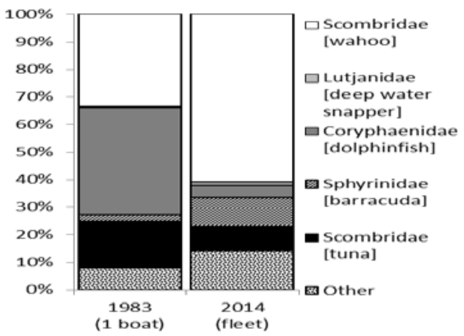


Fig. 4.6 *Catch composition (biomass) of one big boat in 1883 (Leendertse & Verbeek, 1987) and the big boat fleet in 2014.*

The species composition of the whole big boat fleet in 2014 (Figs. 3.8, 4.6) showed a sharp decrease in dolphinfish and an increase in barracuda compared to the 1970s and 1980s (Fig. 4.5) but wahoo remained the most commonly landed species. According to the fishers barracuda is a *"b-choice"* species which is usually targeted trolling close to the reef when large pelagic species such as wahoo, dolphinfish and tunas are unavailable. The length-based assessment model demonstrated that barracuda (Sphyraenidae) appeared to be at high risk, the stock biomass indicator was estimated to be low while fishing pressure was high.

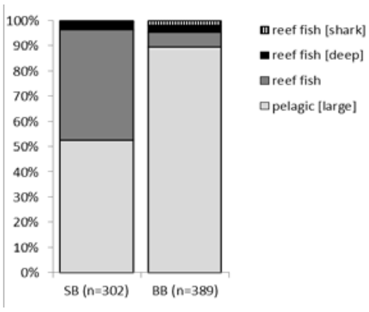


Fig. 4.7 *Species composition (excluding small pelagics) in weight of the boat-based coastal fishery on Curaçao in 2002-2003 (Source: LVV 2003, n = number fishing trips). SB = small boat, BB = big boat.*

The species composition (major groups) of the boat-based fisheries on Bonaire (2014; Figs. 3.8 & 4.4) and Curaçao (2002-2003; Fig. 4.7) appeared similar. Almost 90% of the big boat catch on Curaçao consisted of large pelagics with wahoo (48%), dolphinfish (21%) and blackfin and yellowfin tuna (12%) contributing the most in weight. The catch of the small boats consisted for ca. 50% (in weight) of large pelagic fish, lower than the ca. 85% observed on Bonaire. Wahoo (16%) and blackfin tuna (18%) were the most commonly landed species by small boats on Curaçao (LVV 2003). In recent years regulations on Bonaire have diverted fishing effort from the reef to the pelagic. Since 2010 fish traps are being phased out and a new permit system has been introduced for the use of nets.

Current status: The characteristics of the boat-based artisanal fishery on the west coast of Bonaire does not appear to give any reason for major concern. Both the SB and BB predominantly land large pelagic fish (ca. 90% of the catch weight), with wahoo and tunas being the most important species. Overall, catches appeared reasonable and similar to the few values reported for other boat-based coastal fisheries. Potential reasons for concern are the high fishing pressure on barracuda (SB and BB) and graysby (SB only) and the near absence of dolphinfish in the 2014 landings. In 2010 the harvest of sharks and rays was prohibited, in 2014 sharks were rarely observed in the landings (<1% in biomass) of the boat-based fishery.

Trends: The number of fishers, boats and daily boat activity appeared rather constant since the early 1900s. Major technological changes have been the transition from sail boats to motorised boats and the introduction of GPS and fish finders on most big boats. Fishing gears and methods have changed little, trolling lines are used to target large pelagic fish and handlines are used to catch demersal reef fish. The contribution of reef fish to the landings of the boat-based fishery has declined and both SB and BB mainly land large coastal pelagic species (ca. 90% of the catch in biomass). This change may at least partly have been the result by management (restricting the use of fish traps and nets) diverting SB fishing effort from the reef to the pelagic zone since 2010. According to Johnson and Jackson (2015) most fishers perceived catching fewer and smaller fish than previous generations and mentioned a reduction in catches of both large pelagic fish and reef fish. A reduction in catches of pelagic species was also mentioned by fishers in the early 1980s as reported by Leendertse & Verbeek (1987). The perceived reductions (Johnson & Jackson, 2015) in catch rate of large pelagic species by local fishers can, however, neither be supported nor dismissed by the limited amount of available fisheries statistics. Whether the observed increase in barracuda and decrease in dolphinfish is incidental or structural can only be determined if a basic fisheries monitoring is continued in the future.

4.1.3 Coral reef fisheries: boat-based and shore-based

Table 4.3 *Overview of reported yields (t/km2/year) of reef fisheries in tropical reef ecosystems.*

Area	Fishery	Landings ($t\ km^2\ year$)	Comments	Reference
Bonaire (leeward)	*Shore-based*	1.1	Reef fish only; reef 0-40m, 6.6km^2	This study
	Small boat	0.7		
	Big boat	0.3*		
	Total	2.1		
Hanalei Bay (Hawaii)	Shore-based, small boats	0.8	Reef fish only; reef 0-32m; 4.6km^2	Friedlander & Parrish 1997
Ofu & Olosega (American Samoa)	Shore-based, small boats	2.3	Reef fish only; reef 0-30m, 9.5km^2	Craig et al. 2008
Ono-i-Lau (Fiji)	Shore-based, small boats	2.9-3.7	Reef fish only; reef 0-40m, 20km^2	Kuster et al. 2005
Tulear Region (Madagascar)	Small boats	8.6	Reef fish only; reef 0-50m, 190km^2	Laroche & Ramananarivo, 1995
Pacific islands (43)	Shore-based, small boats	0.3 – 64 Mean = 7.7 Median = 3.9	May include mixture of reef fish, coastal pelagics and reef invertebrates	Dalzell & Adams, 1997
Philippines, Papua New Guinea	Shore-based, small boats	0.4-37 Mean = 15 Median = 14	Include small coastal pelagics (ca. 50%); small areas of active growing reef	Russ 1991 and references therein

**Corrected for BB fishing activity, ~30% on leeward site*

The contribution of reef fish to the total catch of the shore, small boat and big boat (~ca 30% fishing activity on west coast) fishery was used to estimate the total annual reef fish harvest (Table 3.1-3.3, Figs. 3.4, 3.8) along the west coast. In total ca. 13 t of reef fish were harvested in 2014, the estimate yield (t/km^2/year) of reef fish (excluding small and large inshore pelagic fish) of the different fisheries on Bonaire's sheltered west coast is presented in Table 4.4. The shore-based fishery harvested roughly the same amount of reef fish as the boat-based fishery (Table 4.5).

Newton et al. (2007 and references therein) reported coral reef fishery yields (fish, crustaceans, molluscs) ranging between 0.2-40 t/km^2/year with a median yield of 3 t/km^2/year. The reported high yields were often associated with small areas of actively growing coral. More importantly, the high yields were not necessarily sustainable and often resulted in drastic declines in reef fish biomass and shifts in fish assemblages (Birkland, 1997 and references therein). Laroche & Ramananarivo (1995) reported that the Tulear Region (Madagascar) was heavily fished (8.6 t/km^2/year) and fishers reported progressive decreases in fish size. Newton et al. (2007) mentioned a maximum sustainable yield of 5 t/km^2/year for reef fisheries (including reef fish, small and large inshore pelagic fish, crustaceans, and molluscs) and suggested a range between 1-10 t/km^2/year. Kuster et al. (2005) reported that the reefs of Ono-i-Lau (Fijian island) have sustained a yield of between 2.9 and 3.7 t/km^2/year of reef-associated fish (inclusive small and large inshore pelagic fish) over at least a 20-year period. Craig et al. (2008) concluded that the yield of 2.3 t/km^2/year observed in 2002 was sustainable despite the scarcity of large fish. Furthermore, the authors suggest that coral reef fisheries on these outer islands of American Samoa may have been sustainable for millennia based on archaeological excavations.

Compared to the yields reported for other reef fisheries (Table 4.4), it appears that current fishing pressure and resulting yield of ca. 2.1 t/km^2/year of reef fish could be interpreted as fully exploited. Comparing yields between studies remains, however, difficult based on the definition of "catch" (reef fish, invertebrates and/or small and large inshore pelagic fish) and the "area" (depth range and habitats).

Comparing Bonaire's biomass and harvest rates with those of other coral reef systems is another option to assess fishing pressure on Bonaire's reefs. Craig et al. (2008 and references therein) compared reef fish biomass (2.6 t/ha) of Ofuso-Olosega (American Samoa) with the reef fish biomass of 12 lightly fished (3 t/ha, range 1.2-4.6) and 12 fished reefs (1.1 t/ha, range 0.3-2.7) in the Pacific and concluded that the reef fish biomass of Ofuso-Olosega was more aligned with relatively unfished reefs, indicating moderate fishing pressure. Reef fish biomass of Bonaire's west coast reefs 1.1 t/ha and fishing pressure could possibly be considered as moderate but likely fully exploited (*see also section 4.2*).

The harvest rate of reef fish was 1-3% of standing stock on Ofuso-Olosega (Craig et al. 2008) and ca. 1.3% on a Hawaiian reef (Friedlander & Parrish, 1997). Both authors concluded fish stocks were not being severely overfished based on the small fraction of the overall standing stock that was harvested annually. Analysing the data at high taxonomic levels or even the whole reef fish community may, however, mask the fate of individual families or species in the fisheries.

Table 4.4 *Estimate of the fraction of standing stock (0-40m depth) of four key ecological fish families (Houtepen, 2016) and total reef fish landed by shore–based and boat-based on the sheltered west coast of Bonaire.*

Key Ecological Family	Annual landings shore-based fishery		Annual landings boat-based fishery		Combined Landings West Coast (kg)	Standing Stock West Coast (kg)	%
	Landings (%)	Landings (kg)	Landings (%)	Landings (kg)			
Parrotfishes	*1.7*	*200*	*<1*	*25*	*225*	*154250*	*0.2%*
Surgeonfishes	*0.1*	*12*	*<1*	*3*	*15*	*26620*	*0.1%*
Snappers	*13*	*1525*	*<5*	*1575*	*3100*	*74160*	*4%*
Groupers	*6.1*	*715*	*<2*	*610*	*1325*	*7460*	*18%*
Other reef fish	*40*	*4408*	*7*	*4287*	*8365*	*382590*	*2%*
Total reef fish	*60*	*6860*	*11*	*6500*	*13030*	*645080*	*2%*

In Table 4.4 an estimate is presented of the harvested fraction of the standing stock of four key ecological families and the whole reef fish community on Bonaire's west coast. Overall, roughly 2% of the standing stock is harvested annually. The harvest rate appears moderate, indicating that the current exploitation may be sustainable but that the stocks are likely fully exploited. Annual harvest rates varied, however, significantly between the four key ecological families. Only a small fraction (<0.2%) of the standing stock of the herbivorous parrotfishes (Scaridae) and surgeonfishes (Acanthuridae) were harvested. This is a positive characteristic of the fishery as these herbivorous fish families play a key role in maintaining the health of coral reef ecosystems. One of the possible drivers of the phase-shift in Caribbean coral reef ecosystems in the last 40 odd years from coral-dominated to macro-algae dominated reef systems is the decline of herbivorous fish such as parrotfishes and surgeonfishes due to overfishing (Jackson et al., 2014 and references therein). Like in most of the Caribbean, groupers and snappers have been the main target species of the coral reef fisheries on Bonaire (Fig. 4.8).

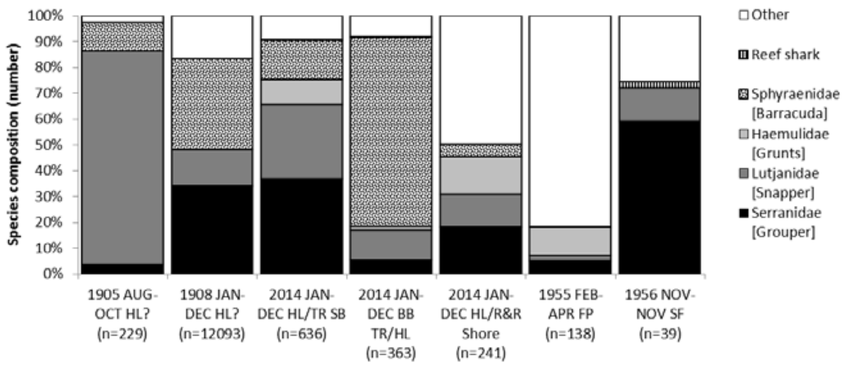


Fig. 4.8 *Species composition (in number) of demersal reef fish and sharks landed by different types of fishing gear between 1905 and 2014. HL = handline, TR = trolling, R&R = rod and reel, FP = fish pot, SF = spear fishing, BB = big boat, SB = small boat, shore = shore fishing and n = number of fish.*

Grouper species like the Nassau Grouper (*Epinephelus striatus*) and Goliath Grouper (*Epinephelus itajara*) used to be relatively abundant throughout their distributional range in the Caribbean and were of particular interest to both commercial and recreational fishers. These slow-growing, late-maturing reef fish are vulnerable to fishing pressure. Intensive commercial fishing since the 1960s and 1970s on spawning aggregations and recreational spear-fishing are most likely the cause for the dramatic decline of these iconic reef fish (Sadovy & Eklund 1999). On Bonaire, large groupers (see historical photographs of Goliath grouper and Fig 4.8) were targeted by the spear-fishers in the 1950s and 1960s. In order to protect these vulnerable large grouper, spear-fishing was banned in 1971 on Bonaire.

In 2014 the harvest rate of snappers was 4% of the standing stock. This is low compared to the harvest rate of groupers which was 18% of the standing stock. Groupers experienced high fishing pressure on the west coast of Bonaire. In addition to the observed high harvest rate, the length-based assessment model suggested that the small grouper species graysby (Serranidae) is at high risk, as for this species the stock biomass indicator was estimated to be low, while fishing pressure is high. Furthermore, the Bonairian fishers interviewed by Johnson and Jackson (2015) mentioned a reduction in catches of reef fish especially groupers like coney and Nassau grouper. Fish surveys over the past 15 years have shown that biomass of groupers is only marginally higher than the Caribbean average. The 2014 sDOV survey demonstrated that on Bonaire's west coast there is a low contribution of large groupers to grouper biomass, a characteristic for highly fished areas with limited management and protection (*see Fig. 4.10*; Chiappone et al., 2000).

The reef fish species composition in the catches of the BB consisted predominantly of barracuda in 2014 (ca. 70% in number; ca. 90% in weight). Barracuda appears to have always been a significant part of the reef fish harvested by the boat-based fishery (Fig. 4.8). Between 2009 and 2014 the species composition of one big boat appeared to have changed significantly, with a decrease in dolphinfish and an increase in especially tuna species and to a lesser extent an increase in the contribution of barracuda to the catches in later years. The increase of barracuda, a “b-choice” species for a fishery targeting large pelagic species, is potentially a reason for concern if it persists. The length-based assessment model (*see*

3.1.3) demonstrated that barracuda appeared to be at high risk, with an estimated low stock biomass and a high fishing pressure.

The estimated harvest of ca. 13 t of reef fish in 2014 had a value of ca. 91 000 USD assuming 7 USD/kg as in Schep et al. (2012). This is considerably lower than the value of the catch of reef-related species of ca. 1 million USD presented by Schep et al. (2012). The value of ca. 1 million USD would translate into an annual catch of ca. 140 t of reef fish. To collect data on fishing participation, assessing attitudes or awareness and/or socioeconomic and demographic profiling of recreational fishers, phone or mail recall surveys are straightforward, easy to administer and relatively cost-effective. However, if detailed information on effort, catch and/or economic activity is required, recall surveys such as used by Schep et al. (2012) are of limited applicability due to the impacts of recall bias, non-response bias, digit preference and/or prestige bias (see Hammen et al. 2015 and references therein).

Current status: Reef fish were landed by both the shore-based and boat-based fisheries. In total ca. 13 t of reef was harvested from the sheltered leeward side of Bonaire by shore fishers (ca. 50%), SB (ca. 35%) and BB (ca. 15%). The yield (2.1 t/km^2/year) was similar to values reported for other coral reef ecosystems and indicated that the status of the reef fish fisheries can be considered as fully exploited. The overall harvest of reef fish was ca. 5% of the standing stock, which appears moderate but differed significantly between fish families. Around 18% of the grouper standing stock on the sheltered leeward side of Bonaire was harvested, which indicated a high, probably unsustainable fishing pressure. The undesirable status of groupers was further demonstrated by the low biomass and high fishing pressure of the graysby, a small grouper species, as indicated by the length-based assessment model. A second reason for concern was the considerable contribution of barracuda to the reef fish catch of especially the BB. More than 90% of the biomass of landed reef fish by the BB consisted of barracuda. The length-based assessment model indicated barracuda to be at risk with low biomass and high fishing pressure.

Trends: Due to a complete lack of historical records of the shore-based fishery it is impossible to quantify positive or negative trends related to changes that may have occurred over time in catch, effort and species composition. The effort of boat-based fishers (number of fishers, boats and daily boat activity) seems to have remained rather similar since the early 1900s. The overall contribution of reef fish to the landings of boat-based fishers appeared to have declined since the early 1900s in favour of large, pelagic fish species. Groupers, snappers and barracuda have been the main target species of the boat-based reef fisheries over the past century. The contribution of large grouper species has declined over at least the last 40 years despite the ban on spearfishing in the early 1970s. The decline of certain grouper species (e.g. Nassau grouper, coney) was also reported by Bonairian fishers interviewed by Johnson and Jackson (2015).

4.2 Status and trends reef fish

On the sheltered West Coast the average biomass of the fish assemblage was 10.3 kg/100m^2 . However, there were significant differences among reef zones. The biomass increased with depth from 7.3 kg/100m^2 in the shallows (zone 1) to 13.2 kg in the upper reef slope (zone 4). On the exposed East Coast the average biomass of the fish assemblage was 8.0 kg/100m^2 ranging from 5.3 (zone 5) to 10.1 (zone 6) kg/100m^2. Because of the differences in reef fish measures (e.g. biomass, abundance, trophic groups etc) betweenamong reef zones, care has to be taken when comparing fish assemblage characteristics with other fish surveys. Sandin et al (2008a) conducted fish surveys on five sites along the upper reef slope (18m) on the sheltered West coast and one site on the exposed East coast of Bonaire. Fish biomasses of 10-15 kg/100m^2, dominated by planktivores, reported by Sandin et al (2008a) were similar to our observations of zone 4 along the sheltered West coast. Overall, the fish biomass along the deeper reef zones of Bonaire's coral reef ecosystem appeared relatively high compared to 27 other sites in the Caribbean (range 0.15-59 kg/100m^2 with 9 sites (mainly marine reserves) higher than Bonaire; Newman et al. 2006). The fish biomass in the shallow areas of Bonaire's coral reef ecosystem, on the other hand, is comparable to 23 other Caribbean reef systems (0.14-26.3 kg/100m^2 with 13 sites (mainly marine reserves) higher than Bonaire; Newman et al. (2006). The near absence of apex predators like sharks (*see* 4.2.5) and large grouper species (*see* 4.1.3 and 4.2.4) remains, however, a reason for concern. Environment, habitat and management regimes impact fish assemblage characteristics and are described in more detail in the section below.

4.2.1 Wave exposure

In Hawaii, the fish community structure of exposed reefs were characterised by lower abundance, biomass, species richness and diversity compared to sheltered sites (Friedlander and Parrish 1998; Friedlander et al. 2003). This difference was attributed to physical conditions and low habitat complexity of exposed sites compared to sheltered sites. A study of the three island groups differing in wave exposure and waterflow suggested that exposed areas were characterised by lower habitat complexity consisting of encrusting calcareous algae and macro-algae and a fish assemblage characterised by mid-water planktivores and piscivores (Floeter et al. (2007).

On Bonaire, habitat complexity did not differ significantly among transects on the sheltered West coast and exposed East coast. However, for safety reasons the shallow reef zone (<4m depth) on the exposed East coast was not surveyed. Along both coasts lines, habitat complexity did increase with depth across the reef zones. Fish abundance was higher on the sheltered West Coast. Species richness did not differ but the diversity (Shannon Index) was significantly higher on the exposed East coast. With regards to the four ecological key families, snapper biomass was higher on the sheltered West coast while on the exposed East Coast grouper and surgeonfish were more commonly observed. Differences in coral reef fish assemblages between exposed and sheltered sites appeared less pronounced compared to the impact of physical disturbance reported for Hawaiian (Friedlander and Parrish 1998; Friedlander et al. 2003) and Brazilian reef fish (Floeter et al., 2007). Furthermore, some of the observed differences, such as the higher presence of (large) groupers on the exposed East coast are likely due to lower fishing pressure than to differences in water movement.

4.2.2 Habitat zones

The habitat zones of Bonaire's fringing reef differed markedly in wave exposure, water depth, water flow, distance to shore and structural complexity. The zonation of the fringing reef is rather homogeneous along the whole shore line with all factors except wave exposure increasing across the habitat zone from shallow to deeper waters. Reef geomorphology is a key factor in structuring reef fish assemblages with a strong positive correlation between habitat complexity and reef fish measures such as abundance, biomass, length, species richness and diversity (Friedlander & Parrish 1998; van Looijengoed 2013; Stoffers 2014, van Kuijk et al 2015; Newman et al. 2015).

Similar patterns were observed on Bonaire's fringing reef where habitat complexity increased across habitat zones from shallow to deeper waters and the reef fish assemblages differed significantly with respect to biomass, abundance, species richness and functional groups. On the sheltered West Coast, abundance (~170 to 430 fish / 100m^2) and biomass (~7.3-13.2 kg/100m^2) increased across the four habitat (depth) zones, species richness also increased across the habitat zones (10 species /50m^2 in zone 1) but peaked in zone 3 (drop-off zone; 16 species / 50m^2) at the top of the reef slope. Similar patterns were observed across the habitat zones on the East coast although the patterns were less pronounced, most likely due to the less stringent zonation of the coral reef compared to the West coast.

The composition of the fish assemblages with regards to functional groups also changed markedly across the habitat zones. Herbivores, including the key ecological Scaridae and Acanthuridae families, decreased across the habitat zones from shallow (~70%) to deeper waters (~20%). Similar negative correlations between depth and herbivore densities have been reported for other coral reefs (Friedlander & Parrish 1998; Newman et al. 2006; Nemeth & Appeldoorn 2009). Within a depth zone, however, herbivore density is positively correlated with habitat complexity (Friedlander & Parrish 1998; Stoffers 2014; van Kuijk et al 2015). Piscivores, including the key ecological Serranidae and Lutjanidae families, increased across the habitat zones from shallow (<5%) to deeper waters (~20%). Van Kuijk et al (2015) demonstrated that with a depth zone, demersal piscivores like Serranidae were positively correlated with habitat complexity. Within the piscivores, sedentary species like Serranidae and more mobile, transient species like Carangidae are often combined, masking potential correlations with habitat characteristic. Friedlander & Parrisch (1998) mentioned that transient piscivores were usually observed along reef sloped but demonstrated limited correlations with habitat characteristics.

The contribution of small planktivores to the total biomass increased across the habitat zones from <5% in the shallows to ~30% (~4.5 kg/100m^2) along the reef slope. Sandin et al (2008a) recorded even higher contributions of nearly 50% of small planktivores (~8 kg/100 m^2) to the total fish biomass along the reef slopes of Bonaire. The planktivore biomass along Bonaire's reef slopes was 10-15 times higher than the reported average planktivore biomass of ~0.5 kg/100m^2 for 27 surveyed deep sites (15m) throughout the Caribbean (Newman et al., 2006). It is unclear if high biomasses of small planktivorous fish are a sign of a disturbed ecosystem. Sandin et al (2008b) demonstrated that in the Northern Line Islands degraded reefs were characterised by high contributions of small planktivorous fish to total fish abundance. A high concentration of nutrients by upwelling or due to human impacts could possibly increase fish production, especially planktivores (Sandin et al. 2008b and reference therein). Recent observations do indicate possible problems with water quality (eutrophication; *see section 4.3.2*) on Bonaire's coral reefs, unfortunately no historical fish surveys of small planktivous fish are available in order to determine a trend over the past few decades. On the other hand, small, schooling planktivores are known to aggregate along reef edges (Hobson 1991) and the majority of the Newman et al. (2006) surveys throughout the Caribbean were conducted on reef terraces (Sandin et al. 2008), providing an alternative explanation for observed differences in planktivorous biomass.

4.2.3 Management zone

In general, the effect of habitat zone on reef fish assemblages along Bonaire's sheltered West coast was significantly more pronounced than the effect of management zone. Habitat complexity (habitat zones pooled) did not differ significantly among the four management zones, although habitat complexity of the "No Fishing" zone tended to be lower than the other three zones (General Use, Klein Bonaire and No Diving). Within each habitat zone, habitat complexity did differ significantly between some management zones. Most notably, habitat complexity in the "No fishing" zone was lower in the shallow habitat zones 1 and 2 (Fig. 3.11)

Overall (all habitat zones pooled), fish biomass and species richness were similar across the four management zones. "Klein Bonaire" had the highest abundance of fish (ca. 400 fish / 100 m^2) and the "No Diving" zone demonstrated a higher species diversity compared to the other management zones. Within each habitat zone, again few differences were found between the management zones. In the shallow habitat zone 1 the “No Diving” fish biomass appeared higher than the other management zones (Fig. 3.16; *see A*ppendix 8.4).

Parrotfish and surgeonfish were less common in the “No Fishing” zone. As discussed in section *4.2.2*, herbivores like parrotfish and surgeonfish are most abundant in the shallow habitat zones and within a depth zone densities are strongly correlated to habitat complexity (Friedlander & Parrish 1998; van Kuijk et al. 2015). The poor habitat quality (low structural complexity) in the shallow habitat zones in the “No Fishing” zone is the most likely explanation for the low occurrence of parrotfish and surgeonfish. The good habitat quality in the shallow habitat zones of the “No Diving” zone is also the most likely explanation for the higher fish biomass (especially parrotfishes).

Hardly any of the expected differences in fish measures (i.e. larger fish size, higher biomass of commercial species) were observed in the “No Fishing” zone compared to the other management zones. However, there was a higher contribution of apex predators to the fish assemblage along the reef slope (habitat zone 4) in the “No Fishing” zone. This does not mean, however, that the establishment of the “No Fishing” zone has been an ineffective. It is of utmost importance that the design of the current survey is not suitable to determine whether or not the “No fishing zone” is effective. In order to determine the effect of management zoning such as a “No Fishing” zone, a BACI (before, after, control, impact) survey design is preferred following changes in the fish assemblages in the “No Fishing” zone and control sites over time. Steneck et al. (2015) demonstrated that mesopredators such as small grouper species (graysby, coney) that experience high fishing pressure (*see section 4.1.3*) showed a relative increase (i.e. comparing sites in the General Use zone and No Fishing zone) since the establishment of the “No Fishing” zones in 2008.

4.2.4 Key ecological families

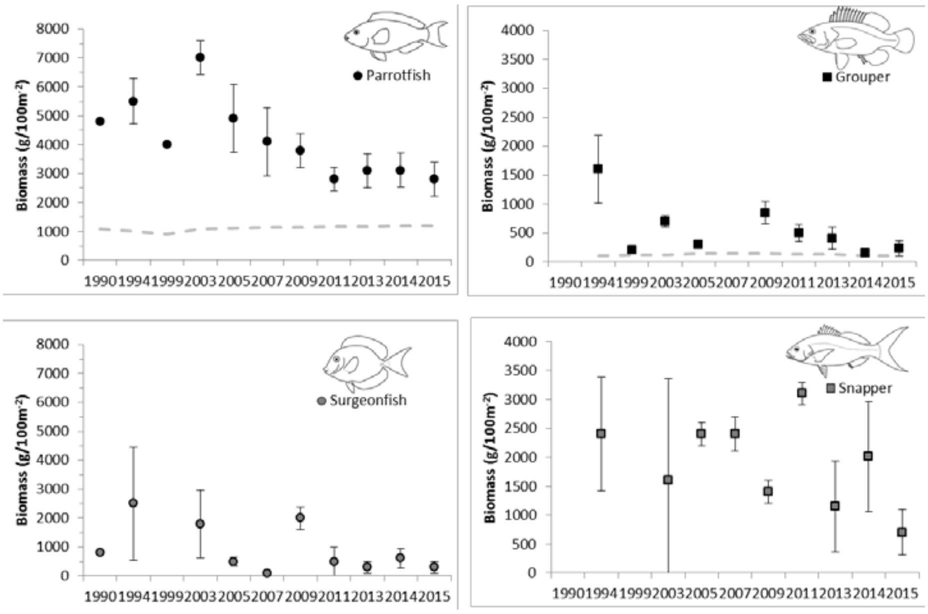


Figure 4.9 *Average biomass of parrotfishes, surgeonfish, groupers and snappers on Bonaire. The grey dotted lines represent the average value for the Caribbean (Jackson et al. 2014). Error bars are 95% CI. Redrawn from van Rooij et al 1998, Hawkins & Roberts 2004, Steneck et al. 2003, 2009, 2013, 2015; Jackson et al. 2014 and references therein; and this study (2014).*

Parrotfishes: The status of parrotfishes is reasonable to good: the biomass of parrotfish appeared higher than the mean biomass observed on coral reefs in the Wider Caribbean Region (Jackson et al., 2014) for the past 25 years. However, parrotfish were in decline between 2003 and 2011 but the decline seems to have stabilized since 2011.

Surgeonfishes: The status of surgeonfishes is good: the mean biomass of surgeonfishes appeared higher than the mean biomass observed on mid-depth (10-15m) reefs in the Caribbean (90-490 g/100m^2, Williams & Polunin 2001; 200-600 g/100m^2, Nemeth & Appeldoorn, 2009) without any obvious trends over time.

Snapper: The status of snappers appears good: the indicator for commercial fish biomass is “good” (see 4.3.2) with snapper biomass contributing >90% to commercial fish biomass. No obvious trends were observed over the past 25 years. Unfortunately Jackson et al. (2014) does not provide a trend in average snapper biomass for the Caribbean.

Grouper: The status of groupers is poor to reasonable at best based comparison of biomass with the Caribbean region (Jackson et al., 2014) and the low contribution of large groupers to total grouper biomass. Since the early 1990s, the biomass of groupers appeared marginally higher than the mean biomass observed on coral reefs in the Wider Caribbean Region (Jackson et al., 2014). However, the grouper species composition in 2015 was dominated by small-sized species such as coney and graysby. (*see Fig. 4.10*). The lack of large grouper species is an undesirable situation. The composition (biomass) of grouper assemblage on the West Coast of Bonaire was similar to the Florida Keys, an area characterised by “heavy fishing pressure and high management”. On the other hand, the grouper assemblage on the East of Bonaire was similar to the Southern Exuma Cays, an area of “low fishing pressure and moderate management” (Chiaponne et al., 2000).

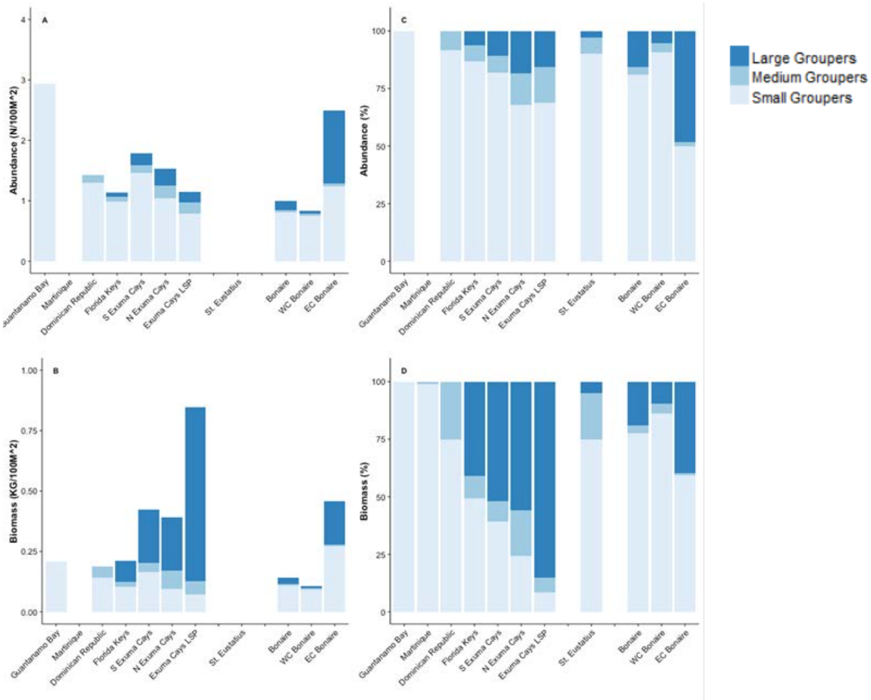


Figure 4.10 *Composition (number, top graphs; biomass bottom graphs) of grouper assemblages in Guantanamo Bay Naval Base, south-eastern Cuba (GTMO), southeastern Dominican Republic (DR), Florida Keys, Southern and Northern Exumas, and the Exuma Cays Land and Sea Park (ECLSP) (redrawn from Chiappone et al., 2000), St Eustatius (de Graaf et al. 2015) compared with Bonaire. From GTMO to ECLSP fishing pressure decreased and management and protection increased.*

4.2.5 Sharks

Sharks were not observed in any of the sDOV transects during the 2014 fish survey. Sandin et al. (2008a) conducted underwater visual surveys on six sites on Bonaire and reported that just a small part of fish biomass was composed of apex predators (sharks, large snappers, groupers and moray eels) and that this was mainly caused by the absence of sharks. No quantifiable historical information is available on the presence of reef-associated sharks on Bonaire. The decline of reef-associated sharks is a pattern observed throughout the most of the Caribbean based on ~77 000 underwater surveys (roving diver technique) (Ward-Paige et al. 2010). These authors also mentioned that sharks other than nurse sharks were largely absent throughout most of the Antilles in the period 1993-2008, despite the observation that around the 1880s sharks were ''*one of the most common types of fish*'' throughout the Leeward Antilles (Watkins, 1924).

In 1908 sharks only formed a minor part of the recorded landings both in number and biomass (<2%, Fig. 4.3). A ban on the harvest of sharks in the waters around Bonaire has been implemented since 2010. During this study no sharks were observed in the shore-based coastal fishery (Fig. 3.4). A few reef sharks were observed being landed by the boat-based coastal fishery (Fig. 4.11) but as expected sharks contributed <0.2% (both in number and biomass, Fig. 3.8) to the landings.

Fig. 4.11 *Examples of landed sharks observed during the 2014 survey of the boat-based fishery on Bonaire.*

Recently a shark protection plan was drafted for the Dutch Caribbean (van Beek et al. 2012, 2014) and in September 2015 the EEZ waters around two of the Caribbean Netherlands islands (Saba and Bonaire) were declared shark sanctuaries by the Dutch Ministry of Economic Affairs and local island governments. The first step towards effective protection is to conduct a base-line survey to assess the current status with regards to elasmobranch diversity, distribution, abundance and population.

Baited Remote Underwater Video (BRUV; Fig. 4.12) is a method to study species richness, relative abundance and accurate length frequency distribution of large mobile fish species such as sharks that are difficult to sample with traditional fish survey techniques such as underwater visual survey (UVC). More importantly, compared to conventional longline surveys, BRUV surveys are a non-invasive method to study shark assemblages across broad spatial scales (Bond et al., 2012; Brooks et al., 2011; White et al, 2013; Espinoza et al., 2014).

Fig. 4.12. *Example EventMeasure software (left), a BRUV deployed on an inshore reef (middle), and a tiger shark (*Galeocerdo cuvier*) recorded during the BRUV survey on the Saba Bank (right).*

BRUV surveys been conducted between 2010-2015 on St Eustatius, Saba, Saba Bank and St Maarten and are planned for Curaçao (2016) and Bonaire (2016 and 2017). The standardized BRUV base-line survey will serve as a reference point to evaluate the performance of management actions on the status of reef sharks on Bonaire.

4.3 Status and trends reef health indicators

4.3.1 Coral and macroalgal cover

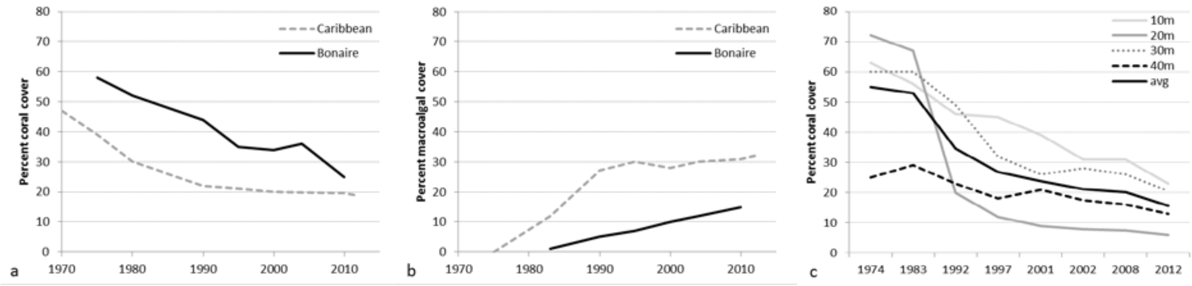


Fig 4.13 *Mean percentage cover of live corals (a) and macroalgae (b) on Bonaire (black line) and for the Caribbean (grey dotted line). Redrawn from Jackson et al. (2014 and references therein). Changes in percentage coral cover at 10, 20, 30, 40m depth and overall mean (black line) at Karpata (c). Rredrawn from www.dcbd.nl).*

Coral cover: The mean coral cover in the Caribbean has declined sharply since the 1970s but appeared to remain more or less stable since 1999 (Jackson et al. 2014). The status of coral cover on Bonaire is reasonable at most because although coral cover is high (Fig. 4.13.a) compared to average coral cover in the Wider Caribbean Region (Jackson et al. 2014), the long-term declining trend in coral cover appears to gradually continue even after 1999. Coral cover (Fig. 4.13c) in the permanent quadrats (3x3m, one at each depth) declined across all depths at Karpata since the 1970s from ~50%to ~20%. Differences were observed between the depth zones with the steepest decline observed at 20m (~70% to <10%) while at 40m coral cover decreased from ~25% to 15%.

Macro-algal cover: The status of macro-algal cover on Bonaire is at most reasonable: macro-algal cover is lower (Fig. 4.13b) than the average macro-algal cover in the Wider Caribbean Region (Jackson et al. 2014), but the overall long-term trend demonstrates an increase in macro-algal cover. Notably, a sharp increase was observed after the 2010 bleaching event. Unlike many other areas in the Caribbean though, the coral reef of Bonaire is not dominated yet by macro-algae.

4.3.2 Reef health index

The Reef Health Index was developed by the Healthy Reef Initiative (Kramer, 2003; McField & Kramer, 2007; Healthy Reef Initiative, 2008; www.healthyreef.org) and the description of the four key reef health indicators is given by Kramer et al. (2015).

The Reef Health Index (RHI) is based on four key coral reef health indicators:

- Coral cover - the proportion of benthic surface covered by live stony corals, contributors to the three-dimensional framework
- Fleshy macroalgae cover – the proportion of benthic surface cover by fleshy macroalgae, an increase in macroalgae limits stony coral recruitment and recovery
- Herbivorous fish – a measure of biomass of herbivorous reef fish (e.g. parrotfish and surgeonfish), these grazing species play a major role in controlling (macro)algae that could overgrow coral reefs
- Commercial fish – a measure of biomass of reef fish (e.g. groupers and snappers) with commercial importance to people

The mean values of the indicators (Table 4.6) are compared to the criteria listed in Table 4.5. The indicators are given a grade from one (‘critical’) to five (‘very good’). The four grades are combined and equally weighted to obtain a RHI score. An overall score of 1-1.8 is “critical, >1.8-2.6 is “poor”, >2.6-3.4 is “fair”, >3.4-4.2 is “good” and >4.2-5 is “very good”.

In 2015 the two indicators for health of the benthic community scored “fair” for coral cover and “fair” for macro-algae cover. Coral cover continued to decline from “very good” in the 1970s to “good” in the 2000s to “fair” in recent years (Erik Meesters, pers. comm.). On the other hand, the indicator for macro-algal cover has been declining from “very good” in the 1980s to “good” in the 2000s with a rapid decline to “poor” after bleaching events in 2010. In the last few years some recovery has taken place and the macro-algal indicator increased to “fair” in 2015.

The biomass of key commercial fish has remained more or less stable over the past 25 years fluctuating between “good” and “very good” but only scored “fair” in 2015. Predominantly snapper contributes to the commercial fish biomass indicator (Fig. 4.8). The key commercial fish indicator only considers total biomass of grouper (and snapper) but does not take into account the species composition over small, intermediate and large grouper species (*see Fig. 4.9*). The low biomass of large grouper species on especially the West Coast of Bonaire is an “undesirable” status regardless of the overall grouper biomass. The biomass of key herbivorous fish remained stable at “very good” since the 1990s.

Table 4.5 *Overview of the criteria for the four key coral reef health indicators (Source Kramer et al., 2015).*

REEF HEALTH INDEX (RHI)					
Indicators	*Very good (5)*	*Good (4)*	*Fair (3)*	*Poor (2)*	*Critical (1)*
Coral Cover (%)	*≥40*	*20.0-39.9*	*10.0-19.9*	*5.0-9.9*	*<5*
Fleshy Macro-algae Cover (%)	*0-0.9*	*1.0-5.0*	*5.1-12.0*	*12.1-25*	*>25*
Key Herbivorous Fish (g/100m^2) (only parrotfish and surgeonfish)	*≥3480*	*2880-3479*	*1920-2879*	*960-1919*	*<960*
Key Commercial Fish (g/100m^2) (only snapper and grouper)	*≥1680*	*1260-1679*	*840-1259*	*420-839*	*<420*

Table 4.6 *Overview of changes in roughly estimated Reef Health Index scores for Bonaire based on data from van Rooij et al. (1998), Hawkins et al. 1999, Steneck et al. (2003), Jackson et al (2014), Steneck et al. (2015), Erik Meesters (pers. comm. coral cover 2015) and current study.*

REEF HEALTH INDEX (RHI)							
Indicators	**1970s**	**1980s**	**1990s**	**2000s**	**2010s**		**2015**
Coral Cover (%)							
Fleshy Macro-algae Cover (%)							
Key Herbivorous Fish (g/100m^2) *(only parrotfish and surgeonfish)*							
Key Commercial Fish (g/100m^2) *(only snapper and grouper)*							
RHI Score							

Mainly due to the decline in coral cover and increase in macro-algae cover the overall RHI score was only “fair” in 2015. The long term trend in declining coral cover and increasing macro-algae cover is a reason for concern. Recent observations indicate possible problems with water quality (eutrophication) on Bonaire’s coral reefs: a) enhanced concentrations of nutrients (Slijkerman et al. 2014; Meesters, pers communication), b) high prevalence of dermal parasites on reef fish near Kralendijk and Cargill salt works (de Graaf & Simal, 2015), and c) the presence of large mats of deep-water (>50m) cyanobacteria (Meesters, pers. communication).

In addition to improving water quality issues to prevent a further the decline of the overall health of the coral reef ecosystems, restoring structural complexity to the shallow reef zones impacted by the die off of *Acropora* species might improve reef health. Coral restoration projects are currently on-going on Bonaire in an attempt to assist the recovery of highly structurally complex frame-work coral species such as elkhorn coral (*Acropora palmata*) and staghorn coral (*Acropora cervicornis*) in the shallow inshore reef zones. These initiatives could probably be supported heavy duty artificial reefs. Unlike farmed live stony coral, artificial reefs can be quickly manufactured and placed on the reef. In due time artificial structures could be replaced by live stony corals if required.

4.4 Management, international obligations and long-term monitoring

A long-term continuation of different standardized surveys will provide the basic information regarding status and trends of key coral reef and fisheries indicators required to fulfil international reporting obligations but more importantly to evaluate adaptive management by responsible island and Dutch authorities (Tables 4.7 and 4.8). Healthy coral reef ecosystems and sustainable fisheries are of key importance for the economy of Bonaire. To ensure sustainable management of the natural resources firstly, a transparent and realistic management plan with clearly defined quantifiable objectives, targets and reference points of fisheries and coral reef health indicators will need to be developed. Secondly, a continuous robust and standardised monitoring programme of indicators will need to be put in place to evaluate to performance and progress of management actions. Thirdly, a transparent decision framework with respect to conservation, coastal development, environmental and fisheries management strategies with active participation of all relevant stakeholders will need to be developed. The current evaluation of status and trends of especially the coral reef and coastal pelagic fisheries was seriously hampered by the lack of basic, robust standardized historical surveys.

Table 4.7 *Overview of local, national and international treaties and conventions and reporting obligations for Bonaire with regards to coral reef fisheries and coral reef ecosystems.*

Treaty, Convention, Organisation	**Species/habitats**	**Survey (Table 4.9)**
Openbaar Lichaam, STINAPA; Ministry of Economic Affairs	Status and trends of reef health, fisheries and elasmobranch indicators to evaluate performance of adaptive management	1,2,3
Food and Agricultural Organisation (FAO)	status and trend landings spiny lobster, conch and mixed reef fish; status and trend fishing effort	1
Convention of Biological Diversity (CBD) [Specially Protected Areas and Wildlife (SPAW)]	status and trends whales and dolphins (*see 2.3 Landing survey*); status and quality coral reef ecosystem.	1,2
Convention on the Conservation of Migratory Species of wild animals (CMS)	status and trends population and distribution sharks	3
International Commission for the Conservation of Atlantic Tunas (ICCAT); note that NL/Bonaire is not a member at present	status and trend catch and effort ICCAT listed fish species (e.g. tuna's, marlin, sharks)	1
International Coral Reef Initiative (ICRI) and its Global Coral Reef Monitoring Network (GCRMN)	status and trends of coral reefs	2

Table 4.8 *Overview of recommended monitoring programme of key coral reef and fisheries indicators to enable local adaptive management and fulfil international reporting obligations.*

Survey	Method	Indicator	Frequency
1	Fishery survey	status and trend catch and effort coral reef fish and coastal pelagic fishery	Annual, continuous
2	GCRMN survey	status and trend key reef indicators; coral cover, macro-algae cover, coral recruitment, coral disease, biomass herbivore and commercial fish, macroinvertebrates, water quality	Annual, FEB-MAR (water quality continuous)
3	sBRUV survey	Status and trend distribution and abundance sharks & rays (and reef fish)	Every 3-5 years.

5. Recommendations

It is recommended to:

a) develop a management plan with clearly defined indicator and quantifiable objectives, targets and reference points with regards to coral reef health, elasmobranchs and sustainable fisheries,
b) continue standardised monitoring of coral reef health, elasmobranch and fisheries indicators; develop and implement a standardised monitoring of water quality and,
c) report results regularly to evaluate the performance of implemented management by comparing the status of the indicators against the quantified targets, objectives and reference points to facilitate adaptive management.
d) enhance the recovery of structural complexity to the shallow reef areas affected by the die-off of frame-work coral species such as elkhorn coral (*Acropora palmata*) and staghorn coral (*Acropora cervicornis*) by coral restoration and (temporary) artificial reefs to improve reef fish biomass.

It is desirable to implement adaptive legislation and regulations to:

a) improve water quality to prevent a further decline of the health of the reef
b) reduce fishing mortality of large grouper and snapper species to as close to zero as possible to enhance the recovery of these apex predators; release large grouper and snappers immediately after capture
c) reduce fishing pressure on small grouper species and barracuda if high fishing persists
d) to prevent a further increase in fishing effort on reef ecosystem

6. Acknowledgements

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7. Quality Assurance

Wageningen Marine Research utilises an ISO 9001:2008 certified quality management system (certificate number: 187378-2015-AQ-NLD-RvA). This certificate is valid until 15 September 2018. The organisation has been certified since 27 February 2001. The certification was issued by DNV Certification B.V.

Furthermore, the chemical laboratory at IJmuiden has NEN-EN-ISO/IEC 17025:2005 accreditation for test laboratories with number L097. This accreditation is valid until 1th of April 2017 and was first issued on 27 March 1997. Accreditation was granted by the Council for Accreditation. The chemical laboratory at IJmuiden has thus demonstrated its ability to provide valid results according a technically competent manner and to work according to the ISO 17025 standard. The scope (L097) of de accredited analytical methods can be found at the website of the Council for Accreditation (www.rva.nl).

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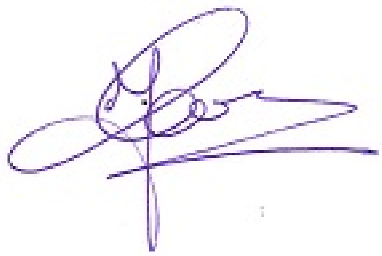
Justification

Rapport 087/16
Project Number: 4316810008

The scientific quality of this report has been peer reviewed by the a colleague scientist and the head of the department of Wageningen Marine Research.

Approved: Dr. JanJaap Poos
Researcher

Signature:



Date: 14th of October 2016

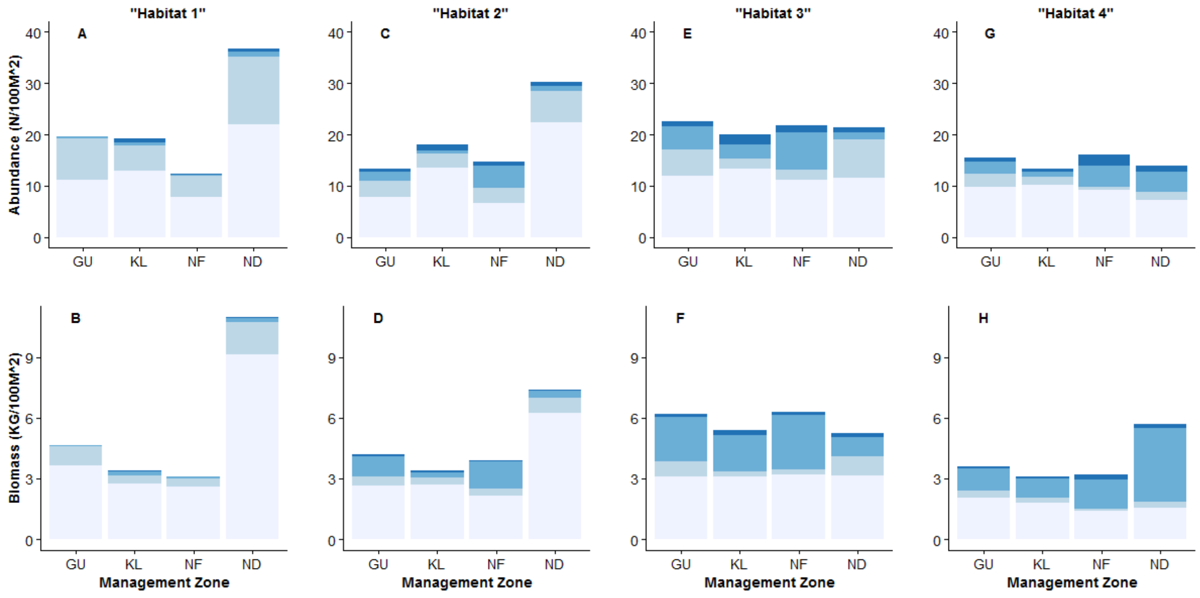
Approved: Drs. J. Asjes
MT member Integration

Signature:

Date: 14th of October 2016

8. Appendix

Appendix 8.1: Abundance and biomass Key Ecological Families per Management Zone

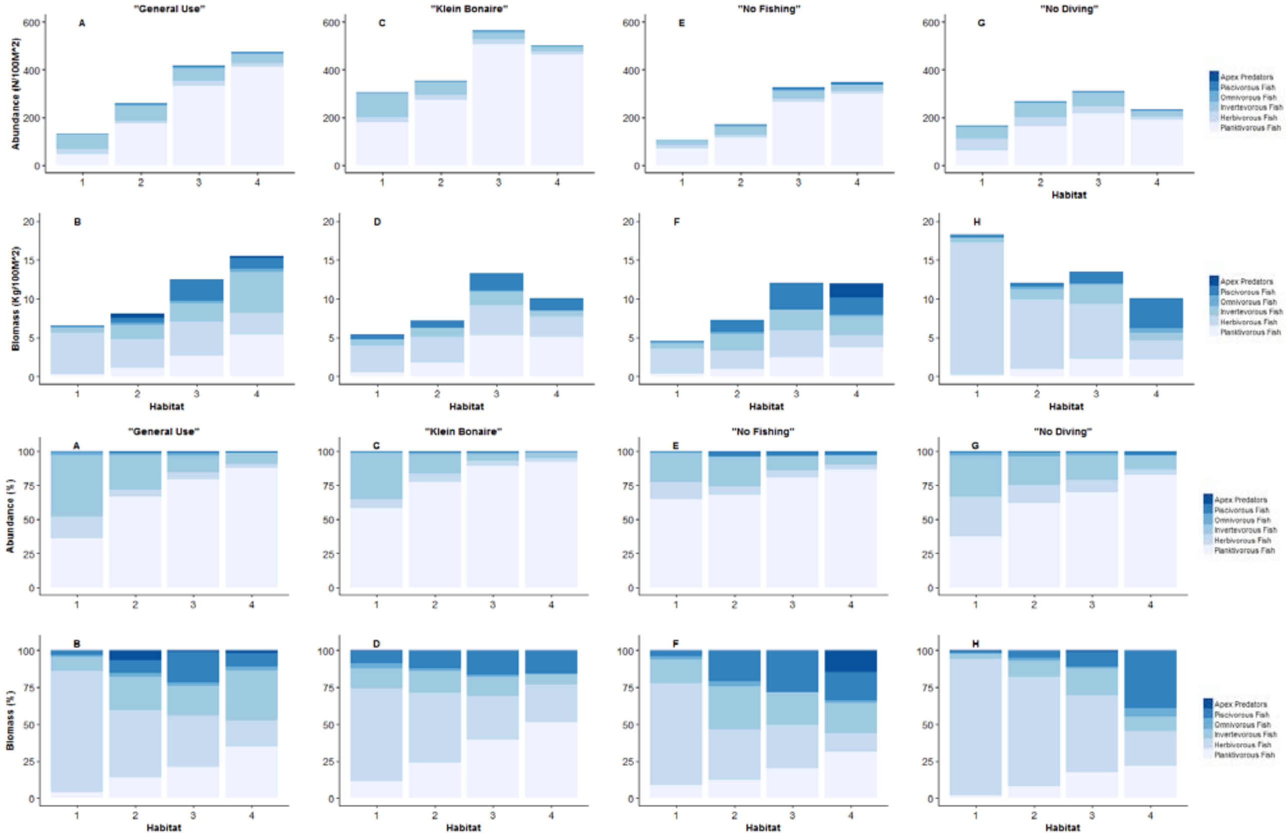


Abundance and biomass of key ecological fish families across management zones for each habitat zone on the

Abundance	Habitat 1				Habitat 2				Habitat 3				Habitat 4			
	GU	KL	NF	ND	GU	KL	NF	ND	GU	KL	NF	ND	GU	KL	NF	ND
Groupers	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Snappers	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Surgeonfishes	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Parrotfishes	A	A	A	A	A	AB	A	**B**	A	A	A	A	A	A	A	A
Biomass	Habitat 1				Habitat 2				Habitat 3				Habitat 4			
	GU	KL	NF	ND	GU	KL	NF	ND	GU	KL	NF	ND	GU	KL	NF	ND
Groupers	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Snappers	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Surgeonfishes	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Parrotfishes	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A

sheltered West Coast of Bonaire. Different letters indicate significant differences between groups (p<0.05; Bonferroni corrected bootstrapped values).

Appendix 8.2: Trophic Groups across Habitat Zones



Fish biomass and abundance across different habitat zones for each management zone on the sheltered West Coast of Bonaire.

Appendix 8.3: History fishing capacity

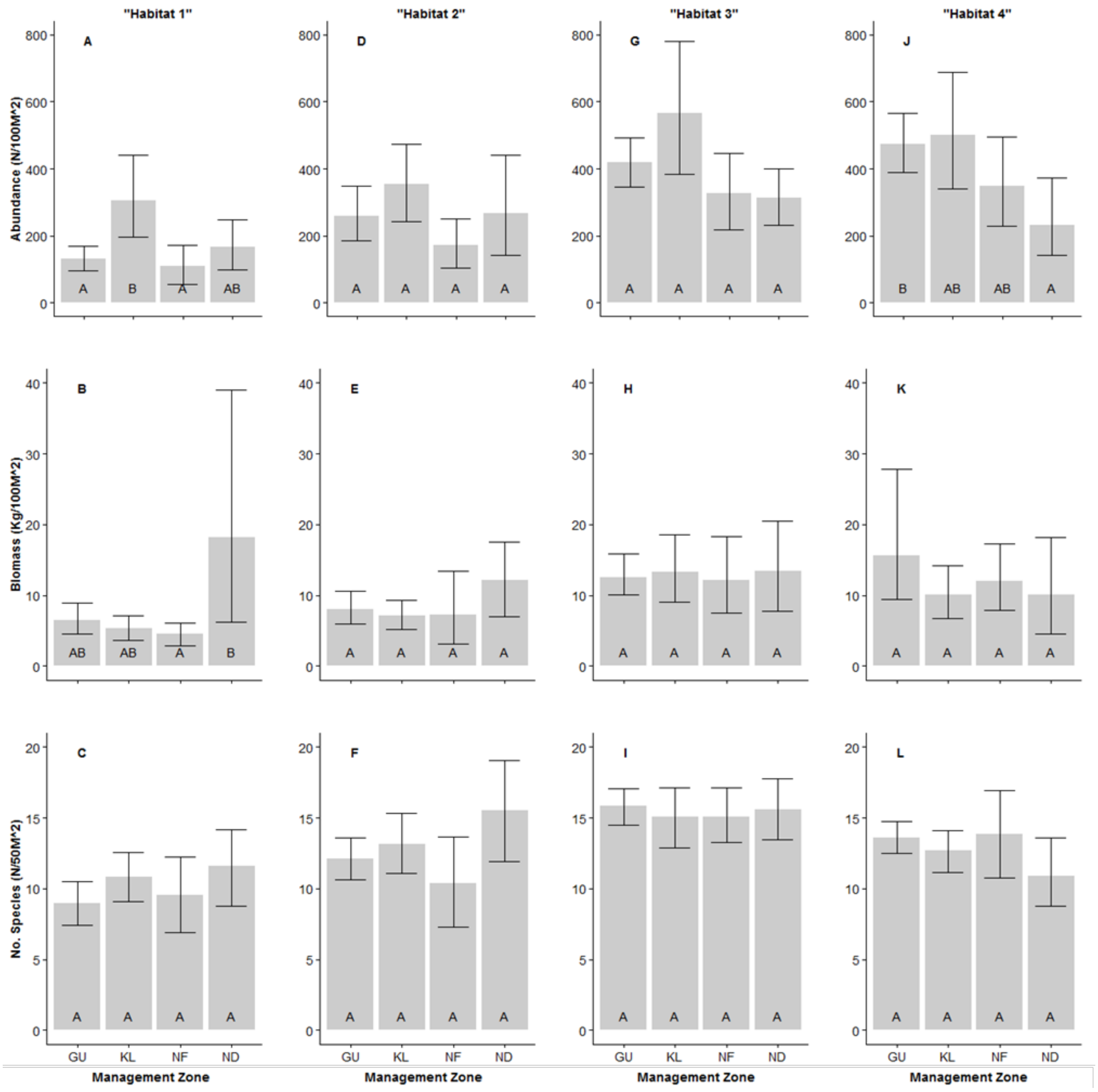
Source: Dilrosun (2004)

Harbour	Small boats (reef fishery)	Big boats (pelagic fishery)
Playa Frans	7	
Popec (haf di piskadó)	4	
Playa	20	13
Playa 'I Lechi	25	2
Lac Sorobon	2	10
Lac Cai	3	
Saliña Abou	3	
Total	64	25

Source: Steneck et al. (2007)

Harbour	Small boats (inshore)	Big boats (offshore)
Playa Frans	9	
Popec (haf di piskadó)		
Harbour Village	23	14
Playa	45	8
Playa 'I Lechi		
Lac Sorobon	4	10
Lac Cai	10	
Other	8	
Total	99	32

Appendix 8.4: Abundance, species richness and diversity per Management



Abundance (n/100m^2), biomass (kg/100m^2), species richness (no species/50m^2) per management zone for the different habitat zones. Error bars represent 95% confidence intervals. Different letters indicate significant differences between groups ($p<0.05$; Bonferroni corrected bootstrapped values).