The status of the Caribbean spiny lobster (*Panulirus argus*) and its fishery in the coastal waters of St Eustatius.
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Abstract

Across the Caribbean fisheries are aimed at fish, spiny lobster and conch, and several stocks of these target species have declined since the 1960s probably due to fishing activities. One of the management regulations that are being applied in order to control and regulate fisheries is the implementation of no-take zones and areas with fishing restrictions. On the island of St Eustatius (Dutch Caribbean) the main fishery is aimed at the Caribbean spiny lobster (Panulirus argus). The St Eustatius Marine Park surrounding the island was created in order to conserve and manage marine resources, including spiny lobsters. In order to create and manage a sustainable spiny lobster fishery on St Eustatius, the current status of the spiny lobster population around the island and its fishery must be investigated. A baseline study of the population structure and recruitment of the spiny lobster population will enable informed decisions for fishery policy makers, and in combination with further research this baseline study can be used to assess changes in the population. To conduct this study existing fisheries data from the year 2012 was used and combined with new data collected in 2013, consisting of both fisheries dependent and independent surveys. In addition, the possibility of using larvae collectors to monitor the recruitment of P. argus was investigated.

In 2012 a total estimated number of 4580 lobsters was landed from both pots and diving together with a total weight of 4546 kg, while in 2013 the total estimated number of lobsters landed is 2917, weighing 3292 kg in total. Fluctuations in P. argus catches have been found throughout the years 2012 and 2013, with lower catches in the period of February-May, which might be attributed to timing of reproduction and migratory movements. Males (mean carapace length 103 mm) were found to have significantly larger sizes than females (mean carapace length 94 mm) throughout the marine park. Also, the mean carapace length was found to be significantly higher inside the no-take zones (120 mm for males and 100 mm for females) than in the adjacent fishing areas (90 mm males and 94 for females), indicating a possible effect of fishing activities. Furthermore, the amount of undersized lobsters (< 95 mm carapace length) landed is large, especially among females (54% of all females landed), which might be caused by uncertainty about the legal minimum catch size among the fishermen. While the size at maturity of female spiny lobsters could not be calculated, results show it lies below 81 mm carapace length. Male size at maturity could also not be calculated due to lack of enough individuals, however, the value was found to be 92.9 mm for the Saba bank, an area very close to St Eustatius. Considering these values, the minimum legal catch size of 95 mm on St Eustatius can be considered sufficient for both males and females. Research on recruitment showed a trend of decrease in the mean number of pueruli larvae (a larval stage of P. argus) caught in June-October, with the exception of a high number of pigmented larvae in August. The mean numbers of juveniles and pigmented larvae caught per collector per month (2.4 and 2.6, respectively) were significantly higher than the mean number of transparent larvae (0.2).

In order to increase our understanding on how the P. argus population of St Eustatius changes over time and to use larval recruitment data to effectively manage the lobster fishery, continuous monitoring of the spiny lobster population status is required.
1. Introduction

Across the Caribbean fisheries target fish, spiny lobster and conch, and stocks of these groups have declined since the 1960s due to increasing fishing activities (Pauly et al., 2002; Chavez and Cooper, 2007). Stocks are groups of organisms which are self reproducing in which each member of the group has certain life history traits, and these stocks are fundamental concepts in managing fisheries (Hilborn and Walters, 1992; Begg and Waldman, 1999). Since exploitation has been shown to usually affect stocks negatively, resulting in depletion and reduced stock complexity, it is therefore important to understand the structure of these stocks in order to design effective management regulations (Begg and Waldman; 1999 Stephenson, 1999; Letourneau et al., 2000). One of the management regulations that are being applied in order to control and regulate fisheries is the implementation of no-take zones and areas with fishing restrictions (Gell and Roberts, 2003).

An important part of the Caribbean fishery is aimed at Caribbean spiny lobster (*Panulirus argus*) and spiny lobster landings have increased from 2,957 tonnes in 1950 to 42,519 tonnes 1996 (FAO, 2013). The rise of tourism in the region caused an increasing demand for spiny lobsters in the last decades, leading to increased fishing activities (Dilrosun, 2000; Chávez, 2001). Over the last 15 years the *P. argus* catches have been declining, which has been attributed to these increased fishing activities (Cochrane and Chakalall, 2001; Winterbottom et al., 2012).

On the island of St Eustatius (Caribbean Netherlands) the main fishery targets Caribbean spiny lobster, with an estimated catch of 4 tons in 2003, valued at 56,000 US$ (Dilrosun, 2004). The reason for targeting spiny lobsters is that they give the highest profits of all species readily available, with an average price of 8-9 $/lb.

To reduce fishing pressure on the spiny lobster around St Eustatius, several restrictions have been placed on the capture of Caribbean spiny lobsters. First of all, the fishermen must register at the fisheries department of St Eustatius to receive a fishing permit. Further regulations state that individuals with a carapace length of less than 95 mm may not be landed (Visserijlandsverordening, P.B. 1991, no. 74, Visserijlandsbesluit, Artikel 3)). The minimum size for lobster was originally set at 87 mm (8¾ in) by the St. Eustatius lobster ordinance passed in 1966. In 1993 the Netherlands Antilles National Fishery Ordinance with the National Fishery Decree came into force. As national laws these superseded the island legislation, and set the minimum lobster size at 95 mm carapace length or 25 cm total length (or total weight of 680 g or tail weight of 200 g) in order to harmonize the fishery regulations with the surrounding Eastern Caribbean countries. This law was inherited unchanged from the Netherlands Antilles in 2010 and became the Fishery Act BES and Fishery Decree BES. The minimum size was implemented to ensure that the lobsters can reproduce before being landed. Another regulation ensuring the reproduction of lobsters is that females carrying eggs (‘berried females’) may not be landed. This way any berried females can still release their eggs, increasing the numbers of the next generation (Dilrosun, 2002).

In addition to these rules and regulations the St Eustatius marine park was created in 1996 in order to conserve and manage marine resources, spiny lobsters being one of these resources. This marine park includes two no-take zones where fishing is not permitted (Fig.1.1) (MacRae et al., 2007). Research has shown that no-take zones have a positive effect
on spiny lobster populations (Cole et al., 1990; Kelly et al., 2000; Kay, 2012), however, before the implementation of both the current fishing regulations and the no-take zones inside the marine park, little research was carried out to determine the status of the Caribbean spiny lobster stock. In order to create and manage a sustainable spiny lobster fishery on St Eustatius, the current status of the spiny lobster population around the island must be investigated (Begg and Waldman, 1999).

Since little is known about the current stock status and population structure of *P. argus* of St Eustatius, a baseline study is required. Such a baseline study will enable informed decisions for fishery policy makers, and in combination with future research can be used to assess changes in the population.

One of the aims of this study is to describe how the lobster fishery on St Eustatius is structured, which will be investigated by collecting basic fishery and stock information on several aspects:
- Number of fishing trips per year
- Types of fishery
- Total estimated lobster catch (number and weight) per year
- Preferred fishing zones around the island
- Reproductive biology – spawning season
- Discarded fish and lobster
- Length frequency and sex ratio landed lobster
- Estimated bycatch of mixed fish

Another aim of this baseline study is to assess the spiny lobster population structure around St Eustatius. This will be investigated using the following research questions:
- Does the spiny lobster population show seasonal changes in abundance (catch), length frequency and sex ratio?

In both male and female spiny lobsters, seasonal and yearly movements from shallow to deeper waters have been observed (Ansell and Robb, 1977). Where females migrate to
deeper water during egg development (June-July) and return to inshore water in December-February, large males tend to participate more in autumn migrations than the smaller males, which might be due to differences in reproductive activity (Goni et al., 2001). In order to investigate the population size, the catch per unit effort (CPUE) per fishing trip will be determined. Although the relation between CPUE and abundance is not always proportional, CPUE can be used as an indirect measure for abundance (Harley et al., 2001; Smith and Addison, 2003; Cao et al., 2011), and therefore changes in the CPUE can signify changes in a populations abundance. When the CPUE changes over time it can have several meanings, depending on the timescale. For instance seasonal patterns in CPUE might indicate shifts in spiny lobster abundance caused by natural phenomena such as migration (Davis, 1977; Herrnkind, 1980; Walters, 2003). In this study CPUE will be used as an indirect measure of *P. argus* abundance. Changes in abundance, carapace length and sex ratio inside the marine park over the course of a year are expected.

- **What is the size at maturity for male and female lobsters on St Eustatius, and how does this relate to the legal catch size?**

  Since the minimal legal catch size of lobsters around St Eustatius is 95 mm, the minimum size at maturity should be smaller than 95 mm in order to ensure that lobsters can reproduce before being landed.

- **What is the effect of no-take zones on mean spiny lobster carapace length?**

  Studies have shown that the mean carapace length of spiny lobsters increases in marine reserves compared to adjacent areas (Cole et al., 1990; Babcock et al., 1999; Kelly et al., 2000; Cox and Hunt, 2005; Kay, 2012). Larger lobsters that might be found inside the marine reserves can produce more offspring than the smaller lobsters outside, which benefits the entire population (MacDiarmid and Butler, 1999). Differences in mean length between no-take zones and the adjacent fishing area are to be expected in this study.

- **With which methods and materials should a larval recruitment monitoring program be executed on St Eustatius?**

  Investigating the recruitment of lobsters into the population over a longer time span will enable predictions of future population changes, which can be used to sustainably manage lobster fishery (Phillips and Booth, 1994). This may reveal whether the population around St Eustatius is self-recruiting and in what way the new recruits contribute to the growth of the population (Butler et al., 2010). This situation is especially desirable because these predictions provide sufficient lead time for fishers and managers to adjust to potentially large future changes in the spiny lobster fishery (Butler et al, 2001).

  This baseline study will be performed by combining the analysis of existing data from the year 2012, and the collection of new measurements on individuals (carapace length, merus length and presence of egg mass or tar spot), sampling the fishery (number of lobsters caught in the fishing zones and accompanying carapace lengths), dive surveys (number of lobster observed inside the no-take zones, sex and carapace length) and using larvae collectors (to investigate the recruitment rate of *P. argus*) in 2013. A combination of this baseline study as a
starting point and continuous monitoring of the islands lobster fishery will enable the detection of significant changes in the spiny lobster population in the future, which can be used to regulate the lobster fishery sustainably.
2. Literature review

In order to investigate the *Panulirus argus* population, information about the life history and biology is needed that might have an influence on certain findings. In this literature review the taxonomy and the life cycle of *P. argus* will be discussed. As well as different life stages, reproduction, migrations and fishery regulations.

Taxonomy

*P. argus* is a member of the infraorder Achelata and belongs to the order Decapoda of the phylum Crustacea. This infraorder consist of two main families; Palinuridae (consisting of the spiny lobsters and furry lobsters) and Scyllaridae (Fig. 2.1).

![Fig. 2.1: The infraorder of the Achelata. A: Palinuridae (A1: spiny lobsters, A2: furry lobsters), B: Scyllaridae. (A1, B: S. Poiesz, 2013; A2: Wikipedia)](image)

The name 'Achelata' is derived from the fact that these two families lack the chelae (claws) which are found in most decapods. Another characteristic of this infraorder is the fact that they have phyllosoma larva (Fig. 2.2). This larva is characterized by a flattened carapace which does not occur outside the Achelata (Scholtz and Richter, 1995). The family of the Palinuridae consists of three main lineages, one of which (Stridentes) includes the genus *Panulirus* (Fig. 2.3) (Palero et al., 2009).

![Fig. 2.2: Phyllosoma larva of *P.argus*, infraorder of the Achelata (Courtesy Southeastern Regional Taxonomy Center, S.C. Department of Natural Resources).](image)
The genus of *Panulirus* has been of interest for scientists for a long time because of its high diversity of species (Ptacek et al., 2001). Within this genus 19 species and subspecies have been identified. The reason that *Panulirus* has a broad radiation is that this genus, after the break-up of the Tethys sea (around 200 million years ago) (Palero et al., 2009), invaded shallow and tropical waters which resulted in the occupation of different types of habitats (George and Main, 1967). In the present day the genus is well represented all over the world, in tropical as well as in temperate climates. Within the genus *Panulirus*, *P. argus* is considered to be the species closest related to the common ancestor of the genus, as it has the most widespread environmental adaptations within the Atlantic Ocean (George, 2006).

**Life cycle of *P. argus***

![Fig. 2.4: Life cycle of *P. argus* (Lipcius and Cobb, 1994).](image-url)
Larval stages of the Caribbean *P. argus*

Newly hatched *P. argus* larvae are called phyllosoma larvae, and are small, flat and transparent. These small larvae are adapted to a life in open waters, comparable to a planktonic life, where they undergo eleven molting stages over a course of several months (Booth and Philips, 1994). During this time the phyllosoma will remain near the surface in the water column.

The development of the larvae consists of 11 stages. During these stages, it undergoes several morphological changes. From stage 1 until stage 3 (Fig. 2.5 and Fig. 2.6), the main changes are the elongation of the hind-body and narrowing of the abdomen. The coxal segments become longer and narrower and the eyes increases in length. During the first three stages, three pairs of legs are present, two of which are biramous. In stage three an outer branch has grown out of the third leg (Lewis, 1951).

![Fig. 2.5: Phyllosoma stage 1 (Lewis, 1951).](image)

![Fig. 2.6: Phyllosoma stage 3 (Lewis, 1951).](image)

During stage 4 - 6 (Fig. 2.7) four walking legs are formed, while the fifth pair of legs are still rudimentary. The eye stalks become longer and the fore-body becomes longer than the hind-body. From stage 6 onwards, the antenna grow longer than the eyes, the abdomen has a large telson and the pleopods are fully formed. The first four legs contain two lobed gills, and the fifth leg is fully developed (Fig. 2.8) (Lewis, 1951).

![Fig. 2.7: Phyllosoma stage 6 (Lewis, 1951).](image)

![Fig. 2.8: Phyllosoma stage 11 (Lewis, 1951).](image)
When the moulting phases are complete, the now called pueruli larvae move closer to shore and have a total body length of 30–40 mm. Research shows that individuals that moved to shore bury themselves in sand or hide in algae or crevices while it is light during the day (Calinski and Lyons, 1983; Booth and Philips, 1994).

After settlement the pueruli will undergo further changes. These changes are subdivided into ten stages. In the first stage the puerulus is transparent with slightly dark red eyes and some pigments on the thorax. The puerulus undergoes pigmentation changes on the newly formed exoskeleton, where the larvae gets more shades of brown. The carapace and body of the puerulus is mostly smooth and flattened (Fig. 2.9). In stage 2 the larva becomes more pigmented. During this stage the larva develops spines and grooves on the dorsal side of its body (Fig. 2.9). In stage 3 the spines and grooves on the carapace are becoming more visible. The endopods also become sturdier (Fig. 2.9). After stage 3, during the last seven stages the main changes are in the development of the pleopods. From stages 4 onwards, males and females can be distinguished by the differentiating development of their endopods (Fig. 2.10) (Lewis et al., 1952). After full development both genders will reach maturity and will be able to engage in reproduction.

During the different phases of larval growth and settlement, it is possible to make larvae settle on artificial surface areas. These artificial 'larvae collectors' enable scientists to study the behavioural patterns of larval and post-larval recruitment. Because spiny lobster larvae have such a long planktonic life (6–18 months; Butler et al., 1999), it is possible that larvae from one area settle in a completely different area. In some instances larvae have been taken from shore more than 1000 km (Booth, 1994). By collecting data on larval recruitment using larvae collectors it might be possible to investigate the influx of larval recruits in different Caribbean islands (Herrnkind and Butler, 1994).
Sexual maturity within the Panuliridea family occurs after the 'maturity moult' (Morgan, 1980), the size at which this happens differ per species and within species. The peak of the reproduction season of *P. argus* occurs between February and April in the Northern part of the Caribbean and year-round south of the Caribbean (Acosta et al., 1997). Mature males are aggressive towards other males, and females move between these males which defend a shelter, indicating that males defend dens (Nevitt et al., 2000). This might indicate a 'lek mating system', where males defend their territory and females 'choose' their mates according to size of the male (MacDiarmid, 1994; Nevitt et al., 2000). During the reproduction period males attach a spermatophore sack to the abdomen of females between the last pair of pereiopods (Lewis, 1951). During the reproductive season, competition occurs between females, which need to mate early in the season with larger males (MacDiarmid and Butler, 1999) in order to ensure an adequate sperm supply. Large males are able to increase or decrease their spermatophore sack size dependent on the size of the females, where small males have limited capacity to adjust their spermatophore (MacDiarmid and Butler, 1999). For larger females it is more beneficial to mate with large males, because they are able to produce more sperm per ejaculate (MacDiarmid and Butler, 1999). Early-mating males encounter the risk for sperm competition later in the season. After the first mating, the females have 28 days before egg laying, and individual females are able to spawn several times per season (Cox and Hunt, 2005). In this period of time the females are able to mate multiple times in order to assure the fertilization of the whole clutch (MacDiarmid and Butler, 1999).

After fertilization, the females produce their eggs and attach them to their pleopods. During this time the females take care of the eggs by attending the clutch with their 5th pair of walking legs (ending in a small claw), to remove fungi and providing it with fresh water (Fig. 2.11). After three to four weeks the phyllosoma larvae hatch from the eggs and begin their planktonic life (Lewis, 1951).

![Female Panulirus argus attending egg clutch with 5th pair of pereiopods, which are bimarous, in order to remove fungi and providing it with fresh water (S. Poiesz, 2013).](image-url)
Migration

After the reproduction season in the northern part of the Caribbean in the months of July and August (Acosta et al., 1997), the weather becomes more stormy during the autumn months in the beginning of October. The first storms in the beginning of autumn cause the water temperature to drop (Kanciruk and Herrnkind, 1978). The spiny lobster is sensitive to these abrupt temperature changes, and will respond by reducing its feeding and locomotion (Herrnkind, 1985). According to Kanciruk and Herrnkind (1978), there seems to be a high correlation between declining ambient temperatures and migratory behaviour. In response to changes in weather patterns, *P. argus* engages in an annual mass migration covering distances of up to 30-50 km in groups of up to 60 animals (Lipcius and Cobb, 1994). During these mass migrations spiny lobsters show single file queuing behaviour which is maintained by contact between the antennules of one individual and the pereiopods of the individual in front (Fig. 2.12) (Herrnkind and Cummings, 1964). This form of locomotion has a hydrodynamic advantage over great distances (30-50km) as it reduces drag (Bill and Herrnkind, 1976; Herrnkind, 1985). Once a migratory group reaches shelter in deeper waters, the individual lobsters will disperse.

Fig. 2.12: Queuing behavior of *Panulirus argus*. lobster II maintains the queue by contact between the antennules and the pereiopods of lobster I (Herrnkind and Cummings, 1964).
Regulations on *P. argus* fisheries

The Caribbean spiny lobster is found all over the Caribbean Sea, from North Carolina to the North of Brazil and from the Gulf of Mexico to the Leeward and Windward Islands (Cochrane and Chakalall, 2001), and its fishery is important in many of the countries within this area. Recent assessments have indicated that the *P. argus* population is being over-exploited in this range (Cochrane and Chakalall, 2001). During the past decades (1950-2000) landings have been steadily increasing from a total of 5000 ton per year to 35000 ton per year (Cochrane and Chakalall, 2001; Fig. 2.13), which gave rise to an increasing concern about the sustainability of this kind of fishery.

![Fig. 2.13: Annual landings (t) of *P. argus* from 1950 to 1998. With the southern, southern central, south central and southern part of the Caribbean where *P. argus* can be found (Cochrane and Chakalall, 2001).](image)

In order to regulate the increased spiny lobster fishery in the Caribbean, fishing restrictions were placed in many of the Caribbean countries. These regulations and restrictions are mainly based on minimum legal landing sizes, limited entry and closed seasons (Dilrosun, 2002). The legal minimum landing size among Caribbean countries differs, from a carapace length of 69 mm in Cuba to 120 mm in Venezuela. In the Dutch Antilles the minimum legal size is 95 mm, which might be considered as a medium size restriction. Next to the minimum legal size, most of the Caribbean countries use limited entry restrictions. This is a system where the number of fishermen and/or the number of fishing units is restricted (Dilrosun, 2002). The last restriction is the implementation of the closed season. The closed season ensures reproduction during the spawning season, protection for the moulting lobsters and growth for the population (Fig. 2.14). Most Caribbean countries have a 4-5 month closed season (Phillips and Melville-Smith, 2006), where the Caribbean Netherlands does not have a closed season. In order to maintain a stable and fertile population across the Caribbean, it is important that the fisheries live up to these regulations and that they are correctly enforced (Dilrosun, 2002).
<table>
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Fig. 2.14: Summary of regional fishery regulations on *P. argus* (FAO Fishery report No. 619, 1998).
3. Materials and Methods

3.1 Study area

This study was conducted in the coastal waters of the island of St Eustatius, (17°33.582’ N; 63° 59. 295’ W) in February - June 2013. St Eustatius is a small island of 21 km² situated in the north-eastern part of the Caribbean and belongs to the Leeward Islands. Together with Saba and Bonaire it forms the Caribbean Netherlands (Fig. 3.1).

Fig. 3.1: St Eustatius is located in the north-eastern part of the Caribbean and belongs to the Leeward Islands (17°33.582N; 62° 59.295W; 4 cm is 460 km) (Google Earth).

Around the island reefs are located off the coast on the southern part and the north-western part of the island. The reefs on the southern part of the island are one of the largest around the island, they are 3 to 4 meters in height and are between 30 to 100 meters in width. The reef formation in the northern part of the island consists of old lava flow formations and large volcanic boulders which form a base for corals to grow on. The reefs are mainly situated in the no-take zones of the marine park (Fig. 3.2)
The two reef zones together, the north-western part of the island and the southern part of the island, form the two no-take zones where fishing is not allowed. The area that surrounds the island from the coast till a depth of 30 meters makes up the national marine park of St Eustatius, which includes the no-take zones in the north and south (White, 2005).

3.2 Study design

In order to determine the population stock and fishery on *P. argus*, catches of fishermen were monitored over the course of five months (February - June 2013) and fishery data obtained in 2012 was used. Catch effort and fisheries catch data were obtained through daily log forms and short interviews. Together with the catch effort and fishery catch data, also biological data of *P. argus* was collected in order to determine size at maturity and the length frequency of *P. argus*. This type of data was obtained by long interviews and during on-board sampling trips. In 2012 biological data has been collected through long interviews as well. During the long interviews the lobsters and fish that were caught and landed in the harbour were measured in length.

The collection of catch effort, fishery catch and biological data from the spiny lobster fishery was conducted through port sampling and during on-board sampling trips. The way in which data was obtained through these procedures was as followed:

Port sampling was divided into three aspects:
- Daily trip logs - collecting effort data
- Short interviews - collecting effort and catch data (numbers, weight, trip duration etc.)
- Long interviews - collecting biological data

On-board sampling trips were used to collect biological data.
3.2.1. Port sampling - Daily trip logs: Each day the harbour was checked for missing boats and these boats were logged as being on a fishing trip.
- Number of trips per day

3.2.2. Port sampling - Short interviews: The duration of the short interview was approximately 5 min, and basic fishery data and effort data was collected (Fig. 3.3)

![Table of fishing gear and species](image)

- Type of gear used per trip
  - Number of pots/dives per trip
  - Soaking time of the pots in days
  - Number of berried females discarded per trip in order to determine the spawning season of spiny lobsters around St Eustatius
  - Number of undersized lobster discarded per trip
  - Which fishing zones were visited per trip (the marine park is divided into 8 separate zones (quadrates) (Fig. 3.4). Zone 4 and 1 being the two no-take zones, zone 2 the anchorage/general use zone, zone 3 the oil terminal and zone 5-8 the general usage/fishing zones).

![Map of marine park](image)

Additional information for other research purposes:
- Number of lionfish
- If the fishermen spotted whales or dolphins
3.2.3. Port sampling - Long interviews

The long interviews were used to collect biological data of the landed catch (Table 3.1). After collecting all their catch the fishermen return to the harbour, were their catch was examined. This biological data consisted of measuring the carapace length (CL; mm), determining the sex of the lobsters and analysing the fish bycatch; determine the species and measure the total length of the fish (tail or fork length in cm, depending on species) (Fig. 3.5). From this point onward, all total fish lengths will be referred to as fork length.

![Fig. 3.5: Measuring the fish's fork length (cm) (S. Poiesz, 2013).](Image)

During long interviews the sex of lobsters was determined by the difference in the fifth walking leg. In females, the fifth or last pair of walking legs (pereiopods) ends in a small claw (biramous pereiopods). Males do not have this claw, with their fifth walking leg ending as a single point (uniramous pereiopods) (Fig. 3.6).

![Fig. 3.6: 5th walking legs (pereiopods) of male (left: uniramous) and female (right: bimarus) (S. Poiesz, 2013).](Image)
Another measurement done on the lobsters was the CL in mm. The carapace was measured from the base of the rostral horns to the posterior end of the carapace (Fig. 3.7).

3.2.4 On-board sampling trips

These on-board sampling trips were necessary because the biological data obtained by long interviews did not cover the entire size range of lobsters, as legislation prohibits the landing of *P. argus* with a carapace length smaller than 95 mm and berried females. On-board sampling trips were therefore used to collect biological data consisting of measuring the CL and merus length of males, CL of females (also females with tarspot and berried females) and counting the number of individuals with a CL smaller than the legal minimum catch size of 95 mm (Table 3.1).

<table>
<thead>
<tr>
<th>Biological data obtained from:</th>
<th>Long interviews</th>
<th>On-board sampling trips</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex</td>
<td>Sex</td>
<td></td>
</tr>
<tr>
<td>CL males (mm)</td>
<td>CL males (mm)</td>
<td></td>
</tr>
<tr>
<td>Merus length males (mm)</td>
<td>Merus length males (mm)</td>
<td></td>
</tr>
<tr>
<td>CL all females (mm)</td>
<td>CL all females (mm)</td>
<td></td>
</tr>
<tr>
<td>CL discarded berried females (mm)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. discarded short individuals (CL &lt; 95 mm)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3.2.5 Size at maturity

For females the presence of an egg-mass or a tarspot on the abdomen was used as a determination for maturity (Grey, 1979; Fig. 3.8). In this study the size at maturity for female lobsters is determined as the CL at which 50% of the females is ‘berried’ or has a tarspot (size at 50% maturity) (Melville-Smith and de Lestang, 2006). The collection of this data is only possible during February-May, which is the reproduction season (Lewis, 1951) and must be collected during the on-board sampling trips as berried females are not landed.
For males the size at morphometrical maturity is assessed based on the allometric relationship between the CL and the length of the merus of the second walking leg. Therefore if a male was measured, it was important to measure to merus of the second walking leg together with the carapace length for the determination of size at morphometrical maturity. In order to measure the merus, the calliper was placed with its points on the ridge of the joints of the merus (Fig. 3.9). When male lobsters become morphometrically mature their second walking legs start to grow faster than their carapace, resulting in a change in the proportion between CL and merus length of the second walking leg. Using regression analysis the point at which this allometric growth of the merus starts can be calculated, leading to the size at morphometrical maturity for male spiny lobsters (Somerton, 1980; Robertson and Butler, 2003; Melville-Smith and de Lestang, 2006).

Fig. 3.8: Female lobster with left a tar spot and right an egg-mass (www.http://shorelifeflorida.com/active).

Fig. 3.9: Measuring the merus length of a male lobster, the calliper was placed with its points on the ridges of the joints of the merus (F. Holtrop, 2013).
3.2.6 Dive surveys inside and outside the no-take zones

In order to investigate the effect of no-take zones on the population size and length frequency of *P. argus*, dive surveys were undertaken. A total of 25 dive sites were surveyed in this study (Table 3.2; Fig. 3.10); eighteen inside the southern no-take zone (Fig. 3.11), four inside the north-western no-take zone and three inside the anchorage/general use zone. The dive sites were sampled in random order.

Table 3.2: The 25 dive locations inside and outside the no-take zones.

<table>
<thead>
<tr>
<th>Dive site</th>
<th>N '</th>
<th>W '</th>
<th>Zone</th>
<th>No-take zone</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Cliffs</td>
<td>17° 27,729</td>
<td>62° 58,767</td>
<td>1</td>
<td>Yes</td>
</tr>
<tr>
<td>Mushroom Gardens</td>
<td>17° 27,759</td>
<td>62° 58,657</td>
<td>1</td>
<td>Yes</td>
</tr>
<tr>
<td>The Humps</td>
<td>17° 27,809</td>
<td>62° 58,680</td>
<td>1</td>
<td>Yes</td>
</tr>
<tr>
<td>Valley of Sponges</td>
<td>17° 27,835</td>
<td>62° 58,938</td>
<td>1</td>
<td>Yes</td>
</tr>
<tr>
<td>Five Fingers North</td>
<td>17° 28,860</td>
<td>62° 58,980</td>
<td>1</td>
<td>Yes</td>
</tr>
<tr>
<td>Five Fingers South</td>
<td>17° 28,898</td>
<td>62° 58,996</td>
<td>1</td>
<td>Yes</td>
</tr>
<tr>
<td>The Ledges</td>
<td>17° 27,793</td>
<td>62° 59,069</td>
<td>1</td>
<td>Yes</td>
</tr>
<tr>
<td>Anchor Reef</td>
<td>17° 27,738</td>
<td>62° 59,118</td>
<td>1</td>
<td>Yes</td>
</tr>
<tr>
<td>The Blocks</td>
<td>17° 27,840</td>
<td>62° 59,105</td>
<td>1</td>
<td>Yes</td>
</tr>
<tr>
<td>Hangover</td>
<td>17° 27,871</td>
<td>62° 59,147</td>
<td>1</td>
<td>Yes</td>
</tr>
<tr>
<td>Anchor Point South</td>
<td>17° 27,825</td>
<td>62° 59,200</td>
<td>1</td>
<td>Yes</td>
</tr>
<tr>
<td>Anchor Point West</td>
<td>17° 27,802</td>
<td>62° 59,212</td>
<td>1</td>
<td>Yes</td>
</tr>
<tr>
<td>Anchor Point North</td>
<td>17° 27,840</td>
<td>62° 59,250</td>
<td>1</td>
<td>Yes</td>
</tr>
<tr>
<td>Barracuda Reef</td>
<td>17° 28,006</td>
<td>62° 59,455</td>
<td>1</td>
<td>Yes</td>
</tr>
<tr>
<td>Nursing Station</td>
<td>17° 28,088</td>
<td>62° 59,495</td>
<td>1</td>
<td>Yes</td>
</tr>
<tr>
<td>Blair's Reef</td>
<td>17° 28,227</td>
<td>62° 59,493</td>
<td>1</td>
<td>Yes</td>
</tr>
<tr>
<td>Crook's Castle</td>
<td>17° 28,315</td>
<td>62° 59,254</td>
<td>1</td>
<td>Yes</td>
</tr>
<tr>
<td>Twin Peaks</td>
<td>17° 27,974</td>
<td>62° 59,472</td>
<td>1</td>
<td>Yes</td>
</tr>
<tr>
<td>Triple Wreck</td>
<td>17° 28,750</td>
<td>62° 59,660</td>
<td>2</td>
<td>No</td>
</tr>
<tr>
<td>Double Wreck</td>
<td>17° 28,792</td>
<td>62° 59,641</td>
<td>2</td>
<td>No</td>
</tr>
<tr>
<td>STENAPA Reef</td>
<td>17° 29,055</td>
<td>62° 59,830</td>
<td>2</td>
<td>No</td>
</tr>
<tr>
<td>Outer Jenkins Bay</td>
<td>17° 30,812</td>
<td>62° 00,114</td>
<td>4</td>
<td>Yes</td>
</tr>
<tr>
<td>Twin Sisters</td>
<td>17° 31,010</td>
<td>62° 00,210</td>
<td>4</td>
<td>Yes</td>
</tr>
<tr>
<td>Gibraltar</td>
<td>17° 31,509</td>
<td>62° 00,004</td>
<td>4</td>
<td>Yes</td>
</tr>
<tr>
<td>Inner Jenkins Bay</td>
<td>17° 30,746</td>
<td>62° 00,057</td>
<td>4</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Fig. 3.10: Map of Sint Eustatius with the 25 dive sites on which a lobster dive survey was done. In yellow the southern no-take zone; In green the southern no-take zone; In blue the north-western no-take zone (Google Earth).

Fig. 3.11: In yellow the eighteen dive sites of the southern no-take zone. In this zone of the island the most surveys were conducted (Google Earth).
The surveys conducted in this study were done on complex reef habitat with two divers and consisted of time based transects of 45 minutes per dive (Cox and Hunt, 2005). During each dive it was assured that the bottom time was at least 45 minutes so the divers had that time to look in each crevice and ledge for spiny lobsters (no time was compensated for measuring lobsters). Each dive the site was searched by the two divers and crevices and holes were examined for resident lobster (Fig. 3.12). When a lobster was found, if possible, the carapace length was measured, the sex was observed, and it was determined if the lobster was in ecdysis and if a female had a tar spot or had an egg mass. Measuring time was not deducted from search time. Measuring the carapace from the lobsters was only possible when they were within the range of the measuring stick. Another way of getting closer to the lobster, is manipulating and luring the lobster out of its crevice by softly touching its antennae. In doing so, the divers were able to gently place the measuring stick alongside the carapace of the lobster and measure its length in centimetres (Fig. 3.13). Berried females were easy to spot, as they were continuously attending the egg masses on their abdomen (Fig. 2.11).

![Fig. 3.12: Large crevice, making home to many resting Caribbean spiny lobsters (S. Poiesz, 2013).](image1)

![Fig. 3.13: After luring the lobster out of its crevice, the diver was able to measure the carapace by placing the measuring stick alongside the lobster (S. Poiesz, 2013).](image2)

Each dive site was surveyed once and were located within three different marine park zones, two of which are designated as no-take zones (Southern no-take zone and Northern no-take zone) while the third zone is a general use area called 'Anchor zone' where fishing is allowed. The dive surveys were conducted during nine weeks in the first half of 2013 in April-June. The dive surveys in all three zones were randomly undertaken during these 9 weeks, in order to rule out any time effect.

In 2005 timed dive surveys were performed by White (2005) on dive sites in-and outside the no-take zones. In this study carapace length data of no-take zones and fishing zones of White (2005) will be compared from carapace length data from no-take zones and fishing zones obtained during this research.
3.2.7 Larval recruitment

In order to investigate the methodology of monitoring spiny lobster recruitment, larvae collectors were used to catch pueruli larvae. During this study three mussel seed rope collectors were used (Fig. 3.14) from a previous short study. In the beginning of the project these three collectors were placed in a shallow area in order to practise with the materials. Together with the mussel seed rope collectors, another type of collector was used for this research. This new type of collector is called the "shaggy" larvae collector (Fig. 3.15). The reason for this switch is that the mussel seed rope collector is quite expensive and unsuitable for very long term use in a tough marine environment. The shaggy collector is a frame of pvc piping of 0.5m x 1m with a mesh of coated chicken wire inside the frame. Polypropylene rope is attached to the coated chicken wire, protruding 20 cm on both sides, and unravelled to create the same spatial structure as the mussel seed rope material. A protocol on how to build this type of collector was made (Appendix 1). A total of 3 mussel seed rope collectors and 10 of the newly designed shaggy collectors were used in this study.

The collectors were placed at three locations around the island (Fig. 3.16) in shallow areas (4-10m depth) on a mostly sandy bottom. During the first two months (April and May) of collector deployment three mussel seed rope collectors were placed in an area called Smoke Alley, five shaggy collectors were placed at Blind Shoal and the other five shaggy collectors in Jenkins Bay. In May it was decided to move one shaggy collector from both Jenkins bay and Blind Shoal to Smoke Alley to compare both types of collectors. Therefore in the last stage of the research all three mussel seed rope collectors and two shaggy collectors were placed in one area (Smoke Alley), four shaggy collectors in an area near the northern no-take zone (Jenkins Bay) and the other four shaggy collectors near the southern no-take zone (Blind Shoal).
Because new moon springtides provide the potential for tidal larvae transport due to an increased water exchange between coastal waters and sea waters (Eggleston et al., 1998) the collection of the data for the collectors needs to be done every month, one week after the new moon (Table. 3.3).

Table 3.3: The dates, one week after full moon, on which the collectors were emptied and the pueruli data were collected.

<table>
<thead>
<tr>
<th>January</th>
<th>February</th>
<th>March</th>
<th>April</th>
<th>May</th>
<th>June</th>
<th>July</th>
<th>August</th>
<th>September</th>
<th>October</th>
<th>November</th>
<th>December</th>
</tr>
</thead>
<tbody>
<tr>
<td>18</td>
<td>17</td>
<td>18</td>
<td>17</td>
<td>16</td>
<td>15</td>
<td>15</td>
<td>13</td>
<td>12</td>
<td>11</td>
<td>10</td>
<td>9</td>
</tr>
</tbody>
</table>

In order to empty the collectors, three persons were needed to do the job. Two persons jumped into the water from the research vessel, captained by the third person. While one of the persons in the water used a collector bag to put around the collector (Fig. 3.17), the other person unclipped the collectors from the mooring. Both persons then closed the bag, in order to prevent the larvae to escape, and swam back to the research vessel. The bag with the collector was then lifted out of the water and brought onboard. There the bag and collector were placed into a large flat bucket (Fig. 3.18), and were shaken very thoroughly in order for the larvae to let go of the collector. After shaking, the collector was placed into the large bucket and both bag and collector were searched for pueruli larvae.

The different types of data shown in Table 3.4 were recorded for each collector separately. When finished, the collector was returned to its mooring and the pueruli were released some distance away from the collectors. A full data overview of the bycatch of the larvae collectors can be seen in Appendix 2.
3.3 Data analysis

3.3.1 Fishery information

For the calculations of basic fishery information, only data from the ten active fishing boats that performed a minimum of ten fishing trips during the periods of April 2012 - December 2012 and January 2013 - June 2013 was used. The catches from three of these boats have been measured during these periods using long interviews and the mean values for the number of lobster landed and their weight were extrapolated to the other 7 boats. Lobster weight was calculated for males and females separately using length-weight relationship formulas as described by Dilrosun (2000). For males the formula is \[ W=6.131765 \times (L/10)^{2.223423} \] and for females \[ W=3.3835 \times (L/10)^{2.4724} \] where \( W \) is the weight in grams and \( L \) the carapace length in mm of an individual lobster. Using the daily trip log the mean total number of fishing trips per day was calculated for both periods and then extrapolated to the years 2012 and 2013. The extrapolated biological data for the ten active fishing boats from the periods mentioned above was also extrapolated to the years 2012 and 2013 and used to calculate the total catches in number of lobsters and lobster weight for both years for pots and diving separately.

3.3.2 Calculating CPUE

Calculating the catch per unit effort will tell us something about the abundance of the spiny lobster population as an indirect measure. Fishing effort is one of the largest factors determining the amount of lobsters landed, and can be explained by the type of fishing. The fishermen on St Eustatius use two main types of fishing, lobster pots and diving. For each of these different fishing methods, the effort will be calculated. Both for using pots and for diving there are several effort units that correlate with the effort.

The effort units for using lobster pots are:
- The soaking time of the pots per fishing trip:
- The total amount of potdays (pots*days) per fishing trip
- The amount of pots used per fishing trip

The effort unit for diving is:
- The duration of each fishing trip

It is important to investigate how the amount of lobsters caught per fishing trip correlates to one of these possible effort units. A clear correlation between the amount of lobsters caught per fishing trip and a specific fishing effort unit indicates that this effort unit is suitable for use in further analysis. For each explanatory value against the number of lobsters caught per fishing trip a double-log model was used as the CPUE distribution was not normal. Because the effort differs for each trip within its own effort unit, it is important to compensate for the effect of differences found in each fishing trip per effort unit, to standardize the CPUE to a standardized trip.
In order to standardize the CPUE, the next formula will be used as described by Tsehaye et al., 2007.

\[
CPUE_i^s = CPU_i \left( \frac{f}{f_i} \right)^\beta
\]

\(CPUE_i^s\) = standardized CPUE

\(\bar{f}\) = The mean value for the selected effort measure

\(f_i\) = The number of effort units used on fishing trip \(i\).

\(\beta\) = The coefficient for this selected effort measure from the GLM.

The obtained standardized CPUE value will be used as indirect measure for the population abundance and will be used in further research.

3.3.3 Standardized CPUE and Carapace length

The data for each of these different aspects were analysed by analysis of variance (ANOVA) with different months and sex as factors, using the statistical package SPSS 20.0™, with the 95% confidence intervals being derived from 1000 bootstrap estimates. By bootstrapping 1000 times with replacement, the mean of these 1000 bootstraps falls within a margin error from what the mean of the sample is (IBM SPSS Bootstrapping 20). The data used to calculate the difference in carapace length between males and females was collected in 2012 and 2013 (Erik Boman for 2012 and Suzanne Poiesz for 2013).

3.3.5 Size at maturity

Male \(P. \ argus\) were considered morphometrically mature on the basis of the relationship between the natural logarithms of the length of the merus of the SPL and the CL as determined by log–log regression analysis (Melville-Smith and de Lestang, 2006). Data processing and analysis were conducted in the statistical computing and graphics program R, version 2.14.0.

3.3.4 Dive surveys

To test for the mean number of lobsters observed over time during the dive surveys and the mean number of lobsters observed per hour (extrapolated from 45 minutes to 60 minutes; Cox and Hunt, 2005), a linear regression with time as covariable was executed. To investigate whether the means of the carapace length of males and females differed between the fishery data, dive survey data and the historical data of White (2005), an analysis of variance (ANOVA) was executed with sex and zones as factors, using the statistical package SPSS 20.0™, with the 95% confidence intervals being derived from 1000 bootstrap estimates.

3.3.6 Larval recruitment

To test whether the recruitment shows monthly changes between each collector site an analysis of variance (ANOVA) with different months and location as factors was conducted, using the statistical package SPSS 20.0™, with the 95% confidence intervals being derived.
from 1000 bootstrap estimates. The different pueruli stages were combined in this test and so were the two types of collectors per site.

To test whether the number of pueruli per stage caught on one site (Smoke Alley) differed from each other, a paired t-test was conducted. During this research two different types of collectors have been used on Smoke Alley. To test whether both collector types showed monthly changes between each other an analysis of variance (ANOVA) with different months and collectors as factors was conducted, with the 95% confidence intervals being derived from 1000 bootstrap estimates.
4. Results

4.1 Fishery information

4.1.1 Fleet, trips and fishery

The fishing fleet of St Eustatius consisted in the period of April 2012 till June 2013 of 11 boats, which have their own individual characteristics, such as length, HP, fishing method used (Table 4.1).

Table 4.1: Characteristics per boat of the fishing fleet of St Eustatius.

<table>
<thead>
<tr>
<th>Boat</th>
<th>Length (feet)</th>
<th>Decked/Undecked</th>
<th>Outboard/Inboard</th>
<th>HP</th>
<th>Fishing method</th>
<th>Number of fishing gear</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boat 1</td>
<td>20</td>
<td>Undecked</td>
<td>Outboard</td>
<td>2x80</td>
<td>Fish/lobster pots, handline, trolling</td>
<td>40 fish/lobster pots</td>
</tr>
<tr>
<td>Boat 2</td>
<td>28</td>
<td>Undecked</td>
<td>Outboard</td>
<td>2 x 200</td>
<td>Fish/lobster pots, handline, trolling</td>
<td>40 fish/lobster pots</td>
</tr>
<tr>
<td>Boat 3</td>
<td>18</td>
<td>Undecked</td>
<td>Outboard</td>
<td>1 x 48</td>
<td>Fish/lobster pots, handline, speargun, scuba, trolling</td>
<td>20 fish/lobster pots</td>
</tr>
<tr>
<td>Boat 4</td>
<td>28</td>
<td>Undecked</td>
<td>Outboard</td>
<td>2 x 115</td>
<td>Handline, trolling</td>
<td>20 fish/lobster pots</td>
</tr>
<tr>
<td>Boat 5</td>
<td>22</td>
<td>Undecked</td>
<td>Outboard</td>
<td>2 x 85</td>
<td>Handline, trolling</td>
<td>20 fish/lobster pots</td>
</tr>
<tr>
<td>Boat 6</td>
<td>18</td>
<td>Undecked</td>
<td>Outboard</td>
<td>1 x 40, 1 x 48</td>
<td>Fish/lobster pots, handline, net, speargun, scuba, trolling</td>
<td>20 fish/lobster pots</td>
</tr>
<tr>
<td>Boat 7</td>
<td>32</td>
<td>Undecked</td>
<td>Outboard</td>
<td>3 x 200</td>
<td>Handline, trolling</td>
<td>20 fish/lobster pots</td>
</tr>
<tr>
<td>Boat 8</td>
<td>22</td>
<td>Undecked</td>
<td>Outboard</td>
<td>1 x 150, 1 x 150</td>
<td>Fish/lobster pots, handline, trolling</td>
<td>20 fish/lobster pots</td>
</tr>
<tr>
<td>Boat 9</td>
<td>28</td>
<td>Undecked</td>
<td>Outboard</td>
<td>2 x 85</td>
<td>Fish/lobster pots, handline, speargun, scuba, trolling</td>
<td>20 fish/lobster pots</td>
</tr>
<tr>
<td>Boat 10</td>
<td>18</td>
<td>Undecked</td>
<td>Outboard</td>
<td>2 x 85</td>
<td>Fish/lobster pots, handline, speargun, scuba, trolling</td>
<td>20 fish/lobster pots</td>
</tr>
<tr>
<td>Boat 11</td>
<td>32</td>
<td>Undecked</td>
<td>Outboard</td>
<td>2 x 200</td>
<td>Fish/lobster pots, handline, speargun, scuba, trolling</td>
<td>20 fish/lobster pots</td>
</tr>
</tbody>
</table>

Table 4.2 gives an overview of data from the daily trip log and long interviews, extrapolated to a full year for both 2012 and 2013. In 2012 an estimated total of 417 fishing trips were made, from which 178 were lobster trips. The estimated total number of 257 fishing trips in 2013 is lower than for 2012, while the estimated number of lobster trips, 180, is similar between these years. The mean number of lobsters landed was 18.5 ± 12.4 in 2012 and 16 ± 10 in 2013, and mean lobster weight was 992.7 ± 284.8 in 2012 and 1128.7 ± 326.7 in 2013. In 2012 the estimated total number of lobster landed is 4580 with an estimated total weight of 4546 kg. For 2013 the estimated total number of lobsters landed is 2917 with an estimated total weight of 3292 kg.

Table 4.2: Data from the daily trip log and long interviews over April - December 2012 and January - June 2013. Estimated total catches for 2012 and 2013 are extrapolated to a full year.

<table>
<thead>
<tr>
<th>Year</th>
<th>Mean total no. of trips per day</th>
<th>Estimated total no. of trips per year</th>
<th>% Lobster trips</th>
<th>Estimated no. of lobster trips per year</th>
<th>Mean no. of pots hauled per trip +SD</th>
<th>Mean no. of lobsters caught per trip + SD (pots and diving)</th>
<th>Mean lobster weight (kg) + SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>2012</td>
<td>1.14</td>
<td>417.1</td>
<td>42.5</td>
<td>177.5</td>
<td>14 ± 10.7</td>
<td>18.5 ± 12.4</td>
<td>992.7 ± 284.8</td>
</tr>
<tr>
<td>2013</td>
<td>0.70</td>
<td>256.9</td>
<td>70.1</td>
<td>180.2</td>
<td>13 ± 10.3</td>
<td>16 ± 10</td>
<td>1128.7 ± 326.7</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Year</th>
<th>Estimated total yearly catch in no. of lobsters (pots)</th>
<th>Estimated total yearly catch in no. of lobsters (diving)</th>
<th>Estimated total yearly catch in weight (kg) of lobsters (pots)</th>
<th>Estimated total yearly catch in weight (kg) of lobsters (diving)</th>
<th>Estimated total yearly catch weight (kg) of lobsters (pots+diving)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2012</td>
<td>3047</td>
<td>1533</td>
<td>4580</td>
<td>3025</td>
<td>1522</td>
</tr>
<tr>
<td>2013</td>
<td>1784</td>
<td>1133</td>
<td>2917</td>
<td>2014</td>
<td>1279</td>
</tr>
</tbody>
</table>
4.1.2 Preferred fishing zones around the island

The fishing zones (Fig. 3.4) for lobster fisheries (pot fishery and diving fishery pooled) are focussed on the Anchorage zone (zone 2) and at the Atlantic side of the island (zone 7 and 8) (Fig. 4.1), with a total of 124 recorded trips in 2012 and 49 trips in 2013 (January-June). In 2012, 37% of the fishing trips were focussed in zone 8, 24% in zone 7 and 22% in zone 2. In the first half of 2013, 41% of the fishing trips were focussed in zone 2, 30% in zone 8 and 21% in zone 7.

The fishing zones for the different types of lobster fishery (pots and diving) are mainly focussed on the Atlantic side (zone 8 and 7) and the Anchorage zone (zone 2). Diving is mainly focussed in zone 8 and 7, a total of 80% (zone 7 and 8 combined) of the diving trips. Where the pot fishery is mainly focussed in zone 8 (32% of the pot trips) and zone 2 (37% of the pot trips).

Fig. 4.1: The percentage of lobster fishing trips per zone in (left) 2012 and (right) 2013, including the current fishing zones (quadrates) around St Eustatius (right).

Fig. 4.2: The percentage of lobster fishing types per zone (data of 2012 and 2013 combined).
4.2 *Panulirus argus* reproduction season

The mean number of berried female lobsters that have been discarded per trip per month show an irregular pattern over the months of January 2012 till June 2013 (Fig. 4.3). The graph shows that the mean number of berried lobster discarded is the highest in the months February and March (3.33 and 2.258 respectively). Also May and July of 2012 and April 2013 show a higher number of berried females (1.27, 1.15 and 1 respectively) compared to the hurricane months, September - January (on average 0.27 berried females per trip). There was no statistically significant effect over the different months (ANOVA: F(14,83) = 1.388, P = 0.177).

![Fig. 4.3: Mean number of berried females discarded per trip per month (April 2012 – June 2013). N is the amount of trips per month. Error bars indicate 95% confidence limits.](image-url)

**Fig. 4.3**: Mean number of berried females discarded per trip per month (April 2012 – June 2013). *N* is the amount of trips per month. Error bars indicate 95% confidence limits.
4.3 Discarded undersized lobsters

No trend can be seen in the discard of undersized lobster per trip throughout 2012 and in the beginning of 2013 (Fig. 4.4). In the months where there were undersized lobster discarded it shows that it was a low number per trip (on average 0.7 lobster per trip).

Fig. 4.4: Mean number of discarded undersized lobster per trip, January 2012 – June 2013. N is the amount of trips (pots and diving) per month. Error bars indicate 95% confidence limits.
4.4 Landed undersized lobsters

A pattern can be seen in the amount of undersized lobsters landed throughout the year (Table 4.3). This data is a combination of both the onboard sampling trips as well as the landed catch in 2012 and 2013. During the winter months (December-February) more undersized lobster are landed (especially females) than during the rest of the year. During these three months the mean percentage of undersized females is 62% compared to about 48% being undersized over the rest of the months. In total 19% of landed males and 54% of females was undersized.

Table 4.3: CL data on catches of female and male lobster over the months. Mean CL and standard deviation are shown including the percentage of undersized lobster over the whole catch during that month per sex by a CL of < 95 mm.

<table>
<thead>
<tr>
<th>Month</th>
<th>Average CL (mm)</th>
<th>Std. Dev (mm)</th>
<th>Number</th>
<th>Undersizes % CL &lt; 95 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F</td>
<td>M</td>
<td>F</td>
<td>M</td>
</tr>
<tr>
<td>January</td>
<td>94,0</td>
<td>104,7</td>
<td>9</td>
<td>10,4</td>
</tr>
<tr>
<td>February</td>
<td>103,0</td>
<td>109,0</td>
<td>10,1</td>
<td>11,7</td>
</tr>
<tr>
<td>March</td>
<td>99,0</td>
<td>106,0</td>
<td>10</td>
<td>11,6</td>
</tr>
<tr>
<td>April</td>
<td>91,0</td>
<td>107,5</td>
<td>7</td>
<td>11,4</td>
</tr>
<tr>
<td>May</td>
<td>91,0</td>
<td>104,0</td>
<td>10,9</td>
<td>14,8</td>
</tr>
<tr>
<td>June</td>
<td>97,0</td>
<td>111,0</td>
<td>10,9</td>
<td>10,3</td>
</tr>
<tr>
<td>July</td>
<td>96,0</td>
<td>106,0</td>
<td>11,4</td>
<td>10,8</td>
</tr>
<tr>
<td>August</td>
<td>93,0</td>
<td>107,0</td>
<td>9,9</td>
<td>8</td>
</tr>
<tr>
<td>October</td>
<td>92,0</td>
<td>98,0</td>
<td>8</td>
<td>11,2</td>
</tr>
<tr>
<td>November</td>
<td>95,0</td>
<td>102,0</td>
<td>9,4</td>
<td>11,9</td>
</tr>
<tr>
<td>December</td>
<td>91,0</td>
<td>103,0</td>
<td>8</td>
<td>12,9</td>
</tr>
</tbody>
</table>

The number of landed undersized lobsters (CL of < 95 mm) differed per month (Fig. 4.5). Where the months of November and January till March 2012 and December of 2012 had a high amount of female undersized lobsters, the amount of male undersized was high during November and February till March 2012 and December 2013.

Fig. 4.5: Mean number of landed undersized lobster (CL of < 95 mm) over November 2012 till May 2013. Error bars indicate SD values for mean number of undersized lobsters.
4.5 Calculating CPUE

4.5.1 Lobster pot fishery

As discussed in section 3.3, fishing effort can be explained by the type of fishing. The first type of fishing discussed is using lobster pots, and can be expressed by different effort units. In the case of pots there are three effort units to be investigated with a double log model to see which correlates best with the number of lobster landed (Fig. 4.6):

- The soaking time of the pots per fishing trip
- The total amount of potdays (pot*days) per fishing trip
- The amount of pots used per fishing trip

![Fig. 4.6](image)

Fig. 4.6: The correlation between effort unit and the amount of lobsters caught per fishing trip. The amount of soaking days (A), the amount of pots per total amount of days (potdays) (B) and the number of pots used per fishing trip.
From figure 4.6 it is clear that there seems to be no correlation between the amount of lobsters landed and the amount of soaking days of the pots (A) and the amount of potdays (B). If there would be a relation between the two, the cloud of dots should be coming from the 0 point as a straight line or a line that flattens out. The results of Fig: 4.6 A and B show that this is not the case. For both the amount of soaking days and the amount of potdays, the \( R^2 \) is low (0.05 and 0.099 respectively) with no significance for the soaking time ( \( P = 0.234 \)) and a significance for the potdays ( \( P > 0.001 \)). The low \( (\text{below} \ 1) \ R^2 \) indicates no correlation between the number of lobsters found and the two effort units and indicates that the variances are poorly explained by the model. The analysis of the amount of pots used per fishing trip (Fig. 4.6; C) shows that there seems to be a correlation with the number of lobster landed per fishing trip. The double log model shows a higher \( R^2 \) value of 0.32 and a significant correlation ( \( P > 0.001 \)), which indicates that 32% of the variance is explained by the model. Now we can conclude that from the three explanatory factors, the amount of pots used on a fishing trip is the most important predictor of CPUE and will therefore be used as an effort measure in this study.

In order to determine if the double log model has the closest fit, the data must first be checked for extreme values. The amount of lobsters landed per fishing trip will therefore be plotted against the amount of pots used per fishing trip (Fig. 4.7). In this plot we can see two values extremely out of place (in red), which might indicate a faulty measure or a mistake in copying data into the database. These two values are possibly coming from a measurement of lobsters from a holding pot. These holding pots are used by fishermen to store great amount life lobsters (20-50 +) inside the harbour, in order to sell all the lobster at once to one buyer. These two points were deleted for further research.

![Fig. 4.7: The number of lobsters caught per fishing trip against the amount of pots used per fishing trip, in red dots the extreme values.](image)
A $R^2$ value of 32% that explains the variance not necessarily indicates that the model has a good fit. Therefore a residuals versus fits plot had to be made, in order to see what patterns are present (Fig. 4.8).

In this way the explanatory variable can be selected that explained most of the variance: the number of lobster pots used during a fishing trip. In order to standardize the CPUE using this variable, the next formula will be used:

$$CPUE_i^{st} = CPUE_i(\bar{f} / f_i)^\beta$$

$CPUE_i^{st}$ = standardized CPUE

$\bar{f}$ = The mean value for the selected effort measure, in this case numbers of pots per fishing trip, in this case 18 pots per fishing trip.

$f_i$ = The number of pots used on fishing trip $i$.

$\beta$ = The coefficient for this selected effort measure from the GLM.

(Tsehaye et al., 2007)
The standardized CPUE stands for the catch per standardised trip (Fig. 4.9). This means that there should be no relationship between standardised CPUE and number of fishing pots, and is shown by the horizontal regression line. Eliminating the effect of a changing amount of lobster pots per fishing trip indicates that any remaining effect represents actual differences in the standardized CPUE (such as seasonal patterns) and that the values found can be used for further research.

Fig. 4.9: The standardized CPUE of the number of pots used per fishing

4.5.2 Lobster diving fishery

In section 3.3, fishing effort can be explained by two types of fishing. The first type of fishing was using lobster pots and the second fishing type is diving. The fishing type diving consist of one effort unit: the duration of each fishing trip. This effort unit will be investigated with a double log model and the standardized CPUE will be calculated (Fig. 4.10).

Fig. 4.10: The correlation between the effort unit fishing duration per trip (hrs) and the amount of lobsters caught per fishing trip.
Figure 4.10 shows that there seems to be a correlation between the amount of lobsters landed and the fishing duration (hrs). The double lob model shows a \( R^2 \) value of 0.36 and a significant correlation (\( P = 0.001 \)), which indicates that 36% of the variance is explained by the model. Now we can conclude that the fishing duration per trip (hrs) is a good predictor of CPUE and can therefore be used as an effort measure in this study.

In order to determine if the double log model has the closest fit, the data must first be checked for extreme values. The amount of lobsters landed per fishing trip will therefore be plotted against the duration of each trip (Fig. 4.11). In this plot we can see no extreme out of place values.

![Fig. 4.11: The number of lobsters caught per fishing trip against the duration of each trip.](image)

A \( R^2 \) value of 36% that explains the variance not necessarily indicates that the model has a good fit. Therefore a residuals versus fits plot had the be made, in order to see what patterns are present (Fig. 4.12).

![Fig. 4.12: The residuals plot of the double log model.](image)
The residuals plot of the double log model (Fig. 4.12) showed a random pattern, not systematically high, low or centred around zero. This plot indicates a good fit of the data.

In order to standardize the CPUE using the effort unit fishing duration per trip (hrs), the next formula will be used:

$$CPUE_i^s = CPUE_i(\bar{f} / f_i)^\beta$$

$CPUE_i^s$ = standardized CPUE

$\bar{f}$ = The mean value for the selected effort measure, in this case the duration (hrs) per fishing trip, in this case 4.3 hrs per fishing trip.

$f_i$ = The fishing duration on fishing trip $i$.

$\beta$ = The coefficient for this selected effort measure from the GLM.

(Tsehaye et al., 2007)

Eliminating the effect of a changing fishing duration per fishing trip indicates that any remaining effect represents actual differences in the standardized CPUE and that the values found can be used for further research.
4.6 Standardized CPUE of pots

To investigate if there are seasonal or annual changes over the spiny lobster catch, the standardized CPUE for pots calculated in the previous section is used (Fig. 4.13).

Figure 4.13 confirms that there is a fluctuation in the catches over different months during a year (data of 2012 and 2013 pooled), with June having a 63% lower mean CPUE (5) compared to the mean CPUE of 16 of all the months together. In September a 87% higher mean CPUE (30) is found than the mean CPUE. There was a statistically significant effect of month on CPUE (ANOVA with 1000 bootstrap) F(11,100) = 4.178, P < 0.001.) A post hoc Tukey-Kramer test showed that the values for June (mean CPUE of 5.8) were statistically different from the months January (21), March (21) and September (30). The mean standardized CPUE of September were statistically different from the values for the April-August (mean of 9.8) and October (13) (Fig. 4.14).
Fig. 4.14: Mean monthly standardized CPUE values for the number of *P. argus* landed from pot fishing pooled for January – December 2012 and January - June 2013. Bars indicate the mean standardized CPUE for traps for that month. The letters A, B and C indicate significantly different groups, months sharing a letter are therefore not significantly different from each other. The horizontal grey line represents the mean standardized CPUE (18 pots) of all months together. N is the amount of pot trips made in that pooled month. Error bars indicate 95% confidence limits.

Fig. 4.14 shows that there are three significantly different groups in the mean standardized CPUE for all months. The months September and June each belong to only a single significant group, with September (group C) having the highest CPUE (30) and June (group A) the lowest CPUE (5). All other months share a group (B) and do not differ significantly from each other in population abundance.
Standardized CPUE of pots per fishing zone

The fishing zones can be divided in the Caribbean Sea side of the island (west) and the Atlantic Ocean (east) side of the island. Both sides were randomly distributed over time. Fig. 4.15 shows the mean standardized CPUE per zone over January 2012 till June 2013. There was nearly a significant difference in CPUE values between the Caribbean side (mean CPUE 15) and Atlantic Ocean (mean CPUE 19) (ANOVA, F(1,72) = 3.375, P = 0.070). Considering the fact that the calculated P value is just above the used α of 0.05, the mean CPUE per fishing zone might be considered as almost statistically different.

Fig. 4.15: Mean standardized CPUE of the Caribbean sea and the Atlantic ocean side of Sint Eustatius. Error bars indicate 95% confidence limits.
4.7 Standardized CPUE of Diving

To investigate if and how the spiny lobster population reacts to seasonal or annual changes, the standardized CPUE for diving is calculated and used (Fig. 4.16).

Figure 4.16 shows that there is a trend in the fluctuation in catches over different months during a year (January 2012 till June 2013 pooled) for the standardized CPUE for diving, with April - July having on average a 24% lower mean CPUE compared to the mean CPUE of 21 for all months together. There was no statistically significant effect of months (ANOVA: F(11,31) = 0.332, P = 0.297).

![Figure 4.16: The standardized CPUE per fishing for diving trip from January 2012 till June 2013.](image)

Figure 4.17 shows that there is a trend in the fluctuation in catches over different months during a year (January 2012 till June 2013 pooled) for the standardized CPUE for diving, with April - July having on average a 24% lower mean CPUE compared to the mean CPUE of 21 for all months together. There was no statistically significant effect of months (ANOVA: F(11,31) = 0.332, P = 0.297).

![Figure 4.17: Mean standardized CPUE of P. argus catches from number of hours diving, pooled data of January 2012 till June 2013. Bars indicate the mean standardized CPUE for that month. The grey line represents the mean standardized CPUE (21) of all months together. N is the amount of diving trips made in that pooled month. Error bars indicate 95% confidence limits.](image)
4.8 Carapace length - over time/between sexes

The mean carapace size of females (94 mm ± 0.38 S.E.; n= 690) landed in November 2011 till June 2013 was smaller than that of males (103 mm ± 0.45 S.E; n=695) (ANOVA: F(1,1383) = 247.042, P < 0.001; Fig. 4.18). The mean length of females was 1 mm below legal catch size (95 mm) in 2011-2013, for males it was 8 mm above the legal catch size. Also most of the large lobsters measured were male, with the largest having a carapace length of 156 mm compared to 138 mm for the largest female.

![Carapace Length Frequency](image)

Fig. 4.18: Carapace length frequency of caught Panulirus argus (mm) over November 2011 till June 2013. The light grey line represent the minimum legal catch carapace length (> 95 mm) for lobsters to be landed on St Eustatius.
The sex ratio of the spiny lobsters landed in January 2012 till June 2013 (data pooled) shows some variation between months (Fig. 4.19). The mean number of lobsters landed per trip follows the same pattern for both males and females with a low number during the months April - October. Only in December a large difference between the number of males and females is found. Looking at both the sex ratio and the number of landed males and females per trip together, not much difference between the sexes can be observed.

Fig. 4.19: The mean number of males and females caught per trip per month of the years January 2012 till June 2013 pooled. The sex ratio (females:males) on the secondary axis.
The mean carapace length of the total catch is influenced by both sex and month separately with $F(10,1383) = 5.312, P < 0.001$ for the months and $F(1,1383) = 135.67, P < 0.001$ for both sexes. The interaction between sex and month was not significant. Figure 4.20 shows that males have a larger carapace length than females in every month (data of January 2012 till June 2013 pooled). Both sexes follow roughly the same fluctuation pattern between months.

Fig. 4.20: The mean carapace length (mm) of males and females caught per month (no data was available for September). Error bars indicate 95% confidence limits for mean CL.
4.9 Size at maturity

Females

To determine the size at 50% maturity for females a sufficient number of small and large lobsters with and without an egg mass or tar spot are needed. The data used for this research is from the on-board sampling. The female size at maturity is defined as the mean carapace length at which 50% of the females is berried and/or has a tar spot. Because for all size classes (carapace lengths of 81 to 124 mm) more than 50% of females was berried or had a tar spot (Fig. 4.30) and the size at maturity for females is calculated as the first length at which 50% or more females is berried or has a tar spot, the 50% point cannot be determined and the analysis of size at 50% maturity for females is not possible.

![Fig. 4.21: The percentage of females that are berried or have a tar spot per 1 mm CL size class.](image)

Males

Because not enough small and large individuals were measured, the allometric relationship between CL and merus length of the second walking leg could not be calculated correctly. Analysing the size at morphometrical maturity for males was therefore not possible (Fig. 4.22).

![Fig. 4.22: The calculation of the allometric relationship between CL and merus length of the second walking leg of males shows that not enough individuals were measured in order to execute a correct calculation.](image)
4.10 Dive surveys inside and outside the no-take zones

The number of lobsters observed during dive surveys declined significantly over the course of the three month period in 2013 (Fig. 4.23). In the first 3 weeks the total mean number of lobsters observed per dive site was 12, while the total mean number of lobsters observed in the second and last 3 weeks were 4.5 and 2.8 respectively. Executing a linear regression from the data in figure 4.24, shows that the number of lobsters observed indeed declines from the beginning of April to the beginning of June with a $R^2$ of 47% and $P < 0.001$, which means that 47% of the variance is explained by the linear model. This decline of lobsters observed during dive surveys is comparable with the findings in figure 4.14, where the population abundance also shows a decline in the course of April until June.

![Graph showing number of lobsters observed during each dive survey from April till June in 2013 within three dive zones. The line indicates a linear decline in number of lobsters observed, with a $R^2$ of 0.47 and $P < 0.001$.]

In order to analyse the number of lobster observed per time unit, each dive survey's time had to be extrapolated to the sample time variable (per hour; Cox and Hunt, 2005). Fig. 4.24 shows the linear regression of number of lobster observed per hour per date (dive survey). The number of lobsters observed per hour per dive survey declines from the beginning of April to the beginning of June with a $R^2$ of 52% and $P < 0.001$, which means that 52% of the variance is explained by the linear model.
Fig. 4.24: Number of lobsters observed per hour per dive survey from April till June in 2013 within three dive zones. The line indicates a linear decline in number of lobsters observed, with a $R^2$ of 0.52 and $P < 0.001$. 

$y = -0.3056x + 12662$

$R^2 = 0.5235$
During the dive surveys, lobster sex was determined and the carapace length was measured. Determining the sex was not always possible and could not be done for 15% of the observed lobsters. There was a statistically significant effect of zones on the mean carapace length of male lobsters (ANOVA: $F(4,752) = 16.4, P < 0.001$). As shown in Fig. 4.25, the mean carapace length found for males in the no-take zones during the dive surveys (120 mm) is significantly higher than the mean carapace lengths found for males in the fishery zones from dive surveys (91 mm), fishery data (103 mm) and historical dive survey data from White (2005) (105 mm), as they belong to significantly different groups (A and B respectively).

For females the effect of zone on mean carapace length was also found to be significant (ANOVA: $F(4,766) = 6.48, P < 0.001$), with the mean carapace length of females measured during dive surveys in the no-take zones (100 mm, group A) being significantly higher than that found for females in the fishery data (94 mm, group B). The mean carapace lengths of females from the dive surveys in the fishery zones and from the historical data from White (2005) did not differ from other groups as they all belong to groups A and B.

The mean carapace length of males is significantly higher than that of females over the different zones (ANOVA: $F(1,1526) = 67.7, P < 0.001$).

![Fig. 4.25: Mean CL (mm) of males and females found in dive surveys (no-take and fishery zones), fishery data (fishery zones) and historical dive survey data from White (2005) (no-take and fishery zones). The letters indicate the different significant groups A and B for both males (black letters) and females (grey letters). N is the number of male and female lobsters measured in each dataset. Error bars indicate 95% confidence limits for mean CL.](image)
4.11 Bycatch of lobster fishery (mainly from lobster pots):
Mixed fish: Number of mixed fish species composition from January - December 2012 and January - June 2013.

Besides catching lobster, the fishermen also catch fish in their pots (Fig. 4.26). In 2012 the amount of fish species landed was 43 with a total of 946 individuals. The species that were landed the most in 2012 were Acanthurus coeruleus (20%), Acanthurus chirurgus (9%) Lactophrys polygonia (14%), Holocentrus adscensionis (6%) and Epinephelus guttatus (9%). In 2013 the amount of fish species landed was 38 with a total of 658 individuals. Of those species the most numerous were (same as in 2012) Acanthurus coeruleus (26%), Acanthurus chirurgus (17%), Lactophrys polygonia (8%) and Holocentrus adscensionis (11%).

Fig. 4.26: Overview of number of caught fish species in 2012 and 2013.
Mixed fish: Biomass (g) of mixed fish species composition from January - December 2012 and January - June 2013.

In 2012 species that had the highest biomass were *Acanthurus coeruleus* (12%), *Lactophrys polygonia* (14%), *Ginglymostoma cirratum* (13%) and *Epinephelus guttatus* (21%). In 2013 the amount of fish species landed was 38 with a total of 658 individuals. Of those species that had the highest biomass were (same as in 2012) *Acanthurus coeruleus* (18%), *Acanthurus chirurgus* (11%), *Lactophrys polygonia* (10%), *Epinephelus guttatus* (14%) and *Sparisoma viride* (13%).

**Fig. 4.27:** Overview of biomass of caught fish species in 2012 and 2013.

The mean fork length (FL) of all the landed fish in 2012 is $23.53 \pm 11.38$ (SD) cm as it is in 2013 with $23.06 \pm 9.94$ (Fig. 4.2).

Fig. 4.28: The length-frequency of total amount of caught fish in 2012 and 2013. In 2012 based on 946 individuals and in 2013 on 658 individuals. Fork length (FL) in cm.

The total landed weight of all fish species in 2012 was 6306 Kg compared to 5055 Kg in 2013. The landed weight during the years differed each month. With a decline from March (21 Kg) to June (9 Kg) in 2012 (in 2013 this decline is visible from March (39 Kg) till May (8 Kg)).

Fig. 4.29: The total weight (Kg) of the total catch of fish in 2012 and 2013. In 2012 based on 946 individuals and in 2013 on 658 individuals.
Mixed-fish: Length-frequency of the five common landed species (numbers)

Graphs of the five of the most landed species were made of 2012 and 2013: *Acanthurus coeruleus*, *Acanthurus chirurgus*, *Lactophrys polygonia*, *Holocentrus adscensionis* and the *Epinephelus cruentatus*. *Acanthurus coeruleus* (Fig. 4.30) and *Lactophrys polygonia* (Fig. 4.32) show the same size distribution over both years. Fig. 4.31 shows that the length distribution of *Acanthurus chirurgus* has shifted to more big sized fish in 2013 compared to 2012 where the number of fish is more equally distributed over different size classes. *Holocentrus adscensionis* (Fig. 4.33) shows the same length frequency pattern for 2012 and 2013, but shows that in 2012 more small (< 20 cm) and big (> 30 cm) individuals were landed. The graph of *Epinephelus guttatus* (Fig. 4.34) shows that in both years same sized animal are landed, with smaller (< 24 cm) and bigger (> 43 cm) individuals in 2012.

Fig. 4.30: Length frequency of *A. coeruleus*. Frequency is number of fish and length is FL in cm. Catches are divided in landed fish in 2012 (black) and 2013 (grey).

Fig. 4.31: Length frequency of *A. chirurgus*. Frequency is number of fish and length is FL in cm. Catches are divided in landed fish in 2012 (black) and 2013 (grey).
Fig. 4.32: Length frequency of *L. polygonia*. Frequency is number of fish and length is FL in cm. Catches are divided in landed fish in 2012 (black) and 2013 (grey).

Fig. 4.33: Length frequency of *H. adscensionis*. Frequency is number of fish and length is FL in cm. Catches are divided in landed fish in 2012 (black) and 2013 (grey).

Fig. 4.34: Length frequency of *E. guttatus*. Frequency is number of fish and length is FL in cm. Catches are divided in landed fish in 2012 (black) and 2013 (grey).
4.12 Larval recruitment

The recruitment of *P. argus* larvae varied between months (ANOVA: F(2,72) = 43.15, P < 0.001) and different locations around the island (ANOVA: F(8,72) = 7.29, P < 0.001), shown in figure 4.35. In Smoke Alley the first month of deployment (March) shows a lower catch rate (4 individuals) than the next five months (April-November), with a mean catch of 24.5 larvae from all pueruli stages and collectors combined over those months. These five months are a different statistical group from the last three months (September-November) that show a lower larval recruitment. These values are in contrast to what is found in the other two collector locations, Jenkins Bay and Blind Shoal, with a much lower mean catch of 1 and 3.8 over all the months.

Fig. 4.35: The mean number of pueruli (all three stages combined) caught for all collectors per site per month, show that the site Smoke Alley has a higher catch rate than the other two sites; Jenkins bay and Blind Shoal. Error bars indicate 95% confidence limits of mean number of pueruli caught.
There was a significant difference in mean number of juveniles and pigmented larvae and the number of transparent larvae collected at Smoke Alley, respectively; $t (31) = 4.826, P = 0.005$ and $t (31) = 3.988, P = 0.014$. For juveniles and pigmented larvae the highest number of individuals was found, with 85 and 95 individuals respectively (Fig. 4.36). The total number of transparent larvae found was the lowest (7).

![Fig. 4.36: The mean number per pueruli stage caught per collectors at Smoke Alley. Error bars indicate 95% confidence limits.](image)
The mean number of pueruli caught in the two different types of collectors used in Smoke Alley, the mussel seed rope collector and the shaggy collector, are shown in Fig. 4.37. There was a significant difference in mean number of pueruli caught between the mussel seed rope collector and the shaggy collectors (ANOVA; F(1, 94) = 3.966, P = 0.049). No significant difference was found between the months in the mean number of pueruli caught for both collector types pooled (ANOVA; F(5, 94) = 1.796, P = 0.121), while both collectors were in the water an equal amount of time.

Fig. 4.37: The mean number of pueruli per month caught in both types of collectors (mussel seed rope and shaggy collector) used in Smoke Alley. Error bars indicate 95% confidence limits.
5. Discussion

Fishery information

The mean total number of fishing trips per day decreased from 1.14 in 2012 to 0.70 in 2013, leading to a reduction in the estimated total number of trips per year. For 2012 the total estimated number of lobster landed from both pots and diving is 4580 with a total weight of 4546 kg, in 2013 this is 2917 lobsters weighing 3292 kg in total. However, the 2013 data was extrapolated from six months to a full year, meaning that a lot of data could not yet be incorporated in these results. The true total yearly catch might be different from the results shown in Table 4.2. Another important factor considering the fishery data is that it is mainly collected from three fishing boats, while ten fishing boats are actively fishing on St Eustatius (de Graaf et al., 2012). Because the data obtained from both short and long interviews was extrapolated from three to ten boats, the number of lobsters landed and their total weight are both estimations and the true values might be different.

The use of different areas around the island by the fishermen when targeting lobster changed slightly between years, as shown in Fig. 4.1. In 2012 all zones except zone 3 (0 %) were visited, and zones 2 (22 %), 7 (24 %) and 8 (37 %) were the main focus of the fishing trips. In 2013 only zones 2, 6, 7 and 8 were fished, and zone 2 (41 %) was more heavily focussed than the previous year. The difference found between the years in fishing zones visited might be caused by changed preferences of the fishermen or by missing data from the second half of 2013. There is also a difference in use of the fishing zones between lobster pot fishery and lobster diving fishery, shown in Fig. 4.2. Where the pot fishery is mainly focussed in zone 2 (37% of the pot trips) and zone 8 (32% of the pot trips), diving is mainly focussed in zone 8 and 7 with a total of 80% (zone 7 and 8 combined; Atlantic side) of the diving trips. The reason that pot fishery is mainly focussed in zone 2 and 8 is that these are the closest fishing zones to the harbour, making pot trips in these zones less time consuming than in other, more distant, fishing zones. However, fishing zone 2 is dangerous when diving for lobsters because it is anchorage zone with a lot of boat traffic, making diving on locations that are not a designated dive-site hazardous. Therefore the closest fishing zones without a lot of boat traffic, zones 7 and 8, are considered the most suitable for lobster diving.

The mean number of berried females discarded per trip per month was highest in February and March (Fig. 4.3), while the mean number of females landed decreases during these same months (Fig. 4.19). The seaward migration of females that occurs during the reproduction season (MacDiarmid, 1991; Goni et al., 2001; Cox and Hunt, 2005) might cause the lower numbers of females being landed because of a reduction in catchability. The lower number of females being landed in combination with more discarded berried females in the same period is an indication of the start of the reproduction season. Also May 2012 and April 2013 show a relatively higher number of berried females, which might be the last months of the reproduction season. These findings are comparable to the reproduction season of P. argus described by Lewis, 1951.

A total of 19 % of males and 54 % of females landed was undersized, and the largest amount of undersized lobsters (64 %) was landed in the winter months (December-February) (Table 4.3). These numbers indicate that there might be some uncertainty about the legal minimum catch size among the fishermen, causing some undersized individuals to be landed.
The CPUE calculated from pot fishery shows a slight significant difference between different fishing zones around the island (Fig. 4.15). Comparing the Caribbean sea side with the Atlantic ocean side shows an almost significance difference, revealing a small trend of higher mean standardized CPUE on the Atlantic side of the island. Although the Atlantic ocean side is rougher (swells, higher currents) in comparison with the calmer Caribbean side, the results are comparable with other studies. MacDiarmid (1991) also showed only little to no correlation between wave surge in the distribution and abundance of *Jasus edwardsii* (a spiny lobster species found throughout coastal waters of Australia and New Zealand).

The standardized CPUE for pot fishing on St Eustatius in 2012 and the first half of 2013 has a mean value of 16 (Fig. 4.14), which is only one third of the mean standardized CPUE on the Saba bank of about 45 in 2012 (van Gerwen, 2013). This large difference in CPUE between these closely located areas can be explained by the difference in the amount of pots used per trip during this period, 13.5 pots per trip on St Eustatius and 79.4 pots per trip on the Saba bank. Since both of the CPUE values were calculated as the mean number of lobsters caught in pots per trip, the higher number of pots used on the Saba bank allows more lobsters to be caught per trip, resulting in a higher mean standardized CPUE value.

**Seasonal changes in CPUE, length frequency and sex ratio**

Changes in catch, length frequency and sex ratio of spiny lobster populations have been observed by researchers for multiple spiny lobster species (including *P. argus*), and have been attributed to moulting and reproduction seasons (Ansell and Robb, 1977; Herrnkind, 1980; MacDiarmid, 1991; Goni et al., 2001) The mean standardized CPUE for pot fishery found in this study showed a pattern during the year (Fig. 4.14), in which the lobster catches were lowest during the summer months (April-August; mean standardized CPUE of 9.8) and highest during the winter months (November-March; mean standardized CPUE of 19.2). Fig. 4.17 shows the same pattern of annual fluctuations in the CPUE from diving fishery (mean standardized CPUE of 21 over all months) as those found from pot fishery. The dive surveys within the boundaries of the marine park and the two no-take zones showed that a decline of lobsters is observed during the summer months (Fig. 4.23) within the no-take zone, which is in agreement with findings in the general use fishing zone of the lobster fishery data (Fig 4.14 and 4.17). These results show the same annual fluctuation in lobster catch as found by White (2005), where the total weight of lobsters landed per month in 2004 declines from January - April and increases in November - December. Both findings indicate similar patterns of migration to deeper waters as found in the general use zones in the marine park. During the reproduction season of spiny lobsters (February-May on St Eustatius) there is a general seaward migration of females from shallow protected areas to offshore areas for reproduction (MacDiarmid, 1991; Goni et al., 2001; Cox and Hunt, 2005). Males stop feeding during the reproduction season, hence the decline in male lobster catchability during the summer period (Kelly, 2001). Therefore, the fluctuations in abundance and number of lobsters observed in the St Eustatius marine park throughout the year seem to be related to the annual timing of reproduction and corresponding migratory movements.

Although an effect of months was observed on the mean carapace length, no pattern is revealed of changes during the reproductive season. In general, females had significantly smaller carapace lengths than males (94 mm and 103 mm respectively, Fig. 4.18). A study in
Belize found a mean carapace length of 79.9 mm for female and 83.8 mm for male *P. argus* (Gongora 2010), which is lower than the values found on St Eustatius. This indicates that the length distribution of *P. argus* shows variation across its geographical range in the Caribbean. In this research a trend is observed of male carapace length decreasing from 109 mm in June to 100 mm in October (Fig. 4.20), which might suggest that large males participate in autumn migrations more often than smaller individuals, probably as a result of reproductive activity (Goni et al., 2001).

The fluctuation in numbers of *P. argus* within the shallow fishing zone shown in Fig. 4.19 suggests that there is little variation in migratory movements between males and females on St Eustatius. When not taking April into account, because of the very low amount of lobsters landed this month, the sex ratio does not change much during the reproduction season. The most extreme sex ratios occur in December (0.55) and August (1.42), but the difference between these values is still relatively small compared to the range of sex ratio values found for *P. argus* by Cox and Hunt, 2005, varying from 0.3 to 5.0. These low differences in sex ratio values are comparable to the pattern of lobster numbers shown in Fig. 4.19, where the lines for males and females are very close together.

**Size at maturity and the legal catch size on St Eustatius**

The collection of the data in order to calculate the size at 50% maturity for females was done throughout the reproductive season (Lewis, 1951). The highest mean number of berried females on St Eustatius were recorded in February and March and declined in April to reach regular levels around May (Fig. 4.3), indicating that the spawning season is during this period. During this time females were checked for an egg mass or tar spot, and their carapace length was measured. The collection of the data for determining the size at 50% maturity for females, was done by measuring berried females and females with a tarspot during on-board sampling trips. In order to calculate the size at 50% maturity, a sufficient amount of small and large female lobsters are needed. Almost all females that were caught by the fishermen had an egg mass or tar spot. Because for all size classes (carapace lengths of 81 to 124 mm) more than 50% of females was berried or had a tar spot (Fig. 4.21) and the size at maturity for females is calculated as the first length at which 50% or more females is berried or has a tar spot, the 50% point cannot be determined and the analysis of size at 50% maturity for females is not possible. In order to calculate the size at 50% maturity for females, more small females (carapace length < 81 mm) must be measured.

Another point of interest is that all the females that were caught during this period, and can be considered mature, were above a certain size (81 mm). If so, than all the females that were measured during this research were already mature and the size at 50% maturity for the female lobsters around St Eustatius should be below a carapace length of 81 mm. Considering this, and the legal catch size of 95 mm around St Eustatius (Fig. 4.18), this minimum catch size might be considered an accurate measure.

Calculating the size at morphometrical maturity for males was not possible in this study, because for males also a sufficient amount of data over the whole range of carapace lengths is needed in order to execute a correct calculation for the size at morphometrical maturity (Fig. 4.22). Another remark on using the length of the merus of the second walking leg is that lobster are able to regenerate lost limbs (Davis and Dodrill, 1989; Dubola et al,
2005). A leg that is being regenerated is much smaller than its counterpart, and in such cases the larger leg was measured.

Research done by van Gerwen (2013) shows that the size at morphometrical maturity for males on the Saba bank is 92.9 mm of carapace length. When it is considered that the Saba bank is relatively closely located to the marine park around St Eustatius and that the size at morphometrical maturity for males might be considered equal in both locations, the minimum legal catch size of 95 mm carapace length on St Eustatius is high enough to allow male *P. argus* to reproduce before being landed. In the results from the dive surveys where carapace length of male lobster were measured in- and outside the no-take zones, we saw that the mean length of male lobster inside the no-take zones was around 120 mm compared to the 90 mm outside the reserves. This indicates that the male lobsters found inside the no-take zones are more often morphologically mature than male lobsters found in the fishing zones, which might lead to a difference in reproductive output between the zones.

According to several studies done on the size at maturity on male and female *P. argus* on different locations, their size at first maturity varies widely on a geographic range (Fonseca-Larios and Briones-Fourzán, 1998), from 45 mm at first maturity for females in the Bahamas to 70 mm for females in the Caribbean (Sutcliffe, 1957). A study done by Maxwell et al., 2009, shows that within a close geographic range near the Florida Keys, the size at first maturity for females ranges from 57 mm carapace length in the Florida Keys to 70 mm carapace length in the Dry Tortugas. Hypothesis for these major differences in (different types of) size at maturity for females and males are offered by Morgan, 1980; Briones-Fourzan and Lozano-Aivarez, 2003 and Melville-Smith and de Lestang, 2006, who suggested that these variations result from differences in water temperature or food availability between locations, so that the smaller size at first maturity corresponds to areas of relatively higher temperatures. Another explanation might be that in heavily fished populations, females reproduce at a smaller size as a 'compensatory response' (Bertelsen and Matthews, 2001; Melville-Smith and de Lestang, 2006). Therefore it is important to determine the size at maturity for every local population for both male and females. By knowing this we might get a better insight in how populations reproduce and how this is affected by seasons and fishery, as well as determining the true size at maturity for the females (size at 50% maturity) and males (morphometrical maturity) around St Eustatius and assessing if the minimum legal catch size should be considered accurate or not.

The effect of no-take zones on mean spiny lobster carapace length

Distinct results are found when comparing the mean carapace length of both males and females between the no-take and fishing zones. The mean carapace length found for males in the no-take zones during the dive surveys (120 mm) is significantly higher than found for males in the fishery zones from dive surveys (91 mm), fishery data (103 mm) and historical dive survey data from White (2005) (105 mm) (Fig. 4.25). For females the effect of zone on mean carapace length was also significant, with the mean carapace length measured during dive surveys in the no-take zones (100 mm) being significantly higher than that found for females in the fishery data (94 mm). It is important to note that the no-take zones in the marine park of St Eustatius consist mainly of high structure reefs, while the adjacent fishing areas contain habitats that are generally less structured. This difference in habitat structure
might influence mean spiny lobster size, making the effect of no-take zones less detectable. However, studies on other spiny lobster species have found no effect of habitat quality on mean size (Wynne and Côté, 2007) or showed that larger lobsters are less dependent on structurally complex habitats (Bellchambers et al., 2010), indicating that the difference in carapace length observed in this study is most likely an effect of fishing activities. No-take zones were also found to have a positive effect on carapace length in other lobster species (Kelly et al., 2000; Davidson et al., 2002). The increase in mean male size inside the no-take zone suggest that some lobsters remain there for longer periods of time and are becoming residents (Cox and Hunt, 2005; Goni et al., 2006). The comparison of dive survey data with fishery data showed that the mean carapace length was greater in the no-take zones than in the fishery zones for both males and females (Fig. 4.25), which demonstrates the role that no-take zones have in the recovery of a population and show the impact fishery has on the *P. argus* population (Kelly et al., 2000). Large spiny lobsters also tend to stay in the no-take zones when given the opportunity as they show more site attachment than smaller individuals (Davis, 1977; Cox and Hunt, 2005).

Having large males in a certain area is shown to have an important impact on the fecundity of the spiny lobster population (Cox and Hunt, 2005). Large female lobsters (carrying larger numbers of eggs than small females) prefer to mate with large male lobsters over small males (MacDiarmid, 1989; Davidson et al., 2002; Cox and Hunt, 2005), because large males carry more sperm and can fertilize the bigger number of eggs that large females carry. The amount of offspring per female correlates with the size of the male (MacDiarmid and Butler, 1999). This suggests that the significantly larger male and female spiny lobsters inside the two no-take zones may have a higher reproductive output than the somewhat smaller individuals found in the fishing zones (Davidson et al., 2002).

**Monitoring program for larval recruitment**

Several locations and materials were investigated for use in a larval recruitment monitoring program on St. Eustatius. With a statistically significant difference the amount of pueruli caught was higher at Smoke Alley than the two other sites Jenkins Bay and Blind Shoal. There are multiple things that need to be taken into account when considering why such a big difference is found between the sites. The first point is that all newly build collectors (shaggy collectors) need at least a few months of soaking time (according to Butler, larvae collector building, at least two months) before they become attractive to larvae. The collectors at Jenkins Bay and Blind Shoal show a slight increase during the months in the amount of lobster caught, which might indicate that the collectors got more attractive over the months after deployment. The collectors at Jenkins Bay and Blind Shoal show a slight increase during the months in the amount of lobster caught, which might indicate that the collectors got more attractive over the months after deployment.

The second point is the characteristics of the location. Both Jenkins Bay and Blind Shoal are located in an area were the depth is greater than the preferred (2-5 meter) depth (Butler, larvae collector building). As well as depth, the habitat of the sites also differs with only sand in Smoke Ally and some more hard substrate and reef available in Jenkins Bay and Blind Shoal. According to Herrnkind and Butler, 1994, the relationship between post larval *P. argus* abundance and habitat is not understood very well. In their research they found that near shore areas with poor settlement substrate (low habitat structure like sand or algae) the amount of pueruli caught in collectors was highest. These results were also found by Phillips
et al., 2001, where inshore sites with low structured substrates showed the highest amount of pueruli caught in collectors. These outcomes correspond with the type of habitat and depth of the near shore bay in Smoke Alley. The habitats used in Jenkins Bay and Blind Shoal vary as the bottom substrate contains reef patches (high spatial structure) with much more settlement places for the larvae. A factor other than bottom substrates that might have resulted in the lower amount of pueruli caught in Jenkins bay and Blind Shoal compared to Smoke Alley, is the difference in water movement and wind speeds. Jenkins Bay and Blind Shoal are located towards both ends of the island (North and South), and these location are more exposed to rough weather than Smoke Alley (own observations). According to Quinn and Kojis, 1997, water movement will have an impact on post larval settlement. Slightly increased water movement will benefit settlement, but a there is a threshold of a maximum flow rate that results in reduces settlement. Increased water flow is a direct result of increased wind movements, and these increased winds and water flows could have the effect of decreased amounts of post larvae settlement (Acosta et al., 1997).

Differences in catch rate of pueruli between months can be seen in Fig. 4.35, where the total amount of pueruli during the spring months are high and then decline over June and July. Research done by Acosta et al., 1997 and Butler et al., 2010 also show an increased post larval influx during the spring months and a decrease in the summer to the winter months. It is hypothesized that during the summer months the wind drops below a certain level so that settlement could not occur (Acosta et al., 1997). These assumptions state that pueruli need a wind and water flow speed up to a certain maximum in order to settle on substrates. Also temperatures play an important role in the settlement and growth of pueruli and therefore the time of settlement during the year is dependent on temporal fluctuations in temperature (Forcucci et al., 1994). The colder winter months will slow down the growth of the pueruli that would have settled during the fall or winter months, so when the temperature increases in the spring months the pueruli will begin to settle more. Therefore the monthly fluctuation of settlement found in this research might be a result of biological and physical processes. Influences due to variations in temperatures, winds, water flows, larval attraction to substrates and time of spawning strengthen these fluctuations (Butler et al., 2010). Fig. 4.36. shows the amount of pueruli caught in Smoke Alley, where the amount of pigmented larvae and juveniles caught exceeds the amount of transparent larvae. Forcucci et al., 1994, also found that the caught pueruli were mostly dominated by non transparent larvae. These findings might be due to the fact that lobsters above a certain size are more easily seen (and therefore collected) on the collector material than smaller and less pigmented individuals, and more practise is needed to fully extract al different types pueruli from the collectors.

During the last two months of the research, two different types of collectors (mussel seed rope collector and shaggy collector) were deployed in Smoke Alley in order to determine which collector type collected the most pueruli. Results in Fig. 4.37 show that there is a slight significant difference between the mussel seed rope and shaggy collector. Considering the fact that the mussel seed rope collectors were already used in the previous year, their start-up soaking time could have been reduced greatly in comparison with the newly deployed shaggy collectors. Another major difference between the two types of collectors is the use of either mussel seed rope or 'fuzzied' polypropylene rope. The downside of this collector is that it is costly and maintenance inefficient. Because of these downsides the shaggy collector was

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introduced, which is comparable with another collector that was used in Mexico and other places in the Caribbean. The newly deployed shaggy collectors might have needed more start-up soaking time than the two months stated for the mussel seed rope collectors. Therefore, in order to make a verdict on which collector is best suited to use in this marine park more time and research is needed.

Monitoring the recruitment of post larvae *P. argus* has as goal to predict fishery catches and managing the fishing effort on the population stock. Monitoring programs in Australia have shown to be very successful in predicting the fishery from post larval supply (Butler et al., 2010). Thus far, predictions on larval recruitment in the Caribbean have not yet reached the same degree as in Australia. Despite this, monitoring the recruitment of post larval settlement in the Caribbean has proven to be useful for other purposes, such as stock assessment and the linkage between recruitment and meteorological or oceanographic phenomena (Butler et al., 2010).
6. Conclusions

- The abundance of *P. argus* around St Eustatius shows seasonal patterns related to the reproductive season due to migrations in February - May, but mean length and sex ratio showed no seasonal changes.

- For both males and females of *P. argus*, the mean carapace length is greater inside the no-take zones compared to the adjacent fishing zones, indicating that no-take zones have the effect of allowing a population to recover from the impact of fishery.

- Although the actual size at 50% maturity for females could not be calculated, the results show it lies below 81 mm. While the size at morphometrical maturity for males could also not be calculated the value was found to be 92.9 mm for the Saba bank, an area very close to St Eustatius. When taking these values into account, the minimum legal catch size of 95 mm might be considered accurate for both males and females.

- A larval recruitment monitoring program on St Eustatius can contribute to predicting future lobster catches, allowing for effective fisheries management. The location of the larvae collectors is an important factor as the bottom substrate should have little structure, and should not be exposed to high winds and currents. During this study mussel seed rope collectors appeared slightly more effective than fuzzy collectors, however, the difference between these collector types must be investigated further to truly decide which type is better.
7. Recommendations

In order to continue this line of research some changes in methodology are recommended. In order to get a better understanding of the population abundance around the island in and outside the reserve and measuring the recruitment, more data over multiple years is needed. By obtaining more data over the course of multiple years, fluctuations of the population abundance (standardized CPUE) might become more clear. With this information it is possible to monitor and act on changes in the population. Monitoring the recruitment over multiple years also provides information on how post larvae react on meteorological and oceanic changes. As well as using the collectors for monitoring purposes, more time is needed to make a decision on which collector type to use in this research. In this research the mussel seed rope collector is proven to be an efficient collector of larvae, where the shaggy collector is not yet proven. A very important factor considering calculating the size at maturity, is staying very consistent with measuring males and females every time the opportunity is there. Considering the fact that measuring females is only possible during reproduction season, enough females of every size possible should be caught and measuring during onboard sampling within this time span. As for males, which can be measured all year round, also individuals of every size class should be measured.

Besides continuing to obtain the same data as collected in this study, measuring the amount of spill over from the reserves might provide an insight to whether the adjacent fishing zones benefit from the reserves as found in other studies (Freeman et al., 2009). In order to do so, lobsters inside the no-take zones should be measured, sex should be determined and they should be tagged dorso-laterally between the first and second abdominal segments with Hallprint T-bar tags (Goni et al., 2006; Fig. 5.1).

![Fig. 5.1: California spiny lobster (Panulirus interruptus) with a hallprint T-bar tag inserted dorso-laterally (Hovel and Neilson, 2001).](image)

Tagging each individual lobster with a unique number enables us to look in detail at small-scale movements. In a tag-recapture study done by Goni et al., 2006, on spiny lobsters, they found that tagging data provided evidence of a lobster density gradient resulting from spill over of lobsters from the reserve. Migration of mobile lobsters from the reserve to the adjacent fishing zone would result in a density gradient from a higher density inside the reserve to a lower density in the fishing zone (Fig. 5.2).
An interesting side effect of a no-take zone implementation suggested by Parsons et al., 2003, is that over time a reserve might harbour mainly sedentary individuals that are residential to that area. In that case, mobile individuals will migrate out of the reserve and will get caught in the adjacent fishing zone. Over a certain time span, all mobile individuals will have moved out of the reserve so only sedentary individuals are present (Fig. 5.2).

Another result that might be expected, as found by Davidon et al., 2002 and Goni et al., 2006, is that the amount of tagged lobsters caught outside the reserve is independent of the distance to the boundary of the reserve up to a certain distance (in the previous research that distance was 1500 meter). This might imply that the lobster population from the reserve supplies the adjacent fishing zone. In order to assess whether fisheries benefit from reserves and if reserves effectively protect the majority of the lobster population, replicates of monitoring the reserve population and caught population over time are needed (Goni et al., 2006; Freeman et al., 2009).
8. Acknowledgements

I would like to thank Dr. Martin de Graaf and Dr. Leo Nagelkerke for giving me the opportunity to do fieldwork on a beautiful island in the Caribbean. It has been an eye opener for me on how to conduct marine research and how to implement and to use different techniques to collect data. My utmost gratitude goes to my field supervisor Erik Boman and my brother in arms Tiedo van Kuijk. Without Erik’s devotion and advice in helping me every day of the week, my research would be a lot harder to complete if not impossible. I thank my fellow student Tiedo, in helping each other with both my and his fieldwork, we were able to discover an even bigger bond in working together.

I thank the fishermen of Statia for their excellent cooperation and laughs during our boat trips and our stays at the fisheries. Also the help of STENAPA and her interns was very much appreciated and helpful. Jessica, Steve, Nadio, Steven, Tess, Olivia, Mandy and Fiona were a great help during Erik’s short absence for captaining the blue runner, emptying the larvae collectors and the conducting the dive surveys. And last but not least I would like to thank Melanie. In the last few weeks of my internship she was a great help during my dive surveys for captaining the research vessel. This research was financed by BO-11-011.05-026 and TripleP@Sea innovation program (KB-IV-007).
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Visserijlandsverordening (P.B. 1991, no. 74) (Visserijlandsbesluit).


Appendix 1
Protocol on how to build a shaggy collector

Materials needed for 1 collector:

- Polypropelene rope that is easy to splice; per collector about +/- 14 meter.
- Two 1 meter of ½” diameter pvc pipes and two 0,5 meter ½” diameter pvc pipes. Next to the pvc pipes, four ½” diameter pvc elbows are needed.
- 0,5 m² coated chicken mesh (1 meter – 0,5 meter)
- Two buoys, flag, weight (+/- 0.25 kilo), garden hose
- A saw, measuring tape, duct tape, knife, tie-rips (+/- 30)
- It is important to have good PVC glue or cement
- Shackle
- 4 concrete blocks
- More rope (to tie the collector to the concrete blocks) that is as long as the depth of where the collector will be placed + 30-40% extra (for slack).

Assemblage of the shaggy collector

Step 1:
After sawing the pvc pipes in the correct length, make sure each ending is well sanded and polished and that the loose bits (see picture) are gone.

Step 2:
Glue each elbow onto a pvc pipe end. After doing this, glue each pipe to another so you create the frame of the collector (make sure the frame is flat, otherwise the loose ends will not fit properly!!)
Step 3:
After making the frame, cut a piece of slightly larger than 1 meter wide of the coated chicken mesh. You want to have a bit more in order to fold both ends over the frame.

Step 4:
After folding both ends over the frame, use tie-rips to fasten the coated chicken mesh onto the frame. Use 2 tie-rips on the short end and 3 tie-rips on the long ends of the frame (place the tie-rips in such a way that they are evenly spread).

Step 5:
Cut three pieces of rope; 2 pieces of length 1,20 meters and 1 of 2,40 meters. Use the 1,20 meter pieces on one side, and the 2,40 meter on the other side of the frame.

Step 6:
Splice the ends of the two shorter ropes to one side of the frame on each corner. The two ends of the rope of 2,40 meter should both be on the other side of the frame spliced on the both corners. (Tip: in order to splice, use duct-tape to tape the three ends of the rope, this will make the splicing easier!!)
Step 7:
Cut 18 pieces of 50 cm of rope. Tie each rope to the coated chicken mesh inside the frame in 3 rows with a knot, and each rows consist of 6 knots. Make sure that each knot has 20 cm of rope on each side of the frame. After knotting all 18 ropes, secure each rope with a tie-rip.

Step 8:
The time consuming part: Fuzzy 36 ropes (that is on both sides of the frame). Fuzzy the entire rope till you have a lot of little wires.

Step 9:
In order to keep the collector in place when it is in the water you want to secure it to 4 concrete blocks using a long rope. Because the collectors are subjected to a lot of waves the rope used for this might shave itself on the concrete blocks. To prevent this, cut 1,5 meter of garden hose and put the last end of the rope through it. Tie a temporary knot in this end of the rope so it doesn’t go back out of the hose again (see left picture), because this end will have to be spliced on the boat just before dropping the collector. On the boat the garden hose with rope has to go through all four concrete blocks and be placed on the bottom (see below). Also splice a loop into the other end of the rope (see left picture) to attach to the collector rope with a shackle.
Step 10:

In order to make the collectors visible when they are in the water, it is wise to add a flag on one buoy (with a weight under the buoy) and write ‘research’ on the other.

Step 11:

Place the collector in the water. Make sure the concrete blocks are placed correctly (on sand, not coral) and that the rope is shave guarded with the hose.
Appendix 2
Bycatch larvae collectors

Together with the spiny lobster larvae, many other small creatures and juveniles were caught in the collectors (Fig. 10.1; Table: 10.1). The families and species that were caught the most in all collectors were: crabs, nudibranches, sargassum filefishes, sergeant major, seastars, shrimps and snails.

Table 10.1: Organisms other than *P. argus* found in the collectors. Of each species or family the amount per month and site is counted, as well as the total number observed.

<table>
<thead>
<tr>
<th>Organism Type</th>
<th>March</th>
<th>April</th>
<th>May</th>
<th>June</th>
<th>July</th>
<th>August</th>
<th>September</th>
<th>October</th>
<th>November</th>
<th>Total observed</th>
<th>No. times observed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arrowcrab sp.</td>
<td>5</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>5</td>
<td>1</td>
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<td></td>
<td>18</td>
<td>7</td>
</tr>
<tr>
<td>Bandtail puffer</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Barjack juv.</td>
<td>1</td>
<td></td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td></td>
<td>2</td>
<td></td>
<td>13</td>
<td>4</td>
</tr>
<tr>
<td>Blennie sp.</td>
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<td>1</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td>13</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blue tang juv.</td>
<td>1</td>
<td>13</td>
<td>15</td>
<td>6</td>
<td>2</td>
<td>4</td>
<td>9</td>
<td>50</td>
<td></td>
<td></td>
<td>7</td>
</tr>
<tr>
<td>Brown chromis juv.</td>
<td>9</td>
<td>4</td>
<td></td>
<td>9</td>
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<td></td>
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<td>23</td>
<td></td>
<td></td>
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<td>2</td>
<td>9</td>
<td>7</td>
<td>21</td>
<td>23</td>
<td>100</td>
<td>70</td>
<td>31</td>
<td>14</td>
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<td>1</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>13</td>
<td></td>
<td></td>
<td>7</td>
</tr>
<tr>
<td>Goby sp.</td>
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<td>3</td>
<td>1</td>
<td>3</td>
<td>10</td>
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<td></td>
<td>6</td>
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<td>Larvae (un-identified)</td>
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<td></td>
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<td></td>
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<tr>
<td>Juvenile fish</td>
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<td>9</td>
<td>13</td>
<td>19</td>
<td>3</td>
<td>4</td>
<td>10</td>
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<td>Latice nudibranch</td>
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<td></td>
<td></td>
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<td>Needelfish juv.</td>
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<tr>
<td>Nudibranch sp.</td>
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<td>6</td>
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<tr>
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<td>5</td>
<td>1</td>
<td>2</td>
<td></td>
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<tr>
<td>Pygmy filefish juv.</td>
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<td>9</td>
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<td></td>
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<tr>
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<td>7</td>
<td>8</td>
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<td>7</td>
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<tr>
<td>Sargassum swimming crab</td>
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<td>7</td>
<td>2</td>
<td>7</td>
<td>8</td>
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<tr>
<td>Sargassum frogfish</td>
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<td>2</td>
<td>7</td>
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<tr>
<td>Sargassum swimming crab</td>
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<td>7</td>
<td>2</td>
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<td>8</td>
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<td>6</td>
</tr>
<tr>
<td>Snail sp.</td>
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<td>126</td>
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<td>5</td>
</tr>
</tbody>
</table>

Fig. 10.1: Other organisms found that might get caught in the collector; from left to right: sargassum frogfish, arrow crab, juvenile fish, nudibranch, juvenile sargassum filefish, juvenile bluetang plus a juvenile sergeant major.
May

June
September

October
November