Toledo Institute for Development and Environment

Commercial Benthic Species UPDATE: 2017–2018
Port Honduras Marine Reserve
Conch, Lobster, Sea Cucumber

Benthic Species Update 2017–2018

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Gratitude and appreciation are also extended to the current and past TIDE Research and Monitoring staff whose time and effort aided in the compilation of this report.

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- Tanya Barona (former marine biologist) - fieldwork logistics support
- Nigel Gomez - data management support

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ACRONYM KEY	
AGRRA	Atlantic and Gulf Rapid Reef Assessment
BFD	Belize Fisheries Department
EDF	Environmental Defense Fund
ERZ	Extended Replenishment Zone
GRMR	Glovers Reef Marine Reserve
GUZ	General Use Zone
LT	Conch Lip Thickness
OUT	Marine Areas Close to but Outside PHMR
PCNP	Payne's Creek National Park
PHMR	Port Honduras Marine Reserve
PRZ	Preservation Zone
RZs	Replenishment Zones (previously NTZs)
SL	Conch Shell length
TAC	Total Allowable Catch
TNC	The Nature Conservancy
TIDE	Toledo Institute for Development and

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1. Program Overview

1.1 Fisheries Assessment Report 2009–2012

In 2013, TIDE research and monitoring department conducted a comprehensive assessment of commercial benthic and finfish species in PHMR, comparing fisheries dependent data (boat and landing site surveys of catch) and fisheries independent data (underwater surveys) from 2009–2012. Mean size, population structure and population density or abundance was determined for each species, comparing different management zones in the reserve [Replenishment Zones (RZs), General Use Zone (GUZ) and outside of PHMR (OUT)].

TIDE has also been consistently conducting underwater surveys of the two most important species, conch and lobster, since 2004 to the present, providing information on their population density/abundance, size and maturity. Since 2011, sea cucumber (*Holothuria mexicana*, common name donkey dung) has also become a significant commercial species. Underwater surveys have been conducted by TIDE for *H. mexicana* since September 2011.

1.2 Benthic Commercial Species Audit 2009–2013

The aim of the 2009–2013 Benthic Commercial Species Audit was to inform adaptive management of Managed Access, then in its third year of implementation, in the Port Honduras Marine Reserve. It was a comprehensive assessment of the health of commercially exploited benthic species in PHMR, by far the largest local fishery products in both income and weight. This was necessary to improve understanding of the complex relationships between commercial benthic species of PHMR, fishing and the environment, and was crucial for informing on the effectiveness and adaptive design of Managed Access. A long-term goal of TIDE's commercial species monitoring programs is to be able to assess stock levels of commercial benthic species and enable sustainable catch quotas to be determined for PHMR. Detailed background information on the program can be found in the 2009–2013 Benthic Commercial Species Audit Report. Since 2014, update reports of the Benthic Commercial Species have been produced by TIDE annually or biennially.

1.3 This Report: Benthic Commercial Species Update 2017–2018

This report summarizes the benthic commercial species queen conch (*Lobatus gigas*), spiny lobster (*Panulirus argus*) and sea cucumber (*Holothuria mexicana*, also known as donkey dung) monitoring conducted by the Research and Monitoring program at the Toledo Institute for Development and Environment during the calendar years 2017-2018. Methods and results are reported for long-term abundance monitoring and morphometric data collected during underwater surveys covering a ten-year period for lobster and conch (2009-2018) and an eightyear period for sea cucumber (2011-2018) in the replenishment zone (RZ), general use zone (GUZ), and outside (OUT) PHMR, with emphasis on informing the effectiveness to date of Managed Access as a fisheries management tool for Belize. A map of monitoring sites for each species in each zone in PHMR can be found in appendices A1-A3.

2. BACKGROUND

2.1 Port Honduras Marine Reserve

The Port Honduras Marine Reserve (PHMR) lies off the coast of Southern Belize. Starting from the mouth of Monkey River, it extends south to 8 km north of Punta Gorda Town and 25 km east to include the Snake Cayes (Robinson et al. 2004). The Marine Reserve covers an area of 414 km^2, incorporating coastline, mangrove cayes, submerged banks and a number of ecosystems of critical importance to local coastal communities and to Southern Belize as a whole. Extensive seagrass meadows cover the shallow-coastal areas and surround an intricate network of mangrove cayes. Thick mangroves cover nearly all of the 138 Cayes within the reserve and border the coastline and estuaries of PHMR. Fringing coral reefs encompass the offshore Snake Cayes and patch reefs are scattered throughout the reserve. These ecosystems are home to a myriad of flora and fauna, which live in delicate balance with one another and their surrounding environment. Some of these organisms are of considerable commercial benefit to the local communities and to the wider economy of Belize, such as the queen conch, sea cucumber and the Caribbean spiny lobster.

PHMR was established in 2000 and is co-managed by the Toledo Institute for Development and Environment (TIDE) and the Belize Fisheries Department (BFD). PHMR is composed of three zones (Fig. 1): 95% is a General Use Zone or GUZ (regulated extractive activities allowed), 4% is a Replenishment Zone or RZ (non-extractive activities only) and 1% is a Preservation Zone or PRZ (research activities only). As such, only 5% of the reserve is under full protection from extraction.

2.2 Buffer Communities

Three main communities depend on the marine resources of PHMR for commercial and subsistence purposes. Known as the “buffer communities”, these are Punta Gorda, Punta Negra and Monkey River Village. Punta Gorda, located 2–3 km south of PHMR is the largest of these, with approximately 6,500 people. Punta Negra, on the central part of the mainland coast of the reserve between Punta Ycacos and Monkey River, is the smallest with approximately 20 residents. Monkey River Village, with approximately 200 residents, is located at the northern end of the reserve on the southern bank of the mouth of the Monkey River. There is approximately 10–15 km between each of these communities. Commercial and recreational residents from these communities’ fish for conch, lobster and various finfish species in PHMR.

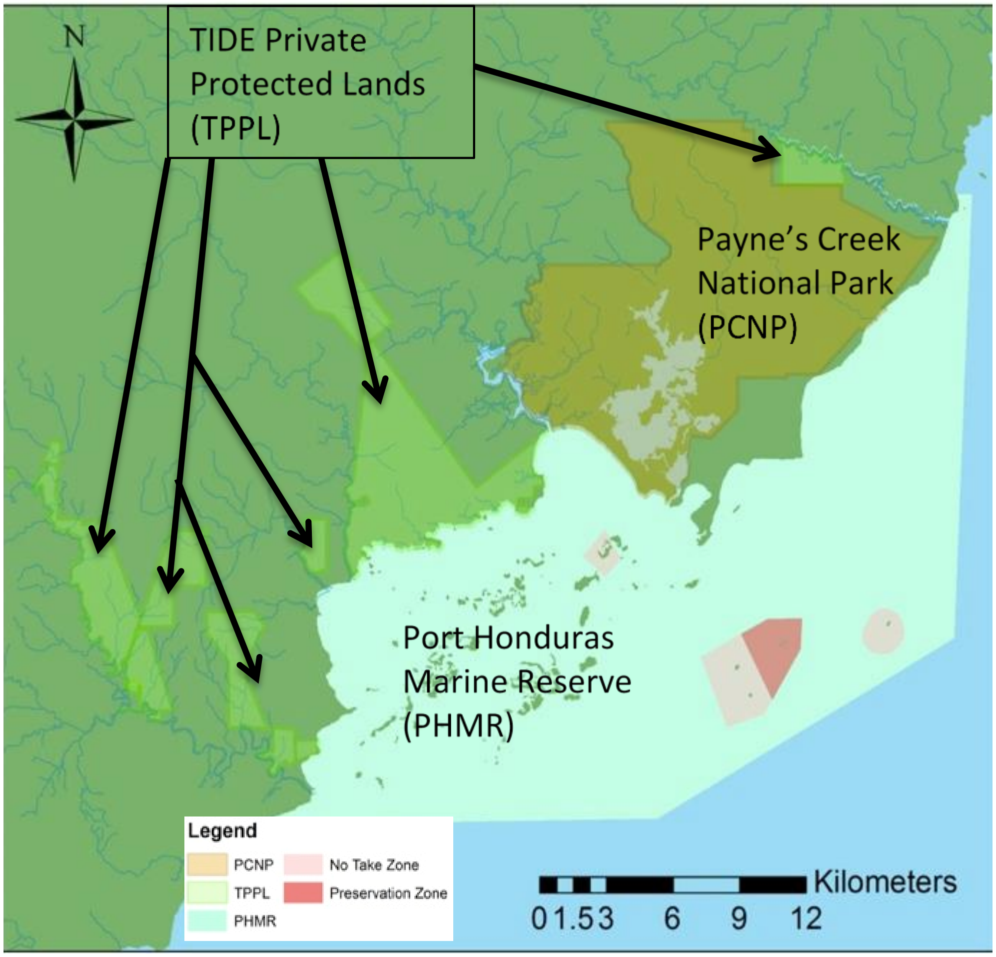

Figure 1. Management zones of Paynes Creek National Park (PCNP), TIDE Private Protected Lands (TPPL) and Port Honduras Marine Reserve (PHMR), showing proposed Replenishment Zones (light & dark pink areas) after 2013 stakeholder consultations, the General Use Zone (GUZ) in lighter blue and Outside the reserve (OUT) in dark blue.

2.3 Replenishment Zones and Spill-Over Effects

It is widely agreed among marine protected area specialists that at least 20% of a marine protected area needs to be "no-take" in order for there to be sufficient spillover into general use areas. This is a theory also supported by the Belize Fisheries Department (BFD). After concern that RZs in PHMR were not meeting this threshold, public consultations were held by TIDE in 2013 with PHMR stakeholders from all three buffer communities. A small extension was agreed upon to encompass West, South and Middle Snake Cayes within one contiguous Replenishment Zone with verbal approval from the Belize Fisheries Department to demarcate the corners of the new expansion with buoys. There proved to be a range of habitat types at the points where the buoys would be deployed requiring different engineering solutions for the different points. There was considerable debate on movement of points to coincide with easier buoy deployment and equipment purchases. This hinderance, combined with no formal designation being written into law by the BFD, and the fact that the proposed contiguous RZ would still fall short of the mandate from the BFD to increase RZs to 20% in marine reserves by 2020, caused the project to lose momentum. Renewed efforts to engage stakeholders in RZ expansion consultations are needed in order to make the BFD mandate to increase RZs to 20% by 2020.

3. MONITORING METHODS

Data on population density, maturity and size frequency of queen conch (*Lobatus gigas*, originally *Strombus gigas*), Caribbean spiny lobster (*Panulirus argus*) and donkey dung sea cucumber (*Holothuria mexicana*) were collected and analyzed. This involved comparison of morphometric data from underwater surveys of lobster, conch and sea cucumber.

3.1 Conch

In the years 2009–2010, conch monitoring took place twice each year, just before the conch season closes in June, and shortly before it opens again in September. Starting in 2011, the first monitoring was moved to July, just after the conch season closed, in order to capture the impact of all open season extraction.

Queen conch populations were monitored at 12 sites strategically placed throughout PHMR from 2004 to 2008, incorporating local fishers' knowledge and habitat information. Since September 2011, 20 sites have been monitored; five in RZs, 11 in the GUZ and four outside the reserve (OUT). At each site, where possible, belt transects are performed with five 50-meter transect lines laid parallel to one another and at least five meters apart. Two divers on each side search a combined 4-meter width along each line. All conch within each 200 m^2 belt transect are counted. At some sites, only three or four were possible due to habitat and depth constraints. In the fall of 2017, permanent transects were placed at the GPS coordinates using a cement-based PVC pipe and marker buoy. The specific number of sites surveyed in each monitoring trip can vary slightly due to weather, resources, and underwater visibility.

Shell length (SL) and lip thickness (LT) are recorded for all queen conch encountered, and the population density (conch per hectare or conch ha^{-1}) is then calculated based on number of conchs found in the area surveyed. Shell lengths (cm) and lip thicknesses (mm) are then divided into standard size "cohorts" (groups of standard increments) to determine population structure via size frequency distribution, or the proportion of the total sample in each size cohort, allowing changes in stock maturity over time to be estimated between 2009 and 2018. This is important for predicting the general fecundity of the population, which likely decreases with diminishing average age/size.

Effectiveness of the shell length-based size restriction of 17.8 cm (7 inches) in protecting juvenile conch is also assessed by analyzing trends in the proportion of the conch population throughout 2009–2018 that was of legal shell length but with lip thickness (LT) below Stoner et al. (2012) lip thickness at maturity estimations of >9 mm for males and >12 mm for female conch. Several studies on lip thickness have been conducted since Stoner et al. (2012) in different regions of the Caribbean (e.g. Foley & Takahashi 2017) estimating even higher values of LT necessary for stock maturity over time. It has been suggested that for the wider Caribbean and for the general fecundity of conch populations and protection of juvenile conchs, LT should be at a minimum of 15 mm (Stoner et al. 2012).

3.2 Lobster

Caribbean spiny lobster (*Panulirus argus*) populations are surveyed at 18 sites within and adjacent to PHMR twice a year, immediately after the closed season begins (15th February), and immediately before it opens (15th June). Sites are located in the RZs (8 sites), GUZ (7 sites), and outside the reserve (3 sites). In 2016, TIDE added four new sights in areas planned for RZ expansion in order to capture the effect of establishment of these areas as RZs in the future. Only three of these sites are currently monitored regularly. These new sites are collectively known as 'Expanded Replenishment Zone' (ERZ) sites with two currently located in the GUZ and one at the outskirt of current RZ zone at Middle Snake Caye. At each site, where possible, either two diver pairs conduct two 30-minute timed swims simultaneously or a 60-minute timed swim is conducted by a single diver pair. For each lobster located, species, gender, maturity (tar spot, eggs) and carapace length are recorded. The number of sites surveyed in each monitoring period and year can vary slightly due to weather, resources, and underwater visibility. Abundance is calculated as the number of lobsters encountered per hour during each timed swim. Carapace lengths were divided into standard size cohorts to determine population structure via size frequency distribution as with conch, enabling estimates of stock maturity and fecundity to be made.

3.3 Sea Cucumber

A moratorium on sea cucumber was enacted in 2017 due to the substantial decrease in sea cucumber population abundances. Nonetheless, regular biannual monitoring continued to be conducted for sea cucumber in 2017–2018. Sampling is carried out at the start and end of the sea cucumber closed season (July 1–December 31) at 16 sites within and adjacent to PHMR using a technique based on that of Amesbury and Kerr (1996). Sites are located in the RZs (5 sites), GUZ (8 sites), and outside the reserve (3 sites). Different habitats in PHMR were stratified to determine habitats suitable for sea cucumbers and within those stratifications, monitoring sites were randomly determined. However, it was ensured that there were monitoring sites within both the RZs and GUZ in order to have comparable data. In the fall of 2017 permanent transects were placed at the site GPS coordinates using a cement–based PVC pipe and marker buoy.

A 11.28 m line (*calculated as*: area of a circle = $\Pi r^2 \rightarrow 400\ m^2/\Pi = 127.32$; $\sqrt{127.32} = 11.28$ m) is attached to a central pole, and two divers swim the line around the pole in a radar-sweep trajectory covering 400 m^2 of habitat. When *H. mexicana* are found, length and width measurements are taken *in situ,* being careful not to touch the specimen as this might cause it to retract. Specimens are then brought up to the boat to be weighed before being returned to their original location. In order to gain population density estimates, the number of *H. mexicana* per hectare is calculated. Mean length and weight are also calculated to determine mean sizes in different management zones.

4. FINDINGS

Conch

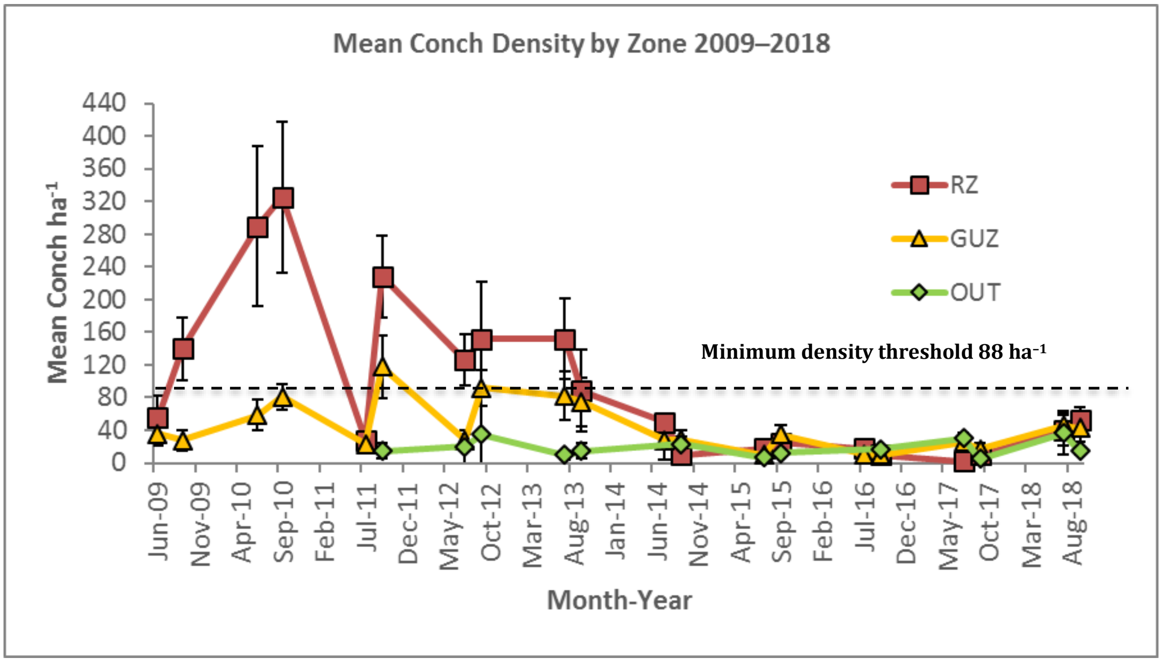

Figure 2. Mean queen conch density, number of conchs per hectare, observed during pre-season and post-season surveys by zone 2009–2018 [Replenishment Zone (RZ), General Use Zone (GUZ), Outside the Reserve (OUT)] [±Standard Error Bars].

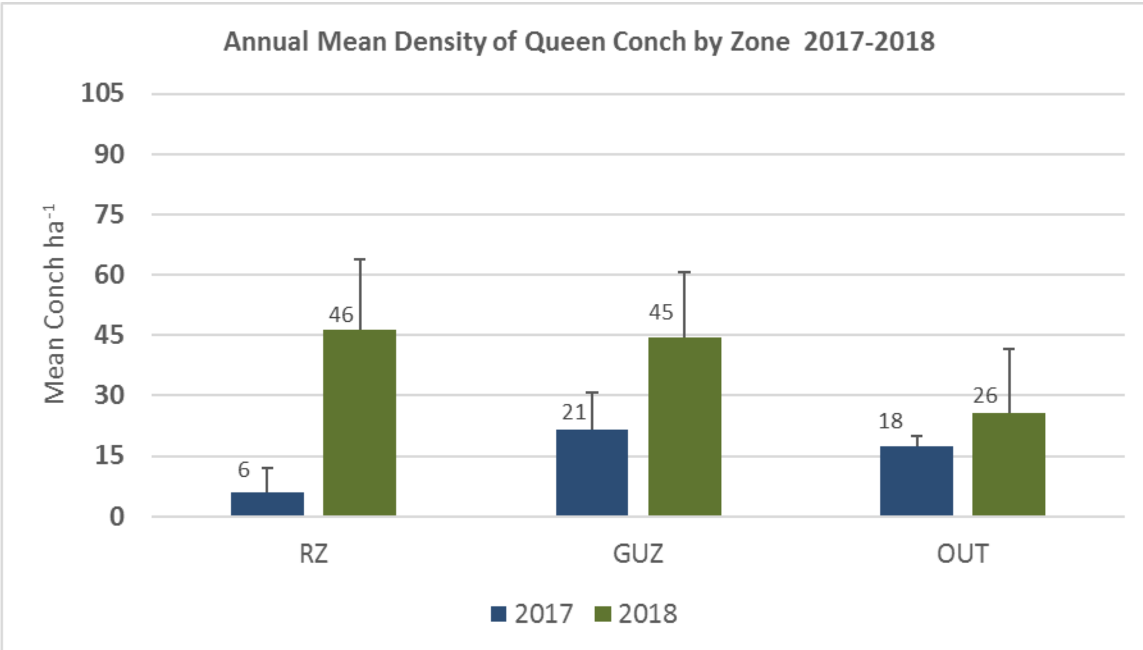

Figure 3. Annual mean density of queen conch, number of conchs per hectare, observed by zone 2017–2018 [Replenishment Zone (RZ), General Use Zone (GUZ), Outside the Reserve (OUT)] [±Standard Error Bars].

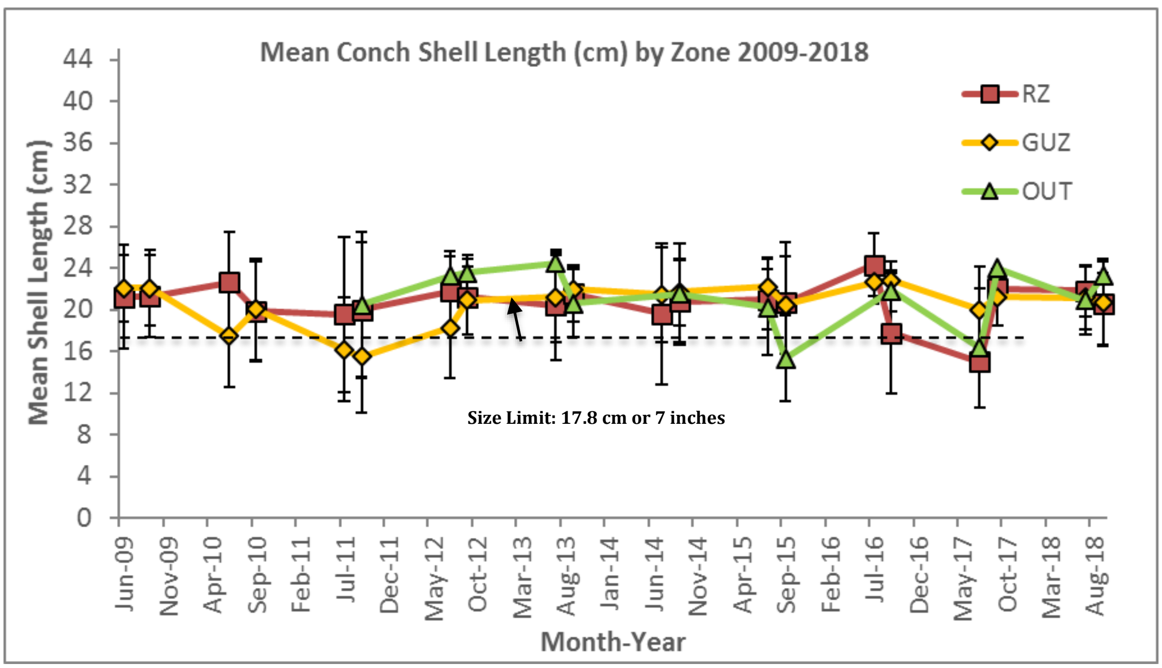

Figure 4. Mean queen conch shell length (cm) observed during pre-season and post-season surveys by zone 2009–2018 [Replenishment Zone (RZ), General Use Zone (GUZ), Outside the Reserve (OUT)] [±Standard Deviation].

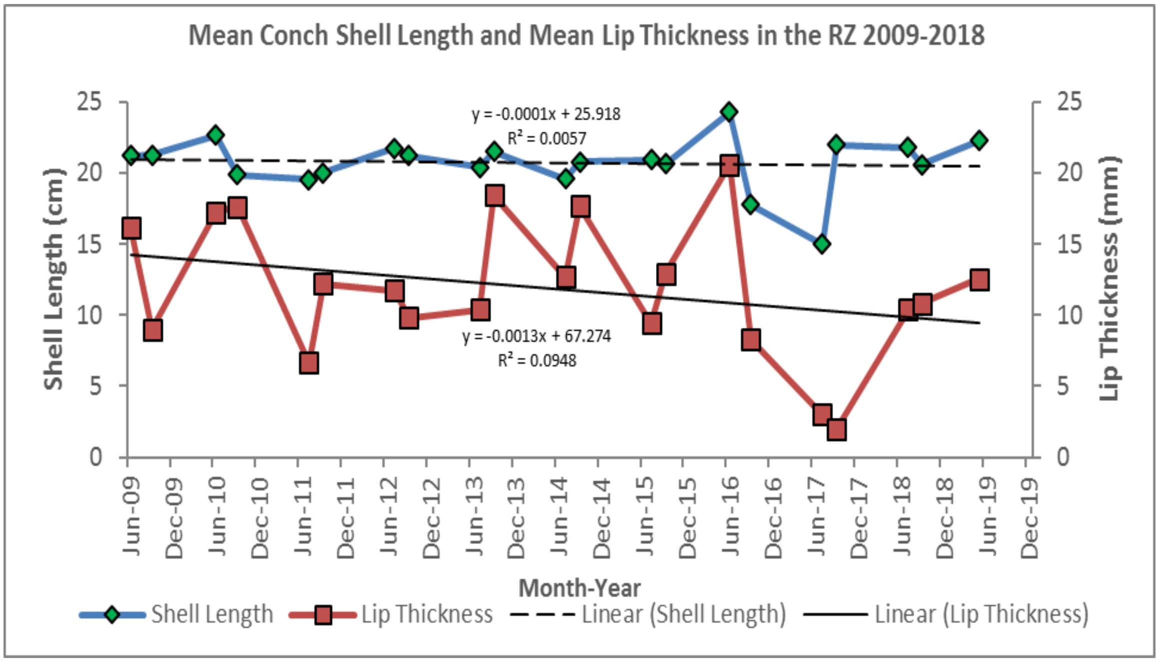

Figure 5. Mean queen conch, *Lobatus gigas,* shell lip thickness vs. mean shell length in the RZs 2009–2018.

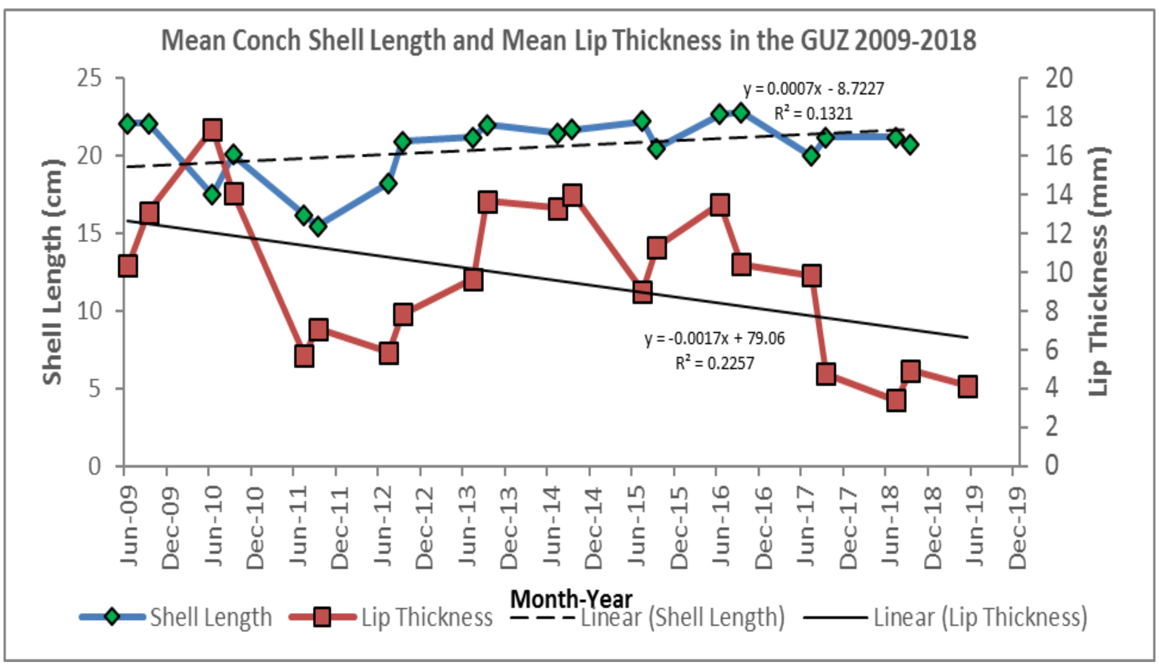

Figure 6. Mean queen conch, *Lobatus gigas,* shell lip thickness vs. mean shell length in the GUZ 2009–2018.

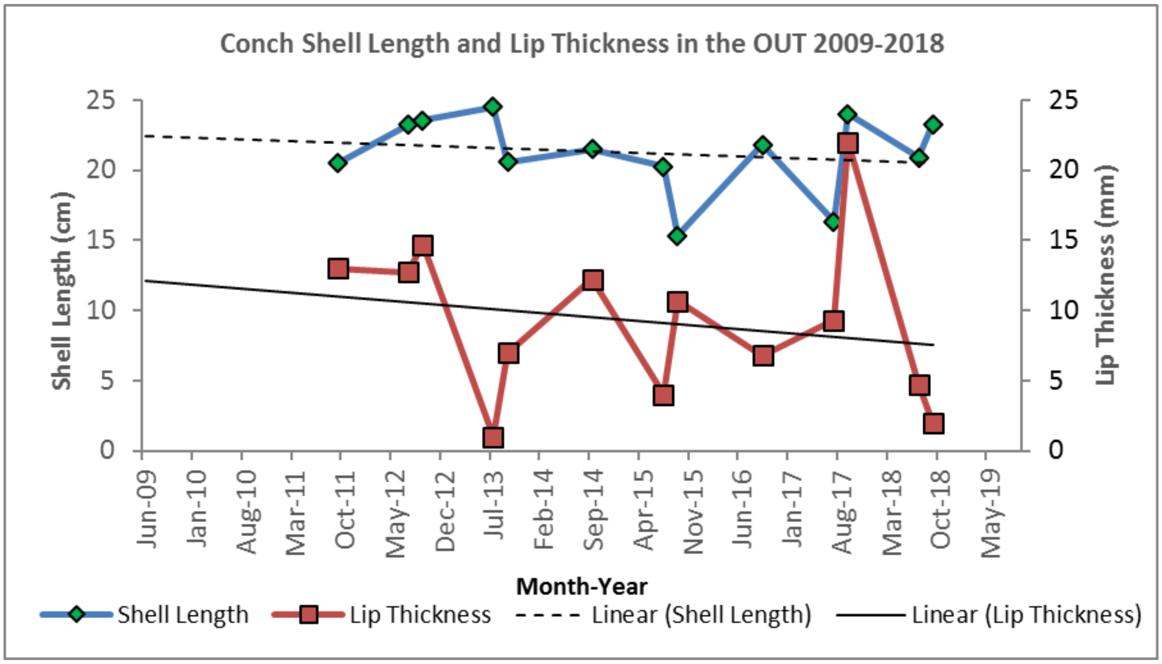

Figure 7. Mean queen conch, *Lobatus gigas,* shell lip thickness vs. mean shell length in OUT 2009–2018.

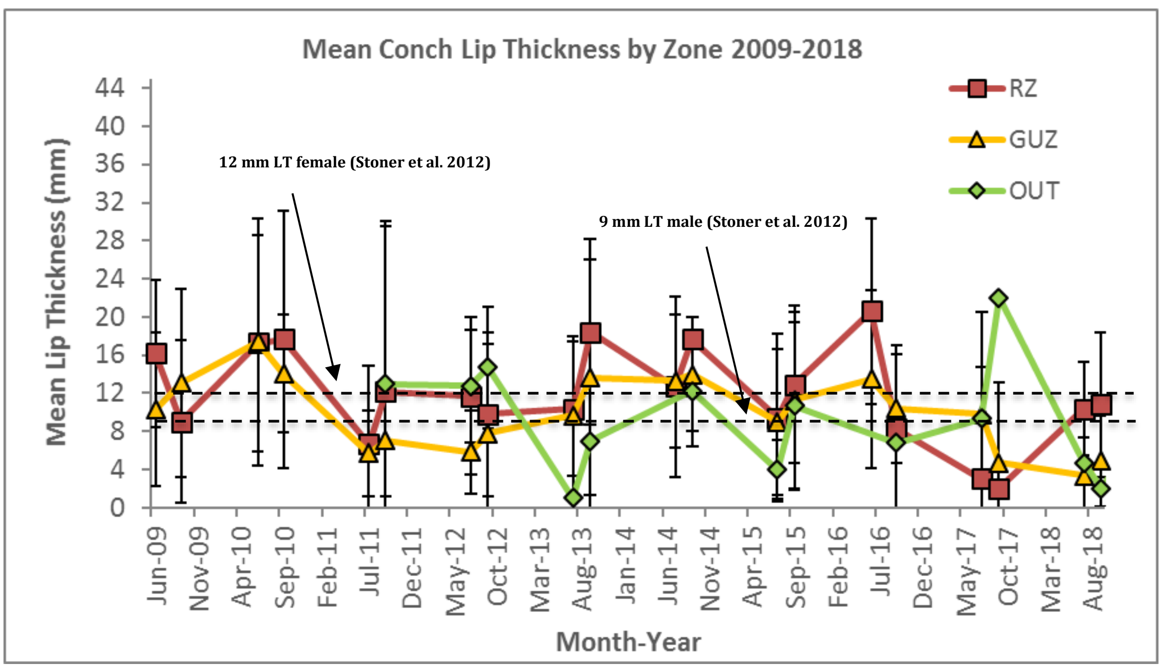

Figure 8. Mean queen conch lip thickness (mm) observed during pre-season and post-season surveys by zone 2009–2018 [Replenishment Zone (RZ), General Use Zone (GUZ), Outside the Reserve (OUT)] [±Standard Deviation].

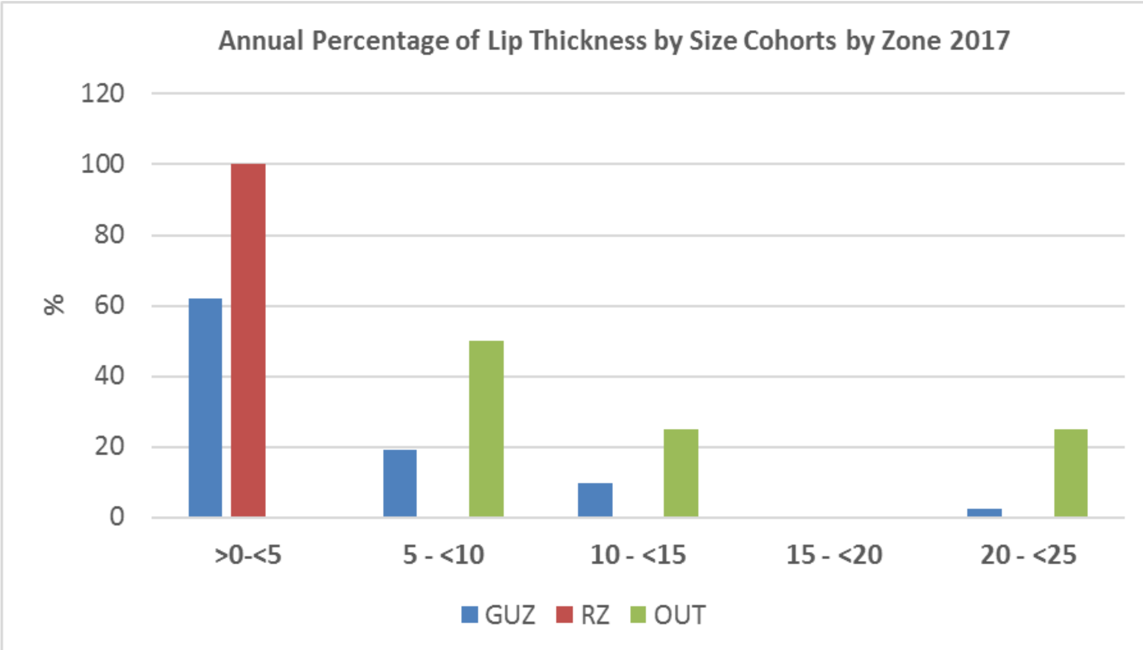

Figure 9. Queen Conch, *Lobatus gigas*, annual percent lip thickness (LT) by size cohorts by zone 2017 [Replenishment Zone (RZ), General Use Zone (GUZ), Outside the Reserve (OUT)].

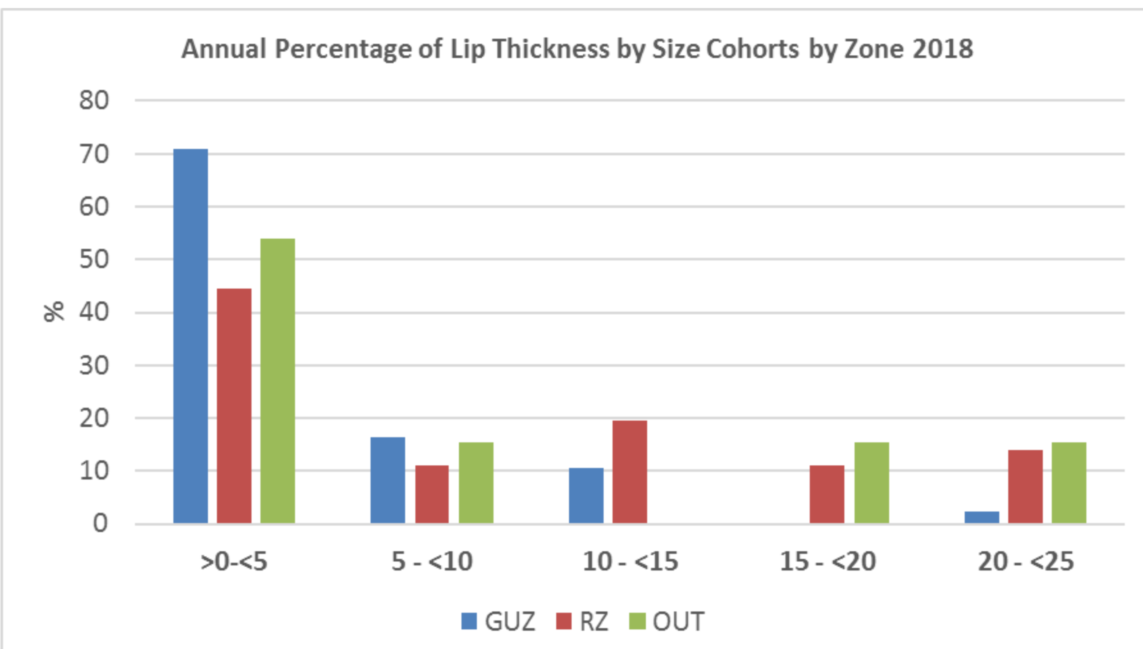

Figure 10. Queen Conch, *Lobatus gigas*, annual percent lip thickness (LT) by size cohorts by zone 2018 [Replenishment Zone (RZ), General Use Zone (GUZ), Outside the Reserve (OUT)].

Results:

- Conch densities in RZs decreased even further in 2017 from the unprecedented 2016 critical lows with conch density at close of season at a dismal 2 ha^{-1}, only increasing slightly to 10 ha^{-1} at opening of season (Fig. 2). The 2017 RZs annual mean conch density was 6 ha^{-1} (Fig. 3). The GUZ showed only slightly higher densities than the RZs with populations assessed at opening of season at 17 ha^{-1}, and GUZ annual conch density ~21 ha^{-1} (Fig. 2 & 3). The OUT sites showed annual conch densities similar to the GUZ at ~18 ha^{-1}. In 2018, the annual mean conch densities in the RZs and GUZ increased to 46 ha^{-1} and 45 ha^{-1}, respectively, with the OUT showing an increase in conch density as well at ~26 ha^{-1}.* Though 2018's increase in conch densities in all three zones is promising, the mean density for the past 5 years has remained continuously below the 88 ha^{-1} minimum density threshold, as determined by the Belize Fishery Department, in all zones.

- Mean conch shell length decreased in 2017 but slightly increased again in 2018 in all three zones with the majority of conchs sampled between 15–25 cm in length and the majority of those of legal shell length (≥17.8 cm) (Fig. 4). The mean shell length since 2009 does not show any major increasing or decreasing trends in the RZs or OUT. The GUZ, however, shows a slight increasing trend from 2009–2018 (Fig. 5,6 &7).

- Mean conch lip thickness (LT) decreased in 2017 in GUZ and RZs and remained low in the GUZ in 2018 (Fig. 8). The mean conch lip thickness increased in the RZs in 2018, yet the majority of conchs sampled in 2017 and 2018 had LT of <10 mm (Fig. 9 & 10). Time series analysis shows a general trend toward decreasing lip thickness in the GUZ and RZs and OUT (Fig. 5 & 6).

- The low densities, below 88 ha^{-1}, continue to have a negative impact on reproductive success, as the likelihood of conch encountering reproductive mates is low. This, combined with low mean lip thickness in all zones, indicates poor recruitment via reproduction, with immature adults being predominant. The fecundity of queen conch, based on scientific literature, ranges from a minimum lip thickness for males and females at 9 and 12 mm (Stoner et. al 2012), to 18 to 20 mm respectively (Foley et. al 2016). The highest percentage of conch sampled in 2017–2018 had lip thickness below literature standards.

*Note: Mean conch density findings for 2017 & 2018 differ from those reported in the PHMR 2018 Annual Report, and the previous quarterly updates for PACT, Summit Foundation and EU after thorough review of all site data sheets and subsequent input of additional, previously missing, data.

Discussion:

- Some progress has been made with the increase in abundance into 2018 as compared to 2014-2017 values. However, the closed seasons have not yet achieved their intended purpose of increasing abundance to healthy population levels by protecting conch during their reproductive season and thus increasing recruitment rates. This leaves the conch population vulnerable to collapse.

- The majority of conchs sampled were of legal shell length (≥17.8 cm). Yet the majority of those sampled showed lip thickness less than literature standards for queen conch fecundity. It has been shown that high fishing (exploitation) rates has typically resulted in an overall decline in the lip thickness of a queen conch population resulting in harvesting of immature conchs, again reducing recruitment rates (Stoner et al., 2012). A better understanding of their spawning locations is needed and the spillover effects of the RZs should be analyzed in greater detail to aid in understanding conch population dynamics in all zones.

- It is known from previous conch size-maturity studies in Belize, as well as other studies elsewhere in the Caribbean, that shell lip thickness is a more accurate proxy indicator of maturity in conch than shell length, which varies by locale (Stoner et al. 2012, Foley & Takahashi 2016). For the past 25 years, scientific literature has suggested lip thickness to be a better criterion for legal harvesting of queen conch (Clerveaux et al. 2005, Stoner et al. 2012, Foley & Takahashi 2016). These observations point to a need for revising the legal framework for managing conch. It is recommended that lip thickness be incorporated into existing legislation to protect immature conch from harvest.

- Existing management tools such as RZs, gear restrictions, and fisher access limitations through Managed Access can have a positive effect on sustainability of the conch fishery (e.g. suitable size limits and appropriate quotas). However, it is the collaboration, transparency and accountability of managers and fishers together that is required to deal with the uncertainty and complexity of nature. Single species stock assessment is simply a tool. Greater diligence, accuracy and honesty, information exchange and risk sharing are needed between managers and fishers to protect the productive potential and resilience of the ecosystem as a whole.

Recommendations:

- Incorporate lip thickness into conch fishery size limit regulations.

- Work with fishers to better understand spawning locations and closely monitor them to substantiate suspected decrease in reproduction.

- Compel fishers to record conch catch diligently and honestly, by showing them the long-term benefits that Managed Access can have on the sustainability of the conch fishery.

- Conduct conch mark-recapture targeted research project to determine spillover effect of existing Replenishment Zones.

- Conduct more outreach to discourage harvesting of immature conch, and ensure demand is only for mature conch.

Lobster

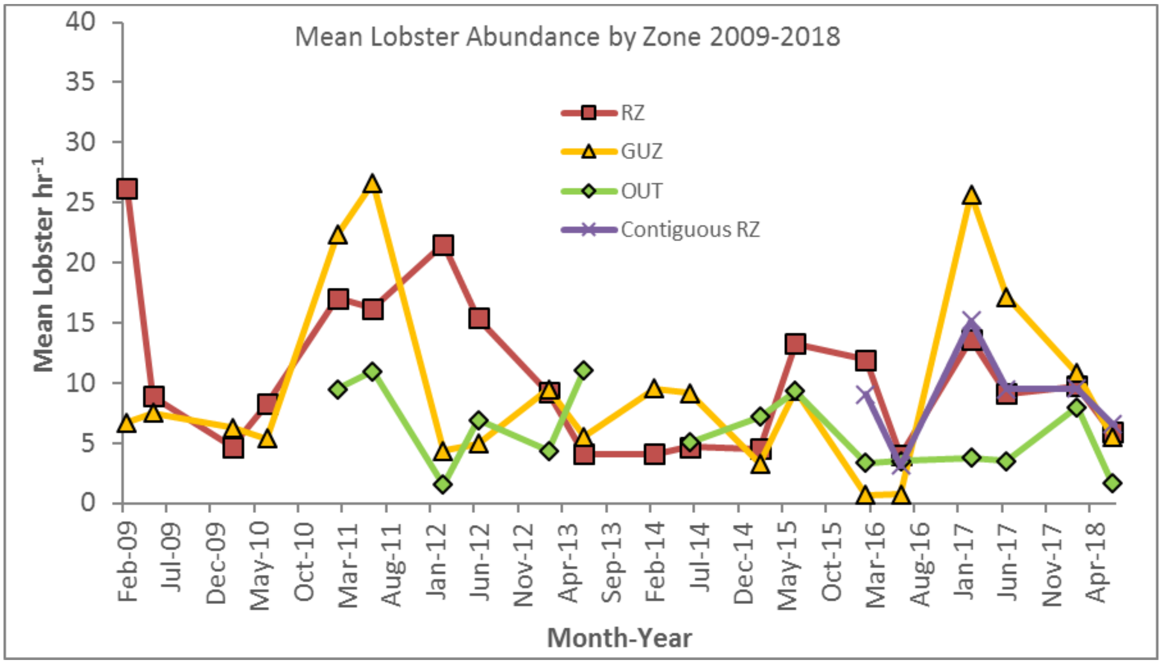

Figure 11. Mean spiny lobster, *Panulirus argus*, abundance (lobster per hour) observed during pre-season and post-season surveys by zone 2009–2018 with added proposed contiguous RZ for comparison with current RZs, GUZ and OUT lobster populations [Replenishment Zone (RZ), General Use Zone (GUZ), Outside the Reserve (OUT), Contiguous RZ].

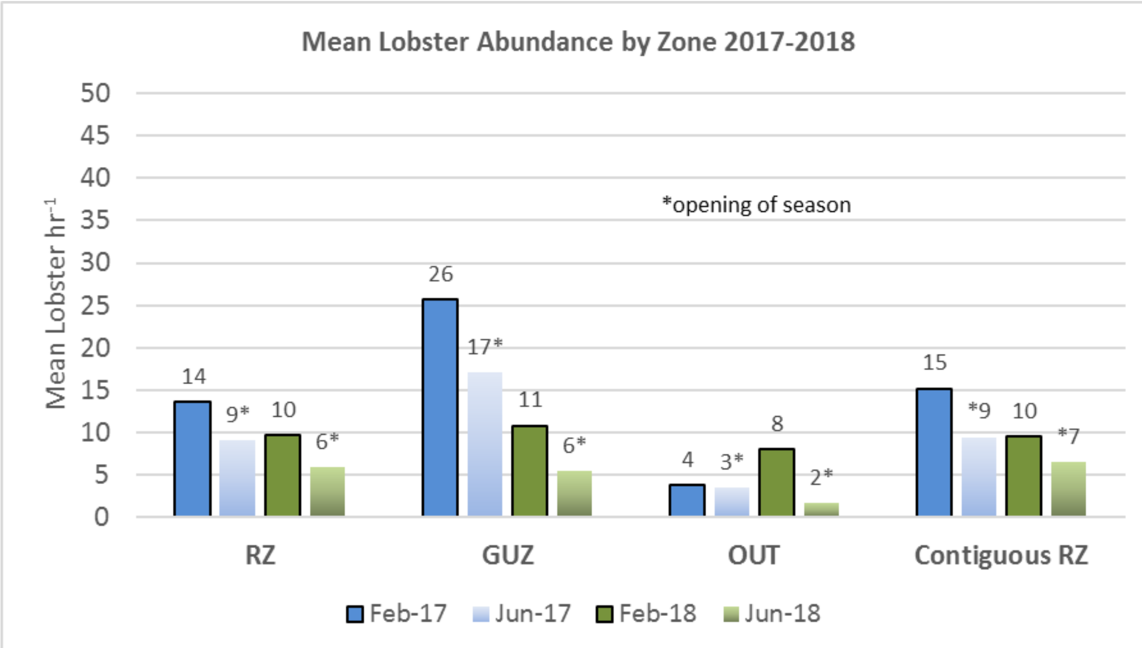

Figure 12. Mean spiny lobster, *Panulirus argus*, abundance (lobster per hour) observed during pre-season and post-season surveys by zone 2017–2018 with added proposed contiguous RZ for comparison with current RZs, GUZ and OUT lobster populations [Replenishment Zone (RZ), General Use Zone (GUZ), Outside the Reserve (OUT), Contiguous RZ].

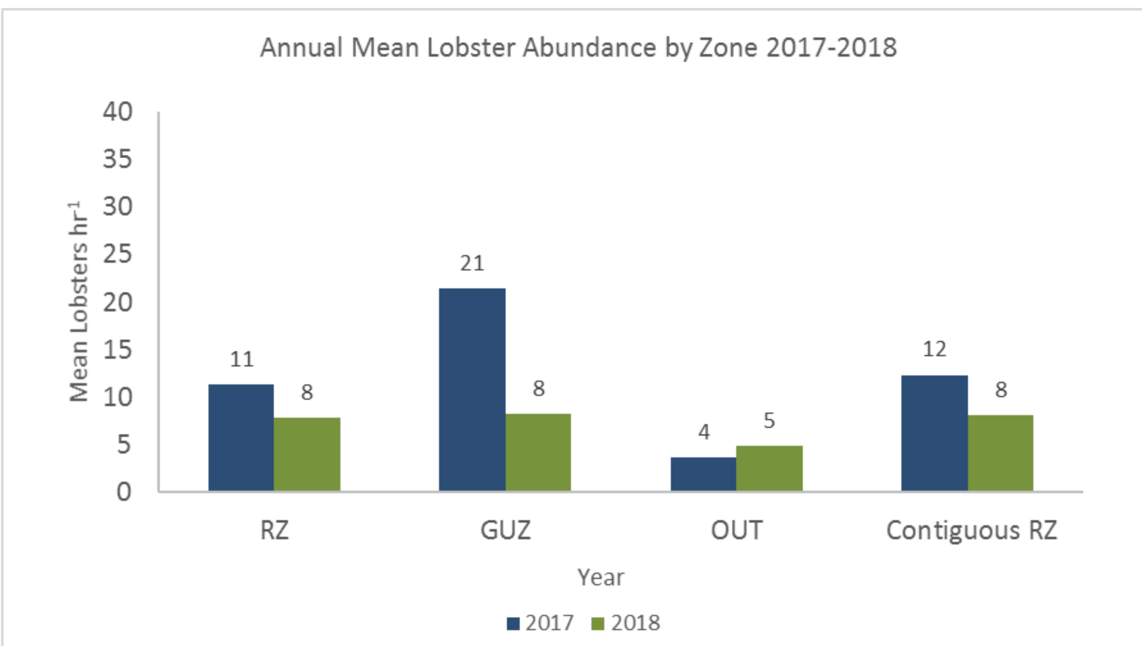

Figure 13. Annual mean spiny lobster, *Panulirus argus*, abundance (lobster per hour) by zone 2017–2018 with added proposed contiguous RZ for comparison with current RZs, GUZ and OUT lobster populations [Replenishment Zone (RZ), General Use Zone (GUZ), Outside the Reserve (OUT), Contiguous RZ].

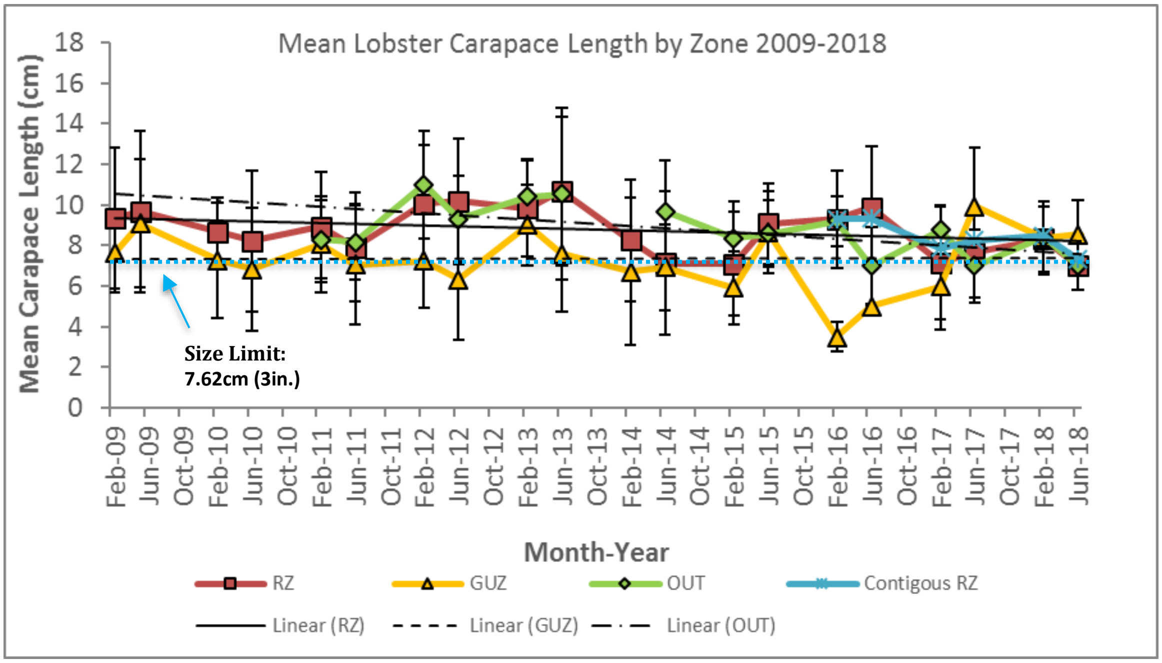

Figure 14. Mean spiny lobster, *Panulirus argus*, carapace length (cm) observed during pre-season and post-season surveys by zone 2009–2018 [Replenishment Zone (RZ), General Use Zone (GUZ), Outside the Reserve (OUT), Contiguous RZ] [±Standard Deviation Bars].

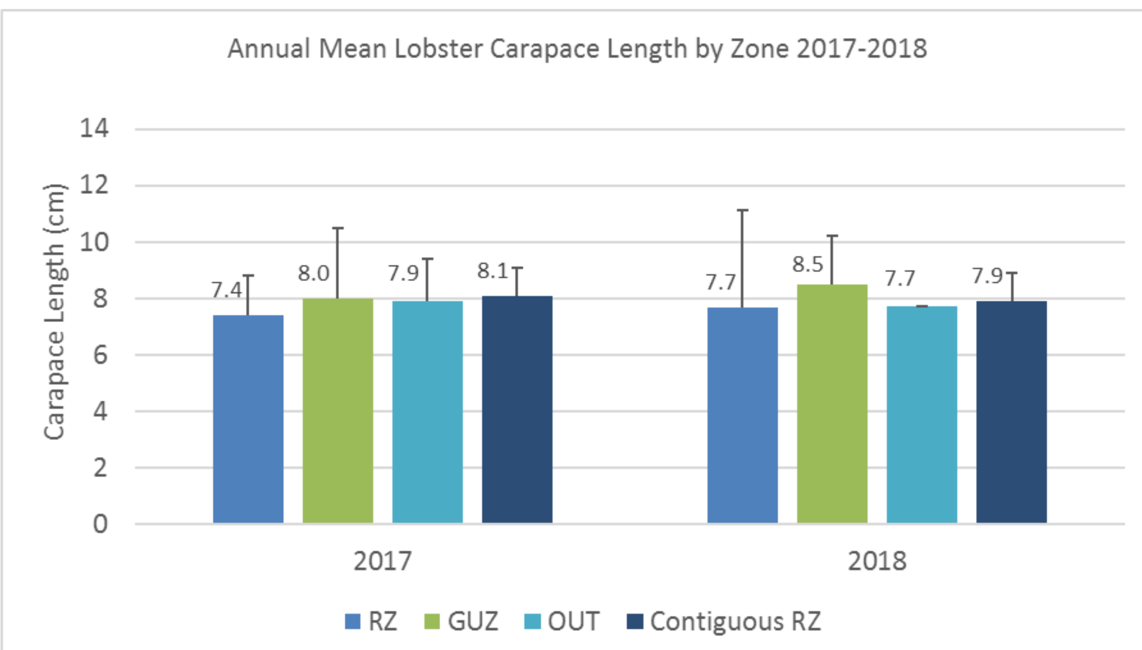

Figure 15. Annual mean spiny lobster, *Panulirus argus*, carapace length (cm) by zone 2017–2018 [Replenishment Zone (RZ), General Use Zone (GUZ), Outside the Reserve (OUT), Contiguous RZ] [±Standard Deviation].

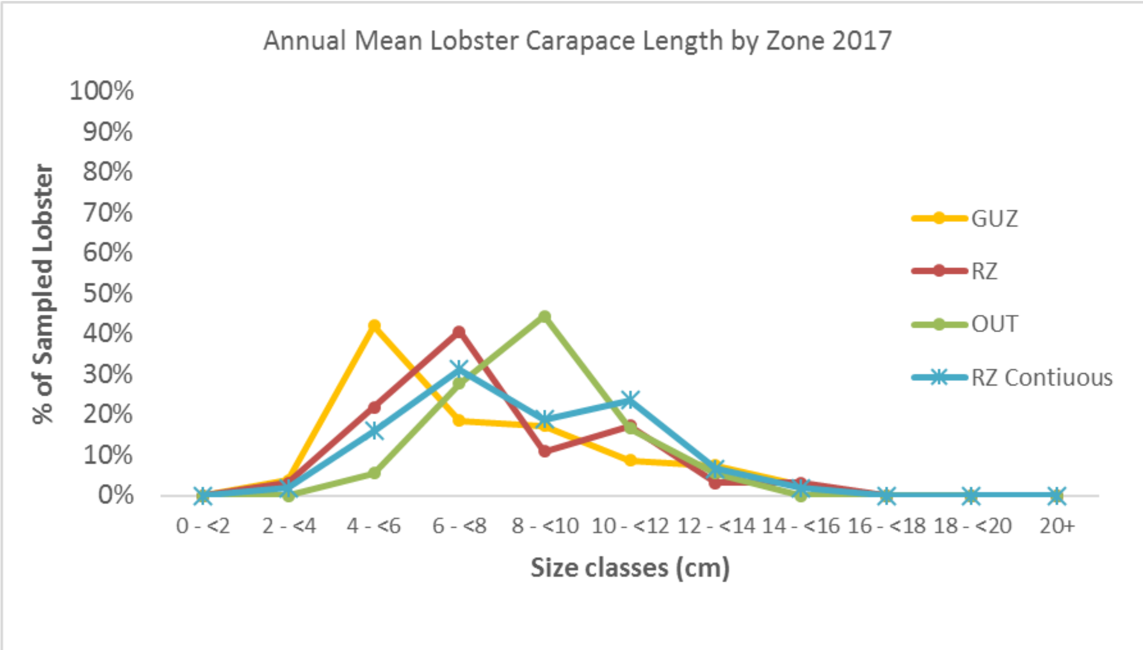

Figure 16. Annual mean spiny lobster, *Panulirus argus*, carapace length (cm) by size distribution by zone 2017 [Replenishment Zone (RZ), General Use Zone (GUZ), Outside the Reserve (OUT), Contiguous RZ].

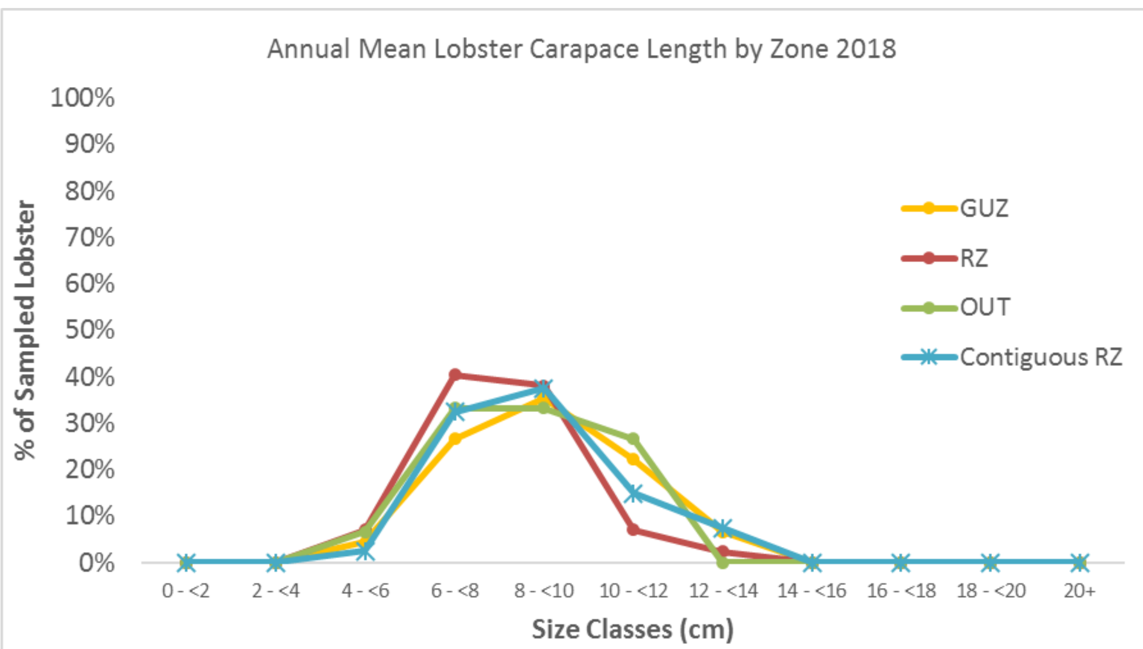

Figure 17. Annual mean spiny lobster, *Panulirus argus*, carapace length (cm) by size distribution by zone 2017 [Replenishment Zone (RZ), General Use Zone (GUZ), Outside the Reserve (OUT), Contiguous RZ].

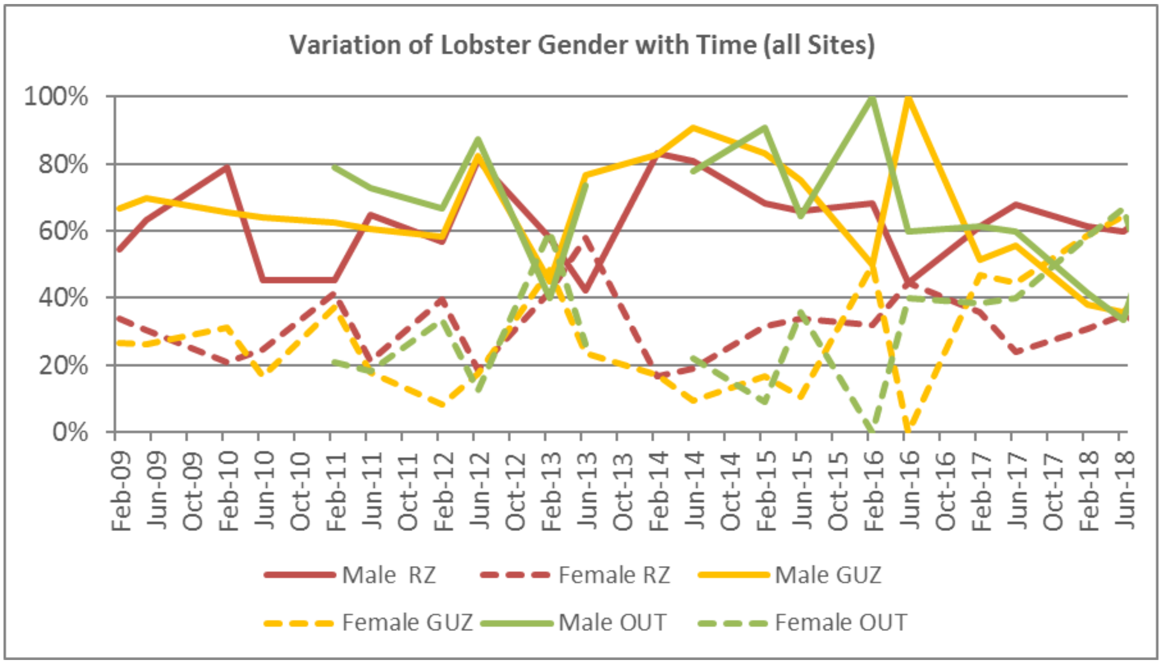

Figure 18. Variation of lobster gender ratio in all zones 2009–2018 [Replenishment Zone (RZ), General Use Zone (GUZ), Outside the Reserve (OUT)].

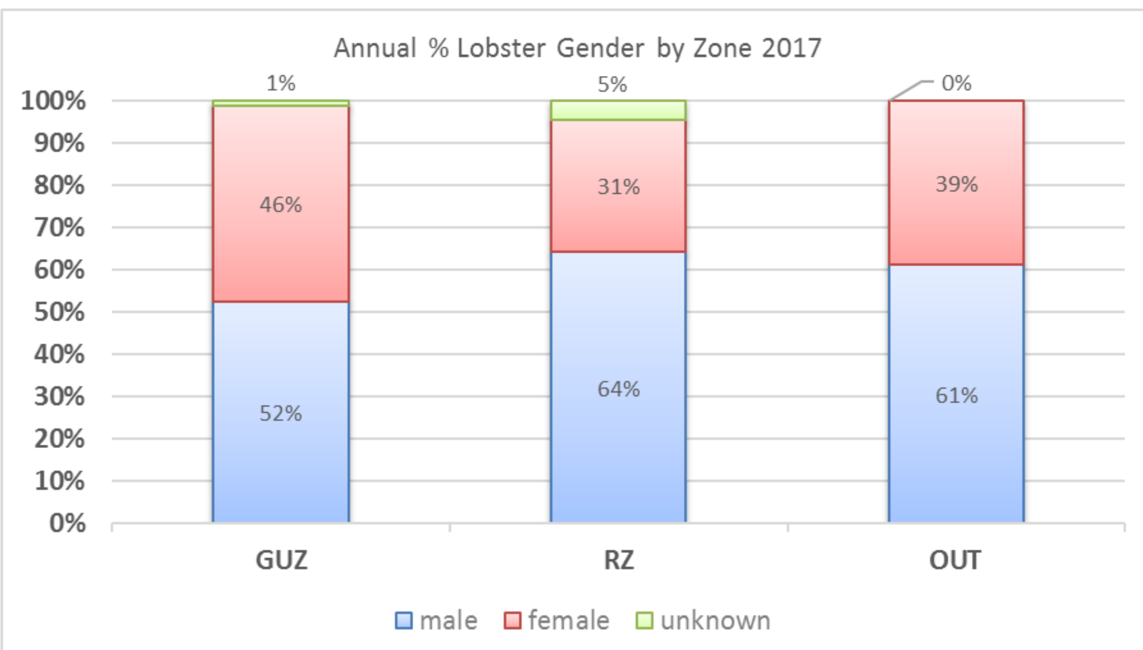

Figure 19. Percent (%) spiny lobster, *Panulirus argus*, gender (male, female, unknown) by zone 2017 [Replenishment Zone (RZ), General Use Zone (GUZ), Outside the Reserve (OUT)].

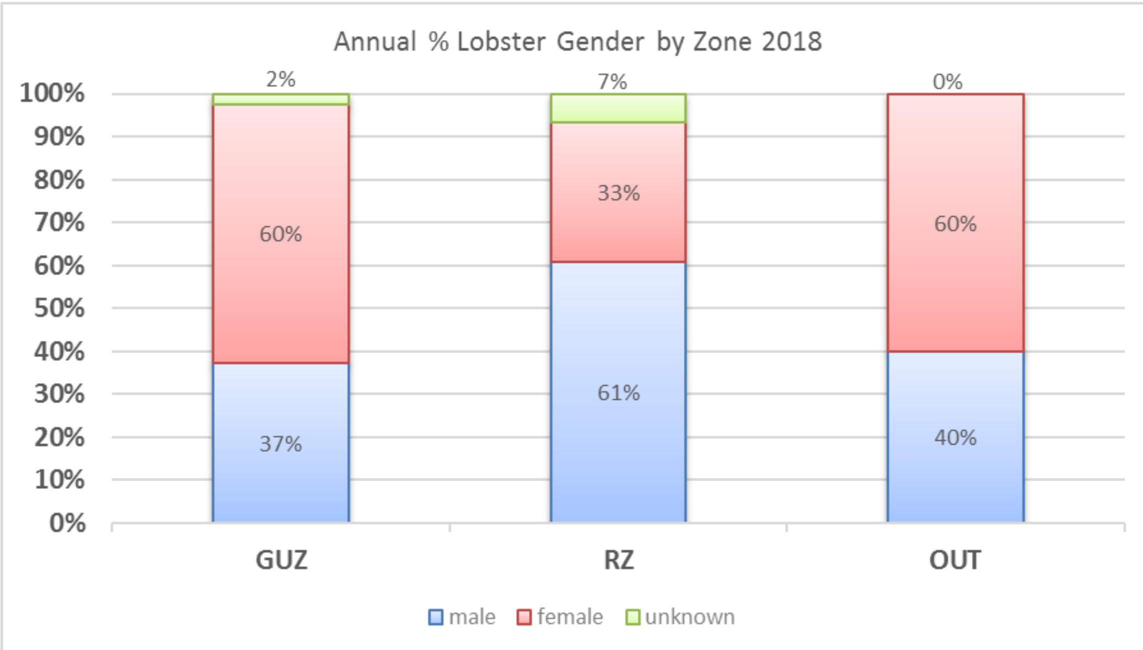

Figure 20. Percent (%) spiny lobster, *Panulirus argus*, gender (male, female, unknown) by zone 2018 [Replenishment Zone (RZ), General Use Zone (GUZ), Outside the Reserve (OUT)].

Results:

- The mean lobster abundance in the RZs in 2017 showed 14 lobster hr^{-1} at the close of the season in February and 9 lobster hr^{-1} at the opening of season in June (Fig. 11 & 12). This was an increase in abundance from <5 lobsters hr^{-1} at opening of season 2016. The GUZ showed a large increase in abundance in early 2017 at 26 lobster hr^{-1} and similar to the RZs, showed a decrease in abundance by the opening of the season to 17 lobster hr^{-1}. Though OUT sites are on lobster preferred coral habitat, the lobster abundance was less than 4 lobster hr^{-1}. In 2018, the mean lobster abundance decreased in both the RZs and GUZ (see Figure 13) with annual mean abundances in both zones at 8 lobster hr^{-1}. As in 2017, there was a decrease in lobster abundance in all zones from the closing to the opening of the lobster season. The planned Contiguous RZ lobster abundance reflected the observed lobster abundances in the RZs in both 2017-2018 (Fig. 11-13).

- Mean carapace length decreased in the RZs in early 2017, but increased in the GUZ from the 2016 low of 3.5 cm to 10 cm at the opening of season (Fig. 14). This trend in the GUZ was accompanied with the increase in abundance from 2016 to 2017, possibly indicating sufficient adult spawning stock and healthy reproductive success. The annual mean carapace length in the RZs and GUZ was 7.4 cm and 8.0 cm, respectively. The annual mean carapace length in OUT and contiguous RZ was also ~8 cm (Fig. 15). In 2018, the mean carapace length in the GUZ at closing and opening of season was ~8.5

cm, an increase from 2017 values. The mean carapace length in the RZs slightly increased in early 2018 to 8 cm in comparison to 2017 values, but decreased again to mean carapace length of 7 cm, below legal-size limit, at the opening of lobster season in June. The RZs annual mean carapace length was 7.7 cm, legal size (see Figure 15). The OUT and Contiguous RZ showed annual mean carapace length at 7.7 cm and 7.9 cm, respectively. Both were higher than the RZs mean carapace length, but below the GUZ for 2018.

- The 2017 annual carapace length size distributions showed approximately 40% of the GUZ were 4-6 cm mean carapace length, the RZs annual carapace length size distribution was 6-8 cm, and OUT was 8-10 cm. The Contiguous RZ showed ~30% annual mean carapace size distribution at 6-8 cm and even greater percentage >8 cm (Fig. 16). In 2018 the size distributions in each zone displayed similar percent ranges of annual mean carapace lengths with the majority between 6-10 cm (Fig. 17).

- The gender ratio in the RZs and GUZ between 2009–2015 exhibited a relatively stable male bias (males ~60–70%; females ~20–40%), with the exception in 2013 when the gender ratio became more equal (Fig. 18). This implied that there were naturally more males then females in the RZs, GUZ and OUT. In 2016, the gender ratio, similar to 2013, became more equal in all zones, but this could have been attributed to the lower abundances in general as seen at the opening of lobster season 2016 (see Figure 11). In 2017, males dominated in the RZs with the female population remaining stable at 20-40%. However, the GUZ and OUT saw the gender ratio again more equal with females at 39% and 46%, respectively (Fig. 19). In 2018, though the male gender continued to be greater in the RZs, it was females that dominated the GUZ and OUT at ~60% with 33% of the females in the GUZ in June 2018 berried.

Discussion:

- Mean lobster abundance increased in the RZs and GUZ in 2017, improving a bad situation in 2016 for lobster when mean abundance decreased to all-time lows at <5 lobsters hr^{-1} at opening of season. However, the mean lobster abundance decreased again seasonally and annually in all zones in 2018 with the opening season at only 6 mean lobster hr^{-1}, similar to 2016 lows. This implies that the lobster population is under more pressure and not being protected enough for steady increases in abundance and reproductive activity and should be closely monitored.

- A decrease in lobsters hr^{-1} was observed from the closed season to the opening of season in both zones in 2017 & 2018, a consecutive trend observed since 2014. This may be partially due to illegal poaching but observations are more indicative to lobster migration patterns. The mean carapace lengths do not show large fluctuations in size in zones over time with the exception of GUZ 2016, and that anomaly most likely is due to low population size measured (n=3) that year. Though the data shows a slight decreasing trend in carapace length over time in the RZs, it does not show this in the GUZ. In fact, the GUZ shows increases of carapace size during closed season since 2014 implying that the closed season is allowing the lobster to grow to maturity.

- The Contiguous RZ showed the same trends as the RZs in mean lobster abundance but differed in mean carapace lengths showing slightly higher values seasonally and annually. The RZs has a higher percentage of immature lobster of mean carapace length <8 cm than the Contiguous RZ in 2017 and 2018 suggesting a greater chance of lobster population fecundity with expansion of the current RZs into a contiguous zone. Additionally, the RZ's may be serving as vital larval recruitment and spill-over into the current General Use Zone.

- It has been suggested that regular fluctuations in population abundances, size distribution and gender ratio in each zone may be attributed to molting, reproductive and feeding activities (MacDiarmid 1991). Additionally, fluctuations in population abundances has been linked to variations in environmental factors (e.g. sea temperature) (Davis 1977). The changes in gender ratio (i.e. changes in normal operational sex ratio) may affect competitive behavior of both sexes competing simultaneously for mating opportunities (Grant & Foam 2002). In 2013 and 2018 where females dominated the GUZ, 11% and 33%, respectively, of the females observed in the GUZ were berried, which may have been a factor in the greater number of females to males observed during this time period. The female population ratio in the RZs has remained steady at 20-40% which again may be indicative of it being a juvenile nursery with spill-over into GUZ

- Overall, lobster populations show signs of reduced sustainability which is of increasing concern. Populations are still in better condition than conch or sea cucumber, but are starting to decrease for more sustained periods of time with less successful regeneration during times of increase.

Recommendations:

- Continue working with compliant Managed Access fishers to show them positive effects on maturity, reproductive capacity and abundance from good management of GUZ, and garner stakeholder support and participation in reporting illegal extraction out of season, illegal extraction in RZs or extraction under size limit.

- Conduct study to determine whether lobster shades located close to current RZs boundaries increase abundance overall by creating artificial habitat or simply attract lobsters from natural habitats in RZs to lobster shades, which may be considered preferable habitat by lobsters.

- Conduct study to determine if environmental factors such as sea temperature, dissolved oxygen, salinity, and pH affect post–larval, juvenile and adult spiny lobster population abundances in PHMR.

- Conduct juvenile lobster spatial and temporal study in the broader PHMR area to elucidate prime lobster spawning and recruitment areas.

- Increase size of RZs to increase distance between lobster natural reef habitat inside RZs and lobster shades just outside RZs. A sufficient distance is needed to ensure lobsters in shades are not simply being attracted away from RZs.

- Increase night time patrols in RZs thus increasing enforcement presence and trial new surveillance technologies such as remote-controlled cameras to protect RZs at night.

Sea Cucumber

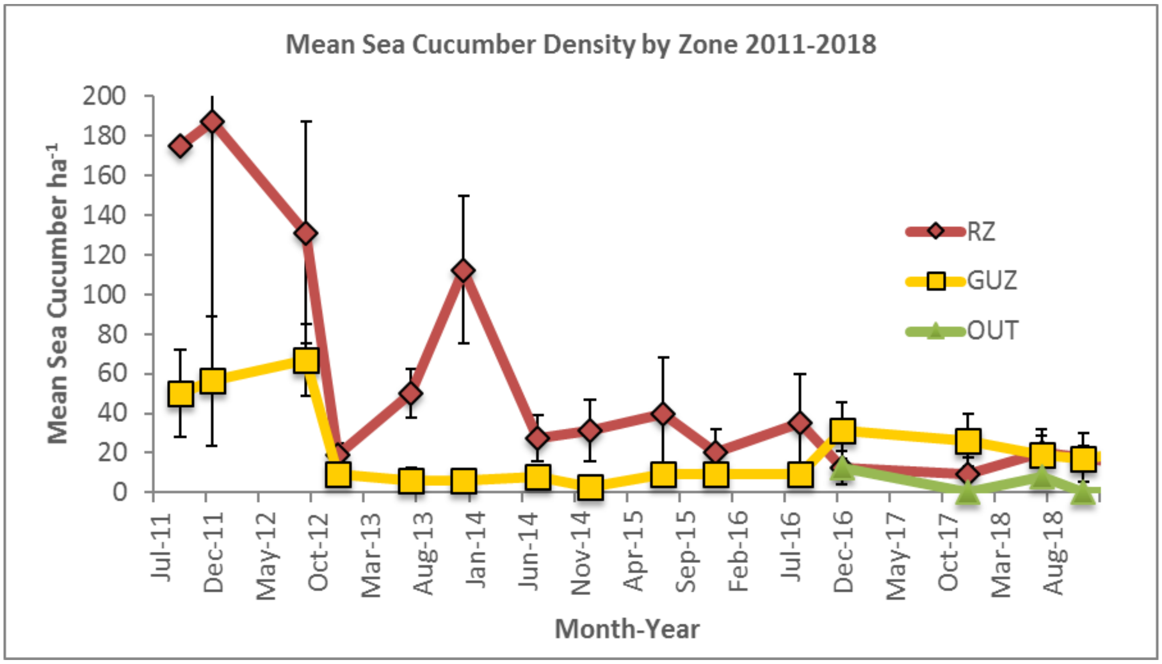

Figure 21. Mean Sea cucumber, *H. mexicana*, density observed during pre-season and post-season surveys conducted 2011–2018 [Replenishment Zone (RZ), General Use Zone (GUZ), Outside the Reserve (OUT)] [±Standard Error Bars].

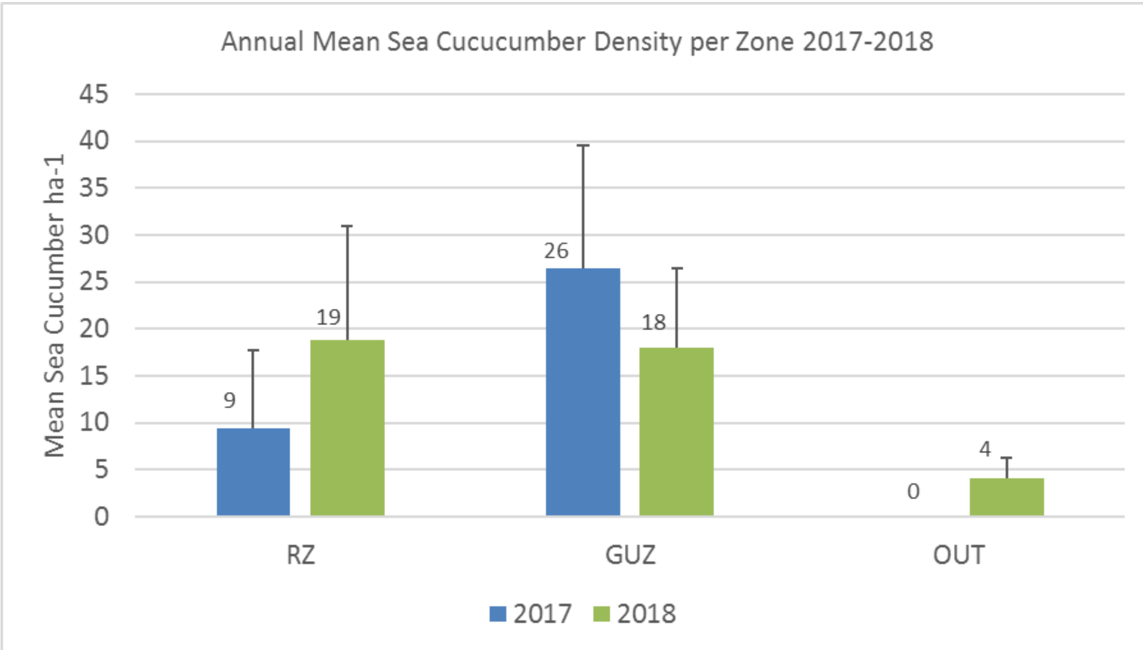

Figure 22. Annual mean sea cucumber, *H. mexicana*, density per zone 2017–2018 [Replenishment Zone (RZ), General Use Zone (GUZ), Outside the Reserve (OUT)] [±Standard Error Bars].

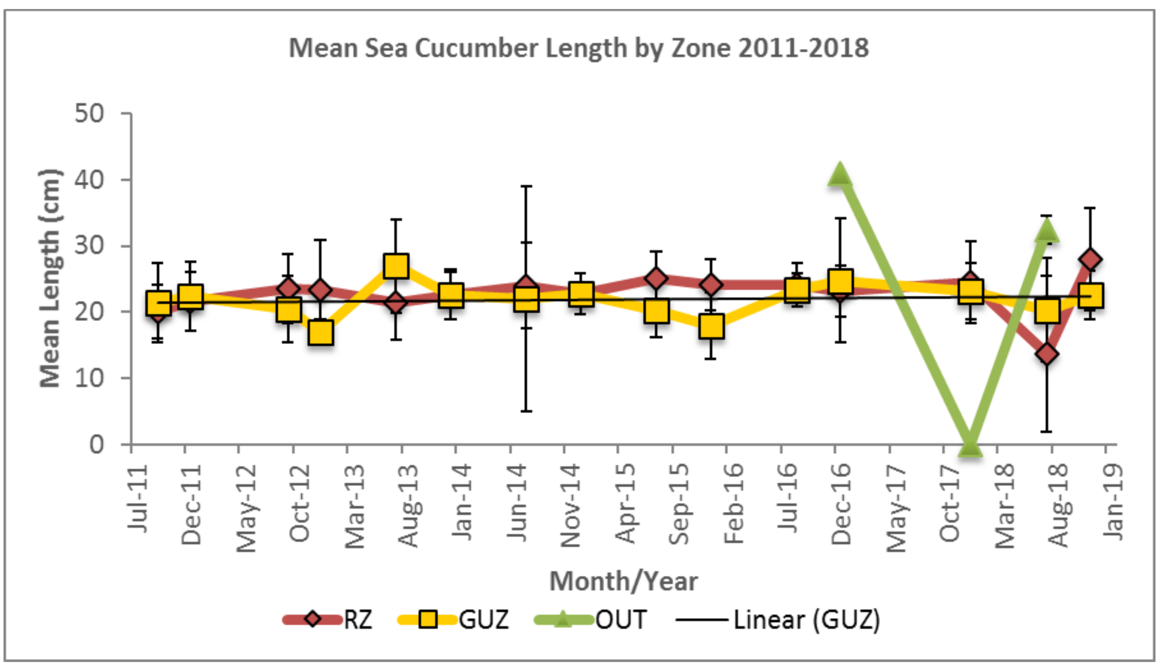

Figure 23. Mean Sea cucumber, *H. Mexicana*, length (cm) by zone observed during pre-season and post-season surveys conducted 2011–2018 [Replenishment Zone (RZ), General Use Zone (GUZ)] [±Standard Deviation]. Note: Zero length means (n=0).

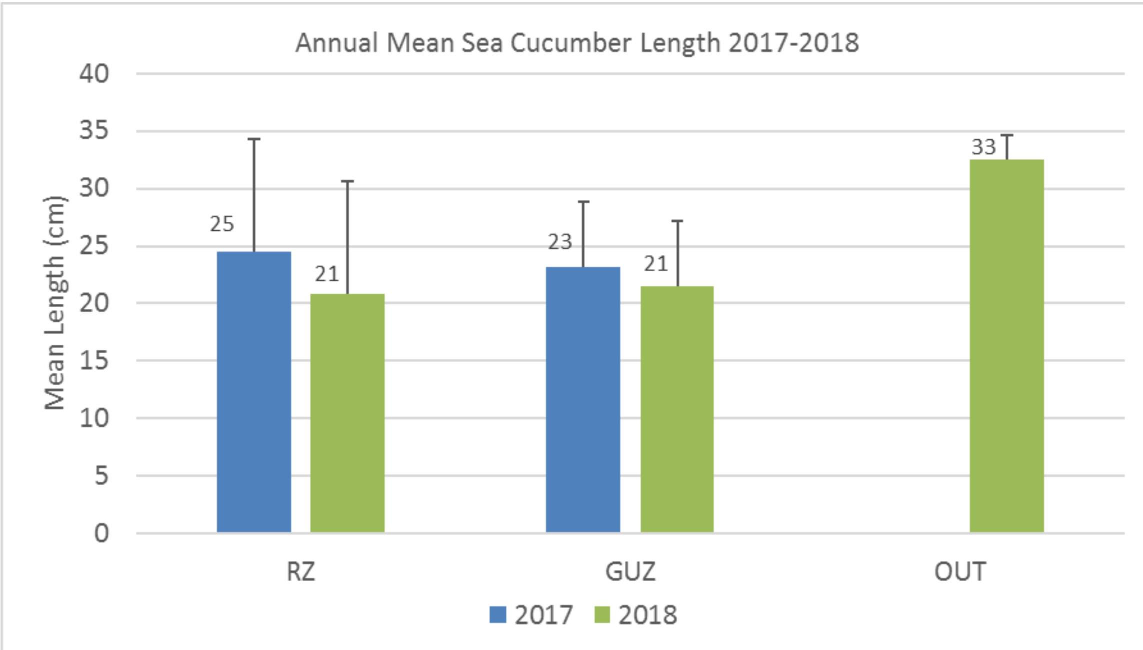

Figure 24. Annual mean sea cucumber, *H. Mexicana*, length (cm) by zone 2017–2018 [Replenishment Zone (RZ), General Use Zone (GUZ)] [±Standard Deviation].

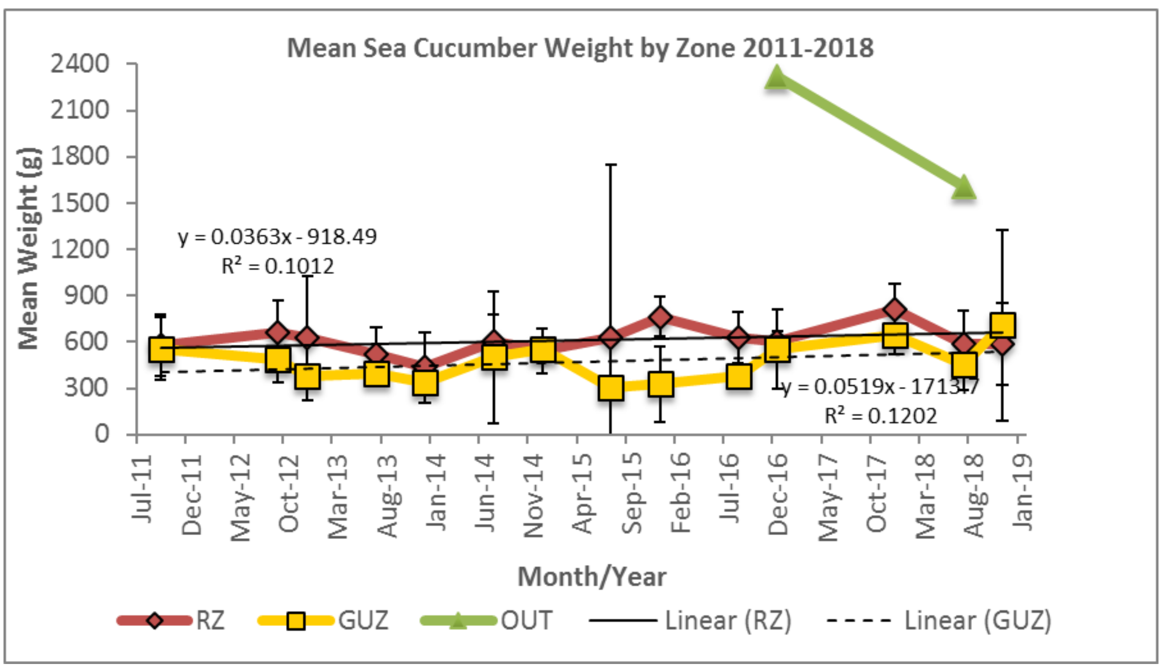

Figure 25. Mean sea cucumber, *H. mexicana*, weight (g) observed during pre-season and post-season surveys conducted 2011–2018 [Replenishment Zone (RZ), General Use Zone (GUZ), Outside the Reserve (OUT)] [±Standard Deviation].

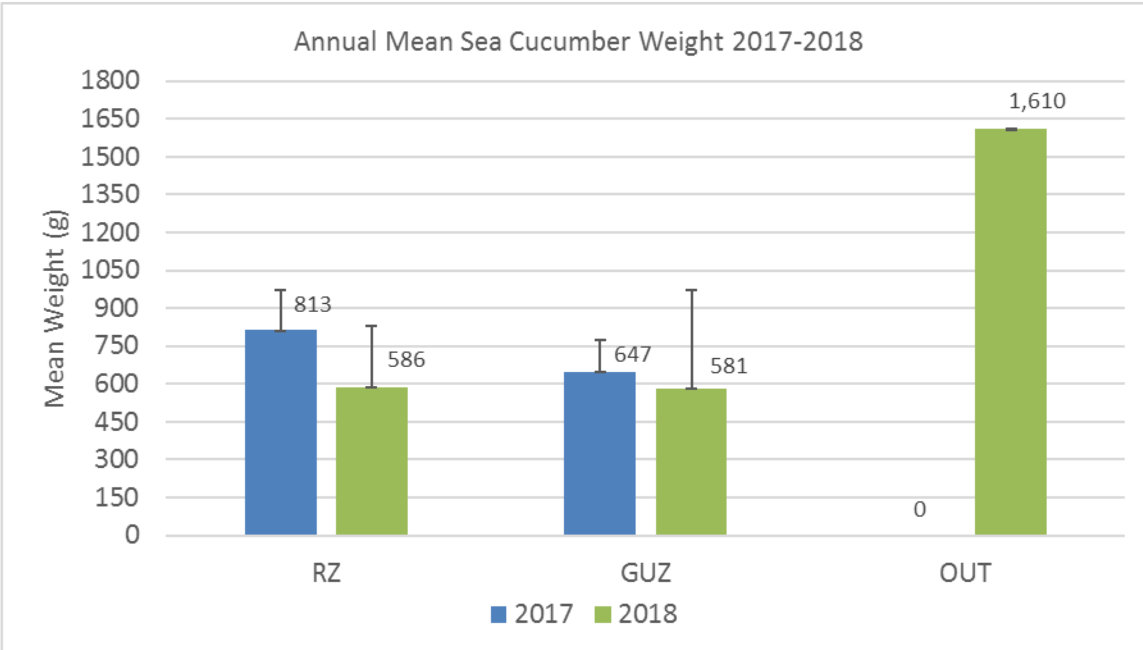

Figure 26. Annual mean sea cucumber, *H. mexicana*, weight (g) 2017-2018 [Replenishment Zone (RZ), General Use Zone (GUZ), Outside the Reserve (OUT)] [±Standard Deviation].

Results:

- The GUZ sea cucumber mean density decreased significantly in 2012 from ~50 ha^{-1} to <10 ha^{-1} in 2013. This trend continued through 2016, though there was a marginal increase at opening of season in the GUZ 2016 (~31 ha^{-1}) (Fig. 21). In 2017, the GUZ mean sea cucumber density was similar to 2016 values at ~26 ha^{-1}, but decreased again in 2018 to <20 ha^{-1} (Fig. 22). A similar dramatic decline in mean sea cucumber population was seen in the RZs starting in 2012 with the exception of 2013 where the density increased to ~113 ha^{-1} and the population seemed to be on the mend. However, the mean density declined again to 20-40 per ha^{-1} until dropping to <20 ha^{-1} in 2016. This trend in the RZs continued into 2017 (~9 ha^{-1}) and 2018 (19 ha^{-1}). The mean sea cucumber density in OUT has been <15 ha^{-1} since monitoring began in 2016. Though a moratorium was placed on harvesting the sea cucumber in 2017, there is no purported difference in mean sea cucumber densities in all zones

- A dramatic decrease in RZs mean sea cucumber densities was observed during closed season in 2012. Since then, though 2015 and 2016 showed slight decreases during the closed season with 2016 mean sea cucumber density recorded only at 13 ha^{-1}, the differences between normal season closing and opening were not notable.

- Since 2011, mean sea cucumber lengths in the RZs and GUZ have ranged from ~17-28 cm with the overall mean and median of the GUZ and RZs 2011-2018 at 22 cm and 23 cm, respectively, showing no outliers in mean values (Fig. 23). The annual mean sea cucumber length in 2017 in the RZs was slightly higher than overall mean at ~25 cm but decreased again in 2018 to 21 cm, similar value to the 2018 GUZ mean sea cucumber length (Fig. 24). There is no purported difference in mean sea cucumber lengths in the GUZ and RZs since 2017. The OUT in 2018, no OUT sites were visited in 2017 for sea cucumber monitoring, showed a slightly higher mean sea cucumber length than both the GUZ and RZ's at ~33 cm.

- The mean sea cucumber weight in the GUZ from 2011-2018 ranged from ~304-707 g, with the overall mean of the GUZ at 471 g and RZs at 611 g and the overall median at similar values of ~471 g and ~601 g, respectively (Fig. 25). The annual mean sea cucumber weight in 2017 increased from 2016 values to 813 g but decreased again in 2018 to 647 g (Fig. 26). The GUZ in 2018 showed a slight increase in weight during the "closed" season, but annual mean sea cucumber weight was similar to 2017 values. There is no purported difference in mean sea cucumber weights in the GUZ and RZs since the moratorium in 2017. The mean sea cucumber weights in OUT were over 2X higher than those found in the RZs and GUZ in 2018.

Discussion:

- The continuous low trend in mean sea cucumber density from 2011-2016 indicated that the closed season was not performing its intended function of protecting adult spawners (i.e. sea cucumber reproduction). In 2017, a moratorium was placed on the sea cucumber fishery, by the BFD, due to the drastic reduction in sea cucumber population since pre-fishery levels. By the end of 2018, the sea cucumber population showed no signs of recovery despite the moratorium. This may be due to a low chance of encountering mates in all zones due to low population levels, poor juvenile recruitment and/or illegal fishing.

- The sea cucumber closed season showed a dramatic decrease in sea cucumber density in 2012, but no notable differences during the closed seasons up to the moratorium in 2017. This could have been due to a low chance of mate encounters as a result of overharvesting during the open season and possible illegal harvesting during the closed season.

- The RZs showed lower mean sea cucumber density than the GUZ since 2014. However, the general trend in the RZs since 2011 is to have slightly higher mean sea cucumber length and mean sea cucumber weight compared to the GUZ. This may imply that the remaining sea cucumbers, though low in density, are currently being protected in the RZs.

- There is no declining trend in mean sea cucumber length or weight in the RZs and GUZ since 2009, indicating poor juvenile recruitment and an overall population skewed towards adults. However, the low densities most likely affect the population recovery rate as there is difficulty in encountering other sea cucumbers to reproduce. The overharvesting of sea cucumber before the moratorium and potential illegal harvesting currently, may have contributed to this trend.

- Sea cucumbers favor seagrass habitats that are more prevalent in the GUZ areas than in PHMR's RZs, such that existing RZs may not be suitable for protecting the life cycle of sea cucumbers. The RZs were established long before there was a sea cucumber commercial fishery. This may contribute to poor spillover from GUZ back into RZs. However, continuously low densities throughout 2013–2018 indicates lack of juveniles from poor reproduction.

Recommendations:

- Continue sea cucumber moratorium until population densities increase significantly and are relatively stable.
- Continue sea cucumber abundance and population structure monitoring to aid in elucidation of the population trends over time.
- The sea cucumber fishery was a lucrative business in terms of Catch Per Unit Effort (CPUE). Increase enforcement presence in PHMR and enforce sea cucumber moratorium.
- Introduce new replenishment zones that protect areas of prime sea cucumber habitat in the sea grass and mudflat areas of PHMR.
- Increase number of monitoring sites to improve statistical robustness of data. Increase size of circle transects from $400m^2$ to $800m^2$ to capture sufficient density data in all areas of severely reduced populations.
- Carry out targeted research project to determine maturity indicators for sea cucumber of PHMR, for use in informing the Adaptive Management Framework.
- Re-establish the water quality program which has important potential implications for management not only of sea cucumber, but coral, seagrass, conch and lobster health as well. As detritus feeders, their major decline may negatively impact benthic water quality (i.e. increased rotting material & lower dissolved oxygen levels)

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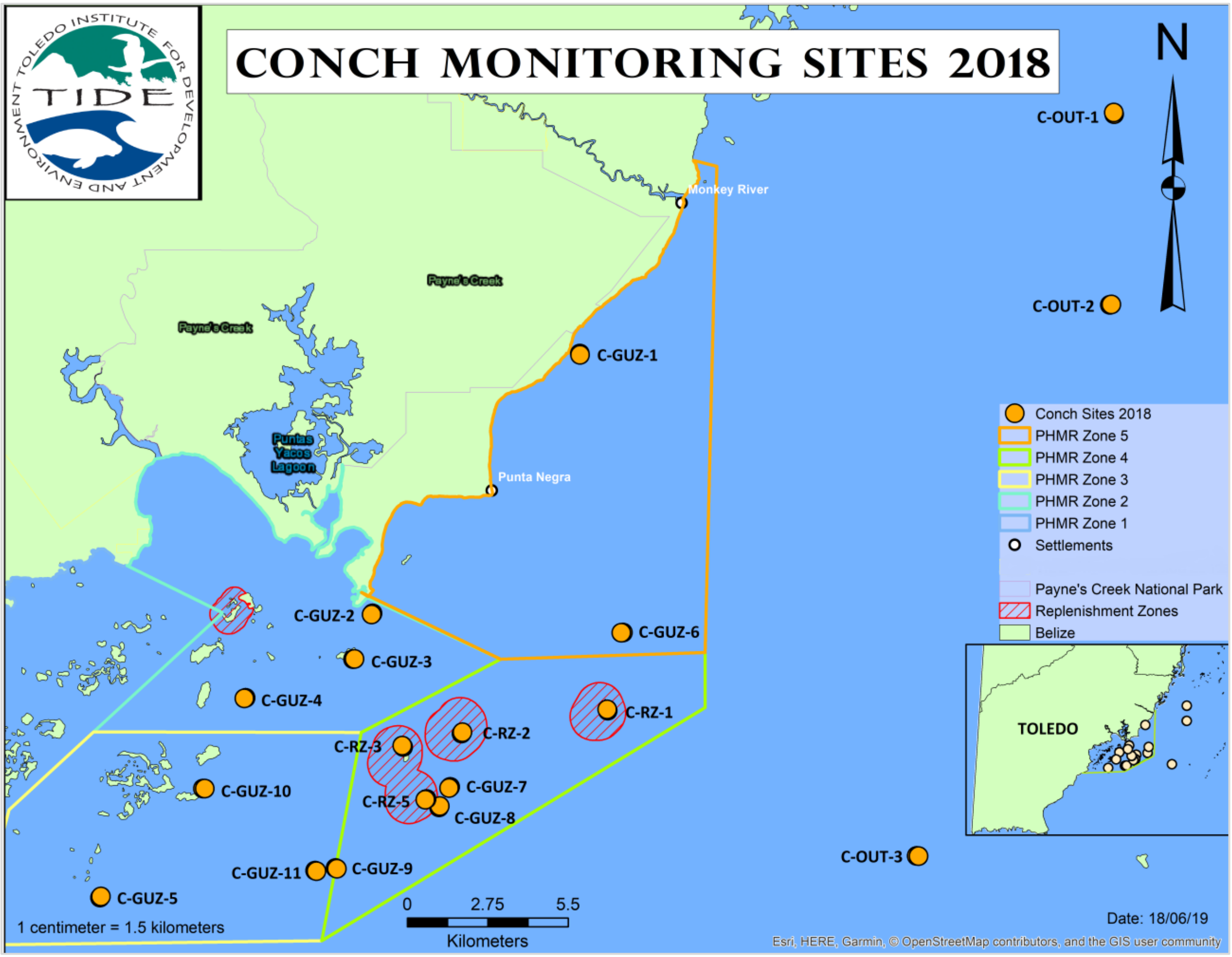
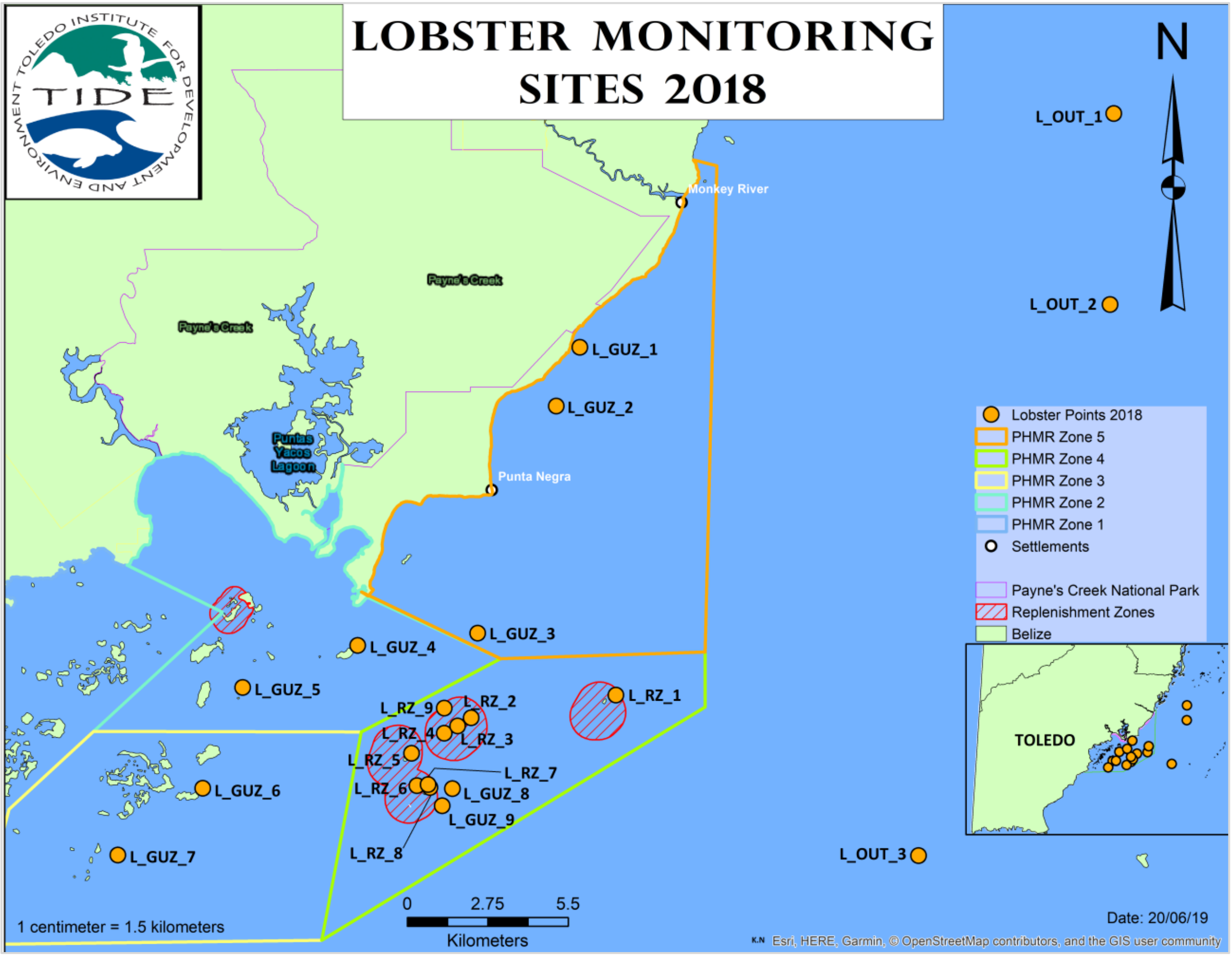
Appendices

Appendix 1. Queen conch monitoring sites 2017 & 2018.



Appendix 2. Spiny lobster monitoring sites 2017 & 2018.



Appendix 3. Sea cucumber monitoring sites 2017 & 2018.