Toledo Institute for Development and Environment

Port Honduras Marine Reserve Benthic Commercial Species Update 2019

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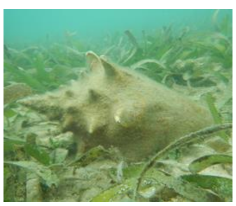

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ACRONYM KEY	
BFD	Belize Fisheries Department
ERZ	Extended Replenishment Zone
GUZ	General Use Zone
Contiguous RZs	Extended Replenishment Zone + RZs
LT	Conch Lip Thickness
NTZ	No Take Zone
OUT	Marine Areas Close to but Outside PHMR
PCNP	Payne's Creek National Park
PHMR	Port Honduras Marine Reserve
PRZ	Preservation Zone
RZs	Replenishment Zones (previously NTZs)
SL	Conch Shell length
TIDE	Toledo Institute for Development and Environment

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1. BACKGROUND

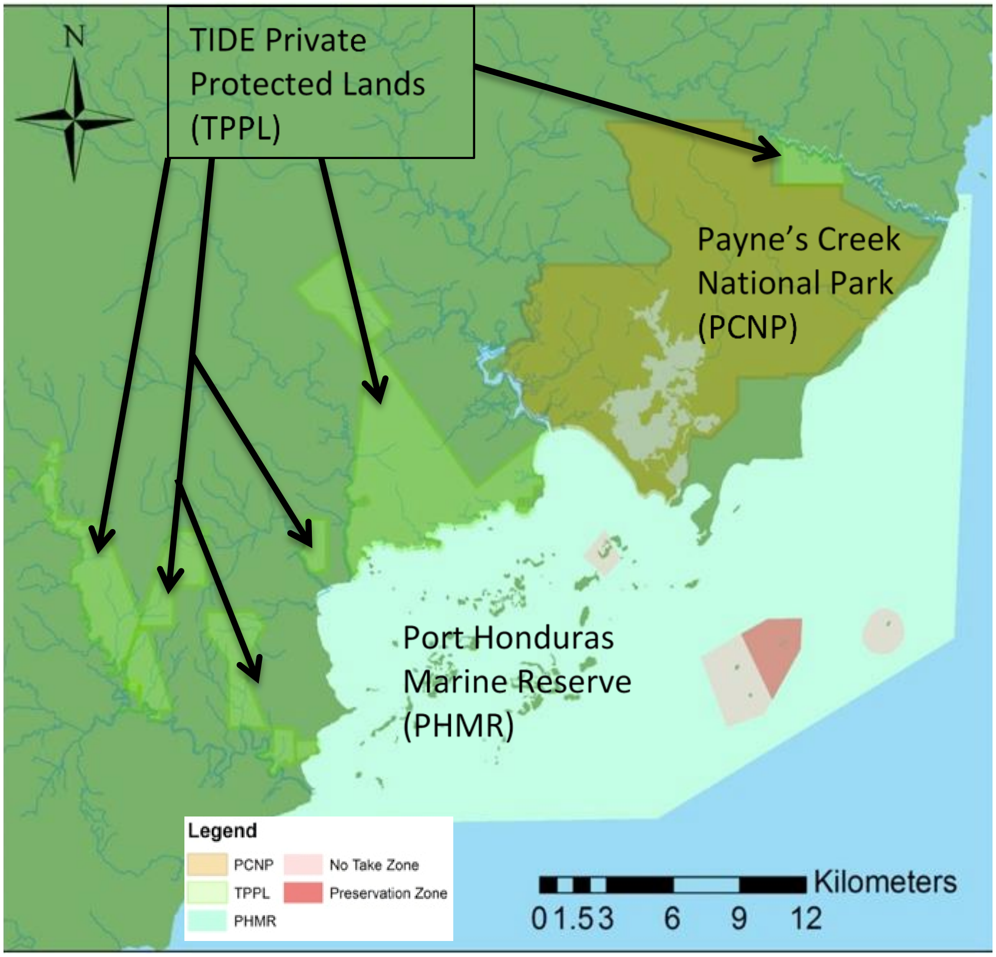
1.1 Port Honduras Marine Reserve

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 a 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 and 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.

1.2 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.



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1.3 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 theory is also supported by the Belize Fisheries Department (BFD). After concerns 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 (Contiguous RZs) 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 hindrance, combined with no formal designation being written into regulations 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.

2. PROGRAM OVERVIEW

2.1 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. In 2011, the sea cucumber, *Holothuria mexicana*, (common name donkey dung) had become a significant commercial species. Underwater surveys have been conducted by TIDE for *H. mexicana* since September 2011. In 2017, the Belize Fisheries Department issued a moratorium on harvesting of *H. mexicana* due to low population levels and continues to be in effect today.

2.2 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.

2.3 This Report: Benthic Commercial Species Update 2019

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 for the calendar year 2019. Methods and results are additionally reported for long-term abundance monitoring and morphometric data collected during underwater surveys covering an eleven-year period for lobster and conch (2009-2019) and a nine-year period for sea cucumber (2011-2019) in the replenishment zone (RZs), 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.

3. QUEEN CONCH MONITORING

3.1 Queen Conch

Data on population density, maturity and size frequency of queen conch (*Lobatus gigas*, originally *Strombus gigas*) were collected and analyzed. This involved comparison of morphometric data from underwater surveys 2009-2019. In the years 2009–2010, conch monitoring took place twice each year, just before the conch season closed in June, and shortly before it opened 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 had been monitored; five in RZs, 11 in the GUZ and four outside the reserve (OUT). In 2019, an additional site OUT was added making the total number of conch sites monitored at 21. In this 2019 report, the planned RZ expansion sites for conch were included in the analysis in order to capture the effect of establishment of these areas as RZs in the future. These RZ expansion sites are collectively known as 'Expanded Replenishment Zone' (ERZ) sites with two currently located in the GUZ. The ERZ sites in addition to the RZs sites are referred to as the Contiguous RZs. 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. The recorded data on 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 2019. 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 2009–2019 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 Results

The annual conch densities in RZs in 2019 increased from 46 conch per hectare in 2018 to 59 conch per hectare in 2019 (Fig. 2). Conch densities at the opening of the season in the RZs were at 86 conch per hectare, a level not seen since 2013 (Fig. 3). This was a 39% increase from opening of season in 2018. The annual conch densities in the GUZ slightly decreased to 38 conch per hectare with population values at opening of conch season similar to 2018 levels at 45 conch per hectare. The OUT sites showed annual conch density similar to levels in 2017-2018 at 15 conch per hectare with opening season population levels at 14 conch per hectare. The annual conch density in the estimated Contiguous RZ was ~72 conchs per hectare; a 72% increase in population density from 2018 levels at 42 conchs per hectare (see Fig. 3).

Mean conch shell length in 2019 was similar to those sampled in 2018 in all three zones ranging from 19-21 cm (Fig. 4). The majority of conchs sampled in PHMR were in the 20-25 cm shell length cohort in both May and September 2019 monitoring efforts (Fig. 5 & 6). There was a slight increase in the percentage of conchs with shell lengths in the 10-20 cm range from closing of conch season in May to the opening of conch season in October 2019. The mean shell length since 2009 does not show any major increasing or decreasing trends in the GUZ, RZs or OUT (Fig. 7-9).

The annual mean conch lip thickness (LT) in 2019 was greater in the RZs than in the GUZ at 11 mm and 6 mm, respectively (Fig. 10). Additionally, the Contiguous RZs showed slighter greater LTs than those found in the GUZ. The lip thickness in the RZs at closing of season showed 25% in the 15-25 mm size cohort and 33% in LT cohort size <10 mm (Fig. 11). At the opening of season, RZs conch lip thickness size cohorts showed a more even distribution of conch LT sizes in the 10-<15, 15-<20, and 20-<25 mm size classes with ~24% less than 5 mm (Fig. 12). The GUZ in May at the closing of season showed a vast majority of conch (~70%) with LT < 5mm. At the opening of season, the GUZ showed >50% of the conch LT in size class cohorts >15 mm and only ~14% with LT <5 mm. The OUT showed a decrease in mean LT from closing of season to opening of season from ~13 mm to 8 mm, respectively. However, the majority of conch were in the 15-<20 mm size class cohort for both May and September monitoring efforts. Time series analysis shows a general trend toward decreasing lip thickness in the GUZ, RZs and OUT (see Fig. 7-9).

3.3 Discussion

The annual conch density at the opening of season in the RZs showed an increase of ~28% from 2018 density levels and a major increase of conch population levels at the opening of season in RZs as compared to 2018. This was the second consecutive year of increases in the conch population in the RZs and the first year since 2013 that the conch density was above 80 conch ha^{-1} at the opening of season. The annual conch densities in the GUZ slightly decreased from 2018 values. The reproductive success of queen conch is highly dependent on population density and the ability of the slow-moving gastropods to find a mate. The critical densities of Caribbean conch population is widely agreed to be 50-100 conch ha^{-1} (Stoner et al. 2012). For the past 6 years, the conch population has remained below the 88 ha^{-1} minimum density threshold, as determined by the Belize Fishery Department, in all zones and continues to have a negative impact on reproductive success, as the likelihood of conch encountering reproductive mates remains low. The increase in conch density in the RZs was good news and may be attributed to a number of factors. One factor could have been the early closure of the conch fisheries in April 2019 by the BFD, potentially protecting conch populations for a longer closed season period during their reproductive season allowing an increase in recruitment rates. A second factor may involve conch reproduction. During the September monitoring, adult conch actively mating were observed along with visual identification of conch benthic egg masses. Exact numbers of mating or egg masses were not recorded. However, oogenesis is believed to be stimulated by mating, so the conch density observed during monitoring in September may have been due to a chemical cue to aggregate to mate, thus potentially leading to an overestimation of the conch densities ha^{-1} in the PHMR. Lastly, the increased conch density in the RZs may be due to diligent fishery management, allowing an increase in queen conch stocks in the protected zones. The 72% increase in the annual estimated Contiguous RZ implies a spillover effect from the RZs into bordering GUZs in 2019.

Mean conch shell length in 2019 was similar to those sampled in 2018 in all three zones ranging from 19-21 cm; legal shell length as determined by BFD. Additionally, the majority were in the 20-25 cm shell length cohort in both May and September 2019 indicating no major shifts in population shell length size occurred.

Mean conch lip thickness decreased in the RZs and increased in the GUZ at opening of season 2019, perhaps implying a spillover effect from the RZs (conch migration) or perhaps the extended closed season aided in conch lip thickness growth in the GUZ and thus fecundity of the population. Conch can grow up to 5 mm in lip thickness annually (Stoner et al. 2018, Stoner and Sandt, 1992). Yet, the LT annual mean values in the RZs and GUZ at 11 mm and

6 mm respectively, were still less than literature standards for queen conch fecundity. Additionally, time series analyses shows a LT decreasing trend in both the GUZ and RZs.

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).

Studies have also 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, thus reducing recruitment rates (Stoner et al., 2012). These observations point to a need to better understand queen conch spawning locations and the spillover effects of the RZs to aid in understanding conch population dynamics in all zones. Also, it points to a need for revising the legal framework for managing conch by incorporating lip thickness into existing legislation to protect immature conch from harvest.

The closed seasons, especially in the GUZ, 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, combined with low mean lip thickness in all zones, indicates poor recruitment via reproduction, with immature adults being predominant. These factors together continue to leave the conch population vulnerable to overexploitation and collapse.

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 national 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.

3.4 Recommendations

- Incorporate lip thickness into conch fishery size limit regulations at 15 mm, potentially providing at least one mating season to occur before harvest.
- Work with fishers to better characterize conch spawning locations and closely

monitor and protect them.

- Expand the replenishment zones to reduce fishing pressure in PHMR.

- 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 and in juvenile connectivity studies.

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

- Conduct conch habitat and depth strata studies to identify less exploited conch populations in PHMR by fishers.

3.5 Figures

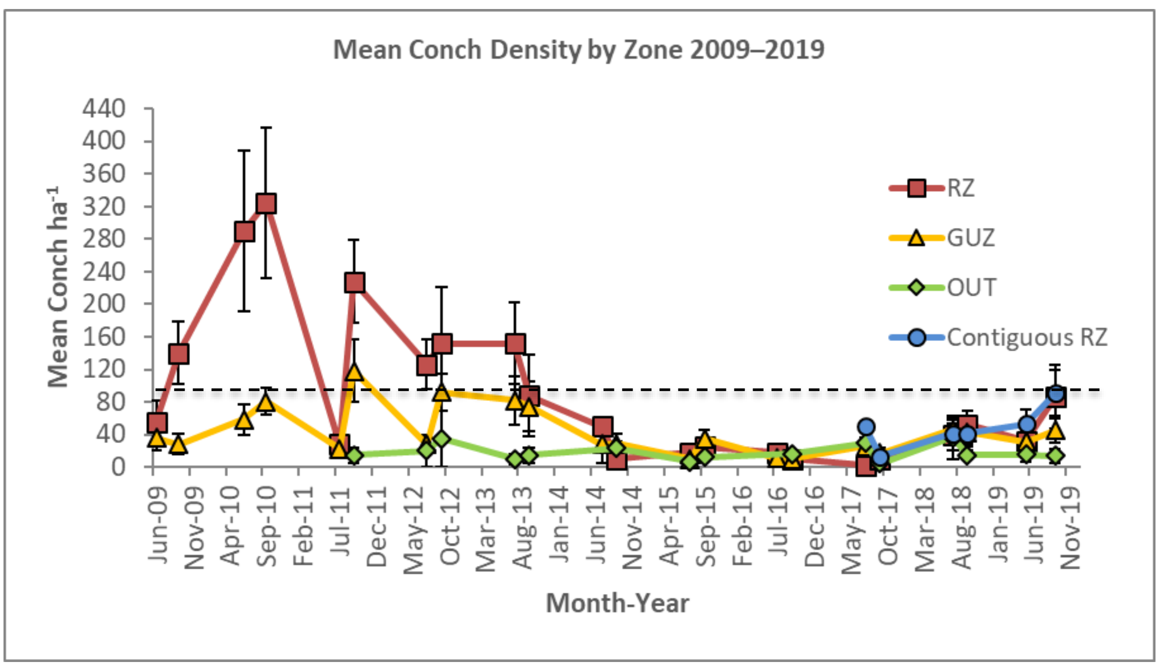
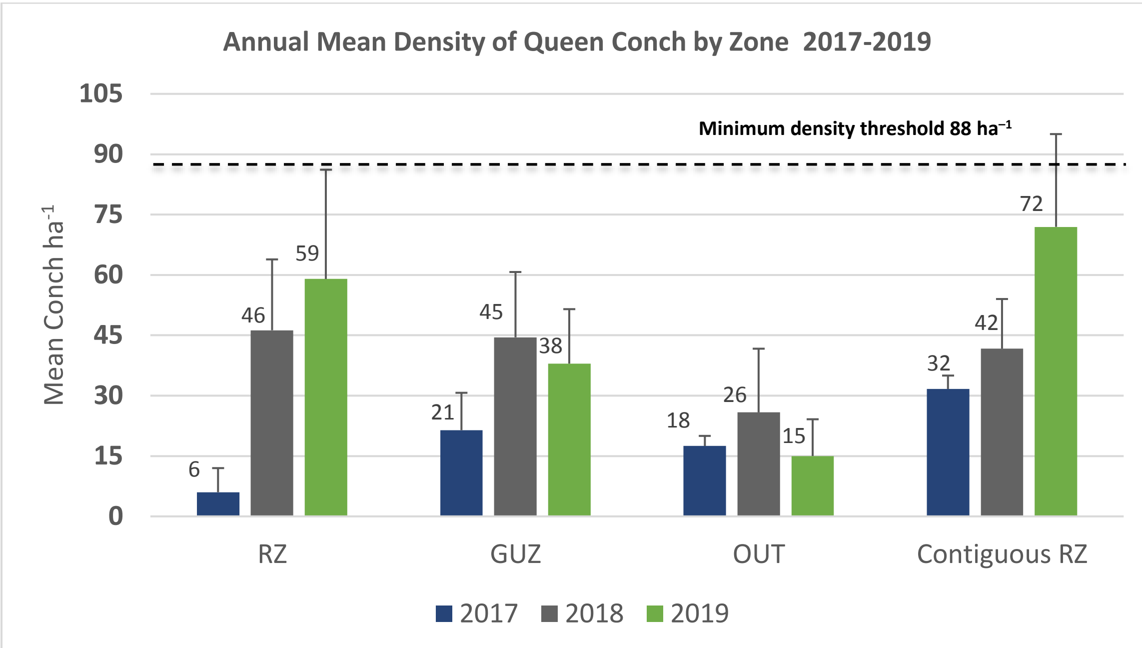


Figure 2. Mean queen conch density, number of conchs per hectare, observed during pre-season and post-season surveys by zone 2009–2019 [Replenishment Zones (RZ), General Use Zone (GUZ), Outside the Reserve (OUT), Contiguous RZ] [±Standard Error Bars].



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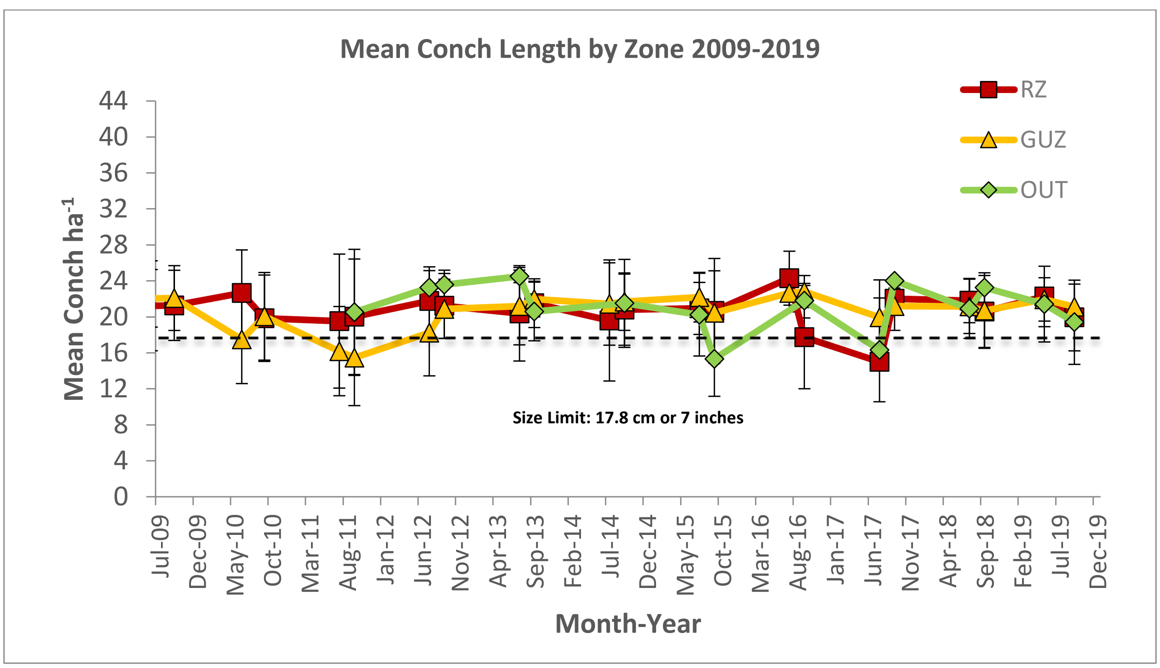

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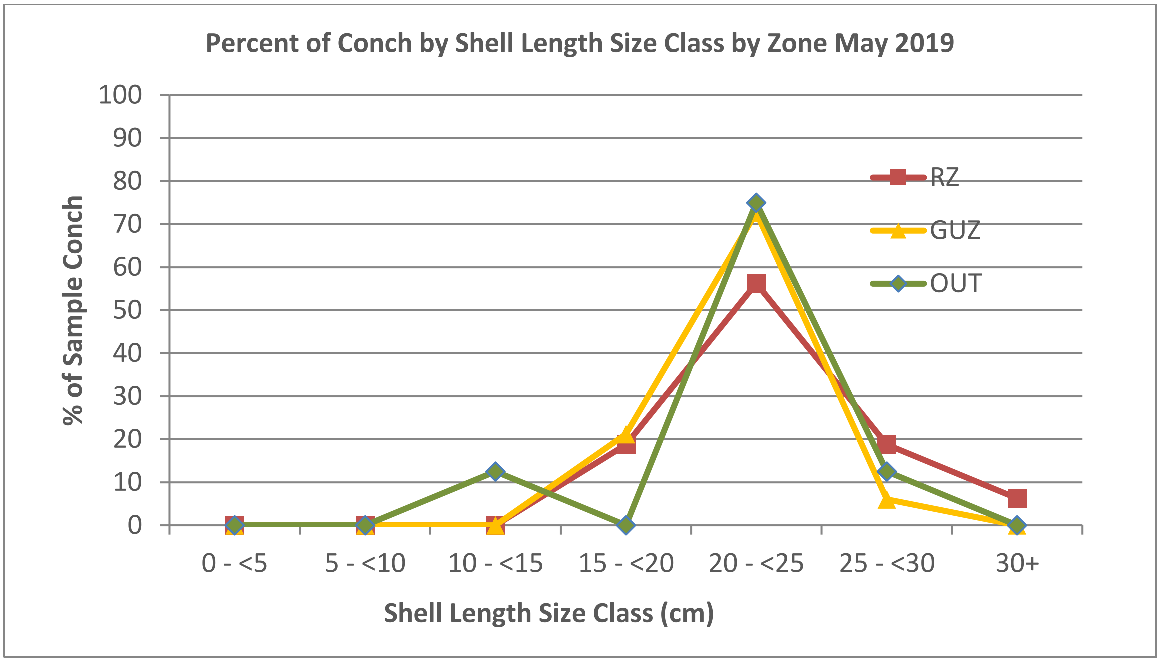

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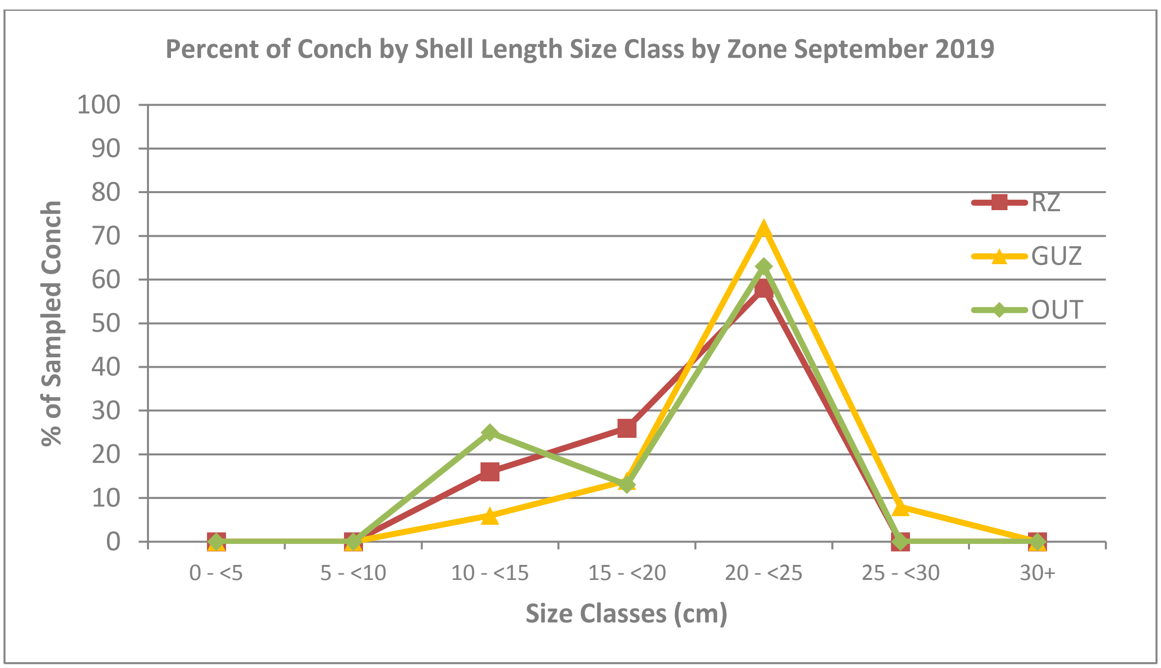

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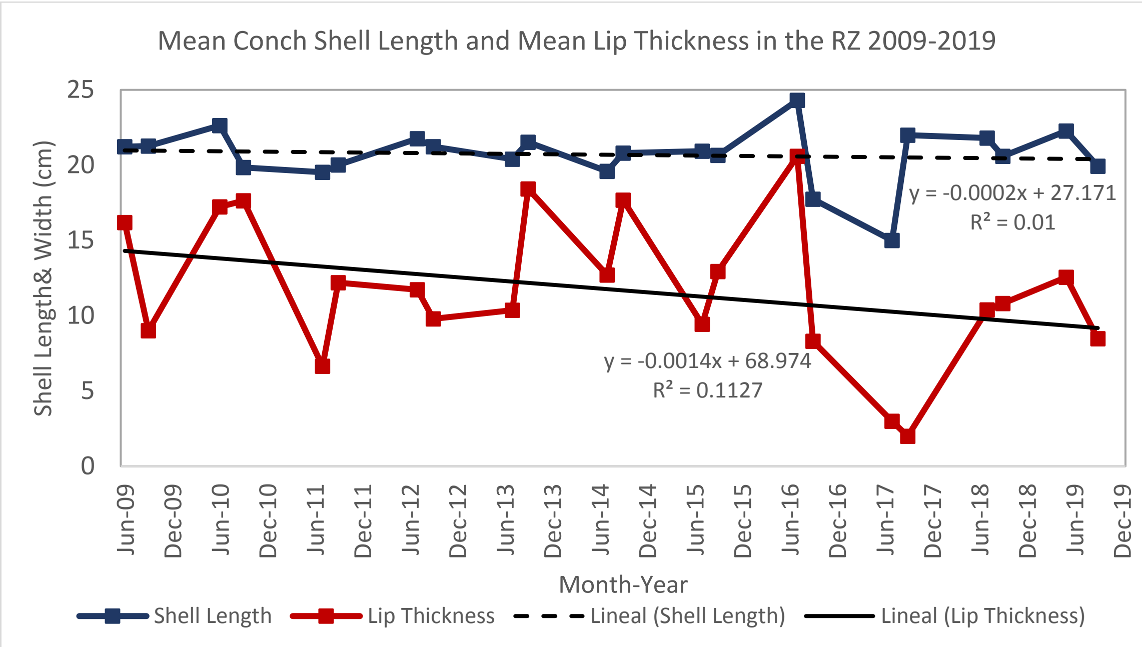

Figure 7. Mean queen conch, *Lobatus gigas,* shell lip thickness vs. mean shell length in the Replenishment Zones (RZ) 2009–2019.

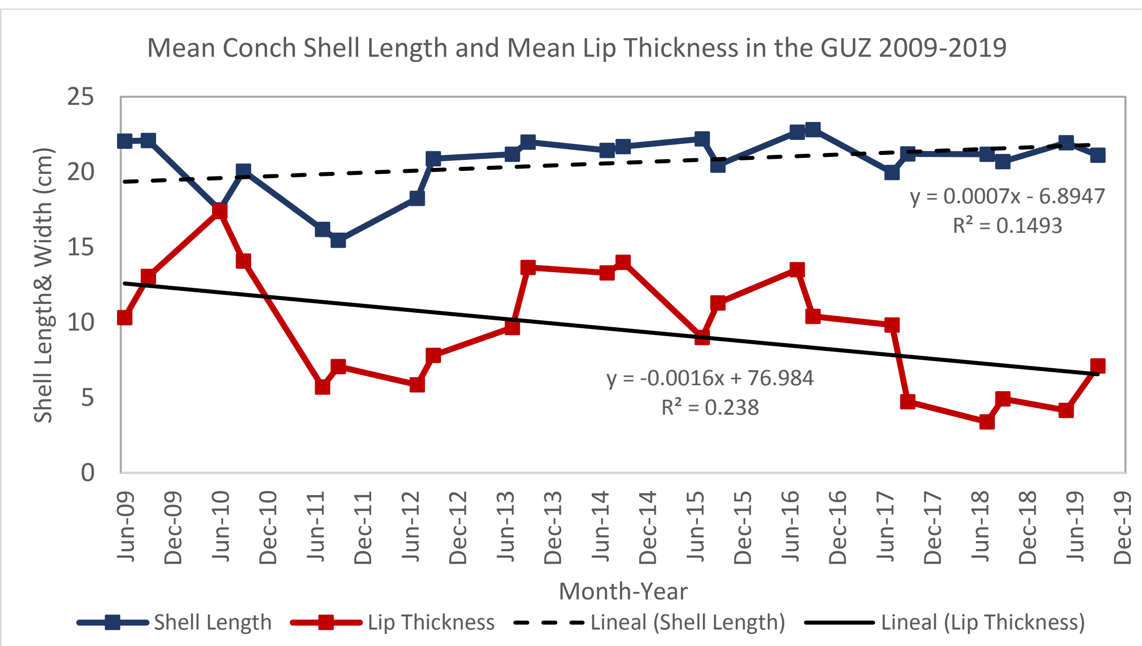

Figure 8. Mean queen conch, *Lobatus gigas,* shell lip thickness vs. mean shell length in the General Use Zone (GUZ) 2009–2019.

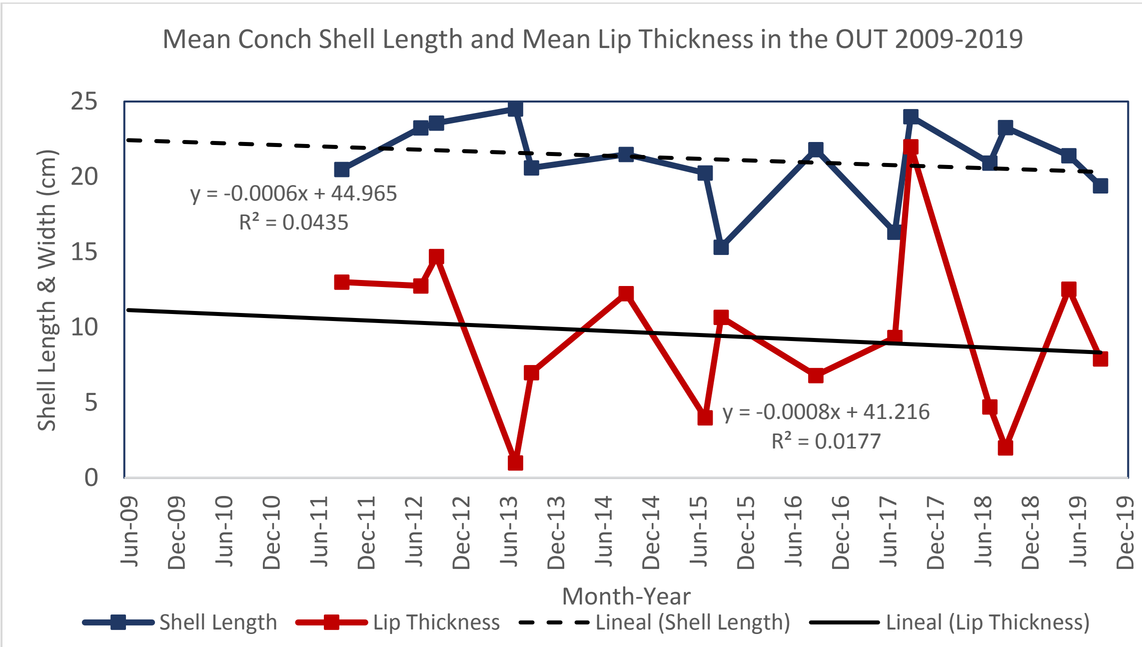

Figure 9. Mean queen conch, *Lobatus gigas,* shell lip thickness vs. mean shell length outside the PHMR Reserve (OUT) 2009–2019.

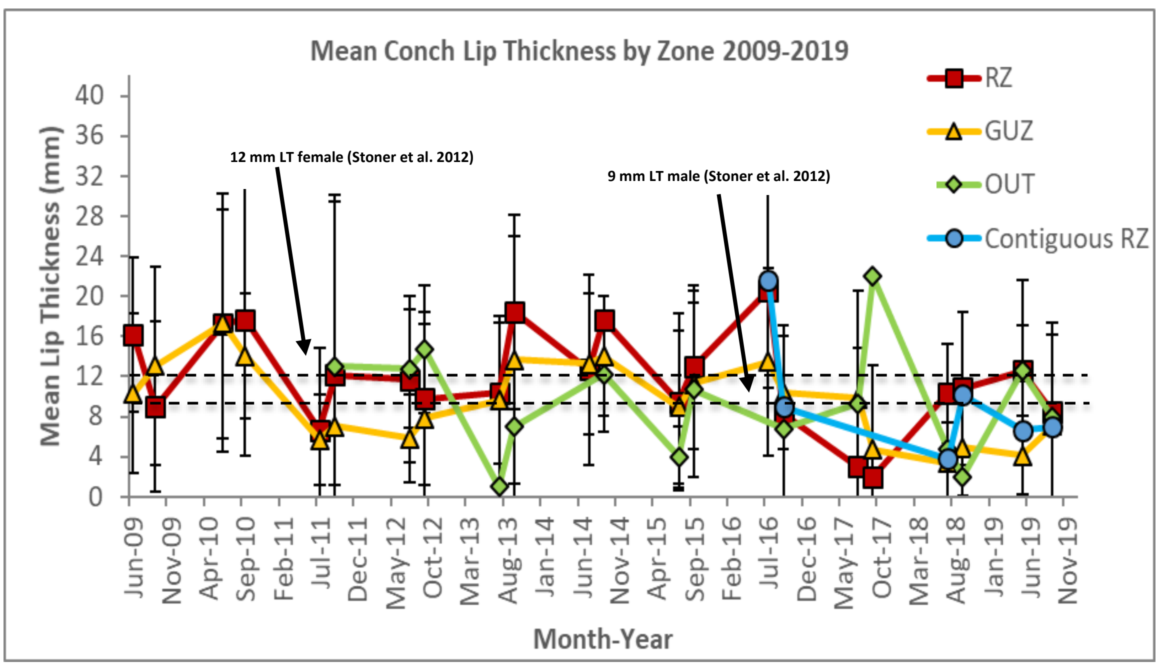

Figure 10. Mean queen conch lip thickness (mm) observed during pre-season and post-season surveys by zone 2009–2019 [Replenishment Zones (RZ), General Use Zone (GUZ), Outside the Reserve (OUT), Contiguous RZ] [±Standard Deviation].

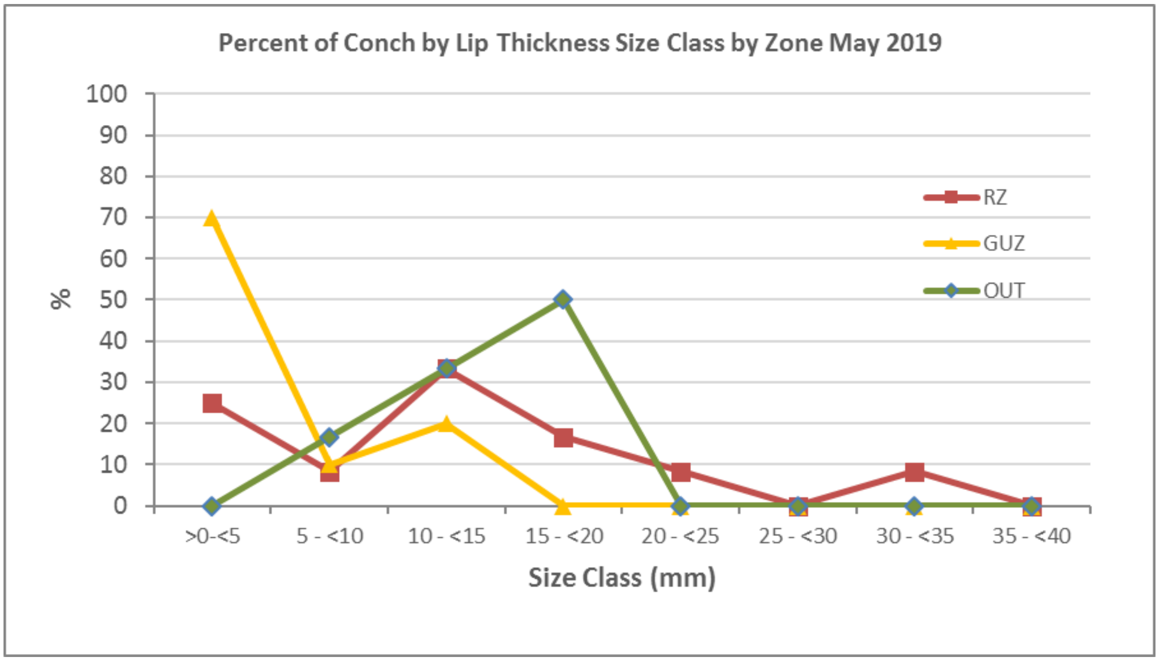

Figure 11. Queen Conch, *Lobatus gigas*, close of season (May) percent lip thickness (LT) by size cohorts by zone 2019 [Replenishment Zone (RZ), General Use Zone (GUZ), Outside the Reserve (OUT)].

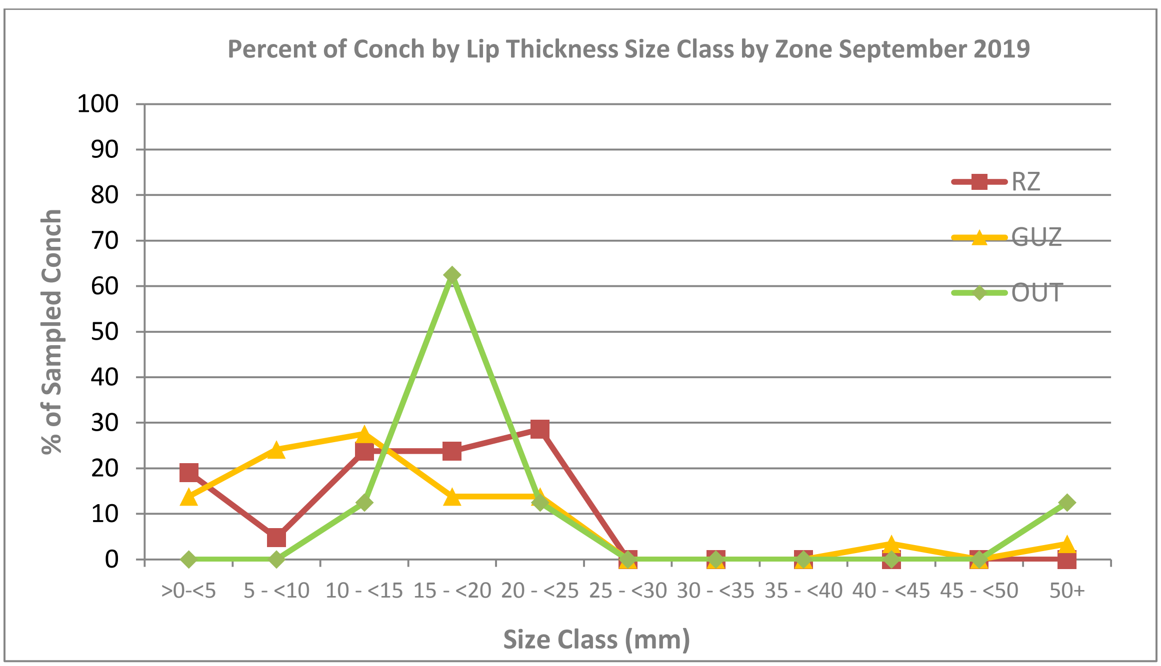

Figure 12. Queen Conch, *Lobatus gigas*, close of season (September) percent lip thickness (LT) by size cohorts by zone 2019 [Replenishment Zone (RZ), General Use Zone (GUZ), Outside the Reserve (OUT)].

4. SPINY LOBSTER MONITORING

4.1 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. The ERZ sites in addition to the RZs sites are known collectively as the Contiguous RZs. 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 enabling estimates of stock maturity and fecundity to be made.

4.2 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. 13). 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 from the 2016 all-time lows, 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}. In 2018, the mean lobster abundance decreased in both the RZs and GUZ with annual mean abundances in both zones at 8 lobster hr^{-1} (Fig. 14). As in 2017, there was a decrease in mean lobster abundance in all zones from the closing to the opening of the lobster season. In 2019, lobster abundance decreased even further in both the GUZ and RZs with annual mean lobster abundance at 4 hr^{-1} and 5 hr^{-1}, respectively. Though OUT sites are on lobster preferred coral habitat, the lobster abundance was <2 lobster hr^{-1}. The planned Contiguous RZ lobster abundance reflected the observed lobster abundances in the RZs in 2017-2019 (see Figure 14).

Mean carapace length decreased in the RZs in early 2017, but increased in the GUZ from the 2016 low of 3.5 cm to 10.0 cm at the opening of season (Fig. 15). 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. 16). In 2018, the mean carapace length in the GUZ at closing and opening of season was ~8.5 cm, a slight 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 16). The mean carapace length in the RZs in 2019 increased to ~9 cm at opening of lobster season, similar to GUZ values, with an annual mean carapace length at 8.7 cm. The GUZ mean carapace length 2017-2019 at opening of season has been steady at ~9 cm. The OUT and Contiguous RZ showed increases in annual mean carapace lengths at 9.0 cm and 8.7 cm, respectively, with Contiguous RZ mean carapace length observed at 10 cm at opening of lobster season 2019, slightly higher than the GUZ and RZs.

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 slightly higher at 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 at mean carapace lengths >8 cm (Fig. 17). 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. 18). The February 2019 mean carapace length size distributions show the RZs with over 60% at >10 cm (Fig.19). This is an increase from 2017 and 2018 values. It was observed in the GUZ that ~50% were <8 cm in size distribution. In June 2019, at the opening of the season, the RZs mean carapace length showed the majority in the 8-<10 cm size distribution (Fig. 20). The GUZ displayed more of a balance with ~20% equally at the 4-<6, 8-<10 and 10-<12 size cohorts. The Contiguous RZ largely mirrored the RZs but showed slightly more percent of mean carapace lengths at <8 cm.

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. 21). This implied that there were naturally more males than 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 21). 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. 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. In 2019, males were once again more prevalent than females with males 65-70% and females ~25-35% in the RZs, GUZ and OUT (Fig. 22).

4.3 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 <2 lobsters hr^{-1} at opening of season. However, the mean lobster abundance decreased again seasonally and annually in 2018 and again in 2019 with the opening season at only 5 lobster hr^{-1} and 6 lobster hr^{-1} in the GUZ an RZs, respectively. The Contiguous RZ showed the same trends as the RZs in mean lobster abundance in 2017-2019. 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 lobster abundance was observed from the closed season to the opening of season in both zones in 2017 & 2018, a consecutive trend observed since 2014. Illegal poaching may play a role, or these observations may be indicative to lobster migration patterns. The difference in mean lobster per hour by season in 2019 was not notable due to the already low lobster abundance observed.

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 that year (n=3). 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 annual mean lobster carapace length in the GUZ has remained steady at 8-8.5 cm in 2017-2019, but the RZs showed a steady increase into 2019, with more lobster at sexually mature size. Larger lobster generally equates to more reproductive success. The Contiguous RZ showed similar trends in size distribution as the RZs in 2019. The expansion of the current RZs into a contiguous zone may enhance the lobster population fecundity.

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 may be indicative of it being a juvenile nursery with spill-over into GUZ.

Overall, lobster populations showed 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.

4.4 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.

4.5 Figures

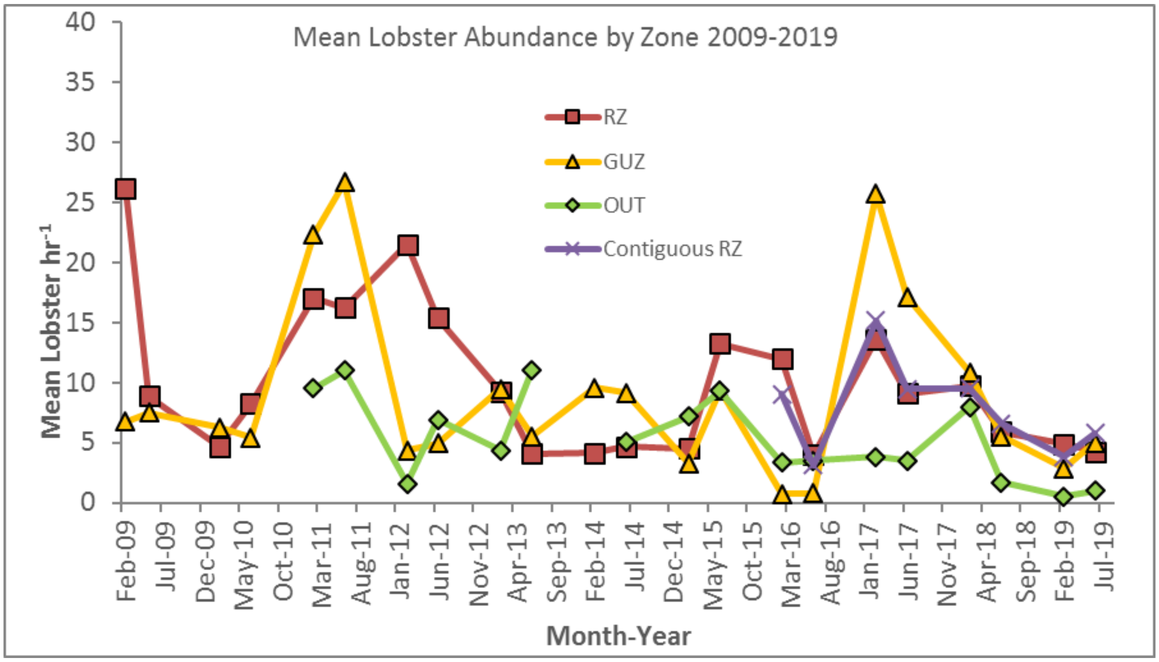

Figure 13. Mean spiny lobster, *Panulirus argus*, abundance (lobster per hour) observed during pre-season and post-season surveys by zone 2009–2019 [Replenishment Zone (RZ), General Use Zone (GUZ), Outside the Reserve (OUT), Contiguous RZ].

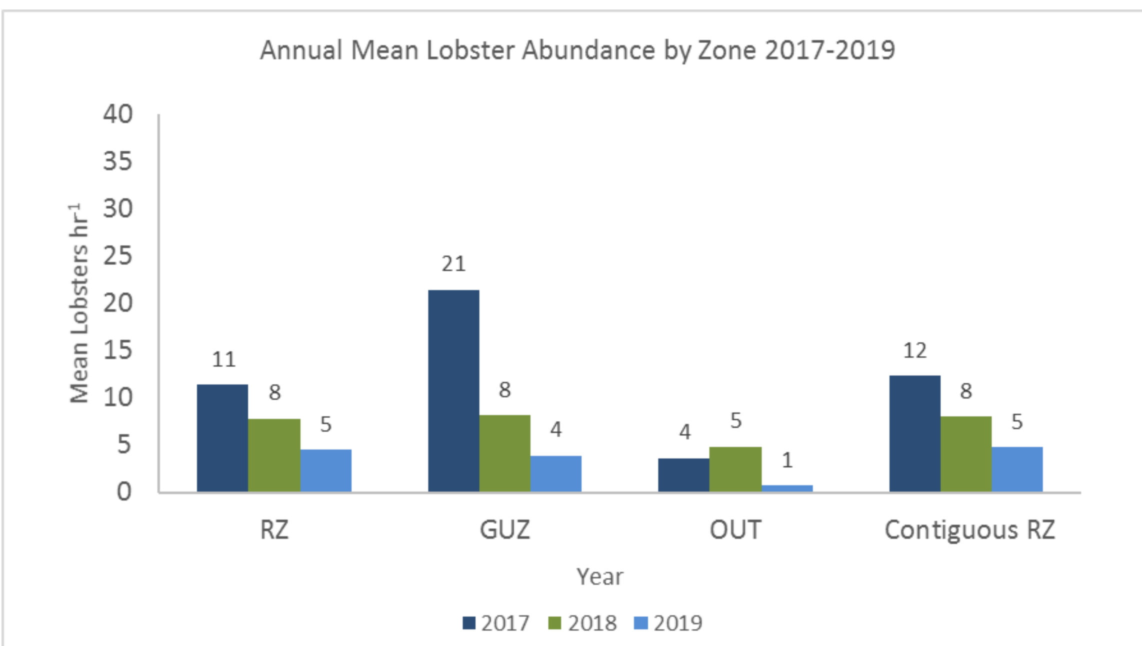

Figure 14. Annual mean spiny lobster, *Panulirus argus*, abundance (lobster per hour) by zone 2017–2019 [Replenishment Zone (RZ), General Use Zone (GUZ), Outside the Reserve (OUT), Contiguous RZ].

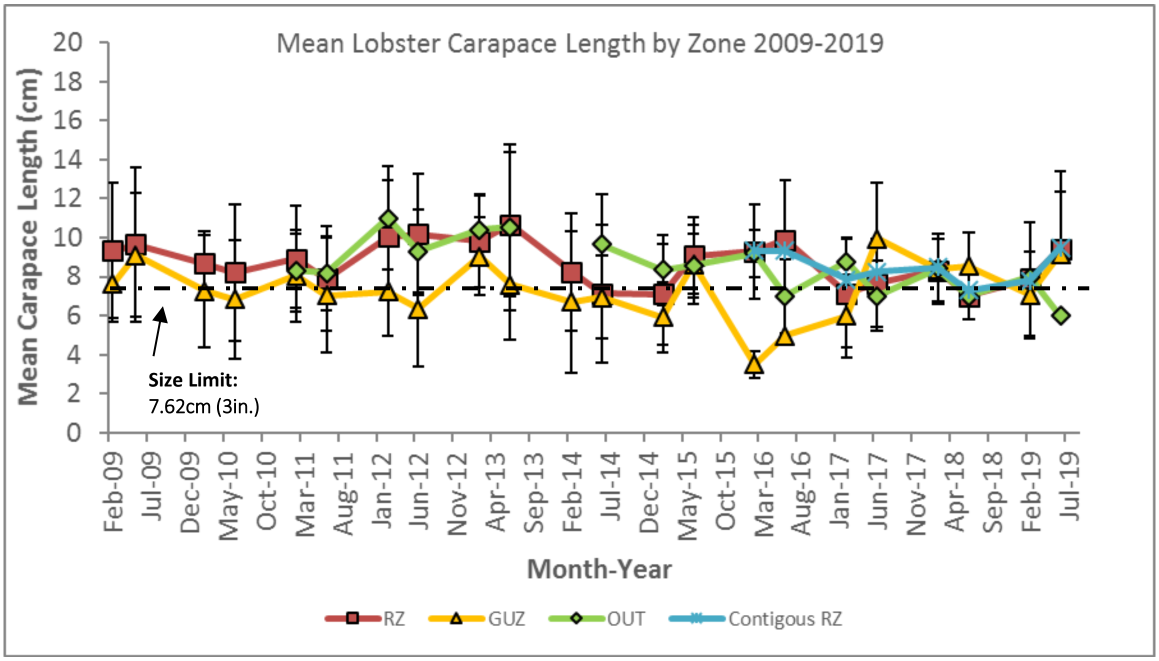

Figure 15. Mean spiny lobster, *Panulirus argus*, carapace length (cm) observed during pre-season and post-season surveys by zone 2009–2019 [Replenishment Zone (RZ), General Use Zone (GUZ), Outside the Reserve (OUT), Contiguous RZ] [±Standard Deviation Bars].

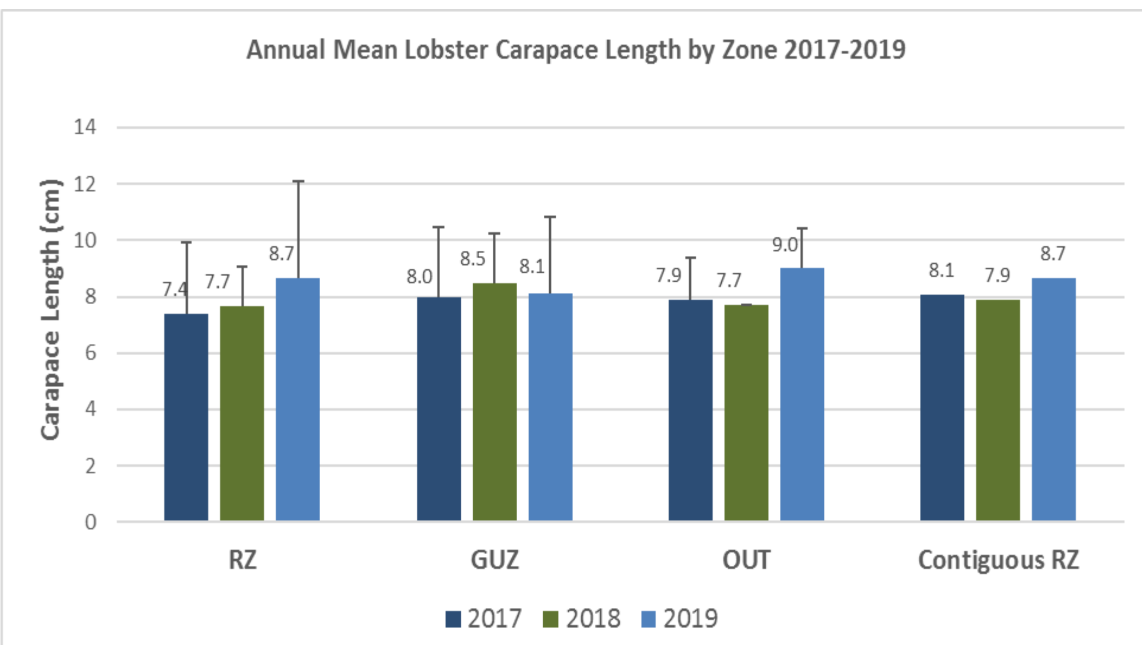

Figure 16. Annual mean spiny lobster, *Panulirus argus*, carapace length (cm) by zone 2017–2019 [Replenishment Zone (RZ), General Use Zone (GUZ), Outside the Reserve (OUT), Contiguous RZ].

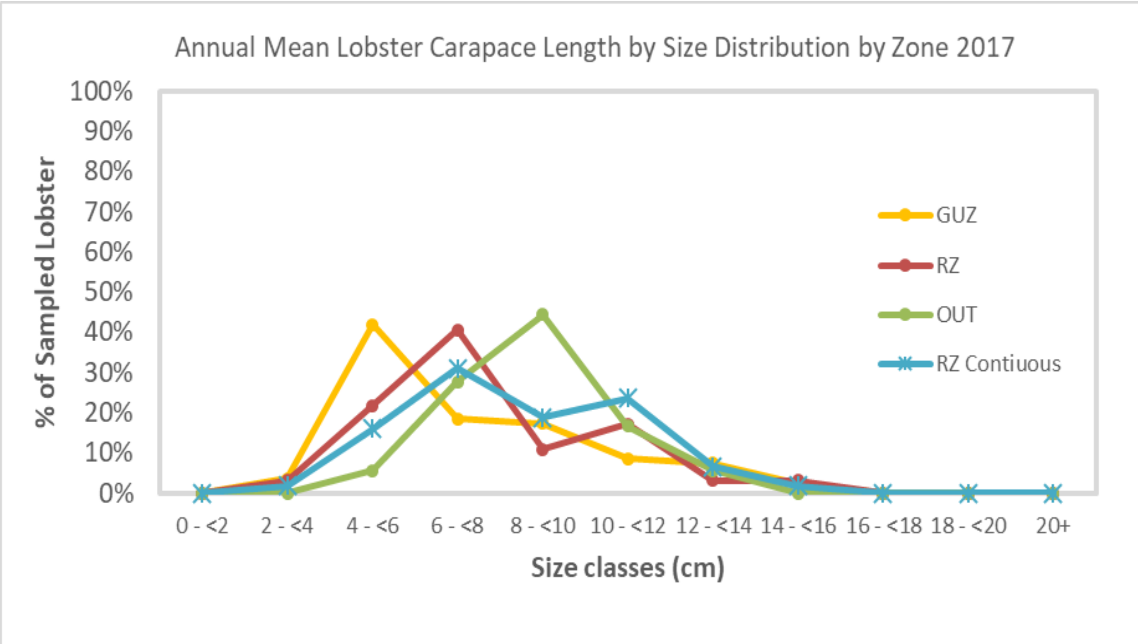

Figure 17. Annual mean spiny lobster, *Panulirus argus*, carapace length (cm) by size distribution by zone 2017 [Replenishment Zone (RZ), General Use Zone (GUZ), Outside the Reserve (OUT), Contiguous RZ].

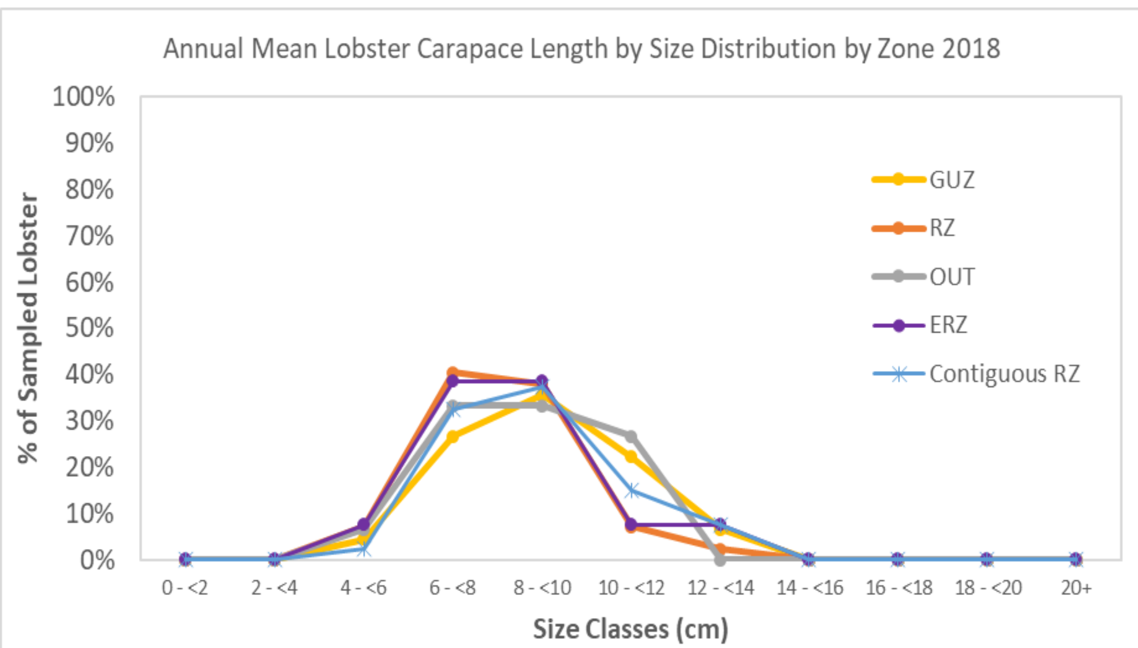

Figure 18. Annual mean spiny lobster, *Panulirus argus*, carapace length (cm) by size distribution by zone 2018 [Replenishment Zone (RZ), General Use Zone (GUZ), Outside the Reserve (OUT), Contiguous RZ].

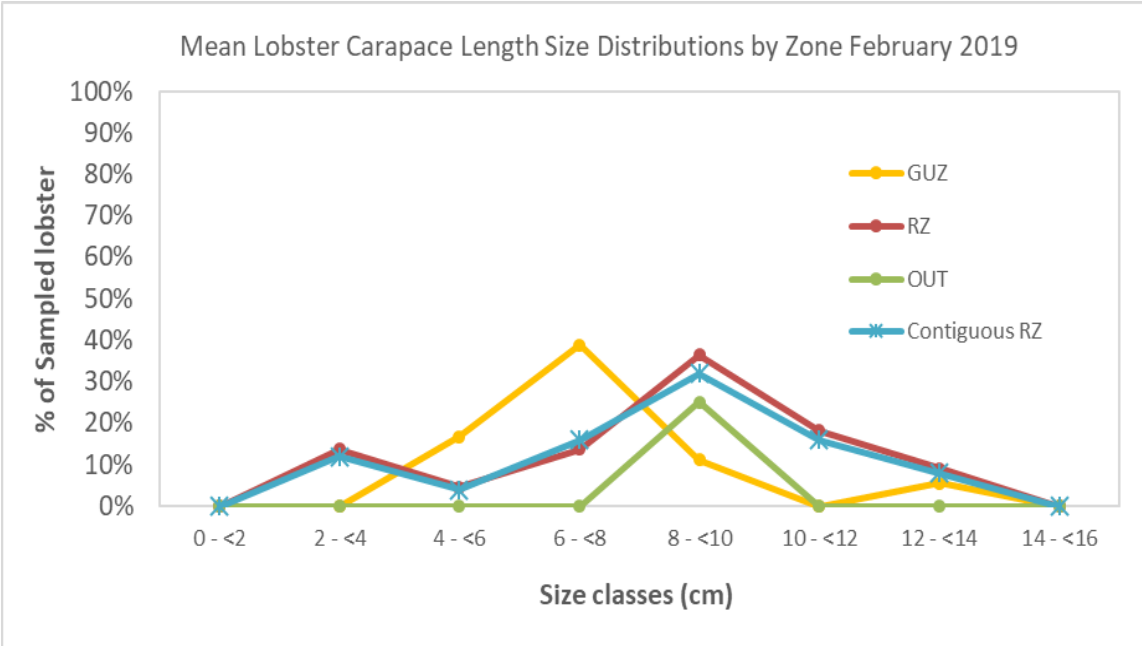

Figure 19. Mean spiny lobster, *Panulirus argus*, carapace length (cm) by size distribution by zone at close of season February 2019 [Replenishment Zone (RZ), General Use Zone (GUZ), Outside the Reserve (OUT), Contiguous RZ].

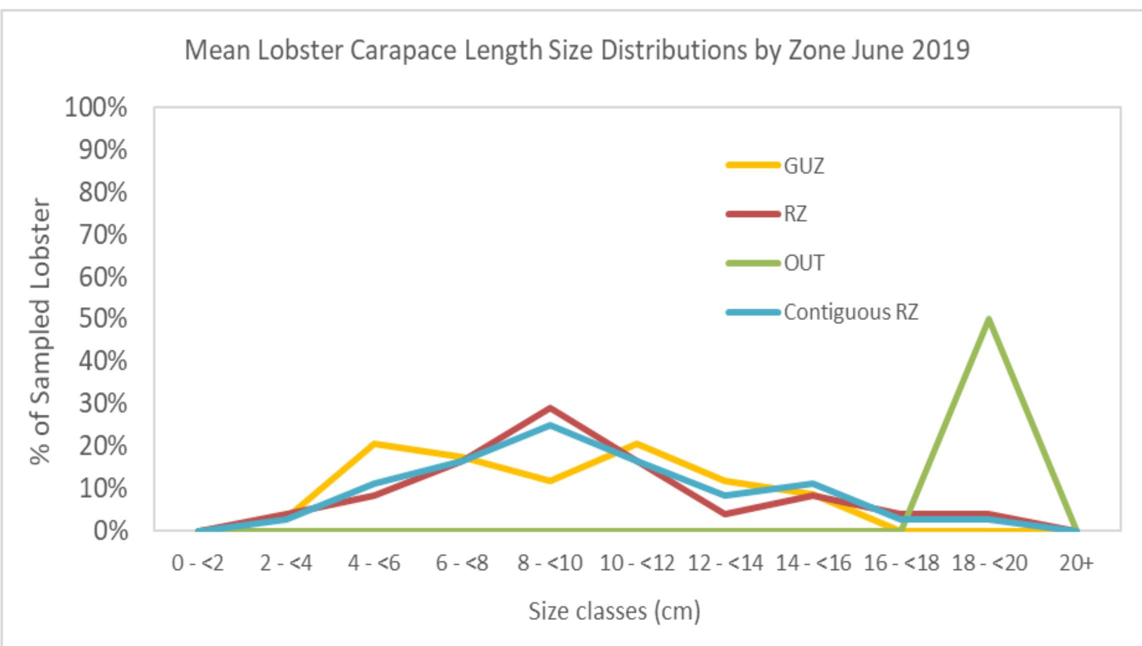

Figure 20. Mean spiny lobster, *Panulirus argus*, carapace length (cm) by size distribution by zone at opening of season June 2019 [Replenishment Zone (RZ), General Use Zone (GUZ), Outside the Reserve (OUT), Contiguous RZ].

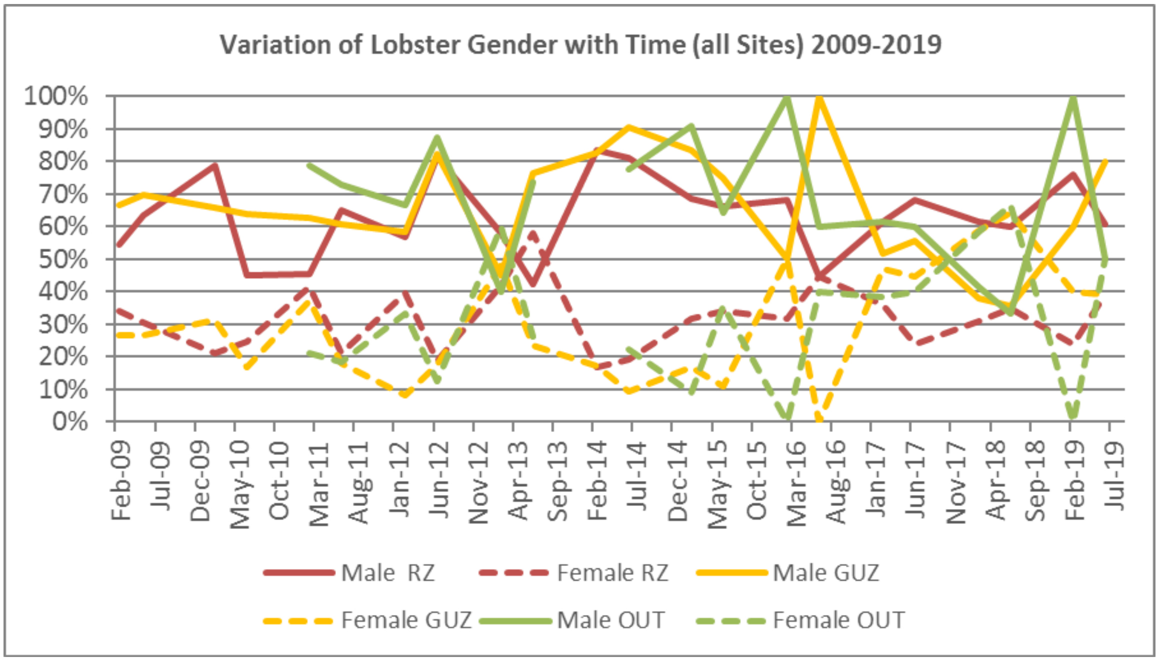

Figure 21. Variation of lobster gender ratio in all zones 2009–2019 [Replenishment Zone (RZ), General Use Zone (GUZ), Outside the Reserve (OUT)].

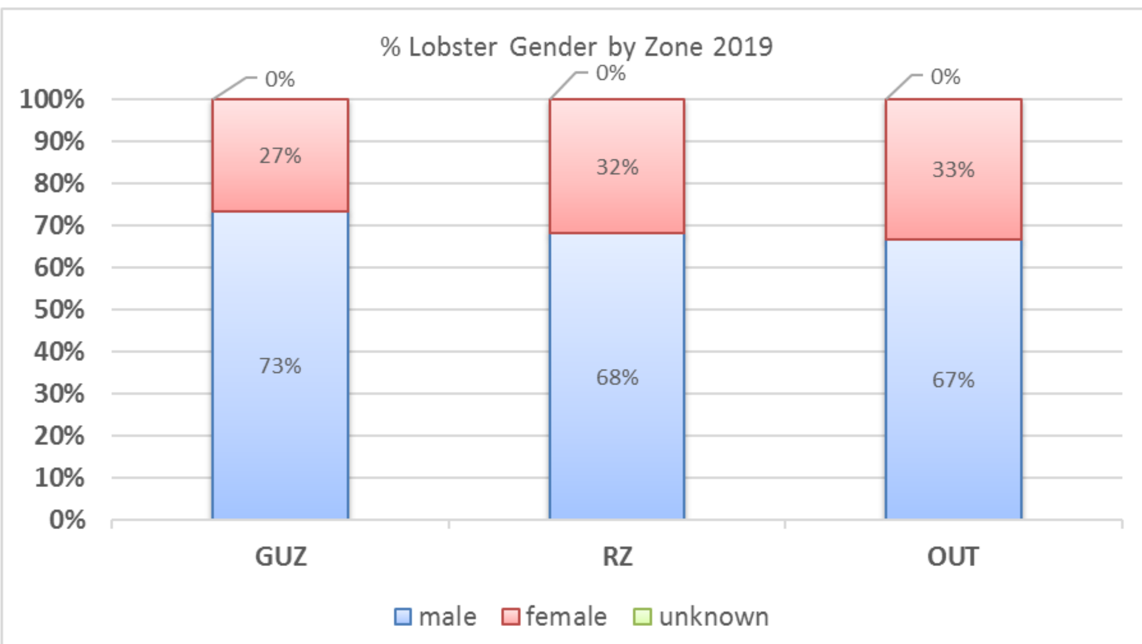

Figure 22. Percent (%) spiny lobster, *Panulirus argus*, gender (male, female, unknown) by zone 2019 [Replenishment Zone (RZ), General Use Zone (GUZ), Outside the Reserve (OUT)].

5. SEA CUCUMBER

5.1 Sea Cucumber

A moratorium on sea cucumber was enacted in 2017 due to the substantial decrease in sea cucumber population abundances. Nonetheless, monitoring continued to be conducted for sea cucumber in 2019. 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.

The sea cucumber monitoring for 2019 was conducted in May. Results showed no sign of recovery with no significant changes in population density since the moratorium in 2017. Due to the continual low abundance of the sea cucumber population, only 1 monitoring survey was conducted in 2019.

5.2 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. 23). 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}, only slightly increasing to 22 ha^{-1} by May 2019. 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 ha^{-1} until dropping to <20 ha^{-1} in 2016. This trend in the RZs of <20 ha^{-1} continued into 2019 (Fig. 24). The mean sea cucumber density in OUT has been <15 ha^{-1} since monitoring began in 2016 and none were found during November 2018 and May 2019 monitoring efforts. Though a moratorium was placed on harvesting the sea cucumber in 2017, there is no significant difference (*P*=.81) in mean sea cucumber densities in all zones since it went into effect.

A dramatic decrease in RZs mean sea cucumber densities was observed during closed season in 2012. Though 2015 and 2016 also showed 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 2017-2019.

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 2011-2019 at 22 cm and 23 cm, respectively, showing no outliers in overall mean values (Fig. 25). The annual mean sea cucumber length in the RZs and GUZ increased from 2018 values from 21-24 cm in the RZs and from 21-28 cm in the GUZ (Fig. 26). This was the highest recorded mean sea cumber length in the GUZ since pre-fishery values. Even so, there was no significant difference (*P*=.64) in mean sea cucumber lengths in all zones since the 2017 moratorium.

The mean sea cucumber weight in the GUZ from 2011-2019 ranged from ~304-707 g, with the overall mean of the GUZ at 483 g and RZs at 614 g and the overall median at similar values of ~489 g and ~602 g, respectively (Fig. 27). In 2019, the annual mean sea cucumber weights increased in both the GUZ and RZs from 2018 values to 650 g in the GUZ with the RZs being slightly higher (Fig. 28). Again, though there was a moratorium placed on the sea cucumber, there was no significant difference (*P*=.16) in mean sea cucumber weights in all zones since 2017.

5.3 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 2019, 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 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 has shown 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 these observations.

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 2013–2019 indicates lack of juveniles from poor reproduction.

5.4 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 and/or revise current methodology.
- 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)

5.5 Figures

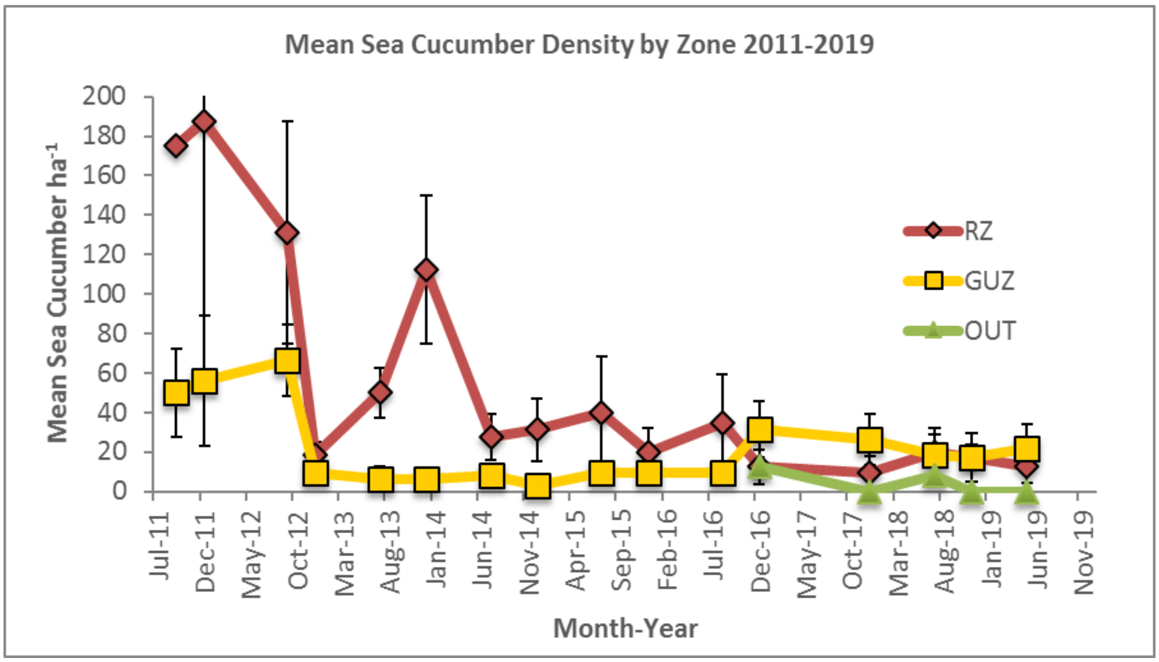

Figure 23. Mean Sea cucumber, *H. mexicana*, density observed during pre-season and post-season surveys conducted 2011–2019 [Replenishment Zone (RZ), General Use Zone (GUZ), Outside the Reserve (OUT)] [±Standard Error Bars].

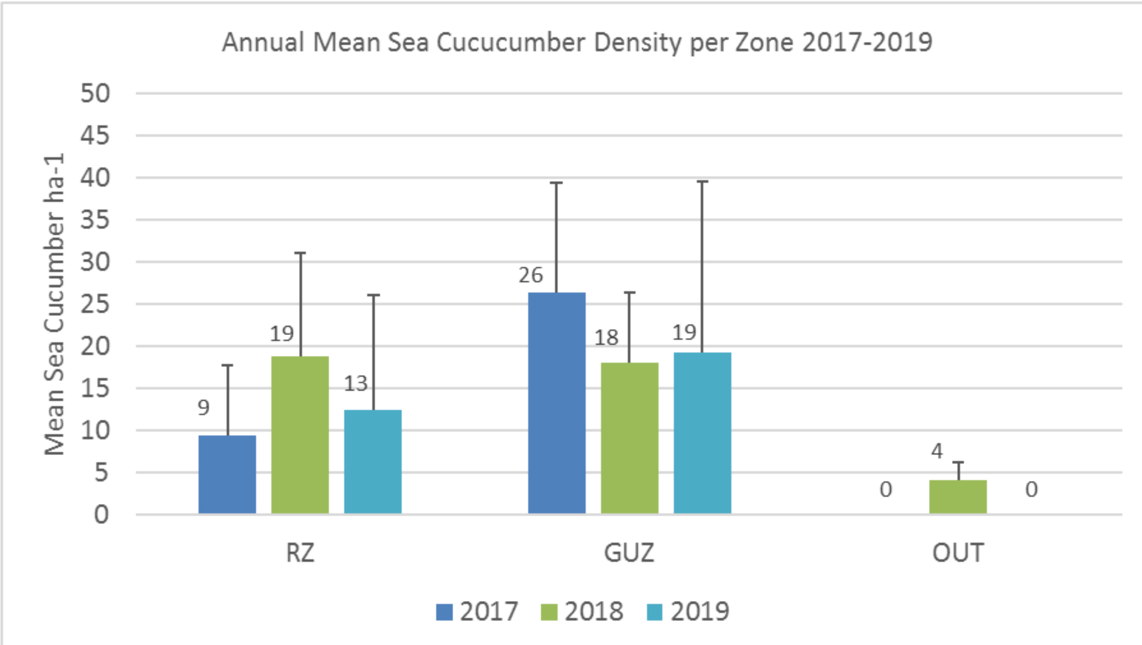

Figure 24. Annual mean sea cucumber, *H. mexicana*, density per zone 2017–2019 [Replenishment Zone (RZ), General Use Zone (GUZ), Outside the Reserve (OUT)] [±Standard Error Bars].

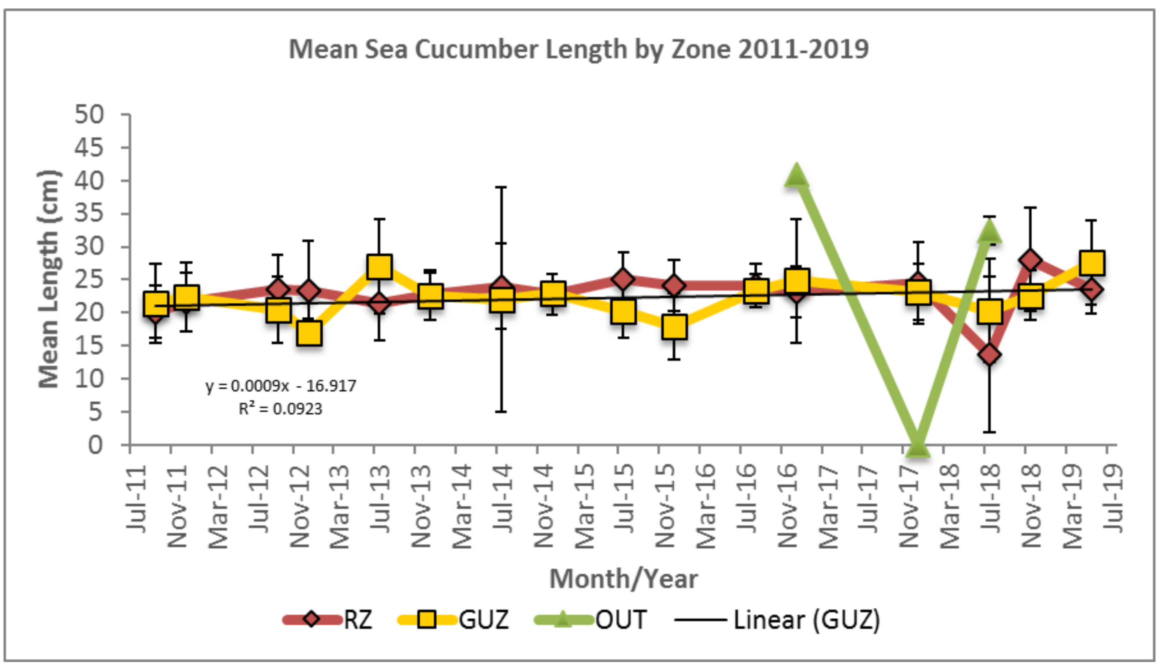

Figure 25. Mean Sea cucumber, *H. Mexicana*, length (cm) by zone observed during pre-season and post-season surveys conducted 2011–2019 [Replenishment Zone (RZ), General Use Zone (GUZ)] [±Standard Deviation]. Note: Zero length means (n=0).

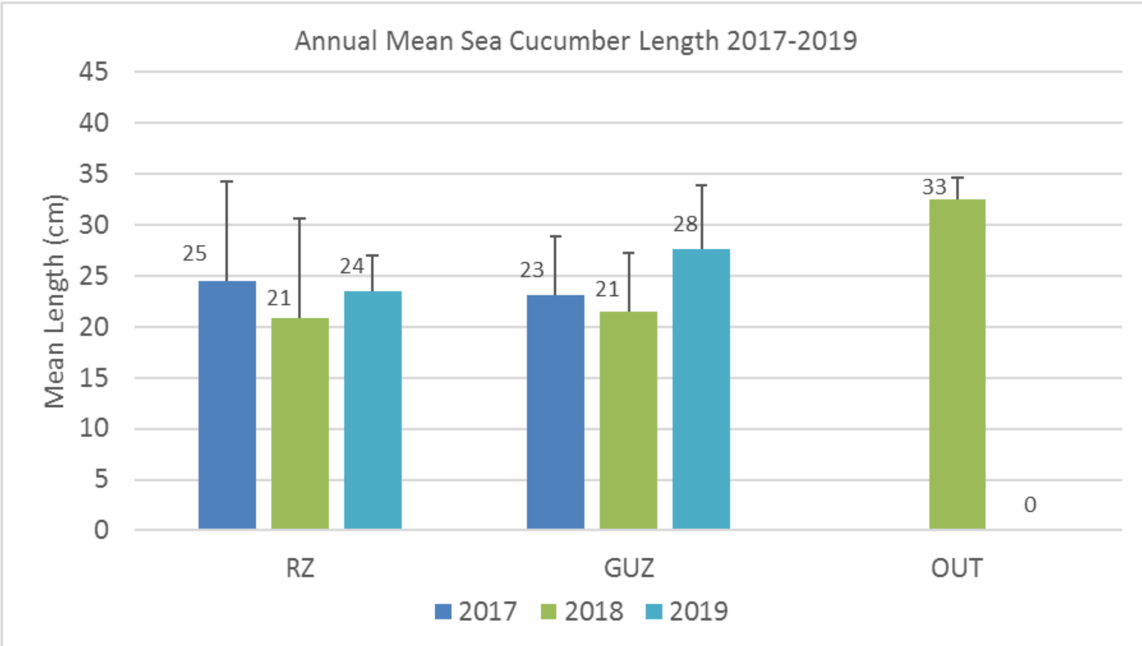

Figure 26. Annual mean sea cucumber, *H. Mexicana*, length (cm) by zone 2017–2019 [Replenishment Zone (RZ), General Use Zone (GUZ)] [±Standard Deviation].

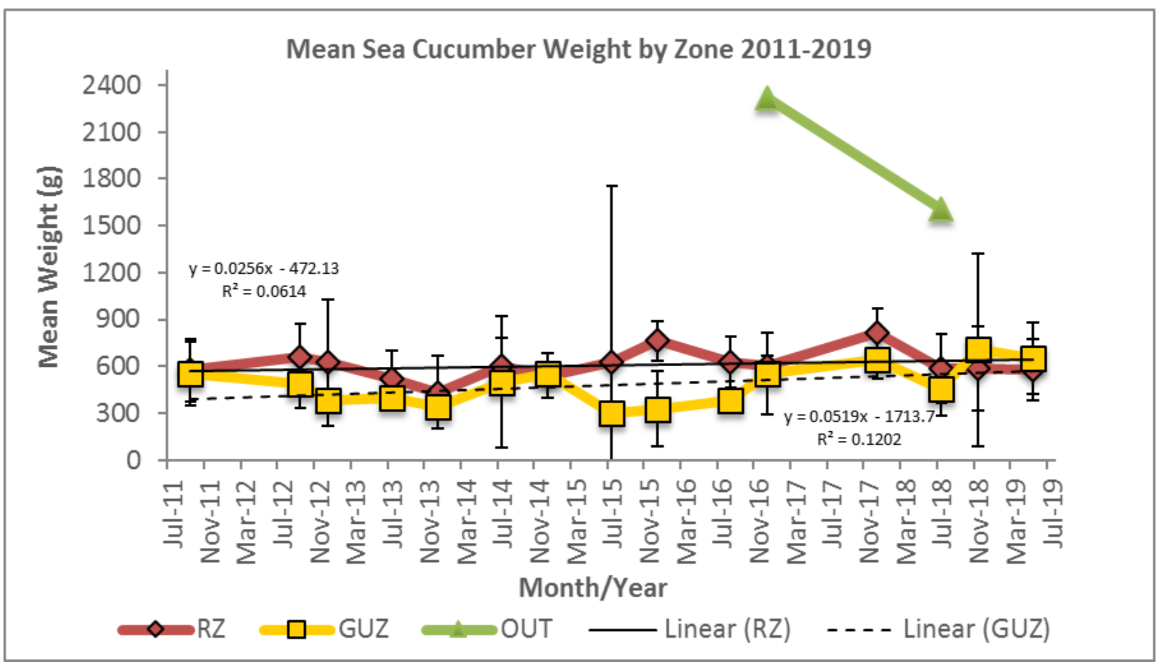

Figure 27. Mean sea cucumber, *H. mexicana*, weight (g) observed during pre-season and post-season surveys conducted 2011–2018 [Replenishment Zone (RZ), General Use Zone (GUZ), Outside the Reserve (OUT)] [±Standard Deviation].

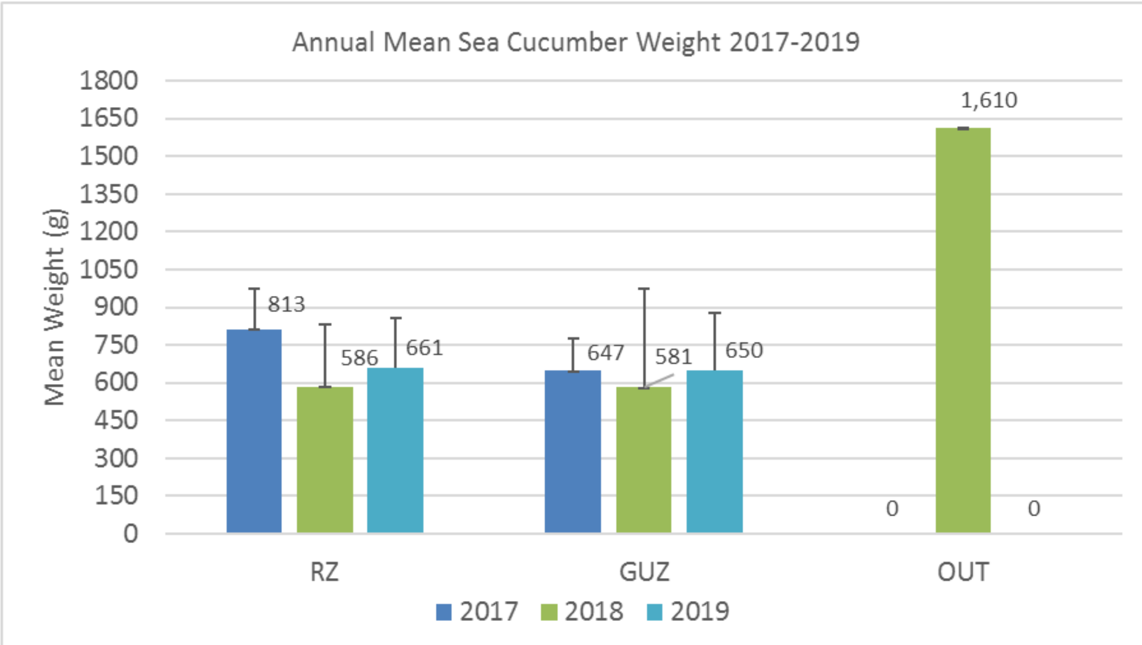

Figure 28. Annual mean sea cucumber, *H. mexicana*, weight (g) 2017-2018 [Replenishment Zone (RZ), General Use Zone (GUZ), Outside the Reserve (OUT)] [±Standard Deviation].

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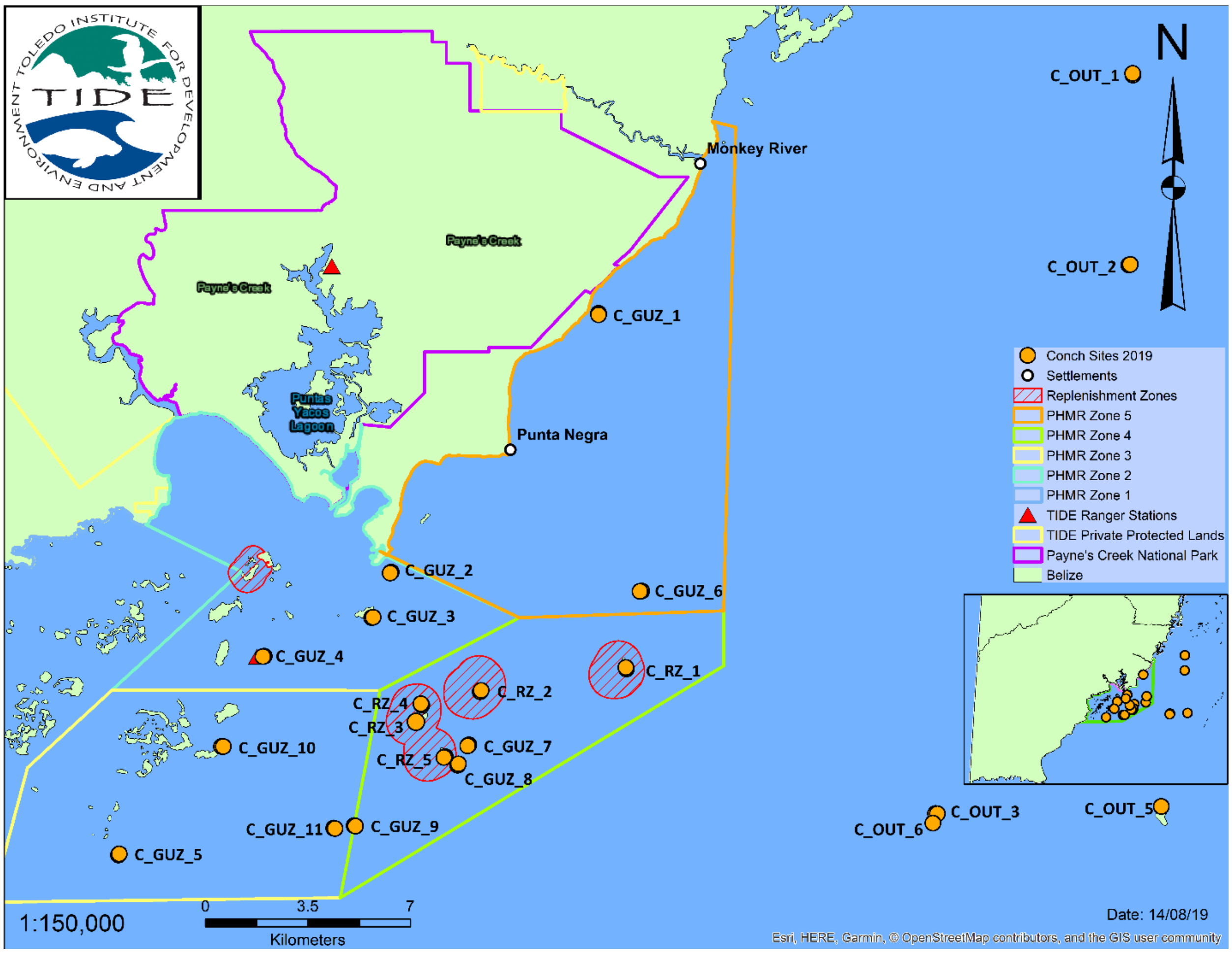
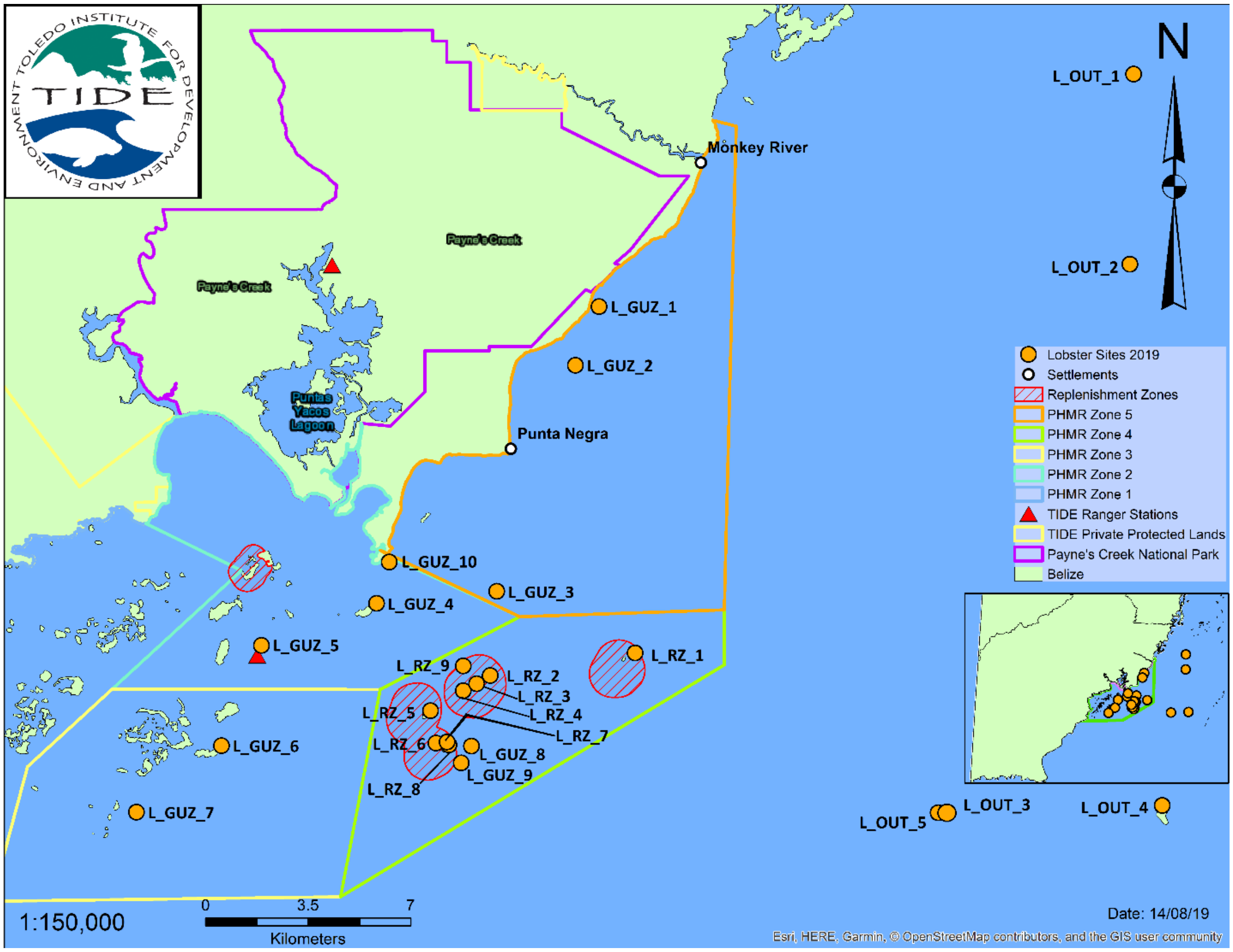
Appendices

Appendix 1. Queen conch monitoring sites 2019.



Appendix 2. Spiny lobster monitoring sites 2019.



Appendix 3. Sea cucumber monitoring sites 2019.