Turneffe Atoll Queen Conch Stock Abundance and Dynamics, 2013-2017

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Introduction

A primary management objective of the Turneffe Atoll Marine Reserve is to reverse declines in production of important commercial species such as Queen Conch. The Turneffe Atoll Management Plan therefore states that assessment of the Queen Conch population and development of a monitoring plan for it are important needs. To meet these needs, we conducted an extensive survey of the Queen Conch resource at Turneffe Atoll in 2013 (Zale et al. 2016). We collected additional data in 2016 to assess changes in the stock since 2013 and to refine monitoring methods. We sampled again in 2017 to assess annual variation of the Queen Conch stock.

Methods

We quantitatively sampled 216 randomly selected sites in nearshore habitat types inhabited by Queen Conch at Turneffe Atoll in 2013 to assess Queen Conch distribution, abundance, and size structure (Zale et al. 2016). Queen conch were counted along four parallel 50 m long × 4 m wide transects at each site (total of 800 m^2 per site) by two scuba divers as per the Long-term Atoll Monitoring Program (LAMP) protocol (Acosta 2004). Transects were spaced about 10 m apart and usually paralleled wind direction to facilitate placement. Transects were defined by 50-m long white 3/16” non-stretchable Dacron ropes deployed from a panga motored backwards and pulled taut. Transect lines were anchored at each end. Buoy lines on each anchor extended to the surface for retrieval. The two divers swam together on either side of the transect line about 1.5 m from the substrate and counted all live Queen Conch within 2 m of each side of the transect line. Distances of Queen Conch from the transect line were measured if the distances were close to 2 m. Shell lengths of all live Queen Conch were measured in situ with calipers, as were lip thicknesses of lipped individuals (4 cm inward from the edge of the middle third of the lip where the lip is fairly straight [no waviness]; Richard Appeldoorn, University of Puerto Rico Mayaguez, personal communication). All Queen Conch were placed upright at their original site of capture after measurement. Depths of all Queen Conch were measured to the nearest foot with a dive computer or manually with a tape in shallow water, recorded, and later converted to meters. Sites less than 1.5 m in depth were surveyed by snorkeling and sites less than 0.25 m in depth were surveyed by wading. One of the divers wore a GoPro video camera to record the actual habitat type along each transect. Habitat classification followed Mumby and Harborne (1999).

We collected 2,385 Queen Conch in 2013, most of which were found in the North, Southwest, and Northeast sections of the atoll, especially in seagrass, sand and algae, and sparse patch reef habitats at depths of less than 5 m (Zale et al. 2016). Overall atoll-wide abundance of Queen Conch in all nearshore habitats at Turneffe Atoll was estimated at about 3.4 million in 2013 (Table 1). We noted significant shifts between summer and winter samples in size and age distributions of Queen Conch. Summer samples included many legal-sized individuals whereas winter samples were dominated by small juveniles (Figure 1). The Queen Conch size shift probably resulted from emergence from the substrates of juveniles between summer and winter combined with the harvest of larger, legal-sized (> 17.8 cm) individuals during the commercial fishing season that began in October. We therefore recommended that future monitoring sampling to assess stock abundance should occur during summer before harvest was initiated and be focused on the habitats and sections where conch were abundant, such as sand and sparse algae, seagrass, and patch reef habitats in the North, Northeast, Southeast, and Southwest sections (Zale et al. 2016).

Our 2013 Queen Conch abundance data were highly variable and not normally distributed. In fact, the data followed no known statistical distribution. Zero values (of number of Queen Conch at a site) were common and abundances at a handful of sites were very high and therefore influential both statistically and with respect to abundance estimation. Confidence limits of abundances and densities were therefore calculated using the bootstrapped percentile method (Efron and Tibshirani 1993; Manly 2007), which can be used on data for which the distribution is unique or unknown. Unfortunately, the resulting confidence intervals are wide because of the highly variable data. Section abundance and density point estimates were calculated conventionally as the sample mean (Lohr 2010, Equation 2.8) because sample site locations were determined through simple random sampling. Total atoll abundance was calculated as the weighted mean of the sample stratum (section) means (Lohr 2010, Equation 3.2).

Statistical consultants at Montana State University recommended that monitoring the status of the stock should entail repeat sampling of as many of the 2013 sites as possible. Resampling of the 2013 sites would minimize variability introduced by site location. We estimated that 60 sites could be reasonably sampled during a 2 to 3 week period each summer (i.e., about 3 to 5 sites per day) and randomly selected a subset of 60 of the 2013 sites in the sections and habitats where most of the Queen Conch occurred (sand and sparse algae, seagrass, and patch reef habitats in the North, Northeast, Southeast, and Southwest sections of the atoll) for resampling in summer 2016. The 60 sites were apportioned among sections in proportion to the areas of the sections made up by the specified habitats resulting in 30 sites in the North, 17 sites in the Southwest, 7 sites in the Southeast, and 6 sites in the Northeast.

We successfully completed sampling of the 60 sites in summer 2016. However, in doing so, we noted that 6 of the sites in part of the Southwest section had no Queen Conch present in either 2013 or 2016. Additional spatial analyses showed that 15 sites in a narrow embayment of the Southwest section south of Crickozeen Creek adjacent to the mangroves was not occupied by any Queen Conch in 2013 or 2016 (Figure 2). The water in that embayment was tinged green and had noticeable suspended particulate matter in it. Substrates under the seagrass were soft and flocculent. The water there is known to be slowly seeping west out of the mangroves on the west side of the atoll, apparently bringing with it dissolved and particulate organic matter from the central lagoon and the mangroves. At sites farther west, within 1.4 km of the reef crest, increased oceanic circulation improved water clarity, substrates were harder, and Queen Conch were often present. The area of the no-conch embayment is about 1,550 ha, which is one-third of the 4,528.9 ha Southwest sampling section. We deleted that area and the sites therein (15 in 2013 and 6 in 2016) from further analyses and sampling, resulting in a total of 54 prescribed sites; deletion of the 6 sites did not affect abundance estimation because their allocation was proportional to the deleted area because site locations were selected randomly. We added additional randomly selected sites before completing sampling in 2016 and 2017 as time allowed. Ultimately, we sampled 65 sites in summer 2016 and resampled 57 of them in summer 2017. Resampling in 2017 afforded the opportunity to assess annual variability in stock abundance, distribution, and population characteristics.

Our primary objectives were to estimate and compare abundances, densities, sizes, spatial and temporal dynamics, and year-class strengths of Queen Conch at Turneffe Atoll in 2013, 2016, and 2017 to enhance understanding and management of this important stock and its fishery.

We also qualitatively assessed southern lugworm (*Arenicola cristata*) mound densities at sites sampled in 2017 to test our hypothesis (based on our earlier anecdotal observations) that southern lugworm and Queen Conch densities were inversely related. Lugworms can destabilize sediments and inhibit settlement success of invertebrates and plants (Flach 1992; Volkenborn et al. 2009; Montserrat et al. 2011). We categorized southern lugworm densities at each site as none (no lugworm mounds), low (a few lugworm mounds), medium (dozens of mounds), high (hundreds of mounds), or very high (thousands of mounds completely covering all of the substrate at a site).

Results

Using only data from comparable sites sampled during summer in 2013, 2016, and 2017 (in sand and sparse algae, seagrass, and patch reef habitats in the North, Northeast, Southeast, and Southwest sections, excluding the no-conch embayment), total Queen Conch summer abundance estimates in the primary Queen Conch sections and habitats at Turneffe Atoll were about 2.7 million in 2013, 1.9 million in 2016, and 1.8 million in 2017 (Table 1; Figure 3). Corresponding densities were 184.3, 131.9, and 127.2 Queen Conch per hectare (Table 2; Figure 4). Total abundance in 2016 was therefore about 70% of that in 2013. Total abundance in summer 2017 was only slightly lower than in 2016, but abundance of legal-sized Queen Conch was much lower in 2017 (about 349,000) than 2016 (about 900,000) (Table 3; Figure 3).

Whereas most of the stock resided in the North section in 2016 (1.2 million individuals), only about 350,000 individuals were present there in 2017 (Table 1). Conversely, abundance increased from about 230,000 to 1.3 million in the Southwest section from 2016 to 2017. These shifts were not offsetting however, because abundances of legal-sized individuals decreased by 526,000 individuals in the North and increased by only 89,000 in the Southwest (Table 3; Figure 3); sublegal individuals made up most of the large increase in abundance in 2017 in the Southwest section. Accordingly, most of the decrease in atoll-wide abundance of legal-sized Queen Conch from 2016 to 2017 could be attributed to the decrease in the abundance of legal-sized Queen Conch in the North section (Figure 3; note the parallel decreases in atoll-wide and North section legal abundances). Densities of legal Queen Conch decreased markedly in both the North and Northeast sections from summer 2016 to summer 2017 (Table 4; Figure 4). Highly efficient harvest during the 2016-2017 commercial fishing season, which has typically focused on the North and Northeast sections of the atoll, was the probable cause for these decreases.

Site-specific density trends were evident among years. Whereas densities at some sites increased while others decreased from 2013 to 2016, densities at almost all sites were stable and low or decreased from 2016 to 2017 (Figure 5); densities at only two sites (in the Southwest section) increased markedly from 2016 to 2017. Densities of legal Queen Conch peaked among years in 2016 at many sites (Figure 6). Relative site densities tended to be consistent among years (Figures 5 and 6); sites with high densities in a given year tended to have high relative densities in other years, although absolute densities varied widely.

The dynamics of the size and age distributions of sampled Queen Conch supported the abundance and density findings (Figure 1). In summer 2016, smaller proportions of the population were made up of small age-1 (< ca. 10 cm) and age-2 individuals (ca. 15 cm) than in 2013 or 2017, whereas the proportion of larger, legal-sized Queen Conch was commensurately larger than in 2013 and 2017. In 2013 and 2017, age-1 individuals were present and sublegal age-2 individuals made up a large proportion of the stock (Figure 1). However, larger, legal-sized individuals were rarer than in 2013.

Year-class strength of Queen Conch varied temporally and spatially (Figure 7). In summer 2013, Age-1 individuals (< 10 cm) were present in all sampled sections of the atoll, indicative of successful reproduction and larval settlement in 2012. Age-2 individuals from the 2011 year-class (ca. 15 cm) were also present throughout the atoll, but especially in the Southwest where the year-class was exceptionally strong. The size of age-2 individuals from the 2011 year-class in the Southeast (ca. 12-13 cm) was smaller than elsewhere on the atoll, suggesting later settlement or slower growth there. In 2016, Age-1 individuals were rare, except in the Southwest section, suggesting limited reproduction or settlement in 2015. Age-1 individuals again made up significant proportions of the North and Southwest stocks in 2017 (numbers captured in the Northeast and Southeast were too low to provide insights from the length-frequency distributions). Whereas age-1 and age-2 individuals were abundant in all years in the Southwest, few age-3 (ca. 20 cm), legal-sized individuals were found there in any year during summer (9 to 18%), suggesting high mortality rates among age-2 and older individuals. In other sections, where the proportions of legal-sized individuals ranged from 25 to 61% during summer, small age-2 individuals that did not recruit to the legal fishery during the fishing season survived to age-3 during the following summer. Natural predation, harvest of sublegal individuals during the fishing season, or out-of-season harvest of legal-sized individuals are possible explanations for the observed size structure in the Southwest section.

Most population characteristics of the Queen Conch stock were unique in summer 2016 (Table 5). The stock had higher proportions of legal, lipped, potentially mature, legal and mature, legal and lipped, legal un-lipped, and legal immature Queen Conch than in either summer 2013 or 2017 (Table 5). The summer 2016 stock also had the lowest proportion of sublegal individuals among the three summers. It therefore offered fishermen ample harvest opportunities. The situation was the exact converse in 2017 when the stock had lower proportions of legal, lipped, potentially mature, legal and mature, legal and lipped, legal un-lipped, and legal immature Queen Conch than in either summer 2013 or 2016 (Table 5), thereby limiting harvest opportunities. Summer 2013 stock characteristics were intermediate between 2016 and 2017 values (Table 5).

Southern lugworm and Queen Conch densities tended to be inversely related (Figure 8). The distribution was roughly wedge-shaped (Terrell et al. 1996), such that Queen Conch densities could be high or low at sites with few or no lugworms but more likely to be low or absent at sites with many lugworms.

Discussion

Our monitoring protocol was sensitive to detecting changes in Queen Conch abundances and population characteristics at Turneffe Atoll. Queen Conch fishermen reported disappointing harvests at Turneffe Atoll during the 2017-2018 commercial fishing season compared to 2016-2017 (Dale Fairweather, personal communication). Our findings were consistent with this observation; estimated abundances of legal-sized Queen Conch were depressed, especially in comparison to 2016 when abundances of legal-sized individuals were high, particularly in the North section of the atoll where much of the fishery is focused. The concordance between our fishery-independent survey and subsequent harvest demonstrates that our techniques and sampling effort (54 or more randomly selected standardized sites in sand and sparse algae, seagrass, and patch reef habitats in the North, Northeast, Southeast, and Southwest sections of the atoll) effectively characterized the Turneffe Atoll Queen Conch stock.

The mechanism for the decrease in abundance in the North section from 2016 to 2017 was apparently harvest; shells of harvested Queen Conch were common in 2017 at sites occupied by many living, legal-sized Queen Conch in summer 2016. The abundant harvestable stock present in 2016 was efficiently fished down and not sufficiently replaced by new recruits from the 2014 and 2015 year classes. Similarly, abundances of harvestable Queen Conch present in summer 2013 were much reduced in December 2013 after 2 to 3 months of harvest. Turneffe Atoll fishermen are remarkably proficient at harvesting almost all of the legal-sized Queen Conch present in shallow waters of the atoll every year. Such complete harvest is potentially sustainable if stock abundances are not dependent on local spawning stock abundances for replenishment and larval settlement is consistent, much as in an agricultural setting where crops are planted and harvested when ripe. However, variability in year-class strengths among years and sections was evident. Such variability can lead to subsequent differences in recruitment to harvestable stocks and inconsistent commercial harvests among years, as seen in 2016-2017 versus 2017-2018. Greater carryover of legal-sized individuals from year to year would buffer the effects of inconsistent cohort abundances. Rotating annual closures among areas of the atoll could facilitate carryover.

The location of the spawning stock(s) responsible for replenishment of the Turneffe Atoll Queen Conch stock remains unknown. Because we observed only 4 Queen Conch egg masses during our sampling in August and September 2016 and only 2 in August 2017, reproduction by local, shallow-water individuals appears to be an unlikely source. Our estimates of the proportion of potentially mature individuals present during summer ranged from about 11 to 16% (Table 5), but these estimates were based on a lip thickness threshold of 4 mm, the thickness at which maturity can first start (Egan 1985). A more realistic threshold of 15 mm, at which individuals are probably mature (Foley and Takahashi 2017), reduces these estimates to 1 to 3% (Table 5). Mature, adult Queen Conch persisted in 2017 in the deep-water spur and groove refuges we identified in 2013 (Zale et al. 2016). A qualitative sample of 32 individuals collected for genetic testing at depths of 15 to 35 m in two grooves in the Northeast section in 2017 had lip thicknesses ranging from 14 to 32 mm and lengths ranging from 13.2 to 24.6 cm. No individuals with thinner lips or without lips were present. Queen Conch inhabiting shallow areas of Turneffe Atoll may be the offspring of these nearby deep stocks or of geographically distant parents. The initial genetic analyses offered scant insight on this issue as little genetic differentiation was evident among Queen Conch from throughout Belize (Steven M. Bogdanowicz, Cornell University, personal communication).

Consistent relative densities of Queen Conch at specific sites suggest that sites differ in habitat quality, larval settlement probability, or both. Because similar sites (in habitat type and depth) at different locations can be inhabited by different abundances of Queen Conch, differential settlement resulting from water circulation patterns is probably influential; some sites with habitat suitable for Queen Conch may thereby not be available to settling larvae. However, Queen Conch abundances can vary by habitat type among sites in close proximity (Zale et al. 2016) that ostensibly are subject to similar settlement rates. Southern lugworm densities may be an additional factor influencing Queen Conch densities through destabilization of sediments and inhibition of settlement (Flach 1992; Volkenborn et al. 2009; Montserrat et al. 2011). A better understanding of the factors affecting Queen Conch distributions and densities at Turneffe Atoll is needed to improve monitoring efficiency and abundance estimation.

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Table 1. Estimated abundances, by section, of Queen Conch (all sizes), with 95% confidence limits, present at Turneffe Atoll in summer and winter 2013 and summer 2016 and 2017. The 1,550-ha Southwest section no-conch embayment and sites sampled within it were excluded from all analyses. Except as noted, only sites in sand and sparse algae, seagrass, and patch reef habitats in the North, Northeast, Southeast, and Southwest sections of the atoll were included.

	Abundance (all Queen Conch, N) (95% CL)				
Section	2013, summer and winter, all sections and habitats, 201 sites, 2,385 Queen Conch	2013 summer and winter 123 sites 2,299 Queen Conch	2013 summer only 103 sites 1,431 Queen Conch	2016 summer only 65 sites 666 Queen Conch	2017 summer only 57 sites 558 Queen Conch
All	3,415,642 (1,940,703 – 5,240,482)	3,423,914 (1,888,375 – 5,331,201)	2,670,786 (1,384,260 – 4,381,910)	1,911,355 (1,138,397 – 2,797,377)	1,843,776 (487,005 – 3,909,663)
North	2,056,165 (877,864 – 3,618,440)	2,117,429 (901,164 – 3,737,087)	1,117,481 (512,914 – 2,039,314)	1,255,844 (629,597 – 1,992,606)	351,637 (190,889 – 535,827)
Northeast	285,392 (142,365 – 457,081)	249,819 (119,334 – 402,610)	166,695 (70,634 – 276,883)	315,731 (46,619 – 741,650)	82,406 (25,899 – 160,103)
Northwest	47,909 (26,008 – 72,548)	--	--	--	--
Southeast	262,227 (99,617 – 473,179)	219,660 (79,758 – 396,173)	265,143 (100,024 – 473,129)	108,915 (17,782 – 242,280)	79,384 (15,877 – 152,418)
Southwest	763,951 (85,705 – 1,798,314)	837,007 (98,758 – 1,945,999)	1,121,469 (137,994 – 2,610,919)	230,865 (29,789 – 518,826)	1,330,350 (33,852 – 3,293,801)

Table 2. Estimated densities, by section, of Queen Conch (all sizes), with 95% confidence limits, present at Turneffe Atoll in summer 2013, 2016, and 2017. The 1,550-ha Southwest section no-conch embayment was excluded from all analyses. Only sites in sand and sparse algae, seagrass, and patch reef habitats in the North, Northeast, Southeast, and Southwest sections of the atoll were included.

	Density (all Queen Conch, N/ha) (95% CL)		
Section	2013 summer only 103 sites 1,431 Queen Conch	2016 summer only 65 sites 666 Queen Conch	2017 summer only 57 sites 558 Queen Conch
All	184.3 (95.9 – 300.8)	131.9 (78.1 – 193.7)	127.2 (33.5 – 267.7)
North	139.0 (63.8 – 252.4)	156.2 (77.5 – 248.8)	43.8 (23.8 – 67.1)
Northeast	98.3 (41.7 – 162.5)	186.2 (27.5 – 436.2)	48.6 (15.3 – 94.4)
Southeast	149.1 (56.2 – 265.2)	61.2 (10.0 – 136.2)	44.6 (8.9 – 85.7)
Southwest	376.5 (46.3 – 872.1)	77.5 (10.0 – 175.0)	446.6 (11.4 – 1,104.6)

Table 3. Estimated abundances, by section, of legal Queen Conch (shell length ≥ 17.8 cm), with 95% confidence limits, present at Turneffe Atoll in summer 2013, 2016, and 2017. The 1,550-ha Southwest section no-conch embayment was excluded from all analyses. Only sites in sand and sparse algae, seagrass, and patch reef habitats in the North, Northeast, Southeast, and Southwest sections of the atoll were included.

	Abundance (legal Queen Conch, N) (95% CL)		
Section	2013 summer only 103 sites 422 Queen Conch	2016 summer only 65 sites 312 Queen Conch	2017 summer only 57 sites 111 Queen Conch
All	744,871 (490,704 – 1,062,315)	907,414 (490,320 – 1,407,472)	348,798 (198,746 – 531,743)
North	465,324 (243,238 – 761,438)	649,690 (281,309 – 1,105,143)	123,910 (73,677 – 180,842)
Northeast	74,872 (28,254 – 129,966)	177,996 (27,547 – 404,730)	51,798 (9,418 – 117,723)
Southeast	66,683 (30,166 – 114,313)	40,010 (13,337 – 75,574)	44,455 (6,351 – 101,612)
Southwest	137,994 (52,569 – 245,322)	39,719 (19,860 – 64,543)	128,635 (16,926 – 284,350)

Table 4. Estimated densities, by section, of legal Queen Conch (shell length ≥ 17.8 cm), with 95% confidence limits, present at Turneffe Atoll in summer 2013, 2016, and 2017. The 1,550-ha Southwest section no-conch embayment was excluded from all analyses. Only sites in sand and sparse algae, seagrass, and patch reef habitats in the North, Northeast, Southeast, and Southwest sections of the atoll were included.

	Density (legal Queen Conch, N/ha) (95% CL)		
Section	2013 summer only 103 sites 422 Queen Conch	2016 summer only 65 sites 312 Queen Conch	2017 summer only 57 sites 111 Queen Conch
All	51.4 (33.9 – 73.5)	62.6 (33.9 – 97.0)	24.1 (13.7 – 36.5)
North	57.9 (30.3 – 95.2)	80.8 (35.4 – 136.7)	15.4 (9.2 – 22.5)
Northeast	44.2 (16.7 – 76.7)	105.0 (15.0 – 236.2)	30.6 (5.6 – 69.4)
Southeast	37.5 (17.0 – 64.3)	22.5 (7.5 – 42.5)	25.0 (3.6 – 57.1)
Southwest	46.3 (17.6 – 82.4)	13.3 (6.7 – 21.7)	43.2 (5.7 – 94.3)

Table 5. Attributes of sampled Turneffe Atoll Queen Conch, 2013, 2016, and 2017. Values in parentheses denote numbers of individuals. Queen Conch with lip thicknesses ≥ 4 mm are considered potentially mature because maturity can first start at a minimum lip thickness of 4 mm (Egan 1985). However, maturity may not be attained until lip thickness reaches 15 mm or more in some individuals (Stoner et al. 2012; Foley and Takahashi 2017).

Attribute	Summer 2013 (168 sites)	Winter 2013 (33 sites)	Summer 2016 (65 sites)	Summer 2017 (57 sites)
Sample total (N)	1,508	877	666	558
Legal (≥ 17.8 cm)	30.9% (466)	16.5% (145)	46.8% (312)	19.9% (111)
Sublegal (< 17.8 cm)	69.1% (1,042)	83.5% (732)	53.2% (354)	80.1% (447)
Lipped	15.7% (237)	3.2% (28)	19.7% (131)	12.7% (71)
Potentially mature (≥ 4 mm lip)	13.5% (204)	1.5% (13)	16.5% (110)	11.1% (62)
Probably mature (≥ 15 mm lip)	3.0% (45)	0.7% (6)	2.1% (14)	1.4% (8)
Legal and potentially mature	12.5% (188)	1.4% (12)	13.8% (92)	7.9% (44)
Legal and lipped	14.5% (219)	2.8% (25)	17.0% (113)	9.3% (52)
Legal, no lip	16.4% (247)	13.7% (120)	29.9% (199)	10.6% (59)
Legal, immature	18.4% (278)	15.2% (133)	33.0% (220)	12.0% (67)
% of legal that are immature	59.6%	91.7%	70.5%	60.4%

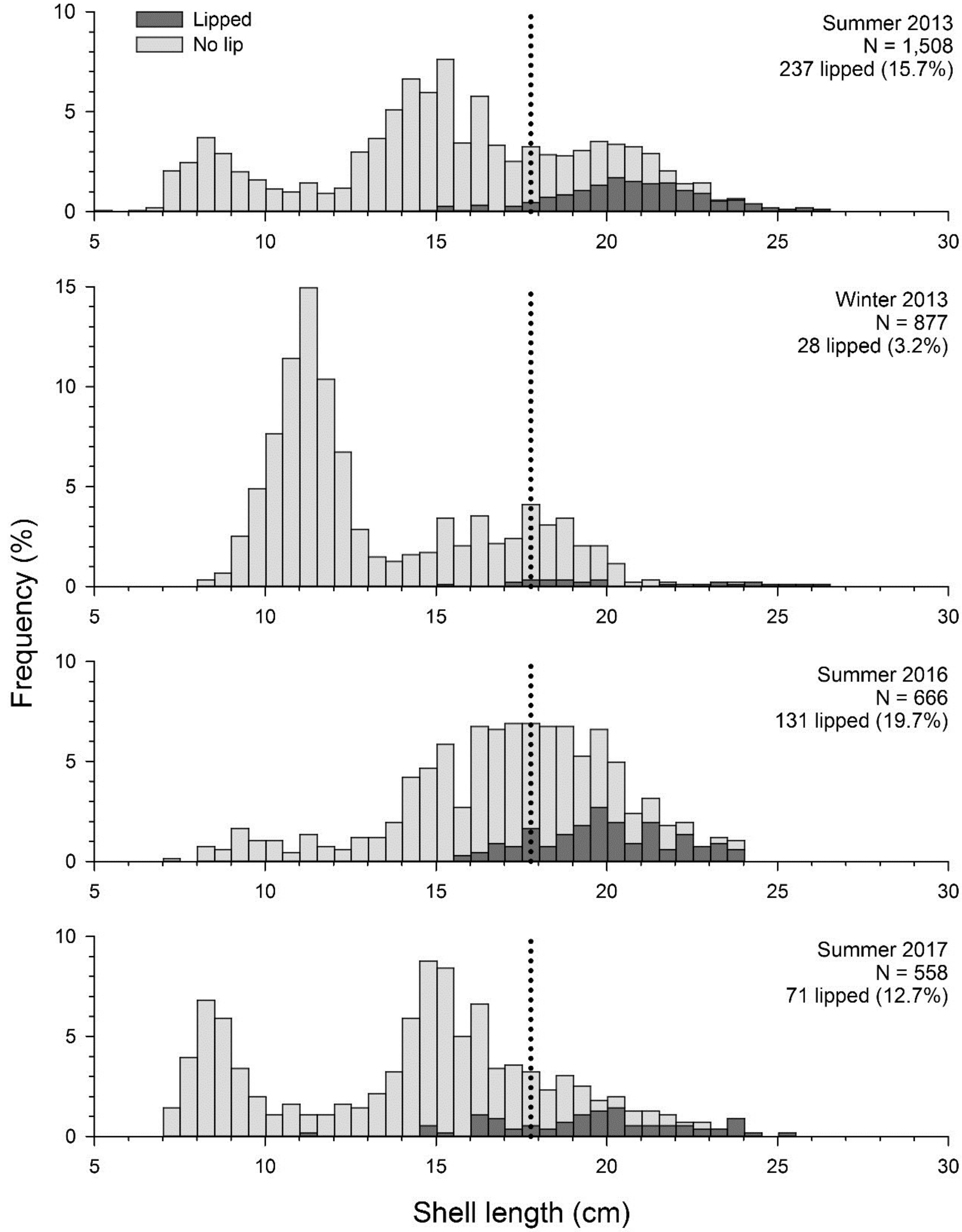

Figure 1. Length-frequency distributions of Queen Conch sampled at Turneffe Atoll in 2013, 2106, and 2017. The dotted vertical line indicates the legal shell length (17.8 cm) for harvest. Lipped conch have reached terminal length and are mature or beginning to mature.

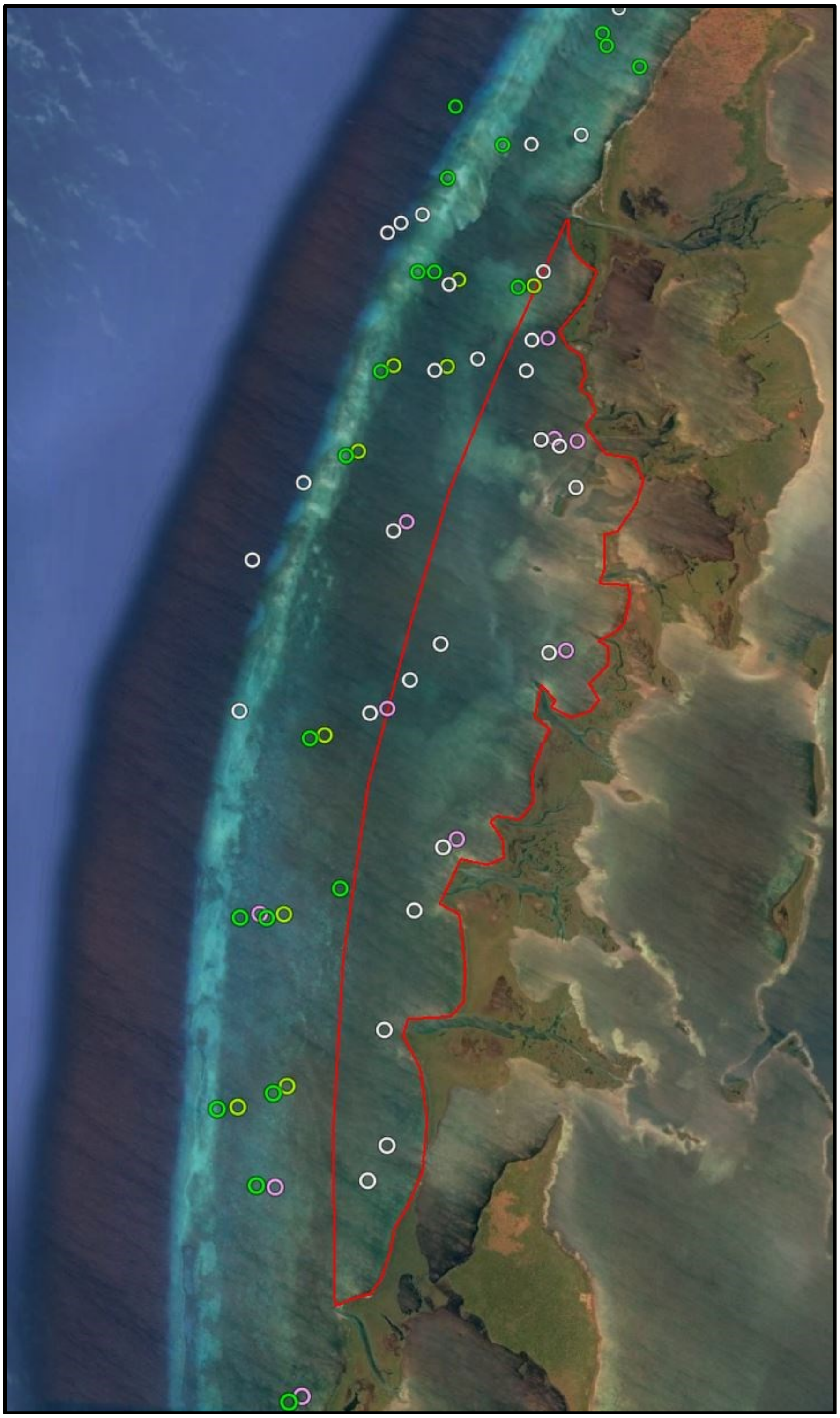

Figure 2. Google Earth image of the no-conch area in the Southwest section of Turneffe Atoll, outlined in red. Green circles represent sites and samples with conch whereas white and pink are sites without conch; both 2013 and 2016 samples are represented.

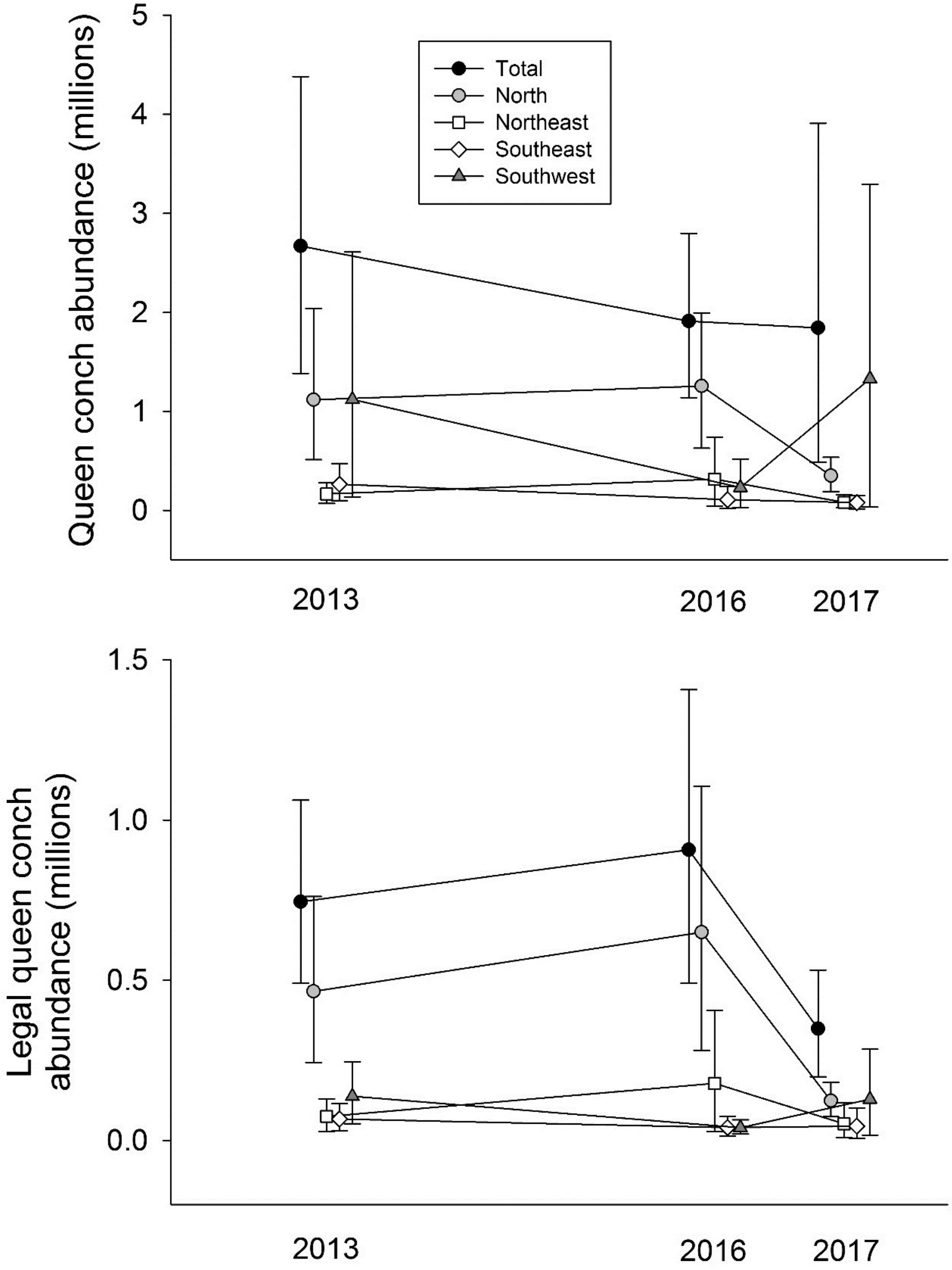

Figure 3. Estimated abundances (N) of all (top) and legal (bottom) Queen Conch (± 95% confidence intervals), total and by section, summer 2013, 2016, and 2017, Turneffe Atoll, Belize.

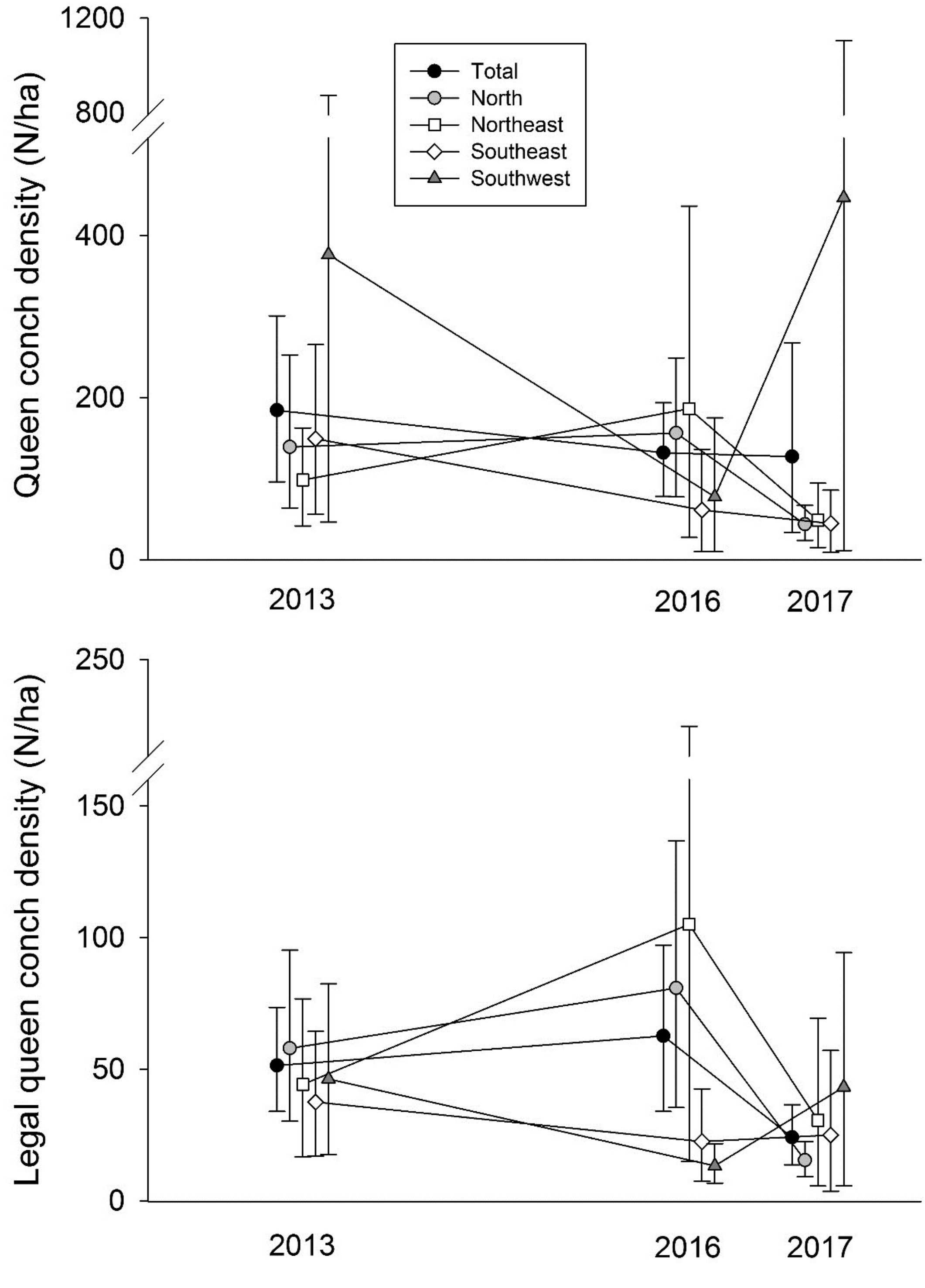

Figure 4. Estimated densities (N/ha) of all (top) and legal (bottom) Queen Conch (± 95% confidence intervals), total and by section, summer 2013, 2016, and 2017, Turneffe Atoll, Belize.

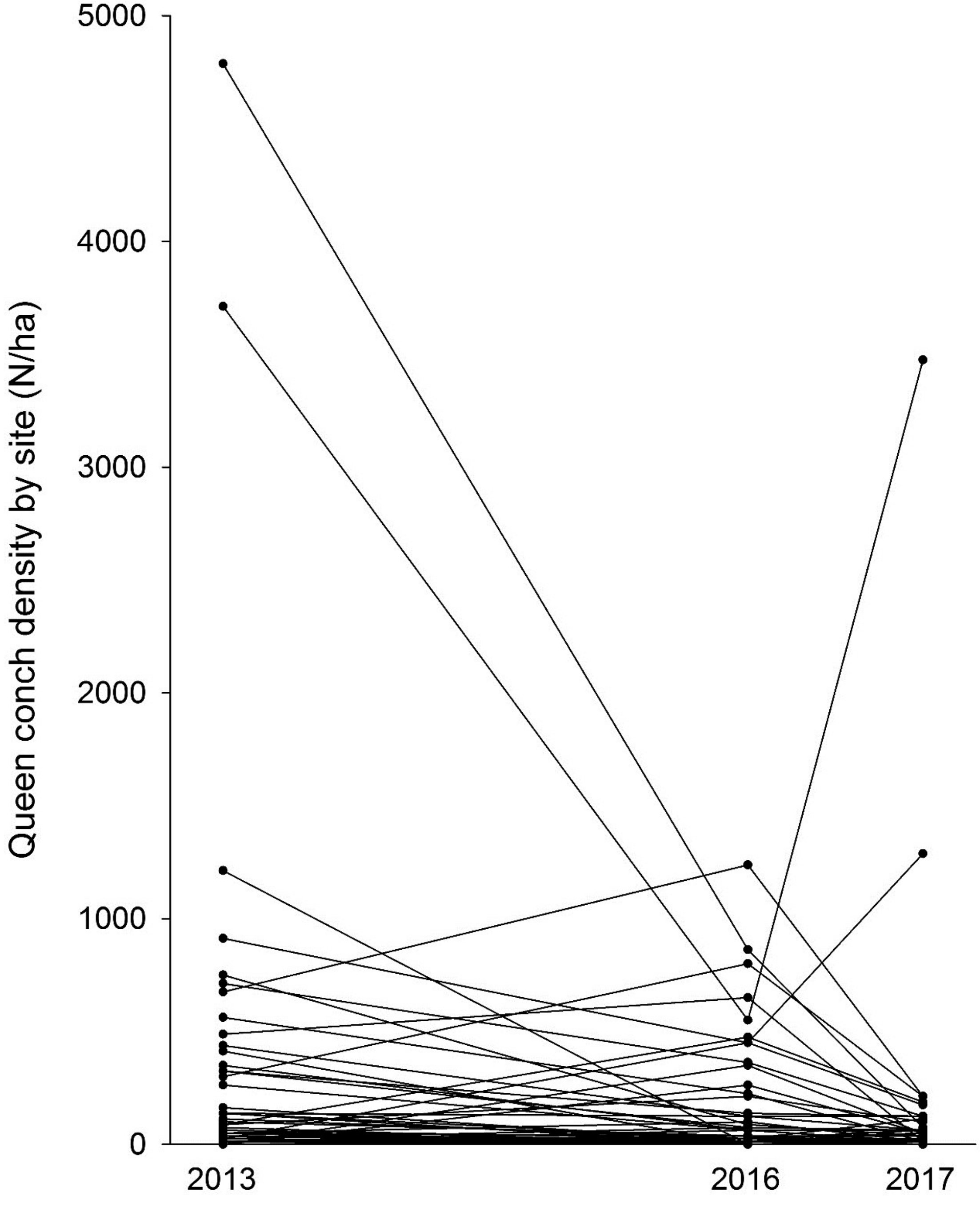

Figure 5. Queen Conch densities (all, N/ha) by site 2013, 2016, and 2017, Turneffe Atoll, Belize.

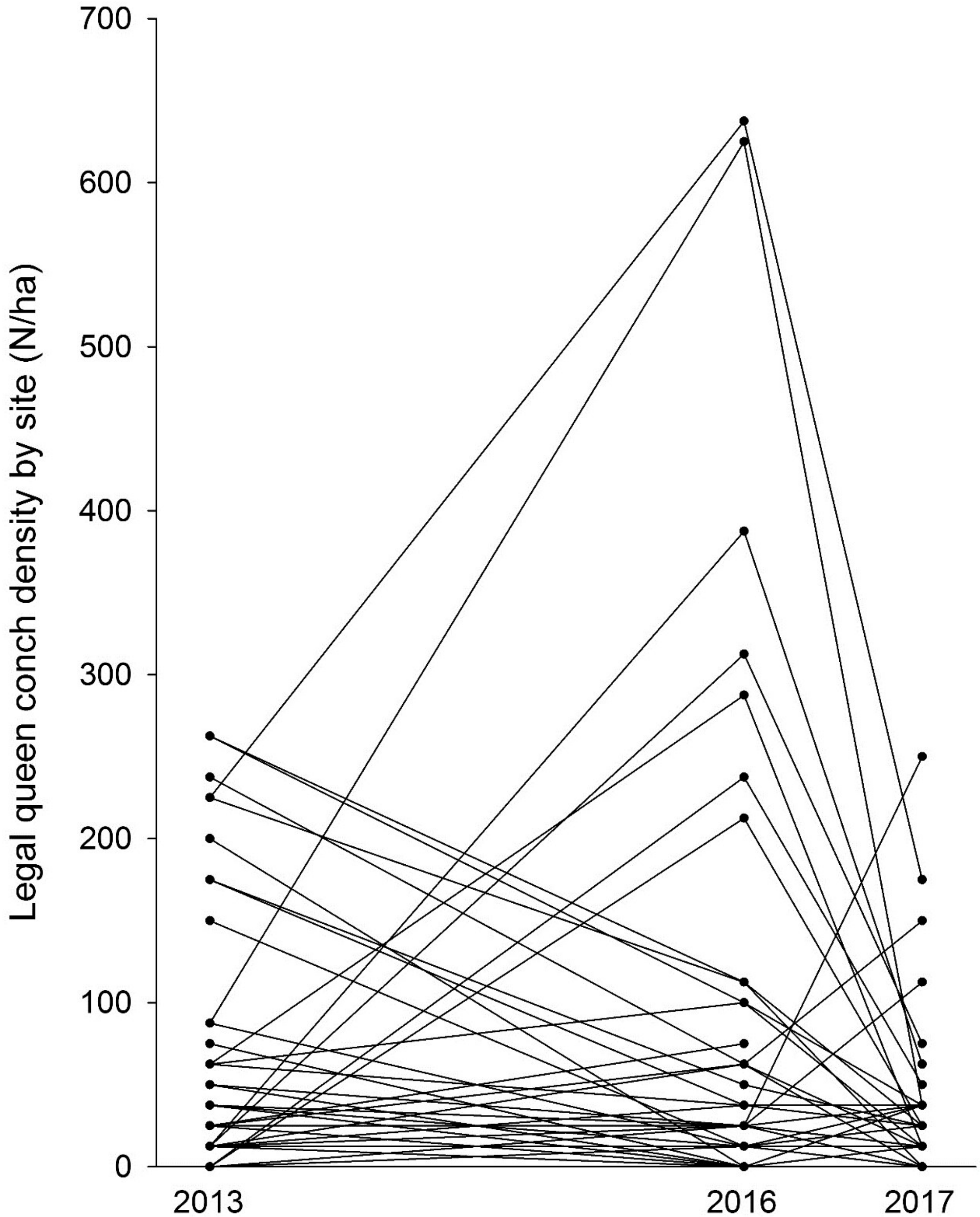

Figure 6. Legal Queen Conch densities (N/ha) by site 2013, 2016, and 2017, Turneffe Atoll, Belize.

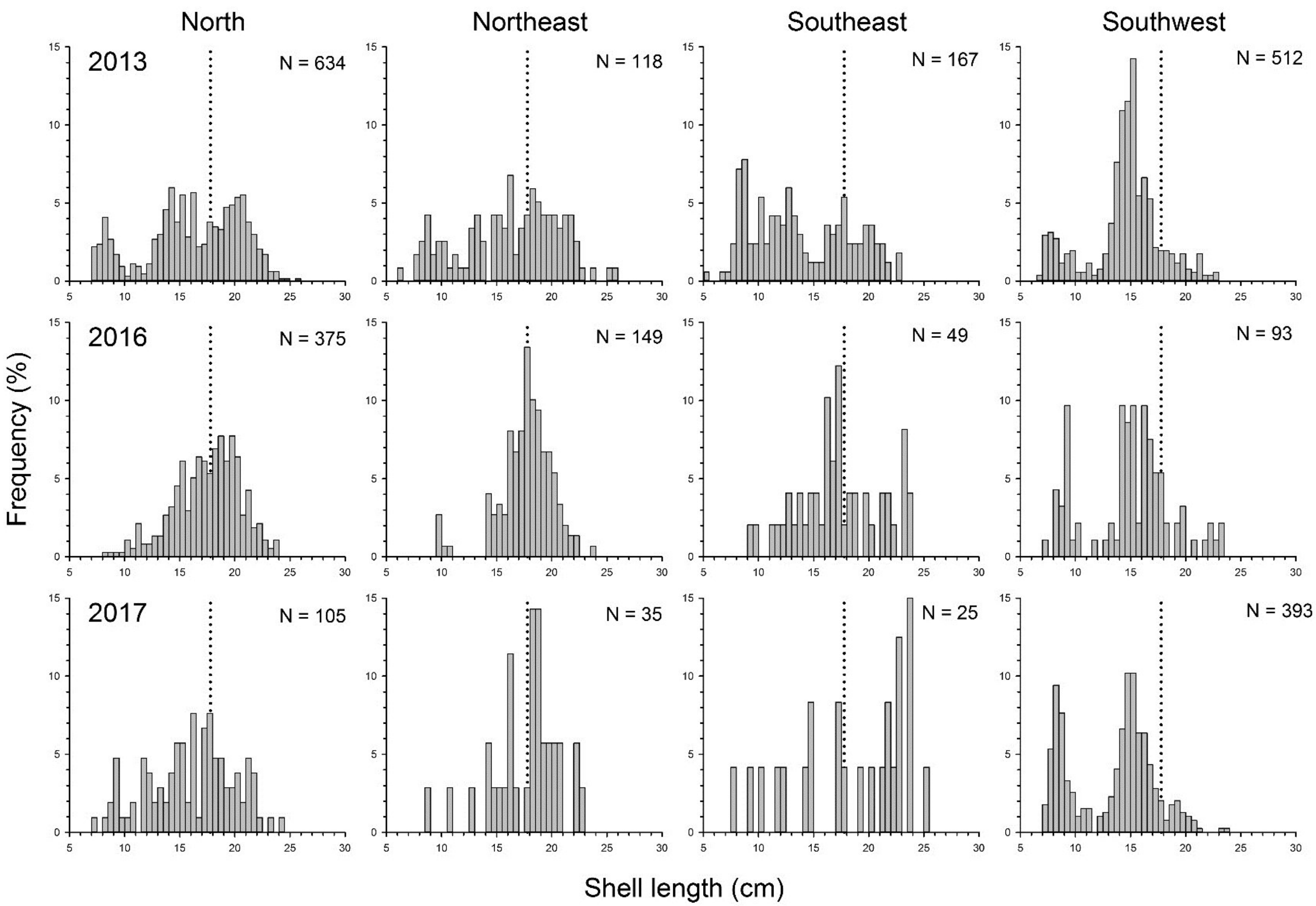

Figure 7. Length-frequency distributions, by section, of Queen Conch sampled at Turneffe Atoll in summers of 2013, 2106, and 2017. The dotted vertical lines indicate the legal shell length (17.8 cm) for harvest.

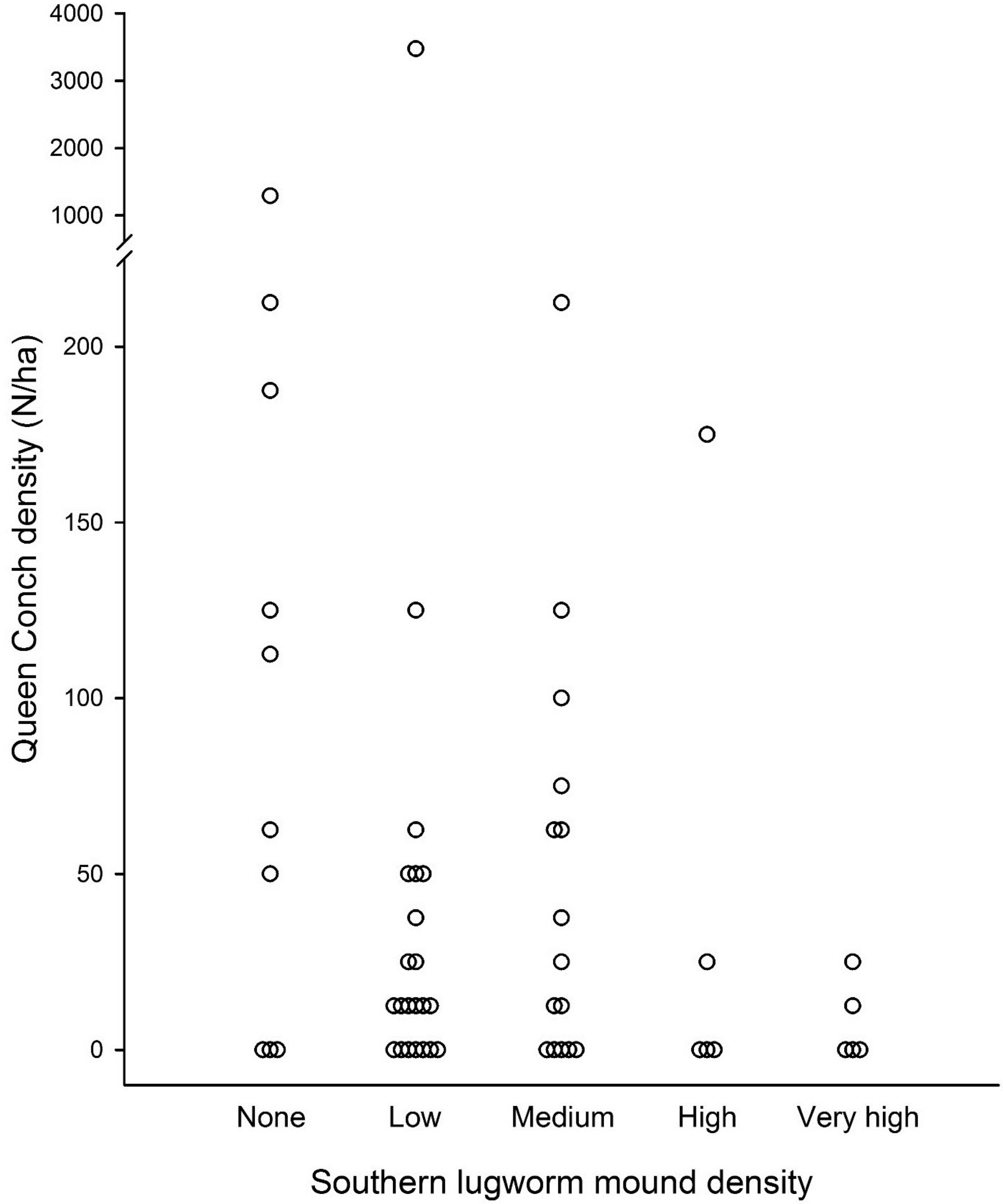

Figure 8. Scatter plot of Queen Conch site densities (N/ha) versus southern lugworm mound density categories, Turneffe Atoll, 2017.