Monitoring and Assessment of Maine's Sea Urchin Resource

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Maine Department of Marine Resources

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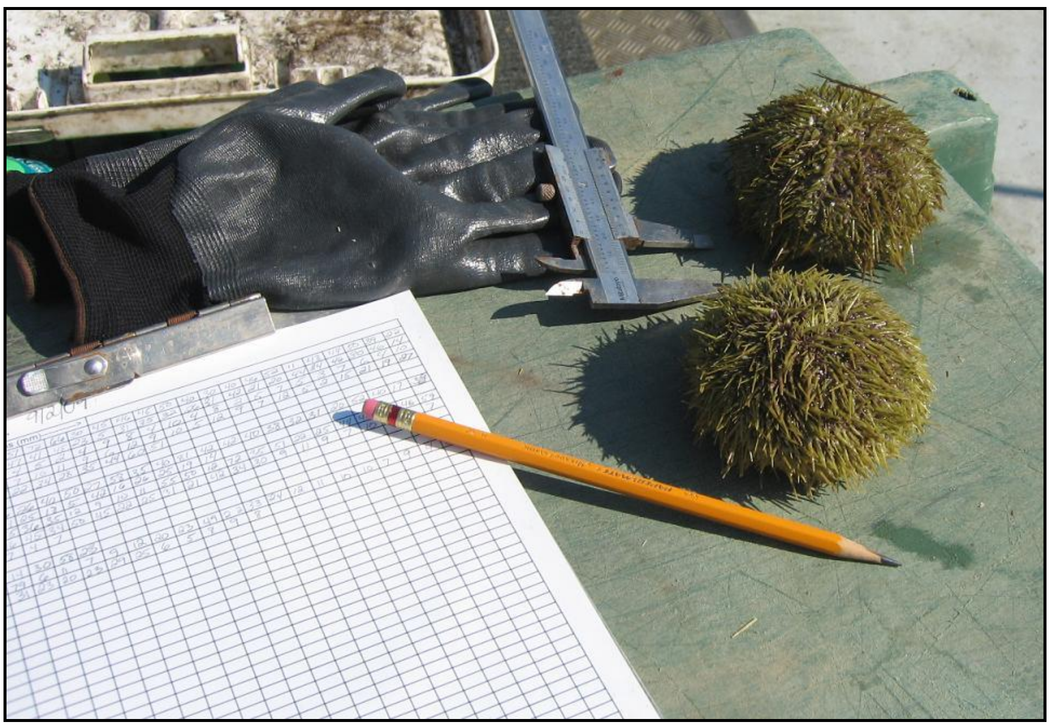

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SEA URCHINS

Margaret Hunter and Robert Russell

Executive Summary:

During September 2014 – March 2020, information about the Maine green sea urchin and its fishery was collected through a commercial fishery monitoring (port sampling) program, and an annual fisheries-independent dive survey. The port sampling program involved collecting landings and fishing effort data during harvester and dealer interviews, and samples of sea urchins from catches were weighed and measured. During each annual dive survey, random and fixed inshore sites were visited by two SCUBA divers, and random quadrats were evaluated for urchin abundance and size, as well as algal cover, lobster and crab abundance, and more. As of spring 2019, sea urchin biomass and abundance in both of the State's management zones were at, or near, time-series lows.

Job #1: Biological Monitoring of the Sea Urchin Resource and Fishery

Background:

The green sea urchin, *Strongylocentrotus droebachiensis* (Müller), has been harvested for human consumption from the Gulf of Maine since prehistoric times. A small commercial fishery for sea urchins has existed in Maine since at least the 1940's, to ethnic markets in Boston and New York, and, in the 1970s, to Europe. The fishery expanded rapidly in 1987 when a market developed in Japan. Sea urchin "roe" is a delicacy in Japan, Europe, and ethnic markets in the USA, and, more recently, other high-end domestic markets (Pols, 2014).

The fishery occurs primarily in shallow waters during the winter, with landings currently occurring between September and March. Urchins are harvested by divers using SCUBA (with an occasional snorkeler) and by draggers, plus a few rakers who stand in the shallows and rake during low tide. In the 2019–20 season, about 58% of the landings were made by about 85 divers, and the remaining 42% by about 65 draggers, according to preliminary dealer reports from harvester swipe cards (Maine DMR, unpublished data).

The Maine coastline is divided into two exclusive management zones (Figure 1a). Landings by zone (from dealer reports) are shown in Table 1 and Figure 2, and exhibit a classic boom to bust fishery.

Purpose:

Determine spatial/temporal patterns in catch, effort, catch per unit effort, size composition, percent roe, and test (shell) condition of dive and drag harvested urchins — fishery dependent data which are useful for resource monitoring, assessment, and management.

Approach, Job #1:

This report covers the period from the beginning of the 2014–15 fishing season through the 2019–20 season, or September 2014 through March 2020, six fishing seasons. Because there is no sea urchin fishing in Maine during the late spring and summer months (April – August), harvest and other fishery-dependent data are collected and compiled for each fishing season, rather than by calendar year.

The commercial sea urchin port sampling program was initiated during the 1994–95 fishing season. A description of the program and methods can be found in Hunter *et al*. 2010. Divers, rakers, and dragger captains were interviewed at landing sites for fishing effort data. Landings data for each harvester were obtained from the buyers, and biological samples were collected, usually from the buyers. We attempted to sample in each of the two management zones (Figure 1a) during the open season at known buying locations, during weather conditions when harvesters were active. Sampling activities were usually confined to locations where at least five harvesters were expected to unload and sell their catches. The sampling schedule was confounded by a complicated season of different fixed open days for the two zones, different days for the two gear types (dive/rake and drag), and the harvesters' choice of either an early or late open season for each zone and gear. This resulted in up to eight different open seasons, which sometimes overlapped. The first season began in September, when management Zone 1 opened for early divers for ten or fifteen days, usually spread over about three–four weeks, and continued as the early Zone 1 dive season closed and the Zone 2 early season opened, usually in October with about three open days per week for both divers and draggers; then the Zone 1 and Zone 2 late seasons for both divers and draggers opened in December, and the Zone 2 late diver and dragger seasons continued for about three days per week through March. Since the advent of harvester swipe cards in 2016–17, harvesters have also been able to choose their limited number of fishing days from a wider number of open days. Because landings, participation in the fishery, and the number of fishing days have declined (Tables 1 and 2), our sampling schedule has been reduced from roughly twice a week when the program began in 1994, to about once every two weeks.

We tried to proportionally allocate the sampling trips to each coastal county where fishing occurred (mostly Knox in Zone 1, and mostly Knox, Hancock, and Washington in Zone 2 — see Figure 1a) by the contribution of the county to overall landings. More interviews and samples were obtained in counties with more buying locations and more landings. The sampling of urchin landings by proportional allocation was complicated by a constant change in the numbers and locations of buying stations during the season. Achieving representative sampling has been a challenge, and random sampling approaches have not worked because of the shifting and mobile nature of the buying stations (mostly trucks parked in an empty lot, and only a few buyers in fixed locations), a limited market which shut some buyers down on some days in some seasons, the complicated season structure described above, and because of severe weather conditions during what is predominantly a winter fishery.

During a sampling trip, as many divers and draggers as possible arriving at the buying station to sell their catch were asked about their fishing experience (diver age and years fishing), effort for the day (bottom hours, away hours, and number of divers on the vessel for divers; towing hours and away hours for draggers), boat length, number of crew, location of fishing (to at least the 10-minute square), depths fished, and number of trays (totes, boxes) sold. The buyers provided total catch (lbs), price, and estimated urchin roe content (%). A random sample of 20 urchins was collected from each catch when possible, and each sampled urchin was weighed, measured (test diameter), evaluated for shell/spine condition, and returned to the buyer.

Findings, Job #1:

The numbers of interviews conducted, sea urchins measured, and calculations of sampling intensity are listed by season in Table 3. Over the past six seasons, program staff interviewed harvesters representing an average of 3.4% of the fishery (by landed weight) and measured an average of 0.021% of the estimated number of landed sea urchins. The numbers of interviews and samples is reported by season, gear, and zone in Table 8. Note that Zone 1 dragger interview data will not be reported here, because there were only eleven total Zone 1 dragger interviews during the six seasons 2014–15 through 2019–20, and there have never been more than three Zone 1 dragger interviews in any one season since 2001–02. Only a few Zone 1 draggers fished during this period — two to eight in any one season.

Daily Landings, Hours Fished, and Landings per Fishing Hour — Information recorded or derived from diver, dragger, and buyer interviews during the 2014–2015 through 2019–20 seasons is shown in Tables 4–11. Median values were chosen as robust estimators that minimize the influence of outliers in harvester data (Perry et al., 2002; Zhang and Perry, 2005).

During the 2014–15 to 2019–20 seasons, the median daily landings for a Zone 1 diver hovered around 725 lbs (329 kg). There was no apparent decline in 2019–20 despite a reduction in the season's daily trip limit for Zone 1, from 12 trays (about 1,000 lbs or 454 kg) to 9 trays (about 750 lbs or 340 kg). This may be due to some divers "fishing up" to the new limit, and/or a concurrent increase in the available opportunity days (Table 2), allowing divers to choose better weather days on which to fish. For Zone 2 divers, the median daily catch was about 580 lbs (263 kg) but the new daily trip limit (reduced from 7 trays (about 640 lbs or 290 kg) to 6 trays (about 550 lbs or 249 kg)) in 2019–2020 likely caused a reduction in median daily catches (to 538 lbs or 244 kg) compared with the previous seasons (Table 4). Likewise, Zone 2 dragger median daily landings were consistently above or near 600 lbs (274 kg) until they declined in 2019–2020 to 536 lbs (243 kg).

There were no obvious trends in diver bottom time or dragger towing time per day over the past six seasons. Median Zone 1 diver bottom time was consistently 4.0 – 4.5 hours and Zone 2's was 3.0 – 4.0 hours; the higher values for Zone 1 compared with Zone 2 probably due to the higher daily limits in Zone 1, described above, or more favorable diving conditions in September (warmer, longer days). Zone 2 dragger median towing time varied from 3.1 to 4.4 hours. (Table 5).

Landings per unit effort (LPUE) is presented as a proxy for catch per unit effort (CPUE) here. However, using LPUE as a proxy for catch rates is problematic, if catch methods and/or discard rates have not been stable. The implementation of culling on bottom rules for Zone 1 divers in 2003 and Zone 2 divers in 2012 may have reduced discard rates. If culling on bottom required more time on bottom for the same amount of landings, diver landings rates would decline. Divers who culled on bottom voluntarily before the regulations were implemented said that divers would soon learn the technique and landings rates would not be significantly affected.

LPUE for both divers and draggers is presented in Table 6 and Figure 3. A comparison of the median pounds per bottom hour summarized from diver interviews conducted during twenty-six consecutive harvesting seasons (Figure 3a), shows that Zone 2 diver LPUE dropped steadily over the first eight years of the series, to what was probably an economic threshold, about 125 to 150 lbs/hr. Zone 1 LPUE had probably declined nearly to that threshold before the project began, and continued to decline during the next four seasons. It improved during the next three seasons and then dropped again, remaining near 125 lbs/hr until 2008–09, and has varied around the 165 lbs/hr value since then without trend. LPUE increased in Zone 2 between 2003 and 2006, but dropped steadily to about 125 lbs/hr during 2010–11 to 2012–13, then jumped to 164 lbs/hr in 2013–14, probably due to the new daily trip limit, and has varied around the 150 lbs/hr value without trend since then. LPUE was usually higher in Zone 2 than in Zone 1 until 2009–10.

Dragger LPUE in pounds per drag-foot-width-towing-hour (Figure 3b) for Zone 2 shows some trends similar to the divers', except that the decline for the first 8 years of the series is not as evident, and there was not a significant increase in 2013–14. Recent LPUE has ranged from 23 to 34 lbs/ft-hr.

Rising or stable LPUE does not necessarily indicate increasing or stable stock abundance, according to our survey results (see next sections) and our analytical analyses (Chen and Hunter, 2003). It is likely that LPUE is not a good index of stock abundance for this fishery, and there is extensive literature on the problems resulting from assuming that commercial catch rates are in proportion to abundance (e.g. Hilborn and Walters 1992, Keesing and Baker 1998, Prince and Hilborn, 1998, Chen and Hunter 2003, Erisman *et al.* 2011). In this case, there are several factors that can keep overall catch rates stable (hyperstability) or even increasing when stock abundance is declining, such as serial depletion, economic thresholds, attrition of the least successful harvesters (see discussion in Hunter *et al.* 2005), aggregating behavior of the stock, and changes in fishing strategy and efficiency.

There is evidence that all of these factors have influenced Maine sea urchin catch (landings) rates. For example, the generally higher rates for Zone 1 divers since 2009–10 (Figure 3a) have been accompanied by a decline in roe content (DMR, unpublished data from dealer reports). Although changes in roe content could be attributed to climate change, a series of bad weather years, or other environmental factors, Zone 2 roe did not exhibit a similar decline during the same time period, suggesting that Zone 1 harvesters may have changed their fishing strategy, from targeting high quality urchins to targeting higher volume, poorer quality urchins.

Fishing Depths — Divers and draggers were asked for their estimates of the minimum and the maximum depths (feet) they fished. The median values of their responses are shown in Table 7 and Figure 4. Fishing deeper may indicate difficulty in finding urchins in shallow depths, which might be of concern to managers, or it may indicate the depth of the kelp-urchin feed line (Miller and Nolan, 2008). There do not seem to be any worrying trends in recent depths fished. Divers generally fished at 6–30 ft (1.8–9.1 m), while draggers were somewhat deeper and more variable from season to season at 10–50 ft (3.0–15.2 m).

Pounds per Tray — Landed sea urchins are usually stored and transported in standard plastic trays (also called totes or boxes), which are easily stacked. During port sampling, samplers counted the total number of trays for each landed catch. Partially filled trays were counted as whole ones, and the average weight per tray for each catch was estimated as the weight of the total catch (from dealer landed weights, after taring) divided by the number of trays. The median average weight per tray for the past 16 seasons is listed in Table 9, by zone and gear type. Note that over the 16 seasons, Zone 1 divers usually had the lightest trays (about 82 lbs, or 37 kg), and Zone 2 draggers usually had the heaviest (about 93 lbs, or 42 kg). These estimates have been useful when evaluating the impact of proposed daily tray limits (trip limits). For the 2013–14 season, a seven-tray daily limit (about 640 lbs or 290 kg) was implemented for all Zone 2 harvesters, and for 2014–15, a twelve-tray limit (about 1,000 lbs, or 454 kg) was enacted for Zone 1. Note that after the tray limits were imposed in Zone 2, the median average weight per tray for Zone 2 draggers declined from an average of 96 lbs to 90 lbs (44 to 41 kg). This is most likely because the tray limits were combined with restrictions on how full the tray could be filled (no mounding up, which draggers tended to do more than divers). For 2019–20, these limits were reduced to six trays for Zone 2 (about 550 lbs) and nine for Zone 1 (about 750 lbs).

Vessel length — Dive boats in Zone 1 are generally smaller than in Zone 2. This may be because most sampling in Zone 1 is conducted in September, when divers can fish from open skiffs. Dive boats in Zone 2 were smaller than draggers, about 25 feet (7.7 m) long vs 39 feet (12 m), during 2014–15 to 2019–20 (Table 10).

Diver age and experience — Interviewed divers in Zone 1 are generally older than in Zone 2, about 57 years old in Zone 1 and 50 years old in Zone 2, during 2014–15 to 2019–20. It is no surprise that diver age and years of experience are increasing with time, since almost no new divers have entered this closed fishery since 2004 (Table 11).

Divers per Boat and Total Dive Boats in the Fishery — Port interviews currently provide the only means of estimating the average number of divers on a boat for the fishery. Knowing this, and the number of divers active in the fishery (from dealer reports), the total number of dive boats in the fishery can be estimated. The number of active dragger vessels in the fishery can be obtained from dealer reports. Dealer reports provide the number of active divers, but not the number of dive vessels, since there can be more than one diver fishing from a given vessel. Since the 1997–98 season, divers have been asked during the interview how many divers were fishing from their boat. The answers have ranged from 1 to 4 divers per boat. We also record how many divers from the same boat were interviewed — if there are multiple divers on a boat, there is not always time to interview them all. In recent seasons, no boats with more than 3 divers have been encountered, and the average number of divers per boat has declined from 1.7 in 1997–98 to 1.4 in 2019–20. Since the total number of active divers in the fishery is known from dealer reports, and we know from observation that there are only 2 boats in the fishery with 3 divers, we can estimate the number of boats with 2 divers and the number with just 1, in addition to the total number of boats in the fishery. In 2019–20 the number of active divers was 85 (from preliminary dealer reports) and the estimated number of dive boats was 63; 2 boats had three divers, 18 boats had two divers, and 43 boats had 1 diver.

Size Distributions — Expanded size (test diameter) frequency information summarized from commercial samples, and expressed as a relative percentage, is shown for the 2014–15 to 2019–20 sampling seasons for each zone, in Figure 5. Size-frequencies were expanded from each sample to the sample's catch, summed for all the samples in the zone, and converted to a relative percentage for each millimeter increment. There was no further expansion to landings or stratification by gear or month. Note that in general, the sea urchins that were smaller than the minimum size limit ($2^1/_{16}$ inches, 52.4 mm), or larger than the maximum size limit (3 inches, 76.2 mm) were not necessarily illegal — the minimum and maximum size regulations each allow for a 5% tolerance by count, that is, a catch may have up to 5% undersized and 5% oversized urchins without being illegal. In the samples collected during 2014–15 to 2019–20 oversized and undersized urchins comprised about 1–2% of the season's sampled urchins.

In Table 12 and Figure 6, median urchin diameter and the first and third quartile diameters are presented over time for each zone. After the increase in the minimum size in 2001, from 2 inches to $2^1/_{16}$ inches (50.8 to 52.4 mm), the median sea urchin diameter in commercial catches has consistently been about 60–63 mm (2.36–2.48inches) in both zones.

Diameter-Weight Relationships — which have been used in our modeling efforts (Chen and Hunter, 2003, Kanaiwa *et al.* 2005) are presented for the 2019–20 season samples, by zone, in Figure 7. Parameters were estimated for each zone for the relationship: Weight = $a \cdot \text{Diameter}^b$.

Evaluation, Objective 1:

The project goals and objectives were attained, by obtaining catch, effort, and biological data over the temporal and spatial range of the dive and drag sea urchin fisheries each season.

Job #2

JOB TITLE: Sea Urchin Resource Survey

Purpose:

Conduct a fishery-independent survey of Maine's sea urchin resource using SCUBA diving techniques, to develop a time series of abundance and biomass indices for the state by region.

Approach, Job #2:

This section covers the period from 2015 through 2019. An annual spring dive survey of the Maine coastline was begun in 2001. The same methods have been used every year since, with minor changes and additions.

The state's coastline was divided into nine survey regions in 2001 (Figure 1b), each of roughly equal economic importance, that is, with roughly equal sea urchin landings in 2000. Each year, at least ten random dive sites were evaluated in each of the nine regions. These sites were chosen randomly from areas with hard bottom (Barnhardt et al, 1996) and a complete depth profile from 0–15m (0–49 ft.). There were five additional fixed sites in each of the nine survey regions. These sites were part of the random pick in 2001, and then were selected to be revisited each year, with input from harvesters, as sites that historically supported urchin populations (fixed sites, Figure 1b). A video camera survey conducted in deeper sites during 2001–2004 was discontinued in 2005 because of problems with the camera cable, and the lack of sea urchins found at the deeper sites in the six westernmost regions.

Some additional, "extra" sites were also selected and evaluated by the crew during 2004–2010. They were dropped to reduce survey costs, and their data are not presented or counted here. Also, regions in which sea urchin populations declined to low levels, especially Regions 1 and 2 in Zone 1, were dropped from the survey in some years to reduce expenses.

At each site, 60 quadrats were evaluated, with some exceptions. Two divers began their dives at about 15 m depth and swam a compass course toward shore. They each carried a 1-m^2 frame made of ¾-inch diameter PVC pipe. They each dropped this frame haphazardly ten times in the 10–15 m (33–49 ft) depth range (stratum), again in the 5–10 m (16–33 ft) depth range, and again in the 0–5 m (0–16 ft) depth range. Occasionally a site would have no hard substrate in the 10–15 m stratum, and sometimes the 5–10 m stratum, and the survey would begin in the next shallower stratum for that site.

All urchins at least 20 mm in diameter within the frame (quadrat) were counted, and the algal cover was evaluated. Algae were classified into functional groups as encrusting, turfing (understory), or canopy (Steneck and Dethier, 1994), and the percent cover of each of these three classifications was determined for each quadrat. Each diver collected all the urchins from one randomly selected quadrat from each depth stratum, brought them to the surface, measured test diameter to the nearest mm, and then released them.

Data elements include stratified arithmetic mean sea urchin abundance (number of individuals per square meter, or $N \cdot m^{-2}$) and estimates of stratified arithmetic mean urchin biomass (grams per square meter, or $g \cdot m^{-2}$), calculated by multiplying the abundance of each diameter size category (1 mm) by weight from a diameter-weight relationship from Scheibling *et al.* (1999) and summing over size categories, for each of three depth strata (0–5, 5–10, and 10–15 m), then weighted (stratified) by stratum area (rock and gravel substrates only, Table 13) for the region (Jones 2005; Grabowski *et al.* 2005).

In 2002 the survey divers began counting and measuring (carapace width) sub-samples of the crabs *Cancer borealis* ("Jonah crabs") and *Cancer irroratus* ("Rock crabs"), which have been reported as increasingly important predators of Maine's sea urchins (Leland, 2002; Steneck et al, 2004). Beginning in 2004, crabs were also sexed. Because of underwater sampling logistics, crabs, if present, were collected in each of the three depths into one sample for the site, instead of maintaining the samples separately by depth stratum as was done for urchins.

Beginning in 2003, lobsters (*Homarus americanus*) were counted, and sea stars (*Asterias sp., Crossaster sp., and Solaster sp.*) with arm lengths greater than about 20 mm were counted and measured (longest arm length in mm).

Beginning in 2007, the invasive white colonial tunicate *Didemnum sp*. was evaluated as either Absent, Present at less than or equal to 50% of cover, or Common at more than 50% of cover, in each quadrat.

Beginning in 2010, sea cucumbers (*Cucumaria frondosa*, orange-footed cucumber) were counted.

The survey and its protocols are described further by Grabowski *et al.* (2005), Jones (2005), and Hunter *et al.* (2010).

Findings, Objective 2:

The numbers of sites visited each year, quadrats evaluated, total counts of urchins, crabs, lobsters, starfish, and cucumbers, and the numbers measured, are presented in Table 14. Note that some regions were not surveyed in some years (Table 15). To estimate summary statistics for the zones with missing regions, data from the most recent past survey for those regions were used in place of the missing data. For example, Region 4, which is in Zone 2, was not surveyed in 2018, so Region 4 data from 2017 were used in the calculations of Zone 2 statistics for 2018.

Sea Urchin Biomass — Biomass indices ($g \cdot m^{-2}$) were generally below 100 $g \cdot m^{-2}$ in regions 1, 2, 3, and 5, and above 100 $g \cdot m^{-2}$ in regions 4 and 6–9 (Table 15a and Figures 8–9). Indices were highest in the shallowest depth stratum and lowest in the deepest during 2014, the most recent year in which all regions were surveyed (Table 16). Note that biomass is consistently lower in Zone 1 (regions 1–3) than Zone 2 (regions 4–9). Biomass in Zone 2 fell steadily from its high of 315 $g \cdot m^{-2}$ in 2001 until 2007, rose to about 196 $g \cdot m^{-2}$ in 2009, declined to a low of 105 $g \cdot m^{-2}$ in 2013, rose to 172 $g \cdot m^{-2}$ in 2015, and has declined steadily to a time series low of 48 $g \cdot m^{-2}$ in 2019. In Zone 1, biomass was highest with a value of 106 $g \cdot m^{-2}$ in 2002, then fell to a time series low of 6 $g \cdot m^{-2}$in 2017 and was 8 $g \cdot m^{-2}$ in 2019. In Zone 1, Region 3 has consistently had the highest biomass and Region 1 the lowest, and Region 3 is where most sea urchin fishing occurs in Zone 1. In Zone 2, Region 9 has consistently had the highest biomass and Region 5 the lowest (Table 15a and Figure 9). Biomass in all regions has declined since the survey began in 2001. The rate of decline was greatest between 2001 and 2004 (Figure 8a) and has slowed after the fishing seasons were drastically shortened in 2004 (Table 2).

Sea Urchin Abundance — Abundance indices (number·m^{-2}) (Table 15b and Figure 10) generally followed the same trends as biomass. The lowest abundances were observed in both zones in 2019. Abundance in all regions has declined since the survey began in 2001.

Sea Urchin Size Distributions — Size (test diameter) distribution plots (Figure 11) from the spring survey often exhibit the bimodality discussed by other researchers (Botsford *et al.* 1994, Vadas *et al.* 2002, reviewed by Scheibling, 1996).

Figure 11 perhaps best illustrates the trends noted in the abundance and biomass indices above. Declines in abundance between 2001 and 2019 have occurred for all sizes of urchins. Median diameters dropped in Zone 1 between 2001 and 2007, but have since risen (Figure 12).

The estimated biomass and abundance of under-sized (less than $2^{1}/_{16}$ inches (52.4 mm)), commercially legal, and over-sized (greater than 3 inches (76.2 mm)) sea urchins are presented in Figures 8b and 10b. Note that legal-sized urchins typically comprise about half of the total biomass, under-sized urchins dominate the abundance, and over-sized urchins are relatively rare.

Algal Cover — Algal cover data from the spring survey are displayed in Figures 13–15. Because the evaluation of percent algal cover is the most subjective observation made during the survey, only data from the one diver who participated in all survey years were included here. Note that adding the percent encrusting, percent understory, and the percent canopy cover together sometimes results in a total percent algal cover greater than 100%.

Since sea urchins are voracious grazers and play an important role in determining the distribution of macroalgae in the rocky subtidal (reviewed by Steneck (2013), Scheibling and Hatcher (2013), and others), one might expect that as Maine sea urchin biomass has declined, the cover of fleshy algae would increase. This may have been the case from 2001 to 2004. The total cover of fleshy algae (understory plus canopy, solid line in Figures 13–14) increased in both zones to a peak in 2004 (Figures 13–14) as sea urchin biomass fell (Figure 9), but after that the fleshy algal values declined in both zones until 2007 and then fluctuated without trend. There does not seem to be any continued negative correlation with urchin biomass, or other long term trend, after 2004. Generally, Zone 2 has had more canopy and encrusting algae, and less understory algae, than Zone 1. Zone 1 tends to have more of the understory red alga *Chondrus crispus* (Irish moss) than Zone 2 (Robert Russell, DMR, pers. obs.). Region 9 has consistently had the lowest values of all types of algae. This may be due in part to the high frequency of dragging activity there, as well as the relatively high abundance of sea urchins. Another reason may be that mud bottoms are sometimes sampled in Region 9. Although data layers with hard bottom (rock or gravel) are used to select the random survey sites, sometimes the site turns out to have a soft, muddy bottom, with urchins present. This usually only happened in Region 9, and we decided to keep those sites. Mud-bottom sites may have urchins in Regions 9 but are unlikely to have much algal cover. Canopy cover was generally highest in the shallowest stratum, and lowest in the deepest stratum, in 2014, the most recent year in which all regions were sampled (Figure 13).

Crab Abundance — *Cancer* crabs (*C. borealis*, the Jonah crab, and *C. irroratus*, the rock crab) have been implicated as major predators of green sea urchins in Maine, preying upon both newly settled juvenile urchins, and adult urchins. See Steneck *et al.* (2013) and Scheibling and Hatcher (2013) for reviews. We began counting crabs during the 2002 spring sea urchin survey, although these crabs become more active and more visible later in the year. The results (abundance in stratified mean numbers per square meter) are displayed in Figures 16–18. The survey data support anecdotal accounts of a “wave” of crabs that moved from west to east along the Maine coastline, with both species (combined) peaking in Zone 1 in 2003 and in Zone 2 in 2005. Time series lows for both species (combined) occurred in Zone 1 in 2011 and in Zone 2 in 2013. Zone means for Jonah crabs were higher than rock crabs, except in Zone 2 in 4 of 19 years. Rock crabs were more abundant in Zone 2 than they were in Zone 1 (Figure 16). In Zone 2, Region 5 generally had the most crabs, with successively fewer to the east; Region 9 consistently had the lowest abundance of both species (Figure 17). There were no clear state-wide trends in crab abundance with depth in 2014, the most recent year in which all regions were surveyed — crabs were most abundant at depths of 10–15m in Zone 1 (Regions 1–3), and at depths of 5–15 m in Regions 4–5, with no obvious trends with depth in Regions 6–9 (Figure 18).

Lobster abundance — Lobsters have been counted since 2003 (Figure 19a), although they too would be more active and available later in the year. Highest abundances have generally been in Regions 1, 2, 3, 5, and 6, and lowest in Region 9. The highest abundance by zone was observed for Zone 1 in 2010 and Zone 2 in 2011. Abundances were at or near time series lows in both zones in 2007 and 2019. Abundances were higher in Zone 1 than in Zone 2 except in 2014 and 2016.

Sea star abundance — Sea stars (*Asterias sp., Crossaster sp., and Solaster sp.*) have also been counted since 2003 (Figure 19b). Abundances declined sharply in both zones between 2003 and 2006 and were at or near time-series lows in both zones in 2019. Survey divers noted that high abundances of sea stars coincided with high abundances of small blue mussels (*Mytilis edulis*).

Sea cucumber abundance — Sea cucumbers (*Cucumaria frondosa*, orange-footed cucumber) have been counted since 2010 (Figure 19c). Abundances have been generally higher in Zone 2 than Zone 1, and were at or near time series lows in both zones in 2019.

Tunicate coverage — Since 2007 the invasive white colonial tunicate *Didemnum sp*. has been evaluated as either Absent, Present at less than or equal to 50% of cover, or Common at more than 50% of cover. The percentage of quadrats with values of Present or Common are shown by region and zone in Figure 20, and were highly variable but generally higher in Zone 1 than Zone 2, and highest in Region 3 and lowest in Region 9. In Region 3, Present or Common peaked in 2016 at 25% of quadrats evaluated.

Evaluation, Objective 2:

The project goals and objectives were attained, by conducting annual dive surveys of Maine's sea urchin (and related biota) resources, and developing a time series of abundance indices and biomass estimates for the state by region and zone.

Dissemination, Jobs 1 and 2:

Reports are compiled and published on the DMR web site at https://www.maine.gov/dmr/science-research/species/seaurchin/research.html. The latest landings, annual LPUE data, and survey abundance and biomass indices are routinely provided to DMR managers and the Maine Sea Urchin Zone Council (SUZC), which provides management advice to the Maine DMR. The pounds per tray data were presented to the SUZC during tray-limit discussions. Survey results have also been provided to the Monterey Bay Aquarium Seafood Watch. The *Didemnum* data have been provided to Maine Sea Grant and the USGS Nonindigenous Aquatic Species Program. All survey data have also been provided to several University of Maine graduate students and faculty over the years (e.g. Wilson *et al. 2013).*

In response to declining sea urchin survey indices, and with industry and SUZC input, the DMR reduced the Zone 2 daily tray limit from 7 trays to 6 trays (about 640 lbs to about 550 lbs), shortened the Zone 2 season from 38 days to 30, and reduced the Zone 1 daily tray limit from 12 trays to 9 (about 1,000 lbs to about 750 lbs), for the 2019–2020 fishing season.

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Table 1. Maine sea urchin landings by fishing season and zone, from NMFS port agent reports through 1995–96, and thereafter from DMR dealer reports. 2018–19 and 2019–20 data are preliminary. Value and Price are not adjusted for inflation.

	Pounds			Metric Tons			Value	Price
Season	**Zone 1**	**Zone 2**	**Total**	**Zone 1**	**Zone 2**	**Total**	**$**	**$/lb**
1987-88			4,074,614			1,848.2	840,104	0.21
1988-89			7,479,854			3,392.8	2,512,549	0.34
1989-90			10,507,781			4,766.3	4,238,658	0.40
1990-91			17,500,228			7,938.1	8,291,892	0.47
1991-92			19,705,059			8,938.2	11,063,187	0.56
1992-93			39,288,946			17,821.3	23,478,555	0.60
1993-94			37,829,393			17,159.3	26,968,165	0.71
1994-95	17,430,440	19,706,850	37,137,290	7,906.4	8,939.0	16,845.4	35,536,073	0.96
1995-96	15,479,639	14,782,860	30,262,499	7,021.5	6,705.5	13,727.0	33,183,441	1.10
1996-97	10,389,420	13,465,189	23,854,609	4,712.6	6,107.8	10,820.4	26,580,434	1.11
1997-98	6,609,750	10,338,950	16,948,700	2,998.2	4,689.7	7,687.9	18,339,532	1.08
1998-99	5,772,995	10,929,943	16,702,938	2,618.6	4,957.8	7,576.4	20,102,119	1.20
1999-00	5,072,148	8,982,967	14,055,115	2,300.7	4,074.6	6,375.4	18,858,460	1.34
2000-01	4,426,427	7,391,533	11,817,960	2,007.8	3,352.8	5,360.6	16,119,624	1.36
2001-02	3,202,928	4,647,644	7,850,572	1,452.8	2,108.2	3,561.0	9,717,479	1.24
2002-03	1,952,361	4,748,271	6,700,632	885.6	2,153.8	3,039.4	8,758,199	1.31
2003-04	1,293,602	5,040,920	6,334,522	586.8	2,286.5	2,873.3	8,860,609	1.40
2004-05	156,803	3,630,293	3,787,096	71.1	1,646.7	1,717.8	5,802,979	1.53
2005-06	112,192	3,740,713	3,852,905	50.9	1,696.8	1,747.7	5,371,416	1.39
2006-07	154,991	2,874,500	3,029,491	70.3	1,303.9	1,374.2	4,581,572	1.51
2007-08	178,550	2,975,853	3,154,403	81.0	1,349.8	1,430.8	5,043,356	1.60
2008-09	138,683	2,960,823	3,099,506	62.9	1,343.0	1,405.9	5,089,928	1.64
2009-10	121,710	2,991,471	3,113,181	55.2	1,356.9	1,412.1	5,902,851	1.90
2010-11	148,767	2,152,991	2,301,758	67.5	976.6	1,044.1	5,143,746	2.23
2011-12	181,226	2,149,873	2,331,099	82.2	975.2	1,057.4	5,081,370	2.18
2012-13	273,371	1,564,810	1,838,181	124.0	709.8	833.8	5,721,560	3.11
2013-14	384,143	1,539,565	1,923,708	174.2	698.3	872.6	5,067,105	2.63
2014-15	377,862	1,635,359	2,013,221	171.4	741.8	913.2	5,553,463	2.76
2015-16	373,174	1,613,029	1,986,203	169.3	731.7	900.9	5,751,001	2.90
2016-17	300,091	1,795,103	2,095,194	136.1	814.3	950.4	6,864,168	3.28
2017-18	272,286	1,869,939	2,142,225	123.5	848.2	971.7	6,397,042	2.99
***2018-19**	214,164	1,753,823	1,967,987	97.1	795.5	892.7	5,898,382	3.00
***2019-20**	207,951	1,275,720	1,483,671	94.3	578.7	673.0	5,276,643	3.56

** preliminary*

Table 2. The number of open fishing days in the Maine sea urchin fishery, annually (top) or seasonally by zone (bottom).

Year	Total Open Days	(No Zones until second half of 1994)
1986	365	
1987	365	
1988	366	
1989	365	
1990	365	
1991	365	
1992	366	
1993	335 (closed Jul. 9 – Aug. 7)	
1994 (first half)	134 (open Jan. 1 – May 14)	

Season	Zone 1 Total Open Days	Zone 2 Total Open Days
1994–1995	228, Aug. 16 – Mar. 31	272, Aug. 16 – May 14
1995–1996	229, Aug. 16 – Mar. 31	212, Oct. 2 – Apr. 30
1996–1997	150, Aug – Mar	170, Aug – Apr
1997–1998	120, Sep – Feb	120, Oct – Apr
1998–1999	120, Sep – Feb	120, Oct – Apr
1999–2000	120, Sep – Feb	120, choice of early or late
2000–2001	110, Sep – Feb	110, choice of early or late
2001–2002	94, Sep – Mar	94, choice of early or late
2002–2003	94, Sep – Mar	94, choice of early or late
2003–2004	94 dive, 84 drag, Sep – Mar	94, choice of early or late
2004–2005	10, Sep dive, Dec drag	45, choice of early or late
2005–2006	10, choice of early or late	45, choice of early or late
2006–2007	10, choice of early or late	45, choice of early or late
2007–2008	10, choice of early or late	45, choice of early or late
2008–2009	10, choice of early or late	45, choice of early or late
2009–2010	10, choice of early or late	45, choice of early or late
2010–2011	10, choice of early or late	45, choice of early or late
2011–2012	10, choice of early or late	45, choice of early or late
2012–2013	15, choice of early or late	36, choice of early or late
2013–2014	15, choice of early or late	38, choice of early or late
2014–2015	15, choice of early or late	38, choice of early or late
2015–2015	15, choice of early or late	38, choice of early or late
2016–2017	15, choice of early or late	38, choice of early or late
2017–2018	choose 15 out of 20, early or late	choose 38 out of 45, early or late
2018–2019	choose 15 out of 20, early or late	choose 38 out of 45, early or late
2019–2020	choose 15 of 43 (early) or 63 (late)	choose 30 out of 40, early or late

Table 3. Maine sea urchin landings, and port sampling summary statistics and sampling rates, by fishing season. 1,000 pounds (lbs) = 453.6 kg.

Season	Total Landings (lbs)	Number of harvester interviews	Total weight of interviewed catches (lbs)	Sampling rate for harvester interviews by catch weight	Mean weight of a sampled urchin (g)	Estimated number of urchins landed	Total number of urchins measured	Sampling rate for measured urchins	Estimated number of urchins/lb
1994-95	37,137,290	404	249,705	0.7%			0	0%	
1995-96	30,262,499	180	115,613	0.4%	99.78	137,575,329	5,585	0.0041%	4.5
1996-97	23,854,609	537	330,568	1.4%	95.91	112,820,251	10,674	0.0095%	4.7
1997-98	16,948,700	464	280,111	1.7%	98.25	78,247,551	9,274	0.0119%	4.6
1998-99	16,702,938	499	308,119	1.8%	101.09	74,942,759	9,839	0.0131%	4.5
1999-00	14,055,115	416	243,592	1.7%	98.86	64,491,089	8,320	0.0129%	4.6
2000-01	11,817,960	343	198,336	1.7%	90.70	59,099,886	5,919	0.0100%	5.0
2001-02	7,850,572	314	167,638	2.1%	91.53	38,906,817	4,560	0.0117%	5.0
2002-03	6,700,632	219	126,003	1.9%	89.82	33,837,499	2,940	0.0087%	5.0
2003-04	6,334,522	166	97,767	1.5%	93.56	30,710,274	1,960	0.0064%	4.8
2004-05	3,787,096	111	70,936	1.9%	89.46	19,201,854	1,420	0.0074%	5.1
2005-06	3,852,905	116	90,881	2.4%	95.11	18,375,906	1,660	0.0090%	4.8
2006-07	3,029,491	117	87,047	2.9%	101.86	13,490,057	1,415	0.0105%	4.5
2007-08	2,949,228	107	74,506	2.5%	105.42	12,689,185	1,260	0.0099%	4.3
2008-09	3,099,506	60	39,902	1.3%	103.44	13,591,481	978	0.0072%	4.4
2009-10	3,113,181	124	86,969	2.8%	100.52	14,048,395	2,112	0.0150%	4.5
2010-11	2,301,633	205	125,185	5.4%	94.68	11,026,962	3,740	0.0339%	4.8
2011-12	2,331,099	130	70,318	3.0%	95.25	11,100,476	2,300	0.0207%	4.8
2012-13	1,838,181	188	106,130	5.8%	100.31	8,312,439	2,780	0.0334%	4.5
2013-14	1,923,708	130	77,053	4.0%	96.04	9,085,641	1,900	0.0209%	4.7
2014-15	2,013,221	105	68,286	3.4%	94.54	9,659,368	2,000	0.0207%	4.8
2015-16	1,986,203	115	74,669	3.8%	98.97	9,102,704	2,080	0.0229%	4.6
2016-17	2,095,194	113	64,648	3.1%	92.41	10,283,877	2,179	0.0212%	4.9
2017-18	2,142,225	106	66,501	3.1%	94.09	10,327,821	1,997	0.0193%	4.8
***2018-19**	1,967,987	106	66,741	3.4%	93.57	9,540,125	1,958	0.0205%	4.8
***2019-20**	1,483,671	89	52,003	3.5%	89.16	7,548,232	1,735	0.0230%	5.1

* Landings are preliminary

Table 4. Median sea urchin daily landings (pounds, lbs) per harvester by management zone and season, for divers (left) and draggers (right). One pound = 0.454 kg.

Diver Median Daily Landings (lbs)				
Season	Zone 1		Zone 2	
	median	std err	median	std err
2004-05	417	49.4	650	50.7
2005-06	585	58.2	680	59.6
2006-07	426	55.0	720	44.6
2007-08	571	106.6	680	41.9
2008-09	603	49.8	600	58.8
2009-10	663	102.7	600	40.8
2010-11	673	61.5	510	36.5
2011-12	667	76.3	567	39.3
2012-13	850	59.1	546	29.7
2013-14	597	104.3	600	16.2
2014-15	714	56.0	619	21.6
2015-16	862	46.9	602	23.8
2016-17	610	67.9	503	49.4
2017-18	689	72.3	598	26.3
2018-19	737	69.0	613	21.0
2019-20	745	60.4	538	13.0

Dragger Median Daily Landings (lbs)				
Season	Zone 1		Zone 2	
	median	std err	median	std err
2004-05	*0 – 3 dragger interviews per season in Zone 1 since 2000-01.*		570	88.3
2005-06			1,005	86.3
2006-07			882	96.8
2007-08			548	99.6
2008-09			638	113.8
2009-10			656	57.2
2010-11			563	52.1
2011-12			502	38.0
2012-13			573	52.1
2013-14			573	34.2
2014-15			629	19.5
2015-16			589	30.8
2016-17			630	19.5
2017-18			611	26.6
2018-19			624	25.9
2019-20			536	26.6

Table 5. Median daily bottom hours fished per sea urchin diver (left) and median daily towing hours per dragger (right), by management zone and season, from harvester interviews.

Diver Median Daily Bottom Hours				
Season	Zone 1		Zone 2	
	median	std err	median	std err
2009-10	4.0	0.33	4.0	0.23
2010-11	4.0	0.32	4.5	0.16
2011-12	3.25	0.46	4.0	0.19
2012-13	5.0	0.23	4.0	0.14
2013-14	4.0	0.30	3.5	0.15
2014-15	4.0	0.23	3.5	0.18
2015-16	4.0	0.23	4.0	0.19
2016-17	4.0	0.38	3.0	0.25
2017-18	4.0	0.34	4.0	0.19
2018-19	4.5	0.40	4.0	0.22
2019-20	4.25	0.38	3.5	0.25

Dragger Median Daily Tow Hours				
Season	Zone 1		Zone 2	
	median	std err	median	std err
2009-10	*0 – 3 dragger interviews per season in Zone 1 since 2000-01.*		4.6	0.25
2010-11			5.0	0.31
2011-12			4.6	0.24
2012-13			4.8	0.28
2013-14			4.1	0.36
2014-15			4.2	0.25
2015-16			4.4	0.33
2016-17			3.1	0.27
2017-18			3.1	0.37
2018-19			3.8	0.26
2019-20			3.4	0.27

Table 6. Median sea urchin landings per unit effort, by management zone and season, for divers (pounds per bottom hour, left) and draggers (pounds per foot of drag width per towing hour, right), from harvester interviews. One pound = 0.454 kg. One foot = 0.305 meter.

Diver pounds per bottom hour				
Season	Zone 1		Zone 2	
	median	std err	median	std err
1994-95	150	8.1	220	11.6
1995-96	126	9.4	208	13.5
1996-97	132	6.4	201	6.7
1997-98	117	6.8	189	7.8
1998-99	154	6.1	185	7.3
1999-00	146	6.0	176	8.3
2000-01	161	10.4	152	7.6
2001-02	136	5.3	130	7.4
2002-03	135	7.5	145	8.7
2003-04	128	10.0	164	14.1
2004-05	120	12.8	150	10.5
2005-06	140	17.4	186	10.5
2006-07	122	11.1	177	10.0
2007-08	122	17.6	152	9.9
2008-09	147	13.7	154	13.3
2009-10	166	18.4	145	9.3
2010-11	158	16.3	124	12.3
2011-12	162	20.4	122	8.0
2012-13	170	13.2	126	5.8
2013-14	153	20.1	164	11.7
2014-15	183	15.1	163	8.7
2015-16	201	11.7	160	9.7
2016-17	122	14.1	126	15.9
2017-18	169	18.1	149	14.5
2018-19	162	9.7	143	10.4
2019-20	177	32.6	154	13.7

Dragger pounds per ft width tow hour				
Season	Zone 1		Zone 2	
	median	std err	median	std err
1994-95	24.6	5.1	31.3	8.1
1995-96	17.9	7.6	28.4	7.7
1996-97	23.1	5.8	24.8	3.4
1997-98	28.1	5.3	28.5	4.2
1998-99	27.2	3.2	33.6	3.5
1999-00	19.4	11.4	28.3	3.3
2000-01	20.6	2.0	29.1	3.9
2001-02	*0 – 3 dragger interviews per season in Zone 1 since 2000-01.*		22.5	2.8
2002-03			25.9	3.2
2003-04			26.4	3.2
2004-05			23.4	3.9
2005-06			35.0	3.8
2006-07			35.2	4.9
2007-08			29.3	11.1
2008-09			28.6	5.6
2009-10			23.5	4.4
2010-11			19.0	3.4
2011-12			20.9	3.4
2012-13			22.6	3.1
2013-14			22.8	4.2
2014-15			26.1	4.9
2015-16			23.0	2.2
2016-17			34.2	4.9
2017-18			33.5	7.8
2018-19			29.4	3.4
2019-20			28.4	5.0

Table 7. Sea urchin fishing depths, by management zone and season, for divers (left) and draggers (right), from harvester interviews. Data are the median minimum depth fished response, and the median maximum depth fished response (feet). One foot = 0.305 meter.

Diver Median Depths (ft)				
Season	**Zone 1**		**Zone 2**	
	Min.	Max.	Min.	Max.
1994-95	10	20	9	20
1995-96	15	35	10	30
1996-97	5	20	6	20
1997-98	6	25	8	25
1998-99	6	22	6	20
1999-00	5	25	6	20
2000-01	10	25	10	25
2001-02	10	20	12	25
2002-03	15	20	15	25
2003-04	20	20	20	30
2004-05	15	20	20	20
2005-06	10	20	20	20
2006-07	10	20	15	20
2007-08	10	20	20	20
2008-09	5	20	20	20
2009-10	13.5	20	12	20
2010-11	10	20	10	20
2011-12	0	15	10	18
2012-13	0	15	10	20
2013-14	0	15	10	20
2014-15	6	15	11	20
2015-16	6	18	20	30
2016-17	7	7	15.5	20
2017-18	18.5	18.5	13.5	19
2018-19	10	20	10	20
2019-20	9	20	6	18

Dragger Median Depths (ft)				
Season	**Zone 1**		**Zone 2**	
	Min.	Max.	Min.	Max.
1994-95	30	42	10	30
1995-96	10	35	10	40
1996-97	11	39	12	50
1997-98	10	40	13	60
1998-99	12	60	16	50
1999-00	22	44	10	40
2000-01	13.5	22	11	40
2001-02	*0 – 3 dragger interviews per season in Zone 1 since 2000-01.*		20	30
2002-03			30	39
2003-04			20	40
2004-05			35	45
2005-06			27.5	40
2006-07			30	40
2007-08			40	40
2008-09			22.5	40
2009-10			25	50
2010-11			20	40
2011-12			20	30
2012-13			15	40
2013-14			20	40
2014-15			27.5	30
2015-16			30	40
2016-17			30	45
2017-18			24.5	30
2018-19			35	50
2019-20			9.5	30

Table 8. Number of sea urchin harvester interviews and samples, by season and management zone, for divers (left) and draggers (right).

Numbers of Diver Interviews and Samples				
Season	Zone 1		Zone 2	
	Interviews	Samples	Interviews	Samples
2014-15	31	30	38	34
2015-16	47	45	37	31
2016-17	27	27	23	22
2017-18	26	25	39	35
2018-19	17	14	44	42
2019-20	6	6	44	43

Numbers of Dragger Interviews and Samples				
Season	Zone 1		Zone 2	
	Interviews	Samples	Interviews	Samples
2014-15	3	3	33	33
2015-16	0	0	31	28
2016-17	1	1	62	59
2017-18	3	3	38	37
2018-19	2	2	43	40
2019-20	2	1	37	37

Table 9. Median pounds of sea urchins per tray, by season and management zone, for divers (left) and draggers (right). One pound = 0.454 kg.

Diver Median Pounds per Tray				
Season	Zone 1		Zone 2	
	median	std err	median	std err
2004-05	83.9	3.91	86.3	2.55
2005-06	87.5	3.00	85.7	1.46
2006-07	80.2	2.81	90.0	2.08
2007-08	81.3	3.18	85.0	2.84
2008-09	83.7	2.88	86.1	2.88
2009-10	85.0	3.31	92.3	1.71
2010-11	81.0	3.25	85.7	1.25
2011-12	82.6	2.16	88.6	2.61
2012-13	81.4	1.48	91.9	1.22
2013-14	87.7	2.61	89.9	0.94
2014-15	81.8	1.83	89.6	1.37
2015-16	82.5	1.92	86.8	1.46
2016-17	79.0	2.27	81.0	3.30
2017-18	79.5	2.32	89.6	1.99
2018-19	80.0	2.96	88.6	1.25
2019-20	82.7	4.14	89.7	1.13

Dragger Median Pounds per Tray				
Season	Zone 1		Zone 2	
	median	std err	median	std err
2004-05	*0 – 3 dragger interviews per season in Zone 1 since 2000-01.*		91.5	3.27
2005-06			95.5	2.83
2006-07			99.4	2.77
2007-08			98.5	3.97
2008-09			91.8	2.69
2009-10			99.4	2.73
2010-11			94.0	2.03
2011-12			98.3	1.76
2012-13			95.7	1.72
2013-14			87.2	2.40
2014-15			90.1	1.36
2015-16			89.3	1.74
2016-17			90.8	1.46
2017-18			88.4	1.91
2018-19			92.0	1.65
2019-20			91.3	1.71

Table 10. Median sea urchin fishing vessel length (feet), by management zone and season, for divers (left) and draggers (right), from harvester interviews. One foot = 0.305 meter.

Diver Median Boat Length (ft)				
Season	Zone 1		Zone 2	
	median	std err	median	std err
2009-10	24	1.84	26	1.15
2010-11	20	1.39	31	0.81
2011-12	20	1.63	31	1.08
2012-13	20	1.47	35	0.94
2013-14	20	1.44	28	1.09
2014-15	20	1.59	25	1.37
2015-16	20	1.18	31.5	1.49
2016-17	23	1.67	21.5	0.43
2017-18	20	0.69	24	1.27
2018-19	19	0.87	25	1.40
2019-20	18	1.31	24	1.35

Dragger Median Boat Length (ft)				
Season	Zone 1		Zone 2	
	median	std err	median	std err
2009-10	*0 – 3 dragger interviews per season in Zone 1 since 2000-01.*		39	0.70
2010-11			38	0.70
2011-12			37	0.76
2012-13			38	0.90
2013-14			38	1.06
2014-15			40	1.12
2015-16			38	1.15
2016-17			40	0.61
2017-18			40	1.01
2018-19			38	0.75
2019-20			40	0.84

Table 11. Median sea urchin diver age in years (left), and median years of experience (right), by management zone and season, from harvester interviews.

Diver Median Age (yrs)				
Season	Zone 1		Zone 2	
	median	std err	median	std err
2009-10	50.0	1.14	42.5	0.87
2010-11	53.0	1.81	44.0	0.67
2011-12	52.0	2.39	42.0	0.90
2012-13	53.0	1.38	43.0	0.68
2013-14	52.5	2.06	44.0	0.83
2014-15	55.0	1.57	45.0	1.53
2015-16	55.0	1.16	46.0	1.12
2016-17	59.0	1.65	56.0	2.27
2017-18	57.0	1.47	49.0	1.03
2018-19	58.0	2.12	51.0	1.09
2019-20	57.5	3.06	52.0	0.94

Diver Median Experience (yrs)				
Season	Zone 1		Zone 2	
	median	std err	median	std err
2009-10	17.0	0.99	19.0	4.02
2010-11	22.0	1.70	20.0	0.42
2011-12	25.0	1.77	20.0	0.66
2012-13	24.0	1.41	21.0	0.29
2013-14	21.0	1.05	21.0	0.36
2014-15	26.0	1.41	23.0	1.23
2015-16	25.0	1.15	24.0	0.53
2016-17	25.0	1.50	25.0	2.87
2017-18	25.0	1.63	26.0	0.60
2018-19	28.0	1.82	27.0	0.50
2019-20	29.0	0.90	28.0	0.71

Table 12a. Mean sea urchin diameters (mm) by season, for management Zone 1, from samples of the landed catch. Note that the minimum legal size changed from 2 inches (50.8 mm) to 2$^{1}/_{16}$ inches (52.4 mm) beginning with the 2001–02 season.

Zone 1 Sea Urchin Diameter Data									
Season	No. of samples	Urchins measured	Mean	Std Dev	Min	1st quartile	Median	3rd quartile	Max
1995-96	111	2,220	60.6	7.1	41	55	60	65	101
1996-97	194	3,880	58.8	6.5	39	54	58	63	90
1997-98	199	3,980	61.2	6.5	44	56	60	65	89
1998-99	230	4,600	60.9	6.5	42	56	60	65	91
1999-00	177	3,540	60.1	6.5	40	55	59	64	88
2000-01	134	2,680	58.8	6.1	43	55	58	62	86
2001-02	96	1,920	60.5	6.4	47	55	60	65	88
2002-03	43	860	61.4	5.5	45	58	61	64	86
2003-04	31	620	59.4	4.3	47	56	59	62	86
2004-05	27	540	60.9	5.0	50	57	60	64	82
2005-06	15	300	61.6	5.0	50	58	60	64	78
2006-07	16	320	61.5	5.3	50	57	60	65	77
2007-08	14	280	61.6	6.4	48	57	60	65	81
2008-09	6	120	61.0	4.9	52	58	60	64	74
2009-10	11	220	63.9	7.0	50	59	62	66	85
2010-11	21	420	67.1	6.9	38	61	66	71	87
2011-12	19	380	63.1	5.6	50	59	63	67	80
2012-13	22	440	63.2	6.5	50	59	63	67	93
2013-14	18	360	63.2	6.0	48	59	63	67	80
2014-15	33	660	61.9	5.6	49	58	61	65	83
2015-16	45	900	61.8	5.7	46	58	61	65	80
2016-17	28	560	62.2	5.9	49	58	62	66	83
2017-18	28	557	61.8	5.8	47	58	61	65	86
2018-19	16	320	61.8	5.4	50	58	61	66	79
2019-20	7	140	61.6	5.0	50	59	62	65	79

Table 12b. Mean sea urchin diameters (mm) by season, for management Zone 2, from samples of the landed catch. Note that the minimum legal size changed from 2 inches (50.8 mm) to $2^{1}/_{16}$ inches (52.4 mm) beginning with the 2001–02 season.

Zone 2 Sea Urchin Diameter Data									
Season	No. of samples	Urchins measured	Mean	Std Dev	Min	1st quartile	Median	3rd quartile	Max
1995-96	169	3,365	60.6	8.9	40	54	59	66	95
1996-97	340	6,794	60.9	8.5	39	55	59	66	94
1997-98	265	5,294	62.4	7.9	41	57	61	67	97
1998-99	262	5,239	62.2	8.1	44	56	61	67	110
1999-00	239	4,780	62.0	8.2	44	55	61	68	99
2000-01	162	3,239	58.7	6.7	44	54	57	63	90
2001-02	132	2,640	59.3	6.1	45	55	58	63	85
2002-03	104	2,080	61.0	6.0	37	56	60	65	81
2003-04	67	1,340	60.3	6.3	45	55	60	65	81
2004-05	44	880	61.6	5.4	51	58	61	65	83
2005-06	68	1,360	61.4	5.9	45	56	60	64	86
2006-07	55	1,095	62.4	6.2	47	57	60	65	85
2007-08	49	980	62.5	6.1	47	57	60	63	80
2008-09	43	858	63.1	6.6	47	58	63	67	83
2009-10	95	1,892	61.6	7.0	43	55	60	65	84
2010-11	166	3,320	61.4	6.5	45	56	60	65	86
2011-12	96	1,920	61.0	6.8	47	55	59	64	87
2012-13	117	2,340	61.8	6.8	47	55	60	65	89
2013-14	77	1,540	62.6	6.2	45	58	61	66	89
2014-15	67	1,340	61.5	6.0	49	57	61	65	88
2015-16	59	1,180	62.5	6.0	49	58	62	67	89
2016-17	81	1,615	61.5	5.7	19	57	61	65	89
2017-18	72	1,440	61.7	5.7	50	57	61	65	85
2018-19	82	1,638	61.7	5.6	48	58	61	65	82
2019-20	80	1,595	61.4	5.6	46	57	60	65	86

Table 13. Spring sea urchin survey — List of regions with estimated area (m^2) of rock and gravel substrates in depths 0–15 m.

Region	Zone	Area (m^2)	Region name
1	1	164,511,949	Kittery to Phippsburg
2	1	73,524,490	Phippsburg-Boothbay-Bristol-Bremen
3	1	128,001,597	Friendship-Port Clyde-Tenants Hbr-Rockland
4	2	273,888,174	Isleboro-Vinalhaven-Stonington
5	2	148,299,821	Bluehill-Swans Is-Mount Desert Is
6	2	61,985,887	Frenchman Bay-Winter Hbr-Corea-Steuben
7	2	179,631,845	Milbridge-Addison-Jonesport
8	2	97,938,299	Roque Is-Machiasport-Cutler-W. Quoddy Head
9	2	52,045,499	Cobscook Bay-Passamaquoddy Bay

Table 14. Spring sea urchin survey — Number of survey sites and quadrats evaluated, urchins counted and measured, Jonah crabs counted and measured, rock crabs counted and measured, lobsters counted, starfish counted and measured, and sea cucumbers counted, by survey year.

Year	Number of Sites	Number of Quadrats	Urchins counted	Urchins measured	Jonah crabs counted	Jonah crabs measured	Rock crabs counted	Rock crabs measured	Lobsters counted	Sea stars counted	Sea stars measured	Cucumbers counted
2001	292	14,072	123,945	14,623	-	-	-	-	-	-	-	-
2002	226	8,510	81,702	10,140	534	467	708	674	-	-	-	-
2003	225	8,793	54,728	8,850	974	863	495	454	313	16,900	881	-
2004	195	8,310	42,274	7,003	1,000	982	286	283	246	7,027	653	-
2005	144	8,080	41,973	6,293	1,093	1,100	284	284	319	7,162	277	-
2006	144	7,570	35,827	4,305	713	696	280	292	292	3,684	239	-
2007	144	7,640	29,056	3,516	424	416	103	91	184	3,588	157	-
2008	144	7,799	41,089	4,867	562	541	189	203	382	3,206	149	-
2009	144	7,711	41,472	5,411	275	271	112	115	435	3,273	234	-
2010	144	7,348	43,370	4,921	212	207	93	96	372	1,828	122	813
2011	144	7,460	25,205	3,095	129	126	83	85	399	1,290	95	923
2012	150	7,380	27,123	3,700	125	112	103	99	342	499	41	632
2013	155	7,814	29,524	3,533	109	104	85	87	235	602	71	589
2014	144	7,007	33,000	3,225	174	174	135	133	267	1,021	83	328
2015	112	5,468	25,607	2,554	131	130	89	89	125	852	63	454
2016	112	5,176	23,246	2,272	227	227	98	95	189	583	53	544
2017	112	5,190	14,294	1,609	202	195	67	63	137	260	35	376
2018	78	3,270	9,162	951	171	166	21	21	75	66	4	110
2019	73	2,590	6,459	779	103	95	??	??	17	34	0	53

Table 15a–b. Spring sea urchin survey — Stratified mean sea urchin biomass (grams per square meter) above and abundance (number per square meter) below, with standard errors (SE), by year, region (1–9), and zone, depths 0–15 m. Note that if a region was not sampled (blank areas in tables), the zone mean and SE for that year were calculated using data for the most recent year that region was sampled.

Sea Urchin Biomass

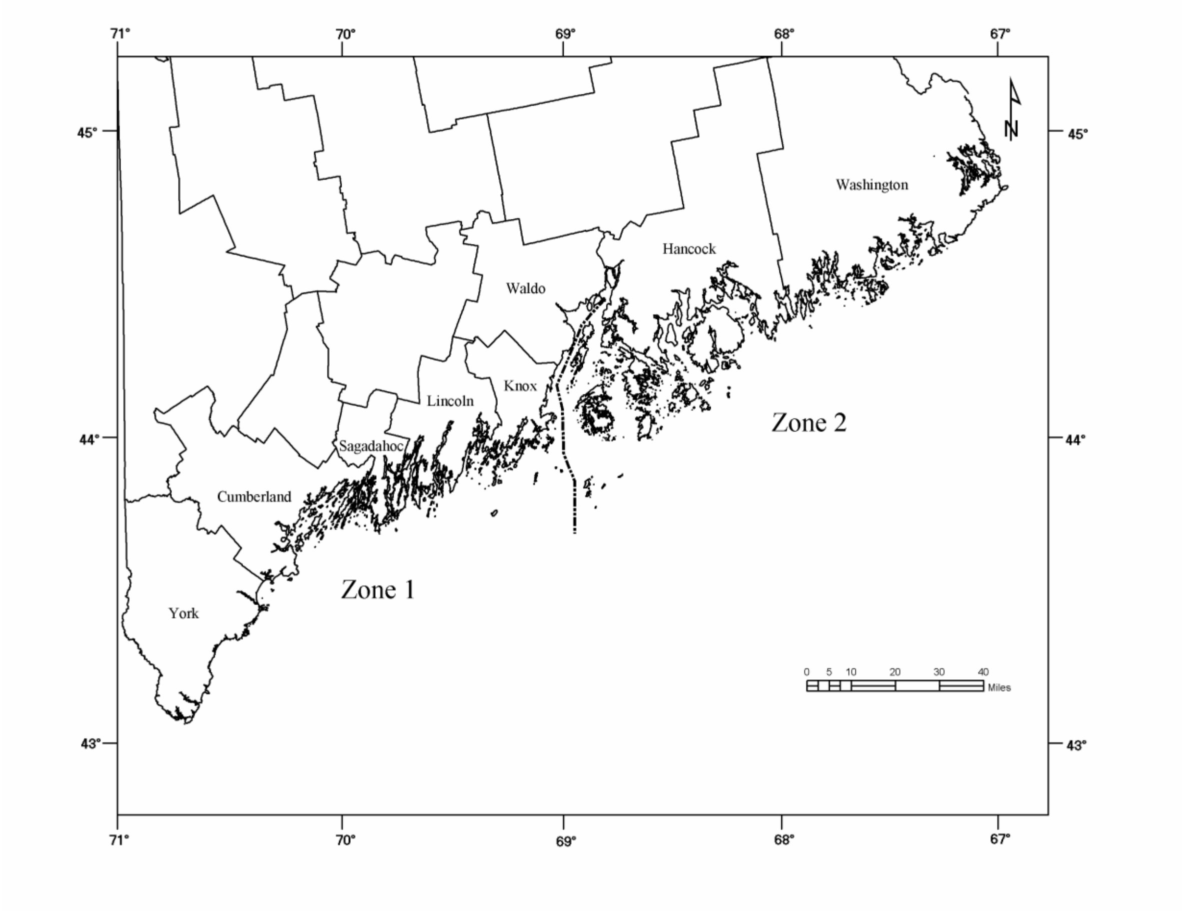
	Zone 1								Zone 2													
Region	**1**		**2**		**3**		**1-3 (Zone 1)**		**4**		**5**		**6**		**7**		**8**		**9**		**4-9 (Zone 2)**	
Year	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**
2001	5.3	2.6	143.1	49.4	206.6	64.5	103.4	24.7	197.4	72.1	100.7	21.6	417.5	80.7	408.3	99.2	585.6	76.6	587.4	81.6	314.8	35.1
2002	6.3	4.4	237.4	71.7	158.4	34.9	105.9	19.0	139.8	51.5	84.0	32.8	456.7	64.4	262.2	68.5	568.4	89.2	565.7	104.2	259.6	27.4
2003	4.5	2.1	60.1	29.9	155.6	40.4	68.5	15.4	89.6	38.5	123.7	45.0	376.2	87.4	225.3	44.2	381.4	58.1	699.7	132.4	221.7	22.2
2004	5.6	4.2	32.2	13.0	24.0	8.0	17.4	4.3	55.7	25.2	63.4	27.3	225.7	71.0	125.1	28.2	336.8	57.0	617.0	108.2	155.1	16.1
2005	1.7	1.1	12.0	4.0	62.9	24.5	25.2	8.6	12.2	8.2	48.4	19.1	227.5	70.9	146.4	41.3	473.6	85.1	435.4	57.6	147.4	15.8
2006	10.9	4.0	24.1	13.0	51.2	28.0	27.6	10.3	90.2	45.5	41.4	19.6	86.9	33.3	76.1	28.9	461.7	83.6	509.6	83.9	149.4	20.6
2007	6.2	2.5	18.5	10.1	14.6	8.1	11.6	3.7	145.9	50.7	68.8	39.4	50.9	20.5	22.4	7.0	323.4	64.8	336.3	59.2	130.9	20.5
2008	5.2	3.2	38.5	25.8	20.6	14.7	17.3	7.4	130.7	59.6	31.2	12.1	164.6	84.8	106.3	30.0	428.1	82.9	376.9	52.9	161.3	24.6
2009	2.2	0.8	14.8	7.1	18.7	5.5	10.5	2.4	87.6	28.3	58.8	17.4	144.5	49.6	265.3	62.1	527.2	124.9	358.8	50.9	196.2	23.2
2010	5.4	1.7	9.9	3.1	81.5	30.9	32.9	10.8	200.0	72.0	77.4	19.2	270.5	114.7	83.8	38.4	329.1	107.4	388.4	45.8	185.0	30.4
2011	0.9	0.3	24.1	10.1	46.7	21.4	21.6	7.8	170.1	56.3	75.3	26.3	86.1	29.6	49.6	26.8	221.7	71.1	306.7	43.3	134.8	22.4
2012			1.5	1.1	44.8	16.3	16.4	5.7	145.3	52.3	47.7	11.4	162.8	47.2	25.5	8.6	213.1	64.0	340.2	49.0	123.0	20.0
2013			2.9	1.3	26.1	11.9	10.1	4.2	55.2	18.2	45.4	18.1	86.9	46.1	75.0	29.8	276.6	71.0	338.3	36.6	104.9	13.5
2014	1.6	1.0	4.9	2.7	76.5	30.5	28.5	10.7	187.4	65.7	35.8	12.9	19.3	6.8	25.0	12.3	337.7	138.3	663.0	220.8	159.6	31.3
2015					134.5	62.4	48.8	21.8	187.7	96.7	30.3	15.4	198.1	140.3	17.0	5.1	497.0	171.2	378.6	40.4	171.6	40.2
2016					160.7	81.6	57.9	28.5	197.6	81.3	55.7	27.2	153.7	68.3	24.4	10.5	204.8	74.6	384.9	56.1	143.0	30.0
2017					11.4	5.0	5.7	1.9	96.8	48.5	52.1	31.4	52.3	25.9	38.1	17.8	257.0	101.3	318.6	45.1	105.8	21.8
2018					40.1	26.4	15.7	9.3			30.4	14.1	20.1	10.5			110.9	62.7	353.7	81.3	84.0	19.3
2019					17.1	9.4	7.7	3.3	36.1	23.4			47.5	40.9			16.7	14.2	249.5	44.2	47.6	10.2

Sea Urchin Abundance

	Zone 1								Zone 2													
Region	**1**		**2**		**3**		**1-3 (Zone 1)**		**4**		**5**		**6**		**7**		**8**		**9**		**4-9 (Zone 2)**	
Year	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**
2001	0.19	0.10	2.86	1.07	3.79	1.35	1.98	0.52	6.08	1.98	4.70	1.29	10.64	2.08	7.20	1.81	12.23	1.83	38.72	6.79	9.25	0.96
2002	0.85	0.78	4.91	1.43	5.12	1.29	3.16	0.64	2.38	0.81	3.03	1.14	12.08	1.87	5.41	1.50	12.35	2.11	46.10	8.38	7.90	0.77
2003	0.36	0.19	1.10	0.43	3.02	0.83	1.44	0.31	2.04	0.79	2.74	0.89	8.38	2.02	3.79	0.80	6.63	1.11	37.76	8.21	5.87	0.67
2004	0.14	0.05	0.73	0.26	0.51	0.17	0.39	0.08	0.99	0.39	1.72	0.76	4.35	1.25	1.89	0.46	5.33	1.02	36.47	7.68	4.37	0.56
2005	0.16	0.08	0.37	0.08	1.54	0.52	0.68	0.19	0.43	0.21	1.16	0.38	6.24	1.75	1.94	0.67	6.87	1.38	28.42	3.74	3.90	0.37
2006	0.55	0.13	0.69	0.27	1.00	0.43	0.73	0.17	2.26	1.12	0.83	0.35	2.08	0.70	0.92	0.37	6.43	1.42	28.13	4.15	3.85	0.51
2007	0.91	0.49	0.34	0.12	0.52	0.18	0.66	0.23	2.86	0.89	1.39	0.73	1.35	0.48	0.21	0.05	5.11	1.28	24.30	4.97	3.54	0.48
2008	0.84	0.45	2.53	1.35	1.14	0.30	1.28	0.35	6.97	2.91	1.43	0.62	4.13	1.57	1.02	0.29	6.32	1.57	29.87	5.90	5.82	1.08
2009	0.13	0.04	0.34	0.10	1.39	0.38	0.61	0.14	3.96	1.07	4.76	1.55	4.31	1.33	4.73	1.70	8.67	2.42	24.32	4.37	6.17	0.72
2010	0.64	0.20	0.32	0.07	3.36	1.10	1.53	0.39	8.49	3.48	3.98	0.63	5.20	2.01	1.35	0.57	5.42	2.08	25.62	3.41	6.57	1.24
2011	0.13	0.04	0.82	0.31	1.28	0.56	0.67	0.21	4.85	1.30	2.95	0.88	1.93	0.57	0.47	0.27	4.09	1.84	16.80	3.07	3.99	0.56
2012			0.07	0.03	0.84	0.18	0.37	0.06	3.88	1.34	2.24	0.44	4.58	1.57	0.42	0.12	5.41	2.10	16.09	2.89	3.84	0.57
2013			0.17	0.03	1.01	0.49	0.45	0.17	1.55	0.33	1.28	0.41	1.72	0.64	0.85	0.33	5.03	1.33	21.84	3.51	3.08	0.32
2014	0.13	0.05	0.38	0.14	2.53	0.87	1.02	0.31	6.31	2.11	0.92	0.28	0.69	0.15	0.32	0.11	6.21	2.56	29.31	7.54	5.04	0.91
2015					3.97	1.50	1.45	0.53	3.47	1.54	0.49	0.21	3.51	2.11	0.46	0.15	8.81	3.60	15.15	3.23	3.65	0.73
2016					4.87	2.28	1.84	0.05	3.79	1.50	1.11	0.50	4.03	1.56	0.47	0.18	3.28	1.29	16.34	4.38	3.33	0.62
2017					0.28	0.07	0.23	0.05	2.50	1.15	1.20	0.64	0.92	0.49	0.33	0.14	4.50	1.81	11.73	2.17	2.49	0.48
2018					0.59	0.31	0.34	0.11			0.58	0.24	0.32	0.15			1.81	1.05	12.22	3.23	2.04	0.46
2019					0.26	0.13	0.22	0.06	1.18	0.28			0.70	0.61			0.35	0.32	9.01	1.98	1.25	0.28

Table 16. 2014 spring sea urchin dive survey — mean sea urchin biomass (grams per square meter) by depth stratum and region. Heavy shading indicates the depth of highest biomass for each region; no shading indicates the depth of lowest biomass. Regions 1–3 are in Zone 1 (red shades, left); Regions 4–9 are in Zone 2 (blue shades, right). 2014 is the most recent year in which all regions 1–9 were surveyed.

Depth stratum	Region								
	1	2	3	4	5	6	7	8	9
1 (0–5 m)	0.7	3.3	152.7	306.6	76.5	22.0	15.4	359.3	813.9
2 (5–10 m)	3.6	9.0	30.8	59.9	18.5	9.6	64.8	291.1	464.0
3 (10–15 m)	0.4	2.2	13.1	0.4	8.3	20.9	11.5	341.8	274.7



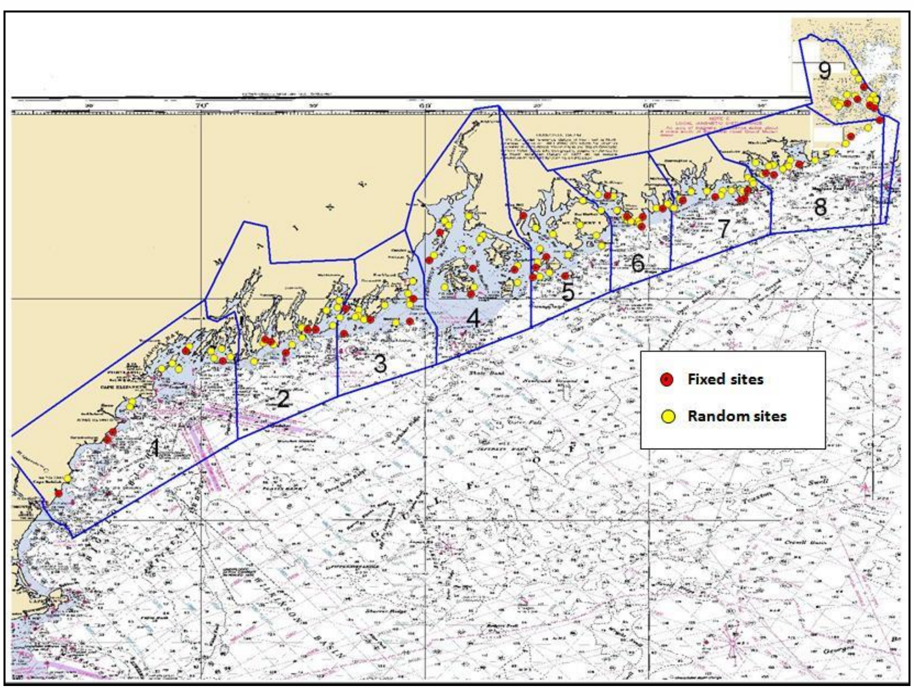


Figure 1a–b. Maine coastal counties and the two sea urchin management zones (above), and the nine survey regions with 2014 survey sites (below).

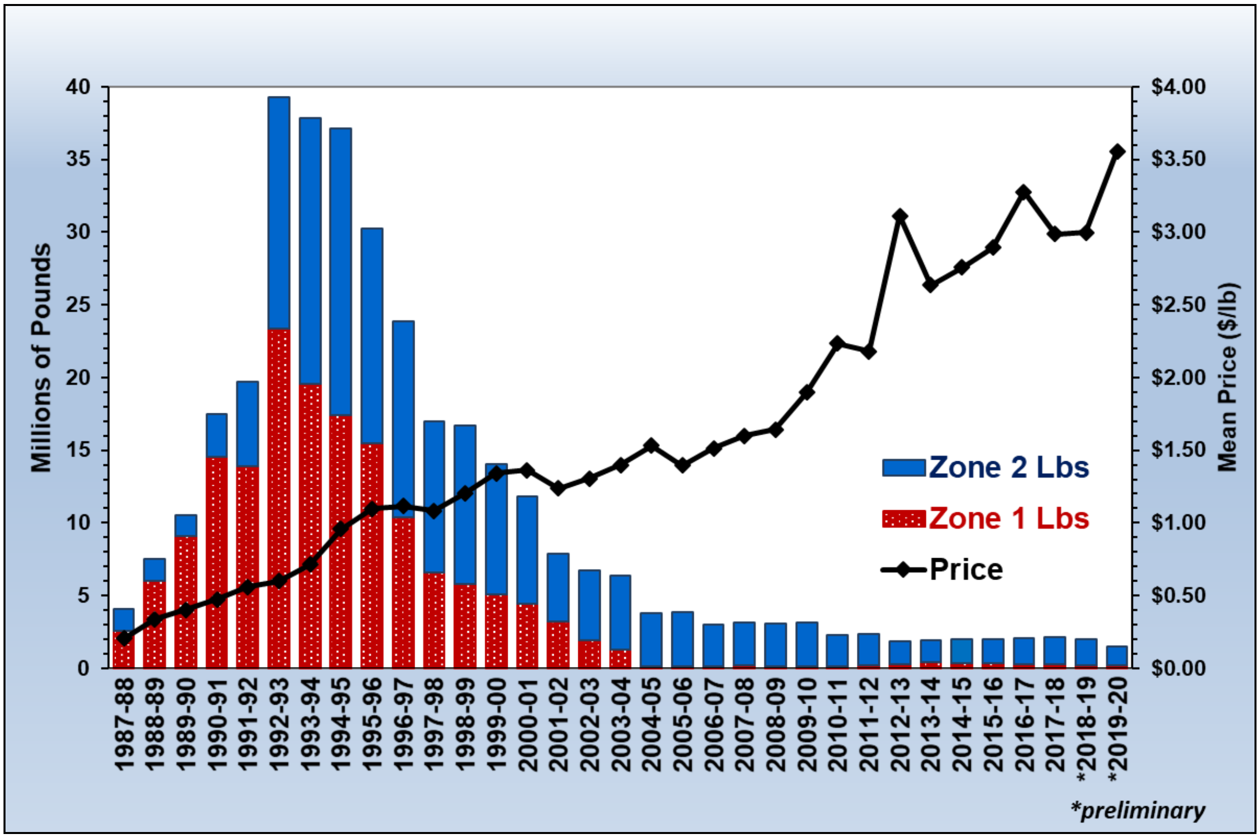
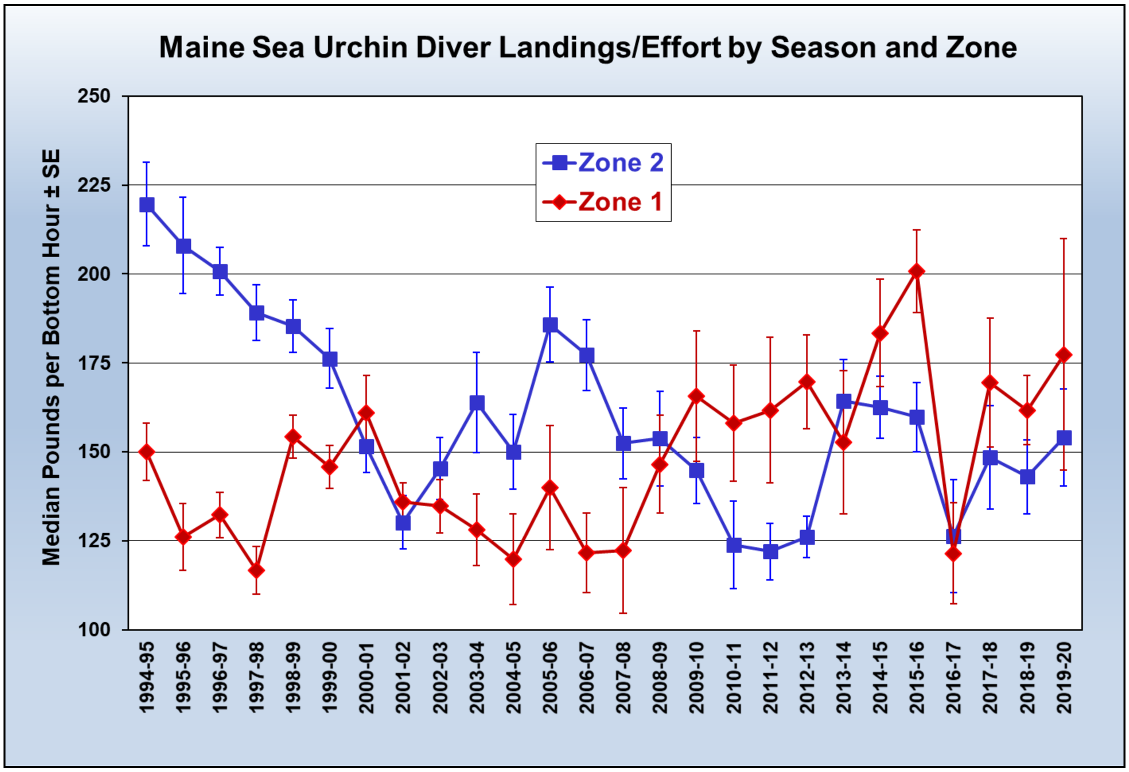


Figure 2. Maine sea urchin landings (millions of pounds) by fishing season and zone, from dealer reports. One million pounds = 454 mt.
*** 2018–19 and 2019–20 data are preliminary.**



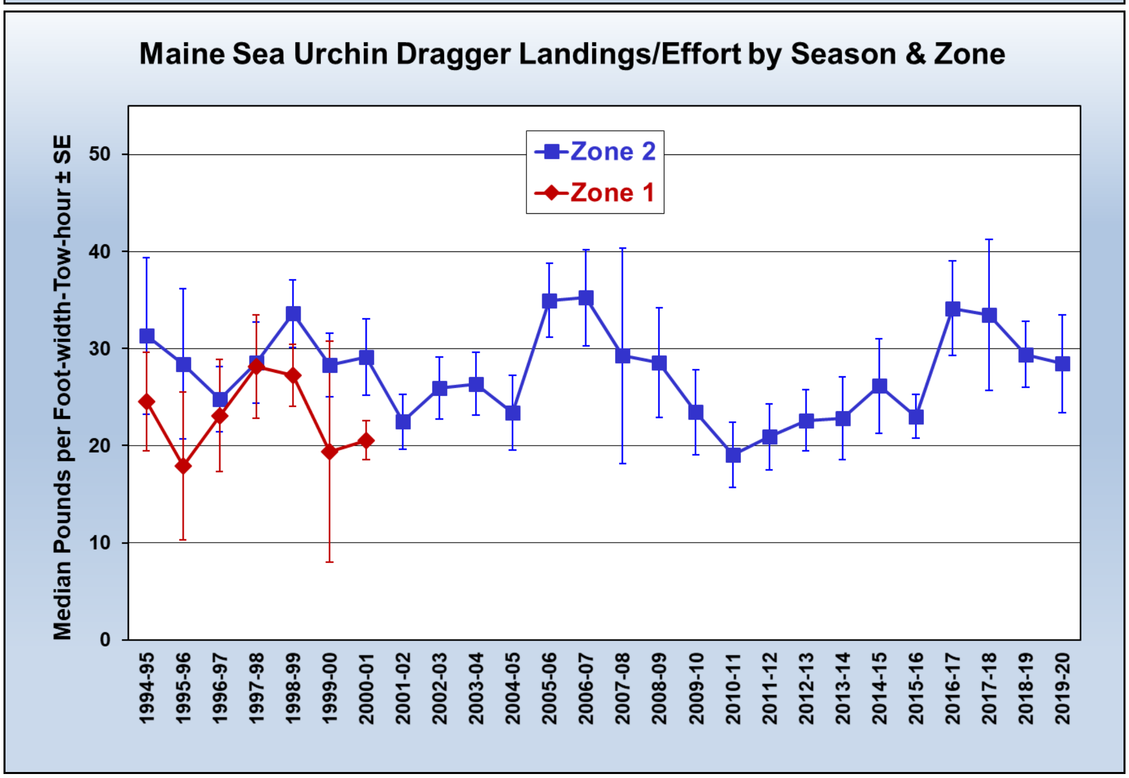


Figure 3a–b. Sea urchin diver (above) and dragger (below) median landings per effort with standard errors, by season and zone, from port interviews. Zone 1 dragger interview data for 2001–02 through 2019–20 are not displayed because there were fewer than four interviews each season. 100 pounds = 45.4 kg.

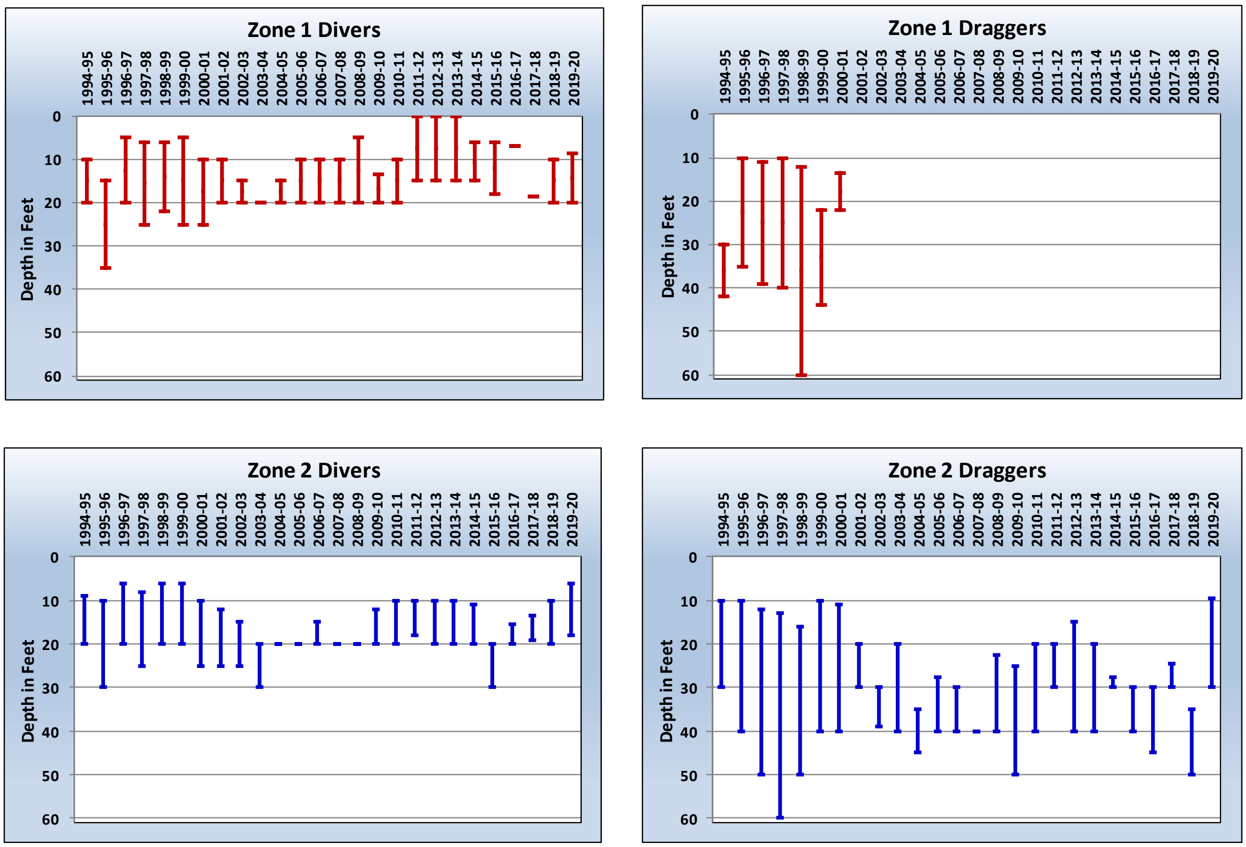


Figure 4. Sea urchin harvester fishing depths from port interviews by season, gear, and zone. Bars indicate the median minimum depth fished (ft) response, and the median maximum depth fished (ft) response. Dragger interview data for Zone 1 for 2001–02 through 2019–20 are not displayed because there were fewer than four interviews each season. 10 feet = 3.0 meters.

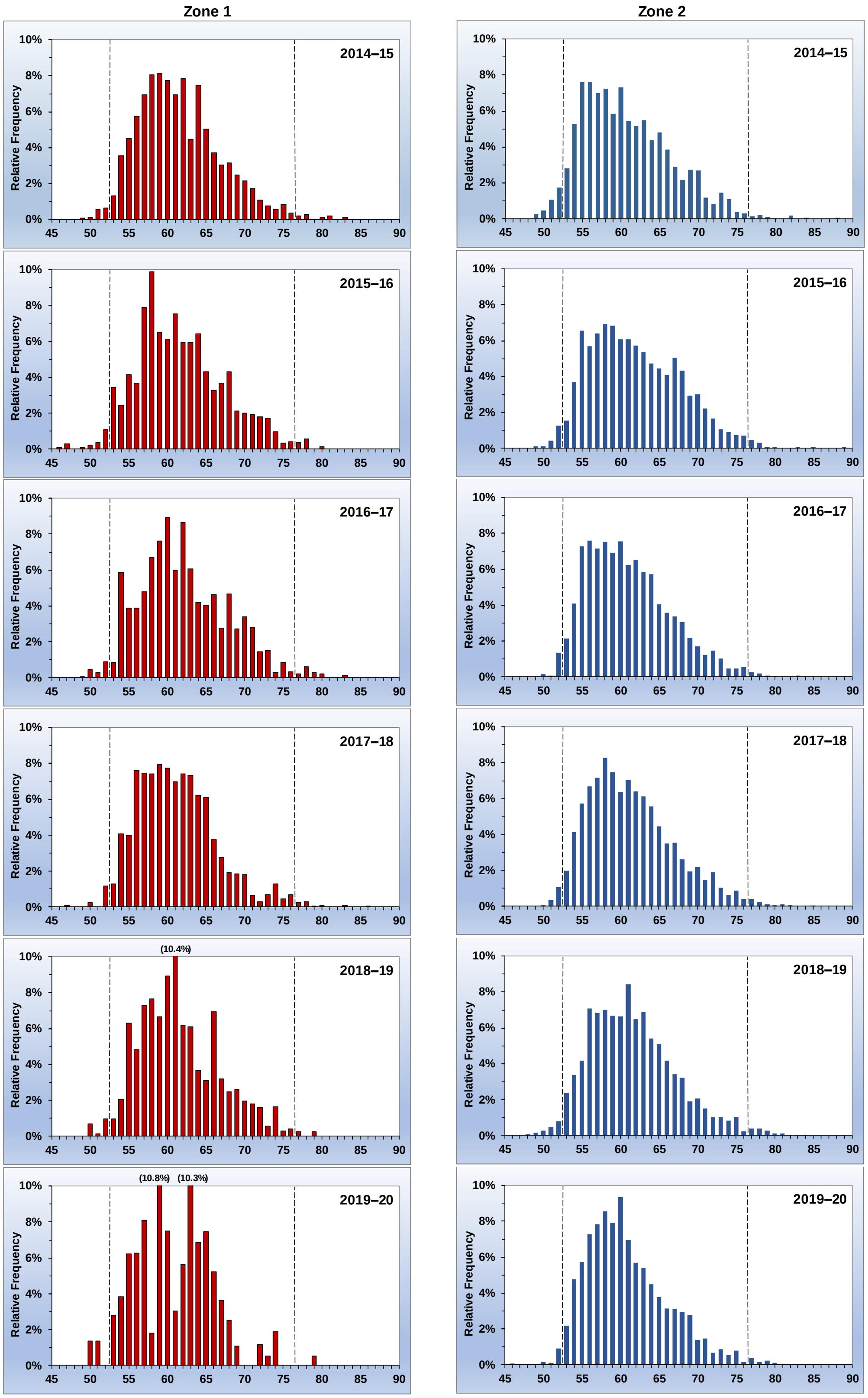
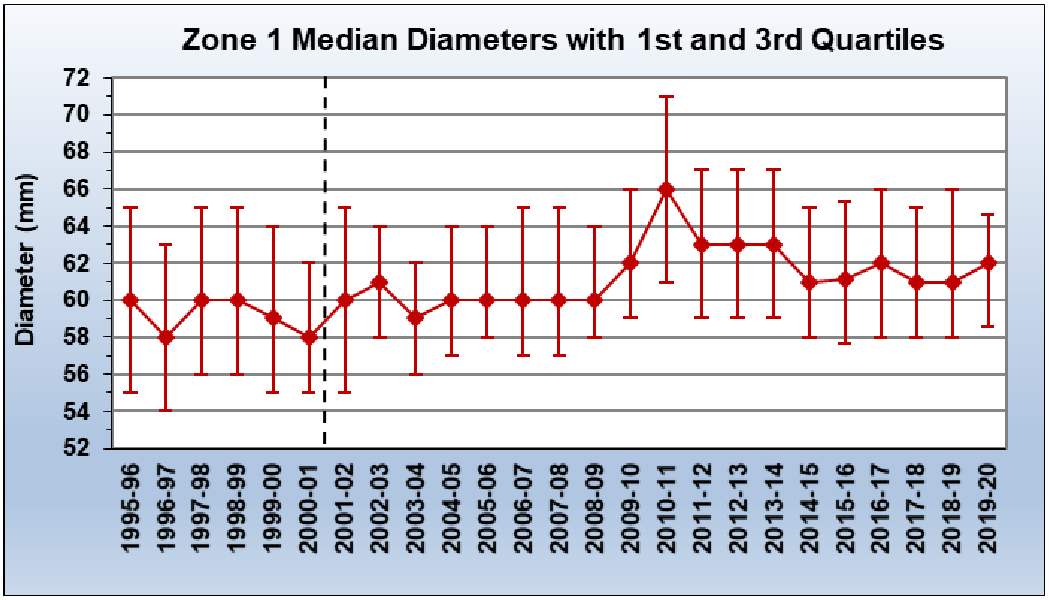


Figure 5. Relative expanded size (test diameter) frequency for Zone 1 (left) and Zone 2 (right) from sea urchin port samples for 2014–15 to 2019–20. Dotted lines indicate the minimum (52.4 mm) and maximum (76.2 mm) legal size limits.



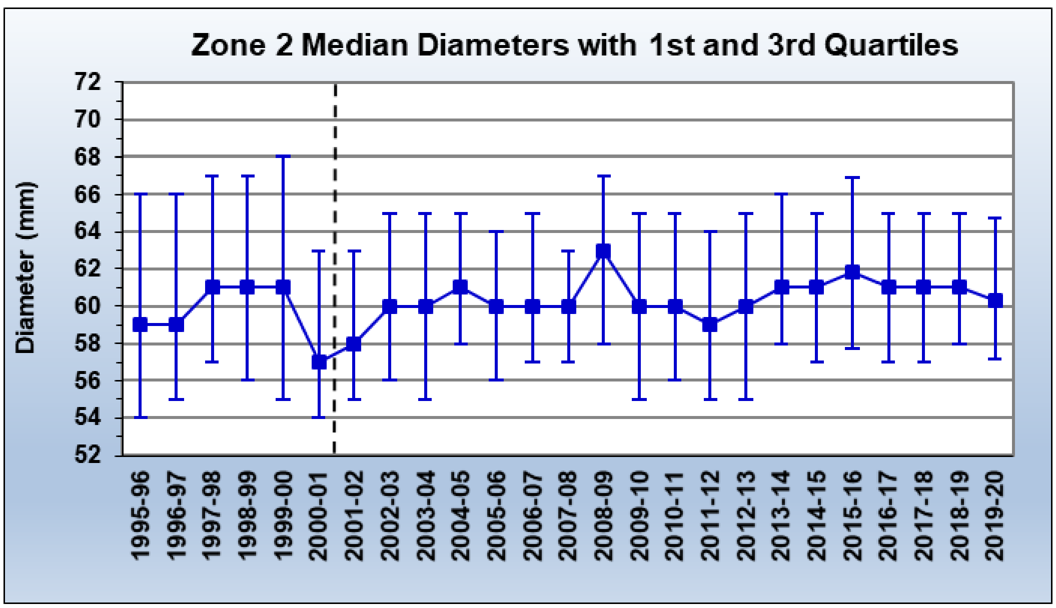
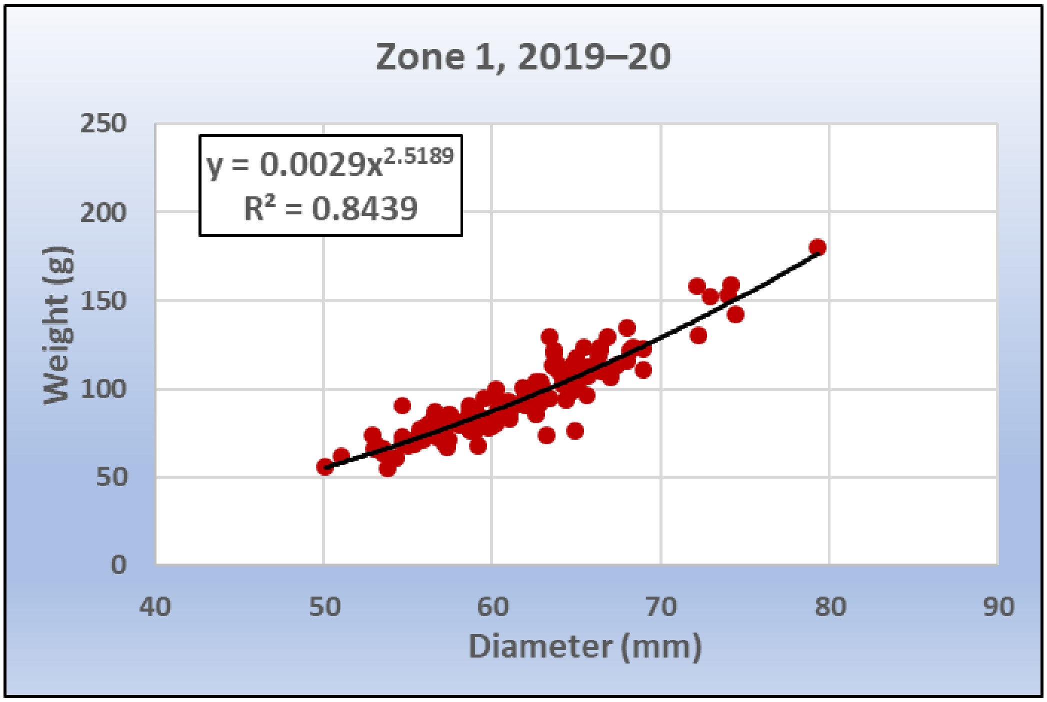


Figure 6. Median sea urchin diameters from port samples, for Zone 1 (above) and Zone 2 (below), by season, with 1st and 3rd quartiles (brackets). Minimum legal size was 2 inches (50.8 mm) until 2001–02 (dotted line), when it increased to $2^{1}/_{16}$ inches (52.4 mm).



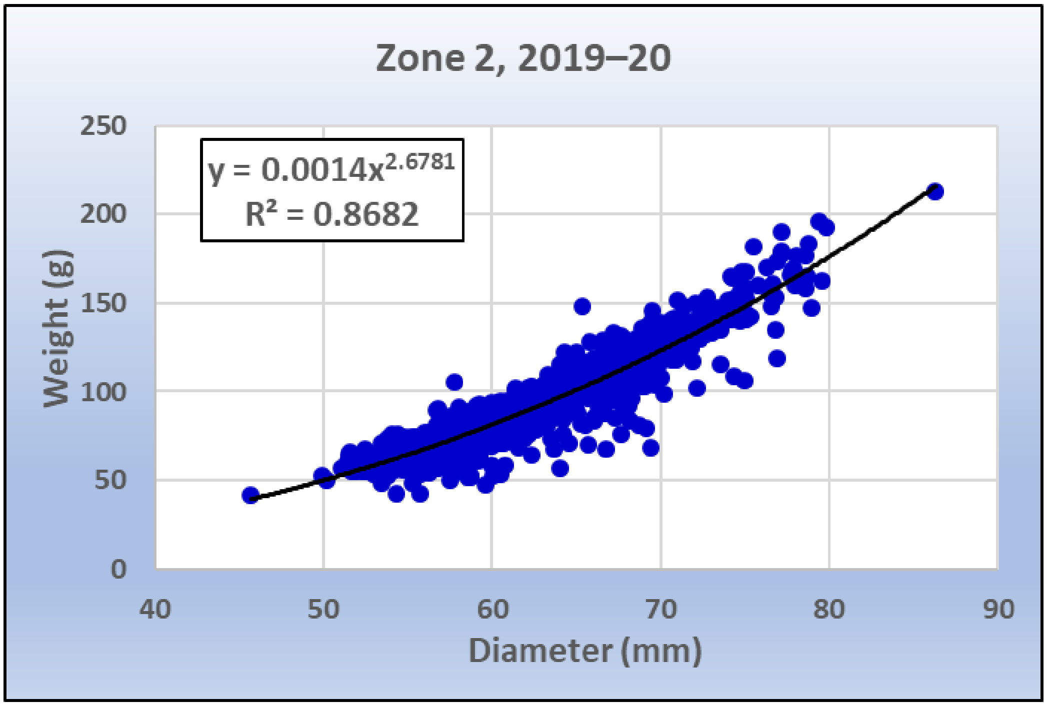
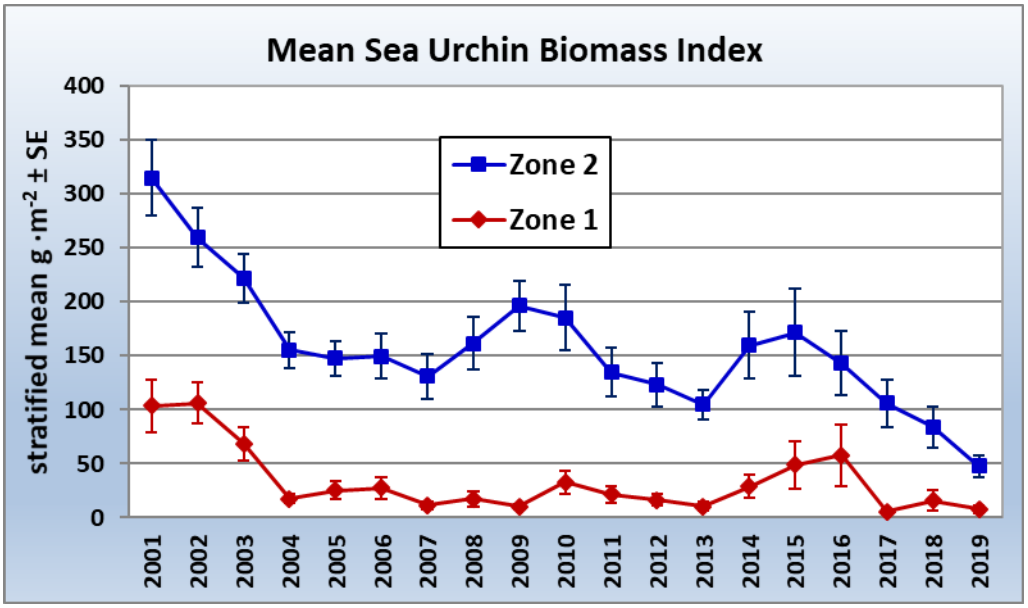


Figure 7a–b. Sea urchin whole wet weights (g) vs. diameter (mm) from 2019–20 season port samples for Zone 1 (above) and Zone 2 (below). Parameters were estimated for each zone for the relationship: Weight = *a*·Diameter^{b} where x=diameter and y=weight.



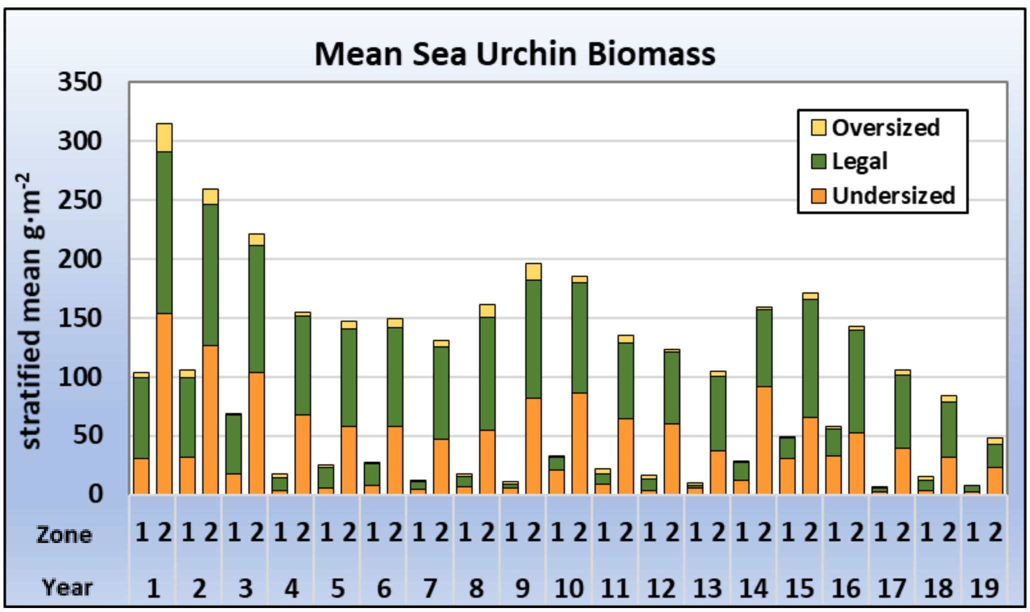


Figure 8a–b. Mean sea urchin biomass (grams per square meter) from the spring dive survey by zone and year with standard errors above, and by zone, year, and size category (sub-legal or undersized, legal, and oversized) below.

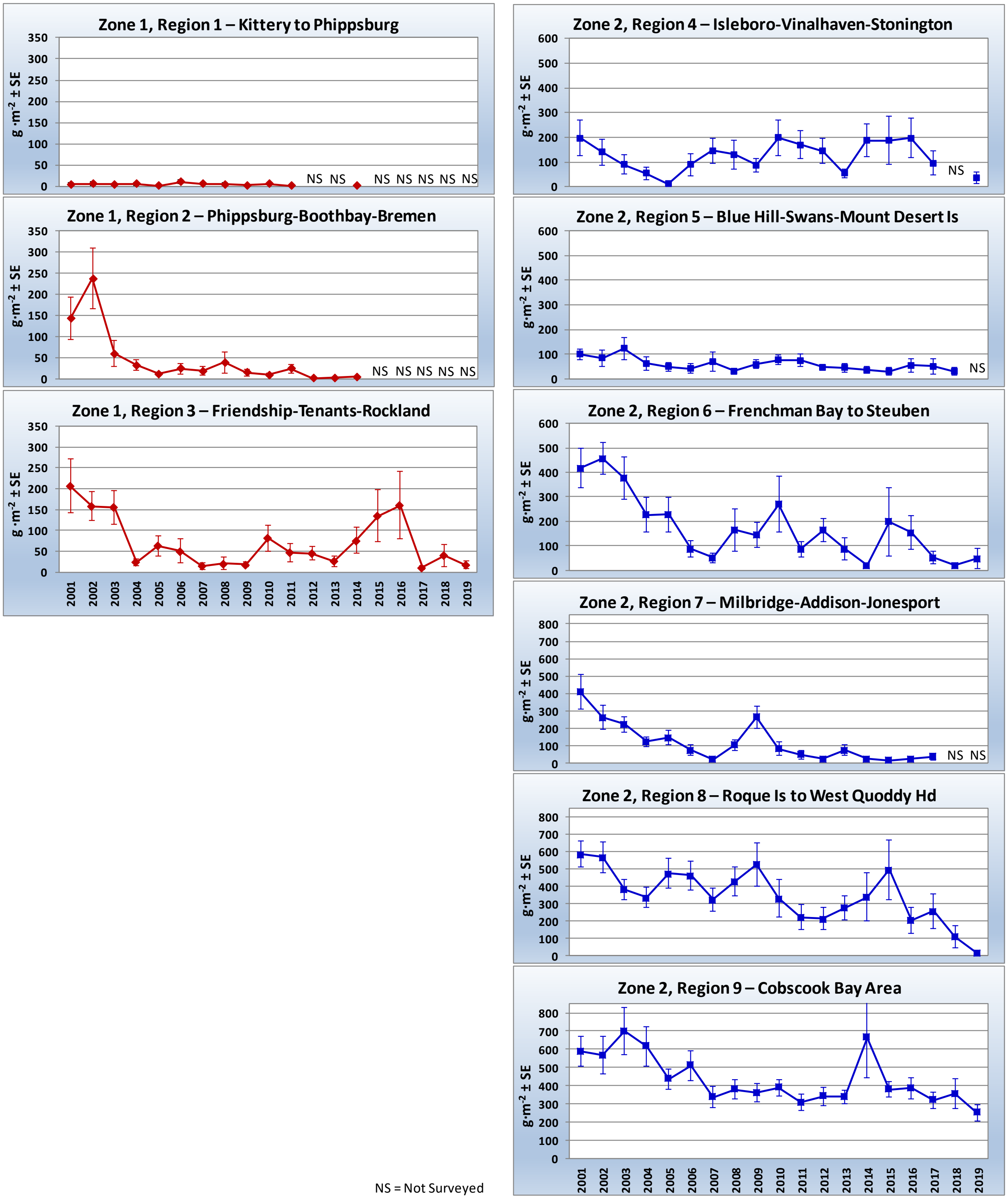
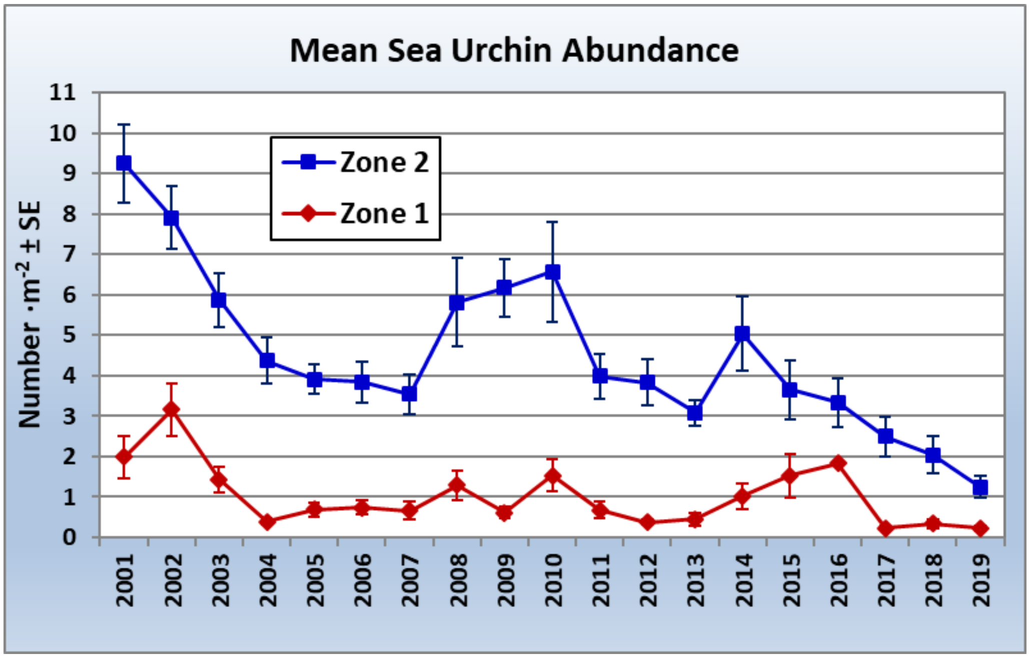


Figure 9. **Mean sea urchin biomass (grams per square meter) from the spring dive survey by region, zone, and year with standard errors. Regions 1–3 are in Zone 1 (left) and regions 4–9 are in Zone 2 (right).**
Note the different Y-axis scales for the Zones.



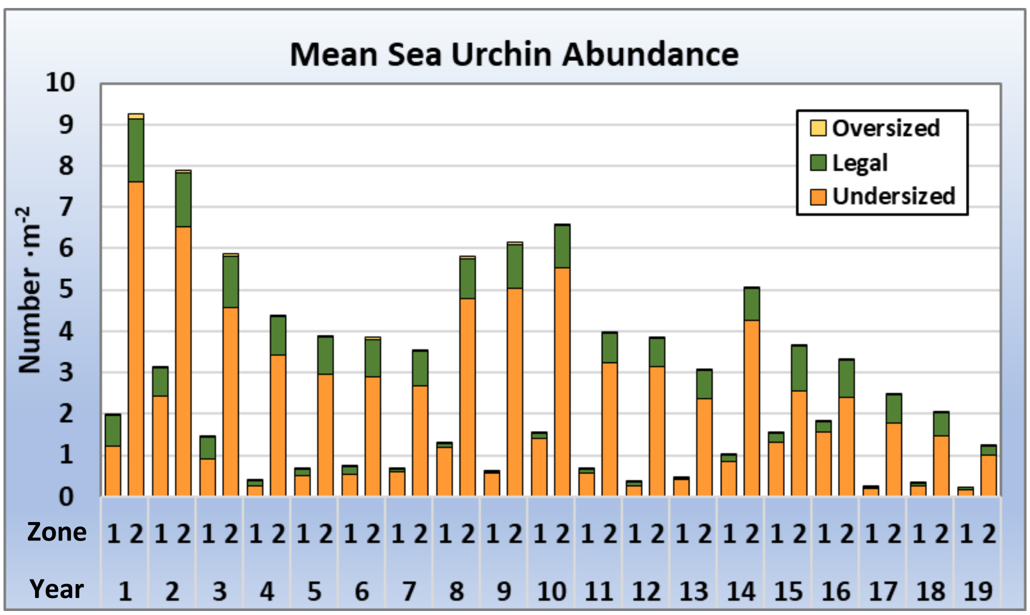


Figure 10a–b. Stratified mean sea urchin abundance (number per square meter) from the spring dive survey by zone and year with standard errors above, and by zone, year, and size category (sub-legal or undersized, legal, and oversized) below.

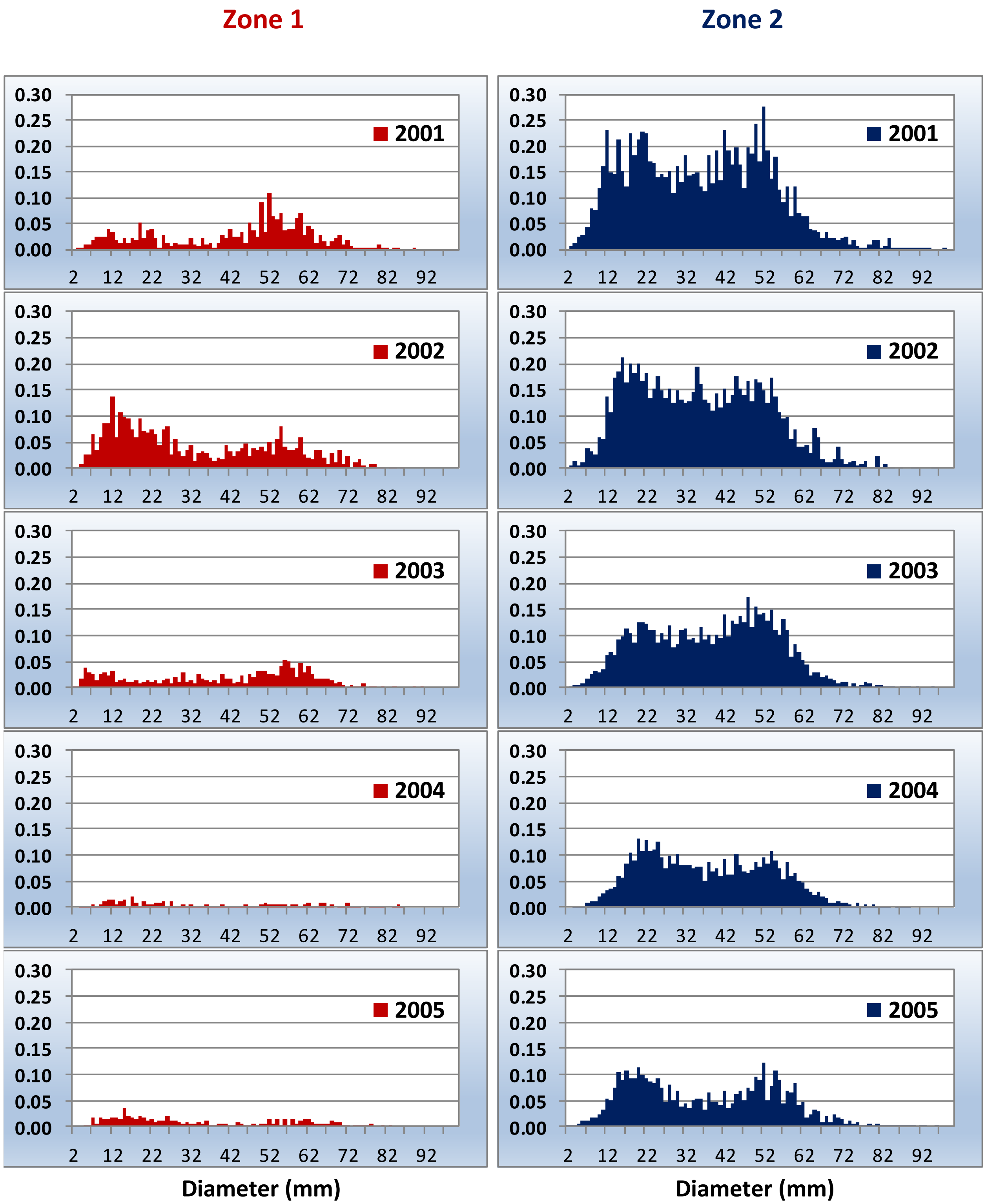


Figure 11. Stratified mean sea urchin abundance (number per square meter) from the spring survey, by zone (Zone 1 left, Zone 2 right), year, and diameter in mm.

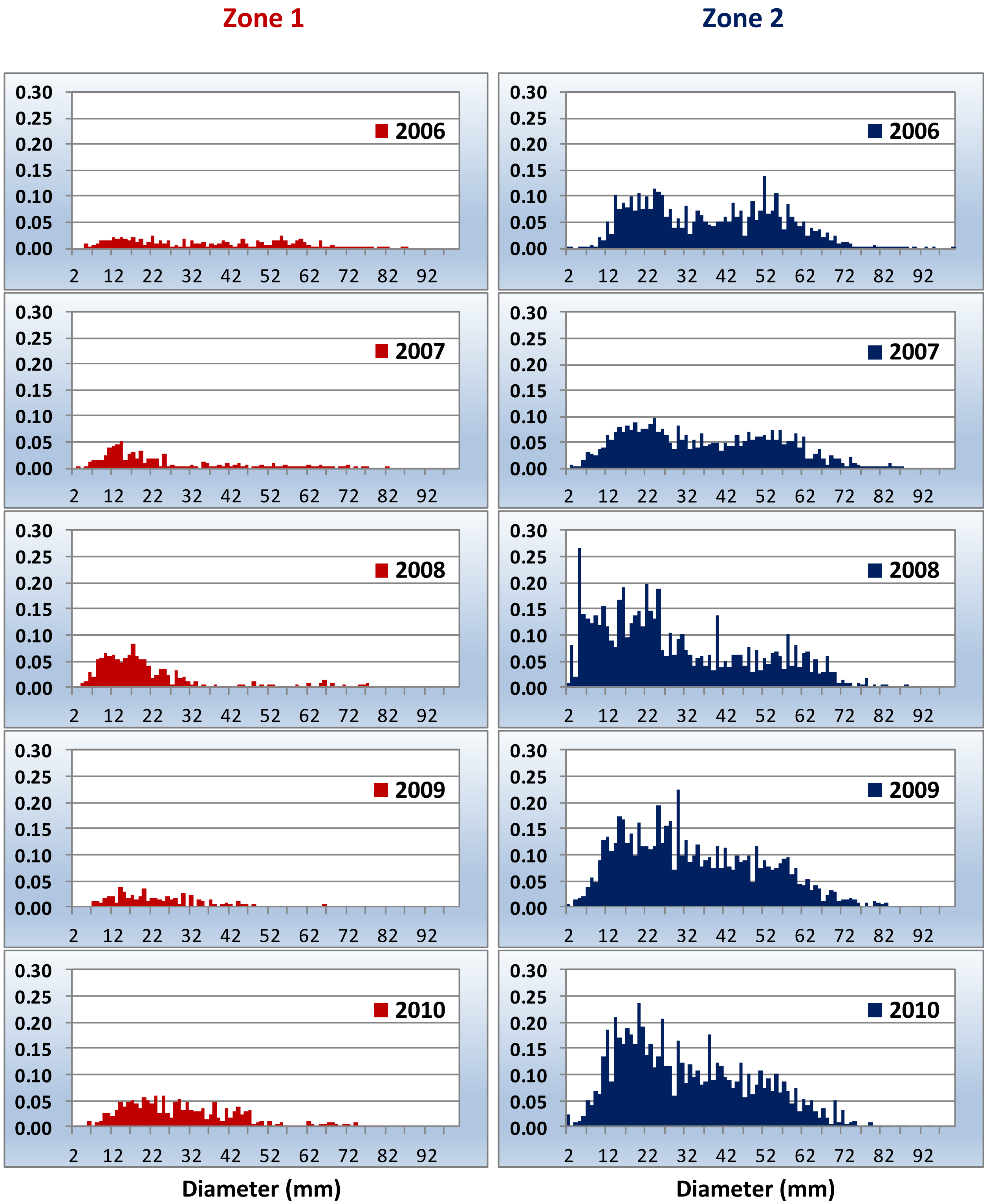


Figure 11. continued.

Zone 1

Zone 2

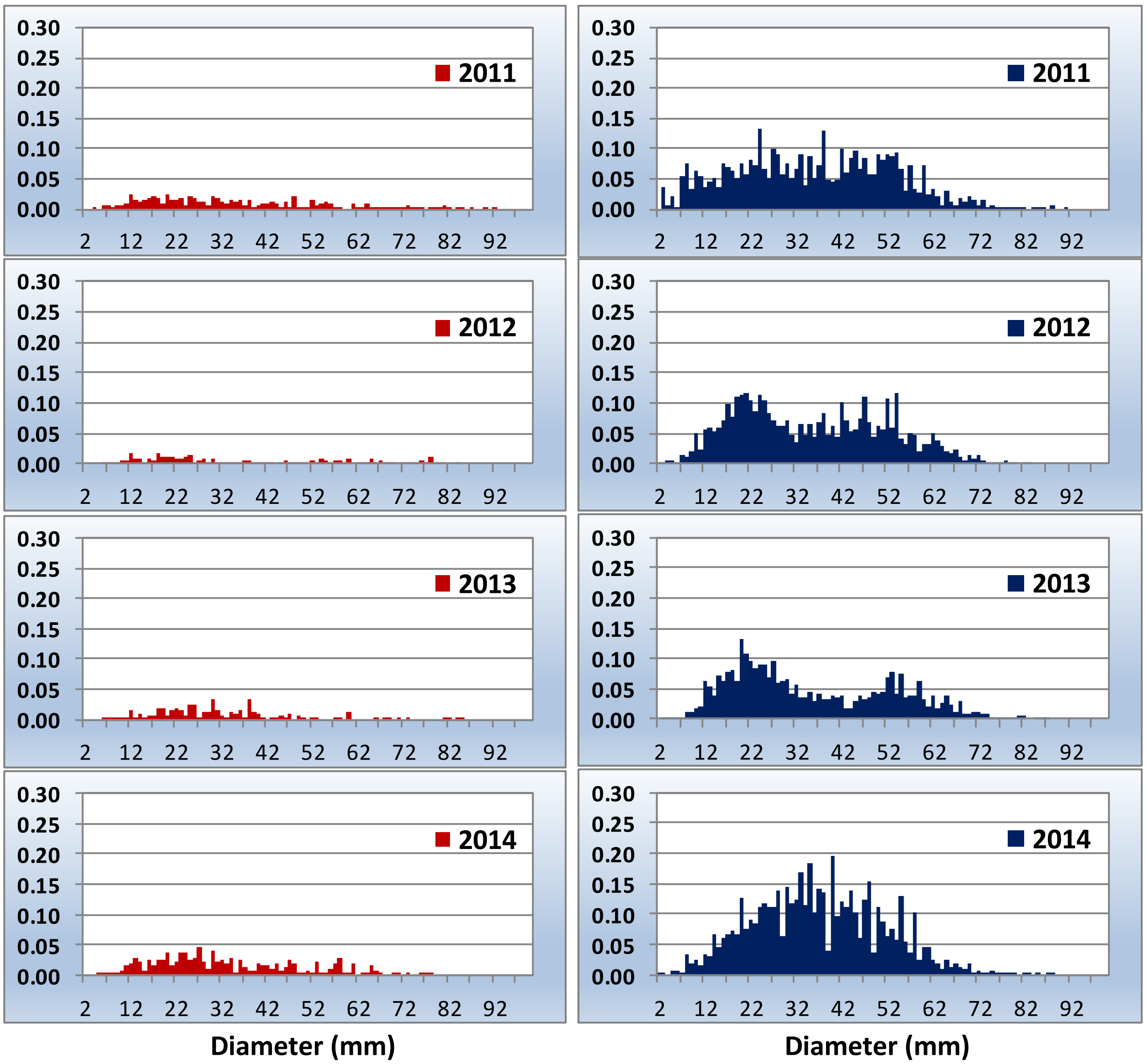


Figure 11. continued.

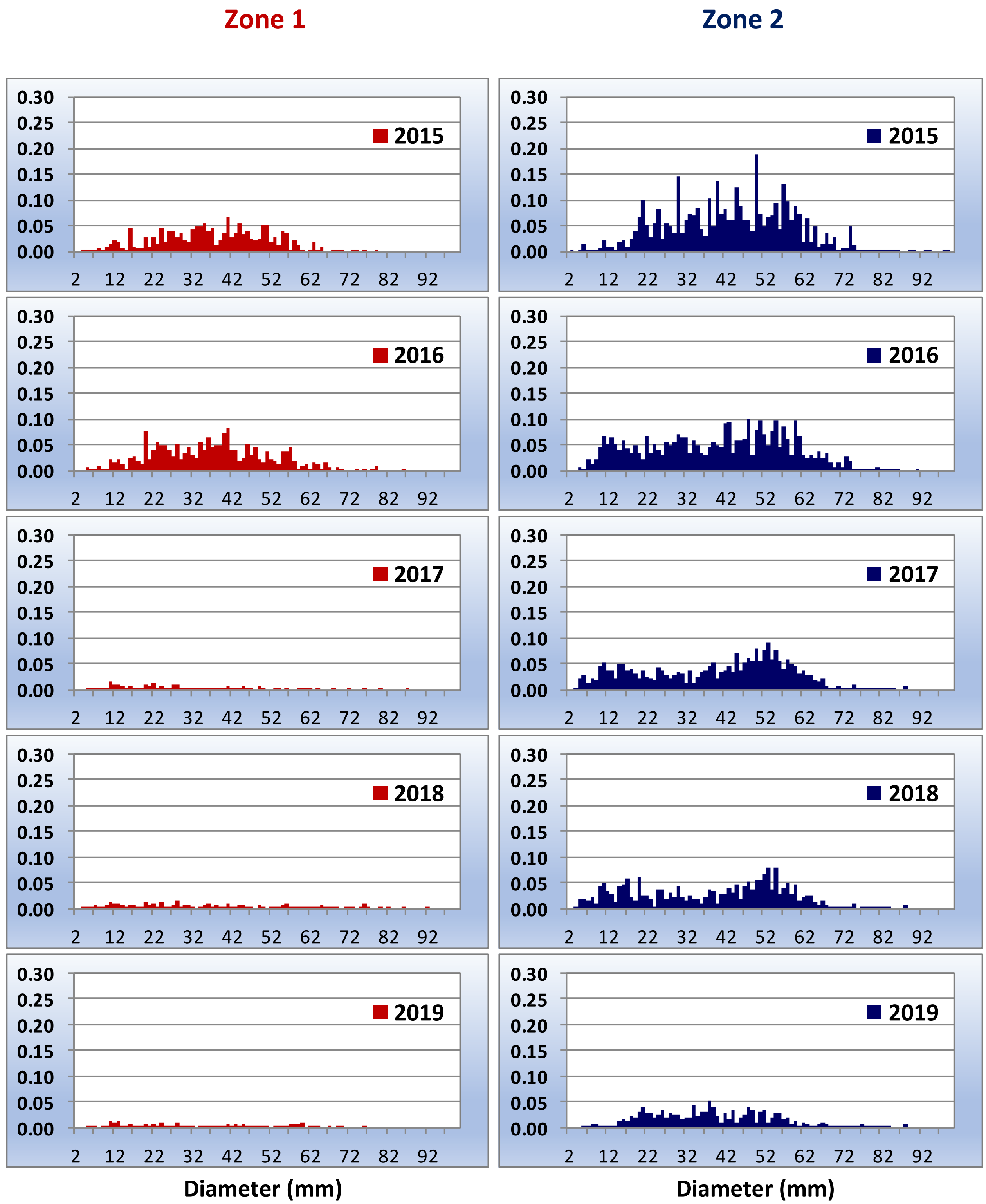
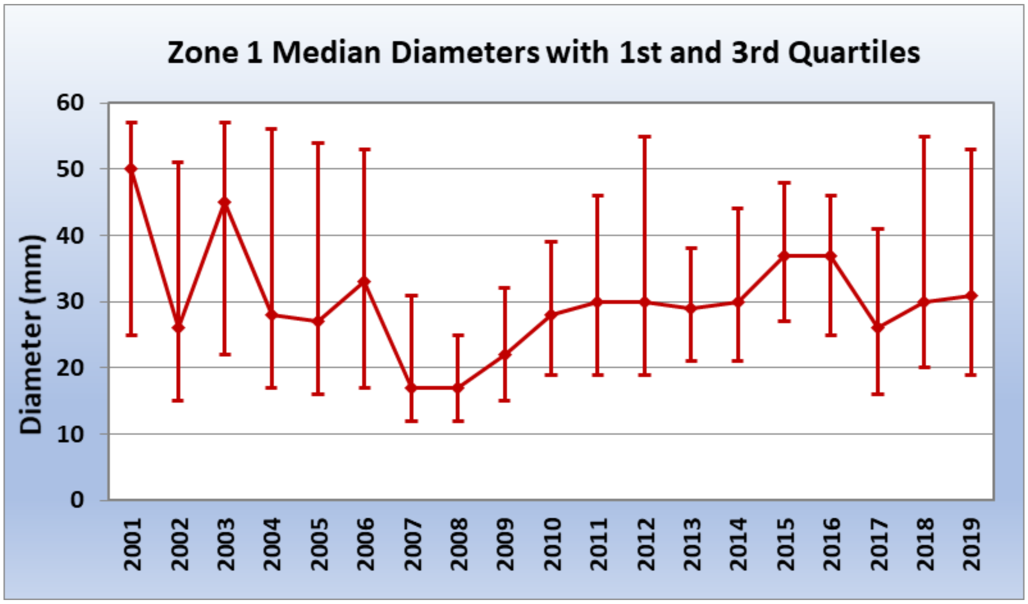


Figure 11. continued.



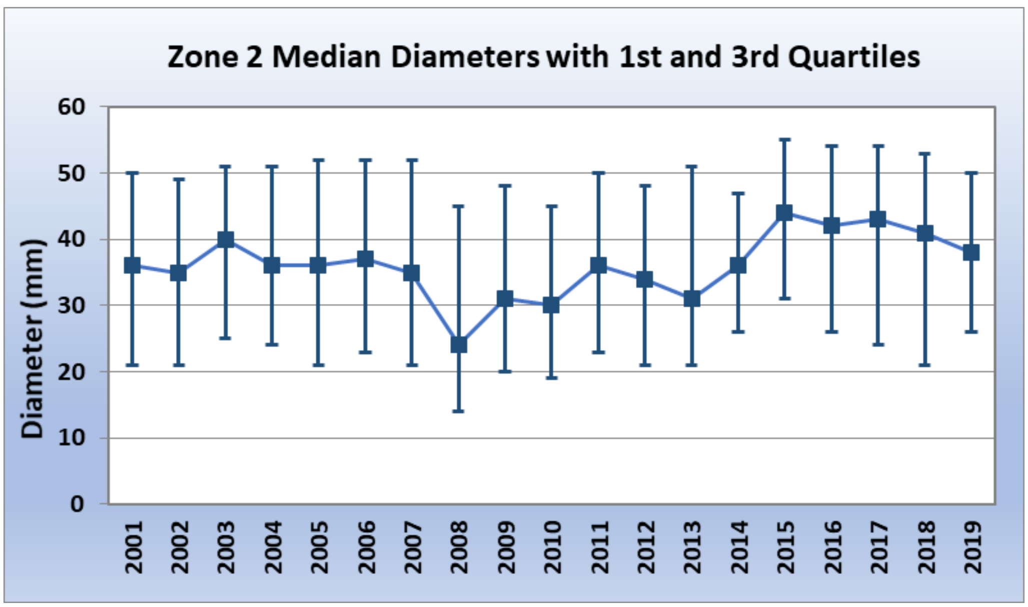
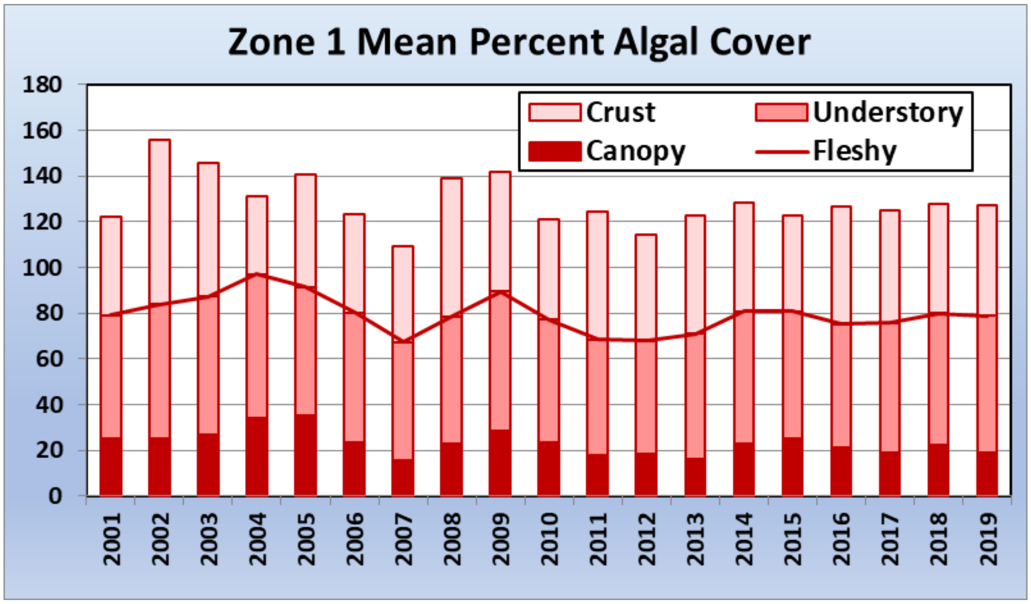


Figure 12. Median sea urchin test diameters (mm) from the spring survey by year, for Zone 1 (above) and Zone 2 (below), with 1st and 3rd quartiles (brackets).



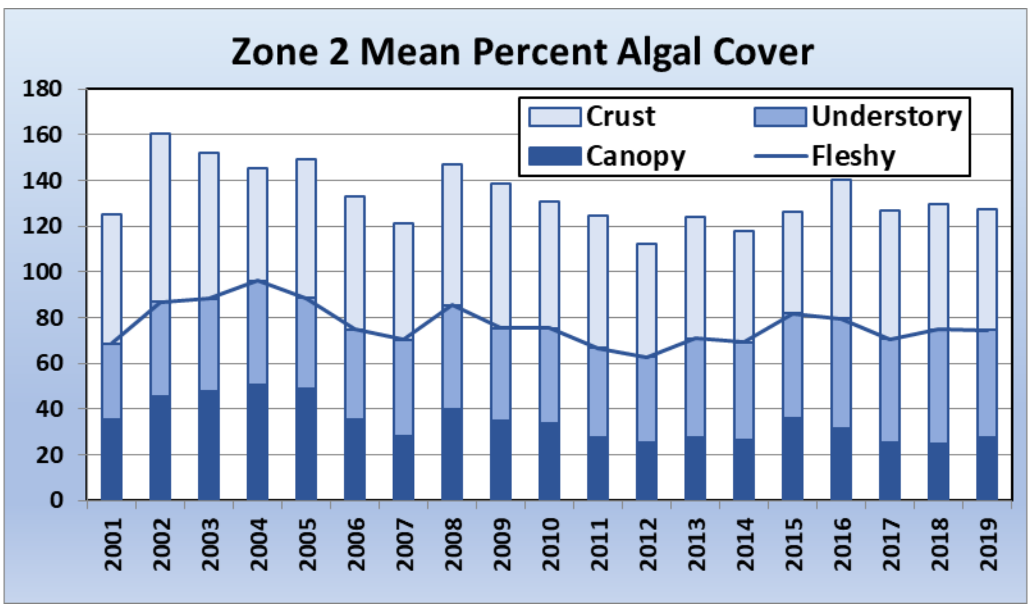


Figure 13. Stratified mean algal cover (%) from the spring survey by algal type, year, and zone, Zone 1 above and Zone 2 below. Note that the total algal cover can be more than 100%. Fleshy algae are the sum of understory and canopy algal types.

Figure 14. Stratified mean algal cover (%) from the spring survey by algal type, year, region, and zone. Regions 1–3 are in Zone 1 (left) and Regions 4–9 are in Zone 2 (right). Note that the total algal cover can be more than 100%. Fleshy algae are the sum of understory and canopy algal types.

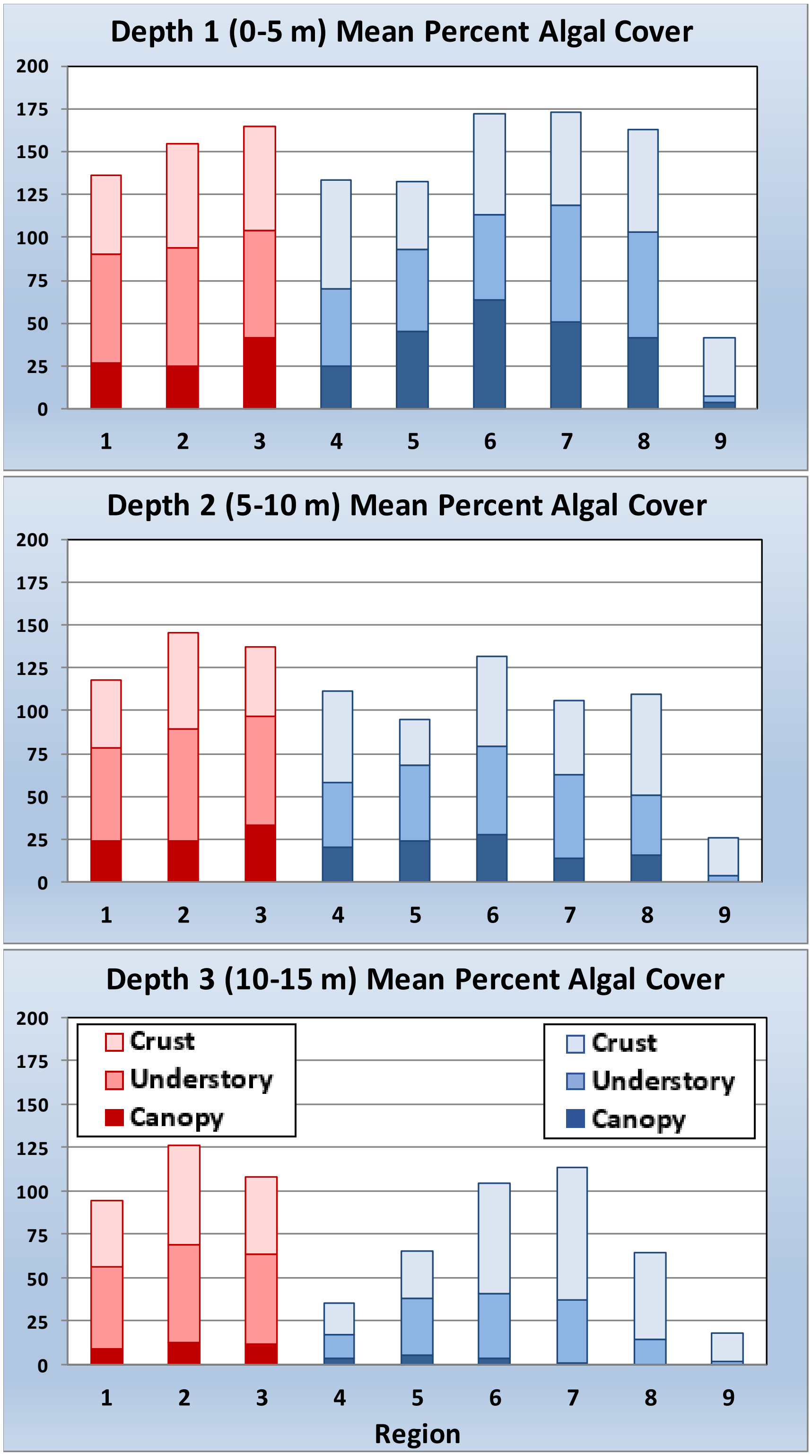
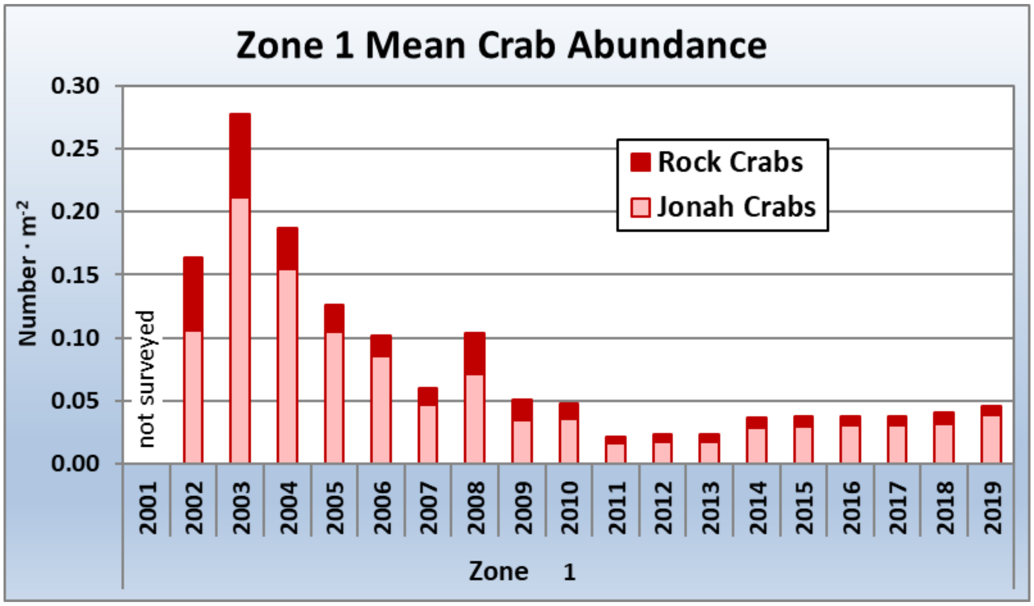


Figure 15. 2014 mean algal cover (%) from the spring survey, by algal type, depth stratum, and region, Zone 1 (regions 1–3, left) in red and Zone 2 (regions 4–9, right) in blue. 2014 is the most recent year in which all regions 1–9 were surveyed. Note that the total algal cover can be more than 100%.



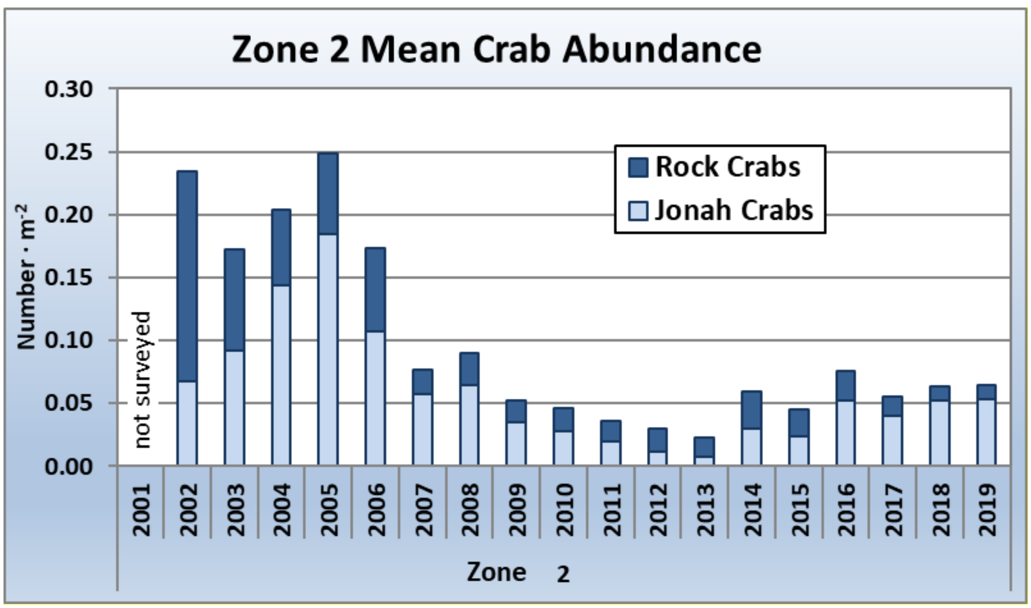


Figure 16. Stratified mean Jonah crab (*C. borealis*) and rock crab (*C. irroratus*) abundance (numbers per square meter) from the spring survey by species, year and zone, Zone 1 above and Zone 2 below.

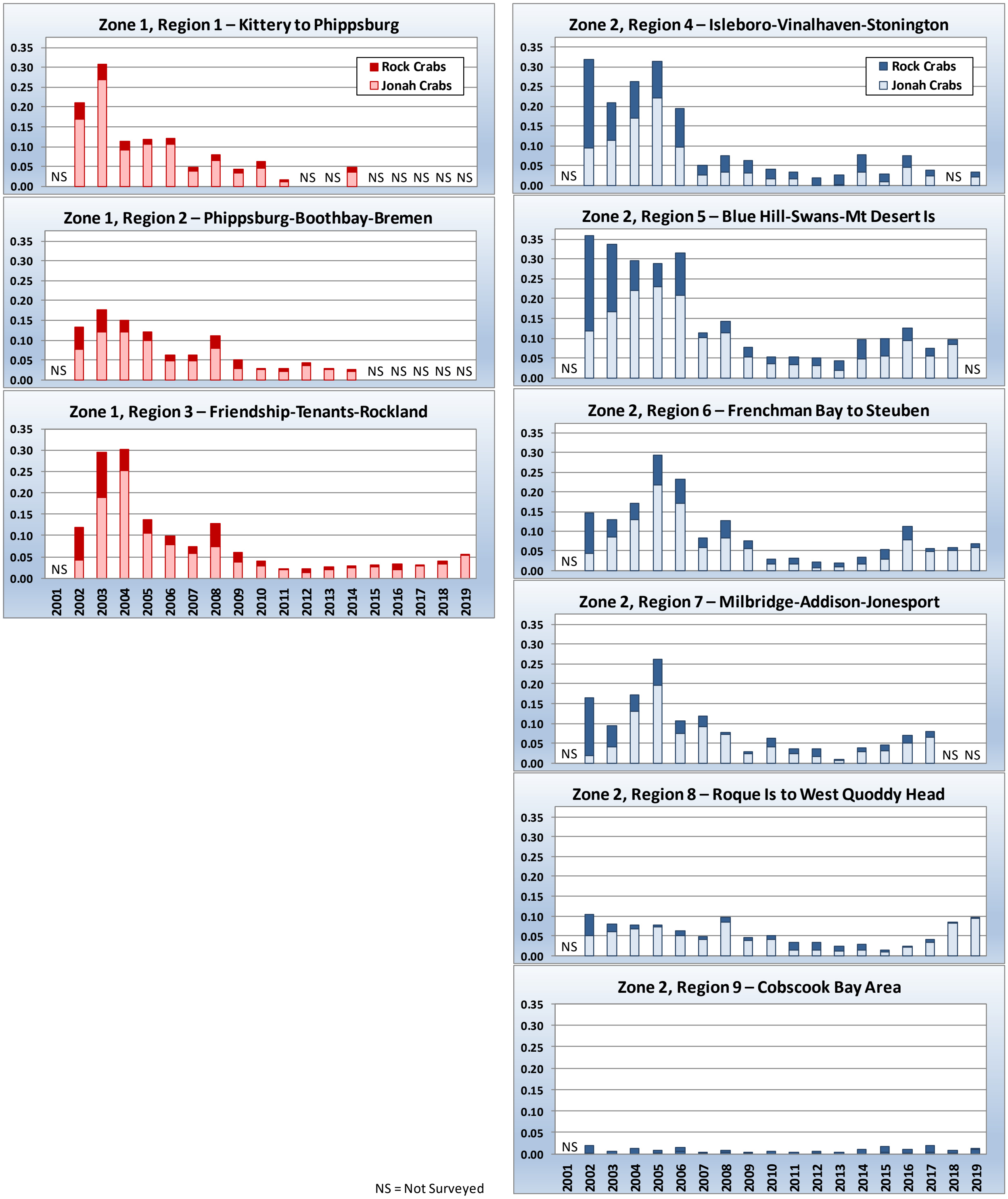


Figure 17. Stratified mean Jonah crab (*C. borealis*) and rock crab (*C. irroratus*) abundance (numbers per square meter) from the spring survey by species, year, region, and zone. Regions 1–3 are in Zone 1 (left) and Regions 4–9 are in Zone 2 (right).

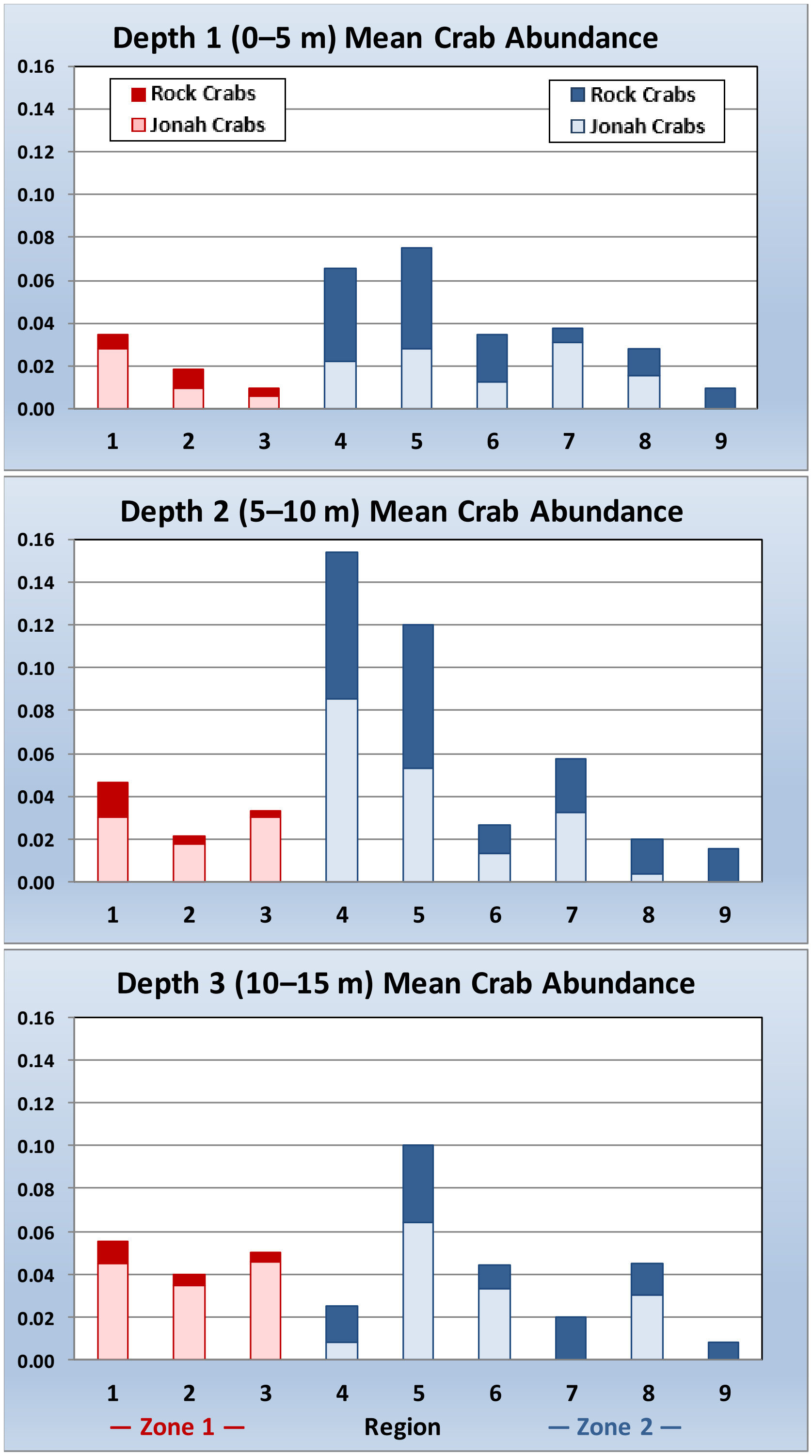


Figure 18. **2014 mean Jonah crab (*C. borealis*) and rock crab (*C. irroratus*) abundance (numbers per square meter) from the spring survey by species, depth stratum, and region, Zone 1 (regions 1–3, left) in red and Zone 2 (regions 4–9, right) in blue. 2014 is the most recent year in which all regions 1–9 were surveyed.**

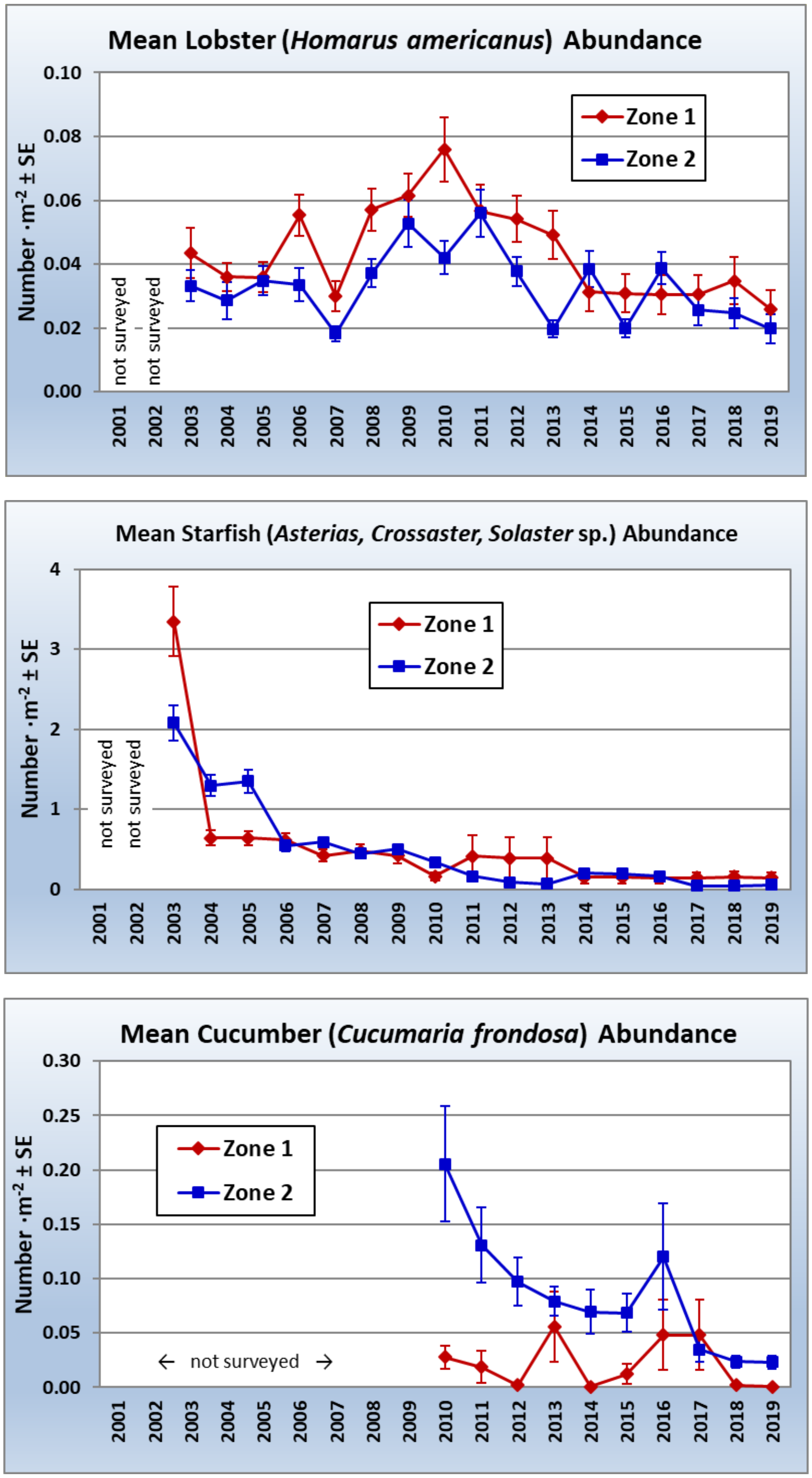


Figure 19a–c. Stratified mean lobster (*Homarus americanus*, top), sea star (*Asterias sp.*, *Solaster sp.*, and *Crossaster sp.*, middle), and sea cucumber (*Cucumaria frondosa*, bottom) abundance (numbers per square meter), from the spring dive survey by zone and year with standard errors.

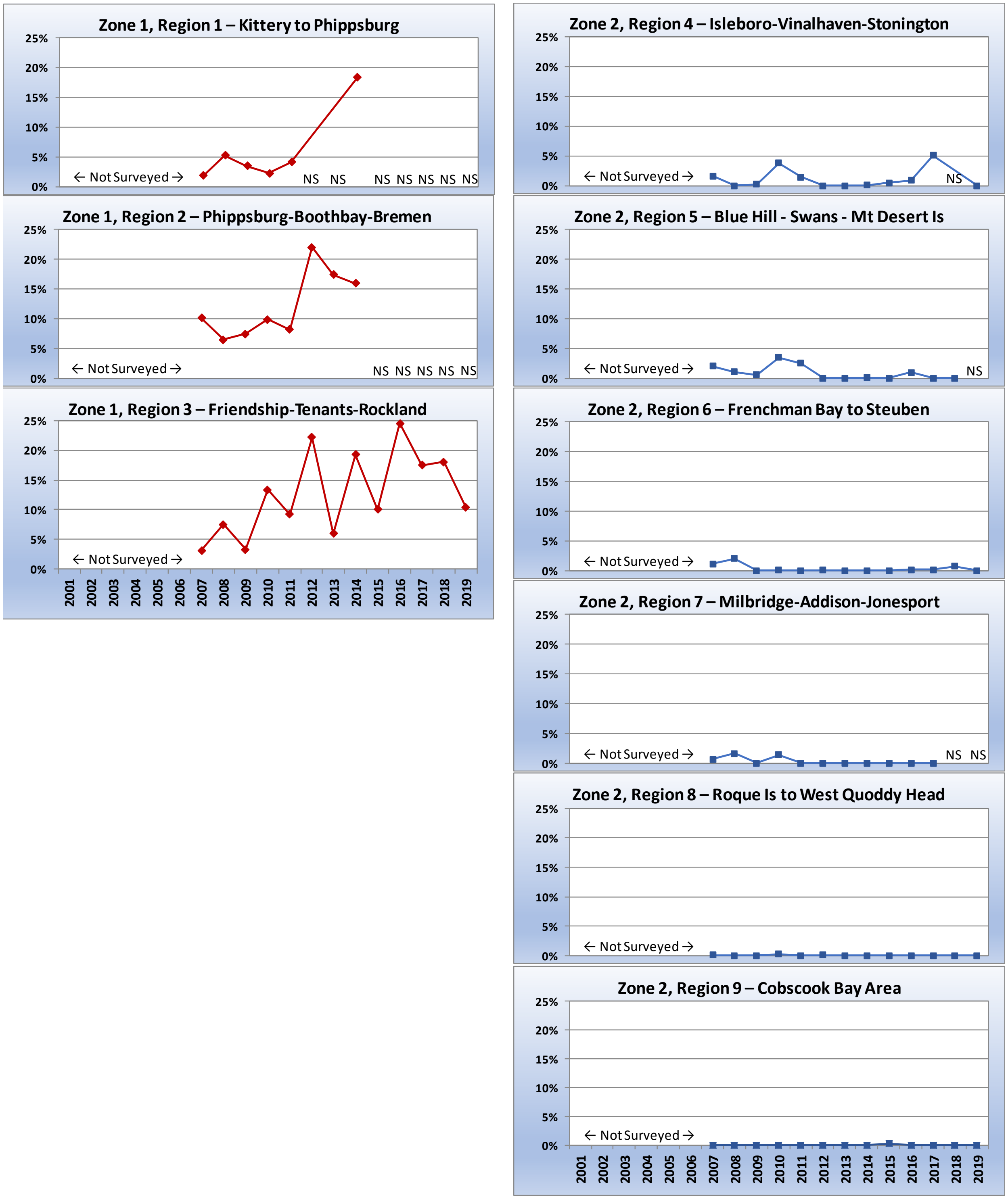


Figure 20. Percent of quadrats with the colonial tunicate *Didemnum sp*. present or common, from the spring survey by year, region, and zone. Regions 1–3 are in Zone 1 (left) and Regions 4–9 are in Zone 2 (right).