Monitoring Maine's Sea Urchin Resource

Photo by Rachel Feeney, Northeast Consortium, September 2009

Maine Department of Marine Resources

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August 1, 2015

SUMMARY

This document summarizes Maine sea urchin fishery information collected by the Maine Department of Marine Resources (DMR) for the period July 1987 through June 2014. Data series include licenses, landings, commercial samples and dockside interviews, harvester logbooks, an annual spring dive survey, and a biannual trawl survey.

INTRODUCTION

The green sea urchin, *Strongylocentrotus droebachiensis* (Müller), has been harvested along the Maine coast for human consumption since prehistoric times (Spiess and Lewis, 2001), and has, in recent years, become one of Maine's most valuable commercial marine resources. This is the only sea urchin species harvested commercially in the Gulf of Maine. Its "roe" is a delicacy in Japan, Europe, and ethnic markets in the USA, and, more recently, other high-end domestic markets (Pols, 2014).

See Chenoweth (1994) and Baron-Taltre (2005) for overviews of Maine's urchin fishery, market, and biology, Wilen and Wessels (1997) for further market analyses, Mottet (1976), Jensen (1974), and Scheibling and Hatcher (2013) for biological reviews, Amory (1994) for a discussion of the Maine sea urchin fishery's history, politics, and social and economic impacts, Lauer (2001) for its socio-economics, Steneck (2013) for ecological role, Taylor (2004) for a review of industry-funded Maine research, Andrew *et al.* (2002) for a review of the status, assessment, and management of the world's sea urchin fisheries, Botsford *et al.* (2004) for a review of biological reference points used in the management of sea urchin fisheries in North America, and Johnson *et al.* (2012, 2013) for reviews of social and biophysical conditions and their implications for management in Maine.

LIFE HISTORY AND HABITAT

The life history of the green sea urchin was reviewed by Scheibling and Hatcher (2013). Sea urchins are echinoderms, belonging to a group of radially symmetrical, invertebrate animals

including starfish, sand dollars and sea cucumbers. They are found in depths from 0 to 300 meters (m), but are most abundant in the shallow, subtidal zone on rock, gravel, or shell bottoms.

The edible part of the sea urchin, referred to as "roe", is both a nutrient-storing and reproductive organ (male or female). The roe develops throughout the summer, fall, and winter, and its size and commercial quality depend largely on the season and the urchin's diet. Sea urchins, which have separate sexes, spawn approximately once a year, probably triggered by phytoplankton blooms (Seward *et al*. 2000; Scheibling and Hatcher, 2013), usually in late winter or spring. The timing varies by about eight weeks along the Maine coast — earlier in the southwest and later in central and northeast regions (Vadas and Beal, 1999). Fertilization is external, and larval sea urchins may drift for 4 to 21 weeks before metamorphosing and settling to the bottom (Scheibling and Hatcher, 2013). In the Gulf of Maine, sea urchins grow to commercial size in about 3 to 14 years (Vadas and Beal, 1999), depending on food availability, and are long-lived (more than 30 years), and relatively slow-growing (Russell 2000). They reach sexual maturity at a size of about 45 mm test diameter (about 1¾ inches), below the current legal minimum size of $2^{1}/_{16}$ inches (52.4 mm) (Vadas and Beal, 1999).

Sources of natural mortality include disease, storm damage, predation on juveniles and adults by fish, birds, crabs, lobsters, and other invertebrates, and predation on larval urchins by other planktonic animals.

Although they are omnivorous, sea urchins prefer to feed ("graze") on kelps and other macroalgae, and play an important ecological role in determining algal distribution and abundance. Their grazing can reduce kelp beds to "barrens", dominated by urchins and encrusting coralline algae. When urchins are removed, fleshy algae may return. This algal habitat, in turn, may create a hospitable environment for small crabs and other predators which feed on newly settling urchins, making it difficult for urchins to become reestablished once they have been removed (Steneck 2013; Steneck *et al*. 2004, 2013) These alternate states (urchin-dominated or algal-dominated) can be locally stable at decadal time scales or longer (reviewed by Chapman and Johnson, 1990; Vadas and Elner, 1992; Steneck 2013; Scheibling and Hatcher, 2013; Filbee-Dexter and Scheibling, 2014). The threshold sea urchin density or biomass

required to "flip" an algal-dominated state back to urchin dominated is higher than that required to maintain the urchin-dominated state (reviewed by Filbee-Dexter and Scheibling, 2014).
In addition to native fleshy algae, invasive bryozoans, tunicates, and algae have impacted urchin habitat, especially in southern Maine (Harris & Tyrrell, 2001).

THE FISHERY

Sea urchin landings in Maine have been recorded since 1933, bound for ethnic markets in Boston and New York (Scattergood 1961). The fishery expanded rapidly in 1987 when a market developed in Japan. This report comprises the period from July 1987 through June 2014.

The fishery occurs primarily in shallow waters, on hard substrate (and some mud bottoms in the Lubec area, Figure 1a), during the winter, with landings currently occurring between September and March. Urchins have been harvested by divers using SCUBA or snorkels and by draggers, plus a few "rakers" who stand in the shallows and rake during low tide. In the 2013–14 season, 60% of the landings were made by divers and rakers, and the remaining 40% by draggers, according to dealer reports.

Drag vessels are typically small, averaging about 37 ft (11.2 m) in length, and are limited by regulation to a drag of no more than 5.5 ft (1.7m) in width. See Creaser and Weeks (1998) for a description of sea urchin drags used in Maine. Draggers typically fish in depths of about 20–30 ft (6–9 m) (from 2011–12 port interviews described below). Divers generally fish alone or in groups of 2 or 3 per boat. They use dry suits, SCUBA gear, standard or homemade catch bags, and small handheld garden-style rakes. Their average depth range is about 10–20 ft (3–6 m) (from 2013–14 port interviews). Their vessels are typically lobster boats, averaging about 28 ft (9 m) in length. Divers are often assisted by tenders, who use a smaller boat to bring the divers to the nearshore urchin beds, then pick up their catches and return them to the mother vessel, where the catches are sorted and over- and under-sized urchins are culled and tossed overboard. There were about 115 active divers, 3 rakers, and 86 active draggers in Maine during the 2013–14 season, according to dealer reports.

Because green sea urchins are most commonly found in the shallow subtidal zone in less than 50 m (Jensen 1974), and, in general, the best quality sea urchin roe is found in the shallowest depths, all fishing trips are single day trips.

Unlike almost any other commercial marine fishery in Maine, the price paid to sea urchin harvesters for the day's catch depends not just on the volume, but also on the "quality" of the catch, usually evaluated by a buyer's inspection of the color, texture, taste, and an estimate of the weight of the roe, expressed as a percentage of total body weight. The best roe is most often found in urchins harvested along a feed line or grazing front, generally at the margins of kelp beds (Chenoweth 1994; Johnson *et al*. 2013).

FISHERY MANAGEMENT

Management of Maine's sea urchin fishery is the joint responsibility of the Maine State Legislature and the Maine Department of Marine Resources (DMR), with advice from the Maine Sea Urchin Zone Council, an industry council with representatives from the harvesting, buying/processing, aquaculture, and research communities that was established in 1996.

No urchin fishery management actions were taken until 1992, when a newly created commercial urchin fishing license for individuals was first required. Since 1994 there have been new management initiatives during almost every session of the state legislature (Table 1). In 1995 the state's coast was divided into two exclusive urchin management zones (Figure 1a). Current management measures include:

- No new fishing licenses issued since 2004.
- Two exclusive harvesting zones (Figure 1a) — harvesters must choose and fish in only one and cannot switch out of a zone unless another licensee switches into it.
- Open season of 38 opportunity days per year for Zone 2 harvesters and 15 days per year for Zone 1, for the 2013–14 season. See Table 2 for past seasons and Table 3 for the 2013–14 season calendars. To stagger the availability of the product over about six months, the two zones have different open seasons; diver and dragger seasons may be

different, and harvesters may select either an early or a late season for their Zone and gear type. The open seasons for the next winter are set by DMR regulations each summer, after consultation with the Maine Sea Urchin Zone Council, an industry advisory council.

- Minimum legal size limit of $2^{1}/_{16}$ inches (52.4 mm) with a 5% (by number) tolerance.
- Maximum legal size limit of 3 inches (76 mm) with a 5% (by number) tolerance.
- Culling (discarding over- and under-sized) at sea required, culling on bottom (to no more than 20% over- or under-sized) required for divers. Zone 2 divers must use large-mesh catch bags; Zone 2 drags must have a large-mesh escape panel.
- Mandatory logbook reporting for both dealers and harvesters.
- Daily landings limits (7 trays, about 640 lbs or 291 kg) were implemented for Zone 2 harvesters for the 2013–14 season; daily limits (12 trays, about 1050 lbs or 475 kg) were implemented for Zone 1 for 2014–15.

DATA SOURCES AND FINDINGS

Fishery Dependent Data — Commercial Licenses

All Maine commercial marine harvesters must be licensed. State licenses specific to sea urchin diving and dragging were introduced in 1992, tenders in 1994, sea urchin buyers and processors in 1994, and sea urchin rakers in 1995. Before 1992, commercial urchin harvesters bought a general type of commercial marine fishing license. Licenses are issued for one calendar year, and may be renewed annually. There has been a moratorium on new urchin harvesting licenses since 2004, and licenses are retired if they are not renewed each year. There was also a moratorium during 1995–1998, and very limited entry (through a lottery system using one in for five out or one in for ten out ratios) during 1999–2004. See Table 4 for historical counts of licenses sold. Note that not all license holders are active (Table 5).

Harvester licenses peaked with a total of 2,725 licensed harvesters in 1994. In 2014 there were 317 licensed harvesters — 156 divers, 139 draggers, 10 rakers, and 12 tribal (mostly draggers). Forty-seven divers, fourteen draggers, and one raker were licensed for Zone 1; the rest were

Zone 2. In 2014 there were eleven licensed buyers and five processors (Table 4). Most of the processors are located in Portland and nearby Scarborough (Figure 1a).

Fishery Dependent Data — Landings

Commercial landings data were collected by National Marine Fisheries Service port agents until the 1996–97 season, when mandatory dealer reporting (to DMR) commenced. Dealers (licensed buyers and processors) who buy sea urchins from harvesters are required to report trip level data: the pounds purchased, date, port landed, harvester license number, harvest method (dive/drag/rake), price, and an estimate of the roe content (% index) for each lot purchased. Almost all landings should be reported through this dealer system; there is little or no recreational catch or catch sold directly to consumers or retailers. 2014 data from dealer logbooks are preliminary at this time, pending audits. Landings data are presented in Table 6 and Figure 2. Estimates of the number of active harvesters, as reported by dealers, are presented in Table 5.

Landings Summary — Landings grew steadily from 1987 to a high of 17,821 mt (39 million lbs) valued at $23.5 million ex-vessel during the 1992–93 season, then declined due to stock declines, management actions (including shorter seasons), and harvester attrition. Landings for the 2013–14 season (preliminary) were 872.6 mt (1.92 million lbs) valued at $5.1 million. Average price per pound has climbed steadily throughout the time series (Table 6 and Figure 2a) reaching a high of $3.11/lb during 2012–13. The three busiest towns (highest urchin landings) during 2013–14 were Lubec, Jonesport, and Tenants Harbor. In calendar year 2014, the Maine sea urchin fishery was the eighth highest in both weight landed and ex-vessel value (ME DMR, 2015, preliminary data).

By Zone and Gear — Landings data for the 2013–14 season by zone, gear (dive/rake or drag) and month are presented in Table 7 and Figure 2b. Zone 1 accounted for 20% of landings (up from 15% the previous season), with 80% from Zone 2. In Zone 1, 79% of the landings were by divers (up from 69% in 2012–13), while the rest were dragged. Divers were limited to fishing in either September to early October or in December, and 65% of their landings occurred in the

early period, due to their choice to fish then, and also longer days and probably better weather. Landings for Zone 1 jumped about 41% between the 2012–13 and 2013–14 seasons (Table 6), because of a 44% increase in diver-days, due to an increase in the number of active divers (Table 5) and perhaps more fishable days because of unusually good weather in September 2013.

In Zone 2 during 2013–14, 55% of landings were dived or raked, and 45% were dragged. The amounts of raked landings were low and are confidential due to fewer than 3 buyers buying from rakers. December was the highest landings month, followed by October and March (Figure 2b).

Price — The highest average monthly ex-vessel prices for 2013–14 were seen in December, followed by October. The overall mean price for the 2013–14 season, $2.63, was the second highest in the time series, after $3.11 in the previous season (Tables 6 and 8b).

Roe — The price of urchins depends on many factors, including the quality of the urchin roe, worldwide supply and demand which is impacted by seasonal holiday markets, and on the Japanese yen–US dollar exchange rate. One measure of "quality" is the roe index — the percent of body weight of the useable roe, which determines yield. Useable roe depends on roe color, texture, form, and taste, and the nature of the buyer's market (low-end to high-end). Dealers are asked to report their estimate of the roe index on their landings reports, and these data are presented in Table 8c and Figures 3a–d. A roe index of 10% is usually acceptable and is often the baseline for setting the price, but reported roe values have varied from about 3% to 25%. Mean roe indices usually peak in February as the urchins approach the late winter spawning season (Table 8c). There is a loose correlation between price and roe, as shown in Figure 3a. In the 2013–14 season, an 8% urchin — considered poor quality but acceptable when demand is high or the buyer wishes to keep a loyal harvester — generally earned $1.35 to $2.00 per pound for the harvesters, while a 12% urchin earned about $2.30 to $2.80/lb. Above about 16%, the relationship is less predictable (Figure 3a), perhaps because some of the higher roe indices occur after December, when worldwide demand (and prices) often drop. Also, buyers sometimes place a cap on the maximum amount they can pay, regardless of quality.

Number of Active Harvesters — Dealer reports also identify the harvester from whom the dealer bought urchins. The numbers of active harvesters (who sold at least two lots in a season) are listed in Table 5. Note that the number of active Zone 1 harvesters increased by 19% between 2011–12 and 2013–14 (concurrent with a lengthening of the season from 10 days to 15 days in 2012–13), while the number of Zone 2 harvesters declined about 21%. In Zone 1, about 43 of 66 licensed harvesters were active (65%), and in Zone 2, about 161 of 264 licensed harvesters were active (61%), in 2013–14.

Harvester Age — The average ages of harvesters who were active during the 2013–14 fishery are also shown in Table 5. Note that there is reason to expect that Maine sea urchin harvesters, particularly divers, will soon "age out" of the fishery, since the mean age of Zone 1 divers was 50 and the mean age of Zone 2 divers was 46.

Number of Trips and Mean Landings per Trip — The numbers of fishing trips by zone, gear type, and month for 2013–14 are shown in Table 9a, and generally show the same trends as the landings data in Table 7. Note that if two divers fish from the same boat on the same day, it is counted as two trips. The most fishing trips were made in December, when the price was highest and the early/late and Zone 1/2 seasons overlapped. Mean landings per trip (Table 9b) were highest for Zone 1 draggers, followed by Zone 1 divers in December. The lowest landings per trip occurred for Zone 2 draggers in January. It is likely that in January many draggers were bringing in small quantities of urchins caught while scalloping, and others may have been scalloping part of the day and urchining part of the day. Zone 2 landings per trip were impacted by the seven tray daily trip limit (about 640 lbs, or 290 kg) first implemented for the 2013–14 season. Mean landings per trip for Zone 2 were 541 lbs (245 kg) in 2013–14, compared with 663 lbs (301 kg) in 2012–13. Mean landings per trip in Zone 1 compared with the previous season increased for divers (651 lbs to 702 lbs) and decreased for draggers (1,507 lbs to 1,325 lbs).

Fishery Dependent Data — Harvester Logbooks

Mandatory logbooks were implemented beginning with the 2010–11 season for Zone 1 harvesters and for 2013–14 for Zone 2. Harvesters must report the date, location fished, amount

of catch landed, and fishing effort (time at sea (away time), mean depth in fathoms, number of dives or number of tows, and average duration of dives or tows) for each day of fishing. 2014 data from harvester logbooks are preliminary at this time, pending audits.

Most Zone 1 fishing trips in 2013–14 were in the Tenants Harbor area near the eastern boundary of Zone 1 (Figure 1a). More than 90% of Zone 1 landings were caught east of 69° 30" longitude (Pemaquid Point). In Zone 2, about 86% of dragger landings and 38 % of diver landings were caught east of 67° 30" longitude (east of Roque Island, east of Jonesport, in Washington County, Figure 1a); the rest were distributed fairly evenly across the rest of the zone.

Zone 1 diver catch rates from logbooks agreed well with port interviews (discussed below) for 2010 and 2011, but diverged in 2012 and 2013. Zone 2 diver catch rates for 2013–14 from harvester log books agree well with port interview results (Figure 4a.).

Total landings from Zone 1 harvester logbooks were compared with landings from dealer logbooks. For 2010–11, the harvesters reported 8% more landings than the dealers did; in 2011–12, harvesters reported 4% less; for 2012–13 harvesters reported 8% less than the dealers, and for 2013–14 there was good agreement on the total amount of Zone 1 landings between harvester and dealer reports. The Zone 2 harvester logbook landings total for the 2013–14 season also agreed well with the dealer reports (within 1%).

Fishery Dependent Data — Port Sampling

A commercial sea urchin port sampling program was initiated during the 1994–1995 fishing season. A description of the program and methods can be found in Hunter *et al*. 2015. Divers, rakers, and dragger captains are interviewed at landing sites for landings and effort data, and biological samples were collected beginning in 1995–1996. Effort data include boat length, number of crew, and away hours, and bottom hours for divers and towing hours and drag width for draggers. Biological data include measurements of diameter (to the nearest mm) and weight (grams) for 20 sea urchins from each catch. The numbers of interviews conducted and sea urchins measured are listed, by season, in Table 10. Over the past five seasons, program staff

interviewed harvesters representing an average of 4.2% of the fishery (by landed weight) and measured an average of 0.025% of the estimated number of landed sea urchins.

Catch Rates — 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, landings rates would decline. Divers who culled on bottom voluntarily before the regulations were implemented told us that divers would soon learn the technique and landings rates would not be significantly affected. Since the LPUE for Zone 1 divers in 2003–04 and for Zone 2 divers in 2012–13 did not seem to decline significantly from the previous season (Table 11 and Figure 4a), they were probably right.

Median pounds per bottom hour was chosen as a robust estimator of LPUE (Perry *et al.* 2002; Zhang and Perry, 2005). A comparison of the median pounds per bottom hour summarized from diver interviews conducted during twenty consecutive harvesting seasons (Table 11 and Figure 4a) 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 level 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. Zone 1 LPUE rose to about 160 lbs/hr during the 2009–10 to 2013–14 seasons. LPUE increased similarly in Zone 2 between 2003 and 2006, but was lower during 2010–11 to 2012–13, at about 125 lbs/hr, then jumped to 164 lbs/hr in 2013–14, probably due to the new daily trip limit. (A trip limit would cause daily LPUE to rise, if, without the limit, catch rates earlier in the day were higher than later in the day, which might happen if the diver became tired or urchins became scarcer at the fishing location during the day.) LPUE was usually higher in Zone 2 than in Zone 1 until 2008–09.

Dragger LPUE (Figure 4b) for Zone 2 shows 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. Only eight dragger interviews were conducted in Zone 1 during the 2002–03 to 2013–14 seasons, because few fished.

Rising or stable LPUE does not necessarily indicate increasing or stable stock abundance, according to our survey results (see next sections) and 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 rise and fall 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, and Ward *et al.* 2013). In this case, there are a number of factors that can keep overall catch rates stable or even increasing when stock abundance is declining (hyperstability), such as serial depletion, economic thresholds and the 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 LPUE rates. For example, the higher rates in Zone 1 during 2009–13 (Figure 4a–b) have been accompanied by a decline in roe content (Figure 3b–d). 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 as steep a decline during the same time periods, 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 are asked for their estimates of the minimum and maximum depths (ft) they fished. The median values of their responses are shown in Table 12 and Figures 5–6. Fishing deeper may indicate difficulty in finding urchins in shallow depths, which might be of concern to managers, or it may just 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 (Figure 5). Also see Figure 6, which compares 2013–14 with 1996–97 (an early year in the program, with the most interviews).

Deeper depths fished in the 1995–96 season (Figure 5) by both divers and draggers in both zones may be due to bias introduced when the port sampling program began late (Dec. 18) and missed the first 3 months of that season. There is some indication that fishing is generally shallower in September and deeper in March–April. Harvesters tell us they can find urchins in the spring that are not yet spawning if they fish deeper, as suggested by Figures 6a–b.

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 count the total number of trays for each catch. Partially filled trays are counted as whole ones, and the average weight per tray for each catch is 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 ten seasons is listed in Table 13, by zone and gear type. Note that Zone 1 divers usually have the lightest trays (averaging about 83 lbs, or 38 kg), and Zone 2 draggers usually have the heaviest (about 96 lbs, or 43 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.

Size Distributions — Expanded size (test diameter) frequency information summarized from commercial samples, and expressed as a relative percentage, is shown for the 2013–14 sampling season for each zone in Figure 7. 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. In Table 14 and Figure 8, median urchin diameter, as well as the first and third quartile diameters, is 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 mm (2.36 inches) in both zones, until 2009–10, when the size in Zone 1 increased, to a median value of 63 mm (2.48 inches) in 2013–14. This increase coincides with increasing catch rates and declining roe content, discussed above. Note that in most years there is generally a wider range of sizes caught in Zone 2 than in Zone 1 (Figure 8), possibly because of a wider geographic range of active fishing grounds in Zone 2 and

the prevalence of small urchins in Cobscook Bay and large ones in the Jonesport area, discussed further under the survey results below.

There may be minimum and maximum size limit compliance problems in the fishery. The legal minimum diameter is $2^{1}/_{16}$ inches, or 52.4 mm and the legal maximum diameter is 3 inches, or 76.2 mm. There is a 5% tolerance by count for undersized and 5% for oversized, so that a legal catch may have up to 5% undersized and 5% oversized urchins, or one undersized and one oversized in our 20-urchin sample. In sampled Zone 1 catches for 2013–14, only about 0.5 % of landed urchins were undersized and 0.2% were oversized (Figure 7a). However, most of the illegal urchins were clustered in just a few of the catches, that is, catches were either very clean (no illegals in the samples) or illegal (2–6 over- or undersized urchins in the sample). Three of the eighteen samples collected in Zone 1 (17%) were illegal for undersized and two other samples of the eighteen (11%) were illegal for oversized, so that 28% of the catches we sampled may have been illegal. For Zone 2 in 2013–14, 7 of 77 (9%) of samples were illegal for undersized and 5 of 77 (6%) were oversized. We rarely encounter a sample that has both over- and undersized urchins.

Also note that the use of a manual measuring board marked in millimeters for measuring urchin diameter, where users are required to round the diameter they read to the nearest millimeter, may have created artificial modes at 60, 65, and 70 mm (for Zone 1, Figure 7a). This user bias for round numbers (also evident in other years) was prevented during the second half of the 2013–14 season by switching to electronic calipers in late December 2013, after all the Zone 1 samples had already been measured.

Diameter-Weight Relationships — which have been used in our modeling efforts (Chen and Hunter, 2003, and Appendix A) are presented for the 1999–2000 and 2013–14 season samples, by zone, in Figure 9. Parameters (a, b) were estimated for each zone for the relationship:

$$\text{Weight} = a \cdot \text{Diameter}^{b}$$

Discards in the urchin fishery — The minimum and maximum size limits do not prevent the taking of small and over-sized urchins; harvesters are allowed to take an illegal animal as long as

it is “culled on board immediately after harvesting and is liberated alive into the marine waters” (Maine Title 12, Ch. 623, §6749-A) with a 5% tolerance by number.

There is little data on the extent of discarding in the fishery. It has varied tremendously, even between divers on the same boat, from less than one bucketful per day for one diver to over half the catch of another diver (Robert Russell, DMR, unpublished data, February 2003). Dragger discard rates vary greatly depending on the underlying size structure of the population being fished (Hunter 2007). There are also reports of very high levels of discarding of small and poor quality urchins in the early years of the fishery (Amory 1994).

An escape panel for Zone 2 drags was required beginning in 2003–04 but it is uncertain whether it is effective in reducing onboard culling and discarding (Hunter 2007). A culling-on-bottom rule for Zone 1 divers was implemented beginning in 2003–04, which required that divers could not bring aboard more than 20% undersized or 20% oversized urchins, meaning that they would have to be somewhat size-selective in their harvesting on bottom, before the urchins were culled to no more than 5% undersized and 5% oversized on the vessel. A similar rule for Zone 2 divers was enacted for 2012–13.

During 2010–11, port samplers asked divers to estimate the number of trays of urchins that were discarded from the vessel. For Zone 1, based on 14 interviews, about 11% of the catch was discarded (by volume). For Zone 2, based on 99 interviews, about 32 % of the catch was discarded. When Zone 2 harvesters were interviewed during 2012–13 (61 interviews), after the culling-on-bottom rule was implemented there, they reported discarding about 17% of the catch.

The fate of the (mostly small) urchins that are culled from catches is not known. There is evidence that green sea urchins exposed to extremes of air temperature or rough handling may not survive, depending on the length of exposure (Robinson and MacIntyre, 1995). Temperature extremes are common during this fishery’s season. Even if they survive exposure and handling, urchins that are culled from a dive vessel anchored in deeper water away from the urchin beds, where the bottom generally lacks feed, may be lost from the system (Hunter 2011). There is also evidence that dragged urchins can be mortally damaged (punctured, crushed, or de-spined) in the

drag, especially in scallop drags, which are heavier than most urchin drags (Creaser and Weeks, 1998).

Fishery Independent Data — Spring Dive Survey

An annual spring sea urchin dive survey along the Maine coastline, stratified by region and depth, was begun in 2001. The state's coastline was divided into nine survey regions (Figure 1b), each with roughly the same sea urchin landings in 1999–2000, so that, by evaluating the same number of sites in each region, sampling effort is distributed roughly in proportion to fishing effort. At least sixteen sites are evaluated in each of the nine regions each year. Sea urchins are counted, samples are measured (test diameter), and algal cover is evaluated, by two divers at a mix of fixed and randomly chosen sites, usually restricted to hard bottom types (rock or gravel substrates), in haphazard quadrats along a transect with a depth profile from 15 to 0 m (49 to 0 ft). Algal cover is recorded for each of three functional algal groups: crustose corallines, understory, or canopy (Steneck and Dethier, 1994). If the taller algal groups are growing above the shorter groups, the total cover can be more than 100%. Note that sea urchin roe content is not measured during the survey. The survey is conducted during late spring, after spawning when roe indices would be low.

In 2002 we began counting and measuring samples (carapace width) of the crabs *Cancer borealis* and *Cancer irroratus*, which have been reported as important predators of Maine's sea urchins (Leland 2002; Steneck *et al*. 2004). In subsequent years, counts of lobsters *Homarus americanus*, sea stars *Asterias rubens* (encountered throughout), *Asterias forbesi* (in southern Maine), and *Crossaster papposus (*encountered only in Region 9*)*, the invasive white colonial tunicate *Didemnum* sp., and commercially harvested sea cucumbers *Cucumaria frondosa* were added to the survey.

Data from a video camera survey that was conducted at deeper sites during 2001–04, abandoned in 2005 because of problems with the cable and the lack of sea urchins found in the six westernmost regions, are not included in analyses here, but were evaluated by Cleaver (2014). Some extra fixed sites, called "industry" sites that were added in 2004 and dropped in 2010 are also not included in analyses here, except in the section below on fixed sites.

Data elements include stratified arithmetic mean abundance (number of individuals per square meter, or $N \cdot m^{-2}$) and estimates of stratified arithmetic mean sea 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). Mean abundance and biomass estimates are calculated for each of three depth strata (0–5, 5–10, and 10–15 m) in each of the nine survey regions for a total of 27 strata, and then weighted by stratum area (rock and gravel substrates only, Table 16).

The survey and its protocols are described further by Grabowski *et al.* (2005), Jones (2005), and Hunter *et al.* (2015). 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 15. Note that Region 1, in Zone 1, was not surveyed in 2012 and 2013. To estimate the Zone 1 means in those years, the 2011 values for Region 1 were used again for 2012 and 2013.

Sea Urchin Biomass — Biomass indices ($g \cdot m^{-2}$) were generally lowest in regions 1–7 and highest in regions 8–9 (Table 17 and Figures 10–11), and highest in the shallowest depth stratum and lowest in the deepest (Table 18). 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 190 $g \cdot m^{-2}$ in 2009–2010, reached a time series low of 105 $g \cdot m^{-2}$ in 2013 and rose in 2014. In Zone 1, biomass was highest with a value of 106 $g \cdot m^{-2}$ in 2002, then fell to below 30 $g \cdot m^{-2}$ in ten out of eleven years between 2004 and 2014. Its time series low was also in 2013 (Table 17, Figure 10). Both zones exhibited an increase in biomass in 2014, and particularly in the biomass of sub-legals (Figure 10b). These increases were driven by higher biomasses in regions 3, 4, 8, and 9, while the other regions declined or stayed about the same as 2013 (Table 17 and Figure 11). In Zone 1, Region 3 has consistently had the highest biomass and Region 1 the lowest. In Zone 2, Region 9 has consistently had the highest biomass and Region 5 the lowest (Table 17 and Figure 11). Biomass in all regions has declined since the survey began in 2001. The rate of decline was greatest between 2001 and 2004, and has slowed or stabilized after the fishing seasons were drastically shortened in 2004 (Table 2). Rank testing

showed that the declines between 2001 and 2004 were statistically significant in regions 3 ,4, 5, 6, and 7 (Hunter *et al*. 2005).

Sea Urchin Abundance — Abundance indices ($N \cdot m^{-2}$) (Table 19 and Figure 12) generally followed the same trends as biomass. The lowest abundance was observed in Zone 1 in 2012 and in Zone 2 in 2013. Abundance in all regions has declined since the survey began in 2001.

Sea Urchin Size Distributions — Size (test diameter) distribution plots (Figure 13) 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 13 perhaps best illustrates the trends noted in the abundance and biomass indices above. Declines between 2001 and 2014 seem to have occurred for all sizes of urchins (Figure 13), with no obvious long-term changes in size distribution for either zone (Figure 14). The mean abundances of undersized urchins in Region 4, and legal-sized urchins in Region 9, have increased since the survey began in 2001. The abundances in all other size groups and regions have decreased (Table 20). In 2014, Region 9 (Cobscook Bay area) had both the highest mean abundance (all sizes) and the highest abundance of undersized, sub-legal (<53mm) urchins, at all depths (Table 21 and Figure 15). Region 8 (Roque Is–Machiasport–Cutler–W.Quoddy Head) had the highest density of legal-sized urchins (53–76 mm), and Region 7 (Milbridge–Addison–Jonesport) had the highest density of oversized urchins (>76 mm).

Exploitable Biomass — Although it is possible to estimate total and fishable (legal-sized) urchin biomass for each region and depth stratum by expanding the density estimates by the areas of likely urchin habitat (Table 16), defining "exploitable" biomass is not straightforward:

1. Not all legal-sized urchins counted during the spring survey will have marketable roe the following winter. No attempt is made during this survey to evaluate roe content or quality. Harvesters tell us they know of areas with "junk" urchins that they try to avoid.
2. The selectivity of the survey divers is probably higher than that of a commercial diver, that is, they will count an urchin that an industry diver might not see or bother with. Dragger selectivity has not been thoroughly studied, although Wahle (1999) suggested

that it is dependent on substrate type, with drags being more efficient on smooth ledge than in cobble habitats.

3. Many of the surveyed urchins are at low density – too low to support the efforts of a diver or dragger. If we assume a threshold of at least five marketable urchins per square meter to support harvest, we found, using the 2009 survey data, that only 16% of the Zone 1 total biomass estimate and 51% of the legal-sized biomass estimate were derived from legal-sized animals in densities of at least $5 \cdot m^2$. For Zone 2, 39% of total urchin biomass and 76% of legal-sized urchin biomass comprised urchins in densities of at least $5 \cdot m^2$.
4. We also don't have a rigorous estimate of the threshold density of urchins required for harvest. Four or five $\cdot m^{-2}$ was suggested by Jones (2005) as more likely than the ten suggested by Grabowski *et al.* (2005). Grabowski *et al.* did their work in 2001, and Jones suggests this threshold has gone down as urchins became more scarce. Higher prices would also support a lower threshold. If divers and draggers require different thresholds, and the proportion of diver to dragger participation changes as divers age out of the fishery, this could also result in shifting definitions of "exploitable". Divers have also told us that they will fish in protected areas on bad weather days that have lower densities than those that would be acceptable on a good weather day, so the definition of "exploitable" can depend on the weather.

Despite these problems, total and fishable biomass estimates could still be useful as long as they were clearly defined and used as indices.

Deep water sea urchin populations — Data from the Maine spring sea urchin survey conducted in deep water (18–38m) using a drop camera during 2001–2004 were evaluated by Cleaver (2014), who found significantly higher urchin densities in deep water in eastern Maine (roughly Zone 2) compared with western Maine (Zone 1). This supports the concept of a "conveyor belt" (Johnson *et al*. 2013), a source of recruitment that could deliver urchins from deeper water refuges to replenish harvested areas in Zone 2. This may be one reason why Zone 2 continues to have higher mean urchin densities than Zone 1 (Figure 12) in fishable depths, despite higher fishing effort (Table 9a).

Algal Cover — See Jones (2005) for an in depth look at the relationships between algal functional group cover and sea urchin density, using data from one year (2002) of the Maine spring sea urchin survey. In general — pooling data from all regions and depths — higher understory and canopy algal cover were both associated with exponentially fewer sea urchins. The highest urchin abundances were found with the lowest understory, the lowest canopy, and the highest crustose coralline algal covers. These findings are consistent with descriptions of the two alternative stable states (dominated by fleshy algae with few urchins, or high-abundance urchin barrens with encrusting corallines) described by other researchers and discussed under Life History and Habitat above.

Algal cover data from the spring survey are displayed in Tables 22–23 and Figures 16–18. 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 used here. Note that adding the percent understory and the percent canopy cover together sometimes results in a total percent algal cover greater than 100%. The total cover of fleshy algae (understory plus canopy, darkest shades in Figure 16) increased in both zones to a peak in 2004, as sea urchin biomass fell (Figure 10), and then declined until 2007, then rose and fell again. There does not seem to be any continued negative correlation with urchin biomass, or other long term trend, after 2004, when viewed at the zone or region level (Table 22, Figure 16). 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 urchin and scallop dragging activity there, as well as the relatively high abundance of sea urchins.

Sea Urchin Biomass and Algal Cover Trends at Fixed Sites — To look at the relationship between urchin abundance and algal cover in more detail, it is useful to review the data from sites that have been monitored repeatedly during the survey. There are five fixed, or "sentinel" sites in each of the nine survey regions. These are sites that 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. There were also two more fixed sites added in each

region in 2005 and discontinued in 2010 that were chosen by the survey crews as particularly interesting or with high urchin abundance, and referred to as "industry" sites. The mean sea urchin biomass (averaged over all quadrats observed at the site) and mean fleshy algal (understory plus canopy) percent cover for these 63 fixed sites (seven per region) are presented for each year in Table 23.

As of 2013, sea urchin biomass decreased at 46 of the 63 fixed sites between the first and last times they were visited; 16 had increased and 1 had not changed (always zero). Of the 46 sites with declining urchin biomass, 32 had declined by at least five-fold, when comparing the average of the first two years with the average of the last two years. Of those 32, 18 had an increase in fleshy algal cover (Figure 17a) and 14 had decreasing or no change in fleshy algae (Figure 17b). This lack of a strong correlation between declining urchin biomass and increasing fleshy algae was unexpected, given the role of sea urchins as major algal grazers discussed above. Upon further inspection, the 18 sites that had increasing algal coverage averaged 57% cover the first year they were surveyed, while the 14 that had declining or unchanging algal cover averaged 97% cover in their first year; that is, they were already algal-dominated when the survey began. Furthermore, pooling all the quadrats for each site over all depths may be obscuring the urchin-algal relationships, which may be more obvious at the quadrat spatial scale (*e.g.* Jones 2005). It is also possible that a certain biomass of small urchins exerts different grazing pressure than the same biomass of (fewer) large urchins (Scheibling & Hatcher, 2013). Further evaluation of these considerations is beyond the scope of this report.

It remains to be seen whether the 18 sites with five-fold urchin decline and increased algal coverage will be stable in that state over the long term. For most, however, the urchin decline had occurred by 2006 and had not been reversed in the seven years since then (Table 23, Figure 17a–b). Of the 30 sentinel sites that are still being monitored that averaged more than 100 $g \cdot m^{-2}$ of urchins in 2001, only nine (one in Zone 1, eight in Zone 2) were still at or above that level in 2013, and only three were above 300 $g \cdot m^{-2}$, the approximate average value suggested by Vavrinec (2003) required to maintain barrens at 10 m depth in midcoast Maine. This lack of urchin-dominated fixed sites in the survey will make it difficult to detect further urchin to algal "flips" if they occur.

Three of the 63 fixed sites (2Y, 4E, and 5H) have exhibited at least a five-fold increase in urchin biomass over the course of the survey, and all three had a decline in fleshy algal cover (Figure 18).

Sea Urchin Biomass Thresholds — Filbee-Dexter and Scheibling (2014) reviewed several studies that estimated a threshold biomass of green sea urchins required to maintain a sea urchin barren (100−600 $g \cdot m^{-2}$), and the threshold biomass required to shift an algal-dominated habitat to sea-urchin-dominated (1−3 $kg \cdot m^{-2}$). It might be possible to evaluate these thresholds for the Maine sea urchin stock and use survey results as biological reference points for management. Vavrinec (2003) estimated a threshold urchin biomass level to maintain urchin barrens as about 300 $g \cdot m^{-2}$ at two sites in Maine at 10 m depth. He also noted that estimated threshold values were different among study sites and depths, and seemed to be lower in eastern Maine. Table 24 and Figure 19 show the percentage of quadrats evaluated during the survey that had at least 300 $g \cdot m^{-2}$ of urchins, by year, region and zone, and reflect the declines over time seen in other indices for both zones.

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 summer. The results (abundance in stratified mean numbers per square meter) are displayed in Table 25 and Figures 20–21. The survey data support anecdotal accounts of a "wave" of crabs that moved from west to east along the Maine coastline, peaking in Zone 1 in 2003 and in Zone 2 in 2005 (Figure 21). Time series lows for the two species combined occurred in Zone 1 in 2011 and in Zone 2 in 2013. Zone means for Jonah crabs were always higher than rock crabs, except in Zone 2 in 2002, 2012, and 2013. Jonah crabs were most abundant in 2002–2003 in Region 1, in 2004 in Region 3, in 2005–2008 in Region 5, and in Region 6 in 2009; by then abundance had declined generally. Rock crabs were consistently most abundant in Regions 4 and 5. Region 9 consistently had the lowest abundance of both species.

Fishery Independent Data — Maine-New Hampshire Spring and Fall Trawl Surveys

The Maine DMR has been conducting a biannual (spring and fall) inshore trawl survey since the fall of 2000. It was designed to complement the federal Northeast Fisheries Science Center groundfish survey. Documentation of the inshore survey protocols (Sherman *et al.* 2005) and annual results (*e.g.* Sherman *et al.* 2013) are available at http://www.maine.gov/dmr/rm/trawl/reports/index.htm.

The survey utilizes fixed and random sites stratified by four depth ranges and five regions. The four depth ranges are: 5–20 fathoms (9–37 m), 21–35 fa (38–64 m), 36–55 fa (65–101m), and greater than 55 fa. From fall 2000 through spring 2014, a total of 2,579 tows were completed successfully; the shallowest site visited was 2.5 fa (4.6 m), and the deepest was 121 fa (221 m). A total of 556 sea urchins were observed in 145 tows, or about 6% of the survey tows. Only two tows caught urchins in the deepest stratum, in November 2006 and June 2014, both in Region 5 east of Jonesport, in 57.5 fa (105 m) and 83.3 fa (152 m) respectively. Ninety-seven of the 145 tows (67%) with urchins were in depth stratum 1, the shallowest stratum. The highest mean weight of urchins per standardized 20-minute tow in a fall survey for a region was 1.07 kg/tow in 2005 in Region 5 (Schoodic Point to Lubec), depth stratum 1. The highest region mean in a spring survey was 0.47 kg/tow, also in 2005 in Region 5, depth stratum 1. Of the 145 tows with urchins, 49 (34%) were in Region 5, despite it having the fewest tows overall (447). Thirty-five (24%) were in Region 4 (Mount Desert Island area), 19 (13%) in Region 3 (Penobscot Bay area), 25 (17%) in Region 2 (Casco Bay and Midcoast), and 17 (12%) in Region 1 (New Hampshire and southern Maine), which had the most tows overall (565). The greatest biomass of sea urchins in a single tow was 1.98 kg, also in fall 2005, east of Jonesport in depth stratum 1.

The tows in eastern Maine in the shallowest stratum were the most likely to catch sea urchins, but, perhaps because urchin occurrence in the survey was relatively rare, there were no obvious trends over time.

ANALYTICAL STOCK ASSESSMENT

Population dynamics modeling is discussed in Appendix A.

ACKNOWLEDGMENTS

Our heartfelt thanks go to Robert Russell, Lessie White, Linda Mercer, Ted Creaser, Kerry Lyons, and Marilyn Lash at or retired from Maine DMR, and to Dr. Yong Chen and his students and colleagues at U. Maine.

LITERATURE CITED

Amory, J. 1994. Urchins! *Salt.* Salt Center for Documentary Feld Studies, Portland, ME, 45: 4–35.

Andrew, N.L., Y. Agatsuma, E. Ballesteros, A.G. Bazhin, E.P. Creaser, D.K.A. Barnes, L.W. Botsford, A. Bradbury, A. Campbell, J.D. Dixon, S. Einarsson, P. Gerring, K. Hebert, M. Hunter, S.B. Hur, C.R. Johnson, M.A. Juinio-Meñez, P. Kalvass, R.J. Miller, C.A. Moreno, J.S. Palleiro, D. Rivas, S.M.L. Robinson, S.C. Schroeter, R.S. Steneck, R.I. Vadas, D.A. Woodby and Z. Xiaoqi. 2002. Status and management of world sea urchin fisheries. *Oceanogr. Mar. Biol. Annu. Rev.* **40**:343–425.

Baron-Taltre, B. 2005. The rise and fall of the Maine sea urchin industry: a failure of management and institutions? Masters thesis. University of Maine, Orono, Maine. 202p. http://www.library.umaine.edu/theses/theses.asp?Cmd=abstract&ID=SMS2005-002

Botsford, L.W., B.D. Smith, and J.F. Quinn. 1994. Bimodality in size distributions: the red sea urchin *Strongylocentrotus Franciscanus* as an example. *Ecol. App*. **4**:42–50. http://dx.doi.org/10.2307/1942113

Botsford, L.W., A. Campbell, and R. Miller. 2004. Biological reference points in the management of North American sea urchin fisheries. *Can. J. Fish. Aquat. Sci*. **61**:1325–1337.

Chapman, A.R.O. and C.R. Johnson. 1990. Disturbance and organization of macroalgal assemblages in the northwest Atlantic. *Hydrobiologia* **192**:77–121.

Chen, Y. and M. Hunter. 2003. Assessing the green sea urchin (*Strongylocentrotus droebachiensis*) stock in Maine, USA. *Fis. Res*. **60**:527–537.

Chen, Y., M. Hunter, R. Vadas, and B. Beal. 2003. Developing a growth-transition matrix for the stock assessment of the green sea urchin (*Strongylocentrotus droebachiensis*) off Maine. *Fish. Bull*. **101**:737–744.

Chenoweth, S. 1994. The green sea urchin in Maine — fishery and biology. Maine Department of Marine Resources, W. Boothbay Harbor, Maine. 10p. http://www.maine.gov/dmr/rm/seaurchin/green_sea_urchin_general_summary.htm

Cleaver, C. 2014. The Maine green sea urchin fishey: scale mismatches, trophic connectivity and resilience. MS thesis. University of Maine, Orono Maine. 63p.

Creaser, E. and W. Weeks. 1998. Sea urchin drag study report. Maine Department of Marine Resources, W. Boothbay Harbor, Maine. 29p.

Erisman, B.E., L.G. Allen, J.T. Claisse, D.J. Pondella II, E.F. Miller, and J.H. Murray. 2011. The illusion of plenty: hyperstability masks collapses in two recreational fisheries that target fish spawning aggregations. *Can. J. Fish. Aquat. Sci.* **68**:1705–1716.

Filbee-Dexter, K. and R.E. Schieibling. 2014. Sea urchin barrens as alternative stable states of collapsed kelp ecosystems. *Mar. Ecol. Prog. Ser*. **495**:1–25.

Grabowski, R.C., T.Windholz, and Y. Chen. 2005. Estimating exploitable stock biomass for the Maine green sea urchin (*Strongylocentrotus droebachiensis*) fishery using a spatial statistics approach. *Fish. Bull*. **103**:320–330.

Harris, L.G. and M.C. Tyrrell. 2001. Changing community state in the Gulf of Maine: synergism between invaders, overfishing and climate change. *Bio. Invasions* **3**:9–21.

Hilborn, R. and C.J. Walters. 1992. Quantitative fisheries stock assessment: choice, dynamics and uncertainty. Chapman and Hall, New York.

Hunter, M. 2007. Testing the effectiveness of various escape panel configurations on urchin drags. Final Report to the Northeast Consortium, Durham NH, 63pp, online at http://www.northeastconsortium.org/projects.shtml and http://www.maine.gov/dmr/rm/seaurchin/research.htm.

Hunter, M., K. Lyons, and R. Russell. 2005. Completion report, interjurisdictional fisheries research monitoring and assessment. Maine Department of Marine Resources, W. Boothbay Harbor, Maine, 70p. http://www.maine.gov/dmr/rm/seaurchin/2004ij.pdf.

Hunter, M., K. Lyons, and R. Russell. 2015. Completion report, interjurisdictional fisheries research monitoring and assessment. Maine Department of Marine Resources, W. Boothbay Harbor, Maine, 70p. http://www.maine.gov/dmr/rm/seaurchin/2015ij.pdf.

Hunter, M. 2011. Examining fishing practices of divers in the Maine sea urchin fishery. Final report to the Northeast Consortium, Durham NH, 67pp, online at http://www.northeastconsortium.org/projects.shtml and http://www.maine.gov/dmr/rm/seaurchin/research.htm

Jensen, M. 1974. The Strongylocentroitidae (Echinoidea), a morphologic and systematic study. *Sarsia* **57**:113–148.

Jones, K. 2005. Monitoring, assessment, and management of the green sea urchin (*Strongylocentrotus droebachiensis*) fishery in Maine. Masters thesis. University of Maine, Orono, Maine. 103p. http://www.library.umaine.edu/theses/theses.asp?Cmd=abstract&ID=SMS2006-005

Johnson, T.R., J. A. Wilson, C. Cleaver, and R. L. Vadas. 2012. Social-ecological scale mismatches and the collapse of the sea urchin fishery in Maine, USA. *Ecology and Society* **17**(2):15. http://dx.doi.org/10.5751/ES-04767-170215

Johnson, T.R, J.A. Wilson, C. Cleaver, G. Morehead, and R. Vadas. 2013. Modeling fine scale urchin and kelp dynamics: implications for management of the Maine sea urchin fishery. *Fis. Res.* **141**:107–117. http://dx.doi.org/10.1016/j.fishres.2012.05.008

Kanaiwa, M., Y. Chen, and M. Hunter. 2005. Assessing a stock assessment framework for the green sea urchin *Strongylocentrotus droebachiensis* fishery in Maine, USA. *Fish. Res*.**74**:96–115.

Keesing, J.K and J.L. Baker. 1998. The benefits of catch and effort data at a fine spatial scale in the South Australian abalone (*Haliotis laevigata* and *H. rubris*) fishery. IN: Proceedings of the North Pacific Symposium on Invertebrate Stock Assessment and Management. G.S Jamieson and A.Campbell, eds. Canadian Special Publication of Fisheries and Aquatic Sciences **125**:179–186.

Lauer, S.R. 2001. Flexible production on the working waterfront: the social origins of the northwest Atlantic sea urchin industry. *Rural Sociology*. **6**(4):532–555.

Leland, A. 2002. A new apex predator in the Gulf of Maine? Large mobile crabs (*Cancer borealis*) control benthic community structure. Masters thesis. University of Maine, Orono, Maine. http://www.library.umaine.edu/theses/pdf/LelandAV2002.pdf

Maine Department of Marine Resources. 2015. Preliminary 2014 Maine landings by species. http://www.maine.gov/dmr/commercialfishing/recentlandings.htm.

Miller, R.J. and S.C. Nolan. 2008. Management methods for a sea urchin dive fishery with individual fishing zones. *J. Shellfish Res.* **27**:929–938.

Mottet, M.G. 1976. The fishery biology of sea urchins in the family Strongylocentrotidae. Washington Dept. of Fisheries, Technical Report 20. 66 p.

Perry, R.I., Z. Zhang, R. Harbo. 2002. Development of the green sea urchin (*Strongylocentrotus droebachiensis*) fishery in British Columbia, Canada — back from the brink using a precautionary framework. *Fish. Res*. **55**:253–266.

Pols, M. 2014. Food & Wine declares urchin roe 'the new bacon'. *Portland Press Herald*. Portland, Maine. May 31, 2014. http://www.pressherald.com/2014/05/31/food-wine-a-national-glossy-declares-uni-from-sea-urchin-the-new-bacon/

Prince, J. and R. Hilborn. 1998. Concentration profiles and invertebrate fisheries management. IN: Proceedings of the North Pacific Symposium on Invertebrate Stock Assessment and Management. G.S Jamieson and A.Campbell, eds. *Canadian Special Publication of Fisheries and Aquatic Sciences* **125**:187–196

Robinson, S. and A. MacIntyre. 1995. Biological fishery information for the rational development of the green sea urchin industry. Final Report for the New Brunswick Dept.

of Fisheries and Aquaculture and the Canada - New Brunswick Co-operation Agreement on Economic Diversification. DFO, Biological Station, St. Andrews, N.B. 90 pp.

Russell, M.P. 2000. Spatial and temporal variation in growth of the green sea urchin, *Strongylocentrotus droebachiensis*, in the Gulf of Maine, USA. In: *Echinoderms 2000 – Proceedings of the 10th International Echinoderm Conference*. pp. 533–538. Ed. M. Barker, A.A. Balkema.

Scattergood, L.W. 1961. The sea urchin fishery. US Dept. of the Interior. Fishery Leaflet 511. 6 pp.

Scheibling, R.E. 1996. The role of predation in regulating sea urchin populations in eastern Canada. Oceanol Acta 19:421–430.

Scheibling, R.E., A.W. Hennigar, and T. Balch. 1999. Destructive grazing, epiphytism, and disease: the dynamics of sea urchin-kelp interactions in Nova Scotia. *Can. J. Fish. Aquat. Sci.* **56**:2300–2314.

Scheibling, R.E. and B.G. Hatcher. 2013. The ecology of *Strongylocentrotus droebachiensis*. In: J. M. Lawrence, ed. *Sea Urchins: Biology and Ecology*. 3rd Edn. Developments in Aquaculture and Fisheries Science **38**:381–412. Elsevier Academic Press, Amsterdam.

Seward, L. C. N., R. L. Vadas, B. Beal., & D.W. Townsend. 2000. Environmental factors influencing spawning in the green sea urchin, *Strongylocentrotus droebachiensis*, in Maine, USA. In: Proceedings of the Workshop on the coordination of research on the green sea urchin in Atlantic Canada, Univ. of Moncton, New Brunswick, Canada. 6 pp.

Sherman, S.A., K.L. Stepanek, and C. King. 2013. Annual Report on the Maine-New Hampshire inshore trawl survey, January 1–December 31, 2012. Report to the NOAA Fisheries Northeast Region Cooperative Research Partners Program. Maine DMR, Augusta Maine. 119p. http://www.maine.gov/dmr/rm/trawl/reports/

Sherman, S.A., K.L. Stepanek, and J. Sowles. 2005. Maine-New Hampshire inshore groundfish trawl survey procedures and protocols. Maine DMR, Augusta Maine. 42p. Online at http://www.maine.gov/dmr/rm/trawl/reports/

Spiess A.E, and Lewis R. 2001. The Turner Farm fauna: five thousand years of hunting and fishing in Penobscot Bay, Maine. *Occ. Publ. in Maine Archeol*. 11:1–120.

Steneck, R. S., and M. N. Dethier. 1994. A functional group approach to the structure of algal-dominated communities. *Oikos* **69**: 476–498.

Steneck, R.S. 2013. Sea urchins as drivers of shallow benthic marine community structure. In: J. M. Lawrence, ed. *Sea Urchins: Biology and Ecology*. 3rd edn. Developments in Aquaculture and Fisheries Science **38**: 195–212. Elsevier Academic Press, Amsterdam.

Steneck, R.S., J. Vavrinec, and A. Leland. 2004. Accelerating trophic-level dysfunction in kelp forest ecosystems of the western North Atlantic. *Ecosystems* **7**: 323–332.

Steneck, R.S., A. Leland, D.C. McNaught, and J. Vavrinec. 2013. Ecosystem flips, locks, and feedbacks: the lasting effects of fisheries on Maine's kelp forest ecosystem. *Bul. Mar. Sci.* 89: 31–55.

Taylor, P.H. 2004. *Green Gold: Scientific Findings for Management of Maine's Sea Urchin Fishery*, Maine Dept. of Marine Resources, Boothbay Harbor, Maine. 36p. http://www.maine.gov/dmr/rm/seaurchin/greengold.pdf

Vadas. R.L. and R.W. Elner. 1992. Plant-animal interaction in the north-west Atlantic. In: John, D.M., Hawkins, S.J., and Price, J.H. (eds). *Plant-animal interactions in the marine benthos*. Clarendon Press, Oxford, pp 33–60.

Vadas, R.L. and B.F. Beal. 1999. Temporal and spatial variability in the relationships between adult size, maturity and fecundity in green sea urchins: the potential use of a roe-yield standard as a conservation tool. Report to the Maine Department of Marine Resources for the project entitled: Research necessary to develop a management plan for the green sea urchin, *Strongylocentrotus droebachiensis*, in the territorial waters of Maine. DMR, Boothbay Harbor, Maine. 47 p.

Vadas, R.L., B.D. Smith, B. Beal, and T. Dowling. 2002. Sympatric growth morphs and size biomodality in the green sea urchin (*Strongylocentrotus droebachiensis*). *Ecol. Monographs* **72**:1, 113–132.

Vavrinec J. 2003. Resilience of green sea urchin (*Strongylocentrotus droebachiensis*) populations following fishing mortality: marine protected areas, alternate stable states, and larval ecology. PhD dissertation, University of Maine, Orono, ME. 127 p. http://www.library.umaine.edu/theses/pdf/VavrinecJ2003.pdf

Wahle, R.A. 1999. An *in situ* study of the impact of sea urchin dragging on the benthos. Report to Maine DMR. 22p.

Ward, H.G.M., P.J. Askey, and J.R. Post. 2013. A mechanistic understanding of hyperstability in catch per unit effort and density-dependent catchability in a multistock recreational fishery. *Can. J. Fish. Aquat. Sci*. 70: 1542–1550. http://dx.doi.org/10.1139/cjfas-2013-0264

Wilens, J.E. and C. R. Wessells. 1997. An economic analysis of the market for Maine sea urchins. Report to the Maine Department of Marine Resources. 88 p.

Zhang, Z. and R.I. Perry. 2005. Use of state-space modeling with a Bayesian approach to estimate target reference points for green sea urchin (*Strongylocentrotus droebachiensis*) stocks in the Queen Charlotte Strait region, British Columbia, Canada. *Fish. Res*. 74: 253-264.

TABLES and FIGURES

Table 1. History of Maine sea urchin management laws (law) and regulations (reg) (Laws and regulations usually go into effect during the late summer.)

Before 1992

- $20 commercial fishing license required annually (law)

1992

- $89 sea urchin licenses required for hand harvesting and dragging annually (law)

1993

- Minimum size limit of 2 inches (law) (Implemented in reg. Jan. 1, 1994)
- Authority to adopt rules on drag size, nighttime dragging, and tolerance on under-sized urchins granted to DMR commissioner (law, see below for implementation in reg.)
- Sea urchin boat tender license required for tenders (law)
- Season closed May 15 to August 7 for 1993, to August 15 for 1994 (law)
- Nighttime harvesting of urchins prohibited (reg, effective May 25, 1994)
- 10% tolerance on sea urchins less than 2 in. (reg, effective Jan. 1, 1994)
- Urchin drag width restricted to 5½ ft. (reg, effective Aug. 14, 1994)

1994

- Research surcharge on licenses: $160/harvester, $500/buyer, $2500/processor annually (law, effective Jan. 1, 1995)
- Sea urchin research fund established (law)
- Moratorium on new licenses (law, effective July 1994)
- Two fishing zones established with seasons (effective Jan. 1, 1995) (LD 1984 law in 1994): Zone 1: Closed Apr. 1 – Aug. 15, Zone 2: Closed May 15 – Oct. 1
- Authority to adopt rules for processor/buyer logbooks granted to DMR commissioner (law)
- Permits for buyers and processors required (law)
- Safety training required for divers, effective 1995 (law)

1995

- Modified season closures (law):
  Zone 1: Apr. 1 – Aug. 31 (not enacted in time for Zone 1 opening on Aug. 16, 1995)
  Zone 2: May 1 – Oct.
- Hand-raking and trapping license added ($89 plus $160 surcharge annually) (law)
- Exception to license moratorium due to medical conditions, and deceased license transfer to family members (law)

- Authority to extend closing dates for entire zones or portions thereof, to conserve spawning urchins, granted to DMR commissioner (has never been exercised) (law)
- License ($89) and surcharge ($35) annually and safety training required for tenders (law)

1996

- Sea Urchin Zone Council established (to advise on selection of fishing days), consisting of appointed members: three draggers, three divers, one buyer, and one processor from each zone plus 2 scientists (law)
- Fishing days limited to 150 per year in Zone 1 and 170 in Zone 2 (law)
- Limitations on switching zones — cap at the zone's previous year's total (law)
- Logbooks required from buyers/processors (reg)
- Modified zone season closure: May 1 – July 31, for both zones (law)
- Draggers not allowed to fish during August or September (law)
- Violations of sea urchin laws result in mandatory $500 fine (law)

1997

- Fishing days limited to 120 per year in each Zone (reg)
- Role of Sea Urchin Zone Council expanded: recommend fishing days, advise on the spending of the research fund, and other matters of interest to the urchin industry (law)
- Harvesters cannot switch zones during the open season (law)

1998

- Role of Sea Urchin Zone Council expanded: recommend limited entry ratio (law)
- Lottery for issuing a limited number of new licenses with a 1:5 exit ratio (law and reg)
- Up to 30% of license surcharge may be used for enforcement overtime (law)
- Two seasons in Zone 2 (harvester chooses one) (law)
  Early: Oct.–Mar. or Late: Nov.–Apr.
- Tender added to Zone Council (law)

1999

- Surcharge may be used for Council support, 30% for law enforcement (law)
- Failure to submit logbook reports may prevent license renewal (law)
- No possession of urchins on boat during no-fishing day (law)
- Mandatory suspension of license for violation of season or zone restrictions (law)
- Condition for switching zones: 1 in for 1 out (law)
- Sea Urchin Zone Council membership changed to 2 buyer/processors per zone (law)
- Six small areas closed for research (reg)

2000

- No exceptions to the license moratorium for medical conditions; no transfer of deceased harvester's license to family members (law)
- Minimum size tolerance reduced from 10% to 5% (reg)
- Season reduced to 110 days per year (reg)
- Maximum size of 3½" established, with a 5% tolerance, to be reduce to 3 3/8" in 2001 and reduced again to 3¼" in 2002 (reg) (but see 2001)
- Casco Bay research area closed for reseeding (reg)

2001

- Season reduced to 94 days per year (reg)
- Minimum size increased to 2 1/16", 5% tolerance (reg)
- Maximum size reduced to 3.0", 5% tolerance (reg)
- DMR given authority to implement limited entry system (law, see 2002 for reg)
- Drag license holder must be on boat, exceptions for multiple license holders, one-time transfer of license allowed (law)
- Surcharge may be used for Council travel expenses (law)
- Mandatory suspension of license for violation of closed areas (law)
- Diving from a vessel with urchins aboard illegal without license etc. (law)
- Processor's surcharge reduced from $2500 to $1000. (law)

2002

- One-time expansion of drag license eligibility (law)
- Limited entry license lottery system as defined in law in 1998 repealed (law) and repromulgated in regulation with minor changes. (reg)

2003

- License lottery exit ratio changed from 1 in for 5 out to 1 in for 10 out (reg)
- DMR commissioner given authority to prohibit new entry to protect fishery from imminent depletion (law)
- Surcharge may be used for safety training and other management programs (law)
- Mandatory $1000 fine for 2nd violation of minimum size rule and mandatory 1- to 3-year license suspension for 3rd violation of minimum size rule within 5 years (law)
- Zone 1 divers must "cull on bottom", 20% tolerance (law and reg)
- Zone 1 dragger season shortened from 94 days to 84 days (reg)
- Western Zone 2 closed for an additional 10 days (reg)
- Zone 2 divers must use large-mesh catch bags (reg)
- Zone 2 draggers must use large-mesh "escape panel" in back of drag (reg)
- License fees increased from $89 to $111 for harvesters and tenders (effective 1/1/04), and from $217 to $385 for buyers and processors (effective 4/1/04), research surcharges unchanged (law)

2004

- Re-opened six of the seven areas closed for research in 1999–2000 (reg)
- License lottery (new entry) suspended indefinitely (reg)
- Zone 1 season reduced from 94/84 days to 10 days (reg)
- Zone 2 season reduced from 94 days to 45 days (reg)

2005

- Choice of early or late seasons for Zone 1 divers (reg)

2007

- Sea Urchin Zone Council restructured, fewer members, some elected (law and reg, not implemented until 2008)

2008

- Tender research surcharge to be divided 50:50 between the urchin research fund and the new scallop research fund (law)

2009

- Whiting River and Denny's Bay area in Zone 2 closed to the taking of scallops and sea urchins until May 1, 2011 (reg) Later changed to May 1, 2012 (reg)
- Choice of early or late seasons for Zone 1 draggers (reg)
- New license for hand harvesting with tender, fee $161, research surcharge $160 (law)
- No more temporary tender license (law)
- Changes to safety training requirements for divers and tenders (law and reg), effective 12/21/09 for new licenses and 1/1/11 for licenses renewed before 8/1/10
- Zone 1 hand harvesters and hand harvesters with tenders fees reduced to $25 and $50 respectively, effective through 12/31/11 (law)

2010

- License fees increased from $111 to $152 for harvesters and $133 for tenders (effective 4/27/10), from $161 to $202 for hand harvesting with tender (effective 7/5/10 but not implemented until 2011 licenses were issued), and from $385 to $443 for buyers and processors (effective 4/27/10); research surcharges unchanged. Exceptions: fees for Zone 1 hand harvesters and hand harvesters with tenders remain $25 and $50 respectively, effective through 12/31/11; and tender research surcharge increased to $50 (effective 7/12/10 but not implemented until 2011 licenses were issued). (law)
- Mandatory logbook reporting for Zone 1 harvesters

2012

- Zone 1 season increased to 15 days (reg)
- Zone 2 season reduced to 36 days (reg)
- Whiting River and Dennys Bay closed area in Zone 2 reopened for 4 days to divers and 4 days to draggers; 10-tote daily possession limits after the first day (reg)
- Zone 2 divers must "cull on bottom", 20% tolerance (reg)

2013

- Zone 2 season increased to 38 days (reg)
- Zone 2 harvester 7-tote daily possession limit (reg)
- Mandatory logbook reporting for Zone 2 harvesters (reg)
- Whiting River and Dennys Bay limited-access area in Zone 2 opened for 9 days to divers and 9 days to draggers (reg)

2014

- Zone 1 harvester 12-tote daily possession limit (reg)

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

Year or Season	Total Days	(No Zones until Jan. 1, 1995)
1986	365	
1987	365	
1988	366	
1989	365	
1990	365	
1991	365	
1992	366	
1993	335	(closed Jul. 9 – Aug. 7)
1994	273	(closed May 15 – Aug. 15)

	Zone 1 Days	Zone 2 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 (Oct–Mar) or late (Nov–Apr)
2000–2001	110, Sep – Feb	110, choice of early (Oct–Mar) or late (Nov–Apr)
2001–2002	94, Sep – Mar	94, choice of early (Oct–Mar) or late (Nov–Apr)
2002–2003	94, Sep – Mar	94, choice of early (Oct–Mar) or late (Nov–Apr)
2003–2004	94 dive, 84 drag, Sep – Mar.	94, choice of early (Oct–Mar) or late (Nov–Apr)
2004–2005	10, Sep dive, Dec drag	45, choice of early (Sep–Jan) or late (Dec–Mar)
2005–2006	10, choice of Sep or Dec.	45, choice of early (Sep–Jan) or late (Dec–Mar)
2006–2007	10, choice of Sep or Dec.	45, choice of early (Sep–Jan) or late (Dec–Mar)
2007–2008	10, choice of Sep or Dec.	45, choice of early (Oct–Jan) or late (Dec–Mar)
2008–2009	10, choice of Sep or Dec.	45, choice of early (Oct–Jan) or late (Dec–Mar)
2009–2010	10, choice of Sep or Dec–Jan.	45, choice of early (Sep–Jan) or late (Dec–Mar)
2010–2011	10, choice of Sep or Dec–Jan.	45, choice of early (Sep–Jan) or late (Dec–Mar)
2011–2012	10, choice of Sep or Dec–Jan.	45, choice of early (Sep–Jan) or late (Dec–Mar)
2012–2013	15, choice of Sep or Dec–Jan.	36, choice of early (Oct–Jan) or late (Dec–Mar)
2013–2014	15, choice of Sep or Dec–Jan.	38, choice of early (Oct–Jan) or late (Dec–Mar)

Table 3. 2013–14 Maine sea urchin fishing season calendars.

2013 - 2014 Sea Urchin Season for Maine Zone 1

O = Open = Closed

Early Season for Divers, Rakers and Trappers

September 2013						
S	M	Tu	W	Th	F	S
1	2	3	4	5	6	7
8	9 O	10 O	11 O	12 O	13	14
15	16 O	17 O	18 O	19 O	20	21
22	23 O	24 O	25 O	26 O	27	28
29	30 O					

October 2013						
S	M	Tu	W	Th	F	S
		1 O	2 O	3	4	5
6	7	8	9	10	11	12
13	14	15	16	17	18	19
20	21	22	23	24	25	26
27	28	29	30	31		

Late Season for Divers, Rakers and Trappers

December 2013						
S	M	Tu	W	Th	F	S
1	2 O	3 O	4 O	5	6	7
8	9 O	10 O	11 O	12 O	13	14
15	16 O	17 O	18 O	19 O	20 O	21
22	23 O	24	**25**	26	27	28
29	30 O	31 O				

Early Season for Draggers

December 2013						
S	M	Tu	W	Th	F	S
1	2 O	3 O	4 O	5	6	7
8	9 O	10 O	11 O	12 O	13	14
15	16 O	17 O	18 O	19 O	20	21
22	23 O	24 O	**25**	26	27	28
29	30 O	31 O				

Late Season for Draggers

December 2013						
S	M	Tu	W	Th	F	S
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	**25**	26	27	28
29	30 O	31 O				

January 2014						
S	M	Tu	W	Th	F	S
			1	2	3 O	4
5	6 O	7	8 O	9	10 O	11
12	13 O	14	15 O	16	17 O	18
19	20 O	21	22 O	23	24 O	25
26	27 O	28	29 O	30	31 O	

Table 3 continued.

2013 - 2014 Sea Urchin Season for Maine Zone 2

O = Open = Closed

Early Season for Divers, Rakers and Trappers

October 2013

S	M	Tu	W	Th	F	S
		1 O	2 O	3	4	5
6	7 O	8 O	9 O	10	11	12
13	14 O	15 O	16 O	17	18	19
20	21 O	22 O	23 O	24	25	26
27	28 O	29 O	30 O	31		

November 2013

S	M	Tu	W	Th	F	S
					1	2
3	4 O	5 O	6 O	7	8	9
10	11 O	12 O	13 O	14	15	16
17	18 O	19 O	20 O	21	22	23
24	25 O	26 O	27	**28**	29	30

December 2013

S	M	Tu	W	Th	F	S
1	2 O	3 O	4 O	5	6	7
8	9 O	10 O	11	12	13	14
15	16 O	17 O	18 O	19 O	20	21
22	23 O	24 O	**25**	26	27	28
29	30 O	31 O				

Late Season for Divers, Rakers and Trappers

December 2013

S	M	Tu	W	Th	F	S
1	2	3	4	5	6	7
8	9 O	10 O	11 O	12	13	14
15	16 O	17 O	18 O	19 O	20	21
22	23 O	24 O	**25**	26	27	28
29	30 O	31 O				

January 2014

S	M	Tu	W	Th	F	S
			1	2	3	4
5	6 O	7 O	8 O	9	10	11
12	13 O	14 O	15 O	16	17	18
19	20 O	21 O	22 O	23	24	25
26	27 O	28 O	29 O	30	31	

February 2014

S	M	Tu	W	Th	F	S
						1
2	3 O	4 O	5	6	7	8
9	10 O	11 O	12	13	14	15
16	**17**	18	19	20	21	22
23	24 O	25 O	26 O	27	28	

March 2014

S	M	Tu	W	Th	F	S
						1
2	3 O	4 O	5 O	6	7	8
9	10 O	11 O	12 O	13	14	15
16	17 O	18 O	19	20	21	22
23	24	25	26	27	28	29
30	31					

Early Season for Draggers

October 2013

S	M	Tu	W	Th	F	S
		1 O	2 O	3 O	4	5
6	7 O	8 O	9 O	10	11	12
13	14 O	15 O	16 O	17	18	19
20	21 O	22 O	23 O	24	25	26
27	28 O	29 O	30 O	31		

November 2013

S	M	Tu	W	Th	F	S
					1	2
3	4 O	5 O	6	7	8	9
10	11 O	12 O	13 O	14	15	16
17	18 O	19 O	20	21	22	23
24	25 O	26 O	27 O	**28**	29	30

December 2013

S	M	Tu	W	Th	F	S
1	2 O	3 O	4 O	5	6	7
8	9 O	10 O	11	12	13	14
15	16 O	17 O	18 O	19	20	21
22	23 O	24	**25**	26 O	27 O	28
29	30 O	31 O				

Late Season for Draggers

December 2013

S	M	Tu	W	Th	F	S
1	2 O	3 O	4 O	5	6	7
8	9 O	10 O	11	12	13	14
15	16 O	17 O	18 O	19	20	21
22	23 O	24	**25**	26 O	27 O	28
29	30 O	31 O				

January 2014

S	M	Tu	W	Th	F	S
			1 O	2	3	4
5	6 O	7 O	8 O	9	10	11
12	13 O	14 O	15	16	17	18
19	20 O	21 O	22	23	24	25
26	27 O	28 O	29	30	31	

February 2014

S	M	Tu	W	Th	F	S
						1
2	3 O	4 O	5	6	7	8
9	10 O	11 O	12	13	14	15
16	**17** O	18 O	19	20	21	22
23	24 O	25 O	26 O	27	28	

March 2014

S	M	Tu	W	Th	F	S
						1
2	3 O	4 O	5	6	7	8
9	10 O	11 O	12	13	14	15
16	17 O	18 O	19	20	21	22
23	24	25	26	27	28	29
30	31					

Table 4. Counts of Maine sea urchin licenses (issued annually for a calendar year)

	Zone 1					Zone 2					Statewide							
Year	Dive	Drag	Rake	Unk	Total	Dive	Drag	Rake	Unk	Total	Dive	Drag	Rake	Unk	Harv. Totals	Tender	Buyer	Proc.
1992											829	246			**1,075**			
1993											1,437	567			**2,004**			
1994											1,725	1,000			**2,725**	843		
1995	611	237	3		851	580	404	5		989	1,191	641	8		**1,840**	736	96	18
1996	501	167	2		670	562	327	4		893	1,063	494	6		**1,563**	730	70	19
1997	405	133	1		539	514	287	2		803	919	420	3		**1,342**	648	65	20
1998	348	95	1		444	460	260	1		721	808	355	2		**1,165**	544	51	18
1999	332	87	2		421	437	252	2		691	769	339	4		**1,112**	538	42	15
2000	313	74	2		389	407	242	2		651	720	316	4		**1,040**	530	31	18
2001	281	65	2		348	383	240	2		625	664	305	4		**973**	453	30	11
2002	246	53	2		301	343	242	1		586	589	295	3		**887**	355	23	12
2003	182	44	2		228	289	224	1		514	471	268	3		**742**	276	18	13
2004	134	30	2		166	261	206	1		468	395	236	3		**634**	212	12	12
2005	106	27	1		134	234	187	1		422	340	214	2		**556**	155	13	13
2006	83	24	0		107	213	178	1		392	296	202	1		**499**	150	13	12
2007	75	24	0		99	195	164	1		360	270	188	1		**459**	142	12	12
2008	61	21	0		82	188	163	1		352	249	184	1		**434**	138	13	12
2009	60	18	0		78	181	152	1		334	241	170	1		**412**	192	12	13
2010*	54	18	0		72	167	157	2		326	221	175	2		**398**	97	11	11
2011*	49	15	0		64	156	159	1		316	205	174	1		**380**	78	7	10
2012*	47	16	0		63	143	143	5		291	190	159	5		**354**	67	11	10
2013*	49	15	0	2	66	125	134	3	2	264	174	149	3	4	**330**	62	9	7
2014*	47	14	1		62	109	125	9	12*	255	156	139	10	12*	**317**	46	11	5

Early vs. Late

Early vs Late

	Zone 1											Zone 2											
	Early				Late					Undcl		Early					Late					Undcl		
Year	Dive	Drag	Rake	Total	Dive	Drag	Rake	Unk	Total	Dive	Drag	Dive	Drag	Rake	Unk	Total	Dive	Drag	Rake	Unk	Total	Rake	Drag	Unk
2003												155	90	1		246	134	134			268			
2004												125	78	1		204	136	128			264			
2005	34		1	35	60	3			63	12	24	115	77			192	119	110	1		230			
2006	41	2		43	40	4			44	2	18	96	69			165	117	109	1		227			
2007	38	2		40	37	6			43		16	90	54			144	105	110	1		216			
2008	36	1		37	25	8			33		12	67	49			116	121	114	1		236			
2009	35	14		49	25	2			27		2	71	55			126	110	97	1		208			
2010*	31	12		43	23	5			28		1	70	59	1		130	99	98	1		198			
2011*	18	11		29	31	4			35			62	62			124	94	97	1		192			
2012*	24	13		37	23	3			26			52	51	2		105	91	90	3		184		2	
2013*	28	12		40	21	2		2	25		1	42	49	1		92	83	85	2		170		2	
2014*	28	11		39	19	3	1		23			38	43	1	3	85	71	82	3	6	162	5		3

Notes:

No tender license until 1994.

No zones until 1995.

No buyer/processor permit until 1995.

No raker/trapper license until 1995.

Entry closed, no new harvester entrants 1995 - 1998.

Limited entry, harvester license lottery 1999 - 2004.

Entry closed, no new harvester entrants after 2004.

* 2010 - 2014 include about 10-20 tribal licenses, mostly draggers.

DMR does not always have information on whether tribal licenses are late or early, or dive, drag, or rake.

Table 5. Numbers of active sea urchin harvesters (sold at least two lots) during the 2011–12, 2012–13, and 2013–14 seasons, and mean age (years) of active harvesters in 2013–14 (bottom). 2014 data are preliminary.

Number of Active Harvesters (sold at least 2 lots) in 2011-12

	Zone 1	Zone 2	Total
Divers	29	111	140
Draggers	7	94	101
Total	36	205	241

Number of Active Harvesters (sold at least 2 lots) in 2012-13

	Zone 1	Zone 2	Total
Divers	32	82	114
Draggers	7	76	83
Rakers	0	2	2
Total	39	160	199

Number of Active Harvesters (sold at least 2 lots) in 2013-14

	Zone 1	Zone 2	Total
Divers	37	78	115
Draggers	6	80	86
Rakers	0	3	3
Total	43	161	204

Mean Age of Active Harvesters (sold at least 2 lots) in 2013-14

	Zone 1	Zone 2
Divers	50	46
Draggers	53	51

Table 6. Maine sea urchin landings by fishing season and zone, from NMFS port agent reports by county through 1995–96, and then from dealer reports.

	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 data are preliminary

Table 7 a–c. 2013–14 landings by zone, gear and month from dealer reports, with pounds (top), metric tons (middle) and as a percentage of the season total (bottom).

Pounds

	Zone 1			Zone 2			State Total
	Dive	Drag	Total	Dive&Rake	Drag	Total	
Sep	182,023	0	182,023	0	0	0	182,023
Oct	15,747	0	15,747	112,467	200,038	312,505	328,252
Nov	0	0	0	86,184	109,143	195,327	195,327
Dec	106,899	79,474	186,373	213,186	236,978	450,164	636,537
Jan	0	*	*	111,248	15,982	127,230	127,230
Feb	0	0	0	154,548	70,101	224,649	224,649
Mar	0	0	0	172,219	57,471	229,690	229,690
Total	304,669	79,474	384,143	849,852	689,713	1,539,565	1,923,708

Metric tons

	Zone 1			Zone 2			State Total
	Dive	Drag	Total	Dive&Rake	Drag	Total	
Sep	82.6		82.6				82.6
Oct				51.0	90.7	141.7	148.9
Nov				39.1	49.5	88.6	88.6
Dec	48.5	36.0	84.5	96.7	107.5	204.2	288.7
Jan		*	*	50.5	7.2	57.7	57.7
Feb				70.1	31.8	101.9	101.9
Mar				78.1	26.1	104.2	104.2
Total	138.2	36.0	174.2	385.5	312.8	698.3	872.6

Percent of Total

	Zone 1			Zone 2			State Total
	Dive	Drag	Total	Dive&Rake	Drag	Total	
Sep	9%		9%				9%
Oct	1%		1%	6%	10%	16%	17%
Nov				4%	6%	10%	10%
Dec	6%	4%	10%	11%	12%	23%	33%
Jan		*	*	6%	1%	7%	7%
Feb				8%	4%	12%	12%
Mar				9%	3%	12%	12%
Total	16%	4%	20%	44%	36%	80%	100%

**December and January are combined for Zone 1 to preserve the confidentiality of January data, and divers and rakers in Zone 2 are combined to preserve the confidentiality of the raker data.*
2014 data are preliminary.

Table 8 a–c. 2013–14 ex-vessel value, mean price per pound, and mean roe indices (%), by zone, gear and month from dealer reports. One pound = 0.454 kg.

Value ($)

	Zone 1			Zone 2			State Total
	Dive	Drag	Total	Dive&Rake	Drag	Total	
Sep	$398,356		$398,356				$398,356
Oct	$33,194		$33,194	$295,653	$536,405	$832,058	$865,252
Nov				$237,401	$258,867	$496,268	$496,268
Dec	$270,069	$145,010	$415,079	$771,998	$656,904	$1,428,902	$1,843,981
Jan		*	*	$282,656	$34,478	$317,133	$317,133
Feb				$409,783	$165,852	$575,634	$575,634
Mar				$445,311	$125,169	$570,480	$570,480
Total	$701,620	$145,010	$846,629	$2,442,801	$1,777,675	$4,220,476	$5,067,105

Mean Price per Pound ($)

	Zone 1			Zone 2			State Avg.
	Dive	Drag	All	Dive&Rake	Drag	All	
Sep	$2.19		$2.19				$2.19
Oct	$2.11		$2.11	$2.63	$2.68	$2.66	$2.64
Nov				$2.75	$2.37	$2.54	$2.54
Dec	$2.53	$1.82	$2.23	$3.62	$2.77	$3.17	$2.90
Jan		*	*	$2.54	$2.16	$2.49	$2.49
Feb				$2.65	$2.37	$2.56	$2.56
Mar				$2.59	$2.18	$2.48	$2.48
Season	$2.30	$1.82	$2.20	$2.87	$2.58	$2.74	$2.63

Mean Roe Index (%)

	Zone 1			Zone 2			State Avg.
	Dive	Drag	All	Dive&Rake	Drag	All	
Sep	9.3		9.3				9.3
Oct	8.8		8.8	12.1	12.8	12.5	12.3
Nov				13.3	12.2	12.7	12.7
Dec	11.0	8.6	10.3	13.7	13.4	13.5	12.9
Jan		*	*	13.4	12.7	13.3	13.2
Feb				13.5	13.3	13.4	13.4
Mar				13.4	11.6	12.8	12.8
Season	9.6	8.6	9.5	13.3	12.8	13.1	12.3

**December and January are combined for Zone 1 to preserve the confidentiality of January data, and divers and rakers in Zone 2 are combined to preserve the confidentiality of the raker data.*
2014 data are preliminary.

Table 9 a–b. 2013–14 number of fishing trips (above) and mean pounds landed per trip (below), by zone, gear and month, from dealer reports. Note that two divers fishing from the same vessel on the same day are counted as two trips. One pound = 0.454 kg.

Number of Fishing Trips

	Zone 1			Zone 2			State Total
	Dive	Drag	Total	Dive&Rake	Drag	Total	
Sep	265		265				265
Oct	28		28	204	365	569	597
Nov				150	202	352	352
Dec	141	60	201	403	454	857	1,058
Jan		*	*	202	55	257	257
Feb				256	137	393	393
Mar				293	124	417	417
Total	434	60	494	1,508	1,337	2,845	3,339

Mean Landings (lbs) per Trip

	Zone 1			Zone 2			State Avg.
	Dive	Drag	All	Dive&Rake	Drag	All	
Sep	687		687				687
Oct	562		562	551	548	549	550
Nov				575	540	555	555
Dec	758	1,325	927	529	522	525	602
Jan		*	*	551	291	495	495
Feb				604	512	572	572
Mar				588	463	551	551
Total	702	1,325	778	564	516	541	576

**December and January are combined for Zone 1 to preserve the confidentiality of January data, and divers and rakers in Zone 2 are combined to preserve the confidentiality of the raker data.*

2014 data are preliminary.

Table 10. Maine sea urchin port sampling summary statistics and sampling intensity. 1000 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	Number of urchins per lb
1994-95	37,137,290	404	249,705	0.67%			0	0%	
1995-96	30,262,499	180	115,613	0.38%	99.78	137,575,329	5,585	0.0041%	4.5
1996-97	23,854,609	537	330,568	1.39%	95.91	112,820,251	10,674	0.0095%	4.7
1997-98	16,948,700	464	280,111	1.65%	98.25	78,247,551	9,274	0.0119%	4.6
1998-99	16,702,938	499	308,119	1.84%	101.09	74,942,759	9,839	0.0131%	4.5
1999-00	14,055,115	416	243,592	1.73%	98.86	64,491,089	8,320	0.0129%	4.6
2000-01	11,817,960	343	198,336	1.68%	90.70	59,099,886	5,919	0.0100%	5.0
2001-02	7,850,572	314	167,638	2.14%	91.53	38,906,817	4,560	0.0117%	5.0
2002-03	6,700,632	219	126,003	1.88%	89.82	33,837,499	2,940	0.0087%	5.0
2003-04	6,334,522	166	97,767	1.54%	93.56	30,710,274	1,960	0.0064%	4.8
2004-05	3,787,096	111	70,936	1.87%	89.46	19,201,854	1,420	0.0074%	5.1
2005-06	3,852,905	116	90,881	2.36%	95.11	18,375,906	1,660	0.0090%	4.8
2006-07	3,029,491	117	87,047	2.87%	101.86	13,490,057	1,415	0.0105%	4.5
2007-08	2,949,228	107	74,506	2.53%	105.42	12,689,185	1,260	0.0099%	4.3
2008-09	3,099,506	60	39,902	1.29%	103.44	13,591,481	978	0.0072%	4.4
2009-10	3,113,181	124	86,969	2.79%	100.52	14,048,395	2,112	0.0150%	4.5
2010-11	2,301,633	205	125,185	5.44%	94.68	11,026,962	3,740	0.0339%	4.8
2011-12	2,331,099	130	70,318	3.02%	95.25	11,100,476	2,300	0.0207%	4.8
2012-13	1,838,181	188	106,130	5.77%	100.31	8,312,439	2,780	0.0334%	4.5
***2013-14**	1,923,708	129	76,410	3.97%	96.04	9,085,641	1,900	0.0209%	4.7

* Landings are preliminary

Table 11. Maine sea urchin landings per unit effort (lbs/hr) medians by management zone and season, for divers (left) and draggers (right), from harvester interviews. One pound = 0.454 kg. One ft = 305 meter.

	Diver pounds per bottom hour			
Season	Zone 1		Zone 2	
	median	std err	median	std err
1994-95	150	8.13	220	11.64
1995-96	126	9.38	208	13.48
1996-97	132	6.40	201	6.73
1997-98	117	6.79	189	7.78
1998-99	154	6.10	185	7.34
1999-00	146	6.00	176	8.34
2000-01	161	10.43	152	7.56
2001-02	136	5.29	130	7.44
2002-03	135	7.51	145	8.71
2003-04	128	9.99	164	14.09
2004-05	120	12.75	150	10.50
2005-06	137	15.34	189	10.81
2006-07	122	11.14	177	9.97
2007-08	122	17.65	152	9.95
2008-09	147	13.74	154	13.34
2009-10	166	18.36	145	9.30
2010-11	158	16.29	124	12.31
2011-12	162	20.40	122	8.00
2012-13	170	13.23	126	5.79
2013-14	153	23.18	164	11.80

	Dragger pounds per ft width tow hour			
Season	Zone 1		Zone 2	
	median	std err	median	std err
1994-95	24.56	5.07	31.33	8.06
1995-96	17.90	7.65	28.42	7.75
1996-97	23.10	5.79	24.80	3.38
1997-98	28.12	5.31	28.53	4.18
1998-99	27.25	3.18	33.61	3.46
1999-00	19.39	11.41	28.31	3.25
2000-01	20.55	2.01	29.14	3.93
2001-02			22.47	2.84
2002-03			25.93	3.23
2003-04			26.38	3.21
2004-05			23.40	3.86
2005-06			34.98	3.81
2006-07			35.24	4.94
2007-08			29.25	11.06
2008-09			28.56	5.62
2009-10			23.46	4.37
2010-11			19.03	3.35
2011-12			20.90	3.41
2012-13			22.60	3.15
2013-14			22.83	4.24

Table 12. Maine sea urchin harvester fishing depths from harvester interviews by season, gear, and zone. Data are the median minimum depth fished (feet) response, the median maximum depth fished (feet) response, and the number of interviews (N). 2012–14 data for draggers are not available yet. One foot = 0.305 meters.

	Diver Median Depths					
	Zone 1			Zone 2		
Season	Min.	Max.	N	Min.	Max.	N
1994-95	10	20	209	9	20	132
1995-96	15	35	97	10	30	113
1996-97	5	20	176	6	20	249
1997-98	6	25	183	8	25	194
1998-99	6	22	229	6	20	193
1999-00	5	25	168	6	20	159
2000-01	10	25	165	10	25	105
2001-02	10	20	146	12	25	120
2002-03	15	20	79	15	25	101
2003-04	20	20	68	20	30	60
2004-05	15	20	30	20	20	51
2005-06	10	20	24	20	22.5	64
2006-07	10	20	26	15	20	55
2007-08	10	20	27	20	20	51
2008-09	5	20	7	20	20	31
2009-10	13.5	20	12	12	20	57
2010-11	10	20	22	10	20	114
2011-12	0	15	18	10	18	53
2012-13	0	15	30	10	20	88
2013-14	0	15	26	10	20	70

	Dragger Median Depths					
	Zone 1			Zone 2		
Season	Min.	Max.	N	Min.	Max.	N
1994-95	30	42	13	10	30	49
1995-96	10	35	11	10	40	47
1996-97	11	39	10	12	50	81
1997-98	10	40	11	13	60	63
1998-99	12	60	7	16	50	67
1999-00	22	44	3	10	40	75
2000-01	13.5	22	6	11	40	60
2001-02				20	30	47
2002-03				30	39	39
2003-04				20	40	38
2004-05				35	45	28
2005-06				27.5	40	26
2006-07				30	40	30
2007-08				40	40	29
2008-09				22.5	40	22
2009-10				25	50	47
2010-11				20	40	67
2011-12				20	30	53
2012-13						
2013-14						

Fewer than 3 dragger interviews per season in Zone 1 since 2000-01.

Table 13. Maine sea urchin harvester median pounds per tray from harvester interviews by season, gear, and zone. One pound (lb) = 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	86.4	2.66	85.7	1.52
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	89.6	0.95

	Dragger Median Pounds per Tray			
Season	Zone 1		Zone 2	
	median	std err	median	std err
2004-05			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

Fewer than 3 dragger interviews per season in Zone 1 since 2000-01.

Table 14. Maine sea urchin diameters (mm) by management zone and season, 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									
Season	No. of samples	Total urchins	Mean	StDev	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

Zone 2									
Season	No. of samples	Total urchins	Mean	StDev	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

Table 15. Maine 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	642	71	589
2014	144	7,007	33,000	3,225	174	174	135	133	267	1,021	83	328

Table 16. List of sea urchin survey regions and depth strata with estimated area (m^2) of rock and gravel substrates.

Region Name	Region No.	Depth stratum	Habitat Area (m^2) for stratum	Habitat Area (m^2) for region
Zone 1				
Kittery to Phippsburg	1	1 (0-5m)	3.89E+07	1.65E+08
		2 (5-10m)	5.98E+07	
		3 (10-15m)	6.58E+07	
Phippsburg - Boothbay -	2	1	2.07E+07	7.35E+07
- Bristol - Bremen		2	2.66E+07	
		3	2.62E+07	
Friendship - Port Clyde -	3	1	5.35E+07	1.28E+08
- Tenants - Rockland		2	3.70E+07	
		3	3.75E+07	
Zone 2				
Isleboro - Vinalhaven -	4	1	1.55E+08	2.74E+08
- Stonington		2	6.40E+07	
		3	5.51E+07	
Blue Hill - Swans Is -	5	1	5.23E+07	1.48E+08
- Mount Desert Is		2	4.95E+07	
		3	4.64E+07	
Frenchman Bay - Winter	6	1	3.81E+07	6.20E+07
Harbor - Corea - Steuben		2	1.20E+07	
		3	1.19E+07	
Milbridge - Addison -	7	1	1.23E+08	1.80E+08
- Jonesport		2	3.66E+07	
		3	2.05E+07	
Roque Is - Machiasport -	8	1	5.40E+07	9.79E+07
- Cutler - W. Quoddy Hd		2	2.66E+07	
		3	1.74E+07	
Cobscook Bay	9	1	3.44E+07	5.20E+07
		2	8.72E+06	
		3	8.90E+06	

Table 17. Maine spring dive survey stratified mean sea urchin biomass (grams per square meter), with standard errors (SE), by region (1–9) and zone (1–2), depths 0–15m, all survey years, not including industry sites. Note that Region 1 in Zone 1 was not surveyed in 2012 and 2013. To estimate the overall Zone 1 means in those years, the 2011 values for Region 1 were used again for 2012 and 2013.

Zone	1								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

Table 18. 2014 Maine spring dive survey stratified mean sea urchin biomass (grams per square meter) by depth stratum and region. Darkest gray shading indicates the depth of highest biomass for each region; no shading indicates the depth of lowest biomass.

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

Table 19. Maine spring dive survey stratified mean sea urchin abundance (number per square meter), with standard errors (SE), by region (1–9) and zone (1–2), depths 0–15m, all survey years, not including industry sites. Note that Region 1 in Zone 1 was not surveyed in 2012 and 2013. To estimate the overall Zone 1 means in those years, the 2011 values for Region 1 were used again for 2012 and 2013.

Zone	1								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

Table 20. Maine spring dive survey stratified mean sea urchin abundance (number per square meter, by zone (1–2), region (1–9), and size category (Undersized, Legal, or Oversized), depths 0–15m, all survey years, not including industry sites. Note that Region 1 in Zone 1 was not surveyed in 2012 and 2013.

Zone	1									2																
Region	1			2			3			4			5			6			7			8			9		
Size	U	L	O	U	L	O	U	L	O	U	L	O	U	L	O	U	L	O	U	L	O	U	L	O	U	L	O
2001	0.16	0.02	0.00	1.75	1.07	0.05	2.29	1.47	0.03	5.06	0.92	0.09	4.09	0.61	0.00	8.52	2.12	0.01	4.65	2.38	0.18	8.89	3.06	0.28	37.69	1.01	0.01
2002	0.82	0.03	0.01	3.24	1.61	0.06	4.08	1.00	0.05	1.35	0.92	0.11	2.51	0.52	0	9.46	2.61	0.01	3.83	1.51	0.06	9.52	2.73	0.10	45.26	0.84	0
2003	0.32	0.03	0.00	0.53	0.56	0.01	1.85	1.16	0.01	1.51	0.50	0.03	1.76	0.97	0.00	6.01	2.38	0	2.26	1.41	0.12	4.13	2.41	0.09	35.98	1.78	0
2004	0.12	0	0.02	0.49	0.24	0.00	0.34	0.16	0.01	0.58	0.41	0.01	1.31	0.42	0	2.64	1.70	0.01	0.93	0.92	0.04	2.74	2.57	0.02	35.13	1.32	0.02
2005	0.15	0.01	0	0.29	0.06	0.01	1.06	0.45	0.02	0.37	0.05	0.01	0.75	0.41	0	4.69	1.55	0	0.86	1.01	0.07	3.47	3.30	0.10	27.25	1.16	0
2006	0.51	0.03	0.01	0.53	0.16	0.00	0.57	0.42	0.00	1.70	0.55	0.01	0.50	0.33	0	1.58	0.49	0.00	0.23	0.66	0.03	3.00	3.23	0.20	26.77	1.33	0.03
2007	0.88	0.03	0	0.21	0.12	0.01	0.42	0.09	0	1.78	1.05	0.03	0.83	0.56	0.01	1.02	0.32	0.00	0.06	0.12	0.03	2.83	2.22	0.06	23.62	0.66	0.02
2008	0.83	0.01	0	2.28	0.21	0.04	1.05	0.09	0	6.10	0.86	0.00	1.19	0.24	0.01	3.03	1.03	0.07	0.24	0.65	0.14	3.18	3.03	0.11	28.93	0.93	0.02
2009	0.13	0	0.00	0.26	0.06	0.02	1.33	0.05	0.01	3.59	0.32	0.05	4.50	0.25	0.01	3.79	0.52	0	3.02	1.60	0.10	4.97	3.51	0.18	22.92	1.39	0
2010	0.63	0.01	0	0.27	0.03	0.02	3.09	0.27	0.01	7.53	0.96	0	3.69	0.28	0	3.12	2.06	0.02	0.79	0.54	0.03	2.92	2.39	0.12	24.57	1.02	0.02
2011	0.13	0	0	0.67	0.14	0.01	1.05	0.19	0.05	3.75	1.10	0	2.64	0.30	0	1.34	0.59	0	0.13	0.29	0.05	2.89	1.08	0.12	15.90	0.90	0
2012				0.06	0.01	0	0.55	0.24	0.05	2.99	0.89	0	1.98	0.26	0.00	3.59	0.99	0.00	0.27	0.12	0.02	4.38	0.98	0.05	14.40	1.69	0
2013				0.16	0.01	0	0.93	0.06	0.02	1.13	0.41	0.01	0.99	0.29	0	0.95	0.75	0.02	0.32	0.46	0.08	3.07	1.93	0.03	20.43	1.41	0
2014	0.12	0.00	0	0.36	0.02	0	2.08	0.44	0.02	5.38	0.93	0	0.67	0.25	0	0.60	0.09	0	0.20	0.08	0.04	3.89	2.29	0.03	27.90	1.41	0.00

Table 21. 2014 Maine spring dive survey mean sea urchin abundance (number per square meter) by region, depth stratum (1–3), and size category (Undersized, Legal, and Oversized).

		Depth Stratum									All depths			All Sizes
		1 (0-5m)			2 (5-10m)			3 (10-15m)						
Zone	Region	Under	Legal	Over	Under	Legal	Over	Under	Legal	Over	Under	Legal	Over	
1	1	0.106	0	0	0.207	0.007	0	0.060	0	0	0.12	0.002	0	0.13
	2	0.098	0.021	0	0.524	0.037	0	0.405	0	0	0.36	0.02	0	0.38
	3	2.911	0.973	0.041	1.473	0.117	0	1.486	0	0	2.08	0.44	0.02	2.53
2	4	8.580	1.498	0	2.248	0.355	0	0.017	0	0	5.38	0.93	0	6.31
	5	1.005	0.564	0	0.401	0.152	0	0.579	0	0	0.67	0.25	0	0.92
	6	0.568	0.098	0	0.767	0.017	0	0.532	0.146	0	0.60	0.09	0	0.69
	7	0.162	0.067	0.013	0.296	0.122	0.175	0.288	0.053	0	0.20	0.08	0.04	0.32
	8	3.776	2.606	0.037	4.145	1.735	0.003	3.878	2.141	0.031	3.89	2.29	0.03	6.21
	9	33.071	1.664	0.003	20.573	1.238	0	15.086	0.594	0	27.90	1.41	0.002	29.31

Table 22. Maine spring dive survey stratified mean percent algal cover by zone (1–2), region (1–9) and type (encrusting above, understory middle, and canopy below), for depths 0–15 m. Note that Region 1 in Zone 1 was not surveyed in 2012–13.

Encrusting Algae											
Zone	1				2						
Region	1	2	3	1-3 (Zone 1)	4	5	6	7	8	9	4-9 (Zone 2)
2001	37	37	53	43	52	44	76	62	70	45	56
2002	62	73	84	72	71	77	95	77	80	31	74
2003	47	73	65	58	68	63	75	58	63	45	64
2004	29	35	40	34	37	53	67	52	63	47	49
2005	39	40	68	49	58	72	80	60	56	35	61
2006	37	43	51	43	50	54	85	66	65	42	58
2007	38	40	49	42	49	51	75	49	55	27	51
2008	65	51	60	60	58	63	81	69	62	28	62
2009	41	67	59	52	60	61	74	71	70	33	63
2010	45	42	44	44	55	46	67	60	65	37	55
2011	52	64	56	56	52	62	72	67	55	29	58
2012		49	37	46	40	46	71	60	58	26	49
2013		55	49	52	42	40	67	75	62	38	53
2014	40	57	50	47	52	31	58	55	57	29	48

Understory Algae											
Zone	1				2						
Region	1	2	3	1-3 (Zone 1)	4	5	6	7	8	9	4-9 (Zone 2)
2001	62	43	50	54	35	40	24	30	37	14	33
2002	59	66	54	59	50	33	18	53	44	6	41
2003	66	63	52	61	46	39	33	46	42	8	41
2004	64	68	58	63	53	49	39	45	42	12	45
2005	61	65	45	56	44	31	23	53	46	5	40
2006	60	64	49	57	47	41	22	45	33	3	39
2007	47	60	54	52	34	40	37	59	60	10	42
2008	57	57	52	56	41	40	36	62	61	8	45
2009	61	65	58	61	38	38	38	55	45	10	41
2010	55	53	53	54	44	31	28	54	52	7	41
2011	50	49	53	51	34	40	34	52	45	7	39
2012		53	48	50	32	31	33	56	49	2	37
2013		59	60	55	42	47	41	54	44	6	43
2014	54	64	60	58	37	42	48	60	46	3	43

Canopy Algae											
Zone	1				2						
Region	1	2	3	1-3 (Zone 1)	4	5	6	7	8	9	4-9 (Zone 2)
2001	24	24	27	25	25	19	29	59	60	16	36
2002	23	18	33	25	42	31	45	63	59	15	45
2003	21	27	34	27	44	32	48	69	62	12	48
2004	25	34	47	34	44	42	55	74	55	15	51
2005	28	27	49	35	43	49	57	65	49	14	49
2006	23	19	26	23	33	27	45	51	36	7	36
2007	16	13	16	15	18	17	43	46	36	16	28
2008	16	23	31	23	27	43	50	56	53	10	40
2009	21	26	40	28	24	31	48	49	49	8	35
2010	14	32	30	23	26	19	44	55	50	7	34
2011	15	21	20	18	19	23	33	44	36	9	28
2012		13	26	18	15	20	35	40	40	7	26
2013		11	20	16	21	17	38	44	36	10	28
2014	19	20	30	23	19	26	45	38	28	3	26

Table 23a–b. Top: Maine spring dive survey fixed sites for Regions 1–3 (Zone 1), mean sea urchin biomass (g·m^{-2}), whether biomass decreased (Dec) or increased (Inc) over the time series, and whether there was a five-fold (5x) decrease or increase.

Bottom: Mean percent (%) fleshy algal cover (understory+canopy) and whether there had been an increase over time at the sites that exhibited a five-fold urchin biomass decline. Note that algal cover can be more than 100%.

Mean Sea Urchin Biomass (g·m^{-2})																					
Region	1							2							3						
Site	1A	1D	1F	1H	1I	1X	1Y	2A	2B	2D	2E	2H	2X	2Y	3A	3B	3D	3F	3H	3X	3Y
Year																					
2001	0	0	0.0	9	71			208	105	50	1030	766			98	46	208	267	808		
2002	0	1	13	2				91	356	18	391	385			57	3	77	485	12		
2003	0	1	0	0				86	14	0	201	437			121	0	9	222	140		
2004	0	3	0	0				1	41	3	54	235			92	0	4	147	20		
2005	0	3	0	0	3	48	0	15	16	4	53	23	6	3	103	4	14	126	26	55	1253
2006	0	4	5	1	12	140	3	28	7	4	44	200	2	6	163	1	3	21	2	0	1
2007	0	3	2	2	0	112	1	55	9	1	3	1	1	463	81	0	0	0	6	2	0
2008	0	5	4	1	1	104	1	47	9	1	6	4	2	369	195	10	1	15	18	2	3
2009	0	6	17	2	2	0	5	16	3	4	3	2	12	868	97	7	8	37	29	5	8
2010	0	3	3	2	0			1	5	0	39	7			96	31	25	68	59		
2011	0	1	0.3	4	0			1	1	1	1	6			209	7	3	16	4		
2012								1	4	1	0	21			147	4	3	9	11		
2013								0	8	2	1	1			151	6	3	0			
Inc or Dec:	same	Inc	Inc	Dec	Dec	Dec	Inc	Dec	Dec	Dec	Dec	Dec	Inc	Inc	Inc	Dec	Dec	Dec	Dec	Dec	Dec
5x Dec?					Yes			Yes	Yes	Yes	Yes	Yes					Yes	Yes	Yes	Yes	Yes
5x Inc?														Yes							

Mean Percent (%) Cover of Fleshy Algae (Understory + Canopy)																					
Region	1							2							3						
Site	1A	1D	1F	1H	1I	1X	1Y	2A	2B	2D	2E	2H	2X	2Y	3A	3B	3D	3F	3H	3X	3Y
Year																					
2001	107	99	89	82	86			51	89	75	49	56			22	113	45	107	87		
2002	72	85	71	73				90	134	82	87	71			32	93	101	99	83		
2003	82	93	123	106				80	132	70	47	79			53	95	74	89	58		
2004	90	101	62	95				106	131	99	116	102			37	126	110	88	105		
2005	105	111	93	90	78	122	88	94	127	83	104	86	87	92	49	88	106	73	64	110	61
2006	97	104	76	96	93	125	91	91	114	83	86	71	67	75	31	95	81	67	52	115	100
2007	72	81	59	75	74	91	79	67	76	64	78	71	73	30	25	81	72	93	43	100	95
2008	75	91	68	84	114	94	87	64	112	89	113	82	82	51	38	80	80	91	63	108	100
2009	78	93	74	95	99	59	79	89	119	96	103	91	96	49	32	90	97	110	78	115	118
2010	82	76	86	63	93			79	117	85	116	83			32	97	79	89	68		
2011	74	84	45	76	95			57	84	59	108	45			25	68	86	97	61		
2012								42	69	65	79	87			27	88	96	91	67		
2013								40	85	47	85	57			33	79	89	106			
Increase?					Yes			No	No	No	Yes	Yes					Yes	No	No	Yes	Yes

Table 23c–d. Top: Maine spring dive survey fixed sites for Regions 4–6 (western Zone 2), mean sea urchin biomass (g·m^{-2}), whether biomass decreased (Dec) or increased (Inc) over the time series, and whether there was a five-fold (5x) decrease or increase.

Bottom: Mean percent (%) fleshy algal cover (understory+canopy) and whether there had been an increase over time at the sites that exhibited a five-fold urchin biomass decline. Note that algal cover can be more than 100%.

Mean Sea Urchin Biomass (g·m^{-2})																					
Region	4							5							6						
Site	4A	4B	4C	4D	4E	4X	4Y	5A	5B	5C	5D	5H	5X	5Y	6A	6C	6D	6E	6H	6X	6Y
Year																					
2001	128	807	188	129	1	168		277	217	16	262	0			1335	724	848	46	22		
2002	179	456	41	368	0		152	439	2	0	316	0			518	297	1191	100	115		
2003	235	317	59	104	0			605	0	0	85	0			193	8	675	16	63		
2004	126	0	1	40	0			114	3	0	4	0			25	0	311	2	13		
2005	82	4	0	5	0	0	24	26	0	1	4	0	86	934	7	0	1109	15	96	427	125
2006	181	0	0	3	0	0	4	82	0	0	4	0	0	630	0	1	427	16	47	283	4
2007	129	0	1	0	0	0	1	100	2	0	0	0	0	145	0	0	169	33	30	2	1
2008	262	166	13	7	0	1	14	73	6	2	7	0	6	309	2	2	756	11	87	190	14
2009	207	59	7	4	30	5	9	219	6	0	41	3	12	8	38	16	315	35	82	2	10
2010	168	86	8	12	111			290	15	3	36	3			4	1	102	22	66		
2011	174	121	1	7	5			263	29	7	16	2			20	4	116	10	111		
2012	92	19	12	4	2			279	27	7	42	1			0	1	74	6	111		
2013	137	12	19	0	14			281	13	0	5	0			2	3	71	0	29		
Inc or Dec:	Inc	Dec	Dec	Dec	Inc	Dec	Dec	Inc	Dec	Dec	Dec	Dec	Dec	Dec	Dec	Dec	Dec	Dec	Inc	Dec	Dec
5x Dec?		Yes	Yes	Yes		Yes	Yes		Yes		Yes				Yes	Yes	Yes	Yes			Yes
5x Inc?					Yes							Yes									

Mean Percent (%) Cover of Fleshy Algae (Understory + Canopy)																					
Region	4							5							6						
Site	4A	4B	4C	4D	4E	4X	4Y	5A	5B	5C	5D	5H	5X	5Y	6A	6C	6D	6E	6H	6X	6Y
Year																					
2001	37	92	40	110	75	84		51	43	94	47	99			55	45	43	82	20		
2002	32	94	63	122	74		56	10	61	107	72	74			63	42	27	86	52		
2003	50	57	72	80	81			10	42	106	86	97			76	59	27	104	40		
2004	79	115	84	119	65			53	90	139	93	96			101	78	69	84	40		
2005	46	79	79	113	90	87	111	28	85	121	79	93	52	35	64	59	50	84	70	52	60
2006	28	109	84	94	91	59	104	33	57	107	52	95	67	41	60	48	45	73	49	50	80
2007	24	82	67	78	85	57	92	18	78	87	65	69	61	56	82	49	42	93	74	62	68
2008	35	58	59	110	91	65	128	41	101	111	88	86	85	83	99	48	89	98	99	51	95
2009	27	89	64	121	77	83	118	20	95	116	95	85	83	60	73	64	82	83	59	94	79
2010	42	61	68	119	81			37	77	117	54	73			93	42	82	91	59		
2011	29	57	72	100	78			16	92	95	84	68			64	53	63	78	28		
2012	40	77	54	92	76			14	71	97	53	66			82	60	79	79	63		
2013	55	84	72	104	63			28	66	97	77	67			83	89	89	89	28		
Increase?		No	Yes	No		No	Yes		Yes		Yes				Yes	Yes	Yes	Yes			Yes

Table 23e–f. Top: Maine spring dive survey fixed sites for Regions 7–9 (eastern Zone 2), mean sea urchin biomass (g·m^{-2}), whether biomass decreased (Dec) or increased (Inc) over the time series, and whether there was a five-fold (5x) decrease or increase.

Bottom: Mean percent (%) fleshy algal cover (understory+canopy) and whether there had been an increase over time at the sites that exhibited a five-fold urchin biomass decline. Note that algal cover can be more than 100%.

Mean Sea Urchin Biomass (g·m^{-2})																					
Region	7							8							9						
Site	7A	7D	7F	7G	7H	7X	7Y	8A	8B	8F	8H	8I	8X	8Y	9A	9B	9C	9D	9H	9X	9Y
Year																					
2001	1008	302	507	1174	3			275	47	931	896	1420			1347	462	430	298	340		
2002	564	294	125	280	169			383	15	629	729				767	454	408	147	385		
2003	396	87	6	0	42			436	6	477	809				498	697	789	262	418		
2004	269	0	1	1	23			87	28	418	651	718		589	676	473	576	355	245		
2005	153	4	27	2	0	948	394	122	15	274	963	552	414	527	559	366	475	153	227	65	102
2006	0	0	0	2	3	793	259	138	56	305	1291	557	461	429	270	401	493	64	250	64	46
2007	0	1	2	11	0	740	976	105	11	130	1366	310	876	508	126	303	376	66	334	30	91
2008	3	0	0	0	0	1590	1060	86	49	293	1392	364	472	390	212	335	351	121	346	58	153
2009	2	1	0	0	0	1060	355	33	19	231	1612	399	700	142	258	242	552	135	332	69	85
2010	2	12	2	1				5	74	316	1870				233	322	388	156	344		
2011	0	2	0	0	0			1	29	75	1406	272			223	315	437	67	293		
2012	30	6	0	0	0			7	3	182	1729	138			170	256	473	277	282		
2013	5	5	0	0	0			12	0	70	1915	23			213	282	566	135	354		
Inc or Dec:	Dec	Dec	Dec	Dec	Dec	Inc	Dec	Dec	Dec	Dec	Inc	Dec	Inc	Dec	Dec	Dec	Inc	Dec	Inc	Inc	Dec
5x Dec?	Yes	Yes	Yes	Yes	Yes			Yes	Yes	Yes		Yes									
5x Inc?																					

Mean Percent (%) Cover of Fleshy Algae (Understory + Canopy)																					
Region	7							8							9						
Site	7A	7D	7F	7G	7H	7X	7Y	8A	8B	8F	8H	8I	8X	8Y	9A	9B	9C	9D	9H	9X	9Y
Year																					
2001	35	43	101	111	147			120	125	63	44	64			0	0	86	19	8		
2002	35	59	125	140	153			77	136	86	52				0	0	79	32	9		
2003	29	69	100	131	120			76	115	108	54				0	0	104	30	6		
2004	49	96	115	138	119			94	121	91	49	72		24	0	0	78	55	8		
2005	48	63	127	125	145	27	88	100	127	75	33	62	60	17	0	0	75	30	0	82	78
2006	39	74	108	88	128	8	67	59	108	58	28	47	80	12	0	0	62	28	1	78	102
2007	41	84	88	70	146	54	75	101	117	91	24	59	61	29	0	0	89	39	1	105	80
2008	54	96	82	79	157	26	84	116	117	98	29	100	66	54	0	0	82	52	3	108	92
2009	49	86	118	123	157	28	88	98	139	98	16	73	77	67	0	0	69	47	1	88	101
2010	85	77	109	98				99	144	57	23				0	1	81	51	0		
2011	49	84	97	84	126			90	100	59	19	55			2	1	52	32	0		
2012	35	85	75	84	121			95	101	85	7	50			0	0	55	31	1		
2013	57	82	72	88	128			90	108	78	28	53			0	0	51	44	0		
Increase?	Yes	Yes	No	No	No			No	No	Yes		No									

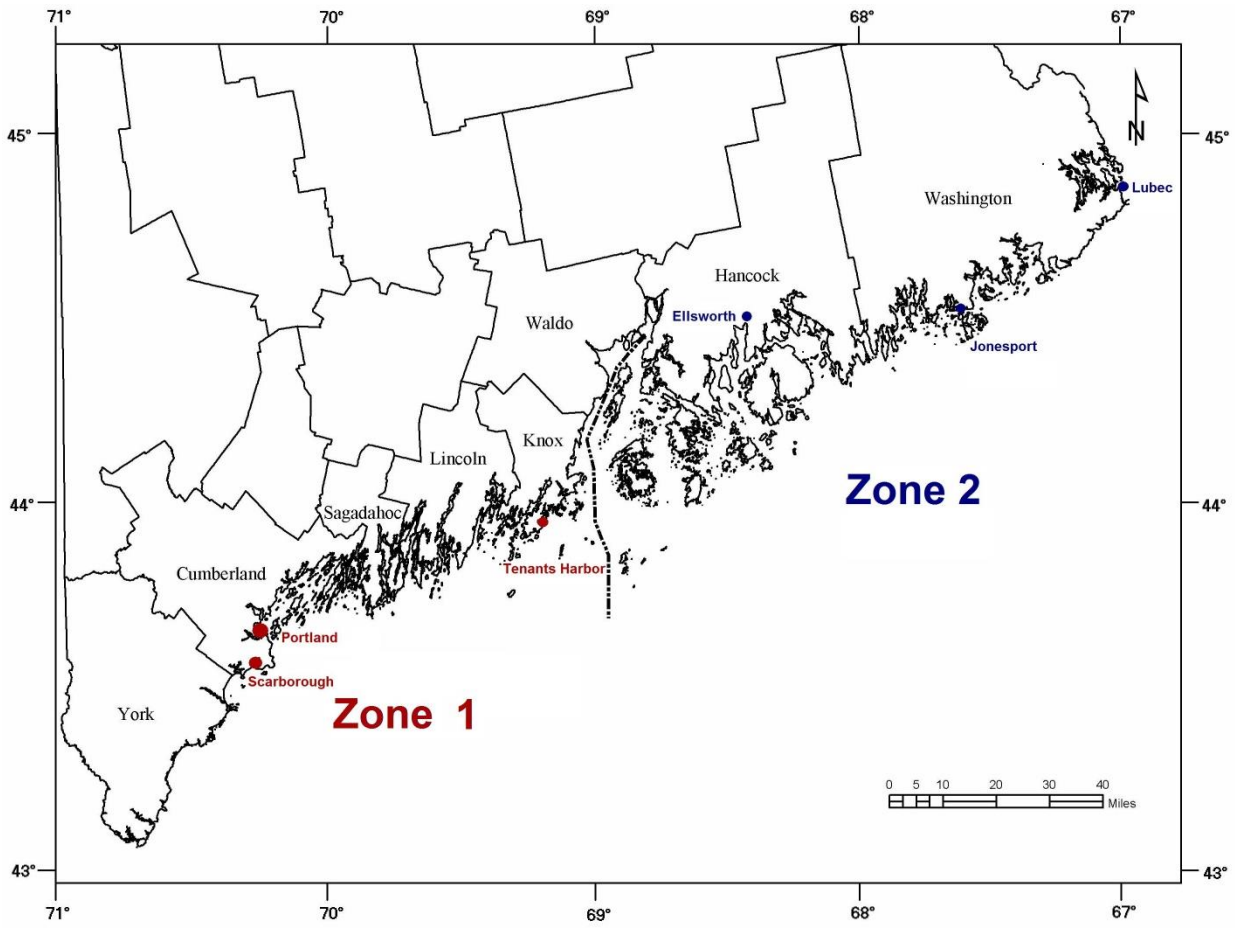
Table 24. Percentage of evaluated quadrats in the Maine spring dive survey that had an estimated 300 g·m^{-2} or more of sea urchins, by year, region, and zone. Note that Region 1 was not surveyed in 2012 and 2013, and its value was assumed to be 0% (unchanged from 2011) for those years when calculating the overall Zone 1 value.

Percentage of Quadrats with at least 300g of Sea Urchins											
Zone	1				2						
Region	1	2	3	1-3 (Zone 1)	4	5	6	7	8	9	4-9 (Zone 2)
2001	0%	10%	16%	9%	11%	11%	37%	38%	54%	61%	35%
2002	0%	18%	17%	12%	8%	8%	43%	27%	51%	48%	31%
2003	1%	5%	14%	6%	6%	9%	28%	25%	38%	53%	26%
2004	0%	3%	3%	2%	4%	4%	12%	18%	33%	54%	21%
2005	0%	1%	4%	2%	1%	4%	15%	15%	34%	47%	19%
2006	0%	2%	3%	2%	7%	5%	6%	7%	37%	42%	19%
2007	0%	2%	1%	1%	9%	5%	4%	3%	30%	35%	14%
2008	0%	2%	1%	1%	7%	3%	9%	10%	35%	34%	17%
2009	0%	1%	1%	1%	8%	6%	8%	24%	37%	31%	20%
2010	0%	1%	7%	3%	13%	8%	14%	5%	25%	40%	18%
2011	0%	2%	4%	2%	12%	9%	7%	3%	19%	29%	14%
2012		0%	5%	3%	11%	5%	12%	3%	18%	33%	13%
2013		0%	3%	2%	4%	5%	4%	7%	22%	35%	14%
2014	0%	1%	7%	3%	15%	4%	1%	1%	20%	44%	15%

Table 25. Maine spring dive survey stratified mean *Cancer* crab abundance (numbers per square meter) by zone (1–2), region (1–9) and species (*C. borealis*, Jonah crabs above and *C. irroratus*, rock crabs below), for depths 0–15 m. Note that Region 1 in Zone 1 was not surveyed in 2012 and 2013. To estimate the overall Zone 1 means in those years, the 2011 values for Region 1 were used again for 2012 and 2013.

Jonah crabs											
Zone	1				2						
Region	1	2	3	1-3 (Zone 1)	4	5	6	7	8	9	4-9 (Zone 2)
Year											
2002	0.170	0.076	0.042	0.106	0.094	0.120	0.044	0.019	0.050	0.001	0.067
2003	0.269	0.121	0.188	0.211	0.114	0.167	0.085	0.041	0.060	0.000	0.092
2004	0.092	0.121	0.252	0.154	0.170	0.221	0.130	0.130	0.069	0.000	0.144
2005	0.107	0.100	0.105	0.105	0.221	0.229	0.217	0.195	0.071	0.002	0.185
2006	0.106	0.048	0.079	0.085	0.098	0.209	0.170	0.075	0.051	0.006	0.107
2007	0.037	0.047	0.059	0.047	0.026	0.102	0.059	0.093	0.040	0.001	0.057
2008	0.065	0.081	0.075	0.072	0.033	0.113	0.084	0.072	0.084	0.005	0.064
2009	0.034	0.028	0.039	0.035	0.032	0.054	0.056	0.023	0.038	0.002	0.035
2010	0.046	0.025	0.029	0.036	0.016	0.037	0.017	0.041	0.041	0.000	0.027
2011	0.012	0.021	0.019	0.016	0.017	0.033	0.017	0.024	0.015	0.000	0.020
2012		0.036	0.013	0.017	0.000	0.031	0.007	0.017	0.015	0.001	0.012
2013		0.027	0.020	0.018	0.002	0.019	0.009	0.007	0.012	0.000	0.008
2014	0.036	0.022	0.025	0.029	0.034	0.048	0.017	0.028	0.015	0.000	0.029

Rock crabs											
Zone	1				2						
Region	1	2	3	1-3 (Zone 1)	4	5	6	7	8	9	4-9 (Zone 2)
Year											
2002	0.042	0.057	0.078	0.058	0.225	0.240	0.101	0.147	0.053	0.018	0.167
2003	0.040	0.055	0.106	0.066	0.094	0.171	0.044	0.052	0.020	0.007	0.081
2004	0.021	0.030	0.049	0.033	0.093	0.076	0.042	0.042	0.009	0.013	0.059
2005	0.012	0.021	0.033	0.021	0.094	0.059	0.077	0.066	0.005	0.007	0.064
2006	0.016	0.015	0.019	0.017	0.097	0.107	0.062	0.032	0.013	0.009	0.066
2007	0.012	0.016	0.014	0.014	0.025	0.012	0.023	0.025	0.007	0.001	0.019
2008	0.016	0.032	0.052	0.032	0.042	0.030	0.042	0.005	0.013	0.003	0.026
2009	0.009	0.022	0.023	0.017	0.030	0.023	0.019	0.005	0.007	0.001	0.018
2010	0.017	0.004	0.011	0.012	0.025	0.015	0.013	0.023	0.009	0.005	0.019
2011	0.005	0.007	0.004	0.0048	0.017	0.021	0.014	0.012	0.019	0.004	0.016
2012		0.008	0.009	0.007	0.019	0.019	0.014	0.019	0.018	0.006	0.018
2013		0.003	0.008	0.0054	0.024	0.024	0.010	0.003	0.011	0.004	0.015
2014	0.012	0.006	0.004	0.008	0.044	0.050	0.018	0.012	0.014	0.010	0.030



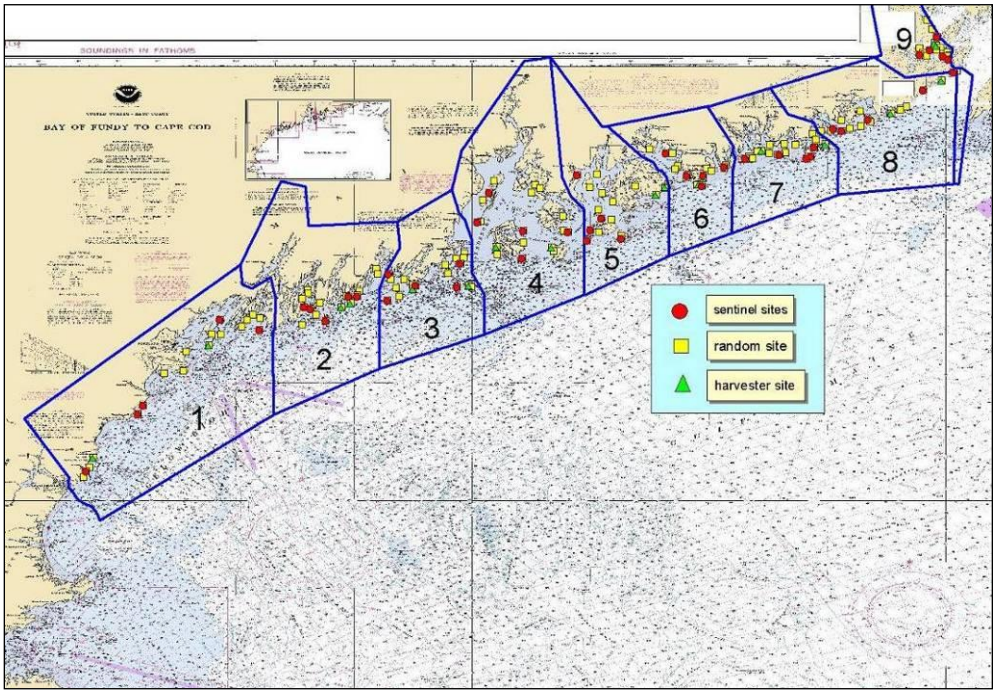


Figure 1a–b. Maine coastal counties and the two sea urchin management zones (above), and the nine survey regions with 2009 survey sites (below).

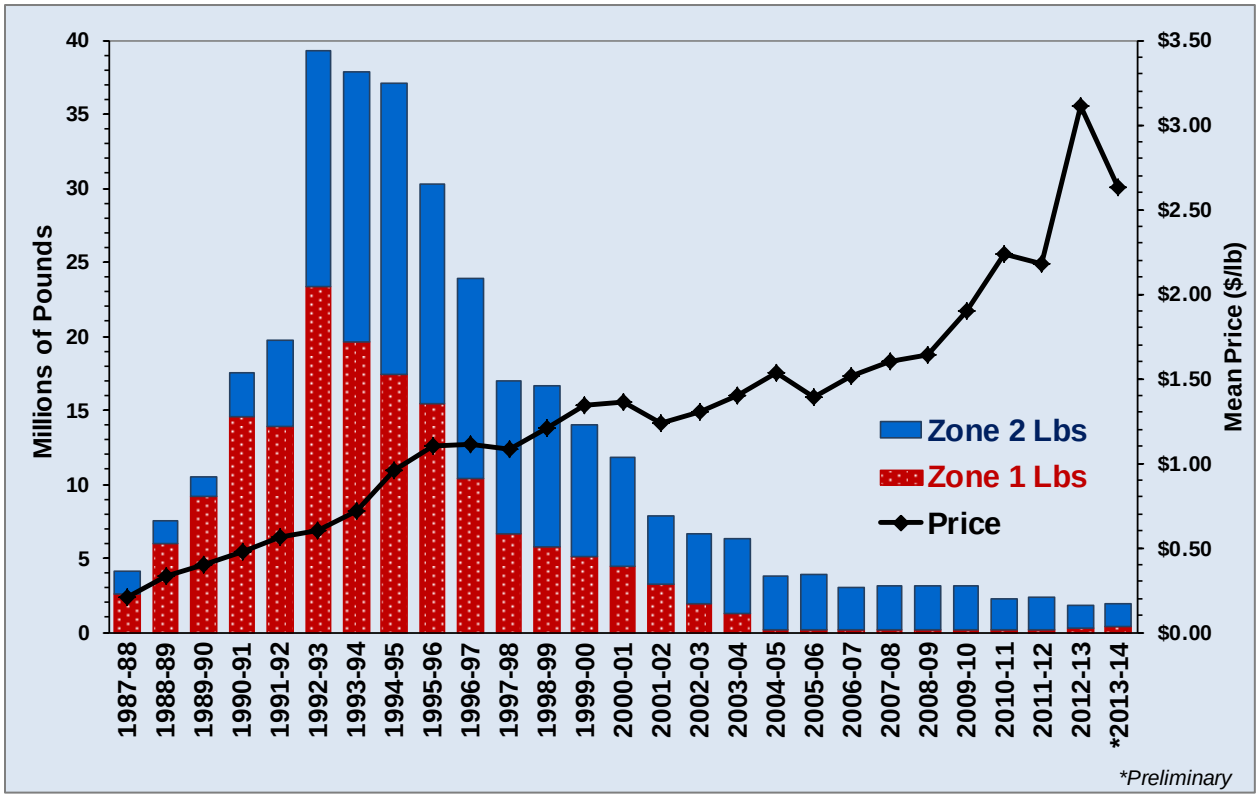


Figure 2a. Maine sea urchin landings (millions of pounds, 1 million = 454 mt) by fishing season and zone, and mean price ($ US) per pound, from dealer reports. Zone landings before 1994 are estimated from county landings from NMFS port agent reports.

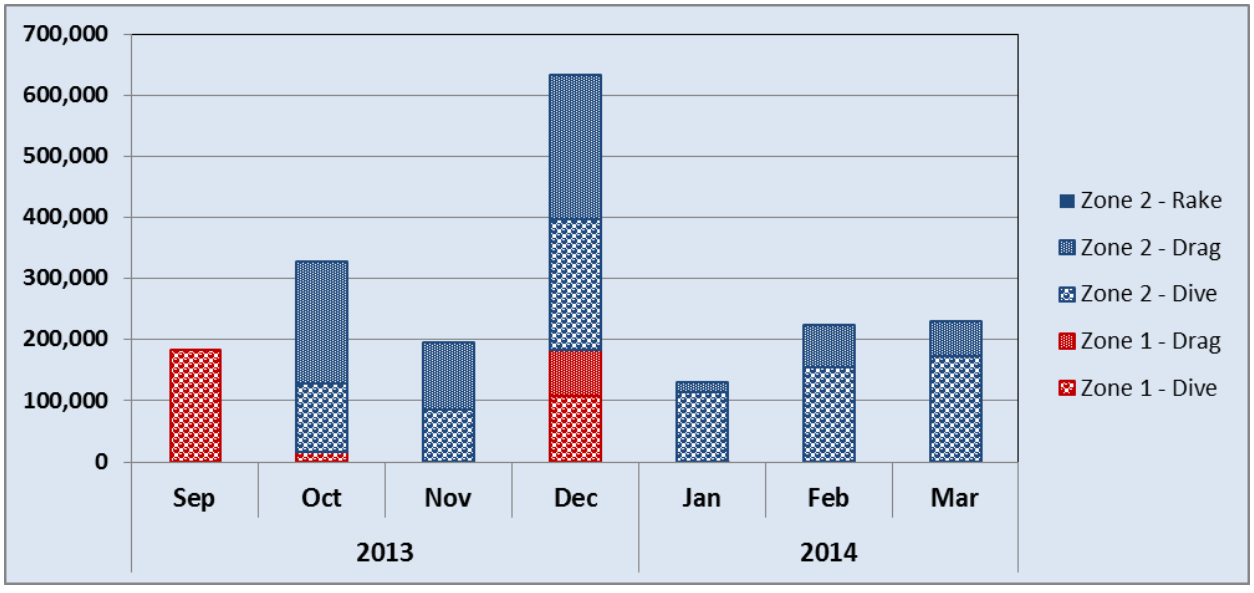


Figure 2b. 2013–14 Maine sea urchin landings (pounds) by month, zone, and gear, from dealer reports.

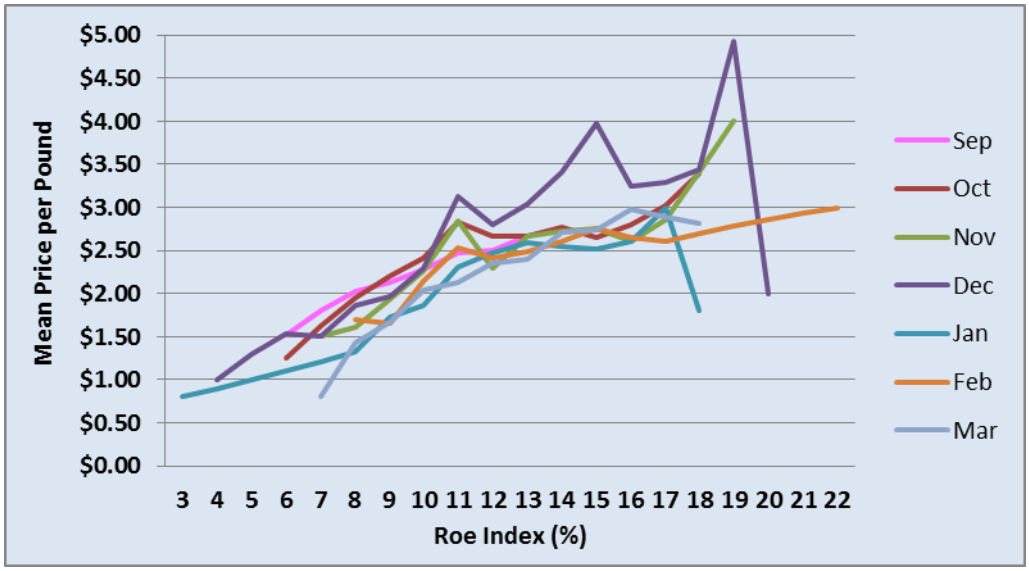
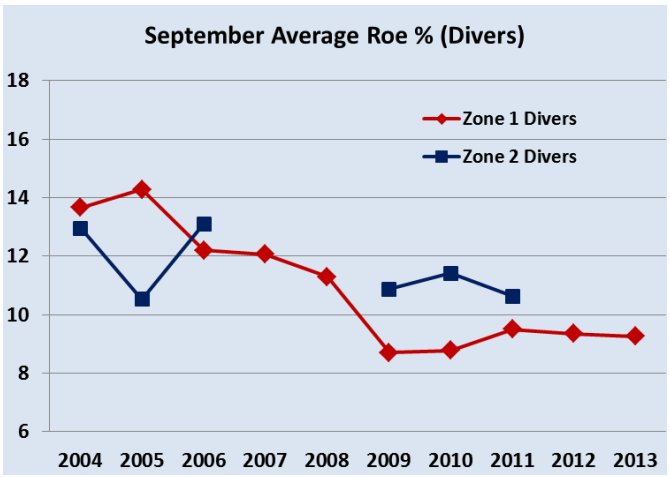
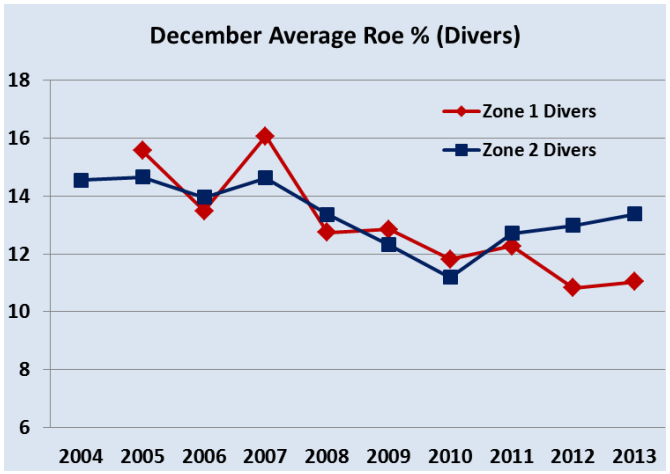


Figure 3a. Relationship between 2013–14 mean price per pound ($/lb) and roe index from dealer reports, by month.





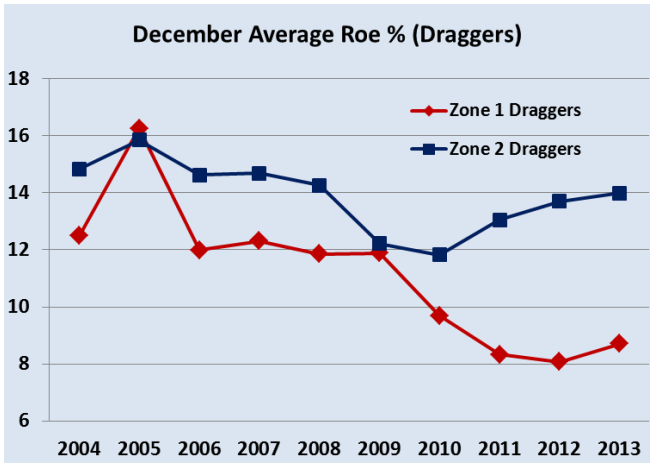
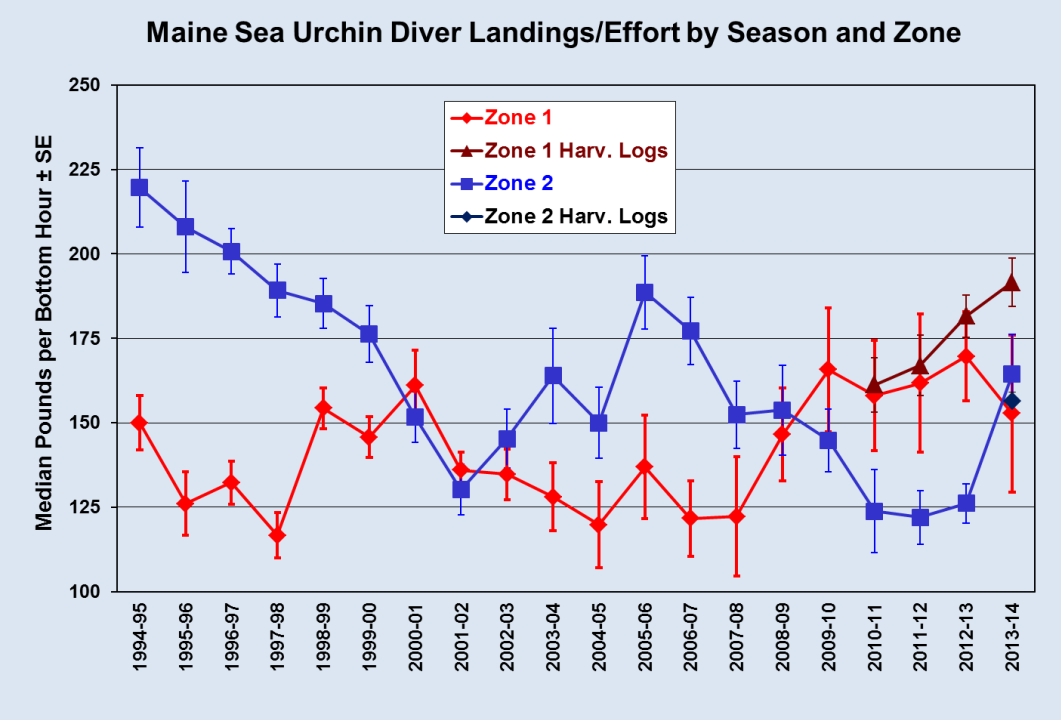


Figure 3b–d. 2004–2013 mean roe indices (%) from dealer reports by month, gear, and zone: Divers in September (top), Divers in December (middle), and Draggers in December (bottom).



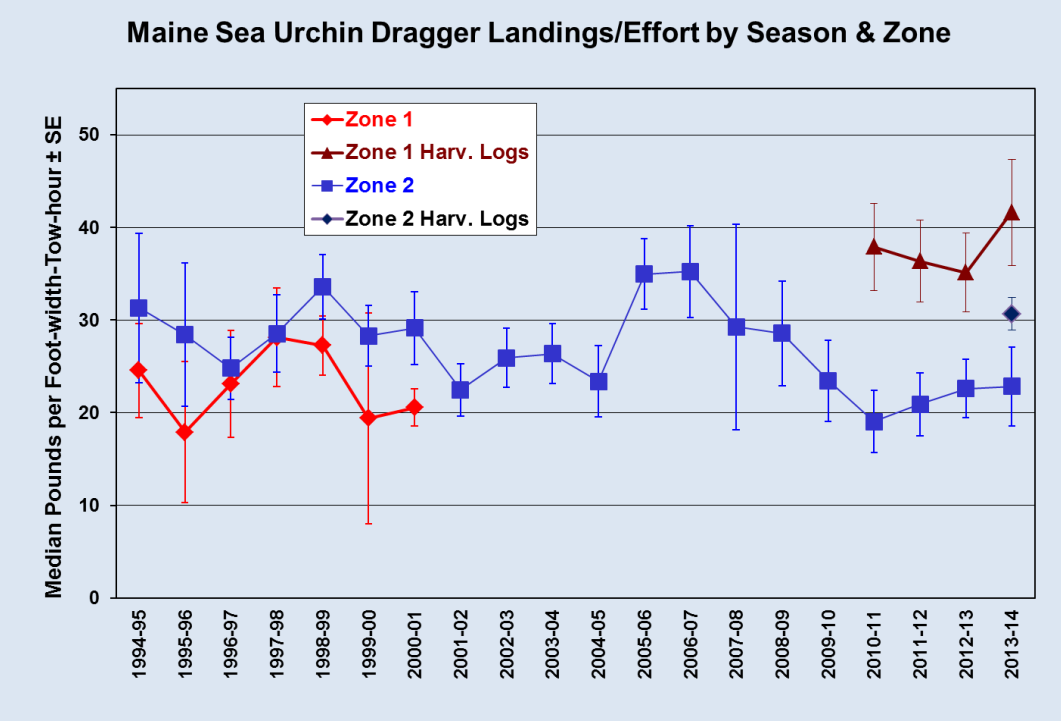


Figure 4a–b. Maine sea urchin diver (above) and dragger (below) median landings per effort by season and zone, from port interviews, and from harvester logs where noted. Zone 1 dragger interview data for 2001–02 through 2013–14 are not displayed because there were fewer than three interviews each season.

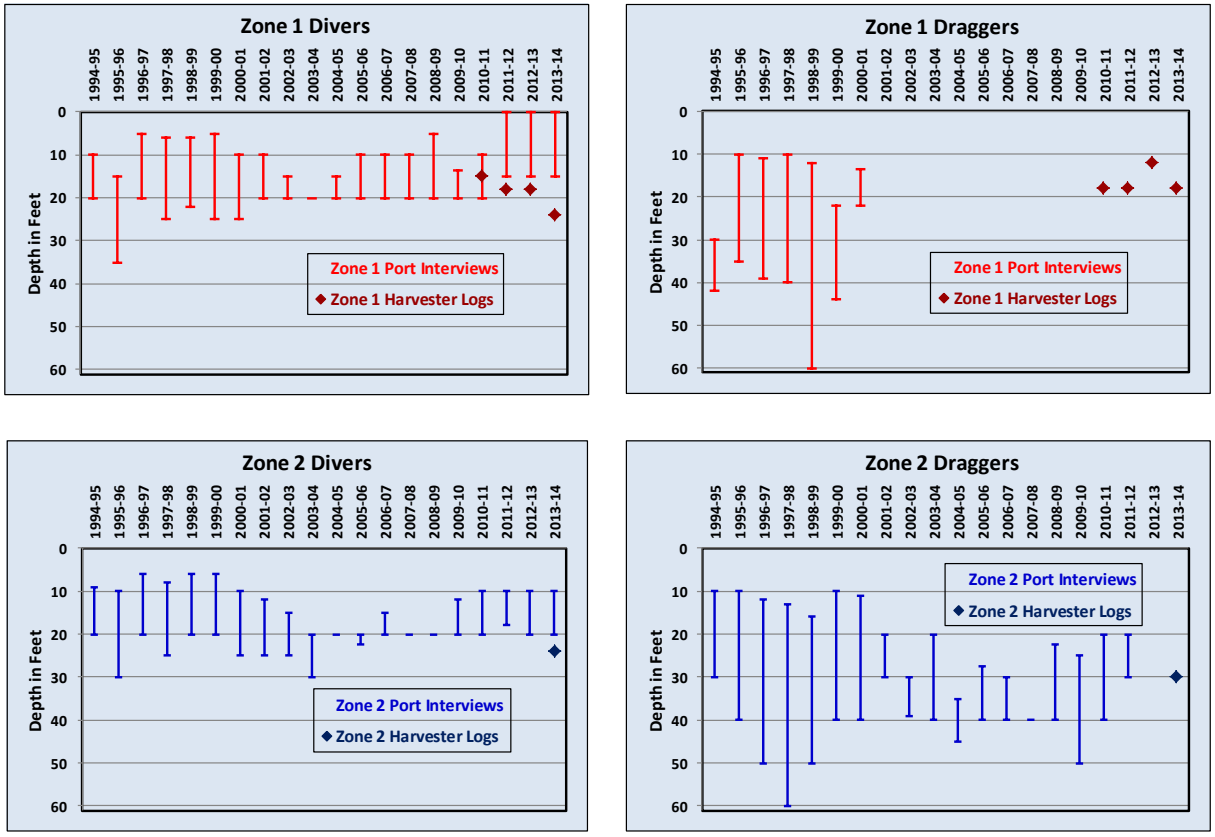


Figure 5a–d. Maine sea urchin harvester fishing depths (feet) from harvester interviews by season, gear, and zone. "I" bars indicate the median minimum depth fished (ft) response, and the median maximum depth fished (ft) response. Diamonds also indicate the median depth fished from harvester log books. Dragger interview data for Zone 1 for 2001–02 through 2013–14 are not displayed because there were fewer than three interviews each season. 2012–14 interview data for Zone 2 dragger depths are not yet available. One foot = 0.305 meter.

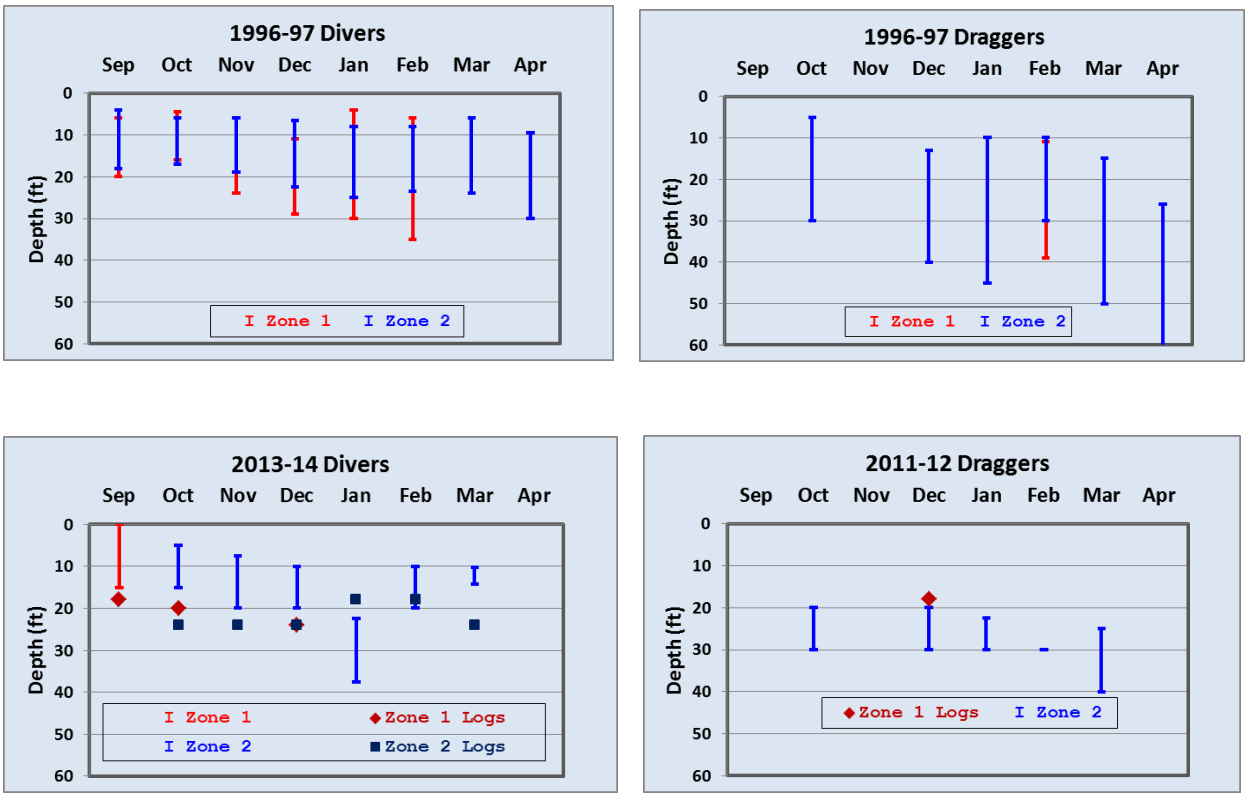


Figure 6a–d. Maine sea urchin harvester fishing depths from harvester port interviews by gear and zone for 1996–97 (above) and 2013–14 or 2011–12 (below). 2012–14 depth data for dragger interviews are not available yet, so 2011–12 is presented. "I" bars indicate the median minimum depth fished (ft) response, and the median maximum depth fished (ft) response. Median depth fished from harvester log books is also presented for 2013–14 and 2011–12. Dragger interview data for Zone 1 in 2011–12 are not displayed because there was only one interview.

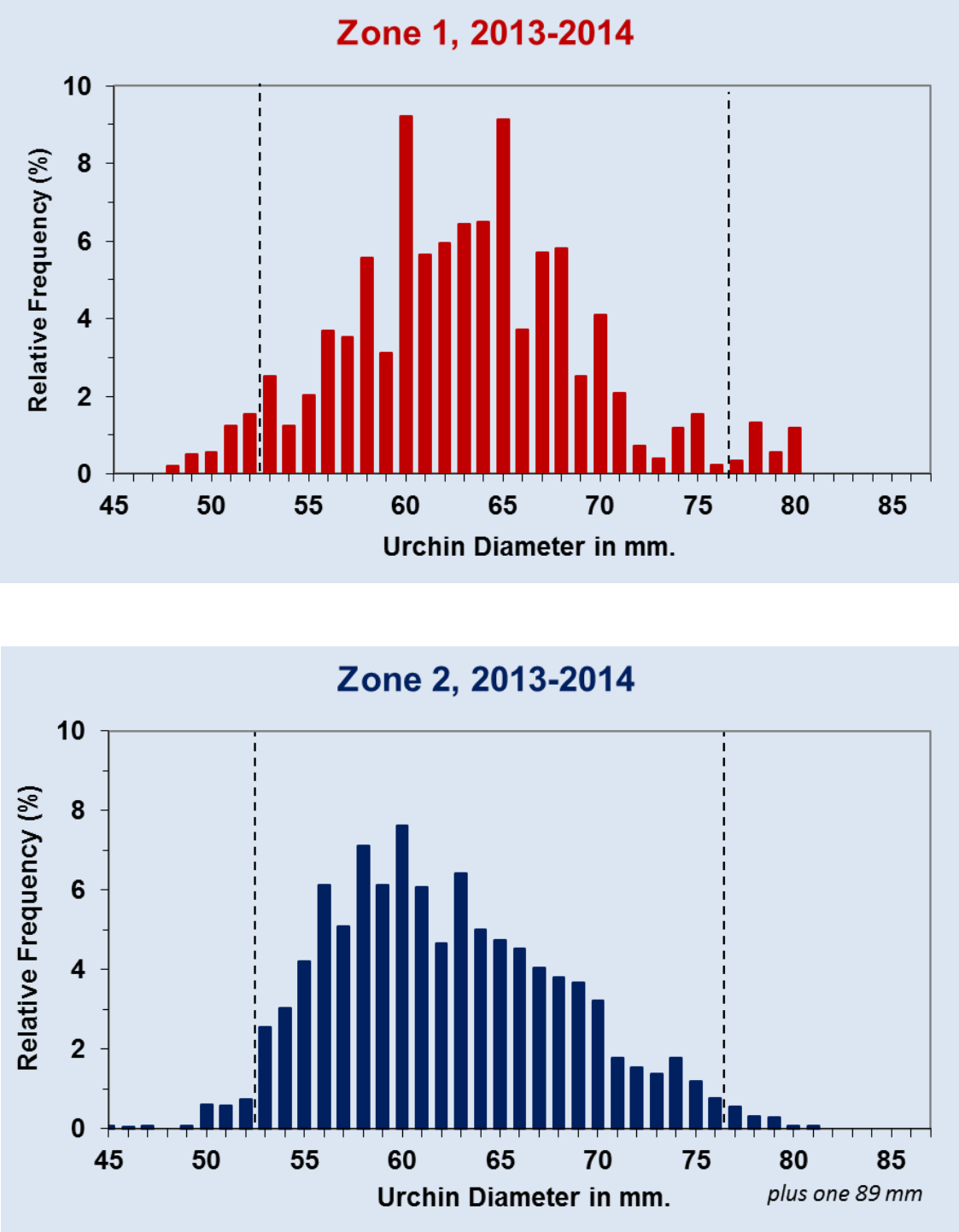
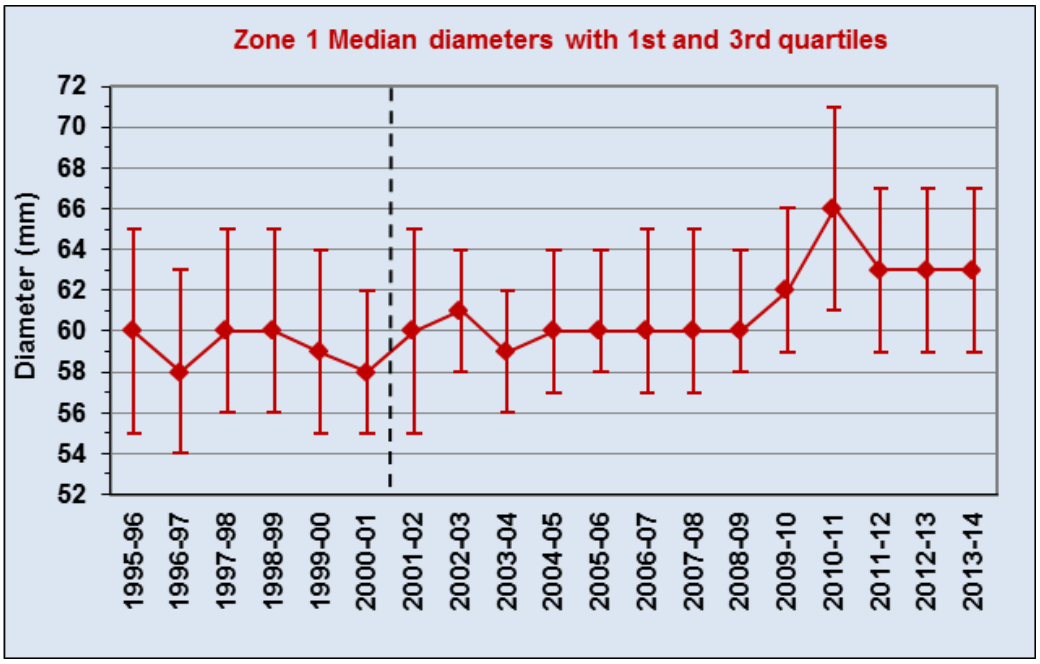


Figure 7a–b. Relative size (test diameter) frequency for Zone 1 (above) and Zone 2 (below) from the commercial sea urchin catch for 2013–14. Dotted lines indicate the minimum (52.4 mm) and maximum (76.2 mm) legal size limits.



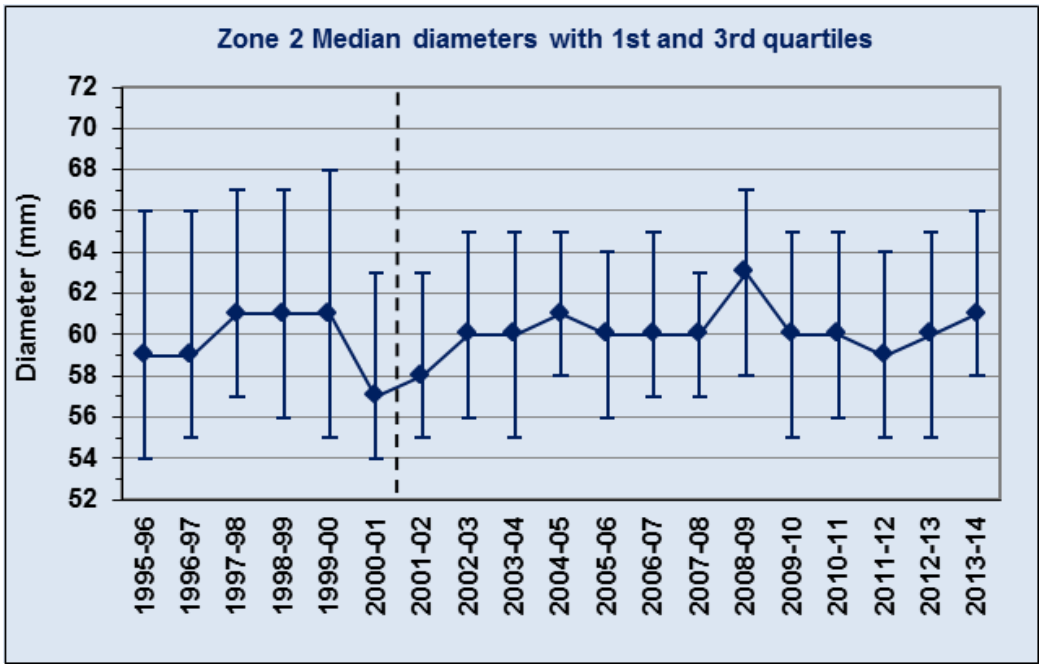


Figure 8a–b. Median sea urchin diameters (diamonds) from commercial catch samples, for Zone 1 (above) and Zone 2 (below), with 1st and 3rd quartiles (brackets). Minimum legal size was 2 inches (50.8 mm) until 2001–02 (dotted line), when it increased to $2^{1}/_{16}$ inches (52.4mm).

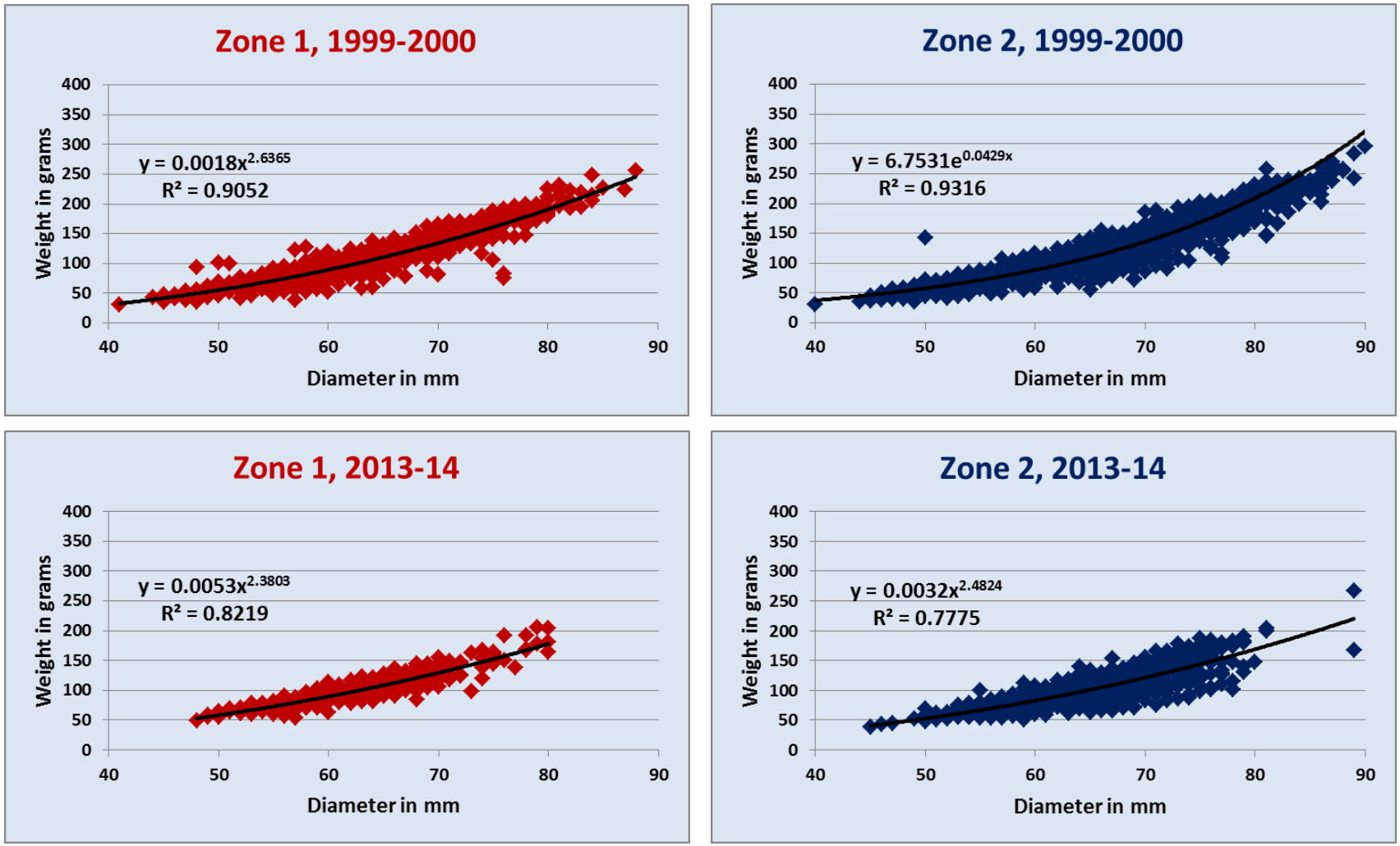
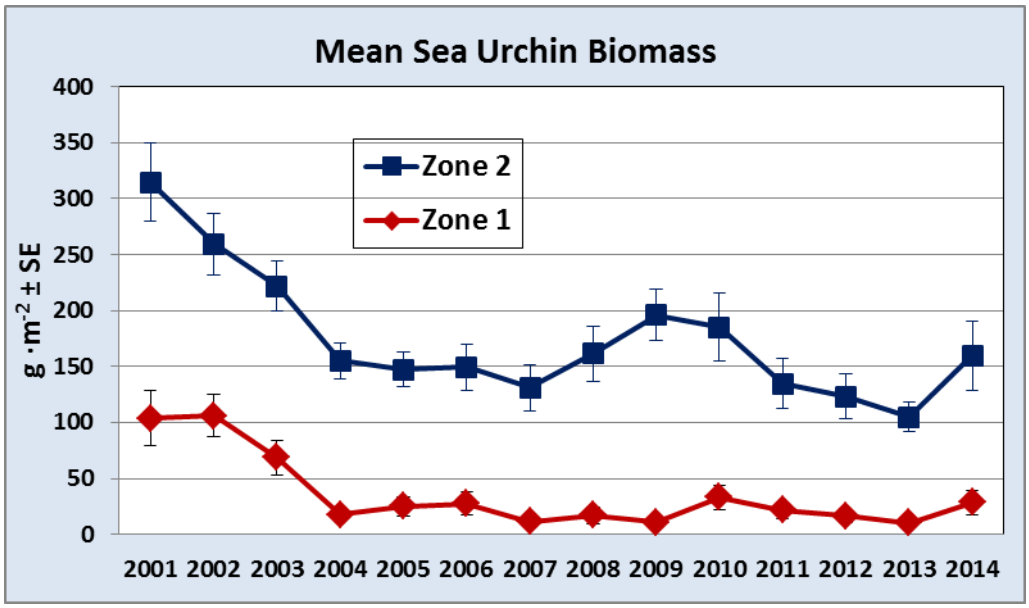


Figure 9a–d. Sea urchin whole wet weights (g) vs. diameter (mm) from 1999–2000 (above) and 2013–14 (below) season port samples of commercial catches for Zone 1 (left) and Zone 2 (right). Parameters were estimated for each zone for the relationship: Weight = a·Diameter^b where x=diameter (mm) and y=weight (g). Note that there was no maximum size limit in 1999–2000.



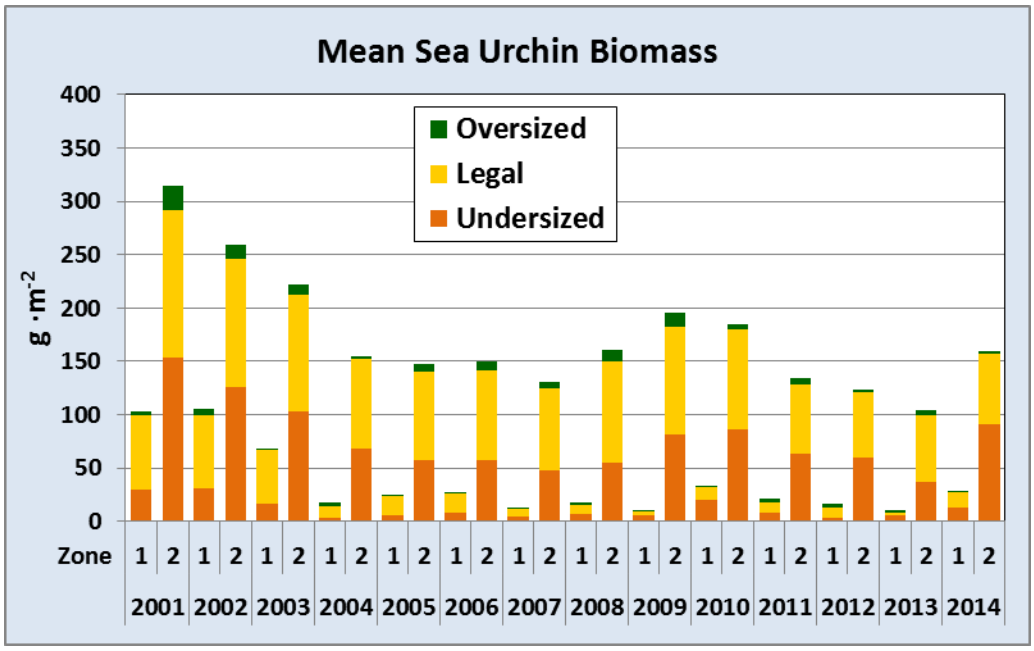


Figure 10a–b. Mean sea urchin biomass (grams per square meter) from the spring dive survey by zone and year with standard errors above and by zone, year, and size category (sub-legal or undersized, legal, and oversized) below.

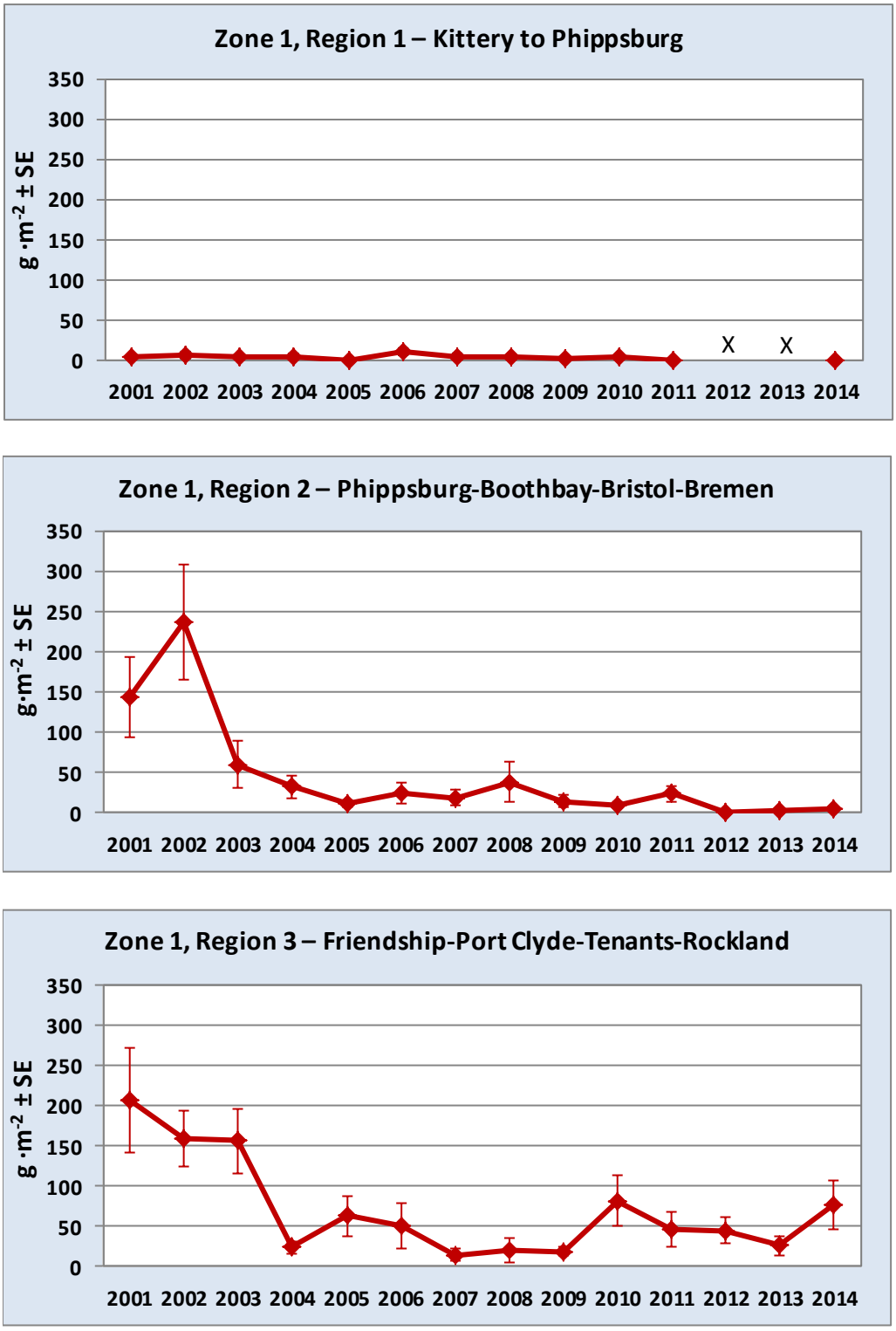
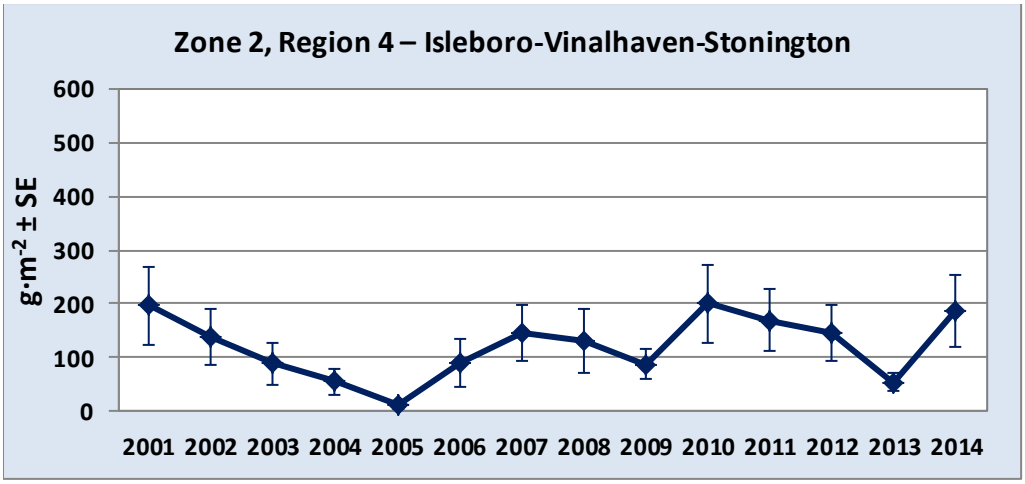
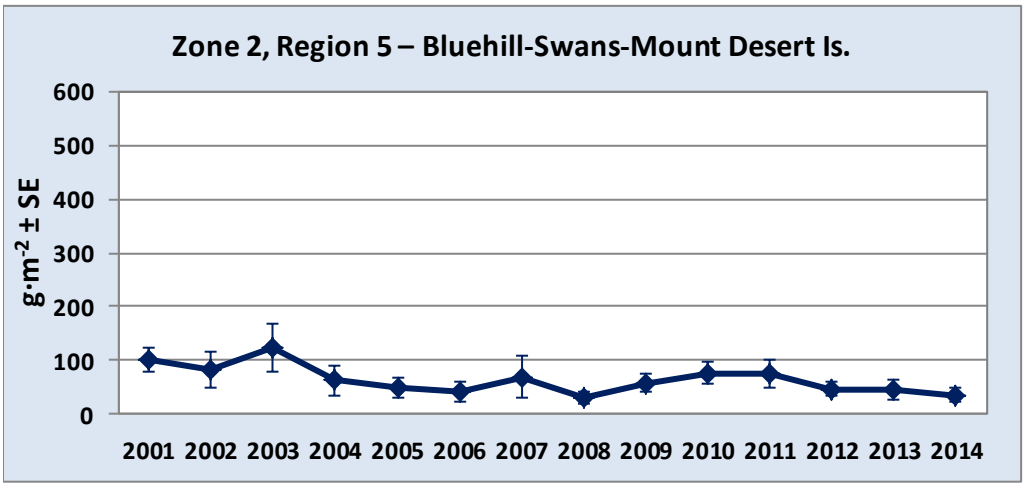


Figure 11. Mean sea urchin biomass (grams per square meter) from the spring dive survey by region and year with standard errors. Region 1 was not surveyed in 2012 and 2013.





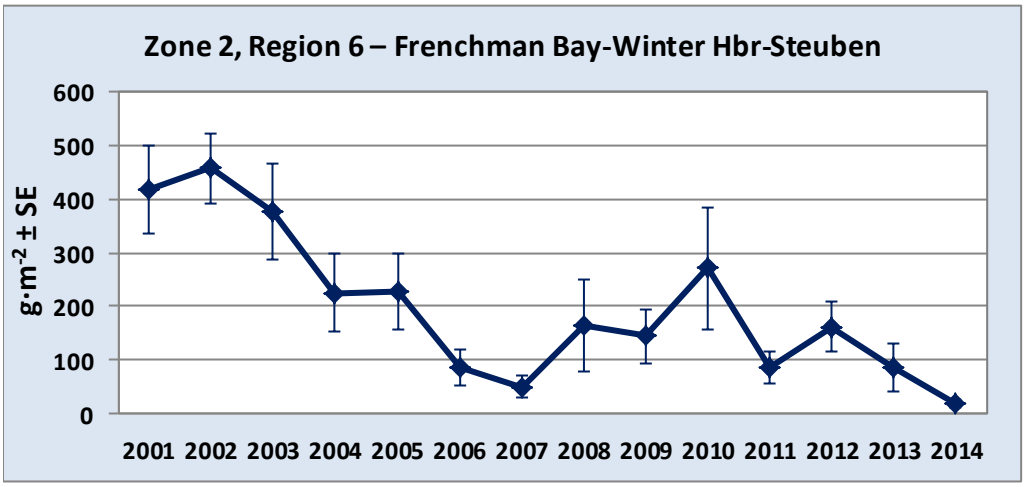
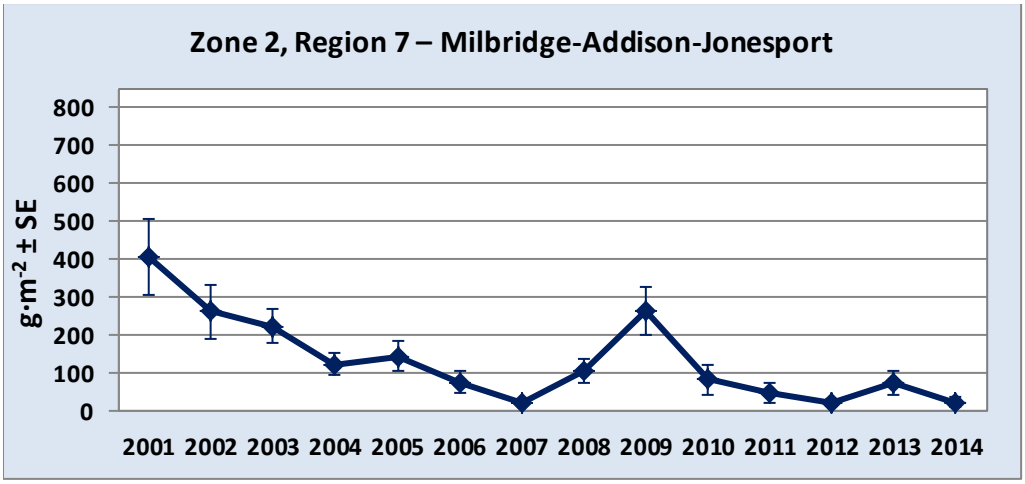
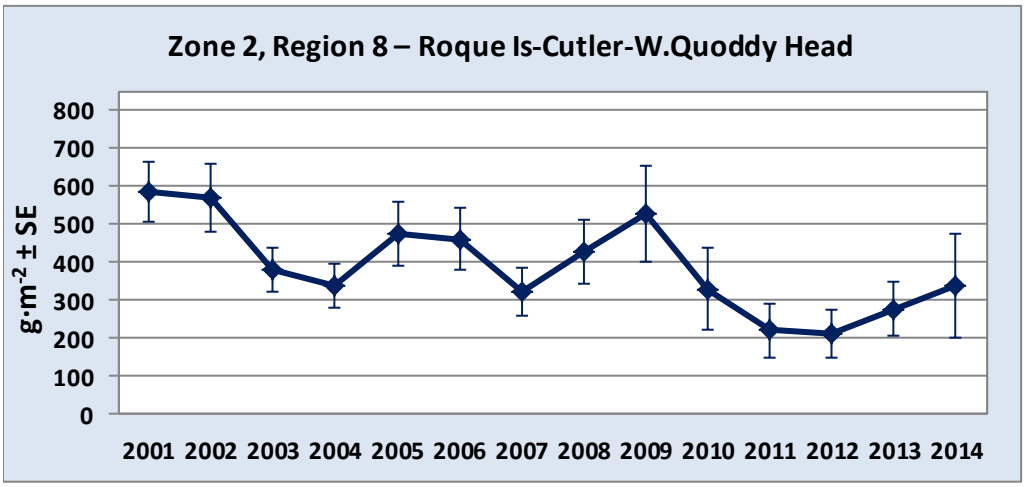


Figure 11 continued. Note that the vertical scale is different from the previous page.





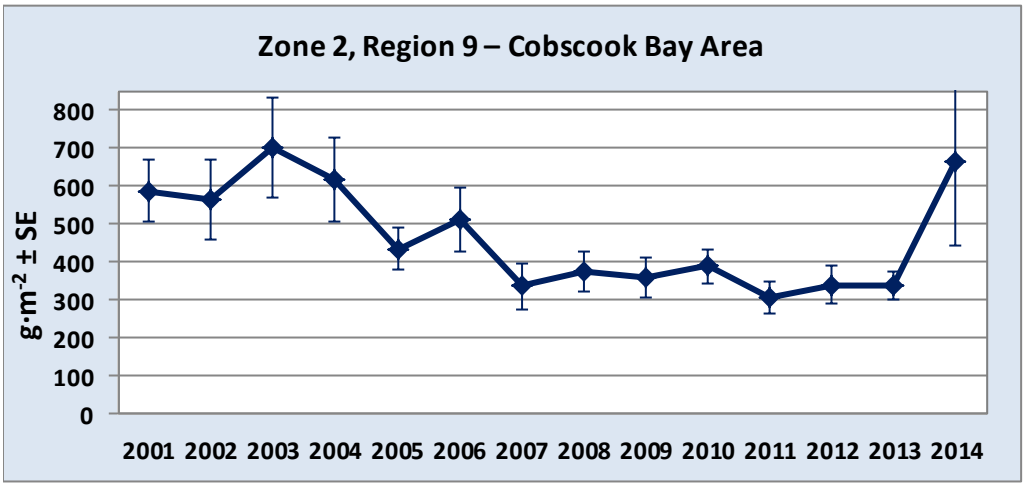
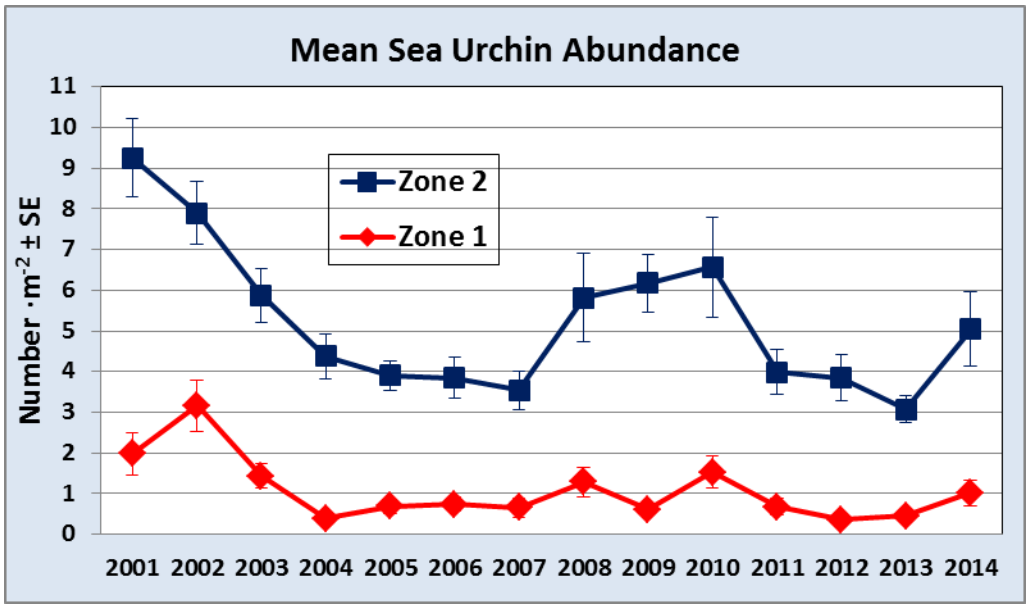


Figure 11 continued. Note that the vertical scale is different from the previous two pages.



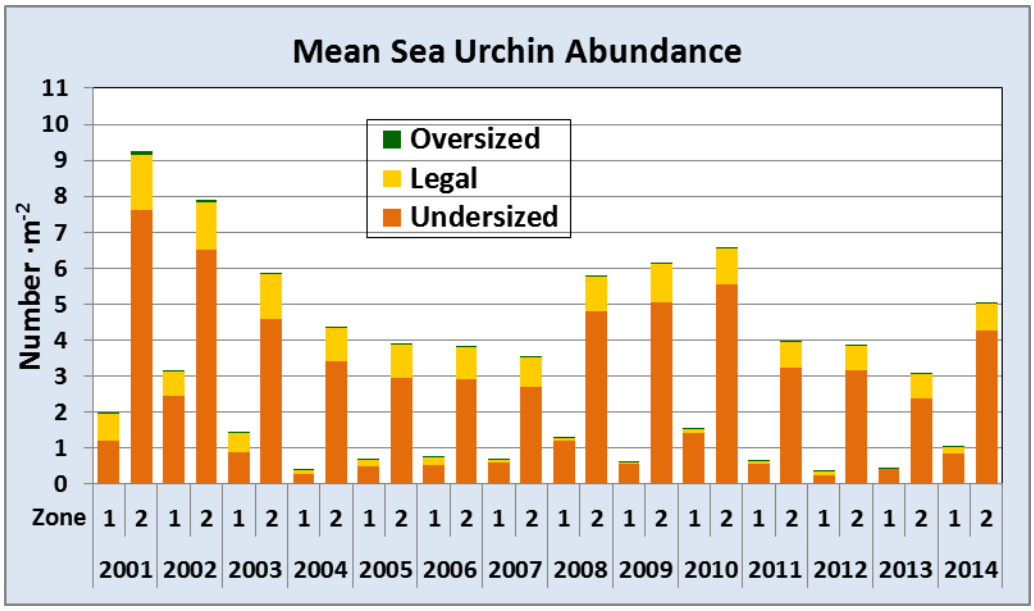


Figure 12a–b. Stratified mean sea urchin abundance (number per square meter) from the spring dive survey by zone and year with standard errors above, and by zone, year, and size category (sub-legal or undersized, legal, and oversized) below.

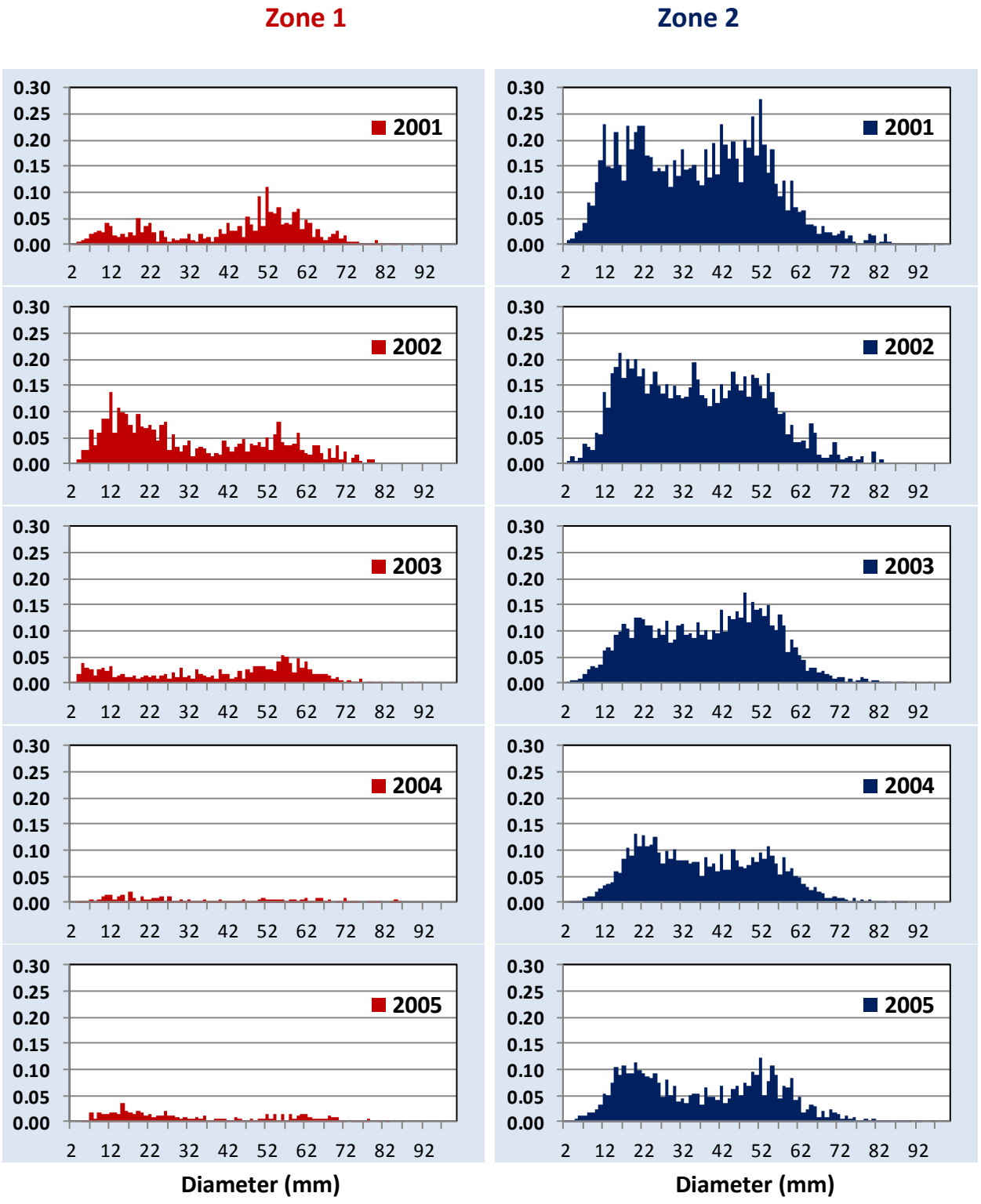


Figure 13. Stratified mean sea urchin abundance (number per square meter) from the spring survey, by zone (Zone 1 left, Zone 2 right), year, and diameter in mm.

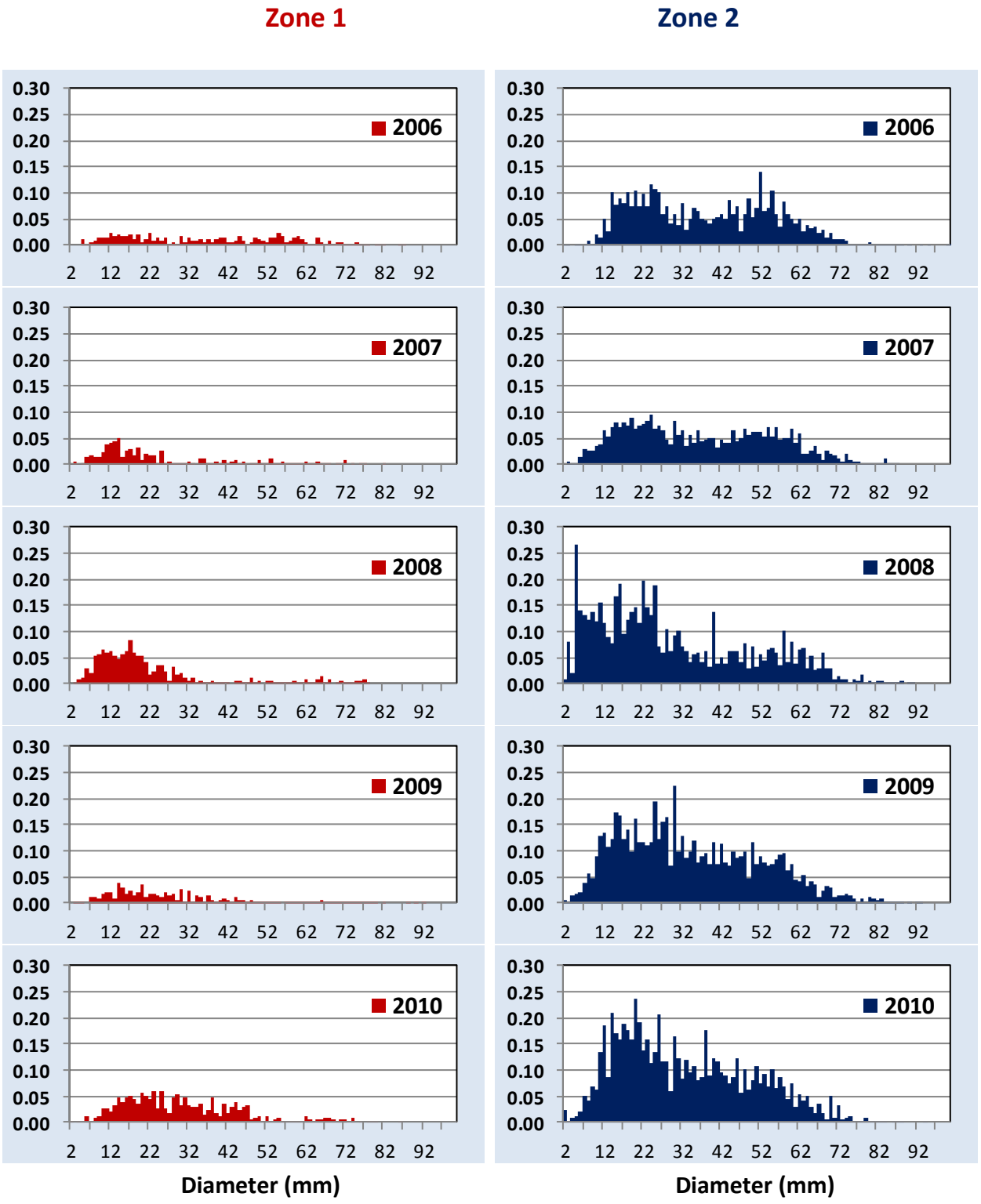


Figure 13. continued.

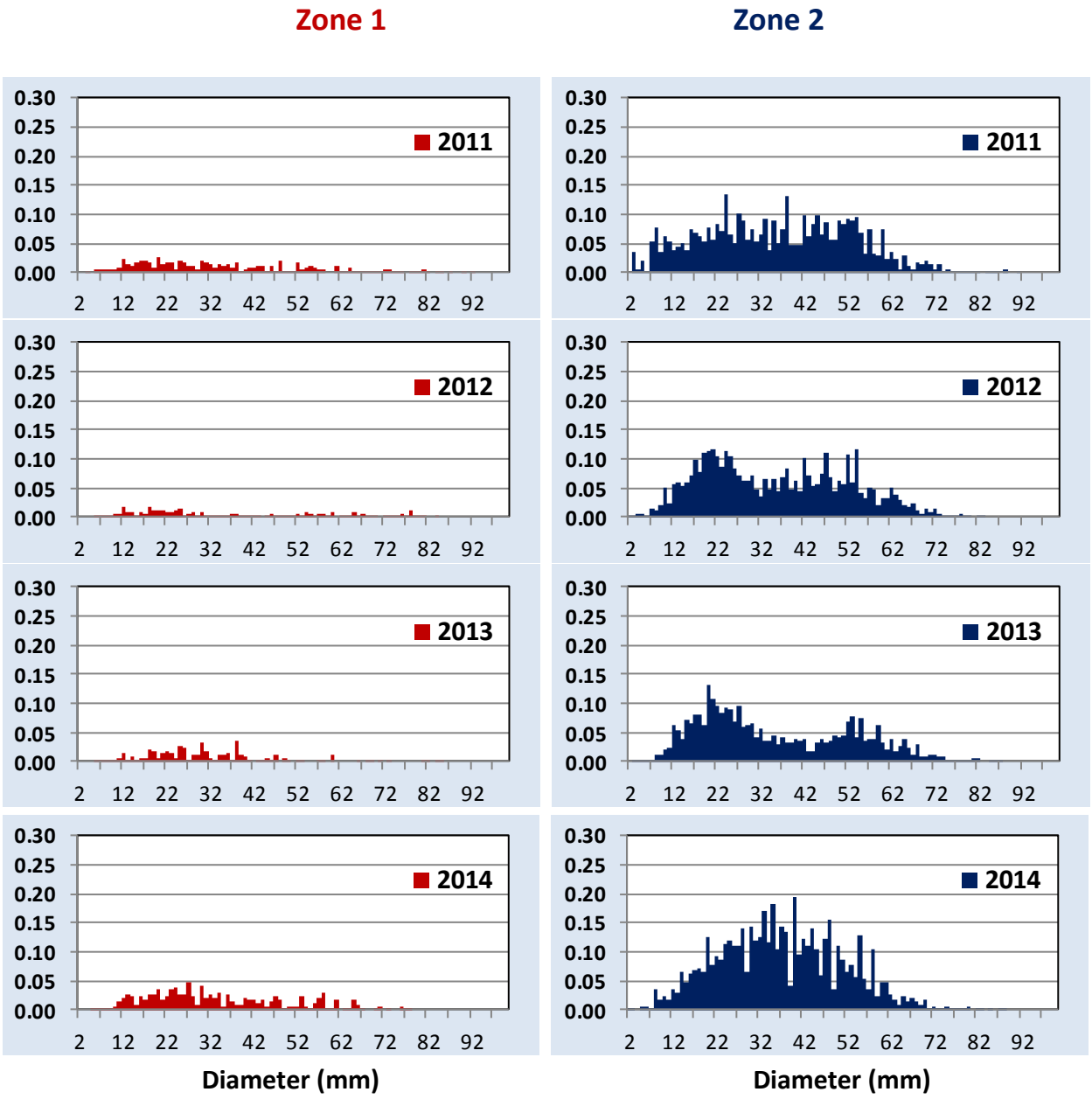
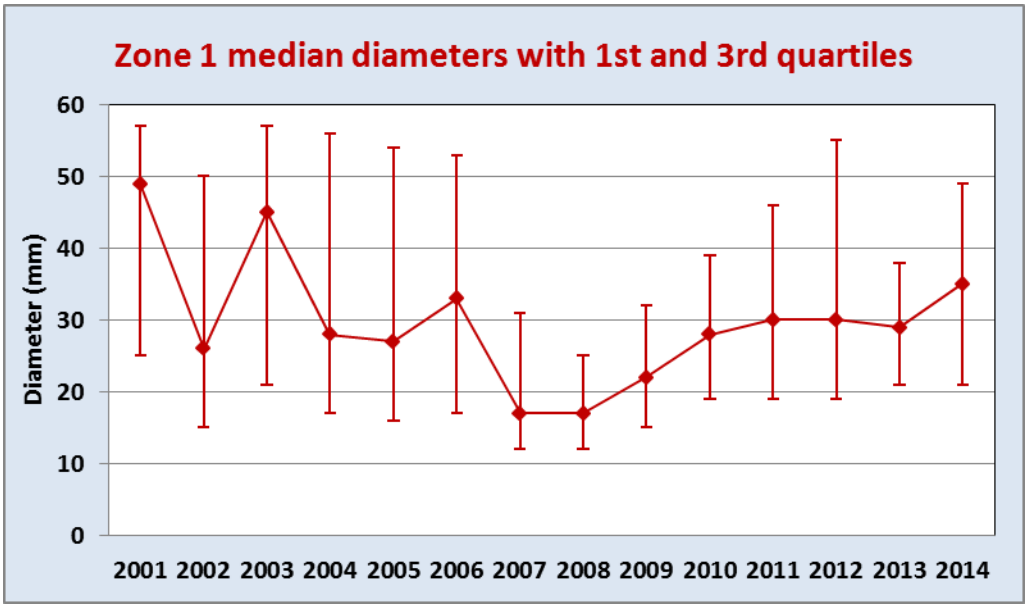


Figure 13. continued.



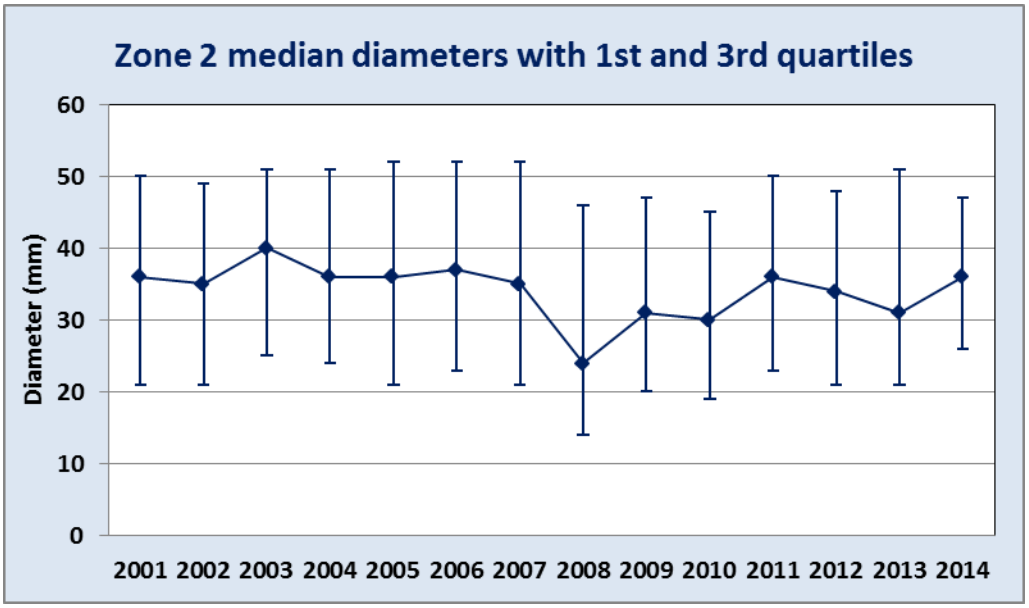


Figure 14. Median sea urchin test diameters (mm) from the spring survey by year, for Zone 1 (above) and Zone 2 (below), with 1st and 3rd quartiles (brackets).

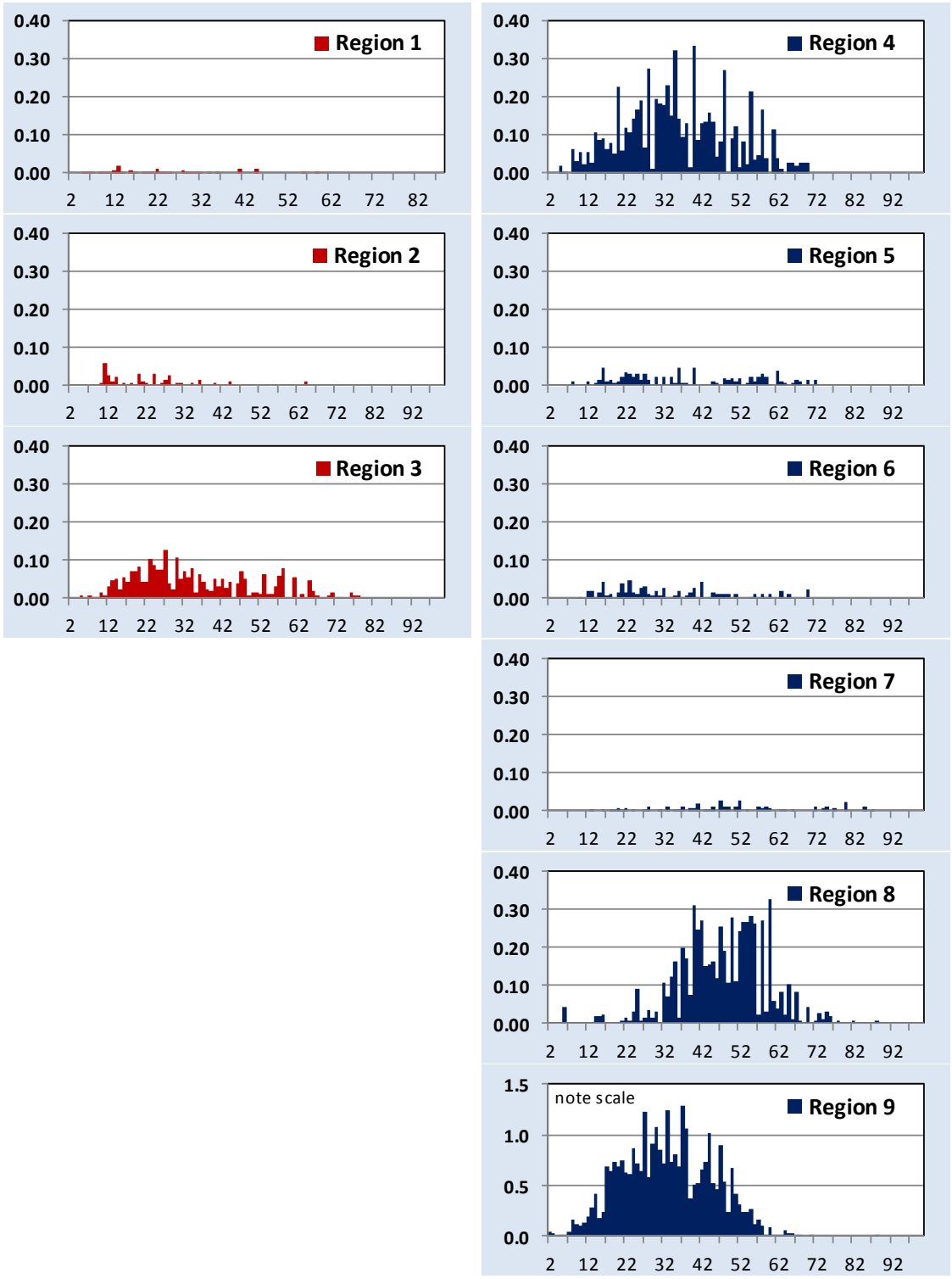


Figure 15. 2014 stratified mean sea urchin abundance (number per square meter) from the spring survey, by region, and diameter in mm, for Zone 1 (left) and Zone 2 (right). Note the expanded vertical scale for Region 9.

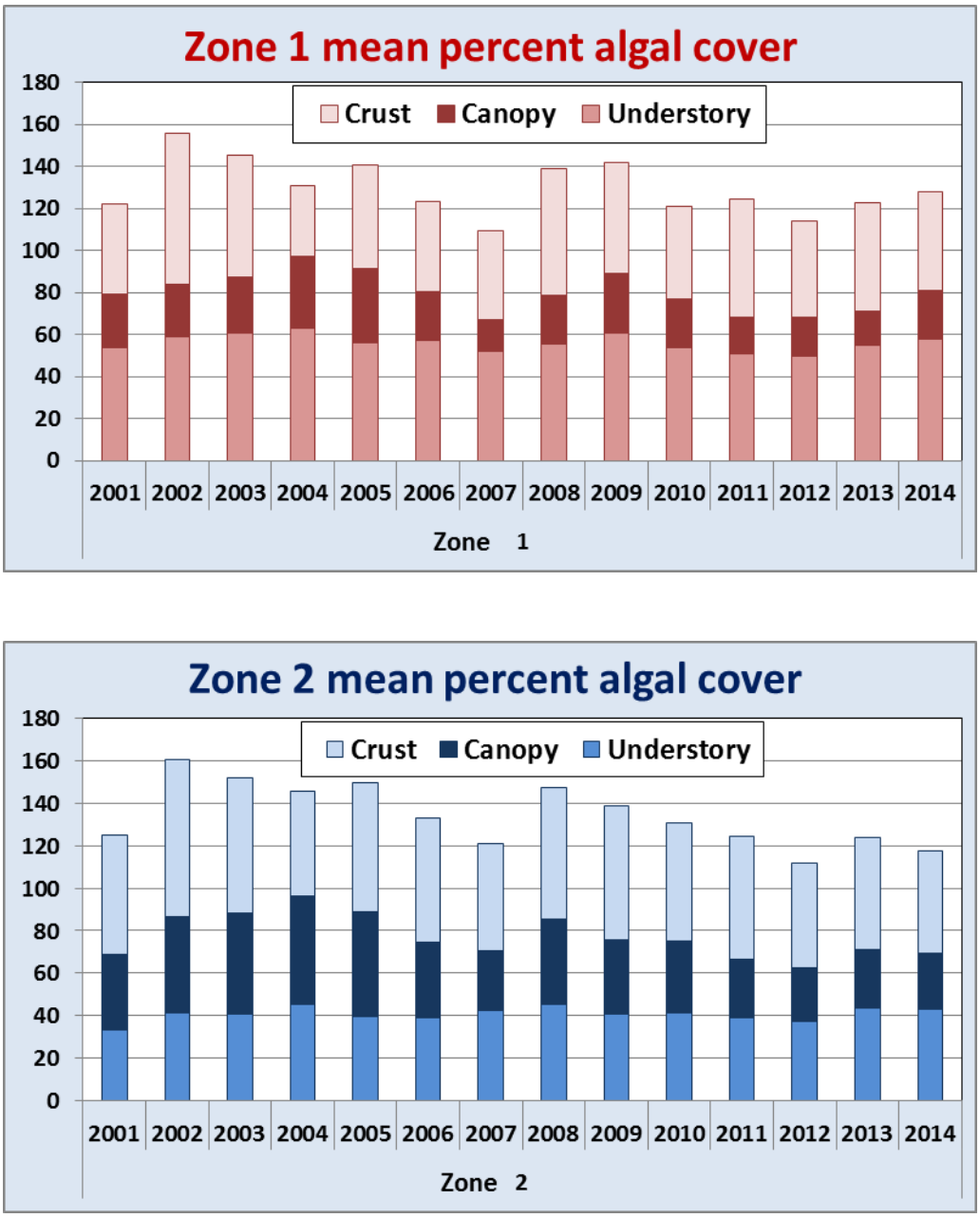


Figure 16. Stratified mean algal cover (%) from the spring survey by algal type, year, and zone, Zone 1 above and Zone 2 below. Note that the total cover can be more than 100%.

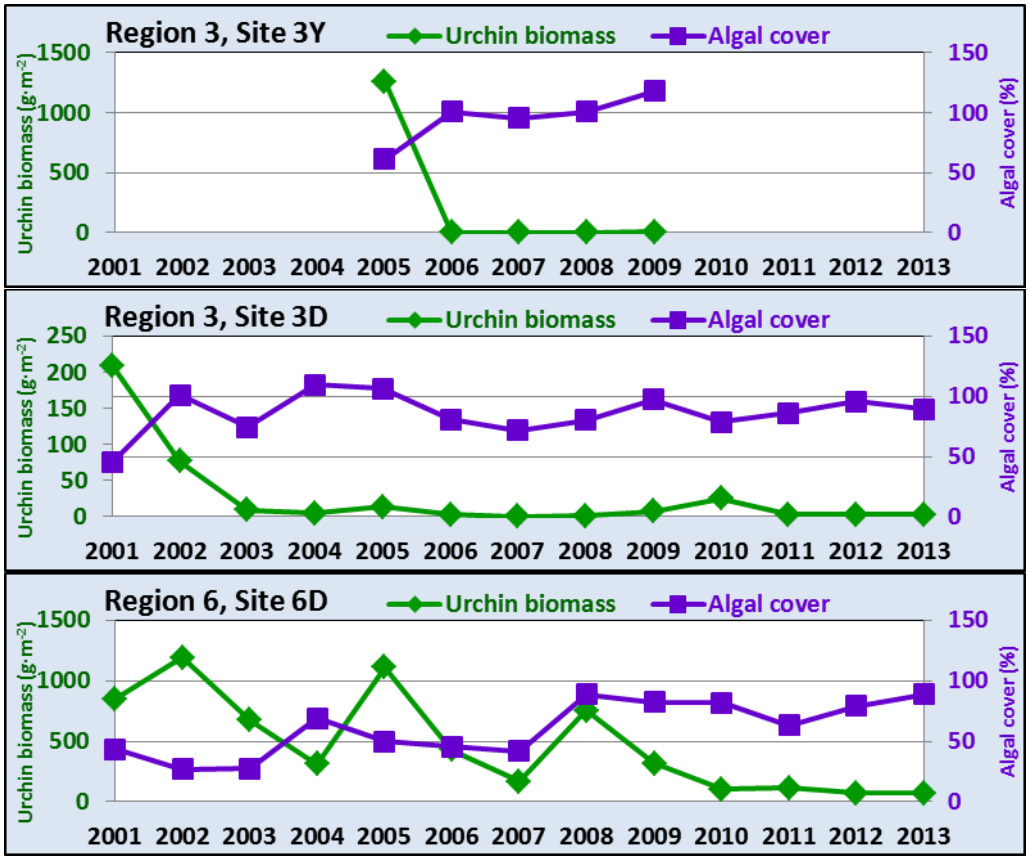


Figure 17a. Examples of spring survey fixed sites where mean sea urchin biomass ($g \cdot m^{-2}$) declined at least five-fold and fleshy algal cover (%) increased with time. Note that fleshy algal cover (the sum of understory and canopy covers) can be more than 100%.

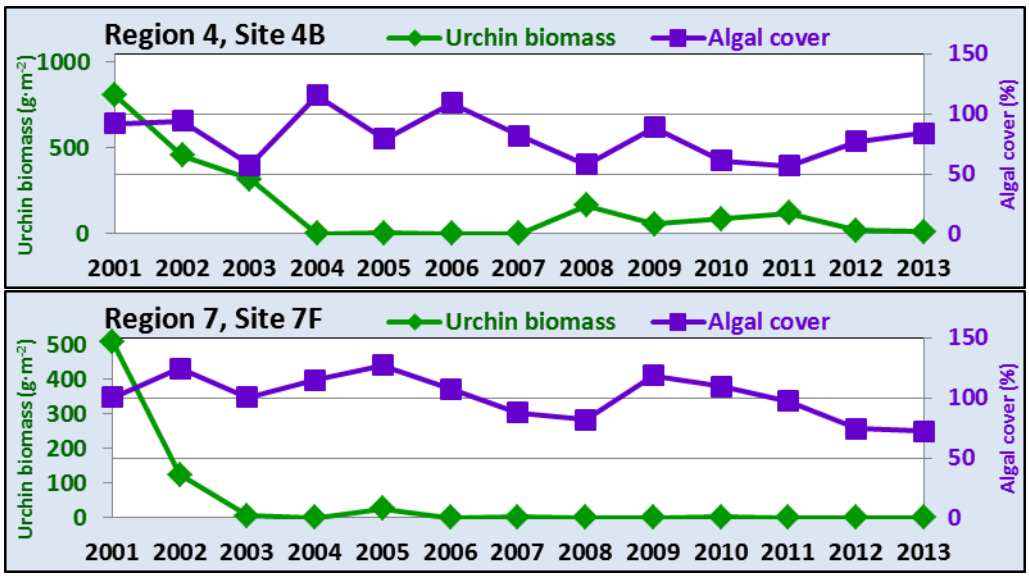


Figure 17b. Examples of spring survey fixed sites where mean sea urchin biomass ($g \cdot m^{-2}$) declined at least five-fold and fleshy algal cover (%) did not increase.

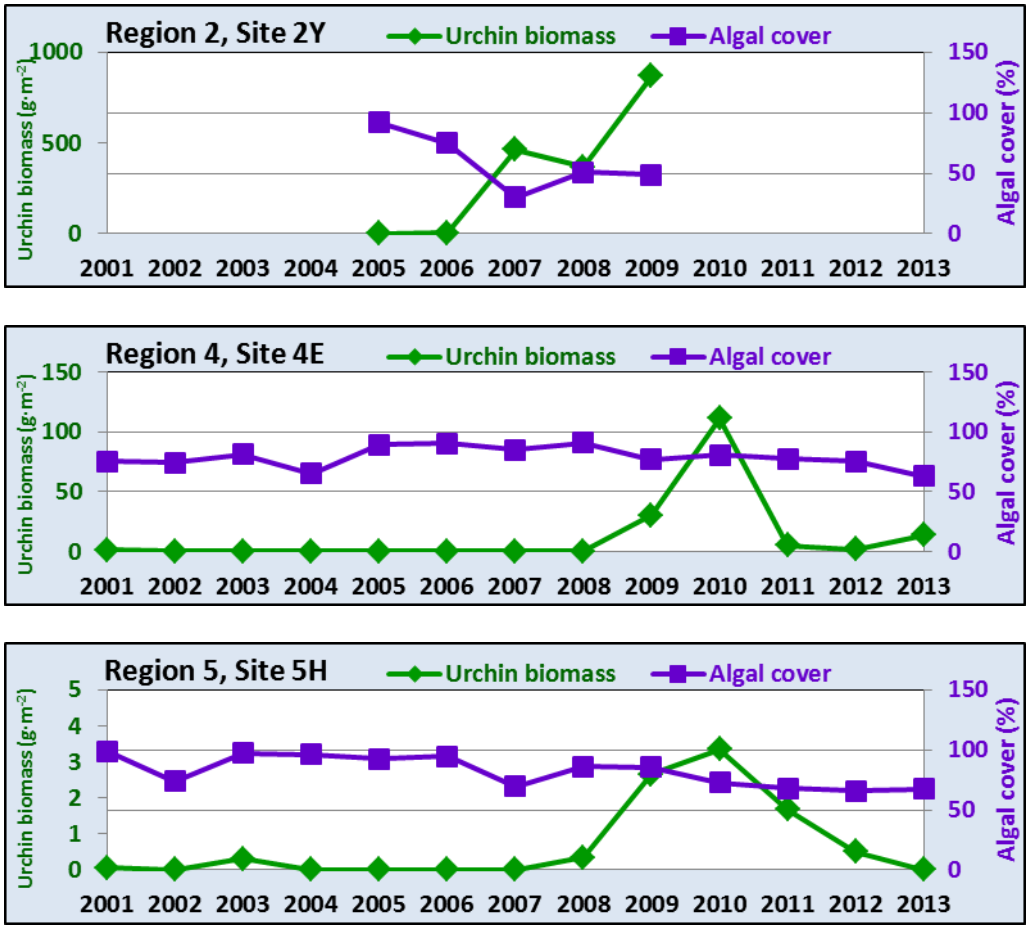


Figure 18. Maine spring dive survey fixed sites where mean sea urchin biomass ($g \cdot m^{-2}$) increased over time at least five-fold.

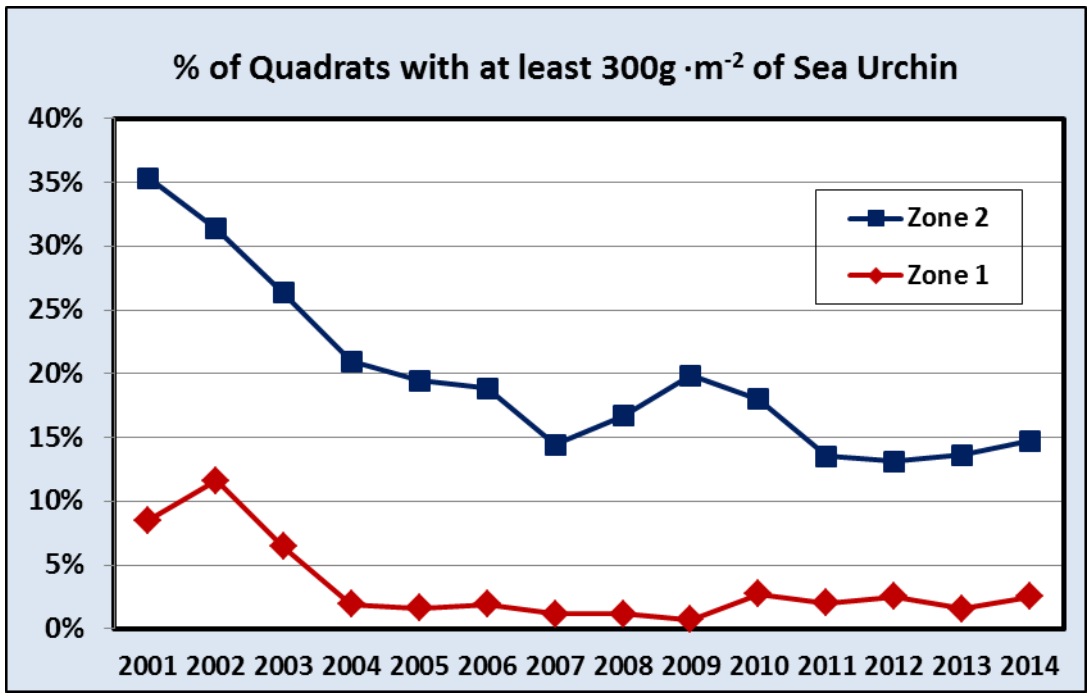


Figure 19. Percentage of evaluated quadrats in the Maine spring dive survey that had an estimated 300 g·m^{-2} or more of sea urchins, by year and zone.

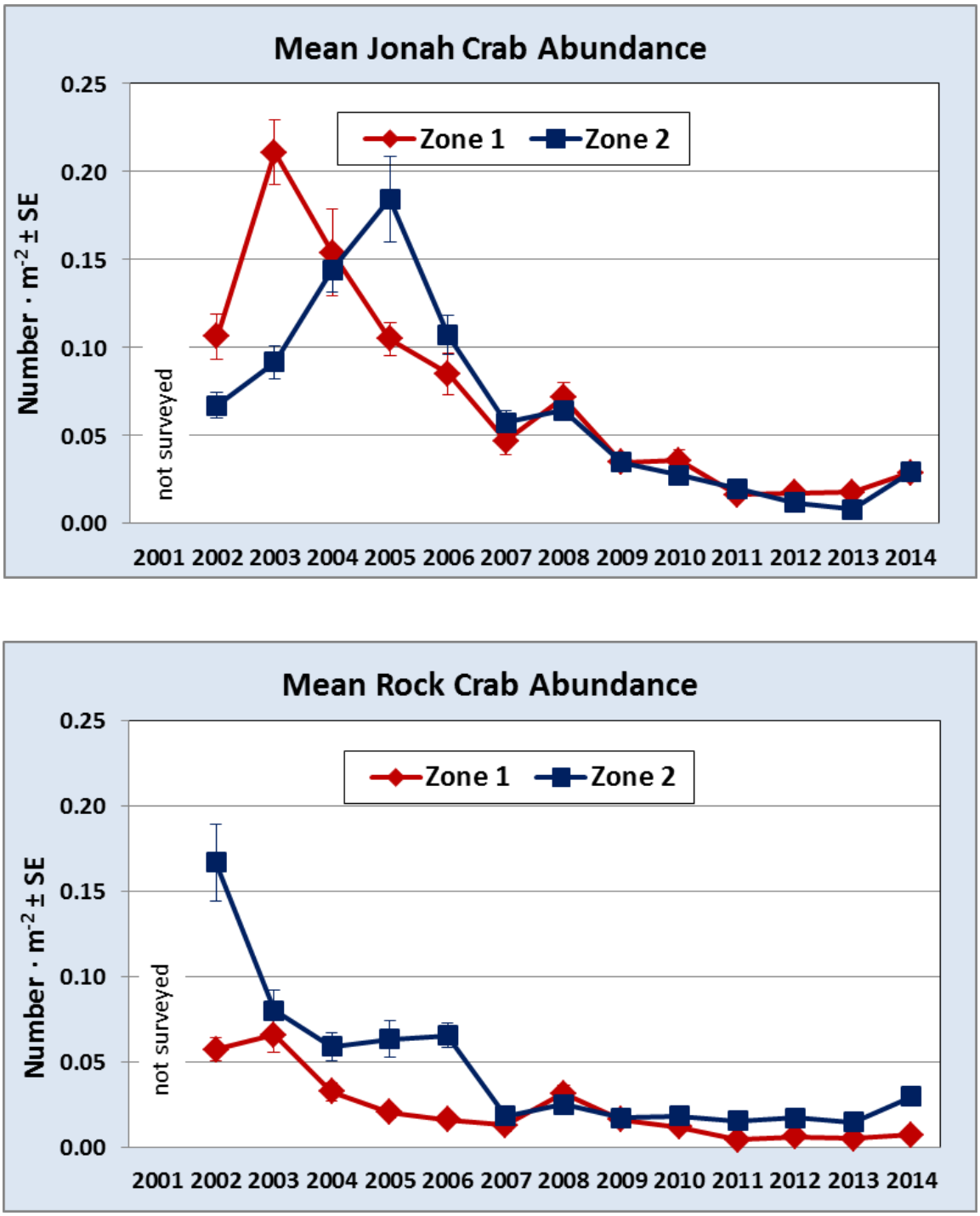


Figure 20. Stratified mean Jonah crab (*C. borealis*, above) and rock crab (*C. irroratus*, below) abundance (numbers per square meter) with standard errors from the spring survey by year and zone.

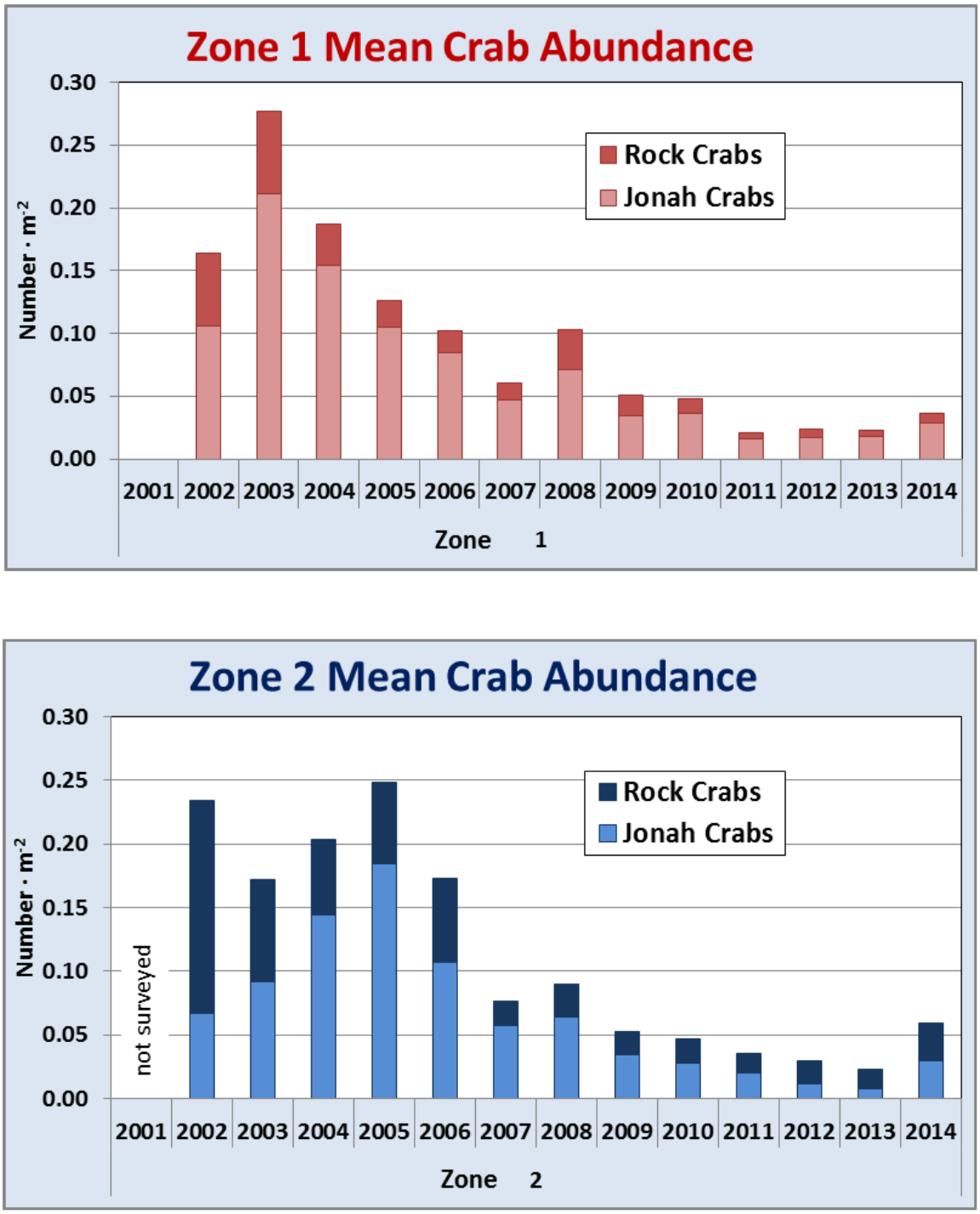


Figure 21. Stratified mean Jonah crab (*C. borealis*) and rock crab (*C. irroratus*) abundance (numbers per square meter) from the spring survey by species, year and zone, Zone 1 above and Zone 2 below.

APPENDIX A

Population Dynamics Modeling

During 2001, a stochastic observation-error length-structured model utilizing a Bayesian approach was developed to describe the dynamics of Maine's sea urchin fishery and stock. It was further tested and refined during 2003 (Chen and Hunter, 2003, Chen *et al.* 2003, Kanaiwa *et al.* 2005) and will be referred to here as "the model".

The model consists of nine sub-models: (1) a growth model; (2) a stock-recruitment model; (3) a catch-at-size model; (4) a fishing selectivity model; (5) a maturation model; (6) an observation model relating observed landings-per-unit-effort to LPUE data predicted from the models; (7) an observational model relating the observed catch size compositions to predicted catch size compositions; (8) an observational model relating the observed survey abundance indices to the abundance indices predicted from the models; and (9) an observational model relating observed survey size composition data to predicted stock size compositions. The first five sub-models describe the fishing processes and the processes determining the dynamics of a fish population, and they were used to generate a model fishery. The dynamics of the model fishery were driven by reported catch. Various fisheries statistics such as catch size composition and stock biomass were predicted from the simulated fishery. The parameters of the sub-models were then fine-tuned using the four observational models by minimizing the differences between observed and predicted fisheries statistics.

Zone Determination — The model was run separately for each of the state's two management zones. Since the zones didn't exist in law until 1995, the zone of the harvest (1 or 2) had to be estimated from county landings data for 1987–1994. Even after 1994, harvest zones were not always reported and had to be estimated. Since the estimated harvest zone was often based on the location of the landing, and harvesters occasionally trucked and landed their catches at locations far from the harvest (most often Portland, in Zone 1), Zone 1 harvests are probably over-estimated, while Zone 2 harvests may be under-estimated, especially before 2004. See Appendix B for further discussion.

Model Input Data — Input data for the model are listed in Tables A1–A2. They consist of:

1. Seasonal landings data from 1987–88 through the 2013–14 fishing season for each zone.
2. Seasonal median diver landings per unit effort in kg/bottom-hour for 1994–05 through 2001–02 from port interviews for each zone. Because LPUE was not considered to be a good index of abundance for this stock (see discussion above) it was only used as model input until the spring survey index became available.
3. Seaonal catch diameter-frequencies from port samples (described above) expanded to catch for 1995–96 through 2013–14 for each zone, as well as the number of urchins measured for each zone and season.
4. The diameter-weight regression coefficients from 1999–2000 port samples for each zone (Figure 9 above). The 1999–2000 season was chosen as being in the middle of the time series.
5. The seasonal minimum and maximum size limits for 1987–88 (none) through 2013–14 (52.4 and 76 mm respectively).
6. Stratified mean biomass indices from the spring survey for each zone and year, for 2001 through 2013. Note that the 2014 survey indices will not be used in the model until there is another year (2014–15) of fishery data.
7. Stratified mean sea urchin abundance by diameter (see Figure 15 above) from the spring survey, by zone and year, for 2001 through 2013, as well as the number of urchins measured for each zone and year.

Note that discards are not considered.

Model Output — Some of the model outputs are listed in Tables A3–A4 and Figures A1–A2. Although model results were used to inform management during 2002–2013, strong residual patterns for the survey index in Zone 1 suggest the model has not fit the data well (Figure A1, bottom). Survey indices have declined faster than the model predictions. For this reason, we do not recommend using the model results for management advice at this time, especially for Zone 1.

Table A1. Population dynamics model input for Zone 1.

	Fishery			Legal Size (diameter)			Survey	
Season	Landings (mt)	N ≥ 40 mm measured	LPUE lbs/hr	Minimum (mm)	Maximum (mm)	Tolerance (%)	Index $g \cdot m^{-2}$	N ≥ 40 mm measured
1987-88	1,174.6							
1988-89	2,727.3							
1989-90	4,138.2							
1990-91	6,598.4							
1991-92	6,319.1							
1992-93	10,582.6							
1993-94	8,876.3							
1994-95	7,906.3		150	50.8		10%		
1995-96	7,021.4	2,220	126	50.8		10%		
1996-97	4,712.6	3,881	132	50.8		10%		
1997-98	2,998.1	3,980	117	50.8		10%		
1998-99	2,618.6	4,600	154	50.8		10%		
1999-00	2,300.7	3,540	146	50.8		10%		
2000-01	2,007.8	2,700	161	50.8	88.9	5%		
2001-02	1,452.8	1,920	136	52.3875	76.2	5%	103.4	966
2002-03	885.6	860		52.3875	76.2	5%	105.9	538
2003-04	586.8	620		52.3875	76.2	5%	68.5	474
2004-05	71.1	540		52.3875	76.2	5%	17.4	184
2005-06	50.9	300		52.3875	76.2	5%	25.2	235
2006-07	70.3	320		52.3875	76.2	5%	27.6	188
2007-08	81.0	280		52.3875	76.2	5%	11.6	99
2008-09	62.9	120		52.3875	76.2	5%	17.3	90
2009-10	55.2	220		52.3875	76.2	5%	10.5	124
2010-11	67.5	420		52.3875	76.2	5%	32.9	150
2011-12	82.2	380		52.3875	76.2	5%	21.6	127
2012-13	124.0	360		52.3875	76.2	5%	16.4	128
2013-14	174.2	360		52.3875	76.2	5%	10.1	42

Table A2. Population dynamics model input for Zone 2.

	Fishery			Legal Size (diameter)			Survey	
Season	Landings (mt)	N ≥ 40 mm measured	LPUE lbs/hr	Minimum (mm)	Maximum (mm)	Tolerance (%)	Index $g \cdot m^{-2}$	N ≥ 40 mm measured
1987-88	673.6							
1988-89	665.5							
1989-90	628.1							
1990-91	1,339.6							
1991-92	2,618.9							
1992-93	7,238.5							
1993-94	8,282.9							
1994-95	8,938.9		220	50.8		10%		
1995-96	6,705.4	3,365	208	50.8		10%		
1996-97	6,107.7	6,794	201	50.8		10%		
1997-98	4,689.7	5,294	189	50.8		10%		
1998-99	4,957.7	5,239	185	50.8		10%		
1999-00	4,074.6	4,780	176	50.8		10%		
2000-01	3,352.7	3,219	152	50.8	88.9	5%		
2001-02	2,108.1	2,640	130	52.3875	76.2	5%	314.8	5,056
2002-03	2,153.8	2,080		52.3875	76.2	5%	259.6	3,430
2003-04	2,286.5	1,340		52.3875	76.2	5%	221.7	3,856
2004-05	1,646.7	880		52.3875	76.2	5%	155.1	2,939
2005-06	1,696.8	1,360		52.3875	76.2	5%	147.4	2,373
2006-07	1,303.9	1,095		52.3875	76.2	5%	149.4	1,527
2007-08	1,349.8	980		52.3875	76.2	5%	130.9	1,275
2008-09	1,343.0	858		52.3875	76.2	5%	161.3	1,499
2009-10	1,356.9	1,892		52.3875	76.2	5%	196.2	2,001
2010-11	976.6	3,320		52.3875	76.2	5%	185.0	1,508
2011-12	975.2	1,920		52.3875	76.2	5%	134.8	1,084
2012-13	709.8	2,339		52.3875	76.2	5%	123.0	1,330
2013-14	698.3	1,540		52.3875	76.2	5%	104.9	1,334

Table A3. Population dynamics model output for Zone 1.

	Biomass Estimates (mt)			Exploitation	Survey		
Season	Recruits	Exploitable (legal)	Total (>40 mm)	Rate	Obs.	Pred.	Resid.
1987	1,626	19,296	19,296	0.06		515.2	
1988	2,272	20,035	20,035	0.14		535.0	
1989	3,273	20,510	20,510	0.20		547.7	
1990	4,841	21,495	21,495	0.31		573.9	
1991	6,834	22,384	22,384	0.28		597.7	
1992	8,982	26,220	26,220	0.40		700.1	
1993	7,071	24,170	24,170	0.37		645.4	
1994	3,189	14,950	19,968	0.53		533.2	
1995	2,079	11,978	15,361	0.59		410.2	
1996	1,589	8,339	10,778	0.57		287.8	
1997	1,541	6,038	8,228	0.50		219.7	
1998	1,418	5,152	7,200	0.51		192.3	
1999	940	4,502	6,021	0.51		160.8	
2000	395	3,719	4,506	0.54		120.3	
2001	222	2,223	2,951	0.65	103.4	78.8	-1.09
2002	93	1,305	1,722	0.68	105.9	46.0	-3.34
2003	68	716	969	0.79	68.5	25.9	-3.90
2004	74	280	509	0.25	17.4	13.6	-0.99
2005	97	307	564	0.17	25.2	15.1	-2.06
2006	77	361	624	0.19	27.6	16.7	-2.02
2007	91	421	678	0.19	11.6	18.1	1.78
2008	68	446	701	0.14	17.3	18.7	0.31
2009	123	498	793	0.11	10.5	21.2	2.80
2010	150	526	927	0.13	32.9	24.7	-1.14
2011	124	601	1,032	0.14	21.6	27.6	0.98
2012	199	697	1,200	0.18	16.4	32.0	2.68
2013	546	724	1,685	0.24	10.1	45.0	5.98

M = 0.12

$F_{0.1}$ = 0.11

B_{msy} = 6,745 mt

MSY = 703 mt

Table A4. Population dynamics model output for Zone 2.

	Biomass Estimates (mt)			Exploitation	Survey		
Season	Recruits	Exploitable (legal)	Total (>40 mm)	Rate	Obs.	Pred.	Resid.
1987	2,519	20,610	20,610	0.03		507.3	
1988	2,677	21,930	21,930	0.03		539.8	
1989	3,124	23,901	23,901	0.03		588.4	
1990	3,819	26,789	26,789	0.05		659.4	
1991	4,795	30,141	30,141	0.09		742.0	
1992	5,801	33,450	33,450	0.22		823.4	
1993	5,541	32,081	32,081	0.26		789.7	
1994	4,079	22,592	28,291	0.40		696.4	
1995	3,238	18,312	23,159	0.37		570.1	
1996	2,760	15,746	19,783	0.39		487.0	
1997	2,589	13,109	16,787	0.36		413.2	
1998	2,608	11,577	15,206	0.43		374.3	
1999	2,219	9,724	12,972	0.42		319.3	
2000	1,792	8,401	11,162	0.40		274.8	
2001	1,635	5,852	9,850	0.36	314.8	242.5	-1.04
2002	1,425	5,860	9,551	0.37	259.4	235.1	-0.39
2003	1,254	5,633	8,987	0.41	221.6	221.2	-0.01
2004	1,117	5,033	8,097	0.33	155.1	199.3	1.00
2005	990	4,867	7,677	0.35	147.4	189.0	0.99
2006	910	4,467	7,085	0.29	160.6	174.4	0.33
2007	889	4,290	6,832	0.31	130.3	168.2	1.02
2008	847	3,957	6,471	0.34	161.3	159.3	-0.05
2009	816	3,597	6,071	0.38	196.2	149.4	-1.09
2010	752	3,186	5,584	0.31	185	137.5	-1.19
2011	646	3,121	5,361	0.31	134.8	132.0	-0.09
2012	553	2,985	5,025	0.24	123	123.7	0.02
2013	437	2,983	4,813	0.23	104.9	118.5	0.49

M = 0.16

$\mathbf{F_{0.1}}$ = 0.145

$\mathbf{B_{msy}}$ = 7,210 mt

MSY = 973 mt

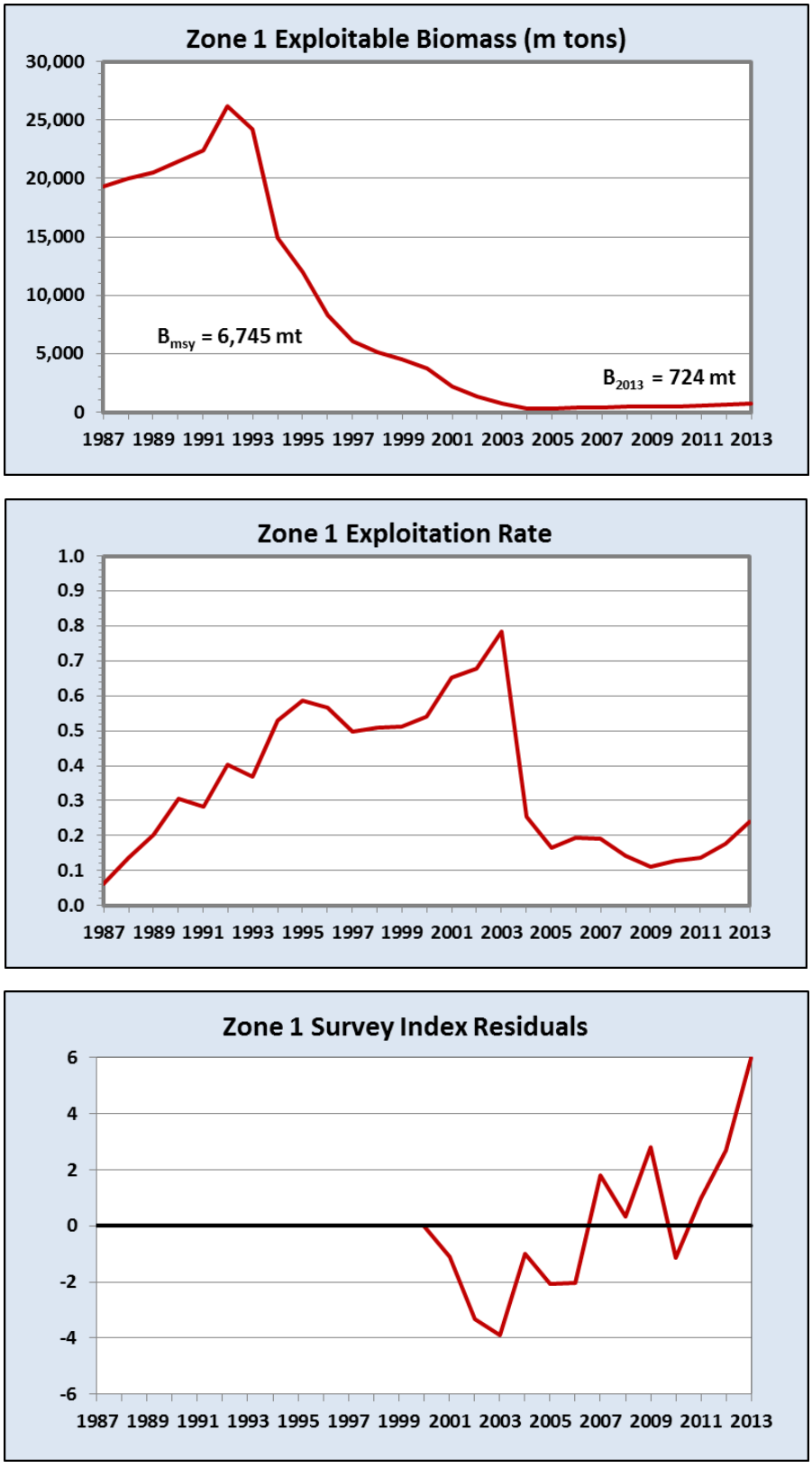


Figure A1. Output from population dynamics modeling for Zone 1: exploitable biomass (mt) top; exploitation rate (%) middle; spring survey index residuals bottom.

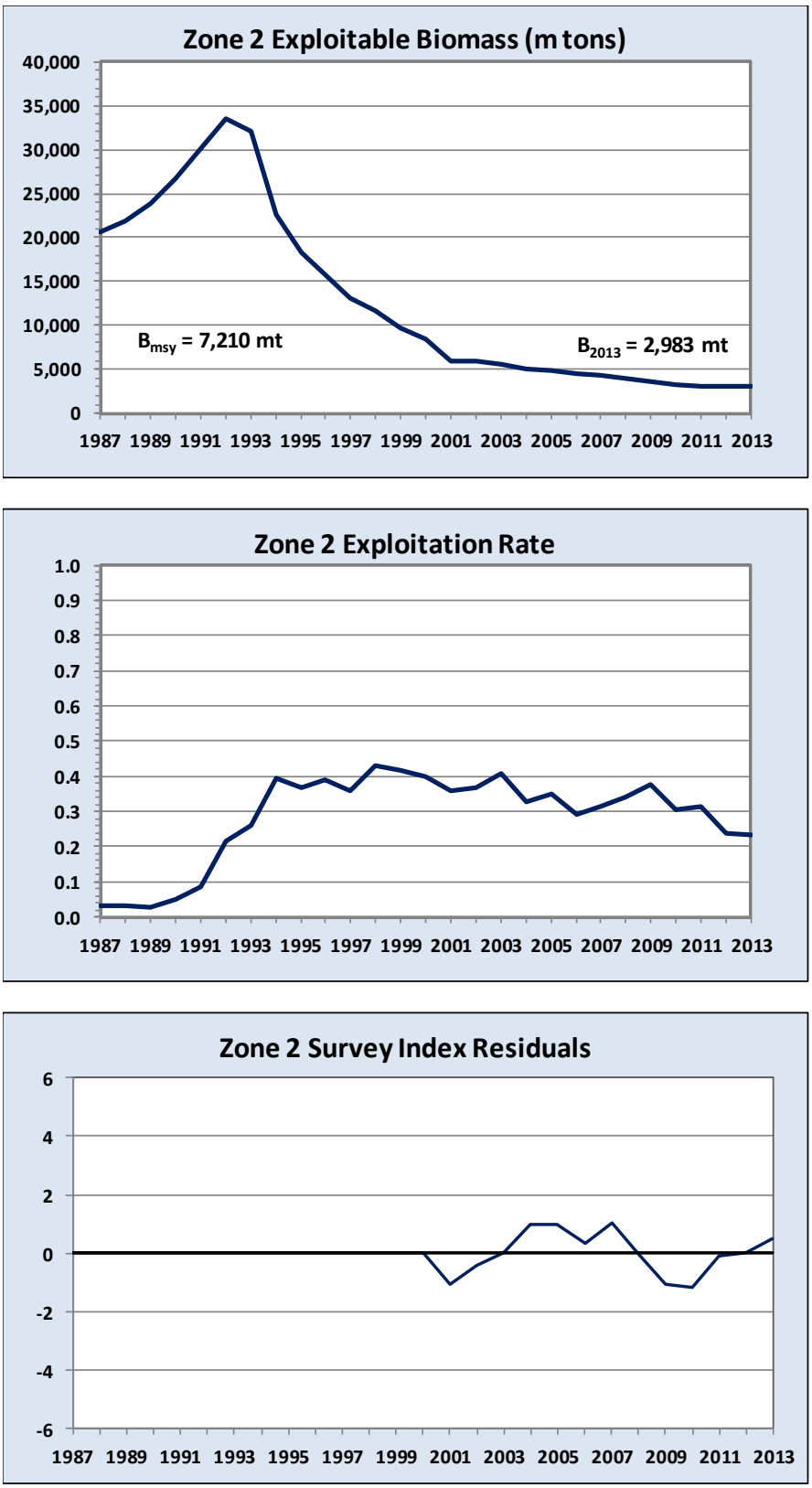


Figure A2. Output from population dynamics modeling for Zone 2: exploitable biomass (mt) top; exploitation rate (%) middle; spring survey index residuals bottom.

APPENDIX B

How a Landing is Assigned to a Zone: Defining Zone 1 and Zone 2 Landings and LPUE for Model Input

Data are presented separately for each of the state's two management zones throughout this report. Ideally, the landings data (used to characterize fishery removals in models) should be based on the zone of the harvest. But the zones did not legally exist before 1995 (see Table 1), and landings data were compiled by NMFS port agents by the county of landing (not harvest) until dealer logbooks were implemented for the 1996–97 season. The dealers were supposed to report the license number of the harvester — which would identify the harvester's zone — but reporting of harvester license numbers was very incomplete in the early years of the logbook program. Beginning with the 2004–05 season, because of the restricted Zone 1 harvesting season, and because dealer reporting of harvester license numbers improved, it became easier to determine the zone of harvest. For these reasons, the zone of harvest was estimated based on the zone of the county of landing before the 1996–97 season, then on the zone of the port of the landing from the 1996–97 through the 2003–04 season, and then based on the reported harvester's zone from 2004–05 to present.

For 1987-88 through 2003-04, York, Cumberland, Sagadahoc, Lincoln, Knox, and Waldo* County landings were assigned to Zone 1, and Hancock and Washington County landings were assigned to Zone 2 (see Figure 1). If the landing county was missing or unknown, the landing was divided between the two zones in the same proportions as the known landings for that month.

Landings by town became available via dealer logbooks during 1996, and landings for Knox County, which straddles the zone boundary, could be divided between Zone 1 and Zone 2. However, there were never any dealer logbook landings in Knox County between 1996–97 and 2003–04 that were not in a Zone 1 port, so, again, all Knox County landings were assigned to Zone 1.

Effort, size, and LPUE data from port samples were assigned to the same zone as the landing of the sampled catch.

Exceptions: If one zone was closed to fishing while the other was open, landings were assigned to the open zone. For example, a landing in Portland (in Zone 1 in Cumberland County) when Zone 1 was closed and Zone 2 was open was assigned to Zone 2. A landing in Portland when both zones were open was assigned to Zone 1. This was most easily calculated at the month-county level.

Season	Exceptions
1987–1994	No exceptions. (Seasons were the same statewide; there were no zones.)
1994–1995	April and May 1995 landings were Zone 2; Zone 1 was closed.
1995–1996	Aug. and Sept. 1995 landings were Zone 1; April 1996 landings were Zone 2.
1996–1997	March and April 1997 landings were Zone 2.
1997–1998	Sept. 1997 landings were Zone 1; March and April 1998 landings were Zone 2.
1998–1999	Sept. 1998 landings were Zone 1; March and April 1999 landings were Zone 2.
1999–2000	Sept. 1999 landings were Zone 1; March and April 2000 landings were Zone 2.
2000–2001	Sept. 2000 landings were Zone 1; March and April 2001 landings were Zone 2.
2001–2002	Sept. 2001 landings were Zone 1; March and April 2002 landings were Zone 2.
2002–2003	Sept. 2002 landings were Zone 1; March and April 2003 landings were Zone 2.
2003–2004	Sept. 2003 landings were Zone 1; March and April 2004 landings were Zone 2.

For 2004–2005 onward, the harvest zone was determined from the zone of the harvester license, or, if missing, estimated from the date and/or the location of the landing.

* There have never been any Waldo County landings reported.