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Author: Geiger, Stephen P.

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ARTICLE

Calico Scallop *Argopecten gibbus* Abundance on the Cape Canaveral Bed and on Florida's Gulf of Mexico Shelf

Stephen P. Geiger*
Florida Fish and Wildlife Conservation Commission, Fish and Wildlife Research Institute, 100 8th Avenue Southeast, St. Petersburg, Florida 33701, USA

William S. Arnold
National Oceanic and Atmospheric Administration, Southeast Regional Office, 263 13th Avenue South, St. Petersburg, Florida 33701, USA

Sarah Stephenson and Keith Fischer
Florida Fish and Wildlife Conservation Commission, Fish and Wildlife Research Institute, 100 8th Avenue Southeast, St. Petersburg, Florida 33701, USA

Abstract
Annual landings of the calico scallop *Argopecten gibbus* fishery in the southeastern United States increased from less than 3,000 kg in 1959 to 19.5 million kg of adductor muscle meat in 1984. The fishery began to collapse in early 1986 in Florida and fell below 1 million kg/year in the mid-1990s. From 2002 through 2011, the only reported landings were 550 kg in 2009, but annual landings of less than 200,000 kg beginning in 2012 indicate the resource rebounded enough in that year to create renewed interest in the fishery. When the fishery was developing, the National Marine Fisheries Service (NMFS) sponsored 59 cruises (1956 through the mid-1970s) to map the distribution of the stock and found the calico scallop stocks on Florida's east coast principally occurred around the 40-m depth contour near the shelf break. By the early 1980s, surveys were no longer routinely conducted. Two surveys in the mid-1990s were dedicated to investigating the collapse of the stock. The present study consisted of eight cruises from 2004 to 2006: four each to the beds off Cape Canaveral on the eastern coast and the poorly documented beds off southwestern Florida. Cruises studying baitfish and cruises in the Gulf of Mexico by the Southeast Area Monitoring and Assessment Program (SEAMAP) yielded data that provided additional calico scallop abundance estimates. Abundant, albeit small, scallops were found on both coasts during three of the four cruises to each coast though none were detected in fall 2004 on either coast. Our results concur with those historic NMFS surveys conducted prior to the period of heaviest exploitation of the resource (1974–1999); the center of distribution for calico scallops on the Cape Canaveral beds still occurs near the 40-m depth contour. The essential habitat for calico scallops, shell base, which was suspected to have declined during the most active fishery periods, was found to have persisted consistently at that depth. There were few scallops with a shell height greater than 40 mm, the minimal size considered acceptable for commercial exploitation.

Subject editor: Patrick Sullivan, Cornell University, Ithaca, New York

*Corresponding author: steve.geiger@myfwc.com

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Fisheries are prone to both long-term trends and very short-term fluctuations in abundance. The changes may be cyclic on both short (Beukema et al. 2001) and long terms (Kimmel et al. 2013), episodic (Powell et al. 2008), or reflect relatively permanent shifts related to changes in the ecosystem (Peterson et al. 2008). In the long-lived Atlantic sea scallop *Placopecten magellanicus* the increase in abundance observed from 1999 through 2005 occurred after new management measures were implemented in 1994 (Hart and Rago 2006). Many scallop species have life spans as short as 1–2 years (Marshall 1963; Wolff 1988), and because many adults have only one chance to spawn, the populations are prone to large and rapid swings in abundance (Maeda-Martínez et al. 1993; Wolff and Mendo 2000). An adaptive management plan that considers such population swings might be more effective than a fixed harvest rate.

The calico scallop *Argopecten gibbus* of the southeastern United States, which can reach maturity at 3 months and typically lives 18–24 months (Blake and Shumway 2006), has also exhibited highly variable abundance. Federal port samplers conducted 11 harvest surveys of seafood dealers from 1927 through 1945, and, of those, three indicated a species of scallop, distinctly separate from the bay scallop *Argopecten irradians*, had been landed in Florida's southwestern counties, Pinellas and Sarasota (Fiedler 1938). The earliest landings of what were thought to be calico scallops were made in Sarasota County in 1927, when 5,800 kg of meat (only the adductor muscle meat is consumed in the United States) was recorded. This other species was recorded as sea scallop, but the Atlantic sea scallop is not found in Florida, while calico scallops are known to be present in abundance immediately offshore of Sarasota, so *Argopecten gibbus* was most likely the identity of the species, though we can never be certain.

The National Marine Fisheries Service (NMFS) began to conduct focused exploratory dredge and trawl surveys for calico scallops in the late 1950s (Bullis and Ingle 1958). Data from numerous NMFS survey vessels were prepared as unpublished cruise reports and were presented to the commercial fishing industry mainly through summary reports (L. L. May, R. O. Maurer Jr., and J. B. Rivers, NMFS, unpublished data; L. L. May, D. L. Sutherland, S. B. Drummond, and J. B. Rivers, NMFS, unpublished data) (Table 1). The fishery had become firmly established by 1961, the most consistently productive stocks located in the Cape Canaveral beds off east-central Florida. The calico scallop fishery was active from 1961 through 2001 (Figure 1; data compiled from NMFS annual landings query for calico scallops [http://www.st.nmfs.noaa.gov/st1/commercial/landings/annual_landings.html] and prior Reports of the Commissioner, U.S. Commission of Fish and Fisheries), having first developed in the northeastern Gulf of Mexico (Bullis and Ingle 1958) before stocks were also found in North Carolina (Cummins 1971), South Carolina (SAFMC 1998), and eventually east-central Florida (Taylor 1967; Cummins 1971). Small numbers of calico scallops have occasionally been landed in Georgia as bycatch in commercial shrimp trawls and have probably not been directly targeted for there. The NMFS conducted surveys through 1968 using dredges, or to a lesser extent various trawls, primarily to identify commercially fishable calico scallop stocks. These surveys targeted known resource areas and minimized random exploration for new fishing grounds. Data were recorded as presence or absence rather than quantitatively when samples were below a threshold that the investigators deemed too low for commercial production, i.e., about one bushel (~35 L) per 1-h tow. Surveys from 1969 through 1976 relied principally on video transects with occasional dredge samples for ground truthing (May, Maurer, and Rivers, unpublished; May, Sutherland, Drummond, and Rivers, unpublished). No directed calico scallop surveys were made from 1976 until the mid-1980s.

The calico scallop fishery achieved a record level of production in 1984 (20 million kg of meat) and employed more than 2,600 people in Florida. The fishery collapse on Florida's east coast began in early 1986 to the point that no scallops were available for harvest on the Cape Canaveral beds (Rockwood and Pompe 1988); it rebounded in 1987. Average annual direct spending by the calico scallop fishing industry during its peak (1984–1987) was around US$23 million, and total indirect economic impact in the region averaged more than $86 million/year (Rockwood and Pompe 1988). Statewide landings in Florida went through another cycle of decline and rebound in the 1990s but still averaged 0.8 million kg of meat. Calico scallop harvests were essentially nonexistent from 2002 through 2012. Modest harvests were achieved in 2013, and 5,100 kg of calico scallop meat was landed in Florida. In 2014 harvests were reported in federal waters off Florida, but catches were landed in other states (federal landings data were not available as of publication date). North Carolina has had no commercial landings of calico scallops in more than a decade.

Many factors may influence the interannual success of the Cape Canaveral calico scallop fishery including disease (Moyer et al. 1993), predation (Schwartz and Porter 1977), senility (Carpenter 1967; Roe et al. 1971), and commercial harvest. Settling scallop larvae requires a hard and stable substrate for attachment and typically use the valves of living and dead mollusk shells (Schwartz and Porter 1977). Traditionally, most calico scallop harvests were made with modified otter trawls using 7.6-cm (3 in) mesh. The process swept the bottom of all living and dead matter, and the entire catch was taken dockside for sorting both calico scallops and nontarget fauna, flora, and substrate. This activity would remove essential habitat for juvenile calico scallops (Nelson et al. 1992), though at least one harvester processed the catch at sea and returned the bycatch to the scallop grounds (SAFMC 1998). This same fisher, one of the last to harvest calico scallops in Florida in the 1990s, indicated he would travel the entire state coastline and would harvest from many nontraditional beds, including the nearshore zone off southwestern Florida around Sanibel–Captiva and Marco islands. Increasingly, the loss of shell is a worldwide concern for shellfisheries (Kraeuter et al. 2003; Guay and Himmelman

TABLE 1. The listed NOAA survey cruises with historical data were conducted from several research vessels: RV *Silver Bay* (SB), RV *Oregon* (OR), RV *Bowers* (BO), RV *Oregon II* (O2), RV *Delaware II* (D2), RV *Bellows* (BW), RV *GeoQuest* (GQ), and RV *Bonnie E* (BE). For most cruises, a general description and hand-drawn map were provided in the cruise report. In the column, Data description, latitude–longitude (LL) indicates that the cruise log provided station location and catch rates (of calico scallops). Common commercial species (CCS) indicates that calico scallops were not necessarily the primary focus of the sampling but that scallops were recorded. For RV *Bowers* cruises, spatial data are generally provided in terms of LORAN lines accompanied with indications of the depth along the LORAN line at which a catch of scallops was made. When the data description indicates text and map (TM) only, we have been unable to locate the detailed cruise logs with station and catch data. LL indicates that the latitude and longitude of the samples were recorded; P–A indicates that presence and absence of scallops was noted, but not abundance; *N* indicates the number of useful station samples. For some cruises (*), only those catches exceeding 1 bushel (∼35 L) were recorded, so the other stations cannot reliably be considered to have had no scallops in their catch; in those cases (OR), *N* is equal to the number of catches exceeding 1 bushel, or when both values are reported, the total number of scallop dredges is included as well (*N*:*N*). GoM: Gulf of Mexico; Atl: Atlantic; FL: Florida; GA: Georgia; NC: North Carolina; SC: South Carolina; Cal. scal.: calico scallops.

Vessel	Cruise	Dates	Location	Data description	*N*
SB	2	Jul 12–29, 1957	GoM, FL	TM, LL, P–A	
	10	Jul 17–Aug 4, 1958	GoM, FL	TM, LL, P–A	
	18	Sep 2–29, 1959	Atl, NC	TM, LL, CCS, P–A	
	20	Nov 21–Dec 13, 1959	Atl, NC	TM, LL, CCS	3
	21	Jan13–29, 1960	Atl, GA–FL	TM, LL, CCS, P–A	
	22	Feb 16–Mar 18, 1960	Atl, NC–SC	TM, LL, CCS.	50
	23	Apr 13–May 6, 1960	Atl, FL	TM, LL	199
	24	May 26–Jun 14, 1960	Atl, FL	TM, LL	41
	25	Jul 13–30, 1960	Atl, SC–NC	TM, LL, CCS	
	26	Oct 11–Nov 15, 1960	Atl, FL	TM, P–A	
	27	Dec 1–16, 1960	Atl, SC	TM	
	28	Jan 18–Feb 10, 1961	Atl, FL	TM	
	29	Feb 27–Mar 11, 1961	Atl, NC	TM, LL, CCS	61
	30	Apr 17–May 11, 1961	Atl, FL	TM, LL, CCS	132
	31	Jul 5–21, 1961	Atl, FL	TM, LL, CCS	118
	32	Aug 18–23, 1961	Atl, NC	TM, LL, CCS	
	33	Sep 23–Oct 6, 1961	Atl, FL	TM, LL, CCS	84
	35	Nov 28–Dec 15, 1961	Atl, FL	TM	
	36	Jan 15–Feb 6, 1961	Atl, FL	TM, LL	22
	39	May 24–Jun 12, 1962	Atl, NC	TM, LL, CCS	1
	41	Aug 21–Sep 7, 1962	Atl, FL	TM, LL	103
	42	Sep 24–Oct 2, 1962	Atl, FL	TM	
	47	Mar 25–Apr 1, 1963	Atl, FL	TM	
	51	Nov 6–19, 1963	Atl, FL	Text, LL	196
	54	Feb 4–16, 1964	Atl, FL	TM	
	55	Feb 25–Mar 4, 1964	Atl, FL	TM, LL, CCS	20
OR	123	Nov 6–20, 1967	Atl, FL–GA	TM, LL, CCS*	27:110
	124	Dec 4–19, 1967	Atl, FL	TM	
	126	Feb 12–29, 1968	Atl, FL	TM, LL, CCS*	120:225
	128	Apr 12–27, 1968	Atl, FL	TM, LL, CCS*	76:130
	130	Jun 10–26, 1968	Atl, FL	TM, LL, CCS*	83:181
	132	Aug 22–26, 1968	Atl, FL	TM, LL, CCS*	37:99
	134	Oct 8–25, 1968	Atl, FL	TM, CCS*	
	136	Dec 9–20, 1968	Atl, FL	TM, LL, CCS*	87:195
BO	85	Jul 21–Aug 5, 1969	Atl, FL	TM (LORAN)	
	93	Jun 17–25, 1970	Atl, FL	TM (LORAN)	
	98	Oct 21–Nov 2, 1970	GoM, FL	TM (LORAN)	
	99	Jan 21–27, 1971	Atl, FL	Cal. scal., no spatial data	
	100	Mar 10–17, 1971	Atl, FL	Cal. scal., no spatial data	
	101	Apr 15–21, 1971	Atl, FL	Cal. scal., no spatial data	

TABLE 1. Continued.

Vessel	Cruise	Dates	Location	Data description	N
	102	Apr 28–May 8, 1971	Atl, GA–SC	TM	
	104	Jun 3–23, 1971	Atl, FL	TMs, LORAN lines	
	106	Jul 17–Aug 17, 1971	GoM, FL	TM	
	109	May 1–Jun 2, 1972	Atl, FL	TM, LORAN lines	
	110	Jul 12–17, 1972	Atl, FL	TM, LORAN lines	
	112	Sep 13–Oct 10, 1972	Atl, NC	TM, LORAN	
	114	Jan 9–26, 1973	Atl, FL	TM	
	120	Oct 25–Nov 18, 1973	Atl, FL	TM, LORAN	
	122	Apr 22–May 16, 1974	Atl, NC	TM	
	124	Aug 13–Oct 23, 1974	Atl, FL	TM	
	128	Apr 26–May 13, 1975	GoM	Text	
	138	Mar 9–26, 1976	Atl, FL	Text	
O2	59	Jun 10–27, 1975	Atl, FL	TM, LORAN	
	65	Mar 19–Apr 8, 1976	Atl, GoM	Text	
	76	Mar 27–Apr 11, 1977	Atl, FL	Text	
	122	Oct 14–Nov 20, 1981	GoM, Atl	Some text	
	165	Mar 16–22, 1987	Atl	LL, CCS	40
D2		Jun 1982	Atl, FL	Text, LL	17
BW		Aug 2–8, 1989	Atl, FL	TM, LL	40
GQ		Nov 20–27, 2004	Atl, FL	TM, LL	59
		Apr 29–May 13, 2005	Atl, FL	TM, LL	59
		Oct 11–18, 2005	Atl, FL	TM, LL	58
		Jul 18–21, 2006	Atl, FL	TM, LL	54
BE		Oct 27–31, 2004	GoM FL	TM, LL	49
		Sep 15–Nov 7, 2005	GoM FL	TM, LL	63
		Apr 17–21, 2006	GoM FL	TM, LL	58
		Aug 21–Sep 22, 2006	GoM FL	TM, LL	60

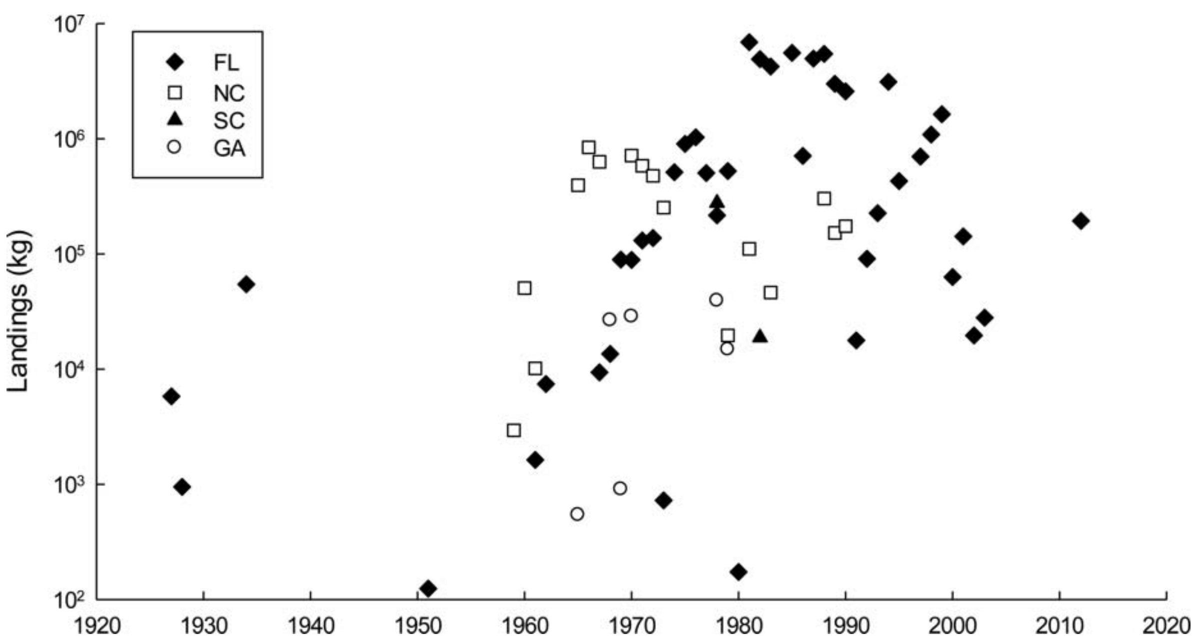

FIGURE 1. Recorded landings of calico scallop meat from southeastern U.S. states: Florida (FL), North Carolina (NC), South Carolina (SC), and Georgia (GA). See text for landings data sources.

2004; Bourgeois et al. 2006). The hypothesis that the removal of calico scallop shell limits the recruitment of scallop larvae is controversial within the industry (SAFMC 1998), and the South Atlantic Fishery Management Council has an ongoing need for habitat surveys to assess the impacts of trawling (SAFMC 1998). According to NMFS landings data, 73 million kg of calico scallop meat was harvested from Florida waters from 1976 through 2000, which represents roughly 10% by weight of the scallops harvested (shell and viscera are not used or reported) and does not measure bycatch, which is highly variable and for which it is difficult to find precise data. The total removal of substrate that serves as habitat would have been colossal given almost four decades of fishing.

Recent landings suggest that stocks of calico scallops may be large enough again to support profitable commercial harvests, and information on their status could be used to guide the management of the fishery. In this study we present information concerning the distribution, abundance, and size distribution of calico scallops and their shell during 2005–2013. Although a comparison with historic studies would be ideal, direct quantitative comparisons of contemporary work with historic studies were not feasible. Historic surveys focused on reporting commercial quantities of catch only and thus excluded zero- and low-catch data. Nevertheless, gross differences in distribution and abundance of calico scallops are compared between the two periods as much as possible.

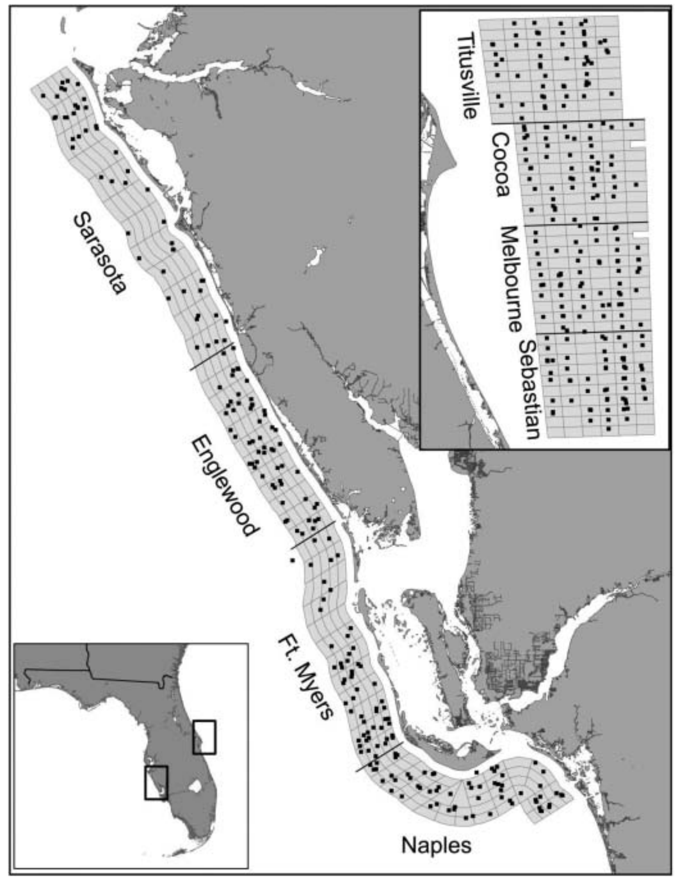

FIGURE 2. Florida east-central and southwestern study sites, 2004–2006. Light gray shaded areas represent the gridded sampling zones; black squares represent stations at which tows were conducted.

METHODS

2004–2006 study.—Dredge surveys were conducted in four sampling periods on each coast. The Cape Canaveral fishing zone located off east-central Florida was sampled during November 2004, April–May 2005, October 2005, and July 2006 from the RV *Geoquest.* The fished zone of the nearshore southwestern Florida shelf was sampled during October 2004, September–November 2005, April 2006 (RV *Bonnie E*), and August–September 2006 (RV *Veliger*, a 6.1-m [20 ft] runabout, and RV *Callinectes*, a 7.9-m [26 ft] runabout).

During each sampling period we conducted ∼15 scallop dredges (Table 1) in each of four latitudinal zones on each coast: east (Sebastian, 27.797–28.045°N; Melbourne, 28.045–28.305°N; Cocoa Beach, 28.305–28.551°N; Titusville, 28.551–28.881°N) and west (Naples, 26.34–26.45°N; Fort Myers, 26.45–26.8°N; Englewood, 26.8–27.1°N; Sarasota, 27.1–27.5°N) (Figure 2). Each zone was divided into a grid of 60 stations resulting in a total of 240 stations for each coast. Stations sampled were randomly chosen in the depth ranges of roughly 20–80 m on the east coast and 5–15 m on the west coast. These depth zones encompassed a large majority of the locations for which we were able to document that historical calico scallop harvests had occurred. On each sampling day we attempted to sample the randomized stations, although we occasionally sampled a different station (typically one closer to shore or that would reduce total daily transit) when weather was inclement or it was getting dark (for safety reasons we sampled only during daylight hours).

Dredges were towed at 1–2 knots for 5 min per sample. The dredge mouth was 0.69 m wide and 0.50 m high, and had a bag length of 1.2 m when a mechanical winch was available (RV *GeoQuest* and RV *Bonnie E*) or 0.42 m wide and 0.25 m high, with a bag length 0.7 m (for the final west coast cruise only). The 0.42-m dredge was deployed from the stern cleat of a standard runabout and retrieved by hand for our final cruise. Both frames were equipped with a net that had a 3-cm (1.25 in)-stretch mesh and a 1-m bridle. Data were recorded as the weight and number of calico scallops caught (kg·min^{-1}·m^{-1} and n·min^{-1}·m^{-1}, respectively) standardized to the width of the mouth of the net (m) and time towed (min).

During each tow we recorded initial and final GPS coordinates as an estimate of the length of the tow. We also recorded start and stop times, water column depth, and the length of the wire deployed. The appropriate wire angle had been determined on preliminary research cruises (data not included), during which we attached a downward-facing, real-time video system to the upper edge of the mouth of the dredge. The length of the cable deployed and tow speed were modified until the lower edge of the mouth of the frame consistently remained in contact with the sediment surface but did not dig deeply into it. The optimal wire-to-depth ratio was about 3.5:1 at 2 knots and increased with depth and vessel speed. The optimal attachment point for the bridle was at roughly 16.5 cm from the bottom of the frame. In practice, the wire was deployed until approximately a 3:1 ratio (west coast) to 4:1 ratio (east coast) was reached, and then the boat speed was decreased until tension occurred on the wire, indicating that the net was towing on the sediment surface. At the east coast stations we were limited to ∼65 m maximal depth because the capacity of the available winch was ∼180 m of wire.

When processing a dredge sample, we weighed the entire catch. In most cases, we sorted the entire catch, but we split some very large samples (>20 kg) into two to four equal subsamples by weight and sorted only one of those subsamples. All scallops from the portion of the sample that was sorted were removed and weighed. Next, the scallop shells and other mollusk shells were each separated and weighed. Shell heights were measured for a maximum of 30 live scallops from each dredge and the first 15 scallops collected in each zone during each season were preserved for histological analysis of reproduction and disease (authors' unpublished data). Many of the spat detected were originally recorded on data sheets to be adults but were later classified as loose spat because their shell heights were less than 23 mm, the size at which sexual maturity has been reported based on gonad color changes (Miller et al. 1979). Scallops as small as 22 mm had ripe gonads and contained both male and female gametes. These were observed in histological sections of gonad examined for *Marteilia*, a protozoan parasite. Any observations of spat (juveniles < 23 mm shell height) were recorded as either loose or attached to substrate. In an attempt to identify settlement substrate and the proportion of total calico shell, for any tow in which spat were observed we calculated the amount of other shell and all other catch. Assuming that the spat had no substrate preference, we calculated the expected frequency distribution of settled spat as the proportion of each substrate type multiplied by the total number of spat observed in the sample. The observed frequency of attached spat and their settlement substrate were compared with this theoretical expected frequency using a simple chi-square test. Loose scallops < 23 mm shell height were considered to be spat as were any attached scallops. Catch data were standardized for time, dredge width, and any subsampling. Graphic representations of the data were created using ArcGIS.

The hypothesis that the density of scallops, scallop spat, scallop shells, and other mollusk shells were equal among stations was tested by ANOVA, with the four latitudinal zones as a fixed factor. Season and coast also served as fixed factors. Because heterogeneity of variances was a common character of the data, Kruskal–Wallis or Mann–Whitney tests were applied to individual hypotheses when appropriate. The null hypothesis that we tested was that all stations had equal density, and that no seasonal variation occurred. The alternative hypothesis anticipated many stations (or seasons) with densities of zero, interspersed with fewer stations (or seasons) supporting relatively high densities.

Supplemental and historical data sets.—Additional Gulf of Mexico data collections from two bottom trawl surveys were provided by the Fisheries Independent Monitoring (FIM) group of the Florida Fish and Wildlife Conservation Commission's (FWC) Fish and Wildlife Research Institute (FWRI). Data from FWRI's annual spring baitfish survey were summarized from 2009 to 2013. Data were also obtained from summer (June and July) and fall (October and November) groundfish trawl surveys conducted by SEAMAP and were summarized for the northern Gulf of Mexico (Gulf) east of the Mississippi River, including Florida's pilot trawl program in 2008 and 2009 in the northeastern Gulf, which was expanded to full-scale sampling in 2010 to the entire eastern Gulf. The focus of these two surveys was fish stock assessment, but both contained data useful to the present calico scallop study.

The study area for the spring baitfish survey encompassed the nearshore waters of Tampa Bay and Charlotte Harbor from 6 to 28 m depth. The study area was divided into two latitude strata based on degrees of latitude. The central stratum spanned from 27°N to 28°N and the southern stratum spanned from 26°N to 27°N. These strata were further divided into two depth strata. The inshore stratum covered depths from 6 to 11 m; the offshore stratum covered depths from 12 to 28 m. For every survey, three transects (lines of latitude) were randomly chosen in each latitude stratum. These transects started at 6 m and ended at 28 m depth, so transect length depended on the slope. Six trawl stations, three in the inshore stratum and three in the offshore stratum, were then randomly chosen for each transect. A balloon trawl (nominal opening, 9.9 m wide and 4.5 m high; 36.5-m trawl bridle lines; cod end stretch mesh, 43.75 mm; 2.2-m^2 china V-doors with nominal weights of 408.2 kg) with a 19.8-m headrope was towed at 3 knots for 30 min at each station. Stations that could not be trawled due to obstructions or hard bottom were skipped and an alternate station selected and sampled. The entire catch for most trawls was processed, though for a few large catches, a subsample was randomly selected for processing and the total value proportionately extrapolated. As many as 50 scallops were randomly selected and then measured (hinge to outer margin of the shell) for determination of length distribution. We present only an overview of the calico scallop data extracted from that larger data set.

The Gulf of Mexico SEAMAP trawl survey used a standard 12.8-m shrimp trawl and a stratified-random sampling design, with stratification based on a combination of depth (23 depth strata from 9 to 110 m), time of day (day or night), and NMFS

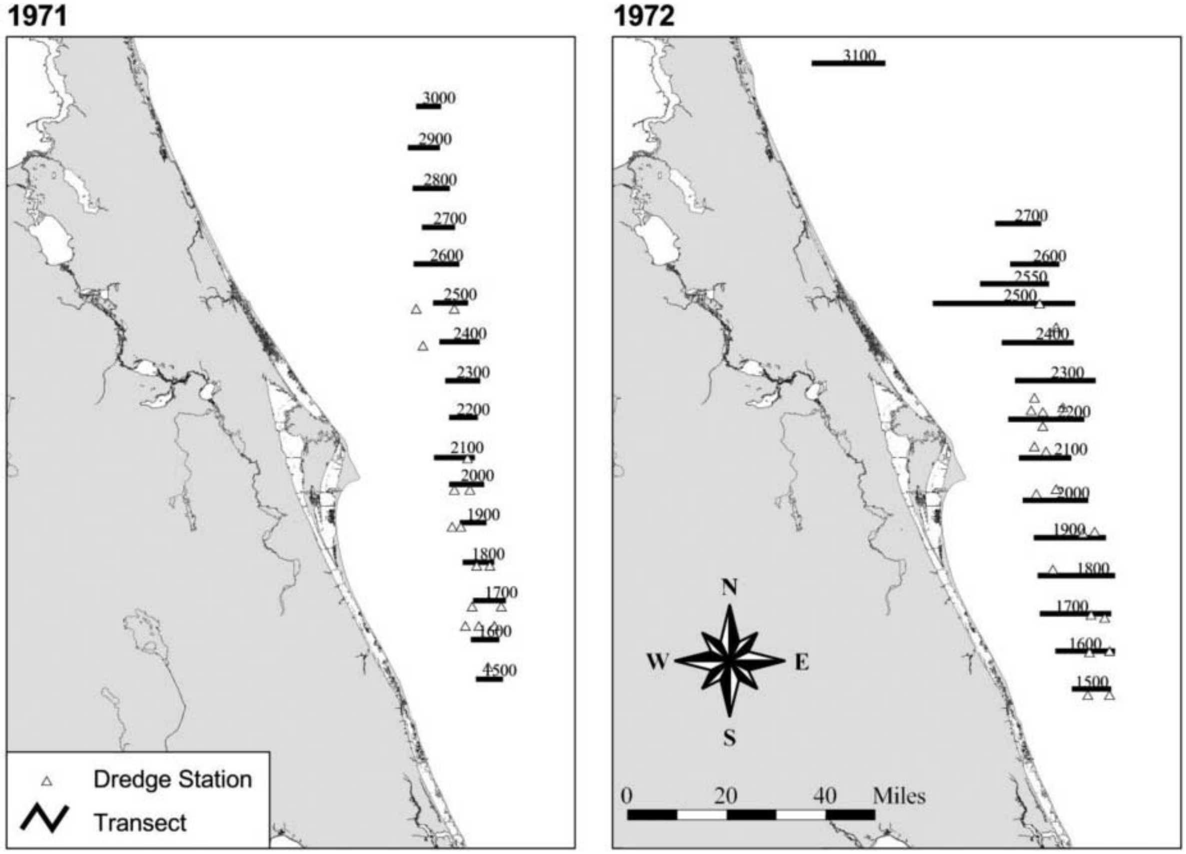

FIGURE 3. NOAA survey locations sampled from RV *George M. Bowers*, 1971–1972. Approximate latitude of each transect line is indicated by the LORAN line (*xx*00), which was the technology used at the time of the survey.

statistical reporting zones. These surveys began in 1981 with summer and fall surveys of coastal waters (9–110 m) from Texas to Alabama (see Switzer et al. 2009 for a full description of survey design). A Florida bottom trawl component was added in 2008 in which a 2-year pilot study in the northeastern Gulf of Mexico evaluated the feasibility of trawling along the west Florida shelf. Full-scale sampling in Florida began in 2010 along its entire Gulf coast. The same year, a new survey design was implemented for the Gulf-wide SEAMAP trawl survey. Overall sampling effort was allocated proportionally among NMFS statistical reporting zones based on proportional availability of sampling habitat (each zone had a different extent of bottom with depths of 9–110 m). In each zone sampling sites were chosen following a simple random survey design. Trawling effort was also standardized to 30 min at each station. The entire catch for most trawls was processed, though for a few large catches a subsample was randomly selected for processing and the total value proportionately extrapolated. As many as 20 scallops were selected and measured (hinge to bill) to determine length distribution.

For a comparison of long-term changes, we categorized historical collections into four data sets: MV *Silver Bay*, 1960–62; RV *Oregon*, 1967–68; RV *Oregon II* and RV *Bellows*, 1980s; and RV *GeoQuest*, 2004–06. Additional information from the 1950s (RV *Oregon*, RV *Delaware*, RV *Bowers*, and RV *Pelican*) and 1970s (RV *Bowers* and RV *Oregon II*) (Figure 3) largely included text-based descriptive reports and exploratory work over a wide region, which were unsuitable for analysis. When possible, we calculated mean catch rates and then standardized individual catches to those mean rates and to tow times and net size. The minimum criteria for inclusion in a data set for a tow included data for latitude and longitude and an indication about the presence or absence of calico scallops.

RESULTS

2004–2006 Study

Eight cruises and 491 tows were attempted, 27 of which were eliminated from the analyses due to lost or malfunctioning gear or when the tow lasted <1 min due to snags. On the east coast 238 of 245 tows were valid, and on the west coast 226 of 246 tows were valid. Over the course of the study 167 of the 240 east coast grid cells and 166 of the 240 west coast grid cells were sampled.

The total catch did not differ between east and west coast samples (Mann–Whitney U-test: $Z = 1.13$, $P = 0.259$). The overall average total catch was 2.10 kg·min^{-1}·m^{-1} (6.44 kg/5-min tow, standardized to the width of the mouth of the net). On the east coast the average catch was 2.30 kg·min^{-1}·m^{-1}, the median sample yielded 0.67 kg·min^{-1}·m^{-1} with a range of 0–51.7 kg·min^{-1}·m^{-1}. On the west coast the average total catch was 1.90 kg·min^{-1}·m^{-1}; the median sample yielded 0.64 kg·min^{-1}·m^{-1} with a range of 0–36.2 kg·min^{-1}·m^{-1}. High within-coast variability precluded detection of differences between the coasts. Catch rates varied seasonally (Kruskal–Wallis test: $H_{3,\ 465} = 21.93$, $P < 0.001$). The initial cruises, in fall 2004, had roughly twice as much total catch as the fall 2005 cruises. The spring and summer cruises were intermediate.

On the east coast there was no statistical difference in total catch between zones; the Sebastian site yielded the highest mean catch but it was not statistically higher than at other sites. There was seasonal variability ($H = 23.69$, $P < 0.001$), with the fall of 2004 yielding the highest catch rates. On the west coast there were differences in total catch between zones ($H = 49.03$, $P < 0.001$). Catch was highest in the Naples zone and lowest in the Englewood zone. There was also seasonal variability ($H = 13.62$, $P = 0.004$), and the fall 2005 cruise yielded the lowest catch rates and other seasons yielded higher catch rates and were not significantly different from one another. There was a very high catch rate in the spring of 2006 in the Naples zone. In other seasons, the difference between west coast zones was reduced.

A total of 3,314 scallops, 1,911 of which were adults, were collected from 154 samples; average shell height of those scallops was 31.4 mm for adults and 10.8 mm for juveniles. On the eastern coast, the greatest number of calico scallops collected in any sample was 205, from a station east of Sebastian Inlet (49.5 scallops·min^{-1}·m^{-1}). Calico scallops were collected in 83 of the 167 grid cells sampled off the eastern coast on at least one cruise (Figure 4). The greatest number of calico scallops collected from any single west coast sample was 213 (253.6 scallops·min^{-1}·m^{-1}), from the region southwest of Sanibel Island. Calico scallops were collected in 45 of the 166 west coast grid cells sampled on at least one cruise (Figure 5).

There was strong seasonal variability in abundance of adult calico scallops ($H = 43.71$, $P < 0.001$). Adults were most abundant on summer cruises, less abundant on fall cruises, and essentially absent in the spring. This pattern was observed on both coasts. Adult scallops were more abundant in east coast samples than in west coast samples ($Z = 3.92$, $P < 0.001$). The median east coast sample yielded 0 scallops (half of the tows had no adult scallops) and an average of 2.11 and a range of 0–49.52 scallops·min^{-1}·m^{-1}. The median west coast sample also yielded 0 scallops, but had an average of 2.35 and a range of 0–253.6 scallops·min^{-1}·m^{-1}. There was no statistical difference in scallop abundance between the east coast zones ($H = 5.87$, $P = 0.118$), but there was a strong seasonal difference ($H = 44.3$, $P = 0.001$) (Figure 4). The yield during the summer cruise exceeded all others; yields were similar for the fall cruises, and the spring cruise had the lowest yield. In the fall 2004 cruise, there were three distinct centers of abundance, all centered shoreward of the 40-m depth contour. In the spring 2005 cruise, adult scallops were not present on the Cape Canaveral fishing grounds. On the west coast there was a strong difference between zones ($H = 46.34$, $P < 0.001$). A consistent trend was for higher scallop abundance southwest of Sanibel Island near the border of the Naples and Fort Myers zones (Figure 5). While the abundance varied seasonally ($H = 15.75$, $P = 0.001$), there were always more scallops in the Naples zone and few north of Boca Grande pass.

Shell height was measured for 1,726 scallops (spat and adults), 1,412 from the east coast and 314 from the west coast (Figure 6). Over the course of eight cruises only 7% of the scallops measured were 40 mm or larger.

The catch rate of spat was highest in samples collected during the summer cruises, a result observed on each coast. Spat were more abundant on east coast scallop beds than on the west coast ($Z = 4.39$, $P < 0.001$). There were 0.96 spat·min^{-1}·m^{-1} (range, 0–26.45) collected in east coast samples and 0.15 spat·min^{-1}·m^{-1} (range, 0–8.21) collected in west coast samples. A high proportion of samples contained no spat. On the east coast, spat were more abundant in samples from the summer cruise than from the other cruises ($H = 93.73$, $P < 0.001$). There was no significant difference between zones ($H = 4.11$, $P = 0.25$) (Figure 4). On the west coast, there were more spat in samples from the Naples zone than from other zones ($H = 16.60$, $P = 0.001$). There were also more spat in samples collected during the spring and summer than during fall cruises ($H = 8.76$, $P = 0.033$). Each of the four west coast zones had at least some spat during one or more cruises. Adult calico scallop abundance in the Englewood and Sarasota zones increased in fall 2006 following the peak in spat observed in spring 2006 samples from those zones (Figure 5).

Spat were more abundant than expected on scallop shell and less abundant than expected on other mollusk shell or on other substrates. This pattern held for analyses of all spat (both coasts combined) ($\chi^2 = 35.83$, $P < 0.001$) and total east coast samples ($\chi^2 = 35.83$, $P < 0.001$) but not total west coast samples ($\chi^2 = 3.11$, $P > 0.05$), although the trend was similar on the west coast where small sample size may have precluded detection of true differences. In each east coast zone during the summer 2006 cruise, the only cruise with a large enough sample to allow examination of spatial variability within a single season, more spat than expected were found on calico scallop shell (Titusville: $\chi^2 = 8.55$, $P < 0.05$; Cocoa Beach: $\chi^2 = 6.93$, $P < 0.05$; Melbourne: $\chi^2 = 13.36$, $P < 0.01$; Sebastian: $\chi^2 = 18.48$, $P > 0.001$) and fewer spat than expected were found on other substrates. In west coast samples there was only one scallop larger than 23 mm that was still byssally attached (2.3% of

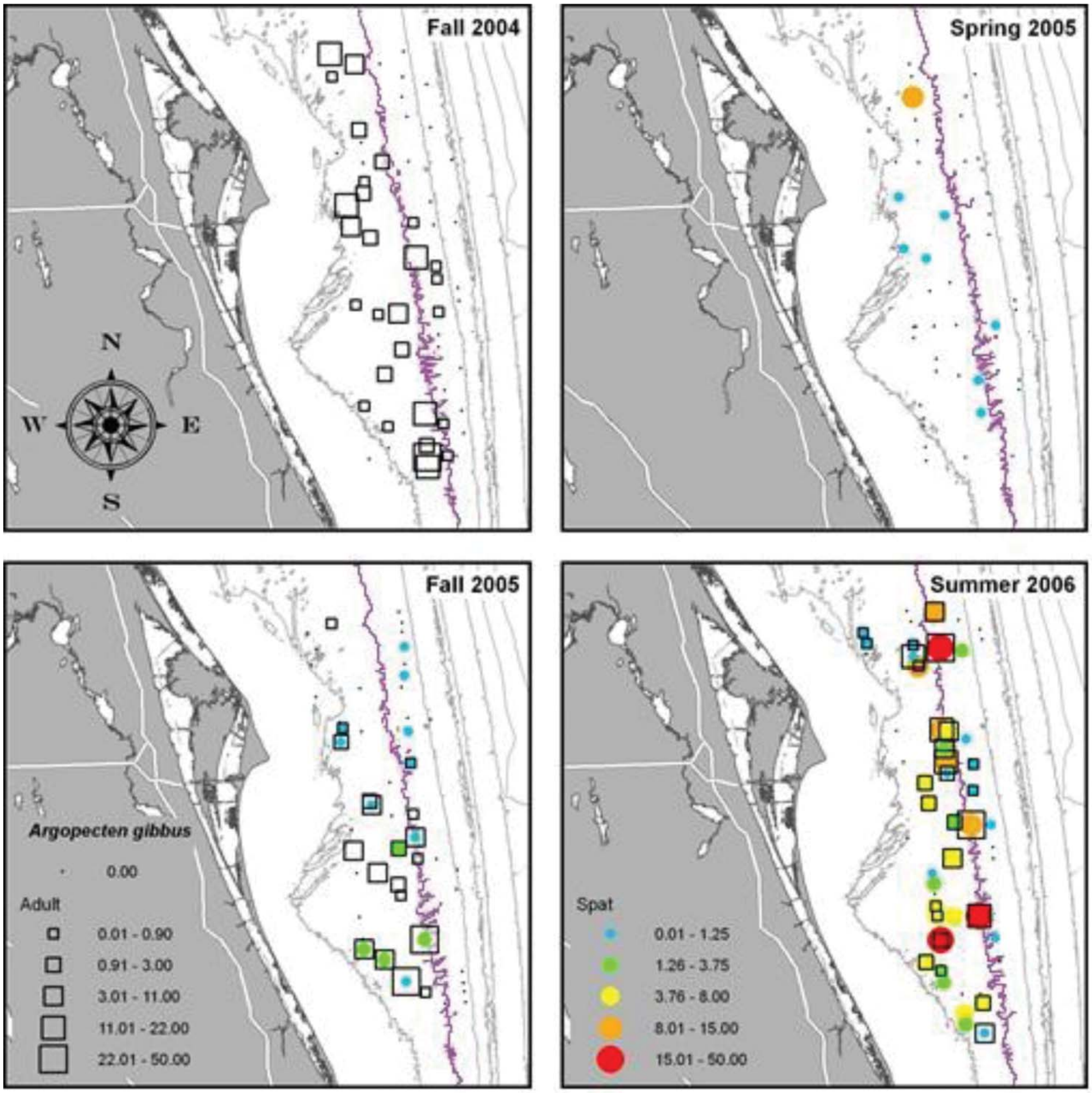

FIGURE 4. Cape Canaveral calico scallop catches (scallops·min^{-1}·m^{-1}), 2004–2006. The 40-m contour line is accentuated in purple. The inshore line is 20 m, successive offshore lines are at 60, 80, 100, 200, 400, and 500 m.

attached scallops were ≥23 mm). In east coast samples there were seven scallops 23 mm or larger still byssally attached (7.4% of attached scallops were ≥23 mm).

There were no seasonal differences in calico scallop shell when the factor "coast" was ignored, but the total weight of shell tended to be most abundant in the two summer cruises, similarly abundant in the four fall cruises, and least abundant in the spring. The prevalence of other shell, however, did differ significantly between seasons, being most abundant in summer, similarly lower in the fall cruises, and least in the spring ($H = 10.71$, $P = 0.013$). When data from each season were pooled to examine differences between coasts, the east coast had much more scallop shell than did the west coast ($Z = 12.36$, $P < 0.001$); there was roughly 10 times more calico scallop shell on the east coast than there was on the west coast. However, the abundance of other shell substrate did not vary by coast ($Z = -1.93$, $P = 0.055$).

On the east coast, calico scallop shell was more abundant in the Cocoa Beach and Sebastian zones than in the Melbourne and Titusville zones ($H = 10.68$, $P = 0.014$). Scallop shell was most abundant in the summer, less abundant during the two fall cruises, and least abundant during spring ($H = 15.72$, $P = 0.001$) (Figure 7). Scallop shell was present in 92% of the valid tows; other shell was present in 95% of the valid tows, albeit at lower density. The prevalence of other shell was more abundant in the Cocoa and Sebastian zones than in the

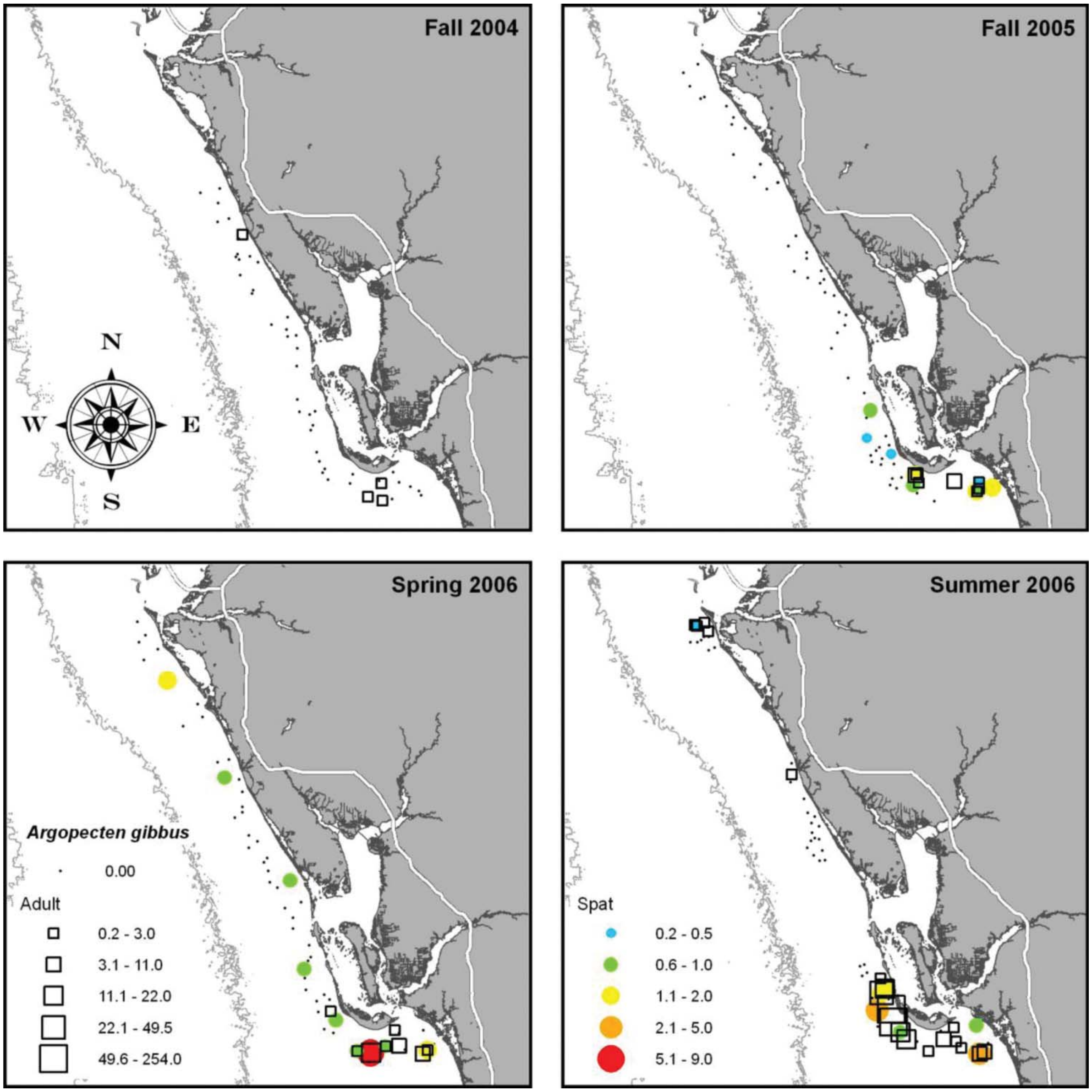

FIGURE 5. Gulf of Mexico calico scallop catches (scallops·min^{-1}·m^{-1}), 2004–2006. The main contour line represents the 20-m isobath.

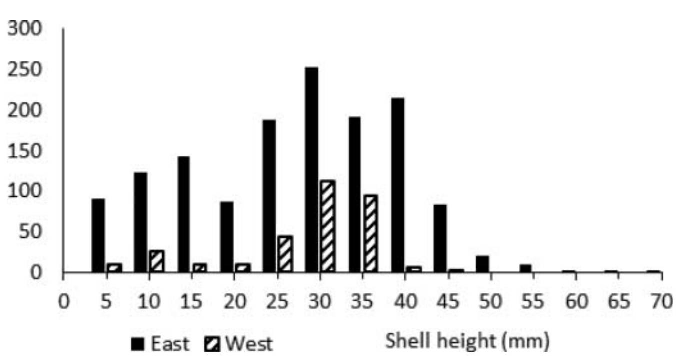

FIGURE 6. Calico scallop size-frequency distribution for all 2004–2006 east coast and west coast collections combined.

Melbourne and Titusville zones ($H = 9.56$, $P = 0.023$). Other shell was more abundant in shallower waters, especially where the 20-m contour extended seaward into the sampling grid in the southwestern corner of the Sebastian zone and northwestern corner of the Cocoa Beach zone. Venerid bivalves were especially abundant in these shoal waters. The abundance of other shell also varied seasonally ($H = 15.38$, $P = 0.002$).

On the west coast, calico scallop shell abundance was highest in the south and less in the north ($H = 20.01$, $P < 0.001$) (Figure 8). The abundance of scallop shell on the west coast varied seasonally ($H = 3.99$, $P = 0.262$) and interactive effects were observed. There was a high abundance of shell in the Fort Myers zone during fall 2004, but this was not detected in later cruises. Scallop shell was more widely distributed (68% of

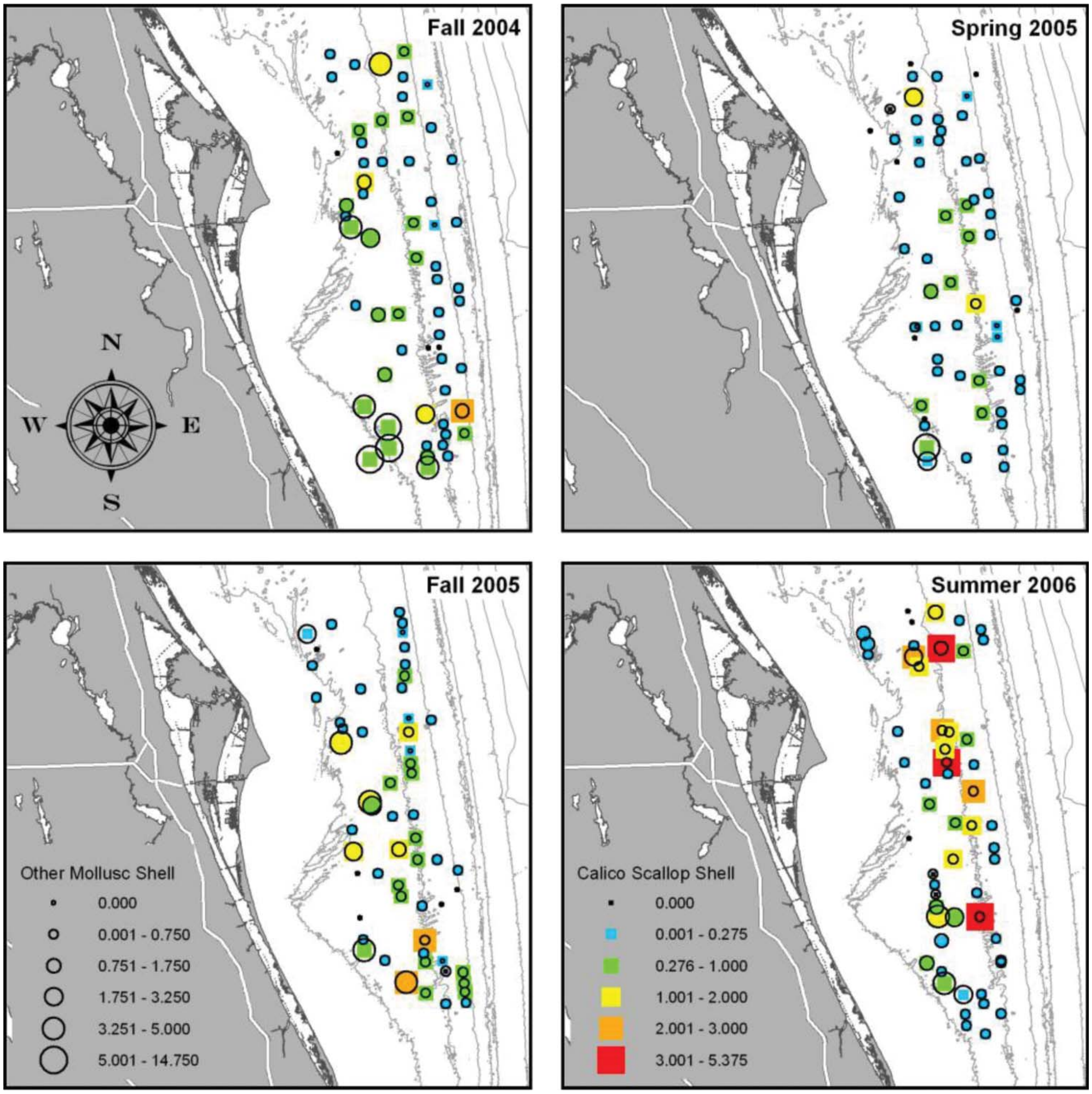

FIGURE 7. Mollusk shells collected (kg·min^{-1}·m^{-1}) in Cape Canaveral samples, 2004–2006.

valid tows) than either adult (17% of valid tows) or juvenile scallops (12% of valid tows). Other mollusk shell was most abundant in the Naples zone but was widespread ($H = 52.11$, $P < 0.001$) (other shell was collected in 84% valid tows) and did not vary seasonally ($H = 1.35$, $P = 0.716$). The Naples zone typically had twice as much other shell substrate than any other zone.

Supplemental and Historical Data Sets

Calico scallops were observed in of 67 of 1,497 SEAMAP tows (Figure 9). The average number of scallops collected in tows that collected scallops was 101.2 per tow (0.4 scallops·min^{-1}·m^{-1}) and ranged from 1 to 1,629 (10.9 scallops·min^{-1}·m^{-1}). The average starting depth for the tows in which scallops were caught was 38 m (19 fathoms), and the average depth of the top 16 tows, i.e., those with 20 or more scallops, was also 38 m (19 fathoms). Calico scallops were observed in two main areas: on the continental shelf from south of Cape San Blas westward to the waters off Alabama and in nearshore areas between Sanibel Island and Tampa Bay. A scattered distribution of scallops also was observed across the west Florida shelf, with the exception of the Big Bend region shoreward of ~20 m depth.

A list of historical data sets for the east coast is provided and includes 1,297 tows of nets or dredges (Table 1). The center of

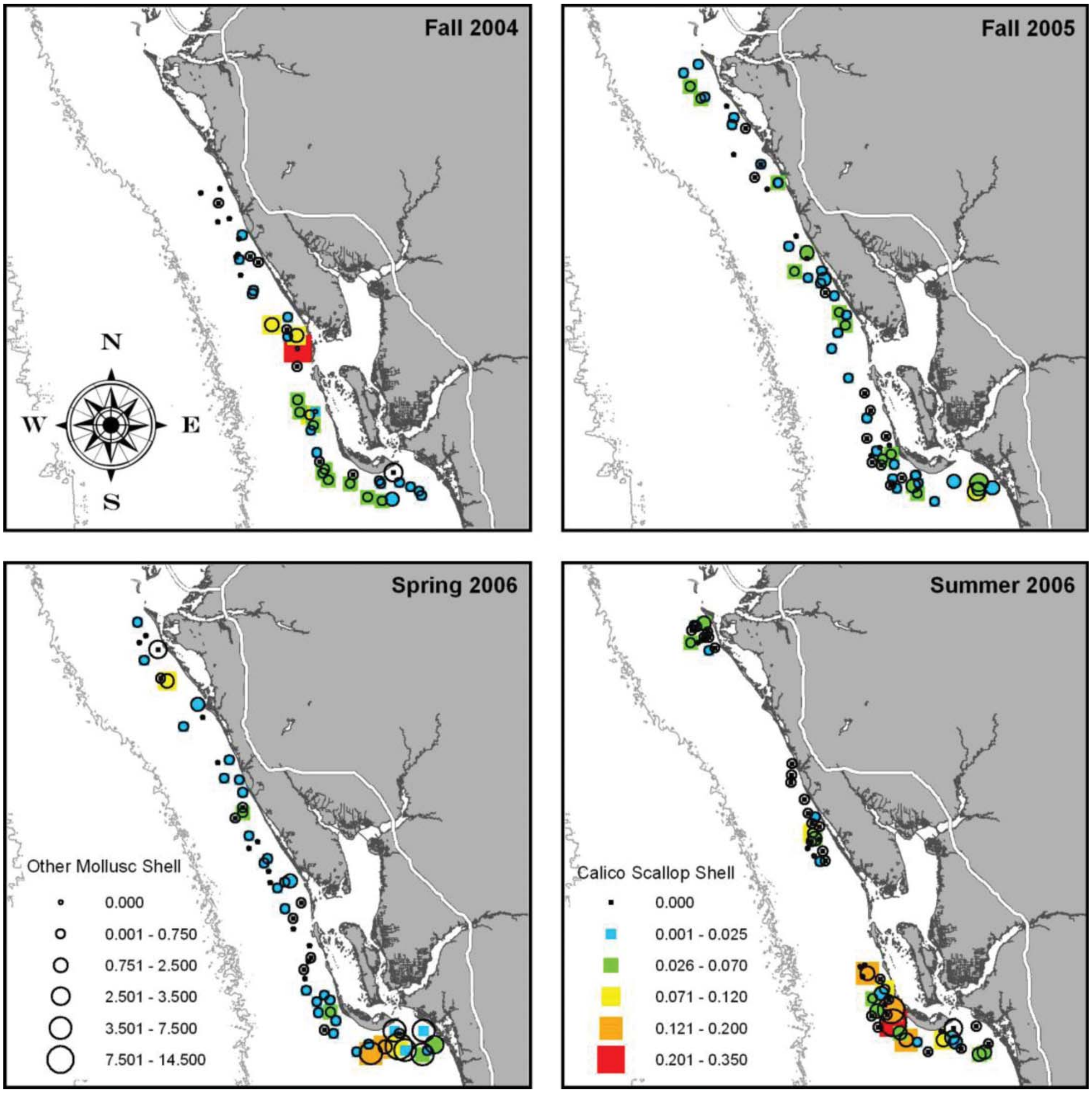

FIGURE 8. Mollusk shells collected (kg·min^{-1}·m^{-1}) in Gulf of Mexico samples, 2004–2006.

the geographic distribution of calico scallops on the east coast was the region of 37–48 m (20–26 fathoms) off Cape Canaveral (Figure 10), which is nearly identical to that observed in the present study. Calico scallops were, and remain, widely distributed on the coastal shelf off Florida, both in the South Atlantic Ocean and Gulf of Mexico. The abundance and distribution of calico scallops observed in the present 2004–2006 study (38% of Atlantic stations, range, 14–56%; 23% of Gulf stations, range, 12–35%) was lower than that reported in previous surveys (Table 2). The Silver Bay cruises had calico scallops present in 71% of the dredges and in 40% of the trawls in Atlantic waters. In trawls conducted in the Gulf for SEAMAP, scallops were found in 4.5% of the samples.

DISCUSSION

Calico scallop beds in this study appeared to cover similar geographic areas as in previous surveys, but the abundance of both scallops and scallop shell in any area was found to change dramatically over several months. Variations in the abundance of calico scallops continue to have a strong temporal component, and large beds can appear and disappear over a short period, which is similar to such findings as those of Roe et al. (1971) and those summarized by Blake and Shumway (2006). There is clearly a widespread distribution on both coasts, which suggests that dense patches still form. Within the Cape Canaveral bed, calico scallops remain the dominant macrobenthic animal, and scallop shell is the dominant substrate in a

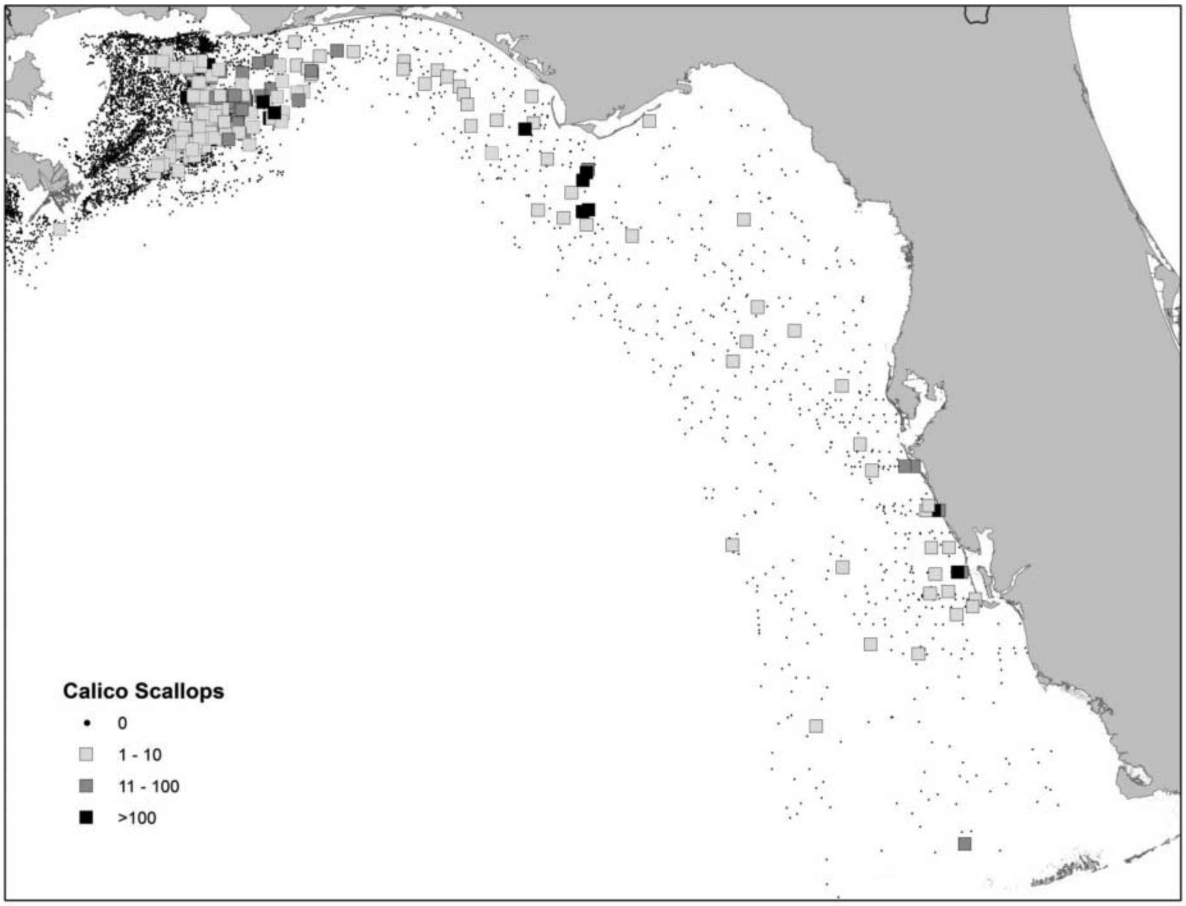

FIGURE 9. Number of calico scallops observed at stations sampled via towed dredges during SEAMAP and baitfish cruises, 2008–2014.

majority of the samples. This is consistent with historical studies, where at times scallops were the only species reported, comprising the total catch. It would appear that in the present study fewer scallops were found on the Cape Canaveral fishing grounds than in previous surveys, which resulted in the reduced total catch weights observed, but abundant shell was available as settlement substrate. During summer 2006, abundance in west coast scallop beds in some tows equaled and exceeded those on the east coast, but these patches were smaller and did not cover large portions of any given zone in any cruise.

Potential problems exist in attempting to compare current work with past studies. One problem is the exclusion of samples for which the intended target was calico scallops, but no catch data were recorded. Some historical reports indicate that catches of less than 1 bushel (~35 L) of any commercial species were not reported. For those studies, calculation of mean catch or even presence-to-absence information is impossible, and the only reliable data are the locations where commercial quantities were reported. It is apparent from past studies and those reported in this study that at a given moment much of the distribution of the species may be outside of the areas of highest concentration. Also, the RV *Oregon* and RV *Bowers* cruises (Table 1) did not use a random sample design; instead the surveys focused on commercially fishable areas, and the objective was to outline the limits of the commercial beds to maximize harvest rates and efficiency.

Another source of bias is the use of a very small dredge in the present study, comparable with the use of a try net in shrimp fisheries, whereas historically commercial gear was used in surveys. Differences in efficiency between gear types also probably contributed to the quantitative differences we observed. Dredges are known to have widely variable efficiencies (Fifas and Berthou 1999) and scallops can avoid them (Caddy 1968; Gedamke et al. 2004). Although in shrimping the efficiency of try nets may be fairly reliable and comparable to that of working gear (Cody and Fuls 1985), similar data for dredges are not available. The intent of this study was not to determine gear efficiency but to explore whether stocks of calico scallops were present at densities that may warrant commercial exploration. Future studies using commercial-scale gear should be able to conduct meaningful quantitative

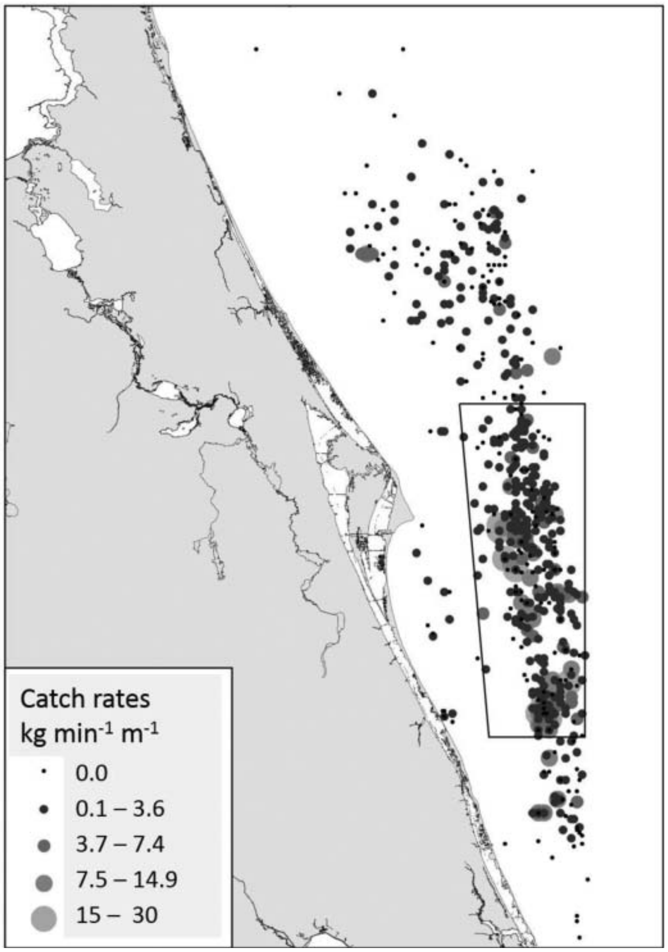

FIGURE 10. Calico scallops catches (kg·min^{-1}·m^{-1}) by MV *Silver Bay*, 1959–1964. See text for a description of the archival data discovery.

historical comparisons using the data set outlined in this study, which will aid the industry in evaluating the stock's commercial potential.

One objective of our study was to determine whether there was any remaining shell bed, considered to be the principal settlement substrate for spat and thus to be essential fisheries habitat. Our focus on shell abundance differed from that of historical studies, which indicated shell presence only when commercial species were not abundant, so direct comparisons do not seem justified. Shell was the principal catch in many tows and could fill the nets quickly. We could not conclude that the shell bed had been degraded to the point where essential fisheries habitat was limiting due to the high catch rate of scallop shell in our samples. In fact, in the present study there were almost no dredges on either coast in which no shell was captured. The condition of the calico scallop bed appeared to be close to its natural, prefishery state at the time of sampling, 2004–2006, when the commercial harvest had been minimal or nonexistent for roughly a decade; the shell bed has remained largely undisturbed for almost another decade since the present study was completed.

The ratio of scallop shell to other shell was much higher on the east coast than on the west coast and was usually the dominant shell type and more abundant than all other species' shells combined. On the west coast, the majority of the shell present was from other mollusks. While scallop spat were shown to prefer scallop shell over either other mollusk shell or other nonshell substrates, they nevertheless used the most abundant substrate available. These alternative substrates were most commonly shell from other mollusks but also included biofouled rock, algae, living organisms (including an unidentified oyster drill), and even moderately fouled trash. Bremec et al. (2008), in a study of the Patagonian scallop *Zygochlamys patagonica*, showed that it might not be the shell that the spat prefer as their substrate, but the fouling organisms for which the shell provides structure. In samples we collected, the fouling organisms on scallop shells were very diverse, as described by Schwartz and Porter (1977), so without directed study, we cannot say what specific substrate the scallops are choosing, the shell or fouling organisms.

The past practice of culling on shore rather than at sea should be avoided. Landings of the entire catch remove both substrate and the associated community, resulting in degradation of valuable low-relief habitat and adding the expense of disposal onshore. Adjoining habitats include inshore low-relief shrimp grounds as well as offshore high-relief habitat (Koenig et al. 2000). This high-relief area is known to harbor commercially valuable fishes such as snappers and groupers, which use the calico scallop beds as forage areas (Schwartz and Porter1977) and a pathway to estuarine juvenile habitat.

The amount of variability in the abundance of scallops between zones was not consistent between coasts. There was no significant variation between east coast zones, which was not entirely unexpected since the sample design was limited to a geographic area known to harbor calico scallops and covered the majority of the depth zone in which they are known to occur. True differences may be masked by high seasonal variation and very large catches in the southwestern corner of the Sebastian zone, where some random sampling stations were located shoreward of the 20-m contour in a region of very abundant marine life and large catches of sediment. The southern end of the sampling grid is also a region where the shelf is relatively narrow, resulting in a rapid increase in water depth and outcroppings of diverse hard-bottom communities along the slope throughout the depth range of the Sebastian zone. The high diversity and productivity may also reflect the proximity of both the Gulf Stream and upwelled bottom waters (Lee et al. 1991; Fiechter and Mooers 2003).

There was significant variation in the abundance of calico scallops between west coast zones. The area southwest of Sanibel Island was identified as a potential location for harvestable stocks in interviews with former calico scallop harvesters. It is a region that receives the ebb-tidal flow from San Carlos Bay

TABLE 2. Summary statistics from six east coast data sets obtained from RV *Silver Bay* (SB) 1959–1964, RV *Oregon* (OR) 1967–1968, RV *Delaware II* (D2) 1982, RV *Oregon II* (O2) 1987, RV *Bellows* (BW) 1989, and RV *GeoQuest* (GQ) 2004–2006 and from SEAMAP (SM) 2008–2014. Data are mean ± SD and maximum $kg \cdot min^{-1} \cdot m^{-1}$ of net width, if available. %P = the percentage of stations at which calico scallops were collected; %CQ = the percentage of stations at which scallops were collected in commercially viable quantities, ~2.5 $kg \cdot min^{-1} \cdot m^{-1}$ for dredges or 0.5 $kg \cdot min^{-1} \cdot m^{-1}$ for nets. *In the OR and D2 the values for dredge, estimates are made from only those stations at which commercial quantities were present, since values of <1 bushel were not reported.

	Dredge			Trawl		
Vessel	Mean $kg \cdot min^{-1} \cdot m^{-1}$	%P	%CQ	Mean $kg \cdot min^{-1} \cdot m^{-1}$	%P	%CQ
SB	10.4 ± 16.8 120.3	71	37	0.67 ± 1.52 8.47	40	10
OR*	14.2 ± 13.1 69.8		46	1.8 ± 2.3 7.50	50	40
O2		43	2		5	0
BW				0.13 ± 0.25 1.25	85	12
D2*	21.0 ± 17.5 75.2		16			
GQ	0.02 ± 0.07 0.55	38	2			
SM					4.5	0

and the Caloosahatchee River, known to be rich in nutrients (Doering et al. 2006), thus increasing primary productivity. Similar increases in benthic productivity appear to occur in the waters off the mouth of Tampa Bay (Vargo et al. 2008). The outlets of both these estuaries have patches of abundant scallops. The west Florida shelf is also susceptible to prolonged periods of northeast winds, which can drive surface waters offshore and induce upwelling in nearshore regions (Yang and Weisberg 1999). The two processes are not mutually exclusive and both increase primary productivity, creating hot spots of diversity and productivity similar to those in more thoroughly described east coast habitats. The data collected during Gulf of Mexico SEAMAP cruises support the hypothesis that calico scallops are more abundant along the shelf edge at 32–40 m and may connect the newly described region near Sanibel Island (Fort Myers and Naples zones) with previously recognized commercial beds off Cape San Blas (Bullis and Ingle 1958) and near the Tortugas shrimp grounds, as well as farther west toward the Mississippi River. At times calico scallops may be much more abundant and widespread on the west Florida shelf than what we observed. Additional anecdotal evidence, such as wracks of dying calico scallops along the Gulf beaches and after strong west-wind events and occasional reports of calico scallop aggregations on and around artificial reefs, underscore the dynamic nature of the coastal zone of this supposedly low-energy and relatively low-productivity region.

Parasitic infection by a protozoan presumed to be *Marteilia* sp. was seen in every calico scallop inspected from both Atlantic and Gulf waters, and late-stage disease, for which pathologies are observed, was common. *Marteilia* or a *Marteilia*-like disease coincided with massive mortalities in the calico scallop fishery in 1986 (Moyer et al. 1993) and, if it is limiting growth to submarket size, is still detracting from the commercial viability of this resource. Few scallops seen in our samples were of commercial size, i.e., 40 mm or larger, a size indicated by Blake and Moyer (1991) to be most profitable (200 scallops per pint). Counts of 60–110 scallops per pint and shell heights exceeding 50 mm were observed in the 1960s (Roe et al. 1971). Sea scallops command higher prices and can outcompete the bay scallop and presumably calico scallop product (Repetto 2002; Blake and Shumway 2006; Naidu and Robert 2006). Seasonal and annual variability in the calico scallop fishery appears to discourage harvesters from reinvesting in this fishery. The lack of scallops of a commercially valuable size may reflect the season during which samples were collected, though commercially viable sizes have been collected in all seasons, and the spatial and temporal patchiness of the species' distribution suggests that at least some samples of predominantly market-size scallops should have been found.

Follow-up studies to evaluate this resource and its rebound to fishable levels in the Atlantic Ocean and Gulf of Mexico are warranted. Future studies should focus on standardized gear, random sampling of adults, juveniles, and habitat (shell substrate), and disease prevalence during all seasons. Surveys in the Gulf of Mexico should focus on nearshore resources, which may exist at the outflows to Tampa Bay, Charlotte Harbor, and the Caloosahatchee River and along the deeper margin of the shelf along the Florida Panhandle and westward.

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