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Benthic studies in upper Buzzards Bay, Massachusetts: 2011/12 as compared to 1955

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Abstract

Precise biodiversity mapping that can be compared over decades would greatly inform the discussion of climate change impacts on species richness and shifts in dominant benthic species. Buzzards Bay, Massachusetts, USA, has a long history of field studies documenting benthic community structure. This bioassessment compares 1955 benthic infaunal sampling results with 2011/2012 samples to determine whether there has been a compositional change. I also compared structural components including grain size and near-bottom temperatures. In addition, benthic temperature rise and fall was logged at 15-min intervals from May to October of consecutive years. There was an observed difference in the benthic compositional structure, substrate and temperature between the 1955 and 2011/2012 station conditions. The 1955 identification of Buzzards Bay as being nutrient poor and having a reported 20.5 °C benthic temperature maximum has changed. Coastal development has brought increased nutrient inputs, and the 2012 bottom temperature maximum was at least 4 °C greater. These conditions contribute to shifts in benthic species dominance, and the substrate itself has been transformed to shell reefs at the stations where the gastropod *Crepidula fornicata* proliferated.

Introduction

The 1955 upper Buzzards Bay, Massachusetts (MA), USA, stations A through H sampled by Howard Sanders (1958) were re-occupied by the Coastal America Foundation to examine changes in the benthic community structure. The original station locations were re-sampled with triplicate Van Veen grabs and a grain-size analysis sample. In addition, the Foundation continues to occupy five stations with temperature data loggers to track the maximum summer temperatures in upper Buzzards Bay.

The warming of Southeastern New England waters, especially in Buzzards Bay, has produced several effects in its biological communities. The harvest of lobsters in this estuary experiences lows in the warmer summer months. The long-term benthic community structure may be stable, but motile species such as lobsters are migrating into cooler waters with higher dissolved oxygen levels. This temporal event has prompted public hearings and speculation by the Massachusetts Division of Marine Fisheries (DMF 2010) that drastic harvest restriction in Buzzards Bay and Southern New England may be necessary. Eutrophication in Buzzards Bay from population increases along the coast has been well documented by the Environmental Protection Agency (EPA) Buzzards Bay National Estuary Program (Buzzards Bay Comprehensive Conservation and Management Plan (CCMP) 2013). Comprehensive benthic community studies of Buzzards Bay have not been conducted in over 50 years, and long-term benthic temperature data are scarce. This combination of warmer waters, eutrophication and predator trophic changes may be influencing the benthic community structure of upper Buzzards Bay and is the subject of this quantitative biodiversity assessment.

The availability of historic benthic community structure and grain-size data gives us the opportunity to quantify changes in species dominance over time. This paper compares the 2012 benthic community structure of upper Buzzards Bay to sampling conducted in 1955 (Sanders

1958). The analysis is limited to shallow (<10 m deep) stations, and slightly different methodologies were used in 1955 and 2012.

This paper examines the following questions:

1 What changes have occurred in benthic species diversity and dominance?
2 What changes have occurred in the substrate grain-size composition?
3 What is known about water quality conditions changing over time?
4 What methodology variability influences the results?

The species richness and diversity indices (*e.g.* Fischer, Simpson and Shannon) and temperature monitoring results reported here give a benchmark of data that can be used to identify future ecological change. Additional sampling needed to further the knowledge of long-term estuarine benthic change in response to climate change and habitat degradation is identified.

Material and Methods

Eight of the 19 original 1955 Sanders (Sanders 1958) Buzzards Bay benthic community structure stations (Fig. 1) were re-sampled with a 0.04 m^2 Van Veen grab. Five temperature and water quality stations were established in upper Buzzards Bay from mid-May through mid-October. All station locations are listed in Table 1.

During 2010, researchers from the Coastal America Foundation obtained the raw data records with the support of the Woods Hole Oceanographic Institution (WHOI) library team (WHOI Records 1956). The original benthic sampling stations A through H were re-sampled in the fall of 2011 (A through D) and 2012 (E through H) to mimic the original October sampling cruises of Howard Sanders. The 1955 sampling methods used a modified Forster anchor dredge with a 7.6 cm sample depth. The 2011–2012 sampling was conducted with 0.04 m^2 Van Veen grabs for better spatial accuracy and a slightly deeper penetration (10.0 cm). The 1955 Forster dredge sample volume and spatial coverage were estimated and compared with the Van Veen spatial coverage and volume. Both were processed with a 500-μm mesh size sieve. Each recent benthic community composition station was sampled with three Van Veen grab replicates. Samples were screened and then preserved in buffered formalin with a rose bengal vital stain. Stereoscopic sorted samples were identified to the species level. The benthic identification keys included: Smith (1964); Gosner (1971); Bousfield (1973); Weiss (1995) and Pollack (1998). The World Registry of Marine Species (www.marinespecies.org) was used to update/correct species synonyms. Benthic station videos are available at http://www.CoastalAmericaFoundation/benthicecology.html. The benthic species richness, dominance and

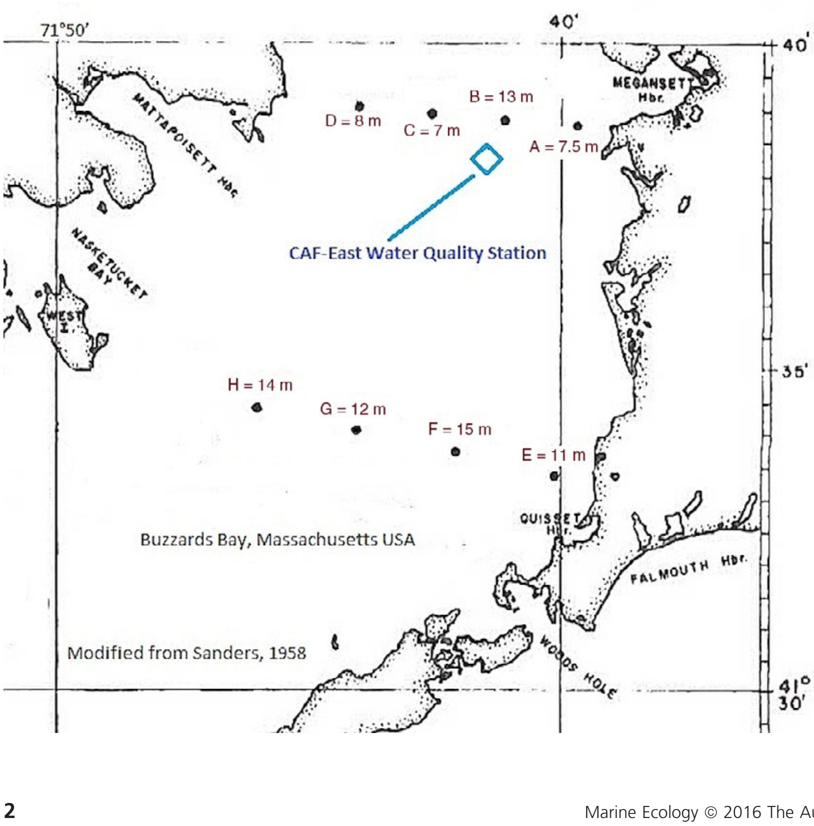


Fig. 1. Sanders (1955) and Coastal America Foundation (CAF) 2011/2012 re-occupied Stations A–H and Water Quality Station CAF-East. Depth is in m.

Table 1. Station locations in Buzzards Bay, Massachusetts, USA.

Station	Latitude	Longitude
Benthic infaunal stations		
A	41°38.779′ N	70°39.677′ W
B	41°38.872′ N	70°41.126′ W
C	41°38.976′ N	70°42.574′ W
D	41°39.076′ N	70°44.023′ W
E	41°33.408′ N	70°40.135′ W
F	41°33.760′ N	70°42.103′ W
G	41°34.106′ N	70°44.067′ W
H	41°34.443′ N	70°46.043′ W
Water quality stations		
Sias Point	41°43.869′ N	70°43.308′ W
Phinney's Harbor	41°43.009′ N	70°37.734′ W
Dry Ledge	41°41.974′ N	70°41.657′ W
CAF East	41°38.797′ N	70°40.748′ W
CAF West	41°39.198′ N	70°42.696′ W

CAF, Coastal America Foundation.

compositional diversity was compared between the 1955 and 2011/2012 samples (*e.g.* Bray–Curtis similarity matrix and DIVERSE) using PRIMER v. 6 (Clarke and Gorley 2006). Diversity indices analysed included Margalef (measure of the number of species present for a given number of individuals), Shannon diversity index (most appropriate for the replicate Van Veen grab comparisons) and also Pielou's evenness index (to analyse equitability of individuals among species), Simpson index, another diversity index (less sensitive to sampling effort) and Fischer (as a good comparison over time). SIMPER (SIMilarity PERcentges) was used to identify species that accounted for the Bray–Curtis matrix and SIMPROF (SIMilarity PROFiles) tested for structure of sample groupings (Clarke *et al.* 2008).

In 1955, Sanders (1958) analysed a subset of the Forster dredge tow for sediment grain size using sieves of 4.0-, 2.0-, 1.0-, 0.5-, 0.25-, 0.125- and 0.062-mm mesh size and silt/clay by hydrometer. The 2011/2012 re-sampling used a separate Van Veen grab sample for sediment grain size as follows: Preparation Method: ASTM D421-85 (2007); Analysis Method: ASTM D 422-63 (2007) – Sieve Nos. 4 (4.750 mm), 10 (2.000 mm), 40 (0.425 mm), 100 (0.150 mm), 200 (0.075 mm) and a Lab SOP: Particle size analysis of sediments – without hydrometer ASTM D4822-88 (2008).

The temperature was sampled every 15 min at 0.5 m above the sea floor at five stations in upper Buzzards Bay. All data can be found in Appendix S1. The temperature stations are Sias Point and Phinney's Harbor [2–3 m mean low water (mlw)], Dry Ledge (4 m mlw), Coastal America Foundation (CAF) East and CAF West (10 m mlw). The CAF East Station is midway between the benthic grab stations A and B at 10 m depth, and those data best represent the depth at the benthic stations A–H (see Fig. 1). The temperature data loggers (duplicate loggers at each station) recorded from mid-May through mid-October in 2012 and 2013 to document the summer maximum temperature rise and subsidence. These data loggers are HOBO™ Water Temp Pro v. 2 from Onset Computer Corporation (Bourne, MA) and have a sensor precision for ±0.21 °C accuracy. All five stations are intended to be occupied for 5 years to provide a benthic temperature benchmark. This ongoing benchmark of the benthic temperature data for all five stations is available at http://www.CoastalAmericaFoundation.org/waterqualitydata.html.

Results

Cogan & Noji (2007) discussed that program drivers such as climate change (temperature increases) and habitat degradation (physical impacts and eutrophication) can be measured as changes in compositional diversity, structural diversity and functional diversity. The results of this comparative sampling exhibit this influence and an interaction of compositional and functional diversity changing the substrate structural diversity (sandy to shell substrate).

Compositional diversity

Benthic species data are compared between the 1955 and 2011/2012 samples in Table 2. The entire data set with Alpha ID codes is presented in Appendix S2 and at www.CoastalAmericaFoundation.org/BenthicEcology.

Bray–Curtis cluster analyses of fourth root-transformed data (Fig. 2) shows good affinity to groups that are *Crepidula fornicata*-dominated, *Polygordius appendiculatus* dominated and *Nephtys/Macoma*-dominated and grouped together all 1955 Sanders stations as *Nephtys/Ampelisca* dominated (except Sanders F – predominantly a silt/clay substrate that grouped with the 2012 *Nephtys/Macoma*-dominated stations).

The number of species in the combined 2011/2012 Van Veen Grab replicates was lower ($P < 0.001$) than the 1955 Forster dredge combined replicate samples (see Appendix S3). Corresponding to the lower number of species observed in 2012, diversity was lower in all of the recent samples as compared with 1955 samples. Margalef diversity index proves that the overall number of species plotted against the total individuals was greater in 1955 ($P < 0.001$). Shannon diversity index, Simpson index and Fischer also show that the proportional abundance of the two sampling events are distinct.

Table 3 shows the dominant species as the per cent of total number of individuals, listed by station with species and substrate identified. These are a comparison of differ-

Table 2. Buzzards Bay benthic community structure data 1955 *versus* 2011/2012. S55-A through H are Sanders' (1958) results, and CAF-A through H are the recent (2011/2012) Coastal America Foundation (CAF) replicates taken at each of the same locations.

Station	S	n	d	J'	Fisher	H'(loge)	1−λ'
S55-A	27	101	5.633656	0.904176	12.06701	2.980016	0.946337
CAF-A1	17	127	3.302928	0.731014	5.276969	2.071119	0.783152
CAF-A2	17	129	3.292308	0.519644	5.24222	1.472261	0.548813
CAF-A3	15	159	2.761938	0.695658	4.062459	1.883877	0.756946
S55-B	30	185	5.555177	0.792211	10.14682	2.694466	0.908343
CAF-B1	8	104	1.507194	0.511477	2.019909	1.063587	0.456871
CAF-B2	7	73	1.398452	0.777438	1.906979	1.512824	0.745053
CAF-B3	12	96	2.409983	0.724988	3.620043	1.801527	0.781579
S55-C	36	274	6.235382	0.621406	11.08712	2.22682	0.735194
CAF-C1	28	353	4.602429	0.654216	7.141915	2.179982	0.755666
CAF-C2	23	174	4.264347	0.69896	7.101502	2.191584	0.784533
CAF-C3	23	445	3.607696	0.555784	5.14325	1.742657	0.702257
S55-D	42	470	6.663706	0.594494	11.15831	2.222023	0.742068
CAF-D1	16	95	3.293897	0.740544	5.510334	2.053225	0.774468
CAF-D2	13	36	3.348664	0.883611	7.304183	2.266417	0.895238
CAF-D3	10	63	2.172268	0.693249	3.348505	1.596264	0.696365
S55-E	30	159	5.721158	0.724375	10.93522	2.463744	0.844917
CAF-E1	19	206	3.378457	0.745498	5.104454	2.195073	0.820601
CAF-E2	31	821	4.47059	0.434152	6.369851	1.490871	0.612766
CAF-E3	17	946	2.335002	0.394501	2.943308	1.117706	0.549289
S55-F	20	153	3.777007	0.691286	6.146344	2.070907	0.803148
CAF-F1	5	23	1.275716	0.808383	1.968089	1.301042	0.715415
CAF-F2	3	16	0.721348	0.838779	1.089987	0.921493	0.575
CAF-F3	6	50	1.278111	0.551226	1.780293	0.987664	0.502857
S55-G	36	316	6.080884	0.715926	10.46395	2.565536	0.873458
CAF-G1	21	129	4.115385	0.696732	7.115767	2.121216	0.804264
CAF-G2	21	230	3.677769	0.569857	5.62156	1.734941	0.674767
CAF-G3	19	210	3.366306	0.56808	5.069839	1.672678	0.658282
S55-H	42	299	7.192423	0.727629	13.31025	2.719638	0.880833
CAF-H1	10	96	1.971804	0.606142	2.808594	1.395694	0.680702
CAF-H2	8	77	1.61149	0.75784	2.244684	1.575884	0.752221
CAF-H3	14	154	2.580926	0.403874	3.741965	1.065846	0.42246

Number of species and all indices were significantly different ($P < 0.001$) when all 1955 samples were compared with all 2011/2012 samples as pooled replicates but the number of individuals was not significantly different ($P = 0.6145$).
Statistical analyses of n and S are in Appendix S3.
S = number of species in each sample; n = number of individuals; d = species richness (Margalef); J' = Pielou's evenness; Fisher = alpha; H'=Shannon and Simpson index = (1−λ).

ent sampling devices (Forster Dredge and Van Veen), with differing volumes and spatial coverage, and single (1955) samples *versus* triplicate (2012) samples. The radically different sampling efforts need to be kept in mind while reviewing these results. Comparing Table 3 data with the Bray–Curtis similarity matrix in Fig. 2, there are obvious shifts in the dominances especially in stations A through D, which are located in the upper area of Buzzards Bay (see Fig. 1).

In sandy substrate the dominance of *Ampelisca* in 1955 ranged from 8% to 50% of the individuals collected. None of the 2012 samples had an amphipod dominance. Most notable is the 2012 *C. fornicata* dominance at Stations A (51%) and D (42%). *Polygordius appendiculatus* also exhibited large percentages of the total number of individuals at 2012 Stations C (54%), E (71%) and F (8%). The silt/clay substrate Stations B, F and H did show a similar *Nephtys/Macoma* assemblage in both the 1955 and 2012 samples.

Correlation profiles analysed by SIMPER and SIMPROF ($\beta > 65\%$, Clarke *et al.* 2008) should also be viewed conservatively given the different sampling techniques (see Appendix S3). SIMPER was used to identify species shifts that accounted for the Bray–Curtis matrix and also showed the *Nephtys/Macoma* grouping. SIMPROF tested for structure of sample groupings. SIMPROF was run using 1000 permutations and the test statistic (π value) with a significance level set at 5% and supported the major subgroup assemblages in Fig. 2.

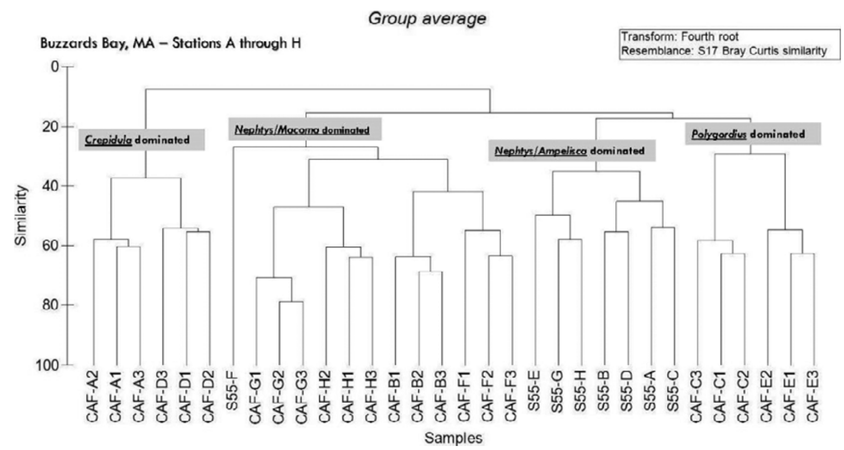


Fig. 2. Bray–Curtis cluster analysis of 1955 and 2011/2012 benthic community composition. CAF, Coastal America Foundation; S, Sanders.

Table 3. Dominant species.

station – year	dominants (% n)	no. of species*	substrate
A – 1955	*Mitrella* (14%)/*Ampelisca* (8%)/*Anachis* (8%)	27	Medium/fine sand
A – 2011/12	*Crepidula* (51%)/*Podarke* (9%)	16.3/27	Gravel (*Crepidula* shell)
B – 1955	*Goniadella* (17%)/*Nephtys* (16%)/*Macoma* (12%)	30	Silt/clay
B – 2011/12	*Macoma* (50%)/*Retusa* (16%)/*Nephtys* (14%)	9.0/15	Medium/fine sand
C – 1955	*Ampelisca* (50%)/*Nephtys* (8%)/*Polycirrus* (7%)	36	Medium/fine sand
C – 2011/12	*Polygordius* (54%)/*Crassicorophium* (5%)/*Pygospio* (5%)	24.7/40	Medium/fine sand
D – 1955	*Ampelisca abdita* (49%)/*Ampelisca macrocephala* (10%)/*Nephtys* (10%)	42	Fine sand
D – 2011/12	*Crepidula* (42%)/*Podarke* (36%)	13.0/20	Gravel (*Crepidula* shell)
E – 1955	*Parvicardium* (33%)/*Nephtys* (18%)/*Glycera* (6%)	30	Medium/fine sand
E – 2011/12	*Polygordius* (71%)/*Drilonereis* (5%)/*Glycera* (4%)	22.3/37	Medium/fine sand
F – 1955	*Nephtys* (37%)/*Macoma* (21%)/*Retusa* (12%)	20	Silt/clay
F – 2011/12	*Macoma* (46%)/*Nephtys* (34%)/*Polygordius* (8%)	4.7/8	Silt/clay
G – 1955	*Nephtys* (23%)/*Ampelisca* (23%)/*Macoma* (8%)	36	Medium/fine sand
G – 2011/12	*Macoma* (60%)/*Nephtys* (14%)/*Laonice* (8%)	20.3/26	Medium/fine sand
H – 1955	*Parvicardium* (29%)/*Nephtys* (9%)/*Ampelisca* (9%)/*Macoma* (7%)	42	Fine sand
H – 2012	*Macoma* (56%)/*Nephtys* (16%)	10.7/16	Silt/clay

*1955 was one Forster Dredge sample and 2011/12 was the average of three Van Veen Grabs and the second (/) number is the all unique species at each station across all three replicate grabs.

%n = number of individuals of the dominant species divided by the average total number of individuals.

Structural diversity

Substrate

Sediment grain-size comparisons are shown in Table 4 and graphed by station in Appendix S4. Appendix S4 also contains 1955 and 2011/2012 grain-size curves side by side to easily compare differences.

In 1955, all stations had less than a 2% of the substrate sampled retained on the 'gravel' component sieve and most had less than 0.1% (Sanders 1958). This gravel-sized substrate material in the 2011/2012 samples is actually large concentrations of *C. fornicata* (Common Slipper Shell Limpet) shells retained and classified on the gravel-sized sieve (see lab notes on grain-size curves in Appendix S4). The 2011/2012 sampling had dense concentrations of *C. fornicata* at Stations A (64% 'gravel') and D (74% 'gravel') and also a larger silt/clay (A = 15% and D = 19%) content than reported for 1955 (A = 1.3% and D = 4.2% for silt/clay).

Station B was predominantly silt/clay (67%) and fine sand (30%) in 2011/2012. The 1955 sampling showed medium (28%) and fine sand (65%). This station also showed high turbidity in several video transects. Its location is at the edge of the navigation channel established in the 1960s, approximately one decade after Sanders' 1955 field sampling effort. This area is heavily scoured by tug boat-assisted tankers and commercial shipping traffic.

Stations C, E and F are generally in good agreement between the 1955 and 2011/2012 distributions of grain size.

Table 4. Grain-size distributions of 1955 (Sanders, S55-) and 2011/2012 (Coastal America Foundation, CAF-) sample stations.

station	% gravel-fine	% sand-coarse	% sand-medium	% sand-fine	%silt/clay
CAF-A	63.74	2.45	11.08	7.80	14.92
S55-A	2.04	4.76	68.37	23.80	1.03
CAF-B	0.32	0.18	3.51	29.38	66.61
S55-B	0.29	0.46	28.12	65.39	5.74
CAF-C	2.87	3.05	60.09	29.55	4.45
S55-C	1.41	1.62	36.76	57.52	2.69
CAF-D	74.12	1.34	2.69	2.86	18.99
S55-D	0.14	0.20	16.38	79.16	4.12
CAF-E	9.36	3.36	52.33	33.64	1.32
S55-E	0.00	0.27	40.22	57.20	2.31
CAF-F	0.00	0.02	0.95	3.74	95.29
S55-F	0.00	0.02	0.36	8.42	91.20
CAF-G	0.01	0.15	23.70	44.70	31.44
S55-G	0.01	0.07	15.39	69.28	15.25
CAF-H	0.02	0.08	12.23	29.81	57.87
S55-H	0.02	0.21	30.19	61.75	7.83

Station C is predominantly medium to fine sands (90% in 2011 and 94% in 1955). Station E is predominantly medium to fine sands, with 86% in 2011/12 and 97% in 1955; a 9% *C. fornicata* shell fraction was present in 2011/12. Station F had a silt/clay dominance in both 1955 (91%) and 2011/12 (95%).

Stations G and H have medium to fine sands and a silt/clay content. Generally, the 2011/12 samples showed more silt/clay content than in 1955. Station G had an 85% medium to fine sand content in 1955 *versus* a 68% medium to fine sand fraction in 2011/12. Station G had a 2011/12 silt/clay content of 31.4% compared with the 1955 silt/clay fraction of 15.3%. Station H had a 91% medium to fine sand content in 1955 *versus* a 42% medium to fine sand fraction in 2011/12. Station H had a higher silt/clay fraction (57.9%) in the 2012 samples than the 1955 (7.8%) samples.

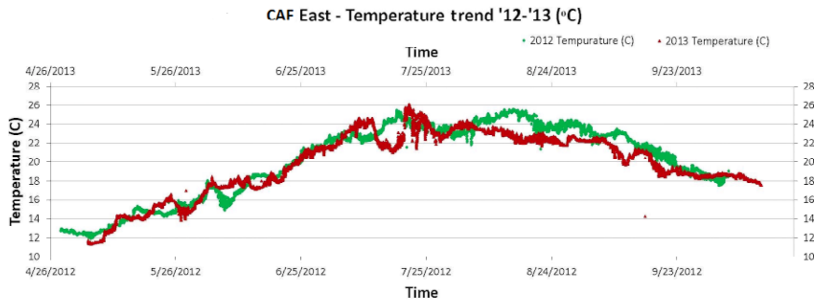
Temperature

The Coastal America Foundation water quality station CAF East (Fig. 1) is representative of the eight benthic sampling stations. This station is located in 10 m of water midway between benthic community Stations A and B. In 2012 and 2013, the maximum bottom temperatures recorded for CAF East were 25.57 °C in August 2012 and 26.11 °C in July 2013. The temperature results are graphed in Fig. 3. Over 15 000 temperature samples were logged between May and October in 2012 and again in 2013. Other shallower stations were also monitored for bottom temperature maximums, and those results are available in Appendix S1 and at http://www.CoastalAmericaFoundation.org/waterqualitydata.html. The shallower sites had higher temperature maximums but are not compared here, as this report is focused on the deeper Sanders (1958) benthic stations.

Functional diversity

The above changes in structural and compositional diversity changed the substrate, the dominant species and the functional feeding modes. Filter feeding was identified by Sanders (1958) as a function of adequate current flow over the benthic community to provide food to the community of filter feeders and facultative filter feeders such as amphipods. In addition, Sanders (1958) identified Buzzards Bay as having low nutrients when compared with Long Island Sound and other bays. Buzzards Bay is now well known for algal blooms and high nutrient concentrations, especially in the upper portions of the bay (Buzzards Bay Comprehensive Conservation & Management Plan 2013).

The most striking change is the formation of shell beds from the gastropod *C. fornicata* in Stations A and D (Fig. 1). This appears to exclude the amphipod population from forming tube mats. *C. fornicata* shell beds are still a filter-feeding community, with interstitial (inter- and below shell) carnivores favored. Stations B, F, G and H continue to be a *Nephtys*/*Macoma*-dominated community – *Macoma* is still a filter-feeding component of the dominant genera, with greatly reduced amphipod and species diversity in 2012. As noted above, Station B may be impacted by ship traffic and prop wash destabilizing the substrate and community composition. At Stations C and E, the dominance in 2011/2012 shifted to the deposit-feeding and surface interface-grazing *P. appendiculatus* instead of the 1955 *Nephtys*/*Ampelisca* community. These also hosted an amphipod component, and



	Recorded samples 2012 # of samples	Recorded samples 2013 # of samples		Maximum temperature 2012 Max. (°C)	Maximum temperature 2013 Max. (°C)	Difference (°C)
April	240	0	April	12.98	-	-
May	2976	2592	May	16.43	16.94	0.51
June	2880	2880	June	22.24	21.63	-0.61
July	2953	2976	July	25.48	26.11	0.63
August	2976	2976	August	25.57	24.34	-1.24
September	2880	2880	September	23.91	22.61	-1.30
October	426	1185	October	19.06	18.89	-0.17
Yearly	15331	15489	Yearly	25.57	26.11	0.53

Fig. 3. Temperature graph for 2012 and 2013 at CAF-East (10 m depth). CAF, Coastal America Foundation.

Fig. 4. *Crepidula* reef at Station A from ROV transects in 2014.

sediment analysis showed relatively stable medium/fine sand concentrations with some increase in shell/gravel in the grain-size analysis.

Discussion

The compositional diversity of upper Buzzards Bay has changed since 1955, with fewer species per sample present in the 2011/2012 sampling. The water temperature structural diversity (benthic temperature maximum) may have changed by several degrees centigrade. The substrate structural diversity (grain size and rugosity) has changed at several stations because of the biotic structure that was added as the functional diversity shifted from facultative suspension-feeding amphipods to filter-feeding gastropods *C. fornicata* (see Figs 4 and 5). No *C. fornicata* were reported in any of the 1955 samples. The *C. fornicata* proliferation formed a rough and complex three-dimensional sessile shell bed on the substrate surface. Shells and live stacks of this species would also induce fines to settle below their rough bed surface. All of these changes may have been driven by increased temperature and nutrient inputs into Buzzards Bay as the landside population increased along with coastal recreation industry development since 1955 (Buzzards Bay Comprehensive Conservation & Management Plan 2013).

In 2011, the US EPA Ocean Survey Vessel BOLD and the Massachusetts Office of Coastal Zone Management (MAC-ZM) conducted benthic sampling in the vicinity of several of the stations reported here (A, B and H). The imagery, grain-size and benthic data from the surveys are available at http://www.mass.gov/eea/agencies/czm/program-areas/sea-floor-and-habitat-mapping/biological-mapping/ – Biological Mapping – Massachusetts Office of Coastal Zone Management's Seafloor and Habitat Mapping Program. The biological information in the imagery is classified according to a modified version of the Coastal and Marine Ecological Classification Standard (CMECS 2012) version 4.0, Benthic Biotic Component (www.csc.noaa.gov/cmecs). It agrees with the grain-size curves reported here, and the imagery confirms Station A's *C. fornicata* dominance (Fig. 6). The classification of Stations B and H as fine (non-gravel) in CMECS agrees with our data. In addition, the high turbidity at Station B is evident in the MAC-ZM photographs.

Sampling variability

The sampling and analysis methodologies among 1907 (Smith 1911), 1955 and 2011/2012 were similar but not identical. The grain-size sieves, temperature sampling frequency at varied locations and the different types of benthic infauna grabs all introduce variability in the accuracy of the comparative results.

The least variable techniques were the grain-size sorting sieves used in 1955 compared with the ASTM D422-63 (2007) methodologies employed in 2011/2012. The division

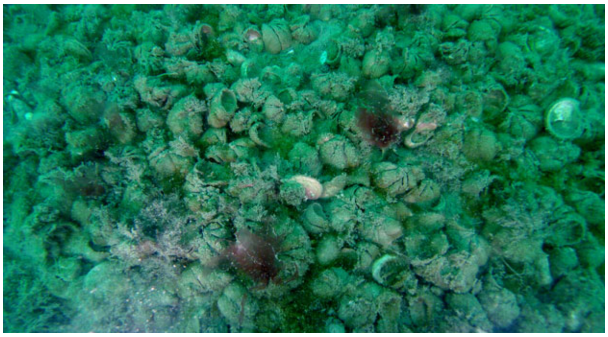


Fig. 5. *Crepidula fornicata* reef at Station D from towed video array transects in 2014.

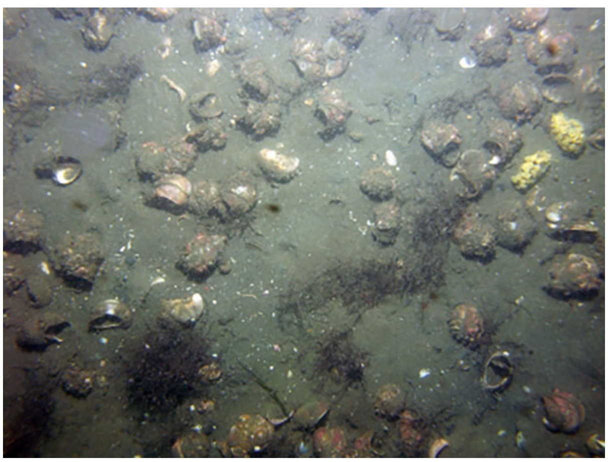


Fig. 6. *Crepidula fornicata* substrate at Station A from the Massachusetts Office of Coastal Zone Management biological mapping program.

between the sand and silt/clay components was at 61 μm in sieves used in 1955 – the recent methodologies defined it at 75 μm. None of the data relied on this distinction for a difference of more than a few per cent. Additionally, the definition of medium and fine sand fractions was at 125 μm *versus* the recent standard of 150 μm. The analysis here compares the differences between sand and silt/clay and does not differentiate between the substrate types of medium and fine sand.

Temperature comparisons can only be described in general because of the nature of the earlier technology, which resulted in occasional casts with no continuous data over consecutive months. In 1907, the reported bottom maximum temperature (21.5 °C) was determined from 19 stations sampled over 2 days in August (Smith 1911). The 1957 temperature maximum (22 °C) cited from Sanders (1958) may have been a reference to the 1907 determination, but no data are available. Benthic temperature data were obtained from the Massachusetts Division of Marine Fisheries temperature station a few kilometers from the CAF East station at a slightly shallower (8 m) depth (D. Perry, personal communication). The 1992 and 1993 temperatures at this station were recorded 12 times per day year-round using Ryan temperature monitors. These monitors were accurate to ±0.3 °C with a resolution of 0.1 °C. This data set recorded 1992 and 1993 temperature maximums of 22.4 and 23.4 °C, respectively. When comparing the 1992/1993 data and the 2012/2013 data, statistically warmer averages ($P < 0.001$) were found for 5 May through 5 October of each year.

The CAF East temperature maximum near the benthic sampling stations (26 °C) was obtained with continuous (every 15 min) data loggers over 5 months for 2 consecutive years. It is the intention of the Coastal America Foundation to obtain temperature maximums for 5 consecutive years while completing re-sampling of the remaining 11 Sanders (1958) benthic stations. This procedure will provide a better benchmark for temperature maximums and the annual variability of various temperature thresholds for future comparisons. With the above variability of temperature measurement techniques, the reported Buzzards Bay benthic temperature in 1955 of 22 °C had increased to approximately 23 °C in the early 1990s and then up to 26 °C in 2013.

The temperature of Buzzards Bay has increased according to lobster harvest data, *i.e.* an earlier and longer warming trend resulting in lobster migration to cooler waters in summer (DMF 2010) and, reducing overall landings. In 2012 and 2013, the maximum bottom temperatures recorded were 25.57 and 26.11 °C, respectively. A more important ecological temperature plateau is the migration response of lobsters into cooler waters at 18.3 °C (65 °F; DMF 2010). Our sensors detected that this threshold was met on 12 June 2012 and 9 June 2013 and remained above this threshold through 30 September 2012 and 8 October 2013. In 1992 and 1993, this 18.3 °C (65 °F) threshold was met later on 18 June (both years) and returned below this threshold on 26 September 1992 and 20 September 1993. Therefore, the common trend between these data sets that are two decades apart is warmer waters earlier in the summer and extending later into fall.

Several other predator species may also respond and migrate to deeper, cooler water, with these temperatures being reached in early June (DMF 2010). This migration of motile predators may also allow for the proliferation of different dominant species, such as *C. fornicata*. Blanchard (2009) identified a 1 °C temperature increase from 1990 to 2000 in a European embayment as contributing to the formation of *C. fornicata* 'reefs' with a loss of crustaceans and other carnivorous macrofauna. There is very little information on the stomach contents of the predators of *C. fornicata*, most likely because C. fornicata' shell would be easily removed and the gastropod consumed as soft tissue. Predators are reported as limited (Blanchard 2009), but crabs (*Cancer* sp.), drills and starfish are reported to consume *C. fornicata*. In Europe, this species is a known invasive, and studies have identified the winter low temperatures as inhibiting the spread of *C. fornicata* (Thieltges *et al.* 2004). Winter low temperatures were not monitored in this study. Additional sampling effort will be needed to further investigate the proliferation of these gastropod reefs in the vicinity of the 1955 benthic stations.

Benthic community structure data are dependent upon the spatial coverage and depth of the substrate that is sieved for each sample at each station. In 1955, Howard Sanders used a modified Forster dredge with a mesh bag to catch the sample. The Forster dredge was designed as an infaunal collection sampler and not as a spatially quantifiable sampler (Forster 1953), such as the 0.04 m² Van Veen. The maximum sample depth of the dredge was 7.6 cm as opposed to the 2011/2012 10.0 cm sample depth. In addition, the recent work had three replicates at each station as opposed to one dredge at each of the 1955 stations. The Forster dredge filled quickly on each tow (G. Hampson, personal communication); i.*e.* filled in seconds and not minutes. The Forster dredge sample had a grain size subset removed. The grain size of the 2011/2012 sampling was taken as an individual station Van Veen replicate (i.e. the full volume of the Van Veen was analyzed for benthic species). Sanders (1958) listed the sample volume of each station (mean of 6947.88 cm^3; SD = 2496.04 cm^3) as generally twice that of the single Van Veen replicate (3142 cm^3).

The spatial coverage (quantity of sample surface area) of the two sampling devices can introduce the most variability. Each 2012 station had 0.12 m² of sampling surface when adding all three replicates grabs. The quantity of the Forster sample was recorded by Sanders (1958), and because the depth and width of the sampler is known (Forster 1953), the approximate surface area of the sample can be defined. The Van Veen bite is 10 cm deep, and the Forster is 7.6 cm, so the latter provides more near-surface species. The calculations reveal that the total of all 1955 samples represent a volume of 55 575 cm^3 as opposed to the 75408 cm^3 in 2011/2012. Stated another way, the 2011/2012 sampling effort examined 26% more sediment than that of 1955. More importantly, the spatial coverage of the 1955 samples was less than that of the recent samples. The Forster dredge was towed across an estimated 7260 cm² surface area, while the Van Veen quantified the infauna of 9600 cm². This difference would lead to expectations that the 1955 stations would collect fewer species than the recent Van Veen stations but, in fact, they sampled more species with less spatial coverage (1955 had 24% less area in the total sampling footprint).

Ecological conditions

Estuarine habitats are, more so than oceanic areas, subject to episodic fluctuations in environmental conditions. Dauer *et al.* (2000) identified benthic community conditions as impacted by coastal population increases and associated nitrogen loading. In Buzzards Bay, the EPA (Buzzards Bay Comprehensive Conservation & Management Plan 2013) reported a total nitrogen loading into the watershed of 2 827 004 kg · $year^{-1}$ and significant algal blooms. The structural changes (*e.g.* eutrophication exacerbated by temperature increases) influence the biodiversity (fewer species per station and lower diversity indices); however, as indicated in Harris & Baker (2012), temporal uncertainty reduces our predictive ability to relate disturbances to the overall biological diversity. Long-term monitoring is needed to understand fully the functioning of any marine environment, including Buzzards Bay, MA.

Figure 3, a fourth root-transformed Bray–Curtis similarity cluster analysis, shows a clear difference in the compositional diversity of the 1955 and 2011/2012 sampling events. Stations A and D show a change to a *C. fornicata* -dominated community. Stations C and E became dominated by *P. appendiculatus*; neither of these species were reported in 1955. The remaining stations generally showed that the 1955 *Nephtys/Ampelisca* dominant genera shifted to a *Nephtys/Macoma* community.

Station A changed from a 1.0% silt clay fraction in 1955 to a 14.9% silt/clay fraction in 2011/2012, and Station D changed from a 4.1% silt clay/fraction to a 19.0% silt/clay fraction (Table 3). Both were dominated by a 'gravel' grain size in 2011/2012, given the shell retention on the larger sieves (63.7% and 74.1%, respectively). The armoring of the substrate and production of fecal matter from *C. fornicata* most likely allowed fines to settle on these stations. This structural change has eliminated the 1955 dominant genera of *Astyris* (*Mitrella*) and *Macoma/Ampelisca* at these stations. It should be noted that these stations (see Fig. 1) are closest to the coast and nutrient run-off sources. In 1955, Howard Sanders (1958) indicated that Buzzards Bay was nutrient poor compared with other northeast water bodies. In the 2013 US EPA Buzzards Bay Program Comprehensive Conservation and Management Plan (Buzzards Bay Comprehensive Conservation & Management Plan 2013), the area was identified as continually being eutrophicated from decades of septic run-off and non-point source pollution. In Europe, species composition observations where *C. fornicata* was absent showed a higher proportion of mobile crustaceans (de Montaudouin & Sauriau 1999). It is likely that nutrient enrichment and winter temperature increases (Blanchard 2009) have allowed *C. fornicata* to proliferate and outcompete crustacean species.

Stations C and E are slightly further from the shoreline, and the percentage of silt/clay was similar between the 1955 and 2011/2012 sampling intervals (all less than 5%). The 1955 *Ampelisca* dominant genera in C and *Cerastoderma/Nephtys* dominant genera in E were replaced by significant concentrations of *Polygordius appendiculatus* along with an *Ampelisca* and *Cerastoderma* community composition. Both were still medium fine sands in 2011/2012, with E showing a 10% gravel component that was mostly *C. fornicata* shell and gravel to 2 cm. *P. appendiculatus* are deposit feeders, surface inter-face grazers and suspended fecal matter feeders. *Polygordius* species seeking sands with high organic content and remaining to feed has been observed on the continental shelf (Rameyl & Bodnar 2008). The higher organic content in these stations favor *Polygordius* dominance, although the total organic content was not analysed here.

Stations B, F, G and H in 2011/2012 clustered (fourth-root Bray–Curtis similarity; Fig. 2) with the 1955 Station F, and all other 1955 stations clustered together as a *Nephtys/Ampelisca*-dominated assemblage. Station F, both in 1955 and 2012, was the only station with almost no sand component, with 91.2% and 95.3% silt/clay, respectively. The other stations in this cluster were medium/fine sands in similar proportions, but each had a higher silt/clay component than did the 1955 samples. There is the possibility that the 1955 Forster dredge and mesh bag may have lost some fines or subsampled a striation, but in general, B (which is impacted by navigation channel dredging), F, G and H went from 5% to 15% fines to 31% to 67% fines. This accumulation of fine material is possibly a result of eutrophication with increased water column and algal primary productivity along with detrital settling. This fine-grained increase favors the deposit feeders *Nephtys* being co-dominant with *Macoma,* which is capable of deposit as well as facultative suspension feeding and prefers more than 20% silt/clay. The sites still supported the active and passive suspension feeding *Ampelisca* spp. in 2012 (discounting B; G and H are very similar to the 1955 *Nephtys*/*Macoma* dominance) – but amphipod presence was much reduced in the more recent samples. *Ampelisca* spp. are an important (if not primary) component of juvenile winter flounder diet (Franz & Tanacredi 1992). This flounder species is of concern in Buzzards Bay due to declining populations, which may be an indication of a lack of prey (amphipods) in Buzzards Bay. *Ampelisca* spp. are well known to have various sensitivities to water-quality parameters (de la Ossa-Carreteroa *et al.* 2012) and are often used in the bioassay testing of sediments (EPA 1991).

In conclusion, the analysis of Stations A through H presented here shows a difference in the compositional benthic ecology of Buzzards Bay between 1955 and 2011/2012. The Coastal America Foundation is continuing to monitor the temperature maximums in Buzzards Bay to establish a benchmark for future reference. The remaining benthic infaunal stations sampled by Howard Sanders in 1955 are scheduled to be re-sampled in 2016 within funding constraints. Towed video array and ROV video transects of the *C. fornicata* beds to complement biodiversity assessment mapping are ongoing (see http://www.coastalamericafoundation.org/crepidulareefs.html). The stomach contents of foraging fish on the *C. fornicata* reefs may also assist in understanding the predator/prey relationships in this system.

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Supporting Information

Additional Supporting Information may be found in the online version of this article:

Appendix S1. Temperature data.

Appendix S2. Benthic identifications.

Appendix S3. Statistical analysis of benthic species data.

Appendix S4. Grain-size curve data.