

Investigation of benthic community change over a century-wide scale in the western English Channel

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*Since the early part of the 20th Century the impact of a range of anthropogenic activities in our coastal seas has steadily increased. The effect of such activities is a major cause for concern but in the benthic environment few studies exist that date back more than a few decades. Hence understanding long term changes is a challenge. Within this study we utilized a historic benthic dataset and resurveyed an area west of Eddystone reef in the English Channel previously investigated 112 years ago. The aim of the present work was to describe the current benthic community structure and investigate potential differences between 1895 and 2007. For each of the four major phyla investigated (Polychaeta, Crustacea, Mollusca and Echinodermata), multivariate community analysis showed significant differences between the historic and contemporary surveys. Echinoderm diversity showed a clear reduction between 1895 and 2007. The sea urchins *Echinus esculentus*, *Spatangus purpureus*, and *Psammechinus miliaris* and large star-fish *Marthasterias glacialis* showed reductions in abundance, in some cases being entirely absent from the survey area in 2007. Polychaetes showed a shift from tubicolous species to small errant and predatory species such as *Glycera*, *Nephtys*, and *Lumbrineris* spp. Within the group Mollusca large species such as *Pecten maximus* and *Laevicardium crassum* decreased in abundance while small species increased. Crustaceans in 1895 were dominated by crab species which were present in similar abundances in 2007, but, the order Amphipoda appeared to show a significant increase. While some of the differences observed could stem from differences in methodologies between the surveys, in particular increases of small cryptic species, the loss of large conspicuous species was judged to be genuine. The study area is an important beam trawling and scallop dredging ground; the differences observed are concomitant with changes generally associated with disturbance from demersal fishing activities such as these.*

Keywords: long-term investigation, Eddystone, benthic community, English Channel, anthropogenic impacts, temporal change

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INTRODUCTION

Understanding long term changes in marine ecosystems is fundamental to understanding and hence managing anthropogenic impacts. Over the past century the strength and range of anthropogenic impacts in coastal seas has increased dramatically with growing global industrialization and urbanization (Daan *et al.*, 1996). Anthropogenic impacts such as eutrophication, pollution, bottom trawling and the effects of climate change are consequently of major current concern to conservation and resource management. However, knowledge of the pristine state of many marine systems, the baseline against which environmental change can be measured, is often lacking. The reason for this is that data collection of adequate quality often started long after most anthropogenic impacts began altering the marine environment. With respect to coastal eutrophication for example, significant anthropogenic inputs of nutrients occurred with the introduction of chemical fertilizers around 1850 together with an intensification of agricultural practices (Smith *et al.*, 1998, van Beusekom, 2005).

However, first measurements of nutrients were only made in the early 1960s, with scientists raising concerns about increasing nutrient levels in coastal waters in the late 1980s (Becker, 1990). Similarly, following the transition from relatively inefficient sailing trawlers to first steam and then later diesel powered fishing vessels (Engelhard, 2008), fishing effort and associated impacts will have increased dramatically since the beginning of the 20th Century, while studies quantifying these impacts only started to appear in the 1990s (Collie *et al.*, 2000, Kaiser *et al.*, 2006). Consequently our current perception of environmental change in the marine environment has largely been based on studies conducted within an already altered environment.

The need for baseline data within the field of benthic ecology was probably clear to some scientists in the middle of the last century. During those years, in concomitance with the increase in power and size of fishing boats, extensive studies were carried out investigating benthic communities in Australia (Poore *et al.*, 1975; Poore & Kudenov, 1978a, b; Poore & Rainer, 1979), Canada (datasets gained from literature, see Cusson *et al.*, 2007 for details), Italy (Vatova, 1949) and England (Holme, 1953, 1961, 1966). Each of them had different aims but included, whether overtly stated or not, the intention of setting quantitative baselines for long term investigations of the benthic communities.

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Studies dating back to the beginning of the last century, the time when research into the ecology of benthic communities was still in its infancy and anthropogenic impacts had only begun expanding, are rare. Although these rare datasets often contain data which would not satisfy the requirements of modern standards, i.e. use of semi-quantitative sampling gear and enumeration, non-replicated sampling, etc, they are the only sources of information which can give us insight into the state of the marine environment before the onset of many anthropogenic impacts.

One of the first published benthic surveys for the United Kingdom was carried out by Allen in 1895 (Allen, 1899) sampling the sub-tidal faunal assemblages of the Plymouth area, including the Eddystone reef located 22 km off Plymouth Sound. Within the present study we used this unique dataset to attempt to establish the extent of benthic community change over a century-wide scale by repeating, in 2007, part of the original survey. In the context of long-term investigation and in the light of the paucity of appropriate databases available, Allen's work is invaluable because of the detailed dataset he compiled. His work is a comprehensive survey of the benthos in the south-west of England in the Plymouth area and the data includes an extensive semi-quantitative species list. Allen's aim was to gain knowledge of the distribution of seabed fauna to explain, where possible, whether differences in the community composition were a response to the nature of the bottom-deposit (Allen, 1899). Subsequent works carried out on the Eddystone grounds confirm the patchy nature of the bottom deposits around the reef. The description provided by the Marine Biological Association Plymouth Marine Invertebrate Fauna (1904), for example, highlights two different types of grounds near the Eddystone grounds: coarse grounds mixed with muddy gravel, on which *Chaetopterus variopedatus* Cuvier, 1827 appeared to be very abundant, and fine grounds mixed with sand characterized by *Cellaria* spp., known to be a nursery environment for several species. On both grounds large echinoderms, such as *Echinus esculentus* Linnaeus, 1758 and *Marthasterias glacialis* (Linnaeus, 1758) and bivalves such as *Aequipecten opercularis* (Linnaeus, 1758) were present in large numbers and generally distributed over the area. A few years later Ford (1923) also identified at least two distinct communities related to the nature of the deposit. Both were described as 'Venus communities with Spatangidae', with an *Echinocardium cordatum*-*Chamelea gallina* assemblage on fine grounds and a *Spatangus purpureus*-*Clausinella fasciata* assemblage on coarser grounds of clean shell gravel. This reinforces the idea that, twenty years after Allen's survey, the area was still characterized by a community whose main components were large echinoderms.

Different historical times have different aims: in the current work we wish to describe the current state of the same benthic community, in the light of the increased importance of conservation and sustainability issues for the marine environment. Revisiting part of Allen's work we aim to highlight potential differences in the benthic community structure between 1895 and 2007. The potential limitations of our approach of comparing two single points in time (rather than a continuous time series) are acknowledged and any conclusions regarding change in composition will be conservative and placed within the context of such limitations.

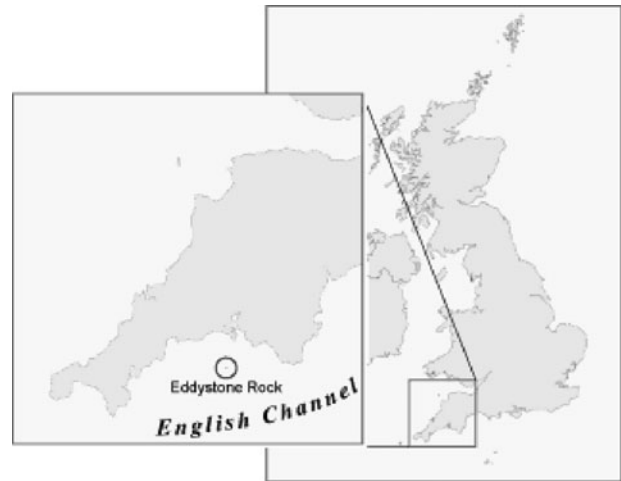


Fig. 1. Location of Eddystone Rock in the south-west of England.

MATERIALS AND METHODS

Selection of sites for the 2007 survey

In the historic survey, Allen used a Naturalist's dredge as well as an otter-trawl for sampling of benthic fauna in an area around the Eddystone Reef (Allen, 1899). For the re-survey, sampling was limited to sites Allen explored by a Naturalist's dredge in an area lying to the west of the Eddystone reef (Figures 1 & 2). Allen did not report faunistic data for each sampling site but published results as a species list from perceived 'grounds', i.e. sites grouped together by Allen on the basis of similar fauna and sediment characteristics (Allen, 1899). Hence in choosing sites for re-sampling it was important to select these also on the basis of 'grounds' rather than individual sites. In this way, six grounds to the west of the Eddystone Reef were selected. The number of sites within each of Allen's 'grounds' varied from one to eleven. Where the original number of sites was less than five, additional sites, not sampled previously by Allen, were added to gain a minimum of five sites sampled per ground in 2007 (Table 1; Figure 2). Additional sites were located in close proximity to already existing sites and within the extent of the ground as indicated by Allen (1899). This additional sampling effort was perceived as necessary to ensure that each ground was adequately described during the re-survey in 2007. The original sampling sites of Allen's survey were given as bearings and distance estimates. To extract latitude and longitude for sampling in 2007 the positions were redrawn within a GIS.

Table 1. Sites grouped by the grounds as described by Allen (1899). The stations highlighted in bold indicate stations which were added to Allen's original survey. Stations with an asterisk signified stations not sampled in 2007.

Grounds	Stations
VII	32*, 38, 54, 69, 70*, 71, 75*, 76, 79*, 80*, 100, 109
IX	93, 117, 118, 119, 120
X	42, 55, 89, 95, 121
XI	8, 9, 46, 47, 84
XIV	35, 41, 58, 59, 74, 85, 88
XVI	10*, 13, 14*, 86*, 87*, 98, 99

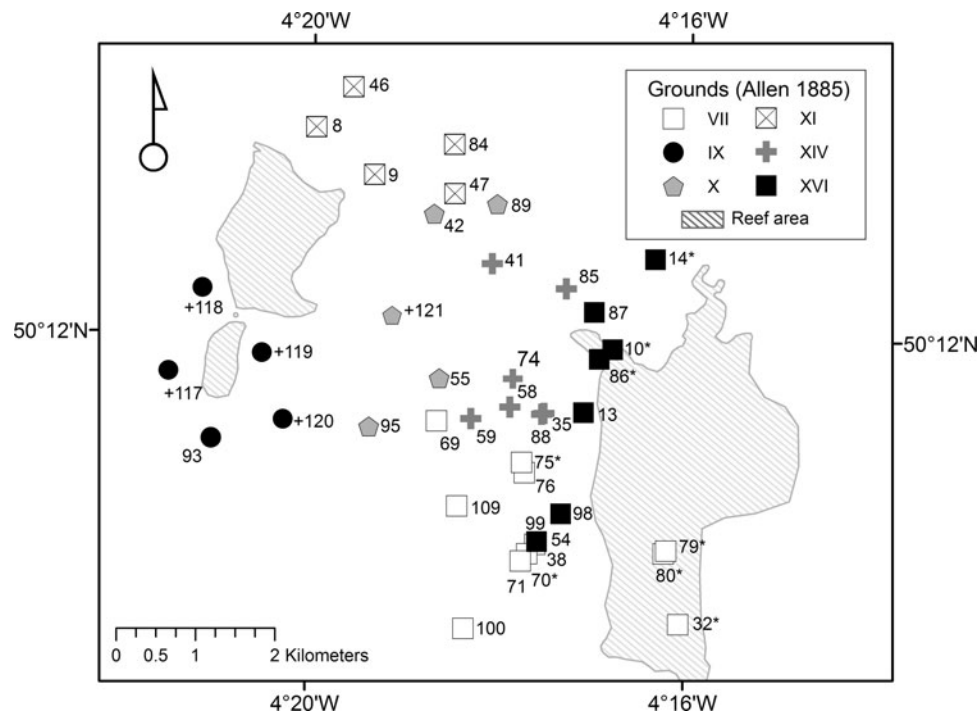


Fig. 2. Eddystone sampling area. Stations sampled and grouped as grounds by Allen (1899). Stations added to the survey in 2007 were marked by a plus while stations not revisited were signified by a star.

Sampling methodology in 2007

Sampling took place in the second half of March 2007 over a period of 5 days during which a total of 41 stations arranged within six grounds were re-surveyed (36 being the original sites and 5 being the stations added for adequate description of the grounds). The dimensions of the Naturalist's dredge used in 2007 were the same as the ones used by Allen in 1895: mouth 2 feet (61 cm), width 10.5 inches (26.67 cm). As no details on mesh size were provided by Allen, a mesh size of 18 mm was used in 2007 which corresponded to the most common mesh size used at the time (see *Encyclopaedia Britannica*, 1888). At each site, one dredge sample, towed for 1 minute, was taken. Once on board, the volume of the sample, which ranged from 3 to 30 l, was recorded. As many samples contained considerable volumes of sediment, a 5 l sub-sample was taken using a volumetric container. This was sieved over a 5 mm mesh to remove large animals and the larger fraction of sediment, and subsequently over 1 mm. The part of the sample retained on the 1 mm sieve was backwashed three times to extract the majority of live specimens from the sediment. All fauna retained was preserved in 4% formalin solution for later identification in the laboratory. Organisms were identified to the lowest taxonomic level, counted and their wet weight determined after dry blotting. Parts of animals which could not be allocated to any species identified were weighed as general biomass.

In addition, at each station a sediment sample was taken using a 0.1 m² Van Veen grab. From each grab a sediment core of approximately 5 cm depth and weighing 100 g was taken. In the laboratory the silt and clay fraction (<63µ) was determined by wet sieving whilst larger fractions were mechanically dry sieved using the Wentworth grade scale (Bale & Kenny, 2006).

Out of the 41 initially selected sites, 5 which were located on the reef, could not be sampled.

Statistical analysis—Eddystone benthic community 2007

Benthic community composition of 2007 was examined with multivariate statistics using the Primer package (v6, Clarke & Warwick, 2001). Non-parametric multi-dimensional scaling (MDS) and CLUSTER analysis on faunal abundance data was used to determine the community structure. The analysis was performed on square-root transformed data and a Bray–Curtis similarity matrix. The cluster analysis was run including the SIMPROF test, which highlights statistically significant evidence of genuine clusters in samples which are *a priori* unstructured (Clarke & Gorley, 2006). The SIMPER routine was used to determine which individual species contributed to the separation between sample groups identified by the CLUSTER and SIMPROF analysis. Possible correlations between the biotic similarity matrix and the abiotic variables were explored using Bio-Env. The routine compares the biotic resemblance matrix (Bray–Curtis similarity) with the abiotic variables resemblance matrix (Euclidean distance) using the Spearman's rank correlation coefficient. Bio-Env is thus able to determine which environmental variable, or combination of variables, shows the strongest relationship with the biological ordination. The abiotic variables considered in this study were depth and values of phi, the sediment particle size parameter.

Taxonomic alignment and transformation of data for comparison of 1895 and 2007

When using historical data and aiming to compare benthic communities over time, one of the most difficult and challenging problems to solve is related to the comparability of datasets. Aims, efforts, methods, taxonomic expertise and the state

of scientific art have changed over the course of time (Reise, 1982) and this makes achieving proper comparisons difficult. For this reason, a crucial stage is the organization and the selection of the data available. Allen (1899) organized his list of species per ground. Therefore this structure was superimposed on the 2007 dataset to attempt a comparison. Species belonging to the phyla of Nemertea, Platyhelminthes, Cnidaria and Chordata, were excluded from the comparison because they were difficult to identify or to match with accuracy with those from the old dataset. Phyla Mollusca, Crustacea, Annelida (Polychaeta) and Echinodermata were analysed to species level. Due to uncertainties in the identification of some species within the groups of Polychaeta and Crustacea and hence concern regarding consistency of identification between the two surveys, it was necessary to convert some species within both datasets to genus level (e.g. *Glycera convoluta* Keferstein, 1862, has been reduced to *Glycera* spp. and *Harmothoe fraserthomsoni* McIntosh, 1897, *Harmothoe imbricata* (Linnaeus, 1767) and *Harmothoe propinqua* (Malmgren, 1867) have all been reduced to *Harmothoe* spp.). Aggregation of species data to higher taxonomic levels such as genus or family can, for many groups, produce multivariate analyses indistinguishable from those based on species data (Clarke & Warwick, 2001).

Owing to the different nature of the historic dataset (semi-quantitative) and the newly collected data (quantitative), transformation of both datasets was needed to allow for a formal analysis. In the 2007 survey, abundance and biomass were recorded, while the historic dataset was composed of descriptive abundance categories, 'Few', 'Moderate' and 'Many' (see Allen, 1889 for details). Both datasets were converted to a four point code; 'absence' (coded as 0), 'few' (coded as 1), 'moderate' (coded as 2) and 'many' (coded as 3). While coding the old dataset was relatively straightforward, the 2007 data required a transformation which avoided allocating categories on a subjective basis. In order to convert the 2007 abundance data to a 4 point scale we forced the frequency distribution of observations in 2007 to conform to the same pattern as in 1895. In 2007 the number of individuals recorded for most species was relatively low, while only a few species were numerically abundant. This general pattern was also reflected in the 1895 data. The cumulative frequency distribution of 2007 within each of the major phyla (Mollusca, Crustacea, Annelida and Echinodermata) was therefore used to define the categories 1, 2 and 3 such that their frequency distribution matched that of 1895 (Table 2).

Statistical analysis—comparison of 1895 and 2007

Community composition of 1895 and 2007 was compared by multidimensional scaling (Primer v.6) using the 6 grounds as replicate samples to describe, in more detail, changes within the four polygenetic groups considered (Mollusca, Crustacea, Annelida and Echinodermata). Each group was analysed separately. The ANOSIM was used to formally test differences in the community composition between the two years. ANOSIM, contrary to the SIMPROF analysis, is an *a priori* test. A SIMPER analysis was performed to investigate the role of individual species contributing to differences between 1895 and 2007 and the top 10 species contributing mostly to the dissimilarity were reported (Table 7). All multivariate analyses were performed on the transformed abundance data.

Table 2. Representation of the way in which survey data were transformed to the three point abundance scale used in analyses (shown by the codes 1–3). Descriptive abundance data in 1895 were transformed by matching the terms, few, moderate and many, to the codes 1, 2 and 3 respectively. Quantitative abundance data in 2007 were transformed to the three point scale by creating classes of abundance such that the % frequency of organisms in each class matched (as closely as possible) the % frequency in 1895.

Code	1895		2007	
	Categories	% frequency	Abundance	% frequency
Mollusca				
1	Few	64	1–6	64
2	Moderate	26	7–16	26
3	Many	10	17–>50	10
Annelida				
1	Few	62	1–4	60
2	Moderate	24	5–10	23
3	Many	14	11–>50	17
Echinodermata				
1	Few	54	1–9	56
2	Moderate	27	10–26	28
3	Many	19	27–>50	16
Crustacea				
1	Few	51	1–5	54
2	Moderate	31	6–18	31
3	Many	18	19–>50	15

Fishing vessel sightings around Eddystone reef

Over-flight data provided by the UK's Sea Fisheries Inspectorate spanning a 10 year period prior to sampling (1997–2007) was used to determine the distribution of present day fishing activities around Eddystone reef. Spotter planes monitoring the compliance of fishing vessels with UK regulations record the geographical position, gear type and activity of fishing vessels irrespective of vessel size. The over-flight data were not used to estimate fishing effort for the different survey stations but to get a general appreciation of current fishing activities in the sampling area. Fishing activities were described by plotting active fishing vessels using GIS and calculating their density per 1 km². To assess the dominant type of fishing activity in the sampling area, vessel sightings were counted in a 10 km radius around Eddystone lighthouse.

RESULTS

Eddystone community in 2007

The cluster analysis of the abundance data collected in 2007 identified 5 significantly different groups ($P < 0.05$) among the forty-one stations sampled (Figure 3). The number of stations within groups varied between 2 and 13 (Table 3). Cluster D with thirteen stations comprised the largest station group with an average similarity of 29.5%. The stations of this cluster were characterized by the polychaetes *Glycera* spp. and *Lumbrineris* spp. as well as by small sized molluscs such as *Lepidochitona cinerea* (Linnaeus, 1767) and *Timoclea ovata* (Pennant, 1777) and the small echinoderm *Echinocyamus pusillus* (O.F. Müller, 1776). The brittle star *Ophiura albida* Forbes, 1839, the amphipod *Atylus*

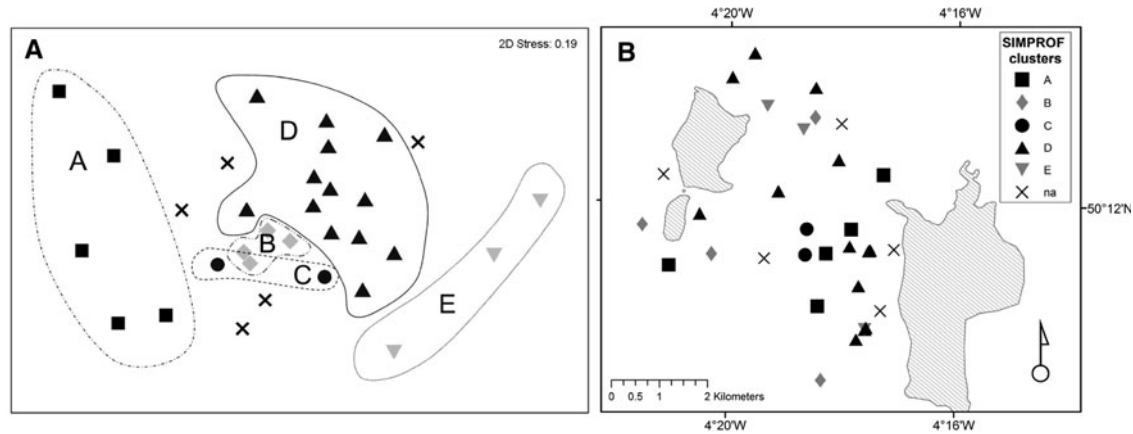


Fig. 3. (a) Multidimensional scaling plot showing station clusters identified by the SIMPROF routine; (b) their geographical distribution around Eddystone reef. Stations marked by an X were stations not allocated to a statistically significant cluster. The hashed area signified the position of the bedrock reef.

vedlomensis (Bate & Westwood, 1862) and amphipods of the genus *Ampelisca* also characterized this ground (Table 4). Within station group A, which comprised 5 stations (22.8% similarity), the small bivalve *Timoclea ovata* (Pennant, 1777) contributed most to the similarity between stations. The crustaceans *Macropodia* sp., *Ebalia tuberosa* (Pennant, 1777), *Galathea* sp. and *Anapagurus laevis* (Bell, 1845) also characterized this cluster, as well as the sedentary tubicolous polychaete *Hyalinoecia tubicola* (O.F. Müller, 1776) and the anthozoan *Alcyonium digitatum* Linnaeus, 1758 (Table 4). Stations of cluster B comprised 4 sites with a relatively high similarity compared to the other station groups (46.71% similarity). Overall, individual species showed a low contribution to the similarity indicating the absence of a few highly characteristic species for this group of stations. Species characterizing stations in the group were the crustaceans *Inachus dorsettensis* (Pennant, 1777), *Pisidia longicornis* (Linnaeus, 1767), *Photis longicaudata* (Bate & Westwood, 1862), *Ebalia tuberosa* (Pennant, 1777) and species of the genus *Ampelisca*. Other species include the mollusc *Aequipecten opercularis* (Linnaeus, 1758) which was found in its juvenile stage attached to hydroids like *Abietinaria abietina* (Linnaeus, 1758) or the bryozoan *Cellaria* spp. Cluster C consisting only of 2 stations (40.8% similarity) showed largely the same characteristic species as cluster B (Table 4), except for the presence of the Devonshire cup coral *Caryophyllia smithii* Stokes & Broderip, 1828 which contributed highly to the similarity of this cluster. Cluster E comprised 3 sites (similarity 24%) dominated by polychaetes of the genus *Glycera* spp. and species of the phylum Nemertea, which together

contributed to over 44% of the overall similarity for this station group. Other species contributing to the ground description were the sedentary tubicolous polychaete *Pista cristata* (Müller, 1776), and other errant predatory polychaetes such as *Lumbrineris* spp., *Eunice dubiatus* Fauchald, 1974 and *Gattyana* spp. Furthermore the crustaceans *Conilera cylindracea* (Montagu, 1804), *Ceradocus semiserratus* (Bate, 1862) and *Ebalia tumefacta* (Montagu, 1808) and the cephalochordate *Branchiostoma lanceolatum* (Pallas, 1774) (Amphioxus) were characteristic of these stations (Table 4).

The Bio-Env analysis showed that the biological data were best correlated with sediment grain size ($P = 0.230$). Yet, this relatively low best P value (correlation coefficient) seems to suggest that the community structure observed in 2007 was only weakly linked to sediment grain size and depth. Details of the sediment composition of the sites are included in Table 5.

The grouping of stations based on the 2007 survey was clearly different to the groupings made by Allen in 1895 (see Figures 2 & 3). Allen grouped his sampling sites into grounds on the basis of species composition and sediment type which could not be reconfirmed by the data collected in 2007 and analysed with multivariate statistical methods. While the stations identified by Allen as belonging to one ground were geographically located in close proximity to each other, the current survey and its classification did not reveal any clear geographical relatedness of station groups.

Comparison of 1895 and 2007

Multidimensional scaling of transformed abundance scale data and ANOSIM showed that species composition between the two years differed significantly ($P < 0.05$) within all polygenetic groups analysed. Overall dissimilarity levels varied between 71 and 80% (Table 7).

ANNELIDA

In 1895 Allen recorded an average of $13 \text{ SD} \pm 3.90$ species of Annelida on the grounds of Eddystone reef compared to $34 \text{ SD} \pm 5.88$ species recorded in 2007. Species characterizing the sampling area around Eddystone reef in 1885 were mainly tube building species such as *Chaetopterus*

Table 3. Sites sampled in 2007, grouped by the grounds as highlighted by the cluster analysis of the data. NA refers to stations not allocated to a statistically significant cluster.

Grounds	Stations
A	59, 74, 85, 93, 109
B	47, 100, 117, 120
C	55, 69
D	8, 35, 38, 41, 46, 58, 71, 76, 84, 88, 99, 119, 121
E	9, 42, 54
NA	13, 89, 95, 98, 118

Table 4. Top ten species identified by the SIMPER routine with the highest contributions to statistically significant station clusters. (B), bivalves; (BY), bryozoa; (C), Crustacea; (Cn), Cnidaria; (G), Gastropoda; (E), Echinodermata; (P), Polychaeta; (PP), Polyplacophora.

Species	Group	Av. abund	Av. sim	Sim/SD	Contrib. %	Cum. %
Cluster A average similarity: 22.75						
<i>Timoclea ovata</i>	(B)	1.28	3.19	1.06	14.02	14.02
<i>Macropodia</i> sp.	(C)	1.24	3.12	1.06	13.7	27.72
<i>Ebalia tuberosa</i>	(C)	1.03	2.73	1.09	11.98	39.7
<i>Hyalinoecia tubicola</i>	(P)	1.03	2.57	1.11	11.3	51
<i>Alcyonium digitatum</i>	(Cn)	0.88	2.39	1.15	10.52	61.51
<i>Galathea</i> sp.	(C)	0.75	1.4	0.62	6.14	67.65
<i>Anapagurus laevis</i>	(C)	0.8	1.16	0.62	5.09	72.74
<i>Cellaria</i>	(By)	0.63	0.69	0.32	3.05	75.79
<i>Adamsia carcinopados</i>	(Cn)	0.63	0.68	0.32	2.97	78.76
<i>Turritella communis</i>	(G)	0.77	0.52	0.32	2.28	81.05
Cluster B average similarity: 46.71						
<i>Inachus dorsettensis</i>	(C)	2.82	2.12	3.67	4.55	4.55
<i>Pisidia longicornis</i>	(C)	2.56	1.82	5.92	3.89	8.44
<i>Photis longicaudata</i>	(C)	2.82	1.79	3.29	3.84	12.28
<i>Aequipecten opercularis</i>	(B)	1.99	1.62	4.95	3.47	15.75
Melitidae	(C)	2.8	1.61	3.87	3.44	19.19
<i>Alcyonium digitatum</i>	(Cn)	2.05	1.61	8.07	3.44	22.63
<i>Ebalia tuberosa</i>	(C)	2.28	1.61	1.81	3.44	26.07
<i>Nereis</i> sp.	(P)	2.28	1.5	3.19	3.22	29.29
<i>Ophiothrix fragilis</i>	(E)	2.35	1.46	2.18	3.13	32.42
<i>Ampelisca</i> sp.	(C)	2.35	1.41	6.19	3.03	35.45
Cluster C average similarity: 40.85						
<i>Caryophyllia smithii</i>	(Cn)	5.1	6.69	na	16.37	16.37
<i>Turritella communis</i>	(G)	3.59	3.86	na	9.45	25.82
<i>Glycera</i> sp.	(P)	4.32	3.61	na	8.84	34.65
<i>Aequipecten opercularis</i>	(B)	2	2.73	na	6.68	41.34
<i>Echinocyamus pusillus</i>	(E)	3	2.73	na	6.68	48.02
<i>Ophiura albida</i>	(E)	2.12	2.73	na	6.68	54.7
<i>Pisidia longicornis</i>	(C)	2.41	2.73	na	6.68	61.38
<i>Timoclea ovata</i>	(B)	3	2.73	na	6.68	68.06
<i>Ophiothrix fragilis</i>	(E)	1.87	2.36	na	5.79	73.85
<i>Alcyonium digitatum</i>	(Cn)	2.44	1.93	na	4.72	78.57
Cluster D average similarity: 29.47						
<i>Glycera</i> sp.	(P)	3.58	3.65	1.72	12.38	12.38
<i>Lumbrineris</i> sp.	(P)	3.2	2.78	0.96	9.43	21.81
<i>Lepidochitona cinerea</i>	(PP)	2.45	2.34	1.11	7.94	29.75
<i>Ampelisca</i> sp.	(C)	2.99	2.27	1.02	7.69	37.45
<i>Timoclea ovata</i>	(B)	2.04	1.8	1.09	6.11	43.56
<i>Echinocyamus pusillus</i>	(E)	2.54	1.51	0.83	5.14	48.7
<i>Ophiura albida</i>	(E)	1.71	1.33	0.88	4.53	53.22
<i>Atylus vedlomensis</i>	(C)	2.11	1.23	0.67	4.17	57.4
<i>Ebalia tuberosa</i>	(C)	1.55	1.17	0.71	3.95	61.35
Melitidae	(C)	1.86	1.1	0.7	3.75	65.1
Cluster E average similarity: 24.02						
<i>Nemertea</i>		4.7	5.41	3.07	22.51	22.51
<i>Glycera</i> sp.	(P)	3.78	5.25	3.5	21.85	44.35
<i>Conilera cylindracea</i>	(C)	2.79	1.94	0.58	8.07	52.42
<i>Pista cristata</i>	(C)	3.44	1.66	0.58	6.92	59.33
<i>B. lanceolatum</i>	(Ch)	1.94	1.62	0.58	6.75	66.08
<i>Lumbrineris</i> sp.	(P)	2.51	1.37	0.58	5.7	71.79
<i>Ebalia tumefacta</i>	(C)	1.63	1.02	0.58	4.26	76.04
<i>Ceradocus semiserratus</i>	(C)	1.76	0.96	0.58	3.99	80.03
<i>Eumice dubitatus</i>	(P)	1.76	0.96	0.58	3.99	84.03
<i>Gattyana</i> sp.	(P)	2.58	0.96	0.58	3.99	88.02

variopedatus Cuvier, 1827, *Hydroides norvegicus* Gunnerus, 1768 and *Thelepus* sp., while errant species apart from *Nereis* sp. and two scale worm species (*Harmothoe* sp. and *Lepidonotus squamatus* (Linnaeus, 1758)), were less typical (Table 6). The SIMPER analysis further highlighted

noticeable differences in abundance between 1895 and 2007 (Table 6). In particular, small errant polychaetes species (i.e. *Eumida sanguinea* (Ørsted, 1843)), as well as errant predatory species (i.e. *Glycera* spp., *Syllis* spp. and *Nephtys* spp.) were common in 2007, but were not recorded in 1895

Table 5. Sediment types (ϕ value) for the stations sampled in 2007. Sediment samples have been processed by wet sieving, graded using the Wentworth scale and then classified on the basis of the Folk (1954) classification.

Ground	Mean ϕ 1895	Mean ϕ 2007	Classification
G7	1.9089856	2.2236269	Sandy gravel
G9	1.3061954	2.4642268	Gravelly muddy sand
G10	1.369713	2.2695483	Gravelly muddy sand
G11	1.3291922	2.1408	Sandy gravel
G14	1.3472603	2.1817	Sandy gravel
G16	1.2707314	1.9932012	Sandy gravel

(Table 7). This trend was contrasted by a decrease in abundance of the large tubicolous polychaete *Chaetopterus vario-pedatus* Cuvier, 1827, which occurred in 'moderate'

Table 6. Top 10 characteristic species with the highest contribution to the overall similarity within the two different sampling years 1895 and 2007 respectively. Species highlighted in bold were species which were characteristic within both years.

Species	1885		Species	2007	
	Av. abund	Contrib. %		Av. abund	Contrib. %
Polychaeta					
<i>Chaetopterus variopedatus</i>	2.17	15.16	<i>Glycera</i> sp.	3	10.28
<i>Hydroides norvegicus</i>	1.67	15.15	<i>Syllis</i> sp.	2.5	7.48
<i>Harmothoe</i> sp.	1.33	11.54	<i>Lumbrineris</i> sp.	2.5	6.87
<i>Thelepus</i> sp.	1.83	9.88	<i>Polynoidae</i>	2.17	5.99
<i>Lepidonotus squamatus</i>	1.33	7.18	<i>Gattyana</i> sp.	2.33	5.88
<i>Nereis</i> sp.	1.17	6.6	<i>Nephtys</i> sp.	2	5.79
<i>Serpula vermicularis</i>	1.17	5.47	<i>Bylgides</i> sp.	2.17	5.29
<i>Branchiomma bombyx</i>	1.33	5.44	<i>Eumida sanguinea</i>	2.17	5
<i>Protula tubularia</i>	0.67	5.24	<i>Nereis</i> sp.	1.83	4.77
<i>Hyalinoecia tubicola</i>	1.17	4.34	<i>Hyalinoecia tubicola</i>	1.83	4.3
Mollusca					
<i>Pecten maximus</i>	1.83	12.46	<i>Timoclea ovata</i>	2.5	19.65
<i>Aequipecten opercularis</i>	1.67	10.47	<i>Aequipecten opercularis</i>	2	14.68
<i>Anomia ephippium</i>	1.67	8.93	<i>Turritella communis</i>	2.17	13.83
<i>Leptochiton asellus</i>	1.5	8.08	<i>Lepidochitona cinerea</i>	1.83	8.39
<i>Emarginula fissura</i>	1.5	7.64	<i>Leptochiton asellus</i>	1.33	8.11
<i>Hiatella arctica</i>	1.5	7.12	<i>Clausinella fasciata</i>	1.5	7.38
<i>Laevicardium crassum</i>	1	6.51	<i>Aporrhais pespellicani</i>	1	5.83
<i>Lima loscombii</i>	1.33	6.38	<i>Hiatella arctica</i>	0.67	4.31
<i>Anomia patelliformis</i>	1.33	5.18	<i>Nucula nitidosa</i>	0.83	3.82
<i>Doto fragilis</i>	1.33	4.77	<i>Modiolus barbatus</i>	0.67	3.62
Echinodermata					
<i>Ophiorthrix fragilis</i>	2.5	15.43	<i>Echinocyamus pusillus</i>	2.67	27.17
<i>Psammechinus miliaris</i>	2.33	13.44	<i>Ophiorthrix fragilis</i>	2.5	26.25
<i>Echinus esculentus</i>	1.67	10.21	<i>Ophiura albida</i>	1.83	16.46
<i>Ophiactis balli</i>	1.83	10.1	<i>Ophiura</i> sp.	1.17	12.06
<i>Marthasterias glacialis</i>	1.83	7.96	<i>Amphiura</i> sp.	1.5	9.83
<i>Asterias rubens</i>	1.67	7.53	<i>Psammechinus miliaris</i>	0.5	2.45
<i>Crossaster papposus</i>	1	7.46	<i>Amphiura chiajei</i>	0.5	2.22
<i>Ophiocomina nigra</i>	1	5.16	<i>Holothuroidea</i>	0.33	0.85
<i>Echinus acutus</i>	1	4.9	<i>Ophiura ophiura</i>	0.33	0.76
<i>Astropecten irregularis</i>	0.83	4.56	<i>Asterias rubens</i>	0.33	0.67
Crustacea					
<i>Galathea</i> sp.	2.17	13.81	<i>Ampelisca</i> sp.	2.67	7.24
<i>Pisidia longicornis</i>	2	13.46	<i>Atylus vedlomensis</i>	2.67	6.93
<i>Macropodia</i> sp.	1.5	8.35	<i>Ebalia tuberosa</i>	2.33	6.17
<i>Scalpellum scalpellum</i>	1.67	8.35	<i>Photis longicaudata</i>	2.33	5.4
<i>Balanus crenatus</i>	1.17	8.08	<i>Melitidae</i>	2.33	5.34
<i>Ebalia tumefacta</i>	1.33	7.01	<i>Inachus dorsettensis</i>	2.17	5.15
<i>Liocarcinus pusillus</i>	1.33	6.87	<i>Pisidia longicornis</i>	2.17	5.01
<i>Ebalia tuberosa</i>	1.33	5.93	<i>Pagurus prideauxi</i>	1.83	4.96
<i>Pagurus cuanensis</i>	1	5.65	<i>Galathea</i> sp.	2.17	4.47
<i>Inachus dorsettensis</i>	1.5	5.57	<i>Maera othonis</i>	2	4.36

abundance in 1895 within most grounds but was not recorded at all in 2007.

CRUSTACEA

Similar to the increase in species number of Polychaeta, the number of crustacean species in 2007 also increased. Allen reported an average of $13 \text{ SD} \pm 4.07$ species in 1895 compared to $39 \text{ SD} \pm 9.58$ in 2007. While in 1895 the area was mainly characterized by species such as *Galathea* spp., *Pisidia longicornis* (Linnaeus, 1767) and *Macropodia* spp., in 2007 the community was dominated by smaller species belonging to the order Amphipoda (Table 7). Of the top ten species highlighted by the SIMPER analysis as contributing mostly to the observed dissimilarity between the two sampling

Table 7. Top ten species identified by the SIMPER analysis to contribute most to the dissimilarity between the two sampling periods 1895 and 2007 for different phylogenetic groups. Arrows indicate direction of change with respect to average abundance scores.

	1885 Mean abundance score	2007 Mean abundance score	Mean dissimilarity	Contrib. %	Direction of change
Annelida					
Average dissimilarity = 84%					
<i>Glycera</i> sp.	0.17	3	3.6	4.28	↑
<i>Syllis</i> sp.	0.17	2.5	2.91	3.47	↑
<i>Bylgides</i> sp.	0	2.17	2.9	3.45	↑
<i>Gattyana</i> sp.	0	2.33	2.85	3.39	↑
Polynoidae	0	2.17	2.75	3.28	↑
<i>Eumida sanguinea</i>	0	2.17	2.68	3.2	↑
<i>Chaetopterus variopedatus</i>	2.17	0	2.68	3.19	↓
<i>Nephtys</i> sp.	0	2	2.61	3.1	↑
<i>Lumbrineris</i> sp.	0.5	2.5	2.5	2.98	↑
<i>Pholoe inornata</i>	0	1.83	2.26	2.69	↑
Mollusca					
Average dissimilarity = 79.57%					
<i>Timoclea ovata</i>	0.17	2.5	4.75	5.98	↑
<i>Turritella communis</i>	0.33	2.17	3.84	4.82	↑
<i>Lepidochitona cinerea</i>	0	1.83	3.63	4.57	↑
<i>Anomia ephippium</i>	1.67	0	3.21	4.04	↑
<i>Pecten maximus</i>	1.83	0.33	2.9	3.65	↓
<i>Lima loscombii</i>	1.33	0	2.74	3.44	↓
<i>Emarginula fissura</i>	1.5	0.33	2.7	3.39	↓
<i>Pododesmus patelliformis</i>	1.33	0	2.61	3.28	↓
<i>Clausinella fasciata</i>	0.33	1.5	2.53	3.18	↑
<i>Hiattella arctica</i>	1.5	0.67	2.53	3.17	↓
Crustacea					
Average dissimilarity = 72.46%					
<i>Ampelisca</i> sp.	0	2.67	3.32	4.58	↑
<i>Atylus vedlomensis</i>	0	2.67	3.28	4.53	↑
<i>Photis longicaudata</i>	0	2.33	2.77	3.83	↑
Melitidae	0	2.33	2.72	3.76	↑
<i>Maera othonis</i>	0	2	2.45	3.38	↑
<i>Ampelisca typica</i>	0	1.5	1.88	2.6	↑
<i>Ceradocus semiserratus</i>	0	1.5	1.78	2.46	↑
<i>Atylus guttatus</i>	0	1.5	1.66	2.29	↑
<i>Pagurus prideauxi</i>	0.5	1.83	1.61	2.22	↑
<i>Urothoe elegans</i>	0	1.33	1.57	2.17	↑
Echinodermata					
Average dissimilarity = 71.48%					
<i>Echinocyamus pusillus</i>	0.83	2.67	5.46	7.63	↑
<i>Ophiactis balli</i>	1.83	0	4.92	6.88	↓
<i>Psammechinus miliaris</i>	2.33	0.5	4.9	6.86	↓
<i>Marthasterias glacialis</i>	1.83	0	4.84	6.78	↓
<i>Echinus esculentus</i>	1.67	0	4.54	6.34	↓
<i>Amphiura</i> sp.	0.17	1.5	3.87	5.42	↓
<i>Asterias rubens</i>	1.67	0.33	3.87	5.42	↓
<i>Ophiura albida</i>	1.33	1.83	3.66	5.12	↑
<i>Spatangus purpureus</i>	1	0	2.86	4	↓
<i>Crossaster papposus</i>	1	0	2.78	3.89	↓

years, nine species belonged to this order (Table 7). However, the larger crab species were present in similar abundances to the ones reported for 1895.

MOLLUSCA

Mollusca showed a decrease in species richness between the two sampling events. Allen recorded an average of 19 SD \pm 6.37 species in 1895 compared to 15 SD \pm 3.38 in 2007. Eddystone reef in 1895 was partly characterized by large bivalve species such as *Pecten maximus* (Linnaeus,

1758), *Aequipecten opercularis* (Linnaeus, 1758) and *Laevicardium crassum* (Gmelin, 1791) (Table 6). The reef was also characterized by epizoic species such as the saddle oysters *Anomia ephippium* Linnaeus, 1758 and *Pododesmus patelliformis* (Linnaeus, 1761) and the slit limpet *Emarginula fissura* (Linnaeus, 1758), which are often found attached to larger bivalve species such as *Pecten maximus* (Linnaeus, 1758). Among the top ten species highlighted by SIMPER as contributing mostly to the overall dissimilarity between 1895 and 2007 were the small bivalves *Timoclea*

ovata (Pennant, 1777) and *Clausinella fasciata* (da Costa, 1778), the gastropod *Turritella communis* Risso, 1826 and the chiton *Lepidochitona cinerea* (Linnaeus, 1767) which all showed a notable increase in abundance from 1895 to 2007 (Table 7). In contrast, larger bivalve species such as the king scallop *Pecten maximus* (Linnaeus, 1758) and the above mentioned saddle oysters and slit limpet showed a decline. *Pecten maximus* (Linnaeus, 1758) was present at all grounds with an average abundance categorized as 'moderate' by Allen in 1895 but its abundance in 2007 was reduced to 'few' in two out of the six grounds investigated and completely absent from the rest.

ECHINODERMATA

The species richness index (S) showed that Allen recorded an average of $14 \text{ SD} \pm 2.86$ species in 1895 compared to $9 \text{ SD} \pm 1.75$ in 2007. While the Eddystone fauna from this group in 1895 was characterized by, among others, large species such as *Marthasterias glacialis* (Linnaeus, 1758) *Echinus esculentus* Linnaeus, 1758 and *Spatangus purpureus* (O.F. Müller, 1776), in 2007 the community was characterized by relatively small opportunistic species such as *Echinocyamus pusillus* (O.F. Müller, 1776), *Ophiura albida* Forbes, 1839, *Ophiothrix fragilis* (Abildgaard, 1789) and *Amphiura* spp. (Table 6).

The spiny starfish *Marthasterias glacialis* (Linnaeus, 1758), the brittlestar *Ophiactis balli* (W. Thomson, 1840), *Echinus esculentus* Linnaeus, 1758 and *Spatangus purpureus* (O.F. Müller, 1776) were absent from samples in 2007 yet all were recorded as abundant or moderately abundant by Allen in 1895 on the majority of grounds (Table 6). Two species showed a significant increase, the tiny sea urchin *Echinocyamus pusillus* (O.F. Müller, 1776) and a brittle star of the genus *Amphiura*. These species were absent from some grounds in 1895 but showed moderate abundance at others. In 2007 they were more consistently abundant across most grounds. It is important to highlight that the loss of echinoderms on the Eddystone grounds is in terms of large fragile species while smaller size echinoderms have increased.

Fishing vessel sightings around Eddystone reef

Fishing vessel sightings were relatively high around Eddystone reef compared to other areas off Plymouth Sound (Figure 4). Analysis of the vessel sightings showed that 65% of vessels in the survey area were beam trawling while 25% were scallop dredging. The remaining 10% of vessels were demersal trawlers.

DISCUSSION

The Eddystone reef area, located in the western English Channel and originally surveyed in 1895, was resurveyed by this study in 2007 after a period of 112 years to determine to what extent community composition had changed. Although we focus on change, it should first be noted that most of the species recorded in 1895 were also found in 2007. Mollusca in 1895 represented 32% of the 353 species collected by Allen while in 2007 they were 16% of the 584 species collected. Echinodermata also showed a significant decline from 24% of the total in 1895 to 9% in 2007. Both Crustacea and Polychaeta showed an increase from 22% to 40% and 35% respectively. On the other hand, from ongoing work carried out by the authors on a larger area on the south-east of the Eddystone Reef, we know that species like the star fish *Marthasterias glacialis* (Linnaeus, 1758), which were not found in the 2007 survey around the Eddystone Rock, although quite often damaged, still commonly occur in the area. Thus the changes reported within this study cannot be viewed as catastrophic changes, but within the limitations of our approach, it was possible to identify patterns of changing dominance of particular benthic species of the community around the Eddystone Reef.

Based on sediment and faunal composition, Allen described geographically distinct communities (Allen, 1899). In 2007 these assemblage groupings were not apparent; multivariate techniques identified groupings which were geographically heterogeneous and did not show a strong association to

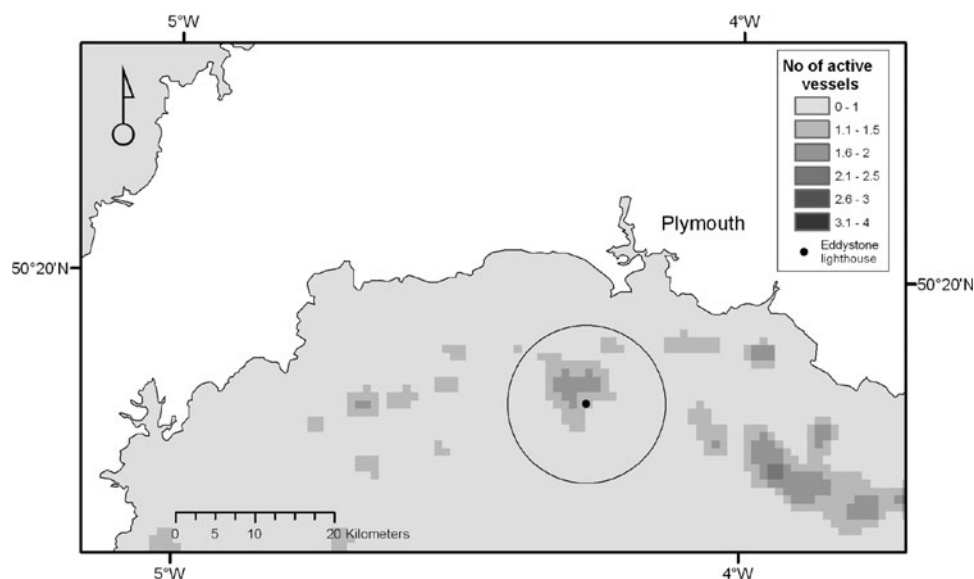


Fig. 4. Distribution and density of fishing vessels sighted by spotter planes in the period between 1997 and 2007 off Plymouth. The circle marks the 10 km^2 radius around Eddystone lighthouse for which the percentage of different fishing vessel types was calculated.

sediment composition. Since we do not possess data for individual sites in 1895 it is not possible to use modern analytical techniques to assess Allen's spatial groupings. However, it is possible that the spatial groupings identified by Allen and the association between sediment type and benthic community structure which existed in 1885 have since broken down. The area around Eddystone Reef has been exposed to intensive trawling activities since the beginning of the last century which may have altered the distribution of dominant species leading to the spatially fragmented community patterns observed in this study. Similarly, chronic trawling activities can also alter sediment composition and bed morphology (Palanques *et al.*, 2001; Trimmer *et al.*, 2005).

In addition to changes observed in assemblage groupings, we identified change at the species level within the phylogenetic groups assessed. These were concomitant with changes generally associated with trawling impacts. Demersal fishing impacts have been shown to reduce abundances of fragile and large bodied animals while facilitating small fast growing opportunistic species (Bergman & Hup, 1992; Jennings & Kaiser, 1998; Duplisea *et al.*, 2002). Results of this study showed that within the Polychaeta a shift occurred from a community dominated by sedentary tubicolous polychaetes such as *Chaetopterus variopedatus* Cuvier, 1827 and *Thelepus* sp. to small errant and predatory species such as *Glycera* spp. and *Nephtys* spp. These predatory polychaetes have been shown to dominate other heavily trawled areas (Frid *et al.*, 1999, Hinz *et al.*, 2009). Similarly within the Mollusca, large species such as *Pecten maximus* (Linnaeus, 1758) and *Laevicardium crassum* (Gmelin, 1791) decreased, while small species such as *Timoclea ovata* (Pennant, 1777) or *Clausinella fasciata* (da Costa, 1778) increased in abundance. Significant species losses between 1885 and 2007 occurred within the Echinodermata. In particular, large bodied fragile organisms such as sea urchins (*Echinus esculentus* Linnaeus, 1758, *Spatangus purpureus* (O.F. Müller, 1776)) and large starfish (*Marthasterias glacialis* (Linnaeus, 1758), *Crossaster papposus* (Linnaeus, 1776)) which are particularly prone to damage from fishing gear (e.g. Jenkins *et al.*, 2001) were recorded in 1895 but were not found by this study in 2007. The Crustacea described by Allen as typical for Eddystone reef were various species of crabs, which occurred in similar abundances in 2007. However, samples collected in 2007 showed a predominance of small Crustacean species belonging to the order Amphipoda.

Due to differences in the time scale between the two surveys and because a detailed description of the methodology for sorting the fauna was not available for the historic survey, it can be argued that some of the differences highlighted in this study could stem from the possible application of different methodologies. In general where species are small and inconspicuous, conclusions regarding increases in their abundance can only be tentative since the greater precision in the sorting of dredged samples in 2007 might have led to a greater possibility of finding such cryptic organisms. However, many of the significant changes reported were due to the loss of large conspicuous fauna. Our sampling effort was equal to that of Allen, but based on Allen's description of sorting we can be confident that we undertook a greater precision of sorting of benthos. Hence any reductions in abundance or total loss of taxa can be described with high levels of confidence.

Besides fishing disturbance, other environmental and anthropogenic drivers could potentially be responsible for

some of the observed changes. Increases in small opportunistic species for example have been related to eutrophication (Rosenberg *et al.*, 1990). However, we are unaware of any evidence for eutrophication being a major problem for this part of the English Channel, unlike for areas of the North Sea (Kroncke, 1988). Hence we consider this factor an unlikely candidate to have contributed to the observed changes. Severe winters have been demonstrated to significantly affect benthic communities by killing many dominant, often long lived species (Ziegelmeier, 1964; Reiss *et al.*, 2006). The last severe cold winter causing such significant changes in offshore benthos in the North Sea dates back to the winter of 1962–1963 (Ziegelmeier, 1964; Reiss *et al.*, 2006). Since then temperatures have consistently increased and have led to relatively mild winter temperatures (Luterbacher *et al.*, 2004). If parts of the benthic communities were killed during the severe winter of 1962–1963 it is not unreasonable to assume that they would have recovered over the past 46 years without any additional disturbance.

Fishing around Eddystone reef was already judged as being considerable prior to Allen's survey, but was mainly composed of long-lining, mackerel, pilchard and whiting fishing (Calderwood, 1893). Most of the fishing fleet will have been composed of relatively inefficient sailing trawlers which were gradually replaced by a growing fleet of more efficient steam trawlers around 1900 and later in the 1950s by trawlers equipped with diesel engines (Engelhard, 2008). Similarly, more efficient fishing gear types became available during this period. Up until the late 1800s long-lining was one of the main fishing practices, which was gradually replaced by bottom impacting gear such as beam and otter trawls (Engelhard, 2008). Scallop dredging, one of the main fisheries around the Eddystone reef, most likely started at the same time as fisheries for scallop in other areas such as the Isle of Man. On the Isle of Man, fishing for scallops commenced in the early 1940s but was only becoming extensive with the introduction of spring loaded toothed dredges in the 1970s which would allow for fishing on rougher grounds such as offshore reef areas (Bradshaw *et al.*, 2000). As scallop dredging has been identified as one of the most detrimental fishing practices to benthic communities together with beam trawling (Kaiser *et al.*, 2006), we assume that these activities will have greatly contributed to the changes described by this paper, particularly with respect to the disappearance of the larger long-lived macrobenthic species.

The interpretation of the differences between the two surveys discussed within this paper is based on the assumption that they represent real long-term changes in benthic communities at the Eddystone reef rather than merely short term variation. Thus, whilst this weakness is acknowledged in interpreting the results of the present study, it has to be appreciated that in the absence of long term time-series this is the only way to investigate temporal changes in benthic communities on a century wide scale. Similarly, the findings of this study add to a growing number of scientific papers (Frid *et al.*, 1999, 2000; Rumhor & Kujawski, 2000; Callaway *et al.*, 2007), which have reported very similar trends giving confidence in the generality of the long term changes reported by this study. Future work at Eddystone will assess the degree of annual contemporary variation in community composition to lend weight to support the conclusions described here, that observed changes in dominance of different benthic species represents long term change.

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