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East of Douglas Experimental Research Area: Three-Year Review

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1 | Introduction

The East of Douglas Experimental Research Area (EDG ERA) was established as an experimental closed area for three years in July 2017, encompassing a region where the queen scallop (*Aequipecten opercularis*) stock had rapidly declined (Figure 1). Prior to closure, there was little sign of improvement in the region. The purpose of EDG ERA was to assess the recovery of a depleted scallop ground during a three-year closure and to test the performance of artificial spat receptors, in the absence of fishing pressure, as a means of artificially increasing scallop recruitment.

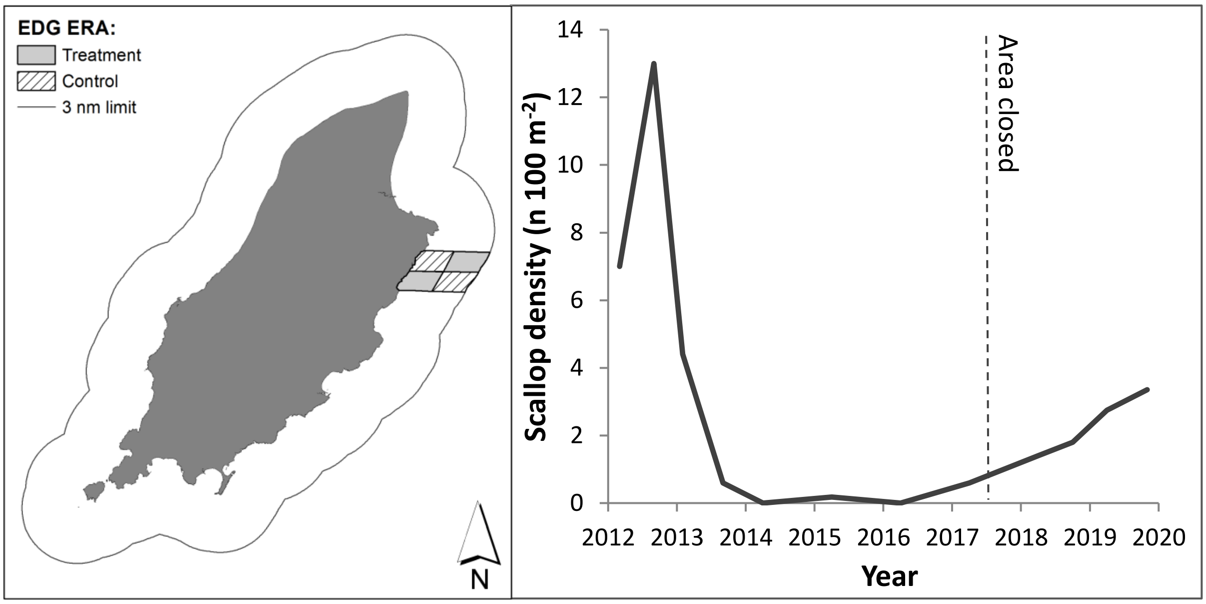

Figure 1. *Left: Map showing the location and survey design of EDG ERA; Right: Mean queen scallop density in EDG ERA from dredge surveys (Prince Madog stock assessment station 29 and recent F.P.V. Barrule surveys*

Since 2017, the area has been monitored annually during autumn (October-November) from the F.P.V. Barrule, including demersal fisheries surveys (beam trawl and dredge) and a drop-down camera habitat survey. Additionally, the annual Prince Madog dredge survey in the spring samples a station within EDG ERA. In May 2019, four trial spat receptors were built and deployed in the area in order to test the design, however this will not have had an effect on the data collected thus far. It is expected that a full deployment and monitoring program for artificial spat receptors will follow.

2 | Methods

The EDG ERA survey design consisted of a grid of 80 sampling stations evenly distributed between two “treatment” areas for artificial spat receptors and two “control” areas for comparison (Figure 2). Random stations were selected for beam trawl surveys each year and for the drop-down camera work in 2018, while dredge sampling took place along eight consistent transects (Figure 2). The GPS position of the vessel was logged every 30 seconds throughout the work.

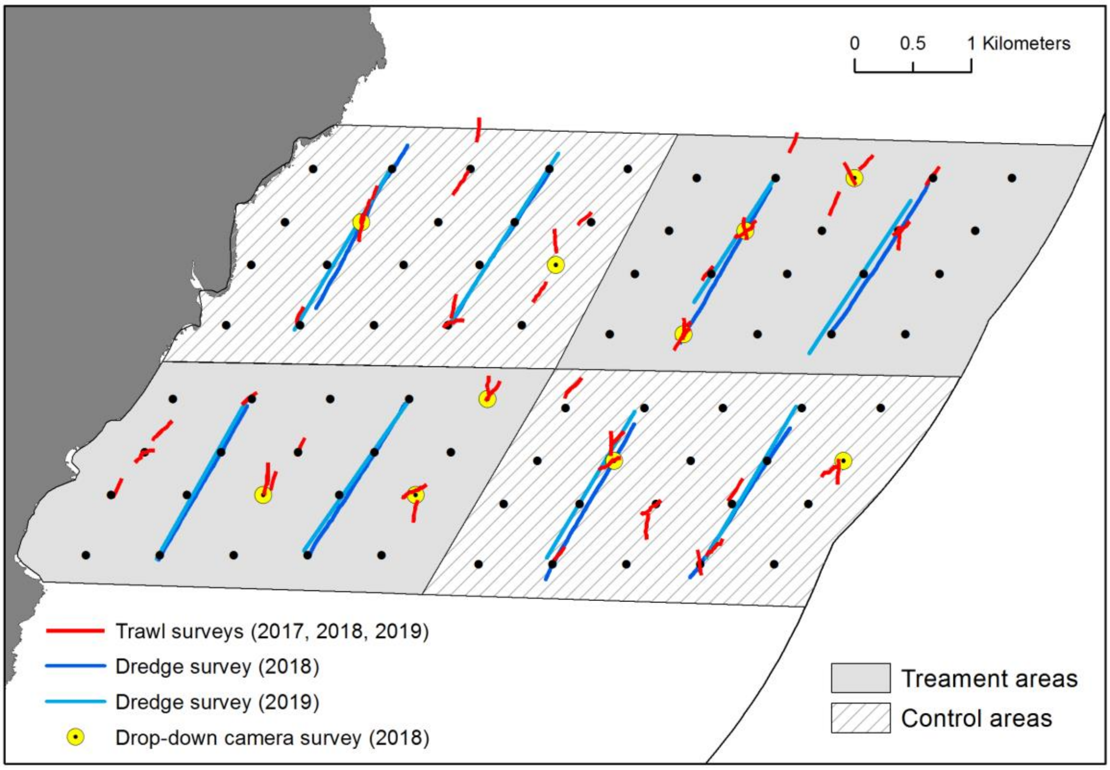

Figure 2. *F.P.V. Barrrule surveys completed in EDG ERA during the three-year experimental closure. Sampling stations indicated by black dots (see Appendix Figure A for station labels).*

2.1 | Beam Trawl

Beam trawl surveys (2m beam) were conducted in October 2017, October 2018 and November 2019 in order to monitor the epifaunal community in EDG ERA (queen scallops and bycatch). Each survey consisted of 16 five-minute tows (1 – 1.5 knots) through randomly selected stations in each of the four areas. Queen scallops in each tow were counted and measured (shell height), and the remainder of the catch sorted into species and counted.

2.2 | Dredge

Dredge surveys (4 x Xm dredges) were conducted in October 2018 and Novebmer 2019 to sample king and queen scallops. Eight 20-minute tows (2.5 knots) were completed each year and in the same positions. Two king scallop dredges (K) and two queen scallop dredges (Q) were used in the following configuration: K, Q, Q, K. As before, queen scallops in each catch were counted and measured (shell height), and king scallops were also counted, measured (shell width), and aged using growth rings on the shells.

2.3 | Drop-Down Camera

A drop-down camera habitat survey was completed in October 2018 in order to explore any potential confounding differences between the four areas of EDG ERA. Seabed substrate is an important factor in determining scallop densities (Kostylev et al., 2003; Howarth et al. 2011). Underwater lights and two GoPros collecting images (1 second^{-1}) and video footage were attached to a metal frame which was lowered by a cable to the seafloor, and the frame was moved at least three times per station. Footage was collected at 10 stations sampled by the beam trawl that same month.

2.4 | Spat Receptor Trial

In May 2019, four trial “X-shaped” artificial spat receptors based on the design of Fegley et al. (2009) were built and two were deployed in each of the “treatment” areas in EDG ERA. The purpose here was to assess the success of this design (Figure 3) in collecting scallop spat, before a full deployment and monitoring program may go ahead, and therefore the receptors were positioned where good scallop densities were found in prior beam trawl surveys (2017/18). Two additional receptors were deployed in Ramsey Bay Marine Nature Reserve, where there is known to be good scallop recruitment, to further evaluate the performance of this design.

Figure 3. *“X-shaped” spat receptor model tested in EDG ERA, inspired by the design of Fegley et al. (2009).*

2.5 | Data Analysis

Fisheries survey catch data (beam trawl and dredge) was analysed in two stages:

1) Baseline comparison of the proposed “treatment” and “control” areas, ensuring no confounding differences present prior to spat receptor deployment;
2) Temporal analysis across three-year closure, identifying any changes/recovery in the area.

To compare “treatment” and “control” areas, two sample t-tests were performed on baseline data (beam trawl – 2017; dredge – 2018). Analysis of variances (ANOVAs) were used to compare data across years. If “treatment” and “control” areas were not found to be significantly different, temporal analyses were performed using pooled data. Square-root transformation was performed where necessary to meet parametric test assumptions.

Response variables examined in this manner were queen scallop density and bycatch community metrics (abundance, species richness, diversity) from beam trawl surveys, and king and queen scallop densities from dredge surveys. To compare bycatch community composition between areas or years, permutational multivariate analysis of variances (PERMANOVAs) were used (adonis, CRAN: vegan). Scallop size distributions were compared between areas and years from histograms (ggplot, CRAN: ggplot2). With regard to dredge catch data, king scallop densities incorporated all four dredges while queen scallop densities were calculated from Q dredges only.

Finally, qualitative substrate categories (e.g. gravelly sand) were assigned to survey stations using the drop-down camera footage, and a one-way ANOVA used to test the relationship between substrate type and queen scallop density (2018 beam trawl data).

3 | Results

3.1 | Baseline Comparison: “Treatment” vs “Control”

There were no significant differences in baseline scallop densities or bycatch between the proposed “treatment” and “control” areas (Table 1). There was also no considerable difference in the range of scallop sizes found in “treatment” and “control” areas, with consistently occurring size cohorts (Figure 4, Figure 5).

Table 1. *Comparison of the proposed "treatment" and "control" areas of EDG ERA using baseline data from beam trawl and dredge surveys. QSC = queen scallop; SCE = king scallop; d.f. = degrees of freedom; t.s. = test statistic; p = significance.*

Response variable			**Area (T vs C)**	
		d.f.	*t.s.*	*p*
Beam trawl (2017)	QSC density (n 100 m^{-2}) [t]	13	-0.68	0.51
	Bycatch community composition [p]	12	1.11	0.34
	Bycatch density (n 100 m^{-2}) [t]	12	1.96	0.07
	Bycatch species richness [t]	12	1.43	0.18
	Bycatch diversity (H') [t]	12	-1.59	0.14
Dredge (2018)	QSC density (n 100 m^{-2}) [t,r]	6	-1.48	0.19
	SCE density (n 100 m^{-2}) [t,r]	6	-1.05	0.33

[t] Two sample t-test
[p] Permutational multivariate analysis of variance
[r] Square-root transformed

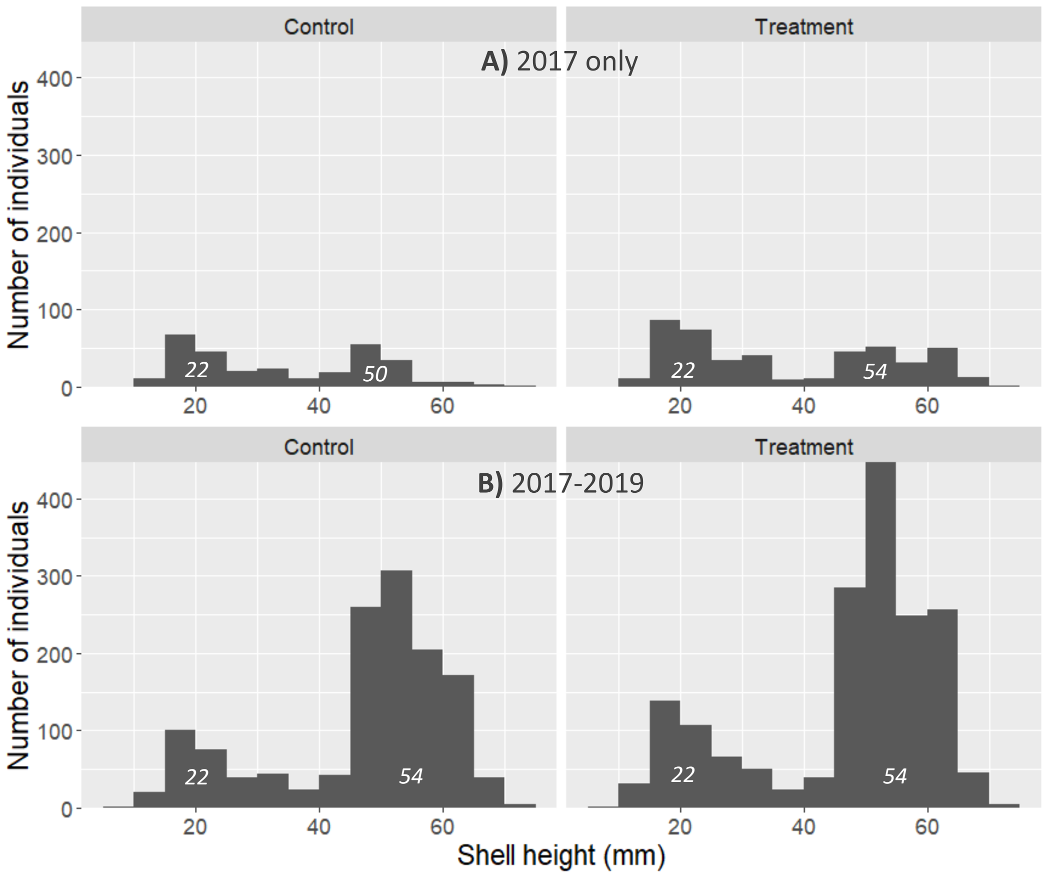

Figure 4. *Size distributions of queen scallops caught in the proposed "treatment" and "control" areas of EDG ERA during beam trawl surveys (A: 2017 only; B: 2017-2019). Median shell heights of size cohorts (<40 mm; ≥40 mm) indicated in white.*

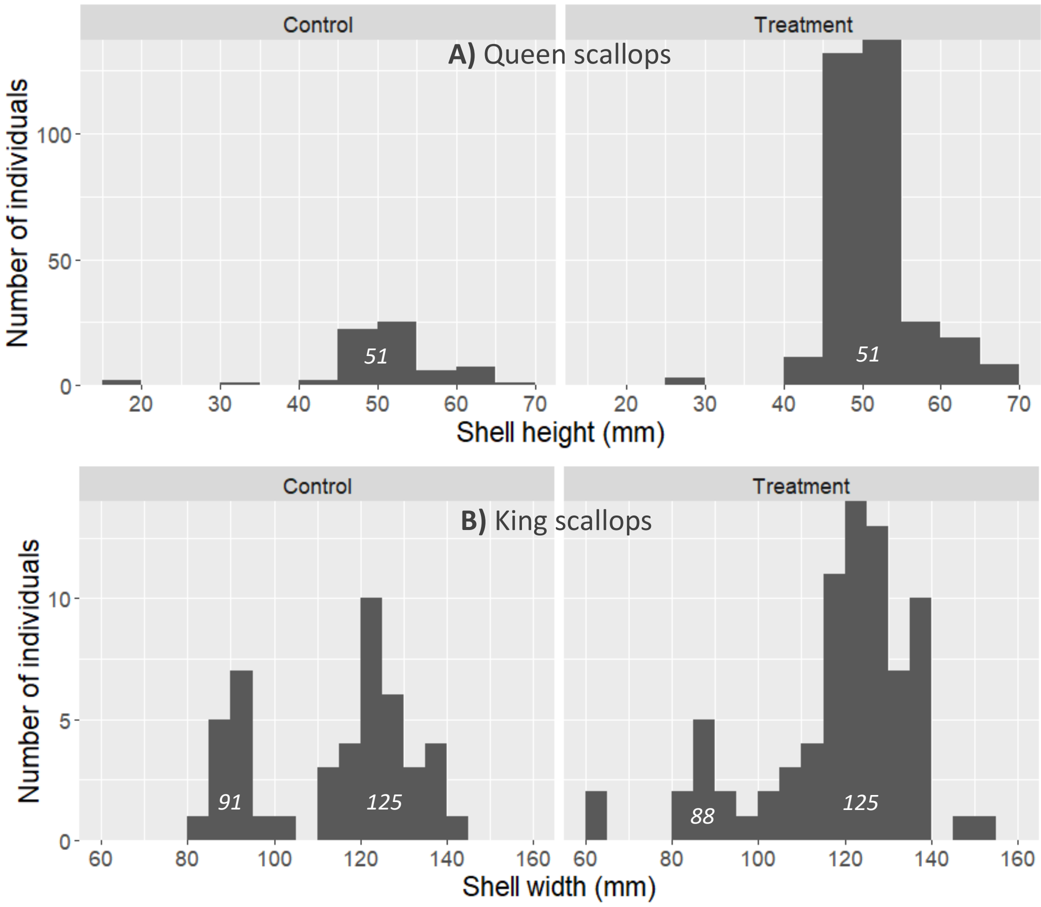

Figure 5. *Size distributions of scallops (A: queens; B: kings) caught in the proposed "treatment" and "control" areas of EDG ERA during the baseline dredge survey (October 2018). Median shell heights of size cohorts indicated in white.*

3.2 | Temporal Analysis

With no significant differences between "treatment" and "control" areas, fisheries survey catch data from EDG ERA was examined as a whole across the three-year closure. Temporal changes in scallop density by area are available in the Appendix (Figure B-C).

There was a marginally significant ($p = 0.05$) increase in queen scallop density from beam trawl surveys over the three years (Figure 6A, Table 2), averaging at 14 ± 2 scallops per 100m^2 in 2017, 17 ± 3 in 2018, and 26 ± 5 in 2019. Mean queen scallop density in dredge surveys nearly doubled from 1.8 per 100m^2 in 2018 to 3.4 in 2019, however this was not significant due to large variation (Figure 6B, Table 2). King scallop densities remained low and did not change significantly from 2018 to 2019 (Figure 6C, Table 2).

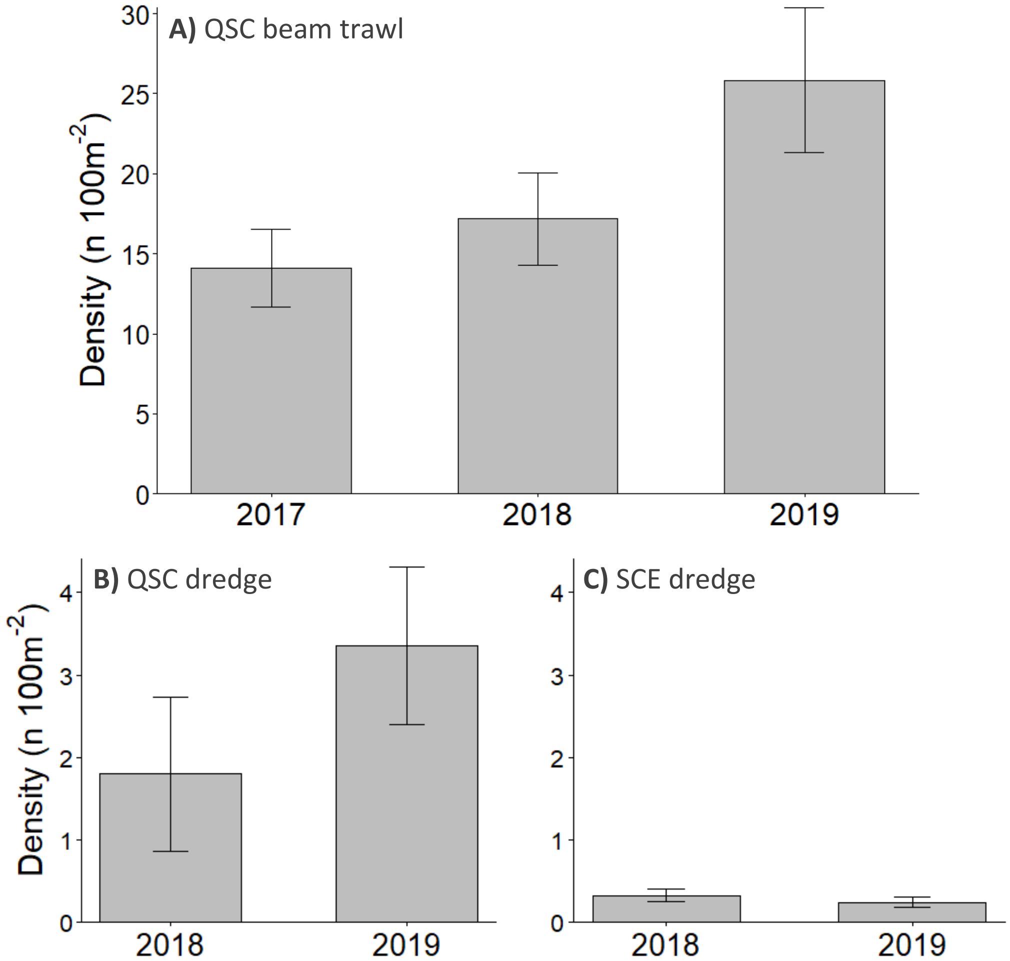

Figure 6. *Mean (± S.E.) scallop densities in EDG ERA from beam trawl and dredge surveys in October 2017, October 2018 and November 2019. QSC = queen scallops; SCE = king scallops.*

Table 2. *Testing temporal changes in EDG ERA using beam trawl (2017-2019) and dredge (2018-2019) survey data. QSC = queen scallop; SCE = king scallop; d.f. = degrees of freedom; t.s. = test statistic; p = significance. Significant results underlined.*

Response variable		*d.f.*	Year *t.s.*	Year *p*
Beam trawl	QSC density (n 100 m^{-2}) [a,r]	2, 44	3.14	0.05
	Bycatch community composition [p]	2, 41	1.89	<u>0.02</u>
	Bycatch density (n 100 m^{-2}) [a,r]	2, 41	0.16	0.85
	Bycatch species richness [a]	2, 41	23.6	<u><0.001</u>
	Bycatch diversity (H') [a]	2, 41	13.5	<u><0.001</u>
Dredge	QSC density (n 100 m^{-2}) [a,r]	1, 14	2.16	0.16
	SCE density (n 100 m^{-2}) [a]	1, 14	0.66	0.43

[a] One-way analysis of variance
[p] Permutational multivariate analysis of variance
[r] Square-root transformed

In beam trawl tows, queen scallop sizes ranged from 8 to 74 mm (shell height) and were distributed between two size cohorts (<40 mm; ≥40 mm) (Figure 7). Although these cohorts were consistent across years, the median size and abundance of scallops in each cohort varied (Figure 7, Table 3). During the three-year closure, mean size increased from 33 to 58 mm, and the proportion of large individuals (≥40 mm) increased from 43 to 88%.

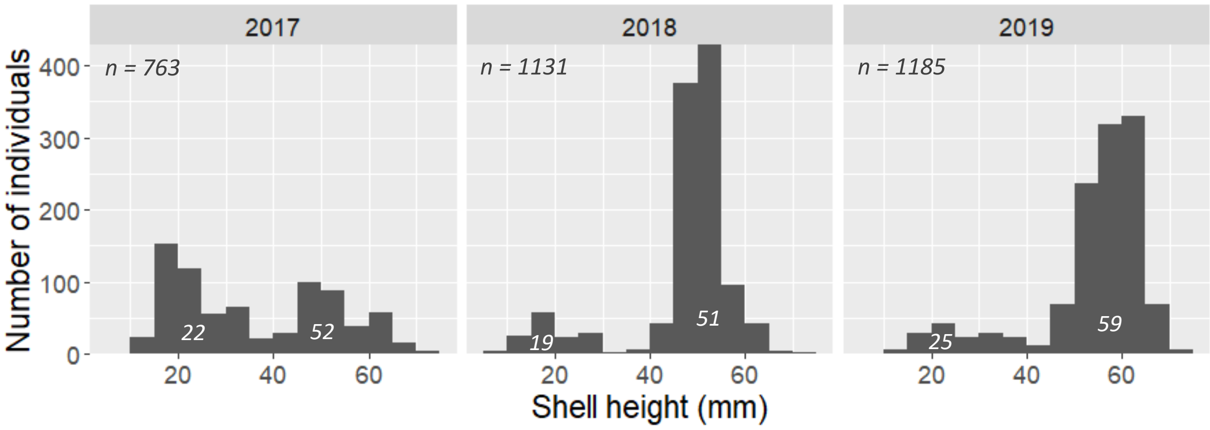

Figure 7. *Size distributions of queen scallops in EDG ERA from beam trawl surveys in October 2017, October 2018 and November 2019. Median shell heights of size cohorts indicated in white. n = number of individuals.*

Queen scallops in dredge catches increased in mean size from 52 to 59 mm (shell height), corresponding to the larger size cohort in the beam trawl data. Individuals in the smaller cohort (<40 mm) are not generally picked up by dredges. The mean size of king scallops decreased slightly from 118 to 115 mm (shell width). Baseline dredge data from 2018 displayed two size cohorts in the king scallop population (≤100 mm; >100 mm), however this was not the case in 2019 (Figure 8). King scallop ages ranged from 1^+ to 10^+ and did not change considerably from 2018 to 2019 (Figure 9, Table 3).

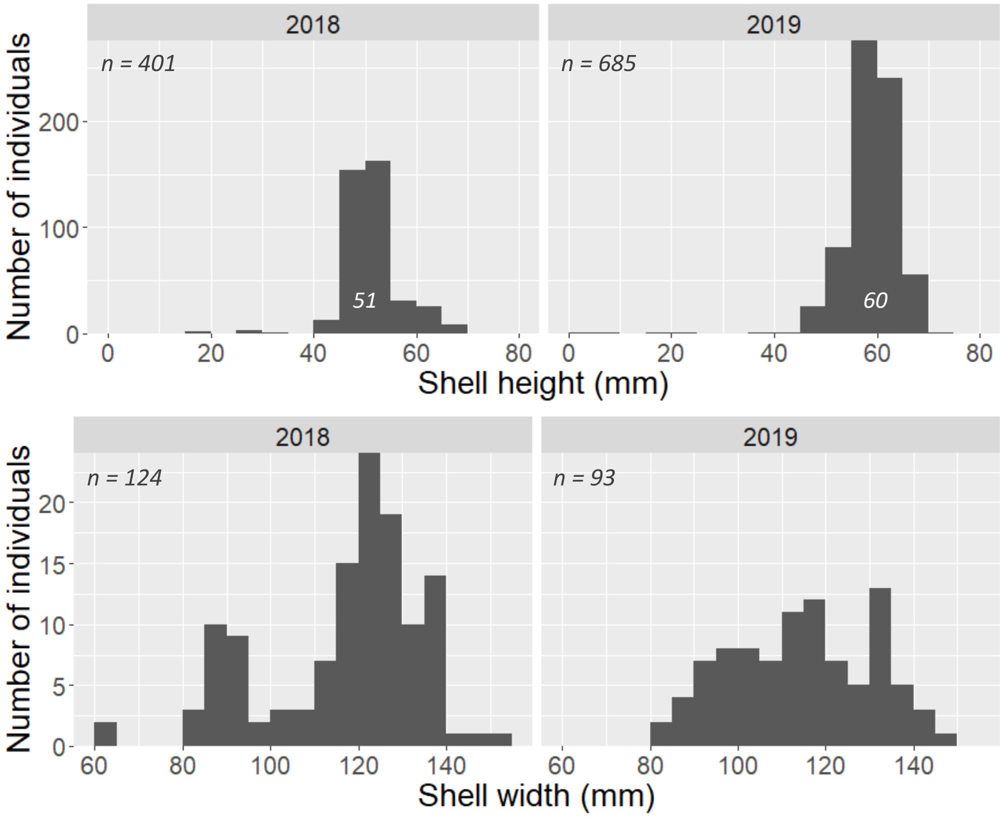

Figure 8. *Size distributions of scallops (top: queens; bottom: kings) in EDG ERA from dredge surveys in October 2018 and November 2019. Median shell heights for queen scallops indicated in white (single size cohort). Median shell widths for king scallops not indicated as size cohorts were not consistent across years. n = number of individuals.*

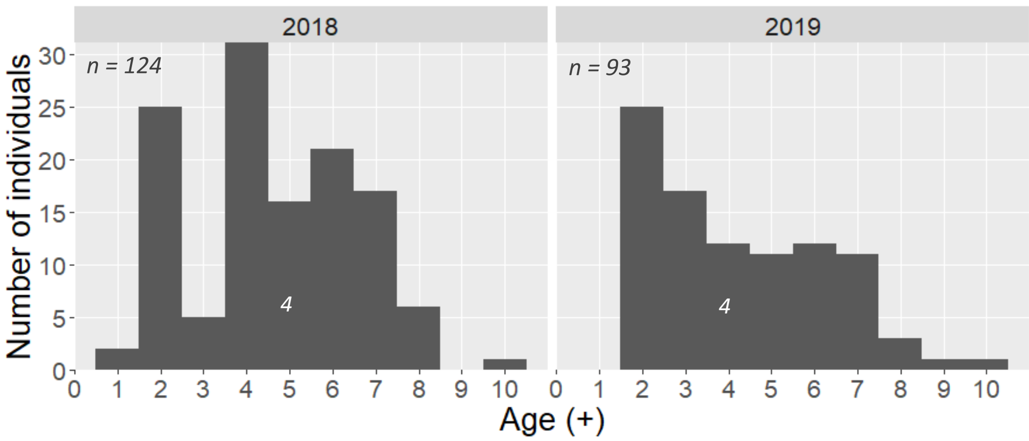

Figure 9. *Age distributions of king scallops in EDG ERA from dredge surveys in October 2018 and November 2019. Median ages indicated in white. n = number of individuals.*

Table 3. *Examining scallop data from beam trawl and dredge surveys during the three-year experimental closure of EDG ERA. QSC = queen scallop; SCE = king scallop. Cohort 1: <40 mm; cohort 2: ≥40 mm.*

Response variable		**2017**	**2018**	**2019**
Beam trawl	QSC mean size (mm)	33	51	58
	QSC cohort 1 median size (mm)	22	19	25
	QSC cohort 2 median size (mm)	52	51	59
	QSC cohort 1 abundance (count)	432	142	142
	QSC cohort 2 abundance (count)	331	989	1043
Dredge	QSC mean size (mm)	–	52	59
	SCE mean size (mm)	–	118	115
	SCE mean age (+)	–	4.6	4.3

Bycatch community composition (beam trawl) significantly varied between years, with increases in species richness and diversity (Figure 10B-C, Table 2). However the total abundance of bycatch did not change over time (Figure 10A), and was generally dominated by common species, which were collectively responsible for ~90% of bycatch abundance (Table 4).

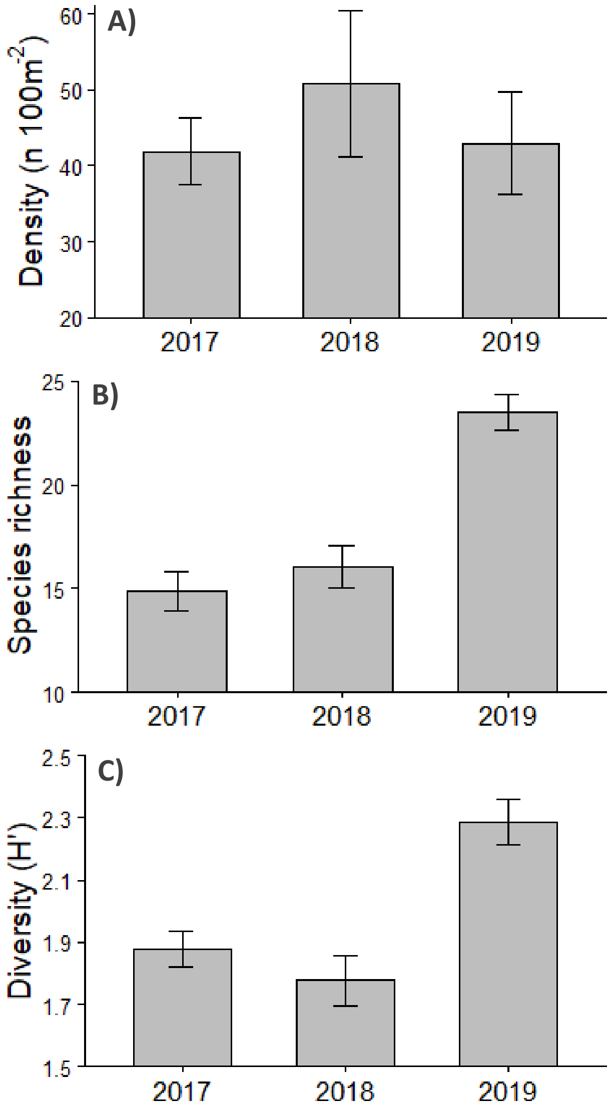

Figure 10. *Comparison of bycatch community metrics (mean ± S.E) from beam trawl surveys in EDG ERA in October 2017, October 2018 and November 2019. A: total abundance/density; B: species count; C: Shannon's diversity.*

Table 4. *Relative abundances of the most common bycatch species in EDG ERA from beam trawl surveys in October 2017, October 2018 and November 2019.*

Species	Mean density (n 100m^{-2})			
	2017	**2018**	**2019**	**Total**
Serpent star (*Ophiura ophiura*)	12.5	6.6	7.8	26.9
Green sea urchin (*Psammechinus miliaris*)	4.6	13.4	7.1	25.1
Common brittle star (*Ophiothrix fragilis*)	4.4	11.1	6.1	21.6
Cloaked hermit crab (*Pagurus prideaux*)	5.6	6.9	4.0	16.5
Common starfish (*Asterias rubens*)	3.2	1.2	1.5	5.9
Serpent's table brittle star (*Ophiura albida*)	-	2.8	2.9	5.7
Spider crab (*Inachus* spp.)	2.2	0.2	1.1	3.5
Dead man's fingers (*Alcyonium digitatum*)	0.1	1.8	1.4	3.3
Common dragonet (*Callionymus lyra*)	1.5	0.9	0.8	3.2
Long-legged spider crab (*Macropodia* sp.)	0.4	0.9	1.9	3.2
Black brittle star (*Ophiocomina nigra*)	1.4	0.2	1.1	2.7
Sea squirt (*Ciona intestinalis*)	1.4	0.2	1.1	2.7
Hermit crab (*Pagurus bernhardus*)	0.6	0.9	0.5	2.0
Common whelk (*Buccinum undatum*)	0.9	0.2	0.4	1.5
Sand star (*Astropecten irregularis*)	0.7	0.3	0.3	1.3
Solenette (*Buglossidium luteum*)	0.5	0.5	0.2	1.2
Harbour crab (*Liocarcinus depurator*)	0.3	0.2	0.5	1.0

3.3 | Drop-Down Camera

Three broad substrate types were classified from the drop-down camera footage: gravelly sand, mixed sand and clean sand (Appendix, Figure D). Stations classed as gravelly sand contained the highest mean density of queen scallops (Figure 11), however this was not statistically significant ($F_{(2,7)}$ = 1.48, p = 0.29).

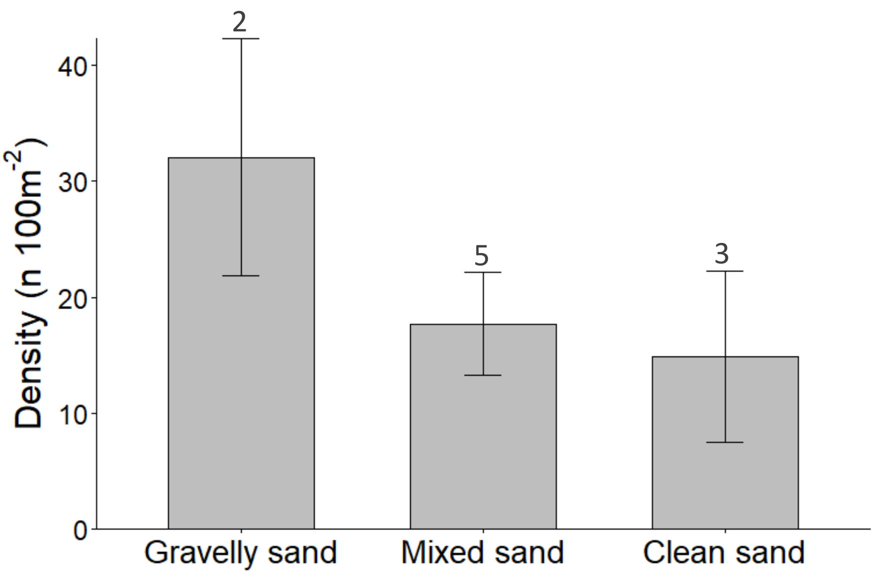

Figure 11. *Mean (± S.E.) density of queen scallops by sediment type, calculated using 2018 beam trawl data for corresponding survey stations. Number of stations in each category noted above error bars.*

4 | Conclusion and Future Work

During the three-year closure of EDG ERA, there were natural improvements in queen scallop abundance and size, and the diversity of bycatch species, with no intereference. 2017 was a strong recruitment year for queen scallops, with 57% of individuals below 40 mm in shell height (beam trawl survey). While 2018 and 2019 saw fewer smalls coming in, the total abundance of large queenies (≥ 40 mm) increased 3-fold in the absence of fishing. Additionally, the percentage of queenies above minimum landing size (≥ 55 mm) increased over the three-year period from 16 to 65% for beam trawl surveys, and from 21 to 87% for dredge surveys.

Although there were clear improvements in the area overall, there was also large spatial variation between individual catches (responsible for large error in mean scallop densities), and this could be due to variation in seabed substrate. Although it was not significant, there was a trend towards gravelly areas containing greater queen scallop abundance. Currently we only have habitat information for 10 stations (13%) in EDG ERA; further drop-down camera work should be completed to build up a complete record of the distribution of substrate types in the area.

The spat receptor design that was trialed in 2019 proved successful in collecting good numbers of queen scallop spat, however there were deployment/enforcement issues that need to be resolved. All four receptors that were deployed in EDG ERA have now been lost despite robust mooring. One was dredged up during the survey in November 2019, and examination showed the mooring rope had apparently been cut. It is hoped that, with revision, a full spat receptor deployment programme may further enhance scallop recruitment in the area and potentially increase recovery rates.

EDG ERA has now been closed for nearly three years and therefore will be under review by DEFA, who will decide whether to continue the experimental closure and spat receptor work or to reopen the area for the queen scallop season in July 2020.

5 | References

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6 | Appendix

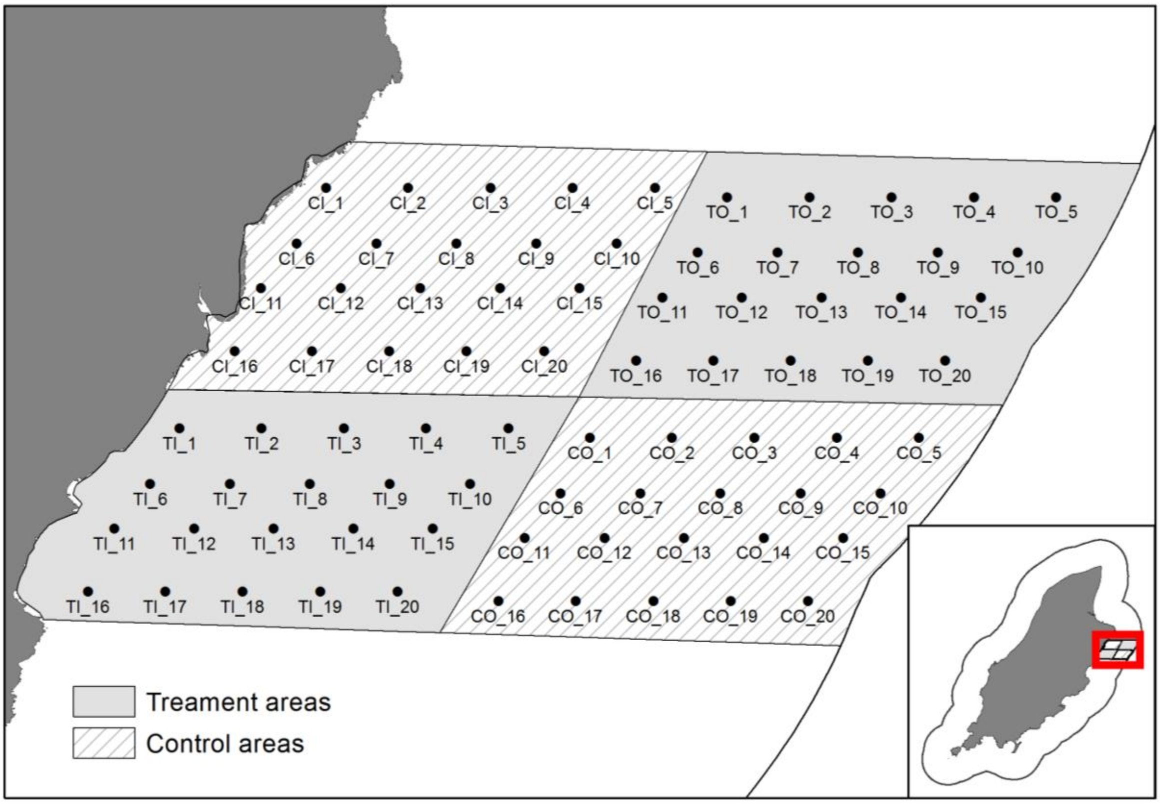

Figure A. *EDG ERA survey station names. T = Treatment; C = Control; I = Inshore; O = Offshore.*

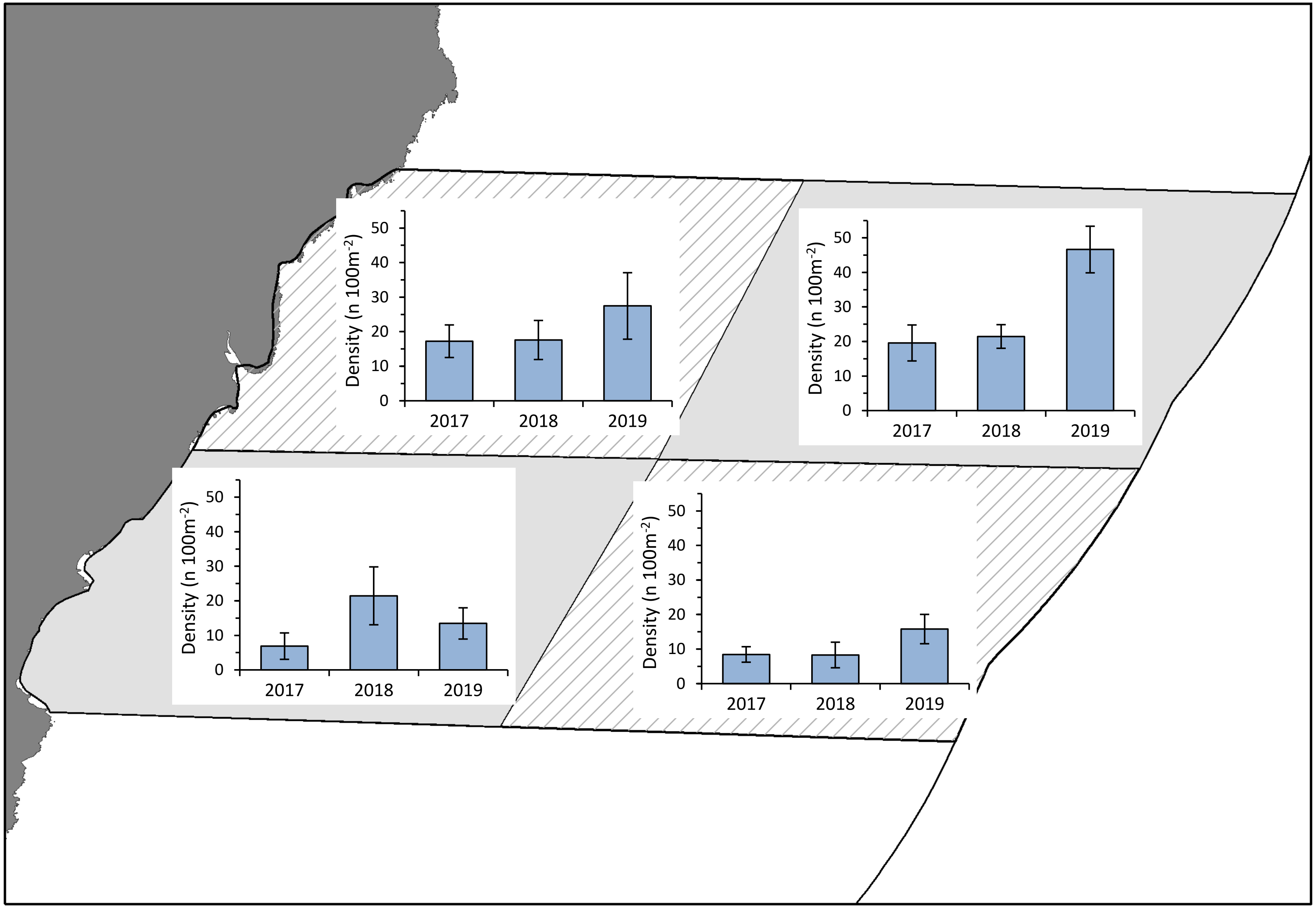

Figure B. *Temporal changes in queen scallop density (mean ± S.E.) by area in EDG ERA, from beam trawl surveys in October 2017, October 2018 and November 2019.*

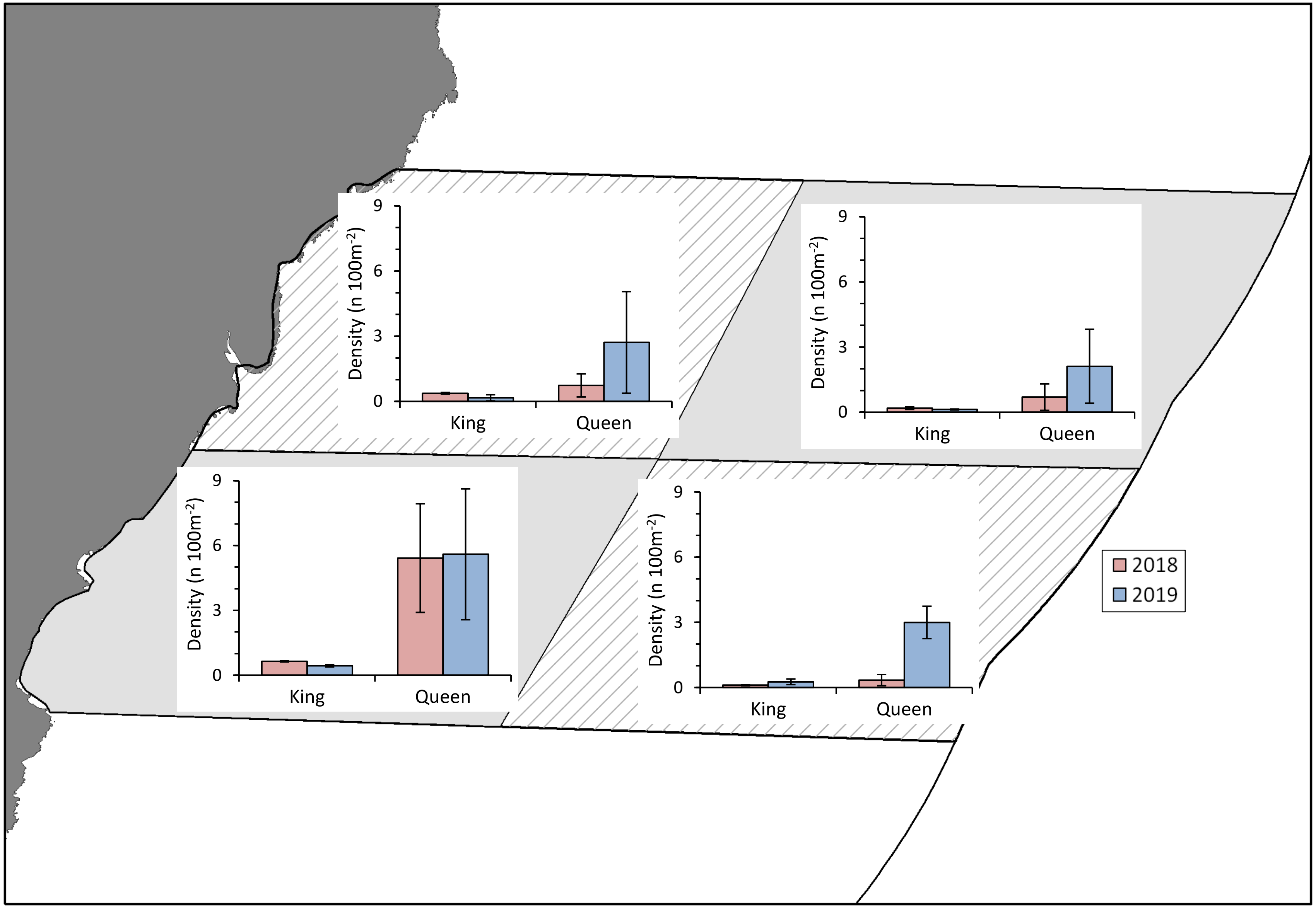

Figure C. *Temporal changes in king and queen scallop densities (mean ± S.E.) by area in EDG ERA, from dredge surveys in October 2018 and November 2019.*

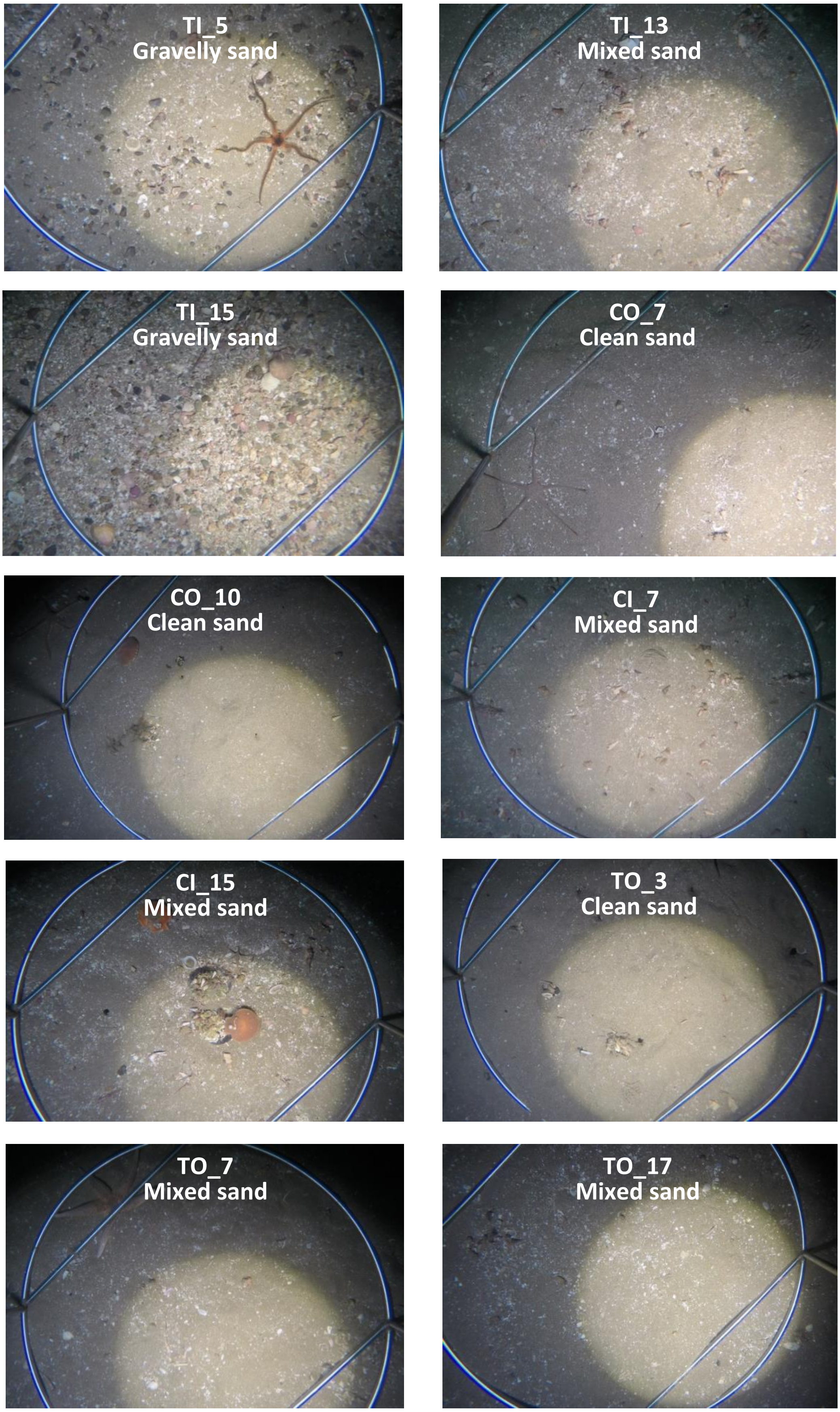

Figure D. *Sediment types qualitatively classified at the 10 survey stations that were sampled during the drop-down camera survey in October 2018.*