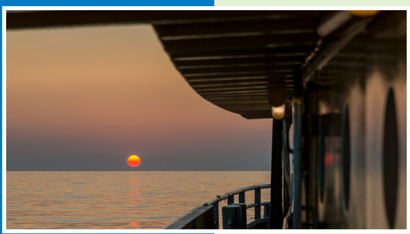
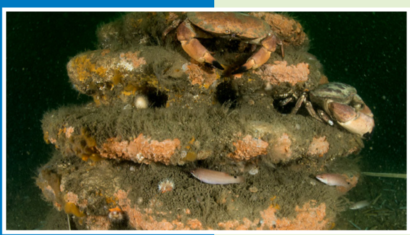
WWF & ARK Nature Borkum Reef Ground oyster pilot

Active restoration of native oysters in the North Sea

Monitoring september 2020





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Status: final

Report nr:	21-029
Project nr:	20-0101
Date of publication:	08 February 2021
Photo credits cover page:	U. van Dongen / Bureau Waardenburg
Name client:	WWF
Qualitiy control:	K. Didderen
Signed for publication:	W. Lengkeek
Signature:	

Please quote as: Kardinaal, W.E.A., J.H. Bergsma, L.J.G.M. van Dongen & F.M.F. Driessen, 2020. WWF & ARK Nature Borkum Reef Ground oyster pilot. Active restoration of native oysters in the North Sea - Monitoring September 2020. Bureau Waardenburg Report no. 21-209. Bureau Waardenburg, Culemborg.

Keywords: North Sea, flat oyster, *Ostrea edulis*, reef restoration.
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Preface

As a result of overfishing, habitat destruction and diseases, shellfish reefs, once occupying about 30% of the Dutch part of the North Sea, almost entirely disappeared.

Since natural recovery seems impossible within decades, World Wide Fund for Nature (WWF) and ARK Nature, in collaboration with Bureau Waardenburg, Wageningen Marine Research and Sas Consultancy, have been working in recent years on recovery opportunities for shellfish reefs in the Dutch coastal zone (Voordelta) and off shore (Borkum Reef Ground, Gemini wind farm and on wreck M435). Within the Borkum Reef area in 2018 the first attempt to actively restore shellfish reefs in deeper parts of the North Sea was conducted. Since then the reef ground has been monitored on a yearly basis. In September 2020 the third expedition to Borkum Reef Ground was organized for studying the current state of the oysters and the progress of the reef bed formation.
This study was initiated and commissioned by WWF Netherlands. We would like to express our special thanks to Get Wet Maritime (Ben Stiefelhagen), the crew of the MS Tender and other crewmembers, Melchior Stiefelhagen, Maarten Slooves and Klaudie Bartelink, WWF representatives Brenda van Doorn-Deden and Emilie Reuchlin-Hugenholtz and our Bureau Waardenburg colleagues Udo van Dongen, Wouter Lengkeek, Karin Didderen and WMR colleague Pauline Kamermans.

Content

1 Introduction

1.1 General background

From historical documentation, we know that epibenthic shellfish reefs, consisting mainly of flat oysters (*Ostrea edulis*), once occupied about 30% of the Dutch part of the North Sea seafloor (e.g. Olsen 1883). Recently, scientist and practitioners throughout Europe have been focusing on the endangered status of *O. edulis* habitats, and there is scope for restoration (Airoldi and Beck, 2007; Farinas-Franko *et al*. 2018; Gercken and Schmidt, 2014; Sawusdee *et al*., 2015; Smaal *et al*., 2015; Smyth *et al*., 2018). Moreover, *O. edulis* reefs are now identified as a priority marine habitat for protection in European MPAs (OSPAR agreement 2008-6, OSPAR Commission, 2011).

In the Netherlands feasibility of the recovery of epibenthic shellfish reefs is estimated as feasible (Smaal *et al*., 2015). The time for restoration of epibenthic shellfish reefs is right and shellfish reef restoration in the North Sea area is now supported by current Dutch and EU government policy, among others through the Marine Framework Directive, for the Dutch North Sea area implemented by the Marine Strategy policy paper, part 3 (Marine Strategy, 2015).

Based on the first findings of natural flat oyster reefs (Christianen *et al*., 2018; van der Have *et al*., 2016) and experiences with epibenthic shellfish reef restoration in the Voordelta, knowledge is being developed for near shore flat oyster reefs (Sas *et al.,* 2017; 2018, Christianen *et al*., 2018).

Connecting projects to this research are the Revifes and Ecofriend research programs. In Revifes, at the Borkum Reef Ground site, research is being done on ecosystem services of naturally occurring reef systems such as stones and *Lanice* (sand mason worm) reefs. The focus of Ecofriend is on reproduction of oysters. To this end, samples were taken and analyzed on site in July 2020.

1.2 WWF & ARK Borkum Reef Ground oyster pilot

The Borkum Reef Ground pilot is the first example of restoration of shellfish reefs in deeper parts of the North Sea. As a first pilot location for offshore flat oyster restoration efforts, the Borkum Reef Ground area was selected, because of the natural presence of hard substrate. Didderen *et al.* (2019) described the results of the first year of monitoring including detailed information on the pilot design and two field reports of two field trips - installation and first monitoring. This report is the follow-up and contains the results of the third field trip in September 2020.

1.3 Objectives

The pilot project, initiated in May 2018, focused on the possibilities for restoration of shellfish reefs in the deeper parts of the North Sea. Main objectives of the project were:

- starting shellfish reefs in deeper parts of the North Sea;
- investigate the key factors for success and failure for active restoration of structure-forming shellfish reefs in deeper parts of the North Sea.

1.4 Reading this field report

This report contains results of monitoring the pilot 28 months after deployment. This third monitoring campaign took place 22-23 September 2020.

2 Methods

Table 2.1 *Overview of all intended monitoring activities. This table is derived from Didderen et al., 2019 where all specific research questions are further elaborated. Thenumbers in the first column correspond with the paragraphs (§) in Chapter 3 where these activities are addressed.*

§	**Monitoring activities**	**Trip 5: Sept 2020**	**Research questions**	**Common**	**Diagnostic**	**Ecosystem**
	Dropcam survey		1-3, 6, 10	X		X
	Temperature measurements		8		X	X
3.2	Oyster measurements:	X	3-10	X		
	Wet weight measurement	X		X		
	Length measurement	X		X		
	Condition assessment				X	
	Gonad development				X	
	DW determining				X	
	Presence of Bonamia				X	
3.1	Visual observation of survival	X	1, 4	X		
3.3	Visual observation of present life forms	X	1, 2, 5, 6	X	X	X
3.4	Visual observation of rack & 3D structure damage	X	9 - 11			
3.5	Visual observation of biofouling and predators	X	9 - 11		X	X
	Visual observation of spat settlement	X	3, 4, 5, 6, 7	X		
3.6	Visual observation of oyster bed development	X	1, 2	X		
10	Larvae sampling & counting		3, 8-10		X	
11	Spat collector		4, 5, 6, 7	X		

2.1 Preparations

Mobilisation

The offshore research team and their equipment were mobilized on September 21st at the Lauwersoog harbour to spend two days at sea onboard of the MS Tender. The research period for the Borkum Reef oyster project was 22 - 23 September. A RHIB was used to bring the divers from the main ship (MS Tender) to the study area (Figure 2.1&Figure 2.2).

Briefing and safety

Onboard of the MS Tender a full briefing was held with the entire research team. In this briefing, everyone was updated on the project goals and instructed on their specific task during diving operations and on-board operations. A full safety briefing and Last-Minute Risk Analysis where also conducted. It was checked that all safety measures (e.g. decompression chamber, medical equipment, communications equipment, safety diver) was operational and had a designated operator.

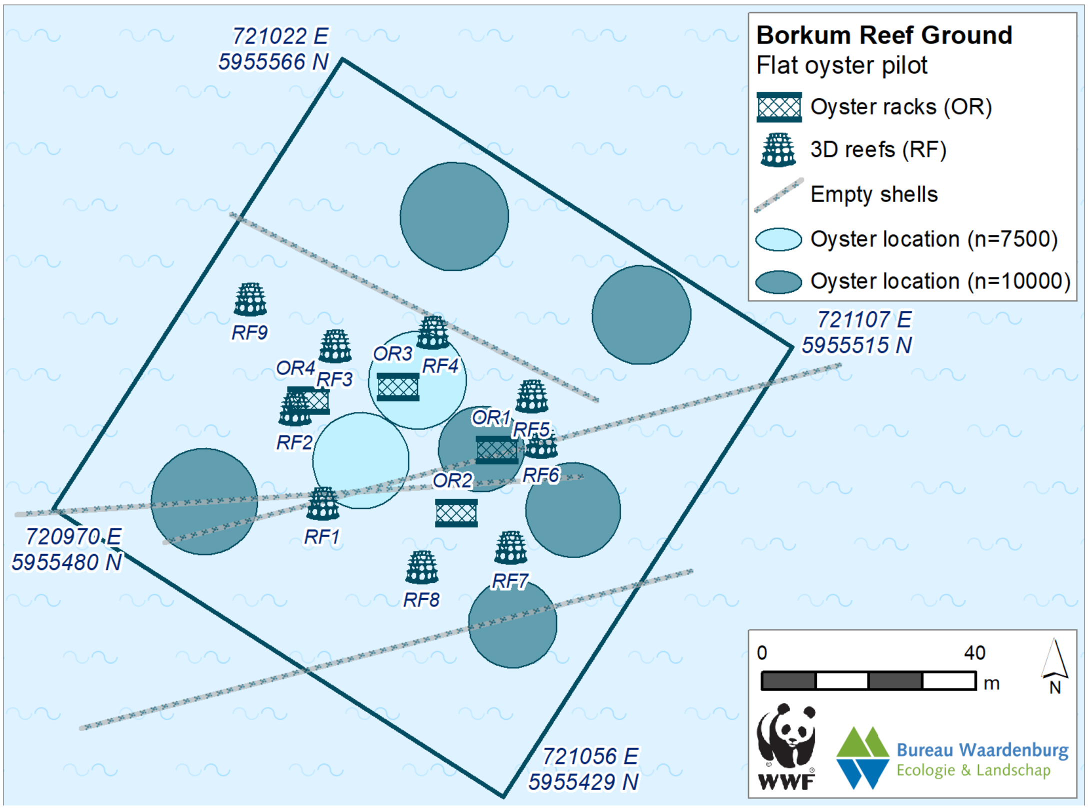

Figure 2.1 Pilot lay out, 9 3D reefs, 4 monitoring racks and 8 patches of oysters were installed on 24 and 25 May 2018.

Diving

Three research dives were made in optimal diving weather conditions on 22 and 23 September 2020. The slack water was short because of spring tide (23-09-2020). Dive times were 48, 52 and 51 min respectively. Diving depth was 26,4 meters. A nitrox

breathing gas and the NOAA diving tables were used. Dive times were all well within the no-decompression limits.
Near bottom the current was quite strong (approaching 0,5 knots) and visibility ranged between 0,5 and 2 meters.

Figure 2.2 Divers making ready for their dive to lift baskets, on board of the RHIB.

2.2 Activities

The monitoring activities of this expedition included:
1. Research racks (2 and 4): retrieval of baskets with oysters for wet weight and length measurements and spat settlement;
2. Dive transects (UVS) for visual observations of oyster density and survival; present life forms / biodiversity; rack & 3D structure condition; marine growth and predators; recruitment / spat settlement; oyster bed development.
3. Replacement of tools: acoustic release as aid for future positioning and a new CTD logger.

Top priority was tracking down rack number 4 (Figure 2.3), because this was the only rack that had not been monitored yet since out placement in May 2018.
Other priority during diving was finding recruits on the seabed during the observations of the transects, as no other (remote sensing) technique is really suitable for finding recruits.

Figure 2.3 *Oyster baskets from rack 4 on deck.*

2.3 Research racks

Acoustic release mechanism

In September 2020, one rack was equipped with acoustic releases (rack 1). Unfortunately, the acoustic release did not work, due to low battery. Therefore, we sailed over the coordinates of rack 4 and deployed a small anchor with a buoy. Thereafter, two divers located two racks (4 and 2) and three of the artificial structures and connected them with a guideline for further orientation. The divers attached a new and clean acoustic release (Frequency 100.1) to rack 4.

Retrieving oyster baskets

Each research rack contained four oyster baskets. The racks can be opened under water. The baskets where retrieved by two divers: packed in a large net and sent to the surface by means of a lifting bag. The net with baskets was then picked up by a small RHIB and transported to the main vessel after the divers finished their dive.

Temperature data

No temperature loggers were retrieved, as rack 3 could not be located. A new logger (CTD) was placed at rack 2 on the central pole.

Oyster survival, length and wet weight

At installation in 2018, each research rack contained 4 baskets with 40 oysters (Table 2.2). Oyster baskets contained different subgroups including “holding tower”, “small” and “large”. (Holding tower: in two baskets per rack the oysters are placed in specific small mounting, enabling monitoring of identified individuals).

Table 2.2 Number of oysters per research rack and basket at time of installation.

Rack number	Basket number	Number of oysters	Comments	Min shell width (mm)	Max shell width (mm)
1	28	40	small	52.1	88.5
Position C3	8	40	holding tower	59.8	88.2
	10	40	holding tower	62.9	92.8
	17	40	large	68.6	111.1
2	21	40	small	40.0	76.3
Position C4	11	40	holding tower	64.2	95.4
	6	40	holding tower	64.5	93.0
	16	40	large	53.5	98.0
3	23	40	small	47.9	76.7
Position C2	3	40	holding tower	62.4	93.7
	12	40	holding tower	56.5	85.9
	25	40	large	71.1	106.1
4	1	40	holding tower	59.3	92.0
Postion C1	5	40	holding tower	64.5	87.2
	24	40	small	45.6	75.0
	32	40	large	73.2	106.1

On September 22th, 2020, research racks 2 and 4 were localised and oyster baskets taken out and brought up to the vessel. All oysters from each rack were handled. As rack 2 was already studied in July 2018, and dead animals were removed from the set-up, the number of oysters per basket was lower than the initial 40 as placed in the racks back in May 2018. Per basket the live and dead oysters were separated, oysters were numbered, biodiversity attached was registered, pictures were made of the retrieval and the percentage survival was established (Figure 2.4). All dead oysters within the baskets of rack 2 were collected and deployed in basket number 16 in order to serve as potential substrate for oyster larvae in the future.

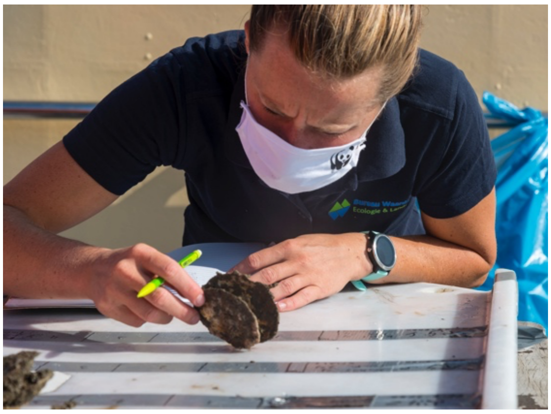

Figure 2.4 Left: Studying biodiversity attached to the baskets and oyster shells. Right: Measuring length, weighing oysters after removal of the attached species.

The live oysters were cleaned from marine growth, weighed (wet weight in gram), measured (shell width in mm) and replaced in their original baskets. Values for wet weight and shell width were compared with initial values obtained in May 2018 and values obtained in September 2020.

Figure 2.5 *Upper: Alive (numbers 1-17) and dead flat oysters of basket 21 (rack 2). After photographing, dead oysters were removed and collected in basket 16 (rack 2). Lower: Alive and dead flat oysters (unsorted) of basket 1 (Holding tower) (rack 4). After photographing, dead oysters were removed, alive oysters were cleaned, measured and weighted.*

Recruitment

No new recruits had settled on live adult oysters. During the three dives no recruits were found on the seabed either. In contrast to earlier expeditions this time local circumstances did not allow to reserve an explicit diving time frame for finding recruits. The search for recruits this year was limited to the search patterns for the racks as illustrated in Figure 2.6.

2.4 Dive Transects UVS

Visual observation measurements were performed on dive 2 and 3 on 22 September. The blue lines in Figure 2.6 depict the different transects that where studied in the pilot area, each dive with two divers doing different measurement per transect.

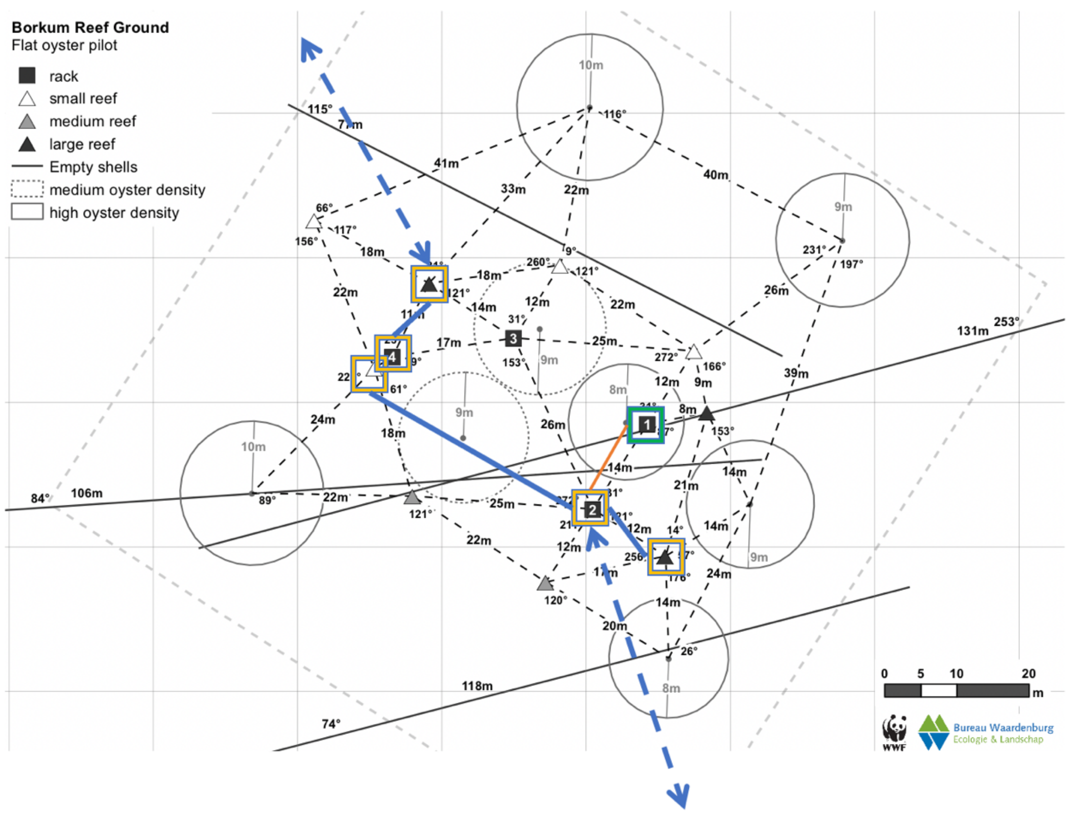

Figure 2.6 *Different dive transects (blue lines) followed in the pilot area on 22 September 2020. Blue lines depict the set-out guideline (transect line) along which the UVS were performed and photos were taken. Orange squares are researched objects. Blue dotted lines depict enter and exit points of the divers. The Orange line depicts an additional transect on dive 3 to retrieve the old acoustic release.*

During dives the following data were retrieved:

- Pilot: Visual observation position and condition of infrastructure, including research racks, 3D-reefs and loose shell material;
- Oysters: Visual observations survival, density and growth of adult oysters, presence of recruits, 5 individuals were additionally collected;
- Risks: Visual observations for predators and other risks to oysters;
- Biodiversity: Visual observations of biodiversity on seabed and 3D reef structures.

Oyster and predator density transects were carried out by following a transect line including a width of 2 meter for visual census. Each 5 meter (translating to 10 m^2) the number of oysters and predators was recorded. Oysters were classed as dead or alive based on visibly wide-open shells when oysters are dead and visible filtering activity from live oysters.

Biodiversity on reef structures was quantified by using a 20x30cm quadrant randomly placed horizontally and vertically on the structures. In each quadrant, all visible species were recorded and named (to the highest taxonomic level of which our taxonomic specialist diver could be certain under water) and their density counted or estimated. This was repeated 8 times.

Additional species on the structures that were not present within the quadrants were also documented. Total biodiversity on the reefs was observed and recorded, in part by photo and video analysis, densities were not quantified. Furthermore, biodiversity found on the seabed along the transect lines was also registered. The length of transect lines was this year shorter in comparison to earlier years. On board, the search for additional fouling species was restricted to one expert, whereas in earlier expeditions at least 2 man focused on this aspect of the expedition.

3 Results

3.1 Oyster survival

Table 3.1 *Flat oyster survival rates in research racks (24 months for rack 2 July 2018 – Sep 20, 28 months for rack for rack 4 May 2018 – Sep 20).*

Rack	Basket	Oyster size	Number at start (May 2018)	Total abundant (Sept 2020)	Alive	Dead	Survival % Sept 2020
2	6	small	40	21	16	5	76
2	11	holding tower	40	16	13	3	81
2	16	holding tower	40	10	0	10	0
2	21	large	40	31	17	14	55
4	1	small	40	40	28	12	70
4	5	holding tower	40	40	27	13	68
4	24	holding tower	40	40	24	16	60
4	32	large	40	40	29	11	73

Oyster survival in racks

Flat oyster survival in rack 4 varied from 60 – 73 % after 28 months (Table 3.1). Minimum survival rate (60 and 68%) was observed for oysters that were placed in the holding towers (basket 5 and 24). This is similar to the observations in 2019, where the survival rates in baskets with holding towers were lower (Didderen *et al*. 2019. It can be assumed that the size of the oysters became too large for the holding towers, which highly likely confined them and therefore hampered them in their feeding / breathing behavior and caused mortality. The holding towers were during this expedition removed from the racks.

Rack 2 was surveyed earlier (July 2018), since al dead oysters were removed back then, the oysters left over were less than the initial 40 per basket (starting back in May 2018). In addition, in July 2018 oyster were partially harvested for fertility and condition index research. Survival of the remaining oysters varied from 0 – 81% after 28 months. In 2020 no oysters were collected for measuring the condition index. Like concluded in 2019 (Didderen *et al.*) survival of large oysters in both racks 2 and 4 was highest.

Figure 3.1 *Adult Flat oysters providing habitat for epifauna species groups (Anthozoa, Hydrozoa, Bryozoa) in sandy substrate with Laniche conchilega.*

3.2 Oyster width and wet weight

Oyster width and wet weight

In September 2020 in total 154 oysters originating from the oyster racks 2 and 4 were measured and weighted.

Flat oyster width in racks varied in September 2020 from 61 – 109 mm, with an average of 84 mm, the range in May 2018 was 40-106 mm (Table 3.2). In September 2020 the wet weight varied from 40-352 g, with an average of 156 g. In May 2018 wet weight varied from 10-287 g. Wet weight measurments are hard to compare since weighing onboard will be influenced by swell and wave-action, and the fouling of other organisms to the oyster shells. The values are indicative.

Table 3.2 Flat oyster length and wet weight in research racks.

Rack	Basket	May 2018 Width (mm) MIN	May 2018 Width (mm) MAX	May 2018 Width (mm) AVG	July 2018 Width (mm) MIN	July 2018 Width (mm) MAX	July2018 Width (mm) AVG	Sep 2020 Width (mm) MIN	Sep 2020 Width (mm) MAX	Sep 2020 Width (mm) AVG	Sept 2020 #oysters alive
2	21	40	76	60	47	82	65	61	90	84	16
2	11	64	95	78	72	89	80	80	92*	87*	13
2	6	65	93	78	68	95	81	x	x	x	0
2	16	54	98	79	61	104	84	76	89*	82*	17
4	1	59	92	79				65	92	78	28
4	5	65	87	77				63**	97	81	27
4	24	46	75	60				44**	88	69	24
4	32	73	106	87				79	109	93	29
						Total Sep 2020		61	109	81	154

Rack	Basket	May 2018 weight (g) MIN	May 2018 weight (g) MAX	May 2018 weight (g) AVG	July 2018 weight (g) MIN	July 2018 weight (g) MAX	July 2018 weight (g) AVG	Sep 2020 Wet weight (g) MIN	Sep 2020 Wet weight (g) MAX	Sep 2020 Wet weight (g) AVG	Sept 2020 #oysters alive
2	21	10	148	36	29	63	46	154	265	193	16
2	11	45	106	78	65	135	94	74	352	212	13
2	6	41	130	82	65	125	94	x	x	x	0
2	16	22	212	100	44	237	129	55	230*	128	17
4	1	37	112	67				44	172	113	28
4	5	26	116	67				50	147	107	27
4	24	9	56	29				40	160	107	24
4	32	32	287	147				88	342	230	29
						Total Sep 2020		40	352	156	154

** In July 2018 rack 2 has been lifted, oysters were measured and some were collected for Bonamia and condition research.*

*** In September 2020 the smallest oysters seem smaller than initially measured in 2018, probably a result of measurement inaccuracy.*

Oysters of the racks 2 and 4 were analyzed and compared to initial values (May 2018) (Figure 3.2). The average width of the oysters in rack 2 (mean ±SD) in 2020 increased around 10 mm in comparison to the initial average size (mean ± SD) in this rack. In rack 4 (mean ± SD) the average increase in size is around 5 mm when oysters of 2020 are compared to the initial sizes in 2018 (mean ± SD).

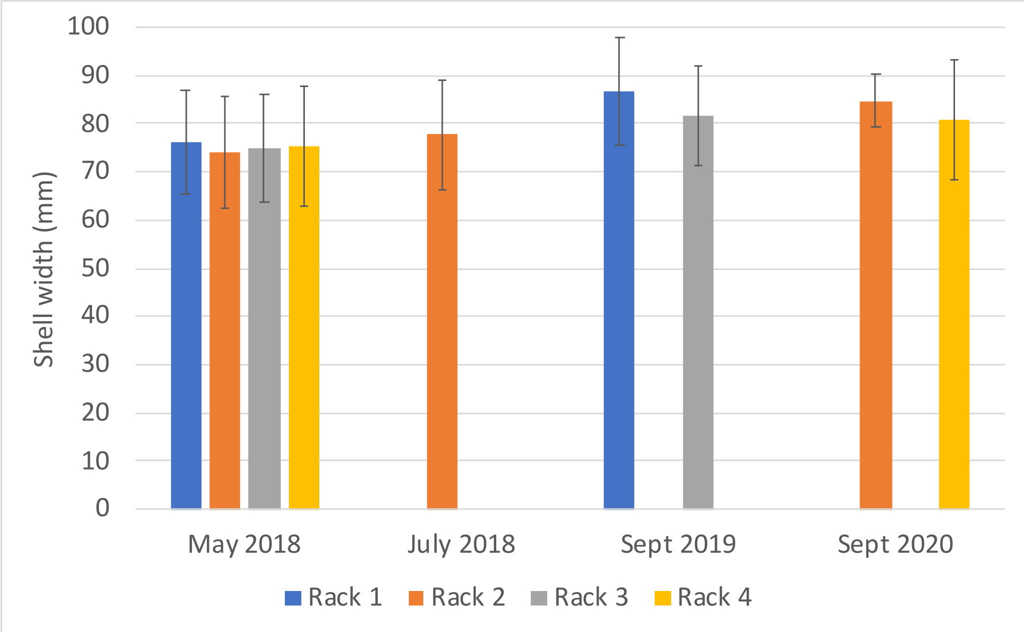

Figure 3.2 *Shell width in mm in initial subsamples (May 2018), rack 2 (July 2018), rack 1 and 3 (September 2019) and rack 2 and 4 (September 2020).*

3.3 Biodiversity

Seabed

The seabed consisted of sandy substrate, with patches of gravel, shell substrate, *Lanice* congregations and oysters. A total of 29 species (16 unique species for this monitoring) was observed on the sand (Table 3.3, Figure 3.4 and Appendix B).

Reefs, racks and flat oysters

Table 3.3 presents data from 8 quadrants in which biodiversity is quantified on the artificial 3D-reef structures (19 species). Substantial biodiversity was also observed on the baskets and flat oysters in the baskets, flat oysters on the seabed, 3D-reefs and research racks (Table 3.3, Appendix B). A total of 68 species were observed on these structures. Noteworthy were the substantial amounts of mobile species such as goldsinny wrasse, butterfish (Figure 3.2) and edible crab that were attracted by the reefs, and young recruits of the cold-water coral dead man's finger (Figure 3.4, Figure 3.5).

Figure 3.3 *Species found in research racks: Ctenolabrus rupestris (Gold sinny wrasse) (left) and Pholis gunnellus (butterfish) (right).*

Table 3.3 *Biodiversity and density of species in the pilot area presented as mean densities per square meter. Data retrieved from 8 quadrants of 20x30 cm.*

Species %	**Common name**	**Mean coverage %**
Porifera sp.		0,70
Electra pilosa		0,20
Escharoides coccinea		1,45
Obelia sp.		0,45
Jassa		2,67
Diplosoma sp.		1,58
Species n		**Mean coverage per m2**
Alcyonium digitatum	Dead mans finger	0,12
Diadumene cincta		0,06
Sagartia elegans	Elegant anemone	0,30
Sagartia troglodytes	Mud sagartia	0,42
Metridium dianthus	Plumose anemone	0,18
Halecium halecinum	Herring-bone hydroid	0,08
Polycera quadrlineata	Four-striped polycera	0,60
Macropodia sp.		0,12
Necora puber	Velvet crab	0,06
Cancer pagurus	Edible crab	0,06
Asterias rubens	Common sea star	0,06
Pholis gunnelus	Rock gunnel	0,06
Ctenolabrus rupestris	Gold sinny wrasse	0,09

A total of **84 species**, mainly mollusc and arthropods, were observed by the divers in the pilot area (Figure 3.4, Figure 3.5, Appendix B, combining seabed and reef, rack, flat oyster data). Traces (empty shells, nudibranch eggs, bones, dead animals) of 8 additional species were observed by the divers, these are not included in the species list. In 2019, only 42 species were reported. In September 2020 biodiversity was mainly studied on hard substrates (3D reef structures, species attached to flat oyster), while there was a focus on biodiversity measurements on the seabed in 2019. A total species list of the monitoring surveys (2019 and 2020) is presented in Appendix B.

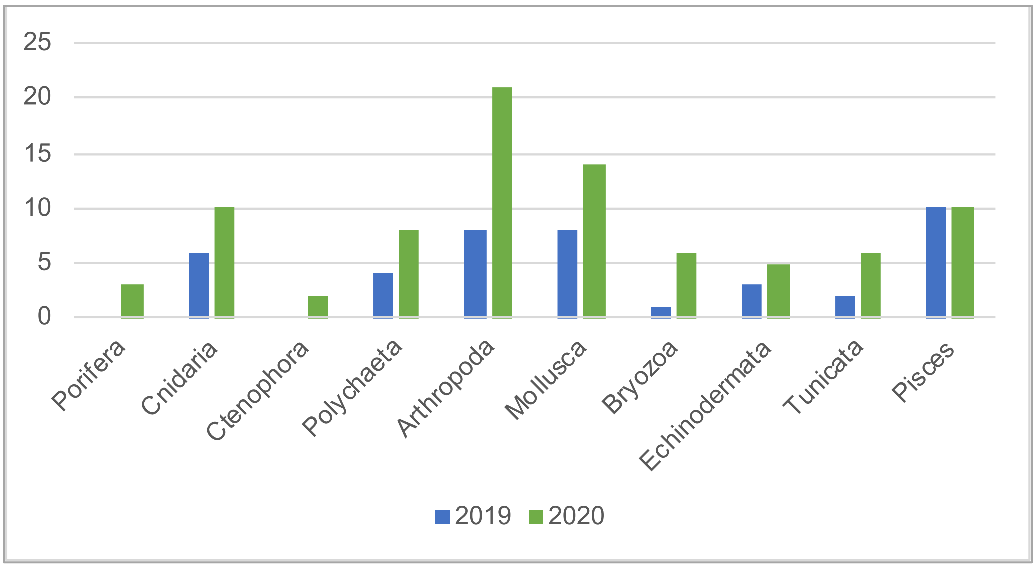

Figure 3.4 *Number of species per phylum found in monitoring surveys (September 2019, September 2020) in the pilot area.*

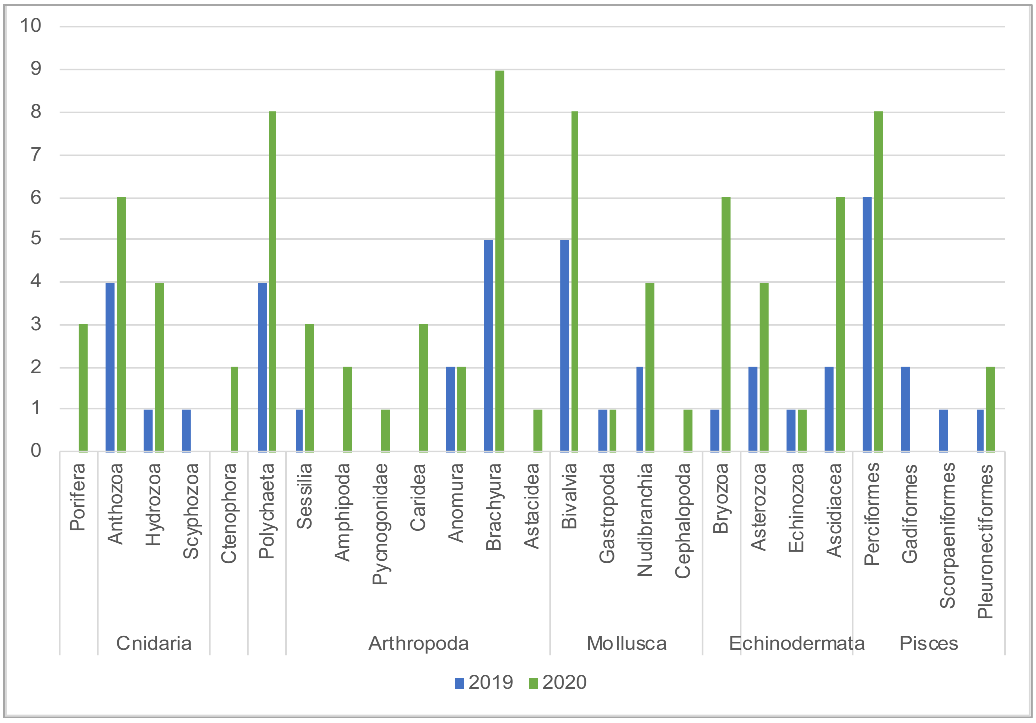

Figure 3.5 *Number of species per group (per phylum) found in monitoring surveys (September 2019, September 2020) in the pilot area.*

Oysters

Although no quantitative data of epifauna growing on the oysters were collected, divers noted a large biodiversity on and underneath oysters. This included eggs of the Atlantic bobtail (*Sepiola atlantica*) (Figure 3.6, left), nudibranchs with eggs, different species of sea anemones, bryozoans and hydrozoans, and the tube worm (*Pomatoceros triqueter*). Furthermore, crab and fish species such as the goldsinny wrasse and goby species hiding underneath oysters and in the reef structures were observed (Figure 3.6, right).

Figure 3.6 *Left: Eggs of the Atlantic bobtail Sepiola atlantica attached to a Flat oyster (basket 6, rack 2).*
Right: 3D Reef structure small 'Jan Willem' with representatives of different taxa groups such as soft coral, anemones, hydrozoans, bryozoans, starfish, crustaceans, tunicates and fish.

3.4 Performance of research rack and 3D-reef structure

Inspection by divers in September 2020 showed structures, both racks and 3D reefs (Jan Willem & Alex) standing upright and intact (Figure 2.3, Figure 3.6, Figure 3.7). Like reported before (Didderen et al., 2019) 3D reef Emilie had toppled sideways, but was intact.
Over the years the 3D structures are developing a small hard substrate community similar to adjacent rocks. Sessile animals like sponges, bryozoa, hydroids, anemones and soft coral (table 3.3) are now fully covering the structure. Attracting mobile species like fishes, squids, sea slugs, start fish and crabs for feeding, reproduction and shelter. For example, the dead mans finger (soft coral) was previously smaller and not on every 3D structure.

Figure 3.7 *Another intact reef structure with high biodiversity attracted, large reef ‘Alex’.*

3.5 Biofouling and predators

Fouling organisms
The reefs where colonised by a diverse epifaunal community, which consisted of benthic and mobile species. Both research racks and reefs were greatly covered in encrusting sessile organisms. This fouling of the research racks could have been unbeneficial to the condition of the oysters in the baskets, but the baskets where not overgrown to a state in which suffocating would be a risk. During inspection of the oysters in the research racks several species where observed to be growing on the oysters, such as blue mussel, hydroid species and the tubeworm *Spirobranchus triqueter*.

Predators
Common starfish (*Asterias rubens*) and edible crab are known predators, especially for young oysters, and were observed in the pilot area (Appendix B). High survival percentage of adult oysters, however, suggests that this is no direct threat to the adult oysters.

3.6 Oyster recruitment and oyster bed development.

Adult oysters are present on the seabed, growing, as observed by their growth edge, and healthy. Within a transect of 1,5 meters wide and 50 meters long 8 alive and 5 dead oysters were observed. This transect is depicted in figure 2.6. The observed density in this transect is lower than was observed in transects during the monitoring in 2019. Outside of this transect, live oysters were also observed on the seabed, but these were not quantified.

Recruitment on the seabed was observed in the pilot area only in 2019. Randomly, 5 alive adult Flat oysters were collected from the seabed, their size and weight were determined (Table 3.4). They will be used for further research (isotope analysis) and stored by -20C in the ReViFES project.

Table 3.4 Random measurement (length and weight) of 5 adult alive Flat oysters collected from the seabed (26,4 meters depth).

	gram	mm
Oyster 1	347	94
Oyster 2	271	87
Oyster 3	243	93
Oyster 4	290	94
Oyster 5	232	92

Additional field observation

Whilst drifting away from the reef during the end of the dive to the south east, patches with higher densities of oyster (3 or 4 together) were observed outside the original placement fields. See also Figure 2.6, the dotted blue line in South East direction.

4 Discussion

Conclusion

The 2020 expedition to the Borkum Reef ground was aimed at monitoring the survival of the oysters as they were deployed in May 2018. Adding to observations in 2019, in 2020 results are positive: adult oysters placed in the research racks survived and increased in size over the 28 months since deployment in 2018. At the same time oysters on the seabed are still present and surviving.
Observed density of oysters on the seabed was fairly low in 2020's quantitative transect, but based on 1 transect, it cannot be concluded if this is indicative for a decreasing overall density or caused by local differences in density within the pilot area.
In 2020 no new recruits are identified, not in the research racks, nor during the study of the seabed. The observed biodiversity increased over the last year, indicating the presence of the oysters serve as an attractive hotspot for various organisms.
Also the 3D reefs develop successfully with more species attracting and obvious growth of the animals inhabiting the artificial structures.
In conclusion, the Borkum Reef Ground oyster reef, that was actively restored in 2018, shows survival, growth, reproduction and recruitment and serves as a reef: a hotspot for biodiversity, with species such as *Ctenolabrus rupestris* (Gold sinny wrasse), *Sepiola atlantica* (Atlantic bobtail), and *Polycera quadrilineata* (four striped polycera).

4.1 Lessons learned

Oyster pilot

The main lessons learned in 2020 are:

- It is possible to introduce installations and flat oysters on the sea floor at a deep (23 meters at low tide) offshore location and retrieve them at a later point in time (28 months) for monitoring purposes.
- The placement of 5500 kg, or 80.000 specimen, adult flat oysters on the sea floor has so far led to the result of flat oyster specimen being alive and showing growth. These results, 28 months after installation, although largely based on qualitative data, are promising.
- On the seabed, alive oysters are still present. Observed densities, both in 2019 and 2020, seem lower than can be expected from the initial placed density. The decrease of the density may be the result of oysters being displaced and moved outside the pilot area due to stormy conditions and are now distributed over a larger area than the initial pilot area.

Monitoring techniques

Earlier lessons learned during monitoring were confirmed in the 2020 fieldtrip:

- Divers can effectively monitor several aspects of the oyster bed in two days' time.
- Using a rehoistable research rack is a good way to get quantitative results of oyster parameters like survival, growth and presence of recruits.

4.2 Recommendations

These positive and promising results encourage further monitoring of the pilot and its long-term effects. In subsequent monitoring expeditions, the following monitoring is recommended:

- Survival and growth of adult oysters
- Monitoring of larval presence
- Density development of adult oysters on the seabed
- Epifaunal assemblages directly related to the oysters
- Biodiversity development on the seabed, also compared to a reference area
- Searching for evidence of adult oysters being moved out of the initial pilot area

Initiate a spat on shell experiment offshore

Offshore conditions are suitable to support flat oysters and the 2019 study showed that the oysters reproduce (Didderen *et al*. 2019). The density of the oysters on the sea bed seems to be decreasing, possibly due to dispersal during storms. The critical density essential for further fertilisation and growth of the reef may be under pressure. A new boost to the pilot area can be the introduction of spat on shell. The method is a cost-effective way to support the reef to become a self-sustaining population. To keep the spat on shell within the pilot area it is essential to have them settle on larger substrates which will be able to withstand currents due to stormy weather.

References

Airoldi, L., M.W. Beck. 2007. Loss, status and trends for coastal marine habitats of Europe. Oceanogr. Mar. Biol. Annu. Rev., 45, pp. 345-405.

Christianen, M. J. A., W. Lengkeek, J. H. Bergsma, J. W. P. Coolen, K. Didderen, M. Dorenbosch, F. M. F. Driessen, P. Kamermans, E. Reuchlin-Hugenholtz, H. Sas, A. Smaal, K. A. van den Wijngaard & T. M. van der Have, 2018. Return of the native facilitated by the invasive? Population composition, substrate preferences and epibenthic species richness of a recently discovered shellfish reef with native European flat oysters (*Ostrea edulis*) in the North Sea. Marine Biology Research, Wageningen.

Coolen, J. W. P., O.G. Bos, S.T. Glorius, W. Lengkeek, J. Cuperus, B.E. van der Weide, A. Agüera García, 2015. Reefs, sand and reef-like sand: A comparison of the benthic biodiversity of habitats in the Dutch Borkum Reef Grounds. Journal of Sea Research: 1 - 9.

Didderen, K., W. Lengkeek, P. Kamermans, B. Deden & E. Reuchlin-Hugenholtz, 2019. Pilot to actively restore native oyster reefs in the North Sea Comprehensive report to share lessons learned in 2018. Bureau Waardenburg / WWF, Culemborg / Zeist.

Farinas-Franco, J. M., Pearce, B., Mair, J. M., Harries, D. B., MacPherson, R. C., Porter, J. S., ... Sanderson, W. G. 2018. Missing native oyster (*Ostrea edulis* L.) beds in a European Marine Protected Area: Should there be widespread restorative management? Biological Conservation, 221, 293–311. DOI: 10.1016/j.biocon.2018.03.010

Gercken, J. and A. Schmidt, 2014. Current Status of the European Oyster (*Ostrea edulis*) and Possibilities for Restoration in the German North Sea. Bundesamt für Naturschutz, Bonn.

Maathuis MAM, JWP Coolen, T van der Have, P Kamermans. (2020) Factors determining the timing of swarming of European flat oyster (*Ostrea edulis* L.) larvae in the Dutch Delta area: implications for flat oyster restoration. Journal of Sea Research 156 https://doi.org/10.1016/j.seares.2019.101828

Pogoda B., B.H. Buck, W. Hagen. 2011. Growth performance and condition of oysters (*Crassostrea gigas* and *Ostrea edulis*) farmed in an offshore environment (North Sea, Germany). Aquaculture 319: 484–492

Reuchlin-Hugenholtz, E. 2018. Plan for the active Restoration of Oysterbeds in Borkumse Stenen; Experiment for the purpose of kickstarting an oysterbed and distilling elements of success for North Sea restoration of oysterbeds. World Wide Fund for Netherlands, Zeist.

Olsen, O.T., 1883. The Piscatorial Atlas of the North Sea, English and St. George's Channels, Illustrating the Fishing Ports, Boats, Gear, Species of Fish (How, Where, and When Caught), and Other Information Concerning Fish and Fisheries. Taylor and Francis, London.

OSPAR Commission, 2011. OSPAR Commission Report of the OSPAR/MSFD workshop on approaches to determining GES for biodiversity. Biodivers. Ser. 56, OSPAR Commission, London.

Sawusdee, A., A.C. Jensen, K.J. Collins, C. Hauton, 2015. Improvements in the physiological performance of European flat oysters Ostrea edulis (Linnaeus, 1758) cultured on elevated reef structures: implications for oyster restoration. Aquaculture, 444 (2015), pp. 41-48, 10.1016/j.aquaculture.2015.03.02.

Sas, H.J.W, Smaal, A.C., P. Kamermans, T.M. Have, W. Lengkeek, 2017. Shellfish reef restoration pilots. Voordelta The Netherlands. Annual report 2016 Ark WNF Bureau Waardenburg WMR Sas consultancy.

Sas, H.J.W., P. Kamermans, T.M. Have, M.J.A. Christianen, J.W.P Coolen, W. Lengkeek, K. Didderen, 2018. Shellfish reef restoration pilots. Voordelta The Netherlands. Annual report 2017. Ark WNF Bureau Waardenburg WMR Sas consultancy. Sas, H., K. Didderen, T. van der Have, P. Kamermans, K. van der Wijngaard & E. Reuchlin, 2019. Recommendations for flat oyster restoration in the North Sea. ARK / WNF, Nijmegen / Zeist.

Smaal, A.C., P. Kamermans, T.M. Have, M. van der Engelsma, H.J.W. Sas, 2015. Feasibility of flat oyster (*Ostrea edulis* L.) restoration in the Dutch part of the North Sea. Report C028/15, IMARES Wageningen UR, The Netherlands.

Smyth, D., A.M. Mahon, D. Roberts, L. Kregting, 2018. Settlement of *Ostrea edulis* is determined by the availability of hard substrata rather than by its nature: implications for stock recovery and restoration of the European oyster. Aquat. Conserv. Mar. Freshwat. Ecosyst., 1–10 (2018),

Walne, P.R., Mann, R., 1975. Growth and biochemical composition in *Ostrea edulis* and C. gigas. In: Barnes, H. (Ed.), Proc. 9th EMBS Aberdeen, pp. 587–607.

Van der Have, T. M. and E. van der Zee. 2016. Terugkeer van de platte oester in de Waddenzee. Verkenning naar een mogelijk herstel van platte oesterbanken in de Waddenzee. Bureau Waardenburg / Altenburg & Wymenga, Culemborg / Veenwouden.

Appendix A

Textbox: Objectives of the Borkum Reef Ground oyster pilot

(Source: Reuchlin-Hugenholtz, 2018)

The following overall objectives are formulated for this project:

1. Kick start shellfish beds in deeper parts of the North Sea;
2. Get insight in the key success and failure factors for active restoration of structure-forming shellfish beds in deeper parts of the North Sea;

More specifically, the 2018 pilot project at the Borkum Reef Ground aims at:

A. Developing a methodology for construction and restoration of structure-forming shellfish beds of mussels and flat oysters.

B. Construction of a pilot flat oyster bed at deeper water in the North Sea at the Borkum Reef Ground area, by placement of:
   - live flat oysters (originating from Norway) at the pilot area of 100x100m.
   - research racks with flat oysters to study survival, growth and reproduction.
   - 3D artificial reefs to study facilitation of oyster bed restoration (incl. elevation).
   - shells (empty) in the surroundings of the live oysters to function as hard substrate for larvae settlement.

C. Learning from the pilot project by studying the following research questions in a field (and laboratory) monitoring programme:
   a. What is the mortality rate of introduced oysters, and what is the cause?
   b. Can the introduced oyster population survive and reproduce, and if (not), why (not) (long-term objective)?
   c. Can the introduced oyster population reproduce: i.e. produce gonads, resulting in larvae in the water column, resulting in recruitment on substrates?
   d. Is biodiversity enhanced in the vicinity of the pilot area, through the formation of a natural reef?
   e. Did oysters in the pilot die, and if so, why?
   f. What are the critical success factors for the pilot project?
   g. What are the critical fail factors for the pilot project?
   h. Is biodiversity enhanced in the vicinity of the pilot area?

All activities in the pilot project are closely monitored, to determine success and failure factors and based on these factors to determine and describe a successful methodology for restoration of flat oyster beds in the North Sea.

Appendix B

Total species list obtained during diving operations in September 2019 & September 2020. In 2020, species observed on the seabed and on structures (Flat oysters in the baskets, Flat oysters on the seabed, 3D-reefs and research racks) are marked.

Total species list		**2019**	**2020**		
Scientific name	Common name			*Seabed*	*Reefs*
Porifera sp.			1		X
Suberites ficus	Fig sponge		1		X
Sycon sp.			1		X
Diadumene cincta	Orange anemone		1		X
Metridium senile	Plumose anemone	1	1		X
Sagartia elegans	Elegant anemone		1		X
Sagartia troglodytes	Mud sagartia	1	1	X	X
Sagartiogeton undatus	Small snakelocks anemone	1	1	X	X
Alcyonium digitatum	Dead mans finger	1	1		X
Hydrozoa sp.	Hydrozoans	1	1	X	X
Obelia sp.			1		X
Plumulariidae			1		X
Halecium halecinum	Herring-bone hydroid		1		X
Chrysaora hysoscella	Compass jellyfish	1			
Beroe gracilis	Melon jellyfish		1	X	X
Mnemiopsis leidyi	American comb jelly		1	X	X
Hediste diversicolor	Ragworm		1		X
Laniche conchilega	Sand mason worm	1	1	X	
Lepidonotus sp.			1		X
Nephthys			1		X
Nereididae			1		X
Pomatoceros triqueter	Tube worm		1		X
Sabellaria spinulosa	Ross worm	1	1		X

Total species list		**2019**	**2020**		
Scientific name	Common name			*Seabed*	*Reefs*
Spionidae	Spionid worms	1		X	
Spirorbidae			1		X
Spirobranchus triqueter	Keelworm	1		X	
Balanus crenatus			1		X
Verruca stroemia			1		X
Sessilia	Barnacles	1	1		X
Corophidae	Amphipods		1		X
Jassa sp.	Tube building amphipods		1		X
Pycnogonidae	Sea spider		1		X
Caridae sp.	Shrimp		1	X	
Crangon sp.	Brown shrimp		1	X	
Pandalus sp.	Northern shrimp		1		X
Pagurus bernhardus	Common hermit crab	1	1	X	
Pisidia longicornis	Long-clawed porcelain crab	1	1		X
Ebalia sp.			1	X	
Macropodia sp.	Long-legged spider crab	1	1	X	X
Inachidae	Spider crabs	1		X	
Liocarcinus holsatus	Flying crab	1	1	X	
Liocarcinus navigator	Arch-fronted swimming crab		1		X
Liocarcinus sp. juv.	Swimming crab juvenile	1	1	X	
Necora puber	Velvet swimming crab		1		X
Carcinus maenas	Shore crab		1		X
Pilumnus hirtellus	Hairy crab		1		X
Cancer pagurus	Edible crab	1	1	X	X
Homarus gammarus	European lobster		1		X
Bivalvia	Bivalves	1	1	X	X
Aequipecten opercularis	Queen scallop	1		X	

Total species list		**2019**	**2020**		
Scientific name	Common name			*Seabed*	*Reefs*
Ensis sp.	Razor shell	1	1	X	
Heteranomia squamula	Prickly jingle		1		X
Kellia suborbicularis			1		X
Modiolus modiolus	Northern horse mussel		1		X
Mytilus edulis	Blue mussel	1	1		X
Ostrea edulis	European flat oyster	1	1	X	X
Magallana gigas	Pacific oyster		1		X
Nassarius sp.			1	X	
Trivia	Cowrie	1			X
Acanthodoris pilosa			1		X
Onchidoris bilamellata	Rough-mantled doris		1		X
Polycera quadrilineata	Four-striped polycera	1	1		X
Aeolidia papillosa	Common grey sea slug	1		X	
Tritonia plebeia			1		X
Sepiola atlantica	Atlantic bobtail		1	X	X
Alcyonidium sp.			1		X
Bryozoa	Moss animals	1	1		X
Bugula sp.			1		X
Electra pilosa	Sea mat		1		X
Escharoides coccinea			1		X
Scrupocellaria scruposa			1		X
Amphipholis squamata	Brooding brittle star		1		X
Asterias rubens	Common sea star	1	1		X
Astropecten irregularis	Sand sea star	1		X	
Ophiotrix fragilis	Common brittle star		1		X
Ophiuroidea sp.	Brittle stars		1	X	X
Psammechinus miliaris	Green sea urchin	1	1		X

Total species list		**2019**	**2020**		
Scientific name	Common name			*Seabed*	*Reefs*
Ascidiacea	Sea squirts	1	1	X	X
Botrylloides sp.			1		X
Ciona intestinalis			1		X
Didemnum sp.			1		X
Diplosoma listerianum		1	1		X
Styela clava	Leathery sea squirt		1		X
Ammodytes tobianus	Small sandeel		1	X	
Aphia minuta	Transparent goby		1	X	
Gobiidae	Gobies	1	1	X	
Pomatoschistus minutus	Sandgoby		1	X	
Parablennius gattorugine	Tompot blenny	1	1		X
Ctenolabrus rupestris	Gold sinny wrasse	1	1		X
Callionymus lyra	Common dragonet	1		X	
Mullus surmuletus	Striped red mullet	1	1	X	
Pholis gunnellus	Rock gunnel	1	1	X	X
Raniceps raninus	Tadpole fish	1			X
Ciliata mustela	Fivebeard rockling	1			X
Agonus cataphractus	Hooknose	1		X	
Limanda limanda	Common dab	1	1	X	
Microstomus kitt	Lemon sole		1	X	

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