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Sea pens and bamboo corals in Skagerrak and the Norwegian trench

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ABSTRACT

This study presents the distribution and abundance of key species of the vulnerable marine ecosystems (VMEs) 'Coral gardens' and 'Sea pen and burrowing megafauna' in Skagerrak and the Norwegian trench. It is based on 543 bycatches from 2017–2021, and 35 ROV dives from 2016-2017. Bycatches were used to indicate distribution and relative abundance of the VME key species while ROV observations provided information on colony densities, associated fauna and damages. Four sea pen species were recorded. *Funiculina quadrangularis* and *Kophobelemnon stelliferum* were widely distributed and most abundant below 200 meters. The few records of *Pennatula phosphorea* were mainly from shallower than 100 meters, and the rare *Balticina finmarchica* primarily occurred below 200 meters. The ROV videos confirmed the pattern from the bycatches, however, colony densities were much higher, and the sea pen *Virgularia mirabilis* recorded in high abundances was not present in bycatches. The coral garden key species *Isidella lofotensis, endemic to Norway*, had a restricted area of occurrence confirmed by both methodologies. The restricted distribution makes it particularly vulnerable. Fishing activities overlap with the VMEs distribution and the observations of sea pen skeletons and the coral predatory anemone *Ptychodactis patula* are indicative of pressure from bottom trawl fishing.

KEY POLICY HIGHLIGHTS

- 'Sea pen and burrowing megafauna' is a widely distributed VME in Skagerrak and the Norwegian trench, an area with intense bottom trawling.
- Recorded sea pen species show different distribution patterns, and vulnerability should be evaluated at species level.
- There is an immediate need for protection of the VME 'Coral Garden' represented by the bamboo coral *Isidella lofotensis* and mapping and monitoring is necessary to evaluate ecological status.
- Trawl bycatches provide valuable information on VMEs, but the precision on position and abundance of colonies is low compared with visual mapping, and trawling is a threat to the VMEs.

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Introduction

Bamboo corals and sea pens are key species of the threatened and vulnerable marine ecosystems (VMEs) 'Coral gardens' and 'Sea pen and burrowing megafauna', respectively (OSPAR 2004; Curd 2010; Buhl-Mortensen et al. 2015). Sea pens can be found locally in high densities on soft sediment and in relatively warm Atlantic waters and they are common in the Norwegian Exclusive Economic Zone (EEZ) shallower than 700 metres (Buhl-Mortensen et al. 2019). Soft bottom gorgonian coral is a category of coral garden that in the Norwegian EEZ is represented by two rare species, *Radicipes gracilis* and *Isidella lofotensis*, that locally can form dense stands on sandy soft bottoms. The former is a cold-water deep-sea species known only from northern Norway while the latter occurs from 200–500 metres and has been reported a few times from the shelf but is mainly recorded from Norwegian fjords (Buhl-Mortensen and Buhl-Mortensen 2014; Buhl-Mortensen et al. 2015). Norway has a national responsibility related to the bamboo coral *I. lofotensis* because it is viewed as endemic to Norway (Buhl-Mortensen et al. 2015, 2019).

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The main human threats to these habitats are activities that physically disturb the seabed, and in particular the demersal fisheries can impact these VMEs through burial, silting and crushing (Pitcher et al. 2022). Commercial fisheries for shrimps and other demersal resources are intense in Skagerrak and the Norwegian trench (Eigaard et al. 2017; Amoroso et al. 2018; Pitcher et al. 2022) and thus represent a potential threat to these habitats (Buhl-Mortensen et al. 2019). The objective of this study is to present the distribution and health status of the 'Coral gardens' key species *I. lofotensis*, and the 'Sea pen and burrowing megafauna' key species *Funiculina quadrangularis*, *Kophobelemnon stelliferum*, *Pennatula phosphorea* and *Balticina finmarchica* in Skagerrak and the Norwegian trench.

Samples and information on the occurrence of VME key species come from two sources: (1) bycatch data from an annual bottom trawl survey with 111 fixed stations conducted by the Norwegian Institute of Marine Research (IMR) from the period 2017–2021 (Søvik and Thangstad 2021) and (2) video records from ROV dives at 35 localities conducted by OCEANA (a nonprofit ocean conservation organization) in 2016 and 2017 (Álvarez et al. 2019). The bycatch data, even though from a gear designed to capture shrimps and demersal fish species, indicate distribution and relative abundance of sea pens and corals while the visual observations provide detailed information from the habitats of local colony densities, associated fauna and fishing related damage to colonies. The distribution of the VME key species is compared with the distribution of the commercial bottom trawl fisheries in the area as an indication of impact from fishing on these habitats.

Materials and methods

Study area

The ocean area Skagerrak is delimited by straight lines from the Lindesnes lighthouse (southernmost tip of Norway) to the Hanstholm lighthouse in Denmark, and from Grenen (northernmost tip of Denmark) to Marstrand in Sweden (Figure 1A). Skagerrak is linked to the brackish Baltic Sea through Kattegat, has a mixed water column and is less saline and less tidal than the North Sea (ICES 2021). The Norwegian trench is a deep channel that cuts into the northeastern part of the shallow North Sea and follows the west and south coast of Norway into Skagerrak, where the deepest part of 600–700 metres depth is located. The bottom sediment of the trench is mud to sandy mud, while the Norwegian coastal areas consist of rocky bottom interspersed with pockets of soft sediment (ICES 2021). In this paper, we will use the term Norwegian trench for the part of the channel west of the demarcation line between the North Sea and Skagerrak.

Survey data

IMR conducts a yearly bottom trawl survey in January to monitor the stock status of northern shrimp (*Pandalus borealis*) and demersal fish species in Skagerrak and the Norwegian trench at 111 fixed trawl stations on soft sediments at 111–540 metres depth (Figure 1B and Table I) (Søvik and Thangstad 2021). With some exceptions, all stations are visited once a year. The sampling gear is a 'Campelen 1800' bottom trawl of 3–5 metres in height and with 48–52 metres door spread. The bottom gear is a rock hopper gear. At each station, the trawl is hauled at 3 knots for 30 min, and each haul covers approximately 0.14 km^2. Bycatch documentation of sea pens and bamboo corals started in 2017 and from the 5-year period 2017–2021, bycatch information is available from a total of 543 trawl hauls. For each trawl haul, the collected sea pens and corals were displayed at the sorting table in the fish-lab and photographed (Figure 2). Species identification and quantification was done after the cruise based on the photos. The few and distinct sea pen species present in the area makes it possible to identify the colonies based on photos. Because colonies were often broken into several pieces during trawling the quantification of colonies in each trawl catch is based on counting the peduncles or holdfasts (the part anchored in the sediment) of each colony. For analyses of abundance and distribution of sea pens and coral, we used the average number in trawl catches over the period 2017–2021 at each fixed survey station.

ROV observations

In 2016 and 2017, 35 video inspections were conducted by OCEANA (Álvarez et al. 2019) at 68–459 metres depth in the study area using ROV equipped with a high-definition (HD) video camera and laser beams as measuring scale (Figure 1B and Table II). The relatively few visually mapped localities provide valuable supplementary information to the trawl bycatches on local density, associated fauna and indications of trawl related damage. The sea pens and corals were identified to species (the few and distinct

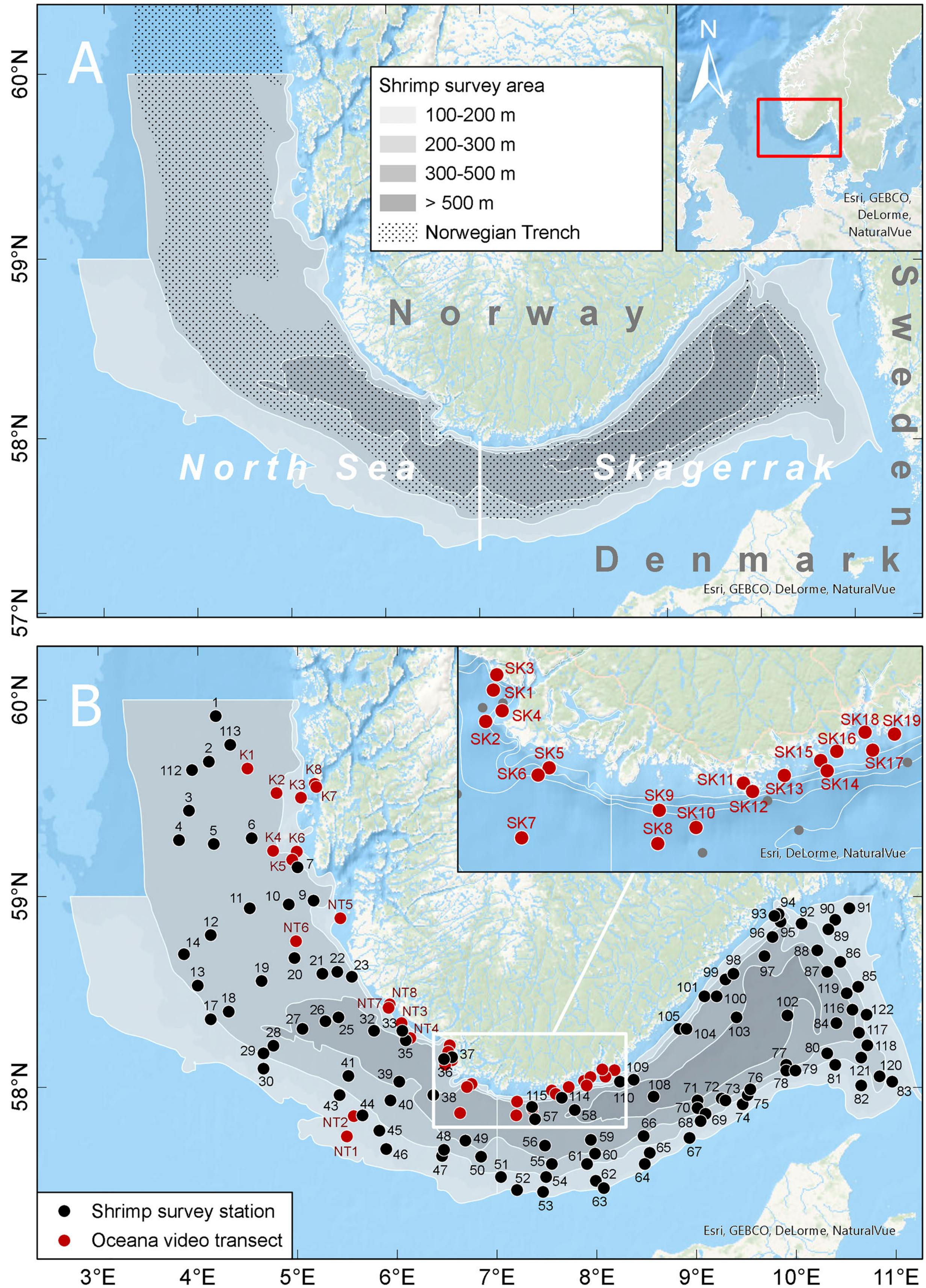

Figure 1. (A) The IMR annual shrimp survey area with depth zones shown in shades of grey. (B) The position of the 111 fixed bottom trawl stations from which bycatch data for the period 2017–2021 were used in this study (black dots), and the 35 localities that was visually mapped by OCEANA in 2016 and 2017 using ROV (Álvarez et al. 2019).

Table I. Station numbers (Stn.) and geographic position for the 111 fixed bottom trawl stations from which bycatches of sea pens and bamboo corals were recorded in the 5-year period 2017–2021 (see map in Figure 1B).

	Position											Position									
Stn.	Lat	Long	Depth	*N*	2017	2018	2019	2020	2021	Stn.	Lat	Long	Depth	N	2017	2018	2019	2020	2021
1	59°55.2′N	04°10.6′E	282	5	x	x	x	x	x	64	57°35.6′N	08°28.7′E	139	5	x	x	x	x	x
2	59°41.5′′N	04°06.8′E	270	5	x	x	x	x	x	65	57°39.1′N	08°31.7′E	166	4	x	x	x		x
3	59°26.4′N	03°54.3′E	277	5	x	x	x	x	x	66	57°44.1′N	08°28.4′E	297	5	x	x	x	x	x
4	59°17.1′N	03°48.8′E	268	5	x	x	x	x	x	67	57°43.9′N	08°55.9′E	120	5	x	x	x	x	x
5	59°16.1′N	04°09.4′E	280	5	x	x	x	x	x	68	57°49.3′N	09°02.2′E	179	5	x	x	x	x	x
6	59°17.9′N	04°32.4′E	272	5	x	x	x	x	x	69	57°51.4′N	09°05.6′E	205	5	x	x	x	x	x
7	59°09.0′N	05°00.0′E	195	5	x	x	x	x	x	70	57°53.1′N	09°00.8′E	368	5	x	x	x	x	x
9	58°58.6′N	05°09.8′E	250	5	x	x	x	x	x	71	57°55.7′N	09°00.5′E	491	4	x	x	x		x
10	58°57.3′N	04°54.5′E	240	5	x	x	x	x	x	72	57°56.3′N	09°15.1′E	300	5	x	x	x	x	x
11	58°56.4′N	04°31.4′E	254	5	x	x	x	x	x	73	57°55.8′N	09°17.2′E	250	5	x	x	x	x	x
12	58°47.9′N	04°07.5′E	285	5	x	x	x	x	x	74	57°54.7′N	09°27.5′E	147	5	x	x	x	x	x
13	58°32.2′N	03°59.9′E	272	4		x	x	x	x	75	57°57.8′N	09°30.3′E	203	5	x	x	x	x	x
14	58°42.1′N	03°51.8′E	272	5	x	x	x	x	x	76	57°59.4′N	09°32.6′E	232	5	x	x	x	x	x
17	58°21.5′N	04°07.9′E	182	5	x	x	x	x	x	77	58°07.4′N	09°53.7′E	310	5	x	x	x	x	x
18	58°23.8′N	04°18.7′E	294	5	x	x	x	x	x	78	58°05.1′N	09°54.1′E	220	4	x	x	x		x
19	58°33.7′N	04°38.4′E	269	5	x	x	x	x	x	79	58°05.2′N	09°59.5′E	181	5	x	x	x	x	x
20	58°40.7′N	04°58.3′E	220	5	x	x	x	x	x	80	58°10.5′N	10°18.8′E	208	5	x	x	x	x	x
21	58°36.0′N	05°14.9′E	252	5	x	x	x	x	x	81	58°06.9′N	10°23.1′E	155	5	x	x	x	x	x
22	58°36.3′N	05°23.8′E	255	5	x	x	x	x	x	82	58°00.5′N	10°39.2′E	176	5	x	x	x	x	x
23	58°35.0′N	05°32.7′E	234	5	x	x	x	x	x	83	58°02.0′N	10°57.8′E	150	5	x	x	x	x	x
25	58°22.1′N	05°24.7′E	328	5	x	x	x	x	x	84	58°20.3′N	10°23.7′E	354	5	x	x	x	x	x
26	58°20.7′N	05°16.7′E	323	5	x	x	x	x	x	85	58°31.8′N	10°37.3′E	156	5	x	x	x	x	x
27	58°18.5′N	05°03.0′E	307	5	x	x	x	x	x	86	58°39.4′N	10°26.2′E	162	5	x	x	x	x	x
28	58°13.2′N	04°45.6′E	286	5	x	x	x	x	x	87	58°36.6′N	10°18.4′E	296	5	x	x	x	x	x
29	58°10.9′N	04°39.4′E	227	3	x			x	x	88	58°43.4′N	10°12.5′E	231	5	x	x	x	x	x
30	58°01.9′N	08°14.0′E	245	2				x	x	89	58°49.5′N	10°19.1′E	155	5	x	x	x	x	x
32	58°18.0′N	05°46.0′E	357	5	x	x	x	x	x	90	58°52.5′N	10°23.2′E	160	5	x	x	x	x	x
33	57°43.0′N	07°56.2′E	430	1					x	91	58°56.2′N	10°31.9′E	150	5	x	x	x	x	x
35	58°16.0′N	05°58.0′E	300	4	x	x	x	x		92	58°51.8′N	10°02.8′E	215	5	x	x	x	x	x
36	58°09.8′N	06°24.5′E	320	5	x	x	x	x	x	93	58°54.8′N	09°49.2′E	251	5	x	x	x	x	x
37	58°09.7′N	06°32.7′E	248	5	x	x	x	x	x	94	58°53.7′N	09°47.0′E	124	5	x	x	x	x	x
38	57°57.8′N	06°21.7′E	335	5	x	x	x	x	x	95	58°51.9′N	09°50.2′E	370	5	x	x	x	x	x
39	58°02.0′N	06°00.9′E	318	5	x	x	x	x	x	96	58°47.4′N	09°45.8′E	400	5	x	x	x	x	x
40	57°55.9′N	05°55.9′E	274	5	x	x	x	x	x	97	58°41.6′N	09°40.6′E	425	5	x	x	x	x	x
41	58°03.7′N	05°30.4′E	273	5	x	x	x	x	x	98	58°36.6′N	09°25′3′E	280	5	x	x	x	x	x
43	57°57.6′N	05°25.0′E	181	5	x	x	x	x	x	99	58°34.1′N	09°17.4′E	290	5	x	x	x	x	x
44	57°50.9′N	05°39.2′E	168	5	x	x	x	x	x	100	58°28.8′N	09°12.0′E	360	5	x	x	x	x	x
45	57°46.3′N	05°49.3′E	157	5	x	x	x	x	x	101	58°28.6′N	09°05.0′E	236	5	x	x	x	x	x
46	57°40.2′N	05°53.6′E	142	5	x	x	x	x	x	102	58°22.7′N	09°54.5′E	510	5	x	x	x	x	x
47	57°38.0′N	06°27.0′E	155	4	x	x	x		x	103	58°22.0′N	09°24.0′E	540	5	x	x	x	x	x
48	57°40.0′N	06°28.0′E	260	5	x	x	x	x	x	104	58°18.5′N	08°54.2′E	310	5	x	x	x	x	x
49	57°43.0′N	06°41.0′E	310	5	x	x	x	x	x	105	58°18.6′N	08°49.6′E	220	5	x	x	x	x	x
50	57°37.9′N	06°50.5′E	299	5	x	x	x	x	x	108	57°56.7′N	08°34.2′E	500	5	x	x	x	x	x
51	57°31.1′N	07°02.1′E	211	5	x	x	x	x	x	109	58°02.4′N	08°22.4′E	401	5	x	x	x	x	x
52	57°26.8′N	07°11.7′E	126	5	x	x	x	x	x	110	58°01.9′N	08°14.0′E	245	5	x	x	x	x	x

(*Continued*)

Table I. Continued.

		Position											Position							
Stn.	Lat	Long	Depth	*N*	2017	2018	2019	2020	2021	Stn.	Lat	Long	Depth	N	2017	2018	2019	2020	2021
53	57°26.5′N	07°27.8′E	111	5	x	x	x	x	x	112	59°39.1′N	03°57.4′E	276	5	x	x	x	x	x
54	57°31.2′N	07°29.1′E	221	5	x	x	x	x	x	113	59°47.0′N	04°19.0′E	281	5	x	x	x	x	x
55	57°35.4′N	07°32.8′E	292	5	x	x	x	x	x	114	57°56.7′N	07°39.0′E	295	5	x	x	x	x	x
56	57°41.1′N	07°29.0′E	357	5	x	x	x	x	x	115	57°53.7′N	07°21.0′E	380	5	x	x	x	x	x
57	57°50.0′N	07°22.6′E	462	5	x	x	x	x	x	116	58°24.6′N	10°33.6′E	250	5	x	x	x	x	x
58	57°52.9′N	07°47.0′E	480	5	x	x	x	x	x	117	58°17.4′N	10°37.6′E	243	5	x	x	x	x	x
59	57°43.0′N	07°56.2′E	430	5	x	x	x	x	x	118	58°13.4′N	10°42.6′E	212	5	x	x	x	x	x
60	57°38.8′N	07°58.9′E	288	4	x	x	x		x	119	58°29.8′N	10°30.4′E	247	5	x	x	x	x	x
61	57°35.5′N	07°54.2′E	240	5	x	x	x	x	x	120	58°03.5′N	10°50.1′E	207	5	x	x	x	x	x
62	57°29.9′N	07°59.4′E	163	5	x	x	x	x	x	121	58°09.4′N	10°39.1′E	257	5	x	x	x	x	x
63	57°27.8′N	08°03.9′E	129	4	x	x	x		x	122	58°23.0′N	10°42.2′E	185	5	x	x	x	x	x
									x				Total	543	109	108	110	105	111

Station depth (m), number of samples (N) and sampling year is provided. x: sample collected. Station numbers lacking in the list have been taken out of the survey.

sea pen species present in the area makes it possible to identify the colonies based on video) and counted when present on video. A 5 cm laser scale was used to estimate the local patch density of colonies based on video frames (stills) at a few localities where the occurrence was high.

Results

In this study the collected or observed sea pen and coral genera are represented with only one species each and for simplicity we are mainly using the genus names for the species in what follows.

Trawl bycatches

From a total of 543 trawl catches collected from the 111 fixed localities (Figure 1B) the sea pens *Funiculina*, *Kophobelemnon*, *Balticina* and *Pennatula* were recorded. In addition, the number of the ophiuroid *Asteronyx* living on *Funiculina* was noted (Table III). This is one of few associated species that clings so hard to its host that they are captured together. The most common sea pen species in the bycatches were *Funiculina* and *Kophobelemnon*; the former was present in more than 50% of the trawl catches and the latter in 10–20%. In total, 1996 and 359 colonies were collected, respectively, with a maximum of 45 and 18 colonies in a single trawl haul.

The geographic distribution of *Funiculina* and *Kophobelemnon* is shown in Figure 3. *Funiculina* is, together with the symbiont ophiuroid *Asteronyx* (brittle star), widely distributed in the study area with the highest abundance in the Norwegian part of Skagerrak and the Norwegian trench. The largest records of *Funiculina* were from depths between 200 and 300 metres (Figure 4A). The abundance of *Funiculina* and *Asteronyx* in bycatches is highly correlated ($R^2 = 0.82$) and the ratio is very near to one to one ($Y = 1.1X$) (Figure 5). In the catches *Asteronyx* was normally attached to the host but some detached specimens occurred.

The distribution of *Kophobelemnon* is more restricted and the highest numbers are from deeper parts of Skagerrak and the Norwegian trench, from depths deeper than 400 metres (Figures 3 and 4A). Records of the sea pens *Balticina* and *Pennatula* were few. *Pennatula* has a shallower distribution than most of the trawl survey stations in the study area, while *Balticina* is rare in Norwegian waters and mainly occurred deeper than 200 metres and in the Norwegian trench. The bamboo coral *Isidella* occurred in low numbers and in total 82 individuals (colonies) were reported based on holdfasts. The largest occurrences were 10 colonies collected at

Figure 2. From each trawl catch at the annual shrimp survey the benthos bycatch was displayed on the sorting table in the fish-lab and photographed. Coral and sea pen species were identified, and numbers estimated based on the number of holdfasts or peduncles observed in the bycatch photos.

Table II. Station information for the ROV localities visually mapped by the organization OCEANA (Álvarez et al. 2019) between 2016 and 2017, date, geographic position and station depth (m) (see map in Figure 1B).

Name	Station	Date	Latitude	Longitude	Depth (m)
Norwegian Trench 1	NT1	28.07.2016	57° 44,250′ N	5° 29,728′ E	130
Norwegian Trench 2	NT2	28.07.2016	57° 50,846′ N	5° 33,854′ E	149
Norwegian Trench 3	NT3	29.07.2016	58° 15,621′ N	6° 07,735′ E	172
Norwegian Trench 4	NT4	29.07.2016	58° 20,420′ N	6° 02,647′ E	104
Norwegian Trench 5	NT5	03.08.2016	58° 53,311′ N	5° 25,735′ E	48
Norwegian Trench 6	NT6	04.08.2016	58° 46,154′ N	4° 59,140′ E	208
Norwegian Trench 7	NT7	07.08.2016	58° 25,223′ N	5° 54,832′ E	107
Norwegian Trench 8	NT8	07.08.2016	58° 26,334′ N	5° 55,409′ E	47
Karmoy ROV 1	K1	10.07.2017	59°39,321 N	4° 29,842′ E	278
Karmoy ROV 2	K2	10.07.2017	59°31,809 N	4° 47,387′ E	227
Karmoy ROV 3	K3	10.07.2017	59°30,490 N	5° 02,081′ E	113
Karmoy ROV 4	K4	11.07.2017	59°14,121 N	4° 45,318′ E	260
Karmoy ROV 5	K5	11.07.2017	59°11,456′ N	4° 56,859′ E	213
Karmoy ROV 6	K6	11.07.2017	59°13,885′ N	4° 59,645′ E	153
Karmoy ROV 7	K7	12.07.2017	59°33,761′ N	5° 11,181′ E	357
Karmoy ROV 8	K8	12.07.2017	59°34,633′ N	5° 10,304′ E	293
N.T. Skagerrak ROV 1	SK1	13.07.2017	59°11,319′ N	6° 30,683′ E	398
N.T. Skagerrak ROV 2	SK2	13.07.2017	59°07,165′ N	6° 28,757′ E	317
N.T. Skagerrak ROV 3	SK3	13.07.2017	59°13,328′ N	6° 31,514′ E	65
N.T. Skagerrak ROV 4	SK4	13.07.2017	59°08,579′ N	6° 32,802′ E	191
N.T. Skagerrak ROV 5	SK5	14.07.2017	59°01,051′ N	6° 44,550′ E	87
N.T. Skagerrak ROV 6	SK6	14.07.2017	59°00,126′ N	6° 41,841′ E	380
N.T. Skagerrak ROV 7	SK7	14.07.2017	57° 51,816′ N	6° 37,657′ E	353
N.T. Skagerrak ROV 8	SK8	15.07.2017	57° 51,047′ N	7° 11,609′ E	459
N.T. Skagerrak ROV 9	SK9	15.07.2017	57° 55,475′ N	7° 11,952′ E	215
N.T. Skagerrak ROV 10	SK10	15.07.2017	57° 53,149′ N	7° 21,147′ E	411
N.T. Skagerrak ROV 11	SK11	16.07.2017	57° 59,061′ N	7° 32,960′ E	68
N.T. Skagerrak ROV 12	SK12	16.07.2017	57° 57,946′ N	7° 35,237′ E	123
N.T. Skagerrak ROV 13	SK13	16.07.2017	59°00,073′ N	7° 43,155°′ E	146
N.T. Skagerrak ROV 14	SK14	17.07.2017	59°00,645′ N	7° 53,849′ E	210
N.T. Skagerrak ROV 15	SK15	17.07.2017	59°02,043′ N	7° 52,168′ E	84
N.T. Skagerrak ROV 16	SK16	17.07.2017	59°03,229′ N	7° 56,227′ E	120
N.T. Skagerrak ROV 17	SK17	18.07.2017	59°03,413′ N	8° 05,192′ E	248
N.T. Skagerrak ROV 18	SK18	18.07.2017	59°05,771′ N	8° 03,263′ E	255
N.T. Skagerrak ROV 19	SK19	18.07.2017	59°05,498′ N	8° 10,583′ E	129

Table III. Data on bycatch in trawl hauls of sea pens and corals and the common symbiont on *Funiculina*, the ophiuroid *Asteronyx*. Number of trawl stations with bycatch, number of collected individuals and colonies, and maximum catch in a single trawl haul per survey year and total for all the years.

	2017	2018	2019	2020	2021	All years
Asteronyx						
No. stations	49	71	87	58	77	342
No. collected	368	406	509	405	642	2330
Max in trawl	30	20	30	30	50	50
Funiculina						
No. stations	52	80	84	67	82	365
No. collected	292	406	405	298	595	1996
Max in trawl	30	20	25	16	45	45
Kophobelemnon						
No. Stations	15	14	10	19	10	68
No. collected	139	37	53	73	56	358
Max in trawl	50	11	11	10	18	50
Balticina						
No. Stations	3	1	0	4	4	12
No. collected	3	2	0	6	6	17
Max in trawl	1	2	0	3	3	3
Pennatula						
No. Stations	0	3	0	0	0	3
No. collected	0	3	0	0	0	4
Max in trawl	0	1	0	0	0	1
Isidella						
No. Stations	4	7	7	4	5	27
No. collected	7	13	24	23	15	82
Max in trawl	3	4	8	10	6	10

trawl station number 35 close to the coast in the Norwegian trench (Figure 3). The main occurrence was deeper than 200 metres (Figure 4B).

ROV observations

Soft bottom sea pens and corals were observed at 17 out of the 35 ROV stations (Table IV). In general, the numbers of sea pens and corals recorded on the video transects were much higher than in the trawl bycatches. The most abundant species, *Virgularia*, was not recorded as bycatch. The largest density of *Virgularia* was observed by ROV from an outer fjord station on the west coast of Norway (K7), which can explain why this small and delicate species was not recorded from the bottom trawl survey that is conducted mainly offshore. The ROV records also had more observations of *Pennatula* compared with the trawl bycatches, mainly related to a station at 68 metres depth close to the coast. *Funiculina* and *Kophobelemnon* were amongst the more common species observed by ROV which is in line with the trawl data, and both occurred in particularly high numbers below 200 metres (Table IV). At station SK6, the density of *Funiculina* was ~3 colonies per m^2 and the anemone *Ptychodactis patula* was found feeding on its tissue (Figure 6). The ROV transects documented the bamboo coral *Isidella* in high numbers at the station SK2 close to the coast, at 317 metres depth (Figure 7). This observation was near the largest trawl bycatches of this coral (station 35) and indicates that the bamboo coral occurs in a rather well-defined and restricted region in the study area. As in the trawl bycatches, the large sea pen *Balticina* was observed only in low numbers.

Discussion

Sampling methodology

Bottom trawls are not designed to collect benthic organisms and depending on substratum and rigging they will collect only a portion of the soft bottom epifauna during a haul. Bycatch records from trawls must therefore be viewed as minimum estimates of densities, and some common species may not even be present in the trawl. Our comparison with videos from the ROV survey conducted by OCEANA showed that all the species present as bycatch in the trawl were recorded in much higher numbers on the ROV stations where they occurred (Figures 6 and 7). This difference is not surprising and in a recent study Mendoca and Metaxa (2021) compared epifauna data from ROV and drop camera with trawl sampling at two stations. They showed that the image-based methods are more efficient in general and particularly in relation to Pennatulacean recruits, in addition the fine-scale distributions could not be elucidated with a trawl. This demonstrates that in addition to being non-destructive, visual mapping is more suitable for monitoring the populations of vulnerable species.

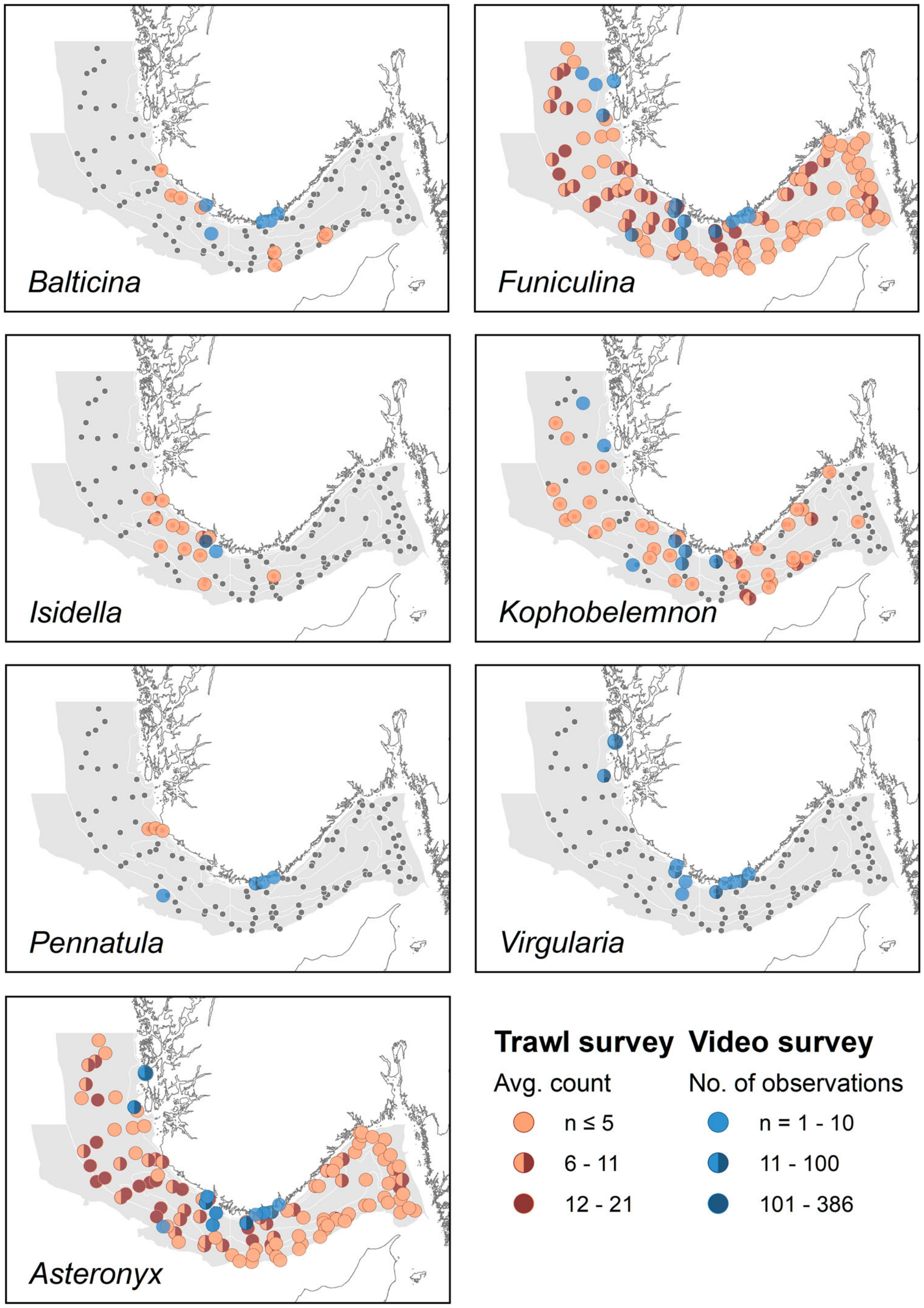

Figure 3. The distribution and abundance of the bamboo coral *Isidella* and the five sea pen species, *Balticina*, *Funiculina*, *Kophobelemnon*, *Pennatula* and *Virgularia* in the study area. For comparison, the bycatch numbers of the brittle star *Asteronyx* that is closely associated with *Funiculina* are also provided. Orange-brown circles show average number of colonies sampled per trawl station during the period 2017–2021 provided in three abundance ranges. Blue circles represent numbers of observed colonies at Oceana ROV stations provided in three ranges.

Also, the small and delicate sea pen *Virgularia*, not present in trawl bycatches, occurred in large numbers on the videos. This can be explained by its small size and its ability to withdraw into the sediment but could also be due to its association with watery fjord sediments that was documented by the ROV transects but not well covered by the trawl survey stations.

The trawl bycatches were documented using photos and detailed inspection of colonies for identification was not possible, however, the sea pens and bamboo coral collected or observed were easy to recognize based on their large-scale morphology. Quantification was sometimes difficult when bycatches were large, and many colonies broken.

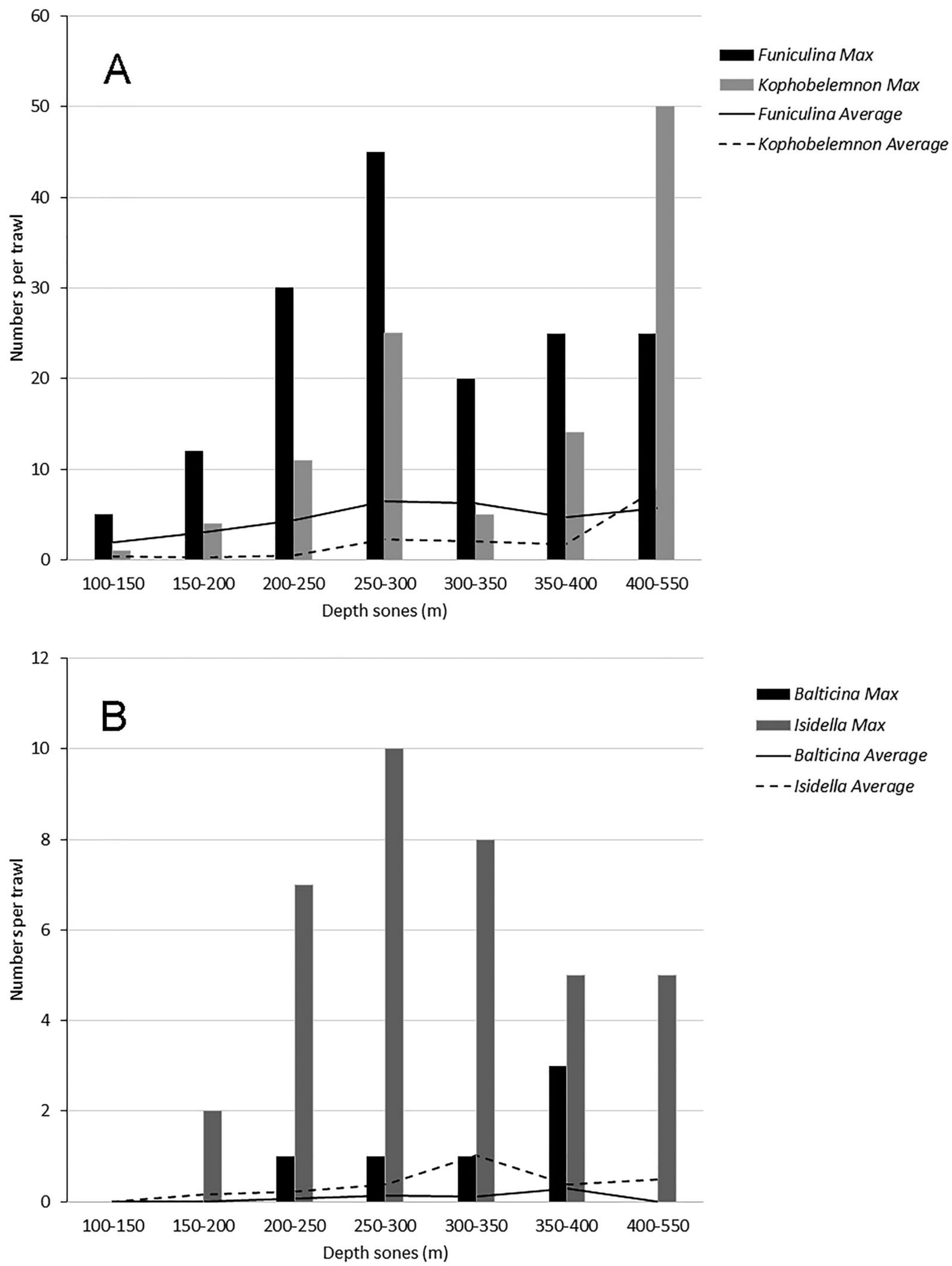

Figure 4. (A) Records of the sea pens *Funiculina* and *Kophobelemnon* and (B) *Balticina* and the bamboo coral *Isidella*, in different depth zones in the study area. Columns are the largest number observed at a station within the depth zone and lines are average for all stations in a depth zone.

This problem was solved by counting only holdfasts or peduncles of colonies, however, the risk of missing out colonies when bycatches were large is substantial and did probably cause a bias towards smaller counts. Thus, we did not use the trawl data to estimate densities of the colonies on the seafloor but instead compared abundances between survey stations based on average numbers in trawl catches from each sampling station from the survey period 2017–2021.

Distribution and vulnerability

Commercial fisheries for demersal species are intense in Skagerrak and the Norwegian trench and represent a potential threat to VMEs in the area. Figures 8 and 9 show the distribution of fisheries with demersal trawl during the last 5-year period. Trawling is most intense on the slope in Skagerrak and the Norwegian trench, and the central deeper part of Skagerrak has

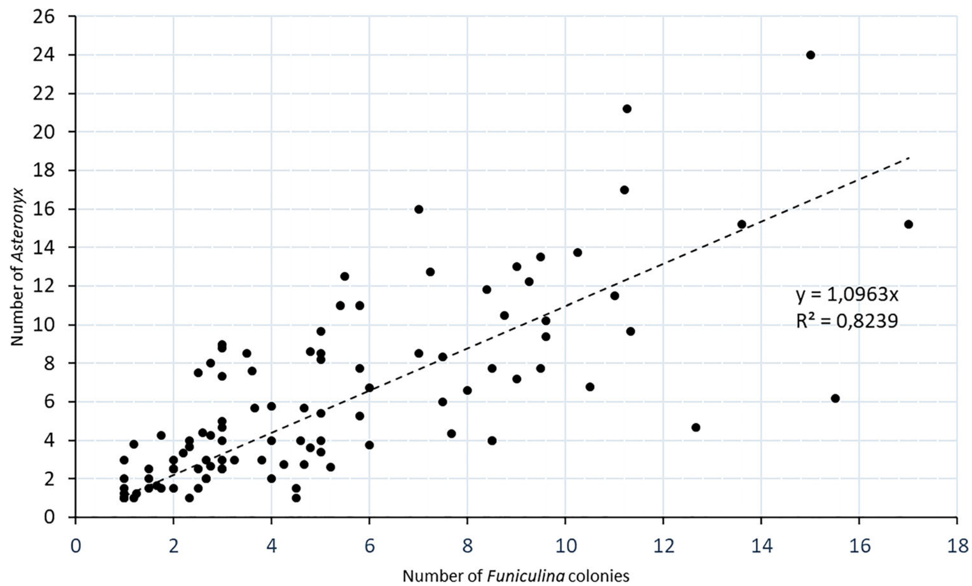

Figure 5. The relation between bycatch numbers for *Asteronyx* and its host *Funiculina*. R^2 and the y value for the linear equation are provided. The equation shows that the relation between the brittle star and its host is close to one to one. The slightly larger value (1.1) indicates that a single colony can have more than one specimen attached, which is in line with ROV observations (see Figure 6A).

Table IV. The 17 ROV stations (out of 35) where observations of sea pens and corals were made.

Name	Station	Depth (m)	Sediment type	*Virgularia*	*Funiculina*	*Asteronyx*	*Kophobelemnon*	*Isidella*	*Pennatula*	*Balticina*	SUM
N.T. Skagerrak ROV 11	SK11	68	Sand, mud, boulders	1					30		31
N.T. Skagerrak ROV 16	SK16	120	Mud, sand, rocks		7				2		9
N.T. Skagerrak ROV 13	SK13	146	Sand, mud	2	5	1			2	5	15
Norwegian Trench 2	NT2	149	Sand, mud		20	9	1		2		32
N.T. Skagerrak ROV 14	SK14	210	Sand, mud	43						9	52
Karmoy ROV 5	R5	213	Sand, mud	16	42	1	5				64
Karmoy ROV 2	R2	227	Sand, mud, boulder		2						2
N.T. Skagerrak ROV 17	SK17	248	Mud, sand, rocks		2						2
N.T. Skagerrak ROV 18	SK18	255	Sand, mud	3	6					6	15
Karmoy ROV 1	R1	278	Sand, mud		10		2				12
Karmoy ROV 8	R8	293	Sand, mud, rocks	11	8						19
N.T. Skagerrak ROV 2	SK2	317	Sand, mud	34	52	30	85	115			316
N.T. Skagerrak ROV 7	SK7	353	Sand, mud	4	35	29	32			2	102
Karmoy ROV 7	R7	357	Sand, mud	386	28	2					416
N.T. Skagerrak ROV 6	SK6	380	Sand, mud	2	95	102	28	5			232
N.T. Skagerrak ROV 1	SK1	398	Sand, mud	6	21	7				2	36
N.T. Skagerrak ROV 10	SK10	411	Sand, mud	16	31	14	22				83
				524	364	195	175	120	36	24	1438

Stations are sorted by depth (in metres) and information on substrate is listed together with observed number of colonies and the ophiuroid Asteronyx associated with Funiculina. Positions of stations are given in Figure 3.

little trawling. Still the overlap with sea pen habitats is large. Figure 9 shows that the highest numbers of sea pens are related to areas that are trawled less than 200 h per grid cell. This relation could be explained by removal of sea pens by trawling, alternatively the best sea pen habitats are not co-occurring with areas where trawling is most intense. The ROV videos from areas with high trawling intensity show damaged sea pens and trawl marks (Figures 10 and 11).

Sea pen VME

Funiculina is widely distributed and occurs in large numbers locally in the study area (Figure 3) but is still under pressure from bottom trawling in most parts of its distribution area (Figure 8). Greathead et al. (2015) has reported this species as of the greatest conservation importance within the Greater North Sea and Celtic Sea. Unlike the other sea pen species, *Funiculina* is unable to withdraw into the sediment (Greathead et al. 2015) and is therefore probably more susceptible to damage from bottom trawling.

Skeletons of dead *Funiculina* colonies were observed at three ROV transects and this, together with the large numbers recorded in the trawl bycatches, indicates that it is vulnerable to bottom trawling (Figure 10). The rare anemone *Ptychodactis patula* was found on *Funiculina* at stations SK6 and SK10 (Figure 6B). This anemone that has been reported to be associated with octocorals (Appelöf 1893) has a morphology adapted to preying on the sea pens (Cappola and Fautin 2000). Tissue damage and exposed skeleton are common on corals, resulting from fishing gear, and this was observed at several

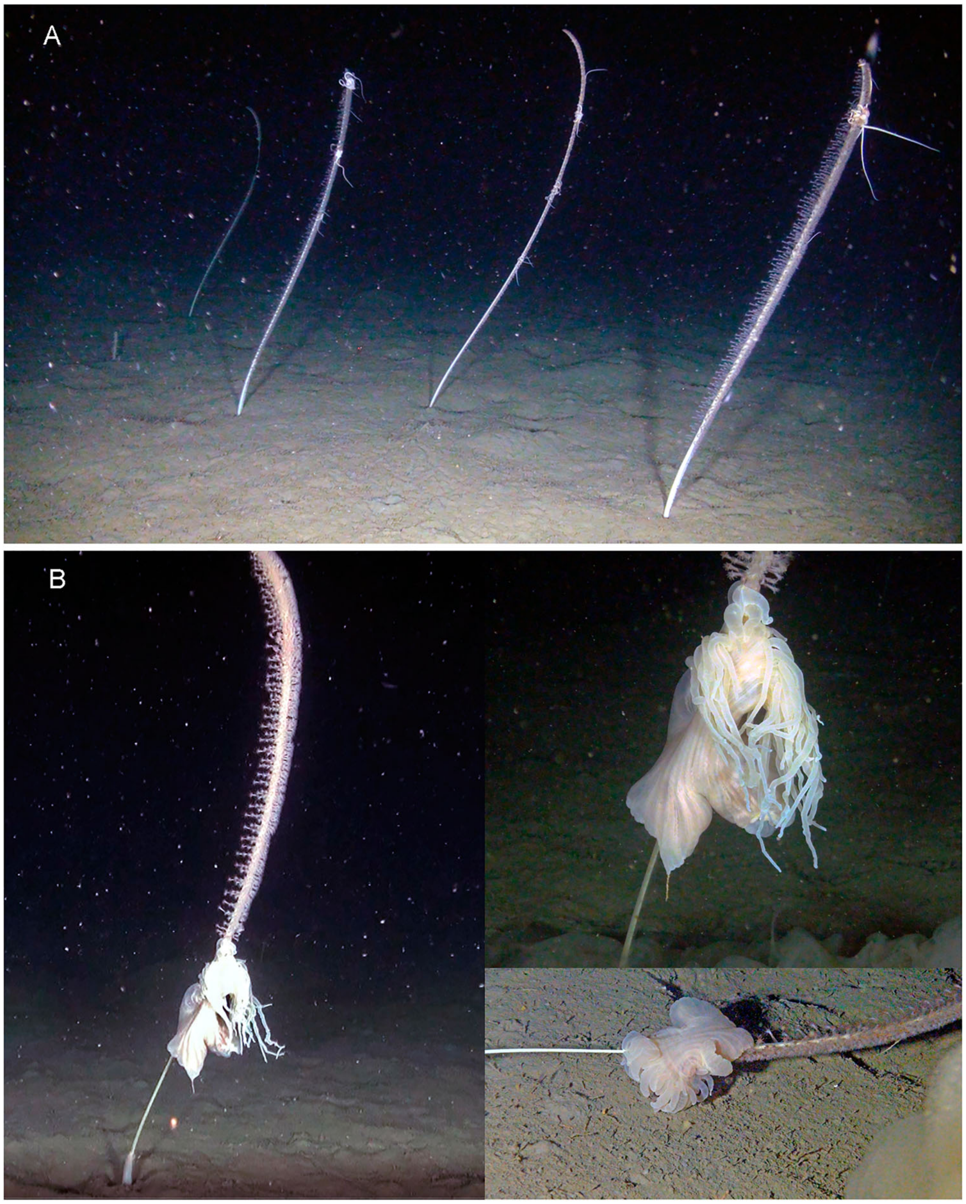

Figure 6. *Funiculina* was the most common sea pen in the trawl bycatches. (A) Photo from ROV transects conducted at station SK 6 showed high densities (~3 colonies per m^2) with the symbiont brittle star *Asteronyx* present on all colonies. (B) The sea pen predator anemone *Ptychodactis patula* was found eating tissue of the sea pen skeleton.

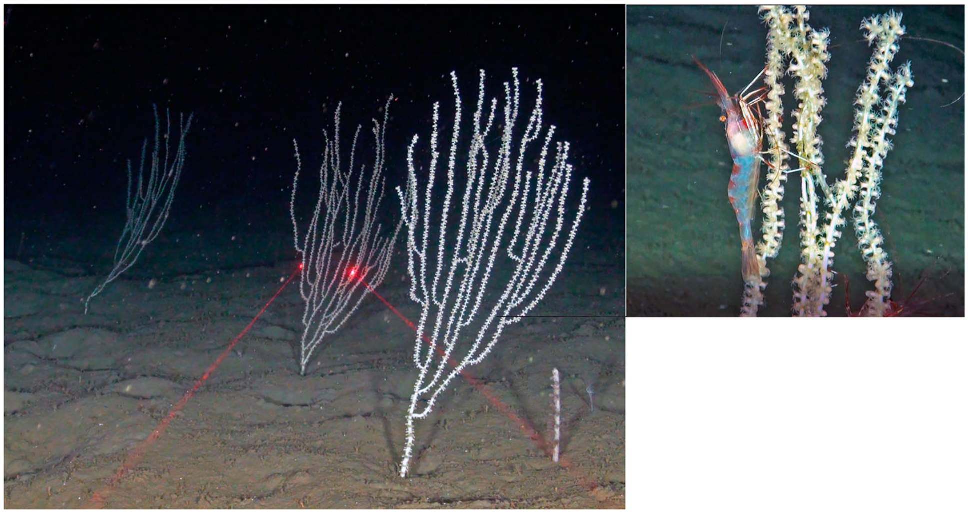

Figure 7. The bamboo coral *Isidella lofotensis* was documented in densities of several colonies per m^2 on video from the ROV station SK2. As do many other gorgonians (laser scale (red dots) is 5 cm), *Isidella* provides a habitat that allows for other organisms, here a pandalid shrimp, to hide amongst the branches away from predators (photo from ROV station SK6).

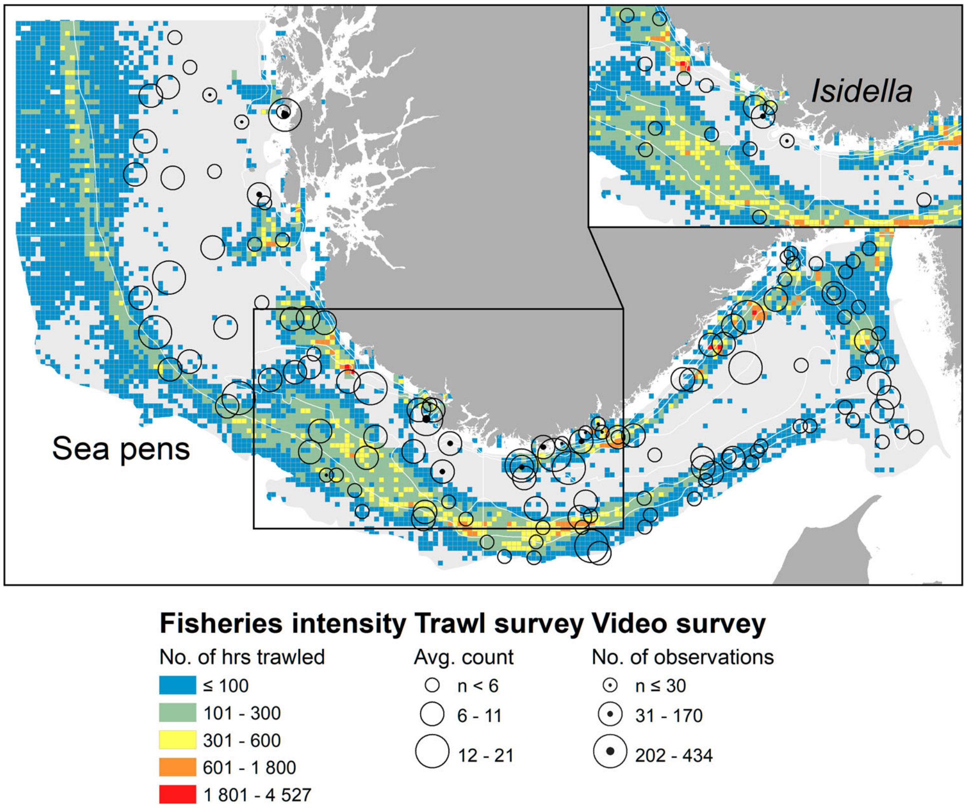

Figure 8. Occurrences of sea pens (all species combined, whole area) and *Isidella* (inserted figure) in relation to bottom trawling intensity in the study area. Fisheries intensity is shown as the number of hours trawled per 5 × 5 km^2 grid cell, using fisheries statistics for 2016–2020 provided by the Norwegian Fisheries Directorate, Open data: electronic reporting (ERS) (fiskeridir.no).

ROV stations (Figure 10). Mortensen et al. (2005) observed that anemones can colonize exposed coral skeleton and then prey on the live parts of the colony. In Figure 6B we can see dead tissue near the anemone where it likely has foraged on the sea pen. The presence of *P. patula* could be related to damage to *Funiculina* from the intense bottom trawling in the area.

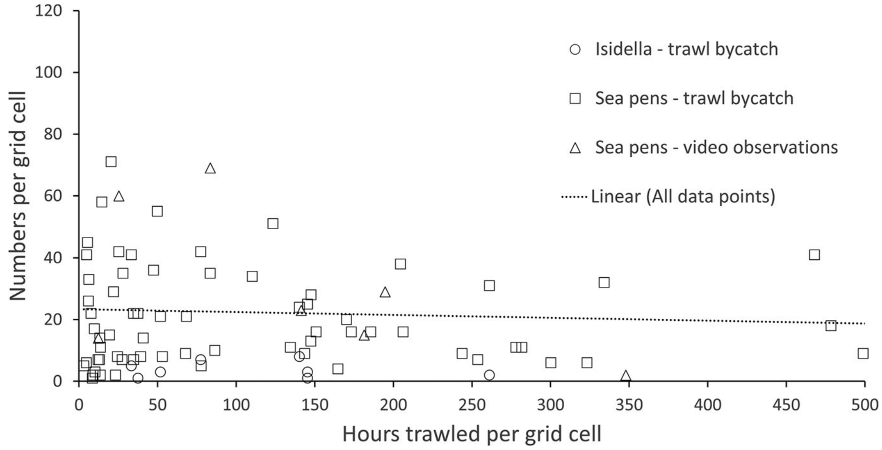

Figure 9. Relationship between trawling intensity (hours per grid cell) and total numbers of sea pens and *Isidella* sampled as trawl bycatch from the IMR shrimp survey from 2017–2021, and sea pens recorded on the OCEANA ROV stations in 2016 and 2017. Recorded colonies are provided as number per grid cell where trawl activity was also recorded (see Figure 8). The dotted trend line shows the relation between recorded number of colonies and fishing intensity.

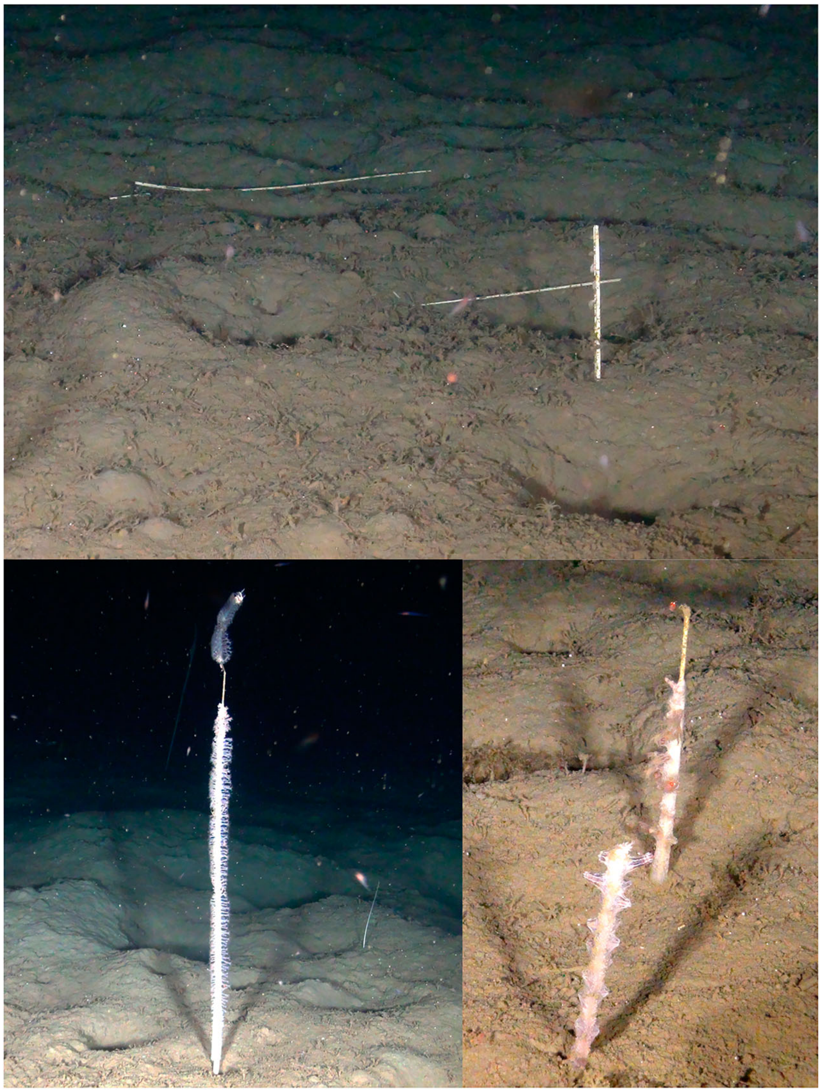

Figure 10. Damage to sea pens presumably from trawling at station SK2. At the top is a *Funiculina* skeleton and to the left below a colony with damaged tip of colony. At the bottom right are two *Kophobelemnon* colonies, the one in the back with damaged tip of colony.

Figure 11. Trawl marks at station NT2. At the top is a *Funiculina* colony in front of lines from chain or bobbins. Below, is a squat lobster *Nephrops norvegicus* in between trawl marks.

Funiculina constitutes an essential habitat to *Asteronyx* (Fujita and Ohta 1988) and provides the brittle star with an elevated position for preying on small pelagic animals, mainly copepods. Catches of *Asteronyx* showed a clear correlation with catches of its host (Figure 5), and they appear to occur in a one-to-one ratio as has been reported by De Clippele et al. (2015) from Norwegian waters. In trawl bycatches the brittle star can lose its grip and the sea pens are often broken. Thus, they may not be evenly distributed amongst the host colonies collected in a trawl. The video records (Figure 6A) show that a single colony can have more than one specimen attached.

Kophobelemnon was like *Funiculina* common and widely distributed in the study area but with a deeper maximum of occurrence (Figures 3 and 4). Finer sediments with a higher water content are probably more suitable for this smaller sea pen that can fully withdraw into the sediment. Even though it occurs in areas with large trawling intensity (Figure 8) its ability to withdraw into the sediment might make it less susceptible to bottom trawling. Even so, the occurrence in the bycatches indicates that it is dislodged by trawl but to a lesser extent than *Funiculina.* ROV observations also documented damage to this species (Figure 10). The squat lobster *Munida sarsi* that is very common in the study area is known to associate with *Kophobelemnon* (De Clippele et al. 2015).

Balticina, a large sea pen with a very limited distribution in the study area, might also be at risk from fisheries.

Coral gardens VME

Isidella lofotensis is the key species of an OSPAR habitat that is at special risk because it occurred only in a very small and well-defined part of our study area. In 2018, 'Bamboo coral forest' was added to the Norwegian Red List for Ecosystems and Habitat Types, under the category of Endangered (i.e. very high risk of becoming extinct). The aim of this list is to give decision-makers better knowledge for biodiversity management, although it does not mandate legal protection. Our observations show that this Red Listed habitat with a very limited distribution in the study area is in an area that is frequently trawled (Figures 8 and 9) and thus is at high risk of local extinction. However, the ROV transect at SK2 showed that *Isidella* can occur in dense populations locally (Figure 7). This species is viewed as endemic to Norway (Buhl-Mortensen et al. 2015) and outside the Skagerrak area it has been reported mainly from fjords (Buhl-Mortensen and Buhl-Mortensen 2014). *Isidella* colonies offer a habitat for shrimps that were observed hiding amongst the branches of colonies (Figure 7). Corals are known to provide valuable habitat for crustaceans (Buhl-Mortensen and Mortensen 2005; Buhl-Mortensen et al. 2010; De Clippele et al. 2015).

Future needs

We have shown that trawl bycatches can provide valuable information on the distribution and abundance of VMEs, but the recorded colonies in bycatches can only provide minimum estimates and come from a sampling method that is a threat to most VMEs. Actual density and health status for VMEs can only be gained by conducting detailed visual mapping in this understudied area. Even so, our results show an immediate need for protection of the 'Bamboo coral forest' in the study area followed by visual mapping and monitoring to allow for evaluation of ecological status and to be able to suggest relevant protection areas based on firm knowledge.

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Disclosure statement

No potential conflict of interest was reported by the author(s).

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