

Distribution and abundance of fish in deep-sea coral habitats

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Abstract

Experimental fishing with long-lines and gillnets was conducted on the continental shelf off southwestern Norway between 150 and 350 m depth. Abundance and distribution of redfish (*Sebastes marinus* L., 1758), ling (*Molva molva* L., 1758), and tusk (*Brosme brosme* Ascanius, 1772) were quantified in *Lophelia pertusa* (L., 1758) coral reefs and in non-coral habitats. The largest catches of redfish were made with long-line fleets set in coral reef habitats. Ling and tusk were also most numerous in coral habitats, although not statistically significant. Fish caught in coral habitats tended to be larger in size than in non-coral habitats. The diet of redfish, tusk and ling included the same prey groups in all habitats, but they differed at the species level. *Lophelia*-reefs may provide a profitable feeding place for tusk. For the planktivorous *Sebastes*, on the other hand, their affinity to the reefs seems primarily to be related to the physical structure offered by the reefs.

Introduction

Lophelia pertusa is a deep-sea colonial bank-forming scleratinian coral (Zibrowius, 1980; Rogers, 1999) that builds structures several hundred metres in diameter and up to 25 m above the surrounding seabed (Hovland et al., 1994; Mortensen, 2000). *L. pertusa* has a wide geographical distribution, ranging from 55° S to 71° N (Dons, 1944; Cairns, 1982), found in the North Atlantic, the Mediterranean, the Indian Ocean and the Pacific Ocean at depths between 50 and 2000 m (Jungersen, 1917; Cairns, 1994). *L. pertusa* in the Northeast Atlantic is often found on the continental shelf and shelf areas from 200 to 400 m depth between 4 and 8 °C (Dons, 1944; Stromgren, 1971). The largest concentrations of reefs in Norway are found along the continental break and the upper slope, at depths of 200-500 m (Fossa et al., 2000).

Lophelia-reefs host a rich fauna of invertebrates and fish (Dons, 1944; Burdon-Jones & Tambs-Lyche, 1960; Jensen & Frederiksen, 1992; Fossa & Mortensen, 1998), with almost 800 species occurring on reefs in the Northeast Atlantic Ocean. The number of species that live on these reefs has been estimated to be three times as high as on the softer

surrounding seabed (U.K. Biodiversity Group, 2000). Recent investigations show aggregations of redfish (*Sebastes* spp.), ling (*Molva molva*), tusk (*Brosme brosme*) and saithe (*Pollachius virens*) on *Lophelia*-reefs (Mortensen et al., 1995; Furevik et al., 1999), indicating that the reefs are attractive as habitats. Deep-sea corals may also play a role in the reproduction cycle of the most common redfish species, *Sebastes viviparus* (Kroyer, 1844) (Fossa et al., 2000).

In the past decade, bottom trawls used in commercial fisheries have been fitted with rockhopper ground gear that minimises escape of fish under the footrope (Engas & Godo, 1989). Rockhopper gear is heavier than many traditional bobbin gear configurations, and allows the footrope to remain close to the bottom while still protecting the net. These heavy gears cause severe negative effects on sensitive benthic habitats, such as the coral reefs (Fossa et al., 2002). Due to increased trawling activity on the deeper continental shelves and slopes, there is an urgent need for better knowledge of the biology and ecological function of deep-sea coral reefs.

The aim of this investigation was to study the potential importance of *Lophelia*-reefs for fish. This was done by performing an experimental fishery with long-

62°N

5°E

Figure 1. Aktivneset (circle) and Stbrmannsneset (triangle) on the continental break off southwestern Norway. Depth isolines in metres.

lining and gillnet to quantify the distribution of redfish, ling and tusk in coral and non-coral habitats. The feeding of fish in these habitats was studied by stomach content analysis.

Study area

The surveys were carried out at Aktivneset and Sormannsneset located at the continental break off southwestern Norway (Fig. 1). The *Lophelia-reefs* in this area cover a depth range of 150-400 m (FossA et al., 2000, 2002). Furevik et al. (1999) gave a description of the bottom conditions based on ROV observations. They showed that the bottom substrate alternated between corals, soft bottom and rocks. Muddy bottom substrate was mostly seen at Sormannsneset. The most conspicuous macrobenthos observed over soft bottom were sponges (e.g. *Phakellia ventilabrum*, Johnston, 1842) and sea pens (e.g. *Pennatula phosphorea*, L., 1758). The fish species on sand and softer bottom included cod, haddock, saithe and greater fork-beard. Skates and ratfish (*Chimaera monstrosa*, L., 1758) were mostly observed at Sormannsneset (Furevik et al., 1999). In the coral habitat, the most commonly observed macrofauna were sponges, gorgonians (*Paramuricea placomus* (L., 1758), *Paragorgia arborea* (L., 1758), and *Primnoa resedaeformis* (Gunnerus,

1763)), soft corals (*Capnella* sp.), squat lobsters (*Munida* spp.), crabs (*Lithodes* sp.), sea urchins (*Cidaris cidaris* L., 1758) and ophiuroids (Furevik et al., 1999). Redfish, tusk and saithe dominated the fish fauna. Redfish was often observed in groups of three to seven individuals. They lay in between or swam slowly just above the coral colonies. Tusk and saithe were typically observed as solitary individuals swimming more actively around the coral branches (Furevik et al., 1999).

Materials and methods

Long-line fishing

The experimental fishery was conducted with the auto-long-line vessel M/V 'Nyvoll Senior' (length: 40.6 m) in June 1999 on Aktivneset. A total of 20 fleets of long-line were set, with 2200-2600 hooks (Mustad EZ-12.0) per fleet (Table 1). The hooks were baited with 50% mackerel, 25% herring, and 25% squid. In 1998, two studies were carried out on Sormannsneset using the long-lining vessel MN 'Nesbakk' (length: 34 m) and the combined gillnet and long-lining vessel M/V 'Anne Beate' (length: 24 m). A total of six fleets were set, with approximately 2400 hooks (Mustad EZ No. 12.0) per fleet. The hooks were baited with mackerel. The fleets were set in two coral habitats which were separated by deeper areas with muddy substrate. Soak times ranged between 3.5 and 10.7 h and may have influenced catch rates. Lokkeborg & Pina (1997), however, showed that most fish taken by long-lines were hooked within the first 2.5 h and there was no relationship between soak time and catch rates. Because of this we have not tried to correct catches for soak time.

Gillnet fishing

A total of 80 gillnets (two leeches of 40 nets each) were set. The monofilament nets were 27 m long and 5 m deep, with 140 mm stretched mesh size (70 mm half-mask mesh size). The total length of the leeches was 2160 m and their total fishing area was 10 800 m². Forty-three nets were set in coral habitats, and 37 in non-coral habitats from the continental slope towards shallower water on the continental shelf.

Table 1. Positions, depths and soak times for long-line fleets (L) and gillnets (G) on Aktivneset (I) and SØrmannseset (II)

Fleet No.	Date	Area	Gear	Position		Depth (m)	Soak time (h)
				N	E		
1	18.06.99	I	L	62.5420	3.5010	296	3.50
2	18.06.99	I	L	62.5005	3.5487	262	6.25
3	19.06.99	I	L	62.6270	3.4483	384	6.75
4	19.06.99	I	L	62.6002	3.5082	302	4.92
5	20.06.99	I	L	62.6212	3.4238	347	7.92
6	20.06.99	I	L	62.5945	3.4763	309	6.08
7	20.06.99	I	L	62.5278	3.4587	302	9.67
8	20.06.99	I	L	62.5633	3.4975	298	10.67
9	21.06.99	I	L	62.6025	3.3083	347	5.83
10	21.06.99	I	L	62.5800	3.5133	294	5.00
11	22.06.99	I	L	62.5723	3.5322	289	5.83
12	22.06.99	I	L	62.5975	3.5883	333	7.92
13	22.06.99	I	L	62.6175	3.6555	333	10.17
14	22.06.99	I	L	62.5942	3.6110	329	8.67
15	23.06.99	I	L	62.5660	3.6085	262	6.00
16	23.06.99	I	L	62.5910	3.6727	347	6.92
17	23.06.99	I	L	62.5682	3.7387	192	9.17
18	23.06.99	I	L	62.5638	3.6275	251	10.50
19	24.06.99	I	L	62.5828	3.5705	272	5.58
20	24.06.99	I	L	62.6050	3.7573	305	9.67
21	04.05.98	II	L	63.0783	5.1213	311	4.67
22	04.05.98	II	L	63.0695	5.1867	278	6.25
23	04.05.98	II	L	63.0800	5.1200	311	6.00
24	04.05.98	II	L	63.0850	5.1250	311	4.00
25	04.05.98	II	L	63.0800	5.1183	311	7.00
26	05.05.98	II	L	63.0900	5.1267	336	7.00
27	03.06.98	II	G	63.0842	5.0957	307	39.00
28	04.06.98	II	G	63.0570	5.0997	322	24.00

Classification of fishing habitats

The number and distribution of coral fragments caught on the long-lines (and gillnets) were used to define three different fishing habitats; coral, uncertain, and non-coral. Coral species caught on the long-lining hooks included *Paramuricea placomus*, *Lophelia pertusa*, *Paragorgia arborea* and *Primnoa resedaeformis*. Table 2 shows the distribution of fish and coral fragments along six long-line fleets that were classified as 'coral habitat', two fleets classified as 'uncertain' and three as 'non-coral habitat'. A long-line consists of about 2200-2600 hooks. Each long-line was divided into 22-26 units, and the numbers of fish and coral fragments were registered for every 100 hooks on each long-line. Every hook was counted and fish and coral fragments received a specific place

and number on each long-line. If the long-line caught many coral fragments along the whole length of the long-line, then that particular long-line was defined as fishing in a 'coral' habitat. If the long-line caught few coral fragments and only in certain sections of the long-line, then that particular long-line was defined as fishing in an 'uncertain' habitat. If the long-line did not catch any coral fragments, or very few, then that particular long-line was defined as fishing in a 'non-coral' habitat. Information from fishermen and echosounders were also used to justify the classification of long-lines in habitat groups.

Stomach analysis

Stomach content was collected from eight arbitrarily chosen fleets from Aktivneset. A total of 80 redfish,

Table 3. Total number of redfish, tusk and ling caught on Aktivneset (I) and Sormannneset (II)

Area	Date	N		
		Redfish	Tusk	Ling
I	18.-24.06.99	1556	2376	302
II	04.-05.05.98	346	609	67
II	03.-04.06.98	457	0	202

80 tusk and 38 ling were analysed. Samples from the oesophagus to the intestine were removed and frozen. The stomach content was identified to the lowest possible taxon. Demersal fish often have empty or destroyed stomachs when they are brought from deep water to the surface, partly as a result of the rapid fall in pressure. This was also the case in the present study and, therefore, the results are only used in a qualitative manner.

Statistical methods

Statview 5.01 (SAS Inc. 1998) was used for the statistical analysis of the fish data. Anova and Tukey/Kramer tests were used to test differences in number and standard lengths of redfish, tusk and ling caught in the three defined habitats.

Results

Fish catches

A total of 2359 redfish (*Sebastes marinus*), 2985 tusk and 571 ling were caught in the two areas (Table 3). Significantly more fish (all fish lumped together) were caught in coral reef habitats than in non-coral habitats with similar fishing effort (Figs 2 and 3). The average catch of redfish was 5.7 individuals per long-line on corals compared to 0.8 individuals per long-line in non-coral habitats. There were 1.6 times more tusk, and 1.7 times more ling on long-lines from coral reef habitats than from non-coral habitats (Fig. 2). Average catch of redfish was 3.6 individuals per gillnet in coral habitats and 2 individuals per gillnet in non-coral habitats (Fig. 3). There were 2.2 times more ling caught per gillnet on corals than in non-coral habitats, while tusk was not caught in gillnets. The commercially important cod, saithe and Atlantic halibut were caught in small numbers in both habitats. Haddock (*Melanogrammus aeglefinus* L., 1758), wolf fish (*Anarhichas*

minor L., 1758) and greater fork-beard (*Phycis blennoides* L., 1758) were mainly caught in coral habitats, while spurdog (*Squalus acanthias* L., 1758), skates (*Rajidae*) and rays (*Torpedinidae*) were numerous in non-coral habitats on Sormannneset, but not in coral habitats.

Fish length

Redfish, tusk and ling caught on corals were generally larger than fish caught in non-coral habitats (Table 4). Redfish and tusk had the highest mean lengths in the catches from the long-lines categorized as 'uncertain' on Aktivneset, whereas ling had the highest mean length when caught on corals. The largest redfish and ling (statistically significant) were caught on corals on Aktivneset, and for ling also in coral habitats on Sormannneset (Table 5). Tusk showed little variation in mean length between the areas. The largest individuals of tusk were found in long-line catches from uncertain and non-coral habitats on Sormannneset (Table 4).

In the gillnet catches, no significant differences in mean length were found for redfish and ling on Sormannneset (Table 5). The highest mean length for redfish was found in non-coral habitats, while the largest individuals of ling were from coral reefs (Table 4).

The diet of the fish

The stomachs of redfish contained exclusively zooplankton in all three habitats (Fig. 4). Copepoda, *Eucyanea* sp. and *Themisto* sp., dominated in coral and uncertain habitats, while *Themisto* sp. and *Calanus finmarchicus* (Gunnerus, 1770) together with other Copepoda were most abundant in fish from non-coral habitats.

Ling preyed on fish and crustaceans. Much of the stomach content was not possible to identify and made it difficult to detect differences in feeding between the habitats.

Benthic decapods, represented by the groups *Munida* spp., *Lithodes maja* (L., 1758) and unidentified Decapoda dominated the food of tusk. The second and third most important food, were fish and polychaetes, respectively.

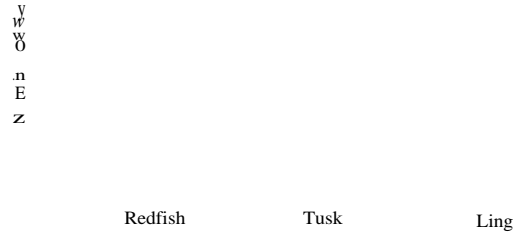


Figure 2. Average catch per long-line with standard deviation in coral reef habitats (grey) and in non-coral habitats (white). Fish catches are averaged for Aktivneset and Starmannseset.

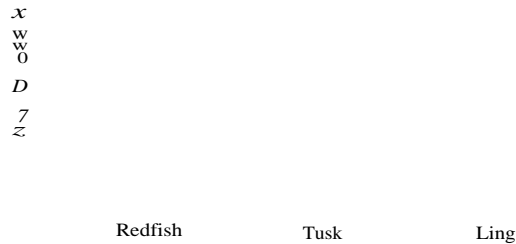


Figure 3. Average catch per gillnet with standard deviation in coral reef habitats (grey) and in non-coral habitats (white) on Sormannseset. Note that tusk was not caught in gillnets.

Discussion

Fish catches

Areas off the coast of mid-Norway, including Aktivneset and Sormannseset, have been important fishing grounds for decades where the fishermen try to position gillnets and long-lines close to the coral reefs in order to obtain higher catches (Fossil et al., 2000). There are, however, very few studies showing the importance of particular deep-sea benthic habitats for fish in these areas. In the northern part of the Mid-Atlantic ridge sub-arctic species such as *Sebastes* spp. and tusk are dominant (Hareide & Games, 1998), an indication that redfish and tusk are associated with deep-sea benthic habitats.

This study shows that fish aggregate on deep-sea coral reefs. Hovland & Mortensen (1999) observed redfish (*S. viviparus* and *S. marinus*), tusk and saithe in *Lophelia*-habitats by means of underwater video. On Aktivneset and Sormannseset, Furevik et al. (1999) observed the same species. Our experimental fishery also registered ling in considerable numbers on *Lophelia*-reefs, although they have seldom been observed by underwater video camera (Furevik et al., 1999). Tusk and ling are commercially import-

ant species in the fisheries off the Faroes and along the Norwegian continental shelf. Norwegian long-line fishermen have indicated that there has been a marked reduction in catches of ling and tusk in areas on the continental shelf previously containing corals (Fossil et al., this volume). The reduction in deep-sea coral habitats due to extensive trawling may explain part of this situation.

The food offish on *Lophelia*-reefs

Stomach samples from deep-water fish are often very difficult to quantify. Fish with closed swimbladders generally lose the stomach content when they are brought to the surface (Gundersen, 1996). This was also the case in the present study and therefore the results are only treated in a qualitative manner.

Redfish mostly fed on copepods and is in accordance with earlier studies. In the Northeast Atlantic, redfish are known to be planktotrophic predators with euphausiids and calanoid copepods, especially *Calanus hyperboreus* (Krtbyer, 1838) and *C. finmarchicus* as important prey (Palsson, 1981; Pedersen & Riget, 1993). The most noticeable pattern in this study was that *Euchaeta* sp. was not registered at all in non-coral habitats while it was a major food item in

Table 4. Total number, mean length and standard error of redfish, ling and tusk caught on Aktivneset (I) and Stbrmanneset (II, IIg = gillnet). The catches are divided into three habitat types: coral, uncertain and non-coral

Area	Species	Coral			Uncertain			Non-coral		
		N	Mean length	Standard error	N	Mean	Standard error	N	Mean length	Standard error
I	Redfish	1120	40.14	0.13	309	40.37	0.19	127	38.23	0.53
I	Ling	165	95.89	1.20	46	91.33	2.70	91	86.96	1.75
I	Tusk	1200	50.88	0.27	526	52.29	0.38	650	51.00	0.33
II	Redfish	239	39.34	0.42	66	36.82	1.01	40	38.50	0.79
II	Ling	44	92.41	1.71	4	84.00	11.02	18	78.50	1.78
II	Tusk	294	56.61	0.39	128	56.91	0.55	187	56.90	0.46
Hg	Redfish	313	41.34	0.27				144	41.76	0.28
IIg	Ling	146	97.72	0.88				56	96.98	1.65

Redfish

Coral N=50	Uncertain N=20	Outside N=10	
			p Copepoda
			<i>O. Calanus finmarchicus</i>
			<i>O. Eucheata sp.</i>
			<i>O. Themisto sp.</i>
			• Euphausiacea
			• Unidentified
			N Polychaeta
			© <i>Eunice norvegica</i>
			M Amphipoda
			E3 Decapoda
			<i>13. Yhtnida spp.</i>
			® <i>Litodes maya</i>
			17 Pisces
			N Gadidae
			<i>O. Micromesistius poutassou</i>
			<i>N. Maurolicus muelleri</i>
			® <i>Argentina silus</i>
			• Unidentified

Tusk

Coral N=50	Uncertain N=20	Outside N=10	
			N Polychaeta
			© <i>Eunice norvegica</i>
			M Amphipoda
			E3 Decapoda
			<i>13. Yhtnida spp.</i>
			® <i>Litodes maya</i>
			17 Pisces
			N Gadidae
			<i>O. Micromesistius poutassou</i>
			<i>N. Maurolicus muelleri</i>
			® <i>Argentina silus</i>
			• Unidentified

Ling

Coral N=25	Uncertain N=3	Outside N=10	
			O Crustacea
			® Isopoda
			O Pisces
			M Gadidae
			• Unidentified

Figure 4. Relative number of food items from major taxonomic groups in stomach contents of redfish, ling and tusk, caught in different habitats.

Table 5. Differences in fish length for Aktivneset (I) and Sormannneset (II). Unpaired t-test where group 1 = coral, 2 = uncertain, and 3 = non-coral. P-values for redfish, ling and tusk are shown for individual areas

Area	Test-	P-value		
		Redfish	Ling	Tusk
I	1,2	0.3846	0.0902	0.0032
I	1,3	<0.0001	<0.0001	0.7826
I	2,3	<0.0001	0.1639	0.0098
II	1,2	0.0089	0.1989	0.6633
	1,3	0.4355	<0.0001	0.6329
II	2,3	0.2440	0.3771	0.9885
	1,3	0.3375	0.6735	-

the two other habitats. Whether this is a consequence of selective feeding or a result of prey availability is not known.

Ling fed on fish and to a smaller degree on crustaceans. In general, this confirms with the results of Bergstad (1991). He found that ling was highly dependent on benthopelagic fish, crustaceans and cephalopods. Tusk preyed predominantly on epibenthic decapods, e.g. *Munida* spp. and *Lithodes maja*, while fish were eaten to a small extent. This is in good agreement with the findings of Mortensen et al. (1995) who report that the squat lobster, *Munida sarsi* (Huns, 1935), is 10 times more common in the coral rubble zone on a *Lophelia*-reef than in the surrounding soft bottom. Bergstad (1991) found that tusk are highly dependent on benthopelagic fish and usually feed in the near-bottom zone.

The diet of benthic fish on the Norwegian continental shelf often reflects prey availability in the area (Hoines & Bergstad, 1999). Results from the present study indicate that each fish species prey upon similar groups, both within the coral-habitat and outside, while adjusting their diet according to what is available in the coral habitat.

Why are fish associated with deep-sea coral reefs?

Fossa et al. (2000) and Mortensen (2000) suggested several hypotheses to explain why some fish seem to be attracted to the reefs; (1) enhanced feeding possibilities, (2) hiding place, (3) nursery area.

In general, redfish seem to be energetically independent of reef production, since they are planktivorous. However, it has been suggested that hydrographically mediated factors can increase the density of zooplankton on the reefs (Mortensen, 2000), as has

been reported in e.g. seamounts (Dower & Mackas, 1996). If this is true, then planktivorous fish might benefit from this enhanced food availability associated with coral reefs. On the other hand, tusk may benefit from benthic production on the reefs since benthic decapods play a significant role in its diet on the reefs. Mortensen (2000) reports a different composition of the associated reef-fauna on the up-current side of the reefs compared to the down-current side, and suggests that this is a consequence of an increased retention of particles on the down-current side. This may increase the sedimentation rate and provide a more favourable habitat for suspension feeders. This is proposed as a mechanism which in general may increase the production of benthic organisms in a reef area (Mortensen, 2000).

Redfish, tusk and ling, all tended to be larger on the reefs than in non-coral habitats. Whether this reflects enhanced feeding conditions on the reefs, or that large fish actively seek the coral habitat, is difficult to evaluate based on the present knowledge.

Gravid redfish with extended bellies have been observed in dense aggregations on the reefs during springtime. It has been hypothesized that juveniles may be released in the coral habitat for the purpose of protection, either of the females or the juveniles, or both (Fossfi et al., 2000). Although close-ups from visual recordings can distinguish between planktonic organisms such as copepods, euphausiids, chaetognaths etc., there are so far no records of larvae or juvenile fish in the coral reef environment (J.H. Fossa, pers. obs.).

The Norwegian Coastguard has inspected 30110 wrecks of ships along the Norwegian coast, including the German battleship 'Scarnhorst' at 298 m depth, which was sunk by allied forces off Finnmark in northern Norway. Video inspections from 'Scarnhorst' showed large concentrations of redfish in a very similar fashion to that observed on *Lophelia*-reefs (J.H. Fossa, pers. obs.). According to Arne Nagell Dahl (the Coastguard, pers. comm.) redfish are always associated with wrecks. *Sebastes* spp. are also often found in the vicinity of large sponges, often 'resting' or hiding in their concavities, and among stones that form distinct features above the bottom (Fossa, pers. obs.). Thus, it seems that it is the physical structure encountered on coral reefs or wrecks, rather than the special nature of corals, that is attractive to the redfish. Nevertheless, we cannot rule out the possibility of a more close biological relation between deep-sea coral reefs and redfish.

Conclusions

This is the first study in the Northeast Atlantic that investigates the abundance and feeding of commercially important fish in deep-sea coral habitats. From our findings we conclude that:

Redfish were significantly more abundant in coral habitats compared to non-coral habitats.

- (2) Ling and tusk were more numerous in deep-sea coral habitats compared to non-coral habitats. The results are, however, not statistically significant.

Redfish, tusk and ling from coral habitats tend to be larger than fish caught in non-coral habitats, although this was not statistically significant.

Redfish may not be energetically linked to reef production while tusk seems to be linked through its feeding habits.

It is hypothesised that the affinity of redfish to coral reefs seems related primarily to the physical structure of the reefs rather than its ecosystem function.

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