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Effet de la pêche commerciale sur le gisement de pétoncles d'Islande (*Chlamys islandica*) de l'Île Rouge dans l'estuaire du Saint-Laurent : impact sur les pétoncles et la communauté benthique.

Effect of the commercial fishery on the Ile Rouge Iceland scallop (*Chlamys islandica*) bed in the St. Lawrence estuary: assessment of the impacts on scallops and the benthic community.

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RÉSUMÉ

Plusieurs études ont montré que la pêche au pétoncle constitue une perturbation majeure des fonds marins. Nous avons tenté d'évaluer les impacts du dragage sur les pétoncles et les communautés benthiques sur le gisement de pétoncles d'Islande de l'île Rouge, situé dans le Parc Marin du Saguenay-St-Laurent. Un échantillonnage photographique ainsi qu'un dragage expérimental ne permettent pas de conclure à un effet de la pêche sur les communautés benthiques de cet écosystème très dynamique (fort courant, zone de remonté d'eau, etc.). De plus, aucune évidence significative n'a été observée récemment montrant une diminution de la taille des pétoncles au débarquement, contrairement à plusieurs études et ceci, pourrait être attribué à un effort de pêche relativement faible. Le milieu étudié, un substrat meuble constitué de sable et de gravier, avec un régime hydrodynamique comportant de très forts courants s'avèrent un milieu où les effets des perturbations causées par les engins de pêche peuvent s'estomper après quelques mois.

ABSTRACT

Many studies have shown that scallop dredging seriously disturb marine substratum. This study was done to evaluate the dredging impact on scallop and benthic communities on the Ile Rouge Icelandic scallop bed, in Saguenay-St-Lawrence Marine Park. The results of photographic sampling and experimental dredging did not showed effects of dredging on benthic communities on this highly dynamic ecosystem (high velocity currents, upwelling zone, etc.). Furthermore, there is no evident sign of a decline in the size of scallops, contrary to many studies around the world and this could be the result of a relatively low fishing effort. The study site, a sandy-gravel substrate with high velocity currents recover in a few months from the impacts of dredging gear.

1. INTRODUCTION

The Ile Rouge Iceland scallop (*Chlamys islandica*) bed is situated near the mouth of the Saguenay River in the St. Lawrence estuary. It is the farthest upstream bed known in the estuary. This bed overlaps two scallop management units and has been harvested by commercial fishermen since 1998. The fishery is carried out partly within the boundaries of the Saguenay–St. Lawrence Marine Park (SSLMP). In 1999, DFO initiated a study, in co-operation with the SSLMP, to assess the effects of the scallop fishery on the Ile Rouge bed.

There is an important and growing concern about the effects of fishing on the sea floor in the present context of species and habitat conservation. In a literature review on this topic, Hartog and Archambault (2002) stated that the impacts may be far-reaching and may include disturbance of both fishery-targeted species and associated species, along with alteration of the physical environment (see also Løkkeborg 2005) for a recent review). Mobile gear dragging over the sea floor displaces marine organisms and stirs up sediment. Dredging for shellfish, particularly scallops, is the type of fishing that causes the greatest disturbance of the sea bottom (Collie et al. 2000; Eleftheriou 2000). Scallop dredging has obvious impacts on bottom substrates because the dredge comes into direct contact with the sea floor, displacing substrate material and resuspending surficial sediments (Currie and Parry 1996; Jennings and Kaiser 1998). The effects of fishing vary with the type of gear used, the bottom substrate, the natural disturbance regime and the species that are present (Collie et al. 2000; Kaiser et al. 1998).

Because it lies within the Saguenay–St. Lawrence Marine Park, the Ile Rouge bed, owing to its geographic location and its conservation status, falls within the jurisdiction of both park management and DFO's Science Branch. A special management context exists because of the need to preserve the commercial resource and conserve the biodiversity of the benthic communities associated with scallop aggregations. The Ile Rouge bed has one of the highest densities of Iceland scallops found in Quebec. However, given the small area (22 km^2, MPO 2003) of the bed and the knowledge gaps that exist in relation to its dynamics, the scallops' growth rate and the provenance of recruits and their renewal rate, a cautious management approach is recommended.

A study has been undertaken to characterize the Ile Rouge bed and to assess the impact of the scallop fisheries. Earlier studies have provided a knowledge base on the biology and ecology of the bed. Arseneau et al. (2002) described the specific characteristics that set this benthic community apart from the communities of adjacent sectors. These authors found that the benthic communities associated with the Ile Rouge bed are characterized by a high abundance of ophiurids, in contrast with communities outside the bed, which are dominated by polychaetes and bivalves.

The present falls under the tread of the research project on fishing gear effects on benthic communities conducted under DFO's Environmental Sciences Strategic Research Fund. The objectives were to characterize the scallop bed and the entire benthic habitat of the sector of the Ile Rouge and secondly to quantify the influence of the scallop dredge on the benthic communities and the population of scallops. The third objective was based on the fact that dense assemblages of benthic fauna and flora could modify the seabed acoustic backscatter, and we try to detect the specific signal of Iceland scallop and the scallop bed located using several acoustic approaches. This objective will not be presented here but was published in the ICES Journal in 2005 (Hutin et al. 2005). The underlying hypotheses were that fishing causes a decrease in benthic species diversity and a change in the dominant species of benthic communities, as well as a decrease in scallop density and size.

2. METHOD

2.1 Study area

The Iceland scallop bed of interest is located in the St. Lawrence estuary, to the east of Ile Rouge. It straddles two fishing areas, Area 16A1 and Area 17A1 (Figure 1). The northern part of the bed makes up Area 16A1 and lies within the Saguenay–St. Lawrence Marine Park. The bed covers an area of about 22 km^2 (MPO 2003). It occupies a shelf in water 20 m to 60 m deep, surrounded by deeper water zones at the head of the Laurentian Channel. Owing to its geographic location and bathymetry, the study area is subjected to strong tidal currents.

2.2 Monitoring of commercial harvesting of the Ile Rouge scallop bed

As part of its mandate to assess scallop stocks in Quebec, the Science Branch of the Maurice Lamontagne Institute conducts regular monitoring of commercial fishing activities. Commercial catch sampling data have been used in the present study to estimate fishing effort on the Ile Rouge bed. The positions of these commercial catches have been used to determine the real extent of the harvested sector. These data represent only partial indicators of the locations dredged, but they are the only indicators available since the position information entered in logbooks is often insufficient for determining all locations dredged, as fishermen record only one vessel position per day of fishing. However, for the purpose of this study we have assumed that these data reflect the extent of annual fishing effort.

Scallop stock assessment also involves periodic research surveys of beds to evaluate scallop abundance. A survey of the Ile Rouge bed was undertaken in June 2002 using an experimental dredge. Thirty-seven stations were sampled using a 2.3 m wide offshore dredge equipped with a 19 mm plastic mesh (Vexar^{tm}) lining in the bag. The dredge tows covered an average distance of 160 m. Figure 2 shows the position of the stations on a sampling grid. The stations were 0.5 nautical miles apart and the grid covered an area of 23.65 km^2. All of the marine organisms found in the basket were identified. A specimen count was done for most species, except those (ophiurids, sea urchins) for which only a qualitative evaluation was possible. All the scallops that were caught were measured. In 2003 a second survey with the same dredge was conducted. Twenty-nine dredge tows where made to among other, precise the extent of the scallop bed. The same data on species was compiled for each tow.

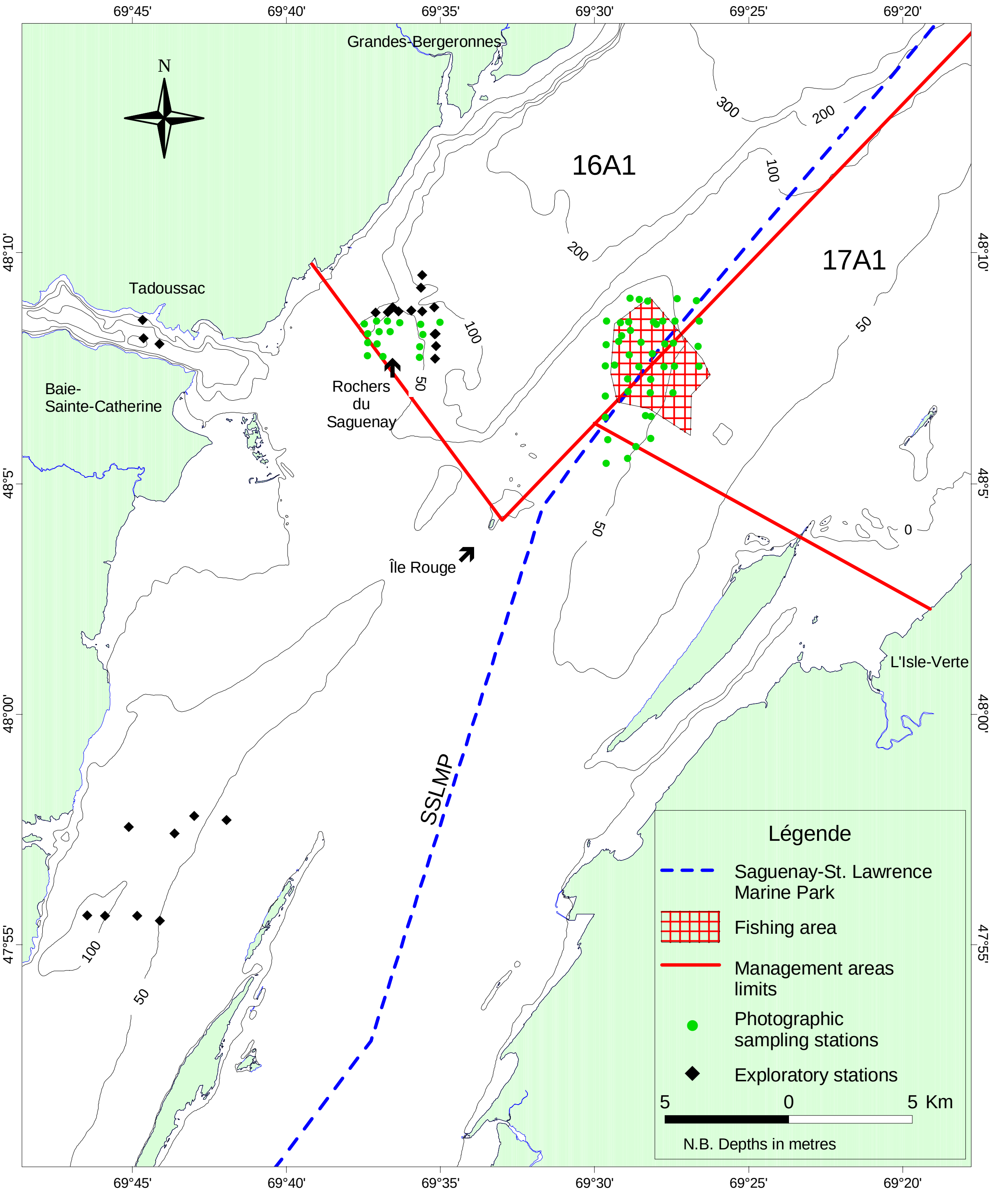

Figure 1. Study area and locations of the photographic sampling on the Ile Rouge Iceland scallop bed and exploring stations in the St. Lawrence Estuary. The dashed line represents the limit of the Marine Park (SSLMP).

2.3 Photographic survey of the epibenthic communities

A photographic method was used to study the epibenthic communities. This survey included the harvested and unharvested sectors of the Ile Rouge bed as well as the Rochers du Saguenay area further upstream. It was carried out during a research cruise from June 9 to 15, 2002. Exploratory work was also done with the aim of identifying control areas in the sector using the photographic survey method. Exploratory work having for goal to reach pilot zones in the sector was also made by a photographic sampling. A few areas upstream from the Ile Rouge bed were visited (Figure 1), but none of them had an appreciable density of scallops or characteristics comparable to the bed of interest. The Ile Rouge bed sectors to be sampled had been selected in advance based on the scallop densities reported by Hartog et al. (2001), and based on the fishing effort values that DFO’s stock assessment section had derived from commercial sampling data.

Within the scallop bed, we identified sampling stations in areas that had been subjected to fishing pressure and stations in areas that had not been fished by superimposing DFO commercial sampling data collected since 1999 on the sampling grid (Figure 1). Stations located more than 0.2 nautical miles from a fishing spot were considered to be unharvested stations. We assumed that the Rochers du Saguenay sector could serve as a control area unaffected by fishing. However, it was determined that this sector would be unsuitable as a control area (see Results section) because of differences in substrate type and scallop density observed in relation to the Ile Rouge bed. The sampling data from this sector are nonetheless included in our analyses to permit comparison with the Ile Rouge bed.

To study the epibenthic communities, we applied a sampling grid to the Ile Rouge bed similar to the one used for the dredge-based research surveys. The 42 stations of this grid were located 0.5 nautical miles apart in an area covering 16.5 km^2 (Figure 1). The grid used for the Rochers du Saguenay sector consisted of 15 stations, located 0.25 nautical miles apart (area = 3.5 km^2). At each of these stations, five photographs were taken in order to characterize the epibenthic communities. This survey was done in June 2002 before the start of the 2002 fishing season and seven to nine months after the 2001 fishing season. The sampling stations were distributed in the three study sectors, namely the harvested and unharvested sectors of the Ile Rouge bed and the Rochers du Saguenay sector (Table 1).

The photographs were analysed using image analysis software (Image-Pro Express, version 4.0). All of the organisms found were identified to the lowest taxonomic level. Abundance data were recorded for each taxon. A grid of 100 systematically distributed points was overlaid on the photographs in order to identify the components (sediments and organisms) located directly beneath the points and to derive percent cover data for the components.

Table 1. Characteristics of the sampling sites in the Ile Rouge scallop bed and in the Rochers du Saguenay sector.

Location	Treatment	No. of stations	Mean depth (m) $\pm$ SD
Ile Rouge bed-1	Unharvested	19	49 $\pm$ 9.8
Ile Rouge bed-2	Harvested	23	45 $\pm$ 7.8
Rochers du Saguenay	Unharvested	15	47 $\pm$ 20.1

2.4 Analyses of the variations observed within the bed

2.4.1 Commercial fishery

The indices recorded since the start of commercial harvesting of the Ile Rouge bed were used to assess variations in the scallop population. The data used are scallop size structure values, fishing effort (measured as number of hours of fishing per metre of dredge width), landings of scallop meat (muscle) and catches per unit of effort. The standard unit of effort is one hour of fishing using a 1 m wide dredge ($kg \cdot h^{-1} \cdot m^{-1}$).

2.4.2 Benthic communities

Multivariate analyses were performed to identify the species assemblage differences between the sectors sampled. A similarity matrix, based on the Bray–Curtis index (Clark and Warwick 1994), was calculated using the untransformed abundance data for each taxonomic group identified from the photographs. This matrix was used to carry out a non metric multidimensional scaling (nMDS) of the sampling stations. The similarity between the sectors of the benthic communities was tested using an analysis of similarity (ANOSIM, Clarke and Warwick 1994). SIMPER analysis was performed to evaluate each taxon’s contribution to the community assemblage in the different sectors. A BIOENV analysis was performed to determine the correlations between the abiotic factors and the benthic community assemblages at the different sampling sites. The abiotic variables introduced into the model were as follows: percentage of different sediment fractions, percentage of shells, depth, fishing intensity (harvested and unharvested sectors), latitude and distance between the island and the stations. The last two variables served to define the geographic position of the stations. The distance between the island and the stations proved to be an important factor; a five-nautical-mile limit between the stations and the island was used in the graphical representation and in the analysis of results (see Results section).

The Shannon diversity index (H'), the species richness (S) of benthic communities and the number of organisms (N) at the sampling stations were compiled, and the between-station variations in these indices were studied through an analysis of variance (hierarchical ANOVA). A balanced experimental design was used in order to satisfy the basic assumptions of analysis of variance. Since the number of photograph suitable for analysis was not equal for every station and because of problems with some photographs quality, we randomly selected an equal number of photograph per treatment and station. In Table 5, we indicate the cases in which a transformation (ln(x+1)) was applied to achieve homogeneity of variance. The factors used in these analyses were the treatments (harvested, unharvested) and the stations, which are nested in the treatments. The analyses were performed solely on the within-bed stations, given that the Rochers du Saguenay sector did not include enough sampling stations.

A probability level of $\alpha = 0.1$ was used in all the statistical analyses, compared with a typical level of $\alpha = 0.05$, in order to increase the power of the tests (Underwood 1996, 1997a). This choice proves to be judicious in the optics of the principle of precaution, allowing us to conclude that an effect is present even if it is weak. This approach has been advocated by a number of scientists in the context of environmental impact assessments (Schmitt and Osenberg 1996; Underwood 1997b, 1999).

3. RESULTS

3.1 Fishing effort and effect on scallops

Commercial fishing has been carried out at the Ile Rouge bed since 1998. The fishing season in areas 16A1 and 17A1 runs from September to December. The commercial sampling data indicate that fishing effort varies from year to year and that fishing pressure shifted during the years 1999, 2000, 2001 and 2002. However, the fishing pressure stayed relatively low after from 2003 to 2005 (Figure 2).

Initially, a Digby-type dredge was used in the commercial fishery. The width of this dredge was 6.1 m in 1999 and 5.5 m in 2000 and 2001. In 2002, an offshore dredge was used. This type of dredge is more efficient. In 2003, fisherman came back with the Digby-type dredge. In 2003 the dredge was 3.7 m and in 2004-2005 it was 5.5 m wide (Table 2). The highest landings for the two fishing areas combined were recorded in 1999 (Figure 2). The decline in landings in subsequent years can be explained by the individual quotas that were established in 2000. In addition, a different approach in fishing strategy was implemented in 2003 (MPO 2005). Since the landings are most exclusively in muscles the strategy is not to attain the maximum catch per unit but to fish scallops with a higher muscle weight. In 2001, the Area 17A1 was not fished. Although fishing effort on the bed was 62% lower in 2002 than in 2001, catch per unit of effort (from the commercial sampling) increased substantially until 2002 (Table 2). Between 2003 and 2005 it varied from 7 kg to 10 kg.

The modal size of the catches decreased from 80 mm to 75 mm between 1999 and 2001; it stood at 74 mm in 2002 (Figure 3). The modal size from the commercial landing increased to 85 mm and 87 mm in 2003 and 2004, respectively(MPO 2005). In 2005 (unpublished data) it was at 84 mm. In 2002 the mean weight of the scallop muscles decreased by 16% compared with the value recorded in 2001. The maximum mean weight was reached in 2003 (11.3 g) with lower values in 2004 (7.9 g) and 2005 (7.7 g). During the research survey conducted in 2002, the scallops harvested ranged in size from 1 mm to 108 mm, with a modal value of 79 mm. In 2003, during a second research survey, it ranged from 2 mm to 106 mm with a modal value of 79 mm.

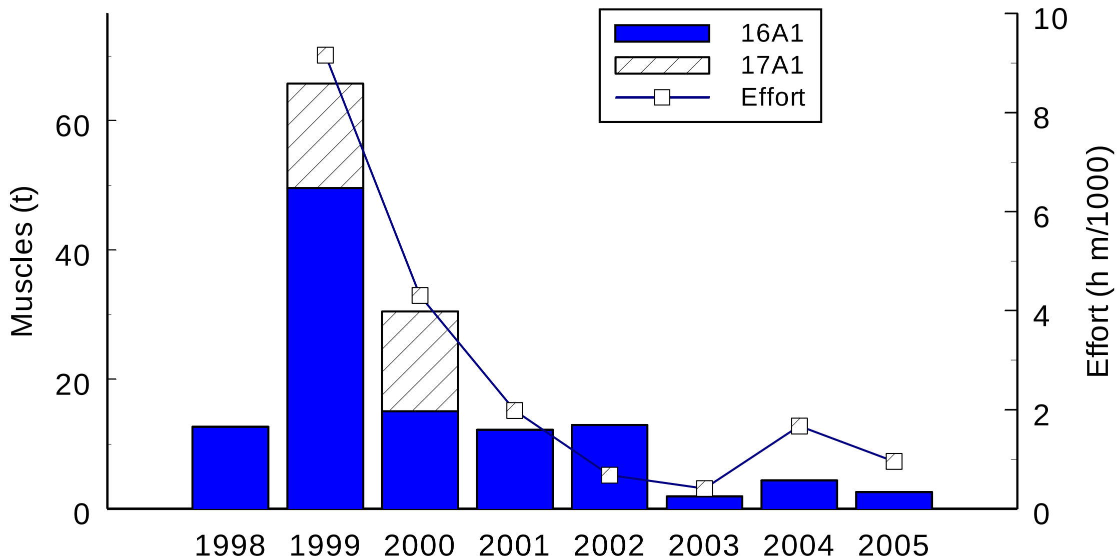

Figure 2. Muscles landing of the Iceland scallop and fishing effort on the Ile Rouge scallop bed between 1998 and 2005 for the two fishing zone (source, MPO 2005).

Table 2. Catch per unit of effort in kilograms of scallop meat taken per hour of fishing and per metre of dredge width ($kg \cdot h^{-1} \cdot m^{-1}$) for the two fishing areas of the Ile Rouge bed; commercial sampling data.

	Gear Type	Scallops ($kg \cdot h^{-1} \cdot m^{-1}$)	
		16A1	**17A1**
1999	Digby-type dredge 6.1 m wide	19	25
2000	Digby-type dredge 5.5 m wide	29	28
2001	Digby-type dredge 5.5 m wide	14	-
2002	Offshore dredge 3.4 m wide	62	-
2003	Digby-type dredge 3.7 m wide	7	-
2004	Digby-type dredge 5.5 m wide	9	-
2005	Digby-type dredge 5.5 m wide	10	-

3.2 Variations in epibenthic communities

3.2.1 Epibenthic community assemblage as a function of the sectors studied

A total of 47 taxa were identified in the photographs, with 10 of these being represented to a greater extent than the others at each of the stations. These taxa are as follows, in order of decreasing importance: *Ophiopholis aculeata*, *Chlamys islandica*, *Strogylocentrotus droebachiensis*, *Gersemia rubiformis*, *Ophiura robusta*, *Sabellidae* sp.1, *Sabellidae* sp.2, an unidentified burrowing bivalve, *Taelia felina* and an unidentified burrowing shrimp. The other 37 taxa were present to a much lesser extent. The ophiurid *O. aculeata* (a brittle star) was by far the most abundant species, accounting for more than 65% of total abundance in all sectors.

The nMDS of the benthic communities in the different sectors and the hierarchical analysis of similarity (ANOSIM) show that the benthic communities do not differ significantly between the sectors (ANOSIM R = -0.198; p = 1; Figure 4. However, they do differ between sampling stations (ANOSIM R = 0.599; $p < 0.001$). By overlaying the sampling grid (showing the positions of the sampling stations on the Ile Rouge bed) on Figure 4, we find that the stations with the most similar communities are those located on the north side of the bed. When the communities are analysed as a function of their respective distance from the island, a significant difference is noted between the communities at stations located more than five nautical miles from the island and those located less than five nautical miles away (Figure 5; ANOSIM R = 0.428; $p < 0.001$). Figure 5 shows that the stations located further from Ile Rouge have more similar communities than stations that lie closer to the island.

The SIMPER analysis shows that the between-sample similarity is greatest (Table 3) for the harvested sectors. The species that contributes most to the between-sample similarity for all sectors is the ophiurid *Ophiopholis aculeata*, which contributes 55%, 48% and 37% for the fished, unfished and Rochers du Saguenay sectors respectively. When distance to the island is considered as a factor for stations within the bed, the between-community similarity is greater for the stations located farthest from the island (Table 3). Dissimilarity is lowest between the harvested and unharvested sectors. A dissimilarity value of 74% is obtained for the sectors as a function of the distance between the stations and Ile Rouge.

Table 3. Benthic community similarity and dissimilarity between the different stations in each of the sampling sectors of the Ile Rouge bed and at Rochers du Saguenay

Location	Similarity (%)	Sectors	Dissimilarity (%)
Bed-unharvested	28	Harvested vs. unharvested	69
Bed-harvested	41	Unharvested vs. Rochers du Saguenay	71
Rochers du Saguenay	32	Harvested vs. Rochers du Saguenay	76
< 5 miles	30	< 5 miles vs. > 5 miles	74
> 5 miles	66		

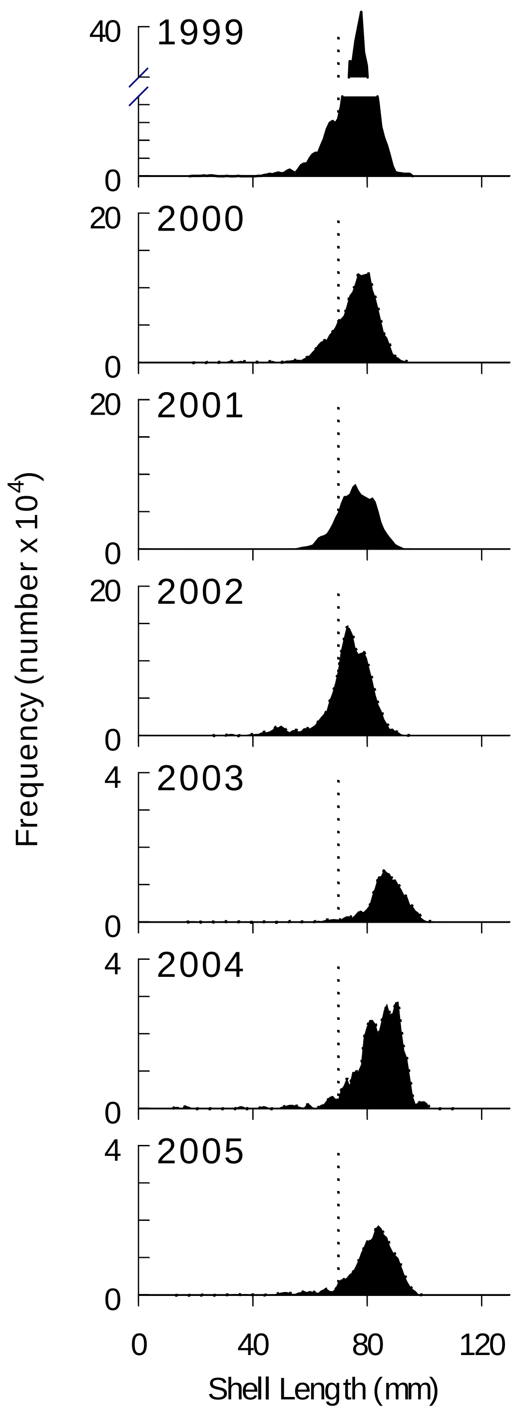

Figure 3. Size frequency of the Ile Rouge Iceland scallop bed based on the commercial catches (source, MPO 2005). The vertical line represents the commercial size

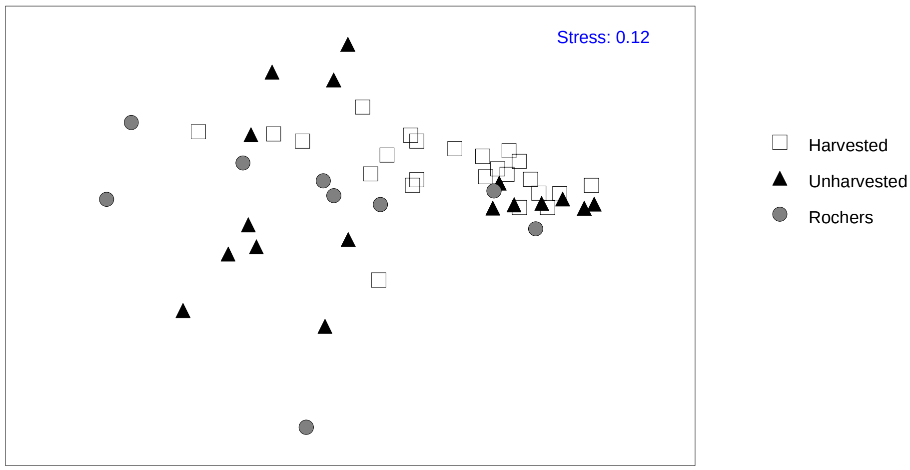

Figure 4. Non-metric multi-dimensional scaling (nMDS) ordinations of benthic community, from the photographic sampling, for the sectors that have been harvested, unharvested and on the Rochers du Saguenay. The centroid for each station was used to calculate the Bray-Curtis similarity.

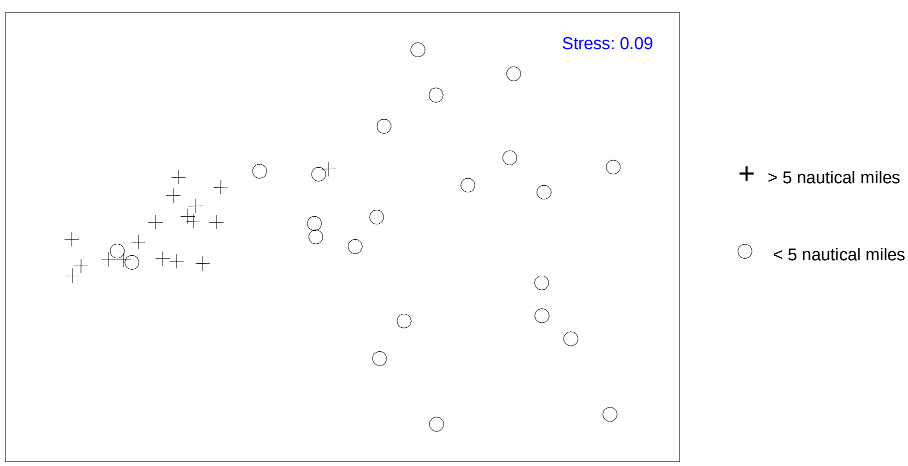

Figure 5. Non-metric multi-dimensional scaling (nMDS) ordinations of benthic community, from the photographic sampling, for the sectors that were located further than 5 nautical miles downstream and less than 5 nautical miles. The centroid for each station was used to calculate the Bray-Curtis similarity.

3.2.2 Univariate analyses of the various community indices

A hierarchical ANOVA was used to study variations in the abundance of the most important taxa (see Methods section) at the sampling stations in the harvested and unharvested sectors of the Ile Rouge bed. Scallop abundance is significantly higher in the harvested sector than in the unharvested sector (Table 4, Figure 6). There is no significant difference between the two sectors with regard to the most abundant species (Figure 6). The group of sessile species includes all species that attach themselves to the substrate. The abundance of this group does not differ between the two sectors of the Ile Rouge bed. Species richness, abundance and Shannon's diversity index do not differ significantly between the two sectors (Table 4; Figure 6). On the other hand, we observe a very high level of variability between the sites, which was confirmed by the classification of the habitat in the area (Hutin et al. 2005).

3.2.3 Epibenthic taxa present in dredges

A total of 53 taxa were identified in the dredge tows made on the Ile Rouge bed. These taxa are more mobile than those observed in the photographs, and they include more fish species. The most abundant taxa are *Ophiopholis aculeata*, *Strongylocentrotus droebachiensis, Chlamys islandica*, *Lebbeus* sp, *Sclerocrangon boreas*, *Crossaster papposus*, *Hyas araneus*.

The non-metric multi-dimensional scaling (nMDS) plot of the benthic communities based on presence/absence data for the two sectors studied in the Ile Rouge bed, followed by an analysis of similarity (ANOSIM), showed that the communities do not differ significantly between the sites (ANOSIM R = -0.074; p = 0.89; Figure 7). The analyses of variances used to detect variations in the abundance of the most dominant taxa at each station show no significant difference between the harvested and unharvested sectors of the bed (p > 0.1).

3.2.4 Relationship between the abiotic components and the benthic communities

Mineral composition data were used to characterize the bottom substrate at the different sampling stations. The substrate is composed of a more important proportion of sand in the Rochers du Saguenay sector and the smallest proportion of sand is found in the unharvested sector of the Ile Rouge bed (Figure 8). The proportion of sand is significantly greater in the harvested sector compared with the unharvested sector (Table 4). The MDS representation of the mineral components of the bottom substrate (Figure 9) shows that there is no clear-cut pattern of substrate composition as a function of the treatments.

ANOSIM confirms that the pattern of substrate composition does not differ significantly between the sectors (p = 0.99).

Table 4. Analyses of variance (ANOVA) of the characteristics of the benthic community and the bottom substrate for harvested and unharvested sectors (treatment) of the Ile Rouge scallop bed; some variables were transformed (see Table).

Variable	Source	df	MS	F	*p*
Ln (scallops +1)	Treatment	1	9.51	10.34	0.003
	Station (TR)	30	0.92	4.63	<0.0001
	error	64	0.2		
Ln (ophiurids+1)	Treatment	1	0.1591	0.03	0.8727
	Station (TR)	30	6.1	22.81	<0.0001
	error	64	0.27		
Ln (sessile+1)	Treatment	1	1.54	1.25	0.2732
	Station (TR)	30	1.23	4.28	<0.0001
	error	64	0.29		
Shells	Treatment	1	1239.84	1.4	0.2466
	Station (TR)	30	887.73	4.95	<0.0001
	error	64	179.44		
Ln (sand +1)	Treatment	1	42.95	23.5	<0.0001
	Station (TR)	30	1.83	5.49	<0.0001
	error	64	0.33		
Richness (S)	Treatment	1	2.04	0.35	0.5566
	Station (TR)	30	5.78	3.47	<0.0001
	error	64	1.68		
Abundance (N)	Treatment	1	1.87	1.21	0.2810
	Station (TR)	30	1.55	1.7	<0.0001
	error	64	0.13		
Shannon's diversity index (H')	Treatment	1	0.54	1.13	0.2969
	Station (TR)	30	0.48	6.27	<0.0001
	error	64	0.08		

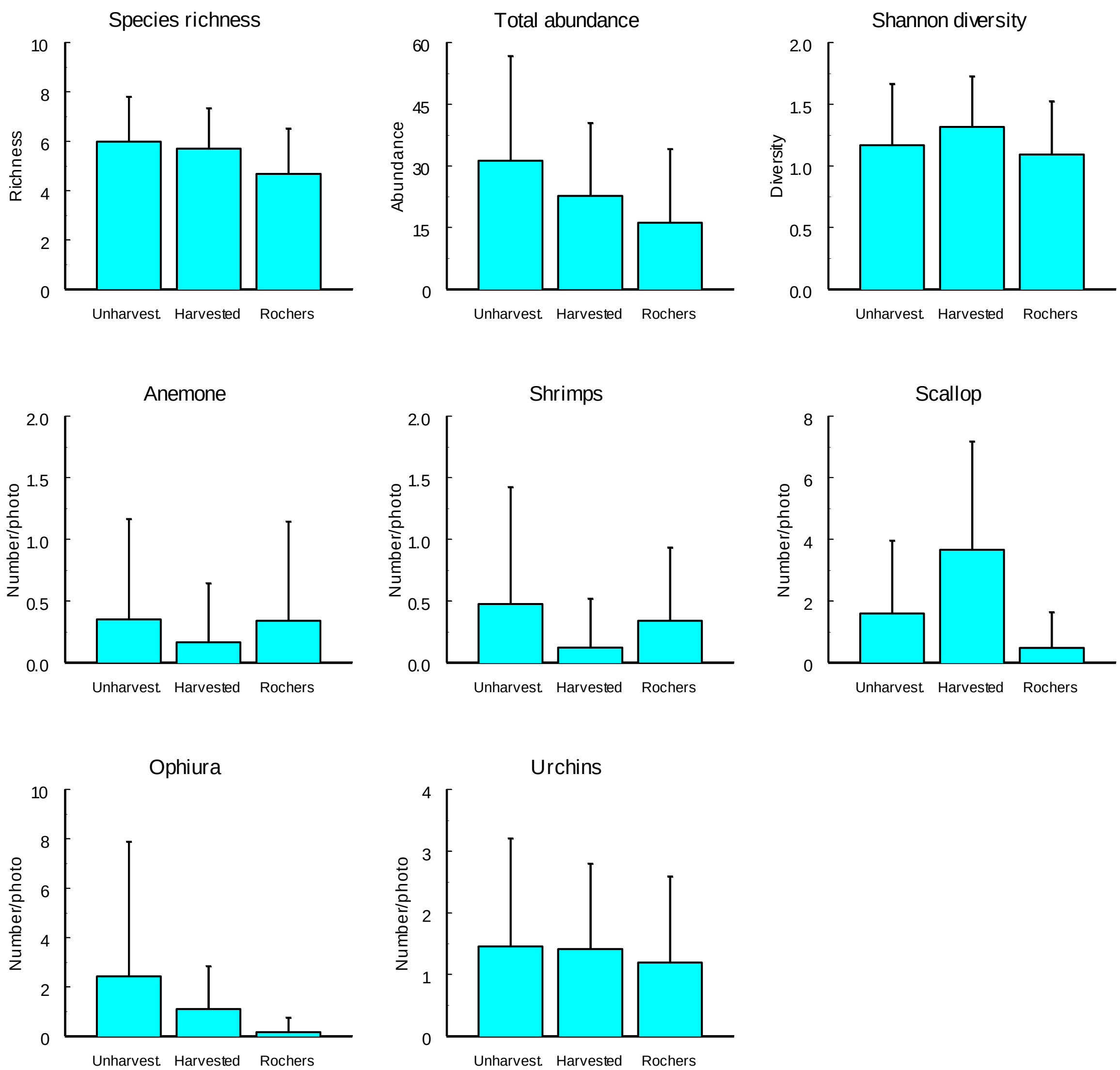

Figure 6: Mean (+SE) species richness, total abundance, Shannon diversity and the abundance of the dominant taxa identify on the photographs for the sectors that have been harvested, unharvested and on the Rochers du Saguenay.

A BIOENV analysis can be used to establish correlations between certain abiotic components and the benthic communities at the different sampling stations. The results of this analysis, using the mean data for each station, show that latitude is the variable that is most strongly correlated with benthic community assemblage at the stations, with a Spearman's rank correlation coefficient of 0.354. The sampling sector (harvested, unharvested and Rochers du Saguenay) is correlated with benthic community assemblage, with a Spearman's coefficient of 0.205. If we consider all of the photographs analysed for each station (instead of mean data), the variable that gives the highest correlation coefficient is the sampling sector, with a value of 0.179. However, if we consider only the stations located within the Ile Rouge bed and exclude the Rochers du Saguenay stations, we find that the "distance from Ile Rouge" variable is positively correlated with benthic community assemblage (Spearman's coefficient of 0.643).

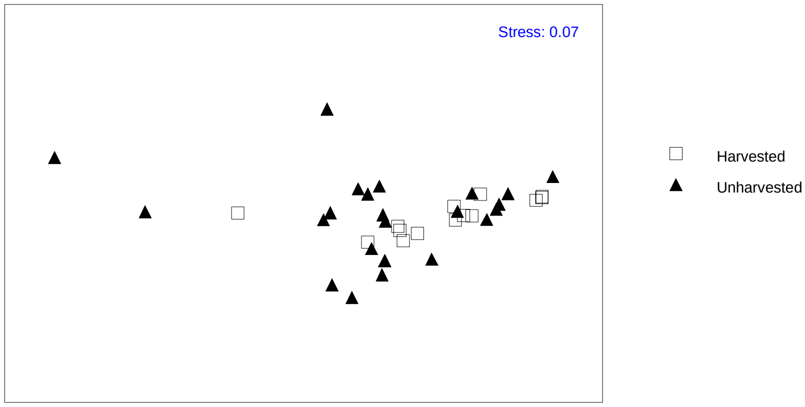

Figure 7. Non-metric multi-dimensional scaling (nMDS) ordinations of the epibenthic community caught with the dredge for the sectors that have been harvested and unharvested. The centroid for each station was used to calculate the Bray-Curtis similarity.

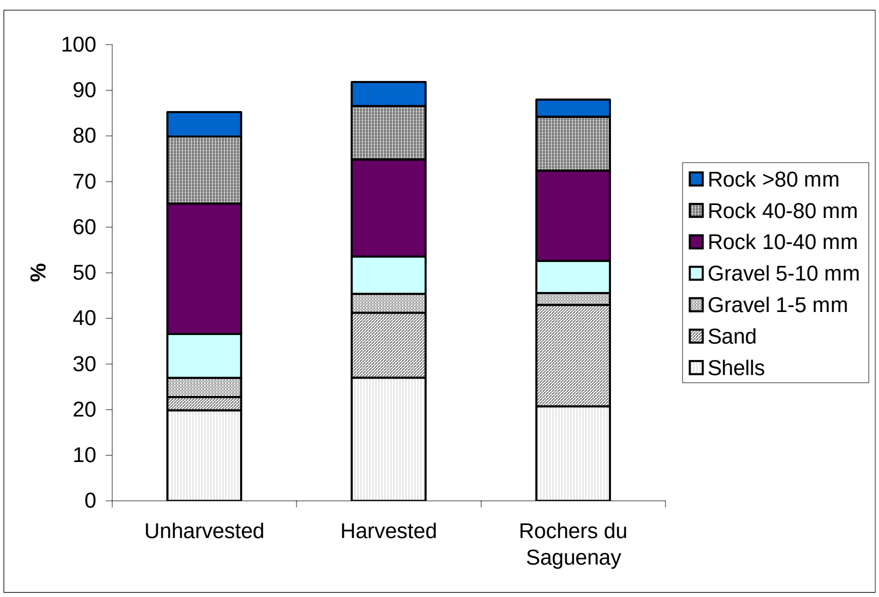

Figure 8. Proportion (%) of the different sediment characterisics for the sectors that have been harvested, unharvested and on the Rochers du Saguenay.

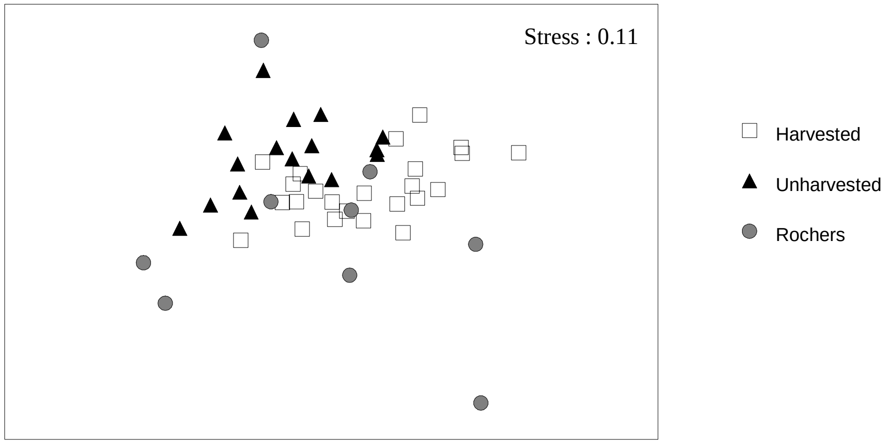

Figure 9. Non-metric multi-dimensional scaling (nMDS) ordinations of sediment characteristics, from the photographic sampling, for the sectors that have been harvested, unharvested and on the Rochers du Saguenay. The centroid for each station was used to calculate the Bray-Curtis similarity.

4. DISCUSSION

4.1 Fishing activities in the Ile Rouge bed

The Iceland scallop bed at Ile Rouge covers an area of just over 50 km^2, with commercial size scallops ($\geq$ 70 mm) present in an area of about 22 km^2 (MPO 2003). In 2002, the biomass abundance index calculated from catch per unit of effort values has increased from the 2001 level, but the size and muscle weight values for individual scallops have decreased. That year a offshore dredge was used and the landings where in shells. The size of the scallops in the 2002 commercial catch samples was smaller than that observed during the initial years of harvesting (MPO 2003) and in the last 3 years (2003, 04 and 05). From 2003 to 2005 the mean shell length was relatively high indicating that there are still large scallops on the bed. Furthermore, the increase in the catch per unit of effort indicates that the scallop biomass of the Ile Rouge bed is still appreciable. The modal size of 79 mm estimated during the research survey is low compared to the value obtained for other North Shore beds, which typically have a mode ranging from 80 mm to 88 mm (Giguère et al. 2000). Scallop densities are much higher in the Ile Rouge bed (0.75 $ind \cdot m^{-2}$ in 2002 and 1.13 $ind \cdot m^{-2}$ for commercial size individuals) than in the other Iceland scallop beds in Quebec, where the highest densities rarely exceed 0.4 $ind \cdot m^{-2}$ (Giguère et al. 2000).

The increase in the catch per unit of effort in 2002 could be attributable to the greater efficiency of the offshore. The efficiency of the offshore dredge has been estimated at 33% for Iceland scallop (MPO 2003). This compares with an efficiency rating of 5% to 15% for the Digby-type dredge (Naidu 1988) when used to harvest sea scallops. Conservative efficiency data for sea scallop catches made with a Digby-type dredge had to be employed because there are no data for Iceland scallops. Iceland scallops are probably easier to catch than sea scallops, since they are less efficient swimmers and tend to attach themselves to the substrate using their byssus threads (Naidu 1988). However, the fishing gear efficiency data must be interpreted cautiously. It is widely believed that the offshore dredge is more efficient that the Digby type, but performance has been found to vary as a function of the habitats harvested. Furthermore, it is difficult to make a general statement about gear efficiency because individual fishers adjust this equipment accordingly.

4.2 Effects of the fishery on scallops

The data on the scallop size over the past years (Figure 3) suggest that the fishery has affected the target species during the first year of exploitation but seems to be stabilized since 2003. The modal size of the scallops captured in experimental dredge surveys was 79 mm in 2002 for the Ile Rouge bed as a whole, which is equivalent to the value obtained in the research surveys conducted in 2000 (Hartog et al. 2001). The discrepancy between the two data sources (commercial sampling data vs. research survey data) probably originates from the fact that scallops caught during commercial sampling come from more localized areas of the bed, whereas the research surveys cover a larger area. In the area affected by the fishery, this would result in a decrease in scallop size, which could be associated with fishing effort. Rochet and Trenkel (2003) perceived the decline in the size of scallops caught as an interesting indicator in studies on the effect of the fishery on these populations. Currie and Parry (1999) showed that the decrease in scallop size could be linked to fishing activities.

It is known that fishing increases the indirect mortality rate for scallops in sectors that are fished. In one study on this topic, Naidu (1988) observed an increase in Iceland scallop mortality in harvested areas compared with unharvested areas. The higher mortality rate was attributable to dredge-induced injuries, scallops returned to the water after spending too much time out of the water or stress associated with displacement by the dredge. In addition, scallops smaller than commercial size are sometimes returned to the water in habitats that are unfavourable for their survival. In the Ile Rouge sector, which is characterized by strong currents, scallops that are put back in the water may be swept far away to inappropriate sites. A low mortality rate of 3% and 1.2% was estimated for the Ile Rouge bed from the number of clappers found in 2002 and 2003. This rate was comparable to that obtained for scallop populations that are not harvested or only lightly harvested (MPO 2003). Harvesting of the bed began only in 1998, and fishing pressure has been relatively light owing to the quotas put in place in 2000. Presently, with a relatively low fishing effort, there is no evident sign of a decline in the size of scallops. One of the most significant unknowns related to this bed is the provenance of recruits. At present, we still do not know whether the population on the bed is perpetuating itself, whether its recruits come from other beds or whether it serves as a source of recruits for beds downstream from it. This information is important for assessing whether the bed is at risk in relation to fishing effort.

4.3 Impact on benthic communities

There is no clear-cut change in the epibenthic communities that could be linked to the fishing activities at the Ile Rouge bed. Figure 5 shows that some stations support similar communities, but this grouping is linked to the geographic position of the stations rather than to any other factor studied, such as fishing effort, water depth or sediment grain size. Indeed, the abiotic variables that are most strongly correlated with species assemblage are as follows: distance between each station and Ile Rouge (r = 0.643) and latitudinal position of the station (r = 0.625). Accordingly, the stations in the northern part of the bed, which are more than five nautical miles away from the island (Figures 1 and 5) have communities that vary little and are largely dominated by the ophiurid *Ophiopholis aculeata,* whereas communities located closer to the island are much more variable and heterogeneous, with a less marked predominance of *O. aculeata*. Stations located further downstream from the island may be subjected to different currents from those located closer to the island (Saucier and Chassé 2000). This would induce variations in species establishment and give rise to different and less heterogeneous communities than those closer to the island. The epibenthic communities described from dredge-based research surveys do not differ significantly between fished and unfished sectors. For this analysis, however, the abundance of the taxa could not be taken into consideration and only the presence of the taxa is considered for the different sites. Hence, two different methods yield similar results for the different communities studied.

The Rochers du Saguenay stations support fewer species and have a lower abundance of living organisms. At a number of stations, no organisms were found on a substrate consisting solely of sand. This sector could not be used as a control area in this study, because it differs too much from that of the Ile Rouge bed overall. The difficulty of finding a comparable site to use as a control area for evaluating the effects of the fishery is an unresolved problem that is often mentioned in the literature (Trush et al. 1995; Kaiser et al. 1998; Collie et al. 2000; Lindegarth et al. 2000).

The effect of fishing depends largely on the type of gear used, the habitat and the different taxa that are present (Collie et al. 2000). Substrate, or bottom type, is one of the factors determining the magnitude of the impacts observed (Kaiser et al. 1998). Sites with loose sediments (soft substrates) recover more quickly than do other bottom types after dredging operations. Collie et al. (2000) suggest that some environments can recover within a period of 100 days after fishing has taken place. The sediments in the harvested sector of the Ile Rouge bed comprise a larger proportion of sand compared with the unharvested sector. This habitat can therefore be expected to recover more quickly than an environment with an appreciable proportion of large rocks. In addition, the presence of natural disturbances may minimize the impacts of fishing in a given area (Kaiser et al. 1996; Prena et al. 1999). The Ile Rouge bed is located in an area of strong currents whose effects extend to a considerable depth. According to a model constructed by Saucier and Chassé (2000), current velocity in this sector can reach 2 m. s^{-1} at a depth of 50 m depending on the tides. Tidal currents could therefore be responsible for the natural variations observed in the benthic communities of the Ile Rouge bed, and this would mask the effects of the disturbance caused by fishing gear. This situation could prevent us from detecting the impacts seven months after the disturbance. Kaiser et al. (1998) have stated that the impacts of fishing on a bottom area with loose sediments disappear after six months. Gear changes between years and spatial variations in fishing effort can reduce impacts. It is important to keep in mind that harvesting of this bed began not very long ago (in 1998); therefore, it may be too early to detect significant adverse effects.

One effect of the disturbances that was reported by Clarke and Warwick (1994) is an increase in the variability of the communities in disturbed environments. It follows from this that fishing is a disturbance that can increase variability in some areas (Lindergarth et al. 2000; Vaele et al. 2000). In the Ile Rouge bed, the epibenthic communities of the harvested sector are less variable than those found in the unharvested sector. However, this variability difference appears to be linked to the position of the stations. The stations with less heterogeneous communities are those located further from the island.

The dominant species of the sectors studied are those that are less vulnerable to fishing gear-induced disturbances. The most dominant species in the three sectors studied, *Ophiopholis aculeata*, is very abundant throughout the study area as a whole. This species likes to hide in accumulation of shells and extend its long tentacles into the water column to capture food (Lituinova 1980). Ophiurids generally show a positive response to the fishery (Currie and Parry 1996; Frid et al. 1999). However, in the sectors studied, it is difficult to conclude that their presence is linked to fishing pressure since they are found in both fished and unfished areas of the bed. *O. aculeata* could be favoured by fishery-induced disturbances because of the increase in food supply and the resuspension of sediments that occur during the initial period after the impact. Seven months later, after a winter possibly characterized by strong currents and mixing, it is unlikely that the presence of ophiurids is due to the effects of the fishery. It seems more prudent to conclude that this environment forms their habitat because of the multitude of openings they can exploit in the accumulation of shells and because of the abundant food supply.

Data obtained from the experimental dredge survey and the photographic survey provide a picture of the communities that were present at the stations in June 2002. It is difficult to speculate about the situation that existed in early fall when the fishery was carried out, that is, whether the dominant species were the same ones and their abundance was comparable. If different species were predominant when the fishery took place, the impact could differ from what we have found in this study. To obtain a more accurate picture of fishing gear effects on the scallop bed, we would need to monitor the stations photographed in this study over a longer period (> 5 years), as this would enable us to track temporal changes in the communities as a function of fishery-related disturbances.

5. CONCLUSIONS

Increasing our knowledge of the biology and ecology of the Iceland scallop bed at Ile Rouge is a crucial step toward understanding the dynamics of this bed and ensuring its sustainable management and conservation. If the bed is to be harvested within a conservation framework such as that established for the Saguenay–St. Lawrence Marine

Park, harvesting issues must be assessed as accurately as possible to permit sound management of the resource and conservation of the supporting habitat. A very special attention should be related in the monitoring of the effect dredging on the habitat and the scallop resources in the eventuality of an increase in fishing effort.

The variation in the epibenthic communities of the Ile Rouge bed can be attributed to the geographic positions of the sampling stations and cannot, at present, be linked directly to the effects of the fishery. Sampling was carried out too long after fishing took place (seven to nine months) to be able to evaluate the short-term effects, and it is widely recognized in the literature that the effects of fishing-induced disturbances disappear quickly, within three to six months, in environments comparable to those studied on the Ile Rouge bed.

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