JOURNAL OF NATURAL HISTORY, 0000, **00,** 1–15

Crustaceans associated with the deep-water gorgonian corals *Paragorgia arborea* (L., 1758) and *Primnoa resedaeformis* (Gunn., 1763)

L. BUHL-MORTENSEN and P. B. MORTENSEN

Department of Fisheries and Oceans, Marine Environmental Sciences Division, Bedford Institute of Oceanography, PO Box 1006, Dartmouth, NS B2Y 4A2, Canada; e-mail: mortensenl@mar.dfo-mpo.gc.ca

(*Accepted 4 February 2003*)

To explore the crustacean fauna associated with deep-water gorgonian corals, suction samples were taken from colonies of *Paragorgia arborea* and *Primnoa resedaeformis* using a Remotely Operated Vehicle. Seven colonies of *P. arborea* and eight of *P. resedaeformis* were sampled from 330–500 m depth in the Northeast Channel off Nova Scotia. A total of 17 species were identified as being associated with the corals. The *P. arborea*-fauna was richer than the *P. resedaeformis* fauna in both abundance and number of species, with 1303 versus 102 individuals and 16 versus seven species, respectively. However, 13 of the species associated with *P. arborea* were from hydroids attached to the coral. Amphipods dominated the fauna both in abundance and numbers of species and the most common species were *Metopa bruzelii*, *Stenopleustes malmgreni*, *Proboloides calcarata* and *Aeginella spinosa.* The isopod *Munna boecki* and the cirripede *Ornatoscalpellum stroemii* were also quite common. The most strongly associated crustaceans were two parasitic poecilostomatid copepods; these are common also on tropical gorgonians and are most likely obligate associates. The frequently occurring shrimp *Pandalus propinquus* probably avoids predation by seeking protection among the coral branches. Shrimp counts from video records showed that visual inspection without physically disturbing colonies will generally not reveal the crustaceans hidden in coral colonies. The galatheid *Eumunida picta* was observed on *P. resedaeformis* colonies. The fauna of the deep-water gorgonians corresponded to the fauna of tropical shallow-water gorgonians in the numerical dominance of amphipods and parasitic copepods; however, species richness is higher and decapods, which constitute a rich fauna on tropical gorgonians, were only represented by two species.

KEYWORDS: Deep-water corals, associated crustaceans, *Primnoa resedaeformis*, *Paragorgia arborea*, remotely operated vehicle, Nova Scotia.

Introduction

Tropical shallow-water corals are well known because of their accessibility, high diversity of associated species and beauty. It is less well known, however, that corals (e.g. scleractinians and gorgonians) are widespread in cold temperate waters

Journal of Natural History
ISSN 0022-2933 print/ISSN 1464-5262 online
http://www.tandf.co.uk/journals
DOI: 10.1080/0022293031000155205

around the world. In the North Atlantic they are most common at depths of 200–700 m (Deichman, 1936; Madsen, 1944; Zibrowius, 1980). They may occur in dense populations locally as reefs or 'forests' constituting high biodiversity habitats (Storm, 1901; Dons, 1944; Jensen and Frederiksen, 1992; Mortensen, 2001; 1
Mortensen and Buhl-Mortensen, 2003). There is growing concern that human 2
activities (e.g. fisheries and oil-exploration) on the continental shelf and slopes in the North Atlantic may represent a threat to these habitats and communities (Rogers, 1999). Furthermore, little is known about the significance of corals as habitat for other species in deep-water ecosystems, and how they may be linked to the shallower shelf and pelagic ecosystems. Research on corals and their associated fauna is necessary to assess the ecological importance of this deep-water community, and to develop sound scientific advice on sustainable habitat and fisheries management of deep-water ecosystems. The actuality of this issue is demonstrated by recent evidence of coral areas damaged by bottom trawling (Krieger, 2001; Fosså *et al.*, 2002). Few recent studies have focused on the associated fauna of deep-water coral habitats (Jensen and Frederiksen, 1992; Mortensen, 2001). The term 'associated fauna' here means any animal found on or in a coral colony and this is also how it will be understood in this study. Corals have a complex architecture that offers a great variety of microhabitats for other organisms and substrata of different age. Sheltered cavities within a colony can contain organically rich sediments, while outer parts provide high water flow with little sedimentation. The arborescent morphology of most corals allows their polyps to be elevated from the relatively still boundary layer close to the substratum into the faster flowing water above (Wainwright and Koehl, 1976). In addition, the orientation of colonies perpendicular to prevailing currents, which is common for many species, maximizes the volume of water passing the polyps (Wainwright and Dillon, 1969; Mortensen and Buhl-Mortensen, 2003). This enables the polyps in the colony to have maximum food access, an advantage that is passed on to any rheophilic, filter-feeding epizoic animal associated with the colony.

Very little is known about the fauna associated with the deep-water gorgonians. It is known, more or less anecdotally, that deep-water gorgonians often house a large assemblage of mobile crustaceans, and attached ophiuroids (Storm, 1901; Strømgren, 1970). The associated mobile animals may represent an important food source for demersal fish, as suggested by Storm (1901) and Cimberg *et al.* (1981), in addition to contributing significantly to the biodiversity. This fauna is difficult to sample and can only be captured selectively by a suction sampler mounted on a remotely operated vehicle (ROV) or a submersible. The recent development of ROVs has provided the opportunity for controlled sampling of specific deep-water habitats and fauna that have not earlier been possible to document in detail. Such sampling is, however, very expensive, limiting the number of investigations and making the few samples highly valuable.

Our main goal in this study is to expand knowledge of the inhabitants of the architecturally complex and rich habitat provided by the deep-water corals, *Paragorgia arborea* and *Primnoa resedaeformis*. A few earlier records exists from this habitat based on non-selective gear (e.g. Sars, 1890–1895; Storm, 1901; Dons, 1944; Vader, 1969), however, it has not previously been selectively sampled and documented. Both coral species are widely distributed and locally abundant in the North Atlantic, on hard substratum in high current areas at a depth range of 300–600 m (Madsen, 1944; Tendal, 1992). We compare the species richness and habitat selectivity of the associated crustacean fauna of these species that are the two largest and most common gorgonian corals on the edge of the Scotia Shelf. In addition, the fauna will be compared with observations from tropical shallow-water gorgonians.

Materials and methods

Environment

The Northeast Channel is a major trough separating the continental shelf of Nova Scotia from that of New England. It is the only deep passage connecting the slope water of the north-west Atlantic Ocean with the Gulf of Maine, with a sill depth of about 230 m (figure 1). The three sampling localities are in the outer part of the channel at the shelf break, at 330–500 m depth. The video observations made while sampling showed that the bottom at these localities consists of gravel, mainly cobbles and boulders, locally covering up to 100% of the sandy seabed. Salinity and temperature at 300–400 m range from 34.87 to 35.05 PSU and 5.74 to 7.64°C, respectively (Petrie and Dean-Moore, 1996). Current measurements are not available for the depth of the sampling areas, but the trough is in general dominated by strong semi-diurnal (M2) tidal currents (Ramp *et al.*, 1985; Smith and Schwing, 1991). The maximum speed 16 m off the bottom at the sill is between 40 and 50 $cm\,s^{-1}$ (Ramp *et al.*, 1985). At the south-western side, a current having the mean magnitude of 2 $cm\,s^{-1}$ is directed outward above 200 m depth. Inflows occurred everywhere else with a magnitude of 3 $cm\,s^{-1}$ towards the bottom (Ramp

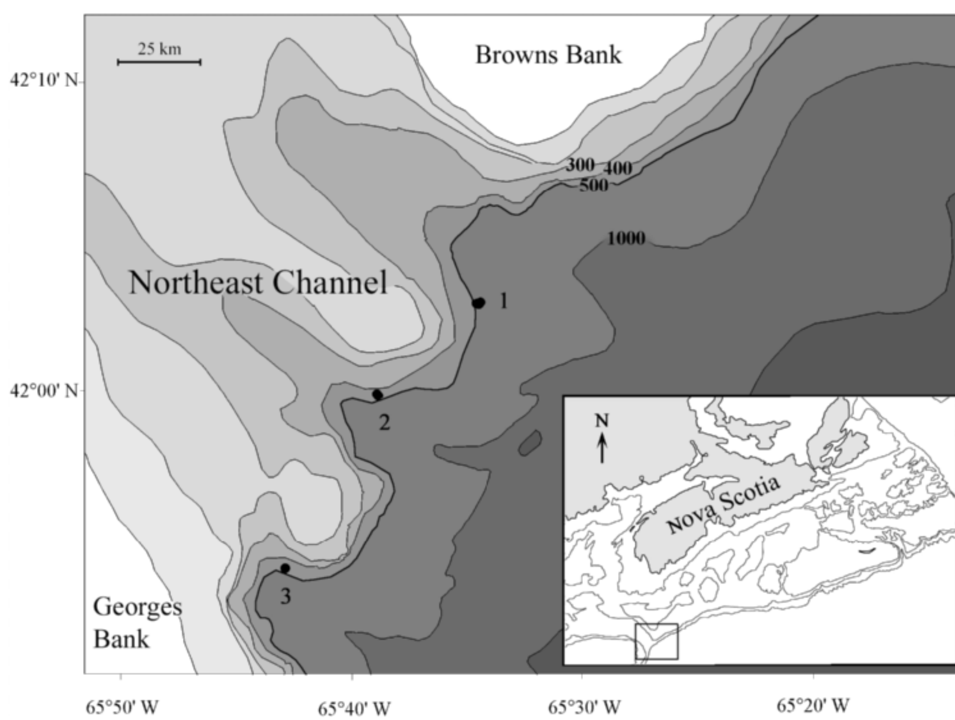

FIG. 1. Position of sampling areas where suction samples were taken by ROV. Depth contours in meters.

et al., 1985). At the three sampling localities *P. arborea* and *P. resedaeformis* occurred in forest-like stands. The densities at these localities were 2–13 and 2–60 colonies per 100 m^2 for *P. arborea* and *P. resedaeformis*, respectively (Mortensen and Buhl-Mortensen, 2003). Both species were often attached to the same boulder.

Sampling and inspection of corals

The mobile fauna associated with *Paragorgia arborea* and *Primnoa resedaeformis* was collected during a cruise in August 2001 using a suction sampler mounted on the ROV, *ROPOS* (model HI-ROV 2000). Designed for scientific purposes, *ROPOS* is fitted with a suction pump that has a capacity of *ca* 2 l s^{-1} and a hose diameter ~8 cm. The water was sieved through a 250 µm plankton mesh mounted inside the eight sampling jars, of 2 l each. Ten suction samples were collected from each of one or two colonies and efforts were made to cover the whole colony when sampling (table 1). The suction time ranged from 1 to 4 min per colony (120–480 l). Samples were preserved in 4% formalin and later transferred to 96% alcohol before identification. The crustaceans were identified to lowest possible taxonomic level. Of the 15 sampled colonies, seven were *P. arborea* and eight *P. resedaeformis* and their size ranges were 90–180 cm and 25–65 cm in height, respectively. Supplementary information was gained from video records made during suction sampling, sampling of coral colonies and transit between sampling sites. All corals observed on video and shrimps visible in the individual colonies, were counted. In addition to the crustaceans, a few specimens of less mobile fauna, e.g. gastropods and polychaetes, occurred in the suction-sampled material. These observations will be presented in another paper dealing with less mobile or sessile fauna found on corals collected as by-catch by the Department of Fisheries and Oceans groundfish survey (Buhl-Mortensen and Mortensen, in preparation). 3

Results

A total of about 1540 crustaceans, representing 20 species, were collected (table 2). Three species are known to be pelagic (e.g. *Themisto compressa*, *Sergestes arcticus* and *Nematosceles megalops*), and are not regarded as part of the fauna associated with the corals. Shrimps of the genus *Sergestes* have, however, previously been observed on deep-water corals (Storm, 1901).

Table 1. Information on suction samples (number indicates sampling area, 1–3).

Species	Suction sample	Position		Depth (m)	Number of colonies	Height of colonies (cm)
		North	West			
Paragorgia arborea	1-A	42°02.79′	65°34.47′	475–477	2	100, 130
	1-B	42°02.85′	65°34.60′	477	1†	150
	2-A	41°59.89′	65°38.95′	426	1	180
	2-B	41°59.85′	65°38.88′	426–446	2	90, 180
	3-A	41°54.30′	65°42.84′	332	1	90
Primnoa resedaeformis	1-C	42°02.83′	65°34.45′	498	1	60
	1-D	42°02.80′	65°34.48′	476	2	40, 50
	2-C	41°59.94′	65°38.90′	410–426	2	55, 43
	2-D	41°59.87′	65°38.91′	432	1	65
	3-B	41°54.33′	65°42.92′	334–367	2	25, 45

†Coral colony with hydroids.

Table 2. Abundance and number of crustacean species in 10 samples from gorgonian coals.

	Samples from *Paragorgia arborea*						Samples from *Primnoa resedaeformis*						
Sample number	1-A	1-B	2-A	2-B	3-A	Sum	1-C	1-D	2-C	2-D	3-B	Sum	Total
Number of colonies	2	1†	1	2	1	7	1	2	2	1	2	8	15
Ostracoda													
Paradoxostoma sp.	–	5	–	–	–	5	–	–	–	–	–	0	5
Synasterope abyssicola (G. O. Sars)	–	–	–	–	1	1	–	–	–	–	–	0	1
Copepoda													
Buprorus sp.	1	–	–	–	–	1	–	–	–	–	–	0	1
Enalcyonium cf. *olssoni* (De Zulueta)	–	–	–	–	–	0	–	1	–	3	2	6	6
Lichomolgidae indet.	236	18	7	148	123	532	–	–	–	–	–	0	532
Cirripedia													
Ornatoscalpellum stroemii (M. Sars)	–	133	–	–	–	133	–	–	3	–	–	3	136
Cypris larva	–	5	–	–	–	5	–	1	–	–	–	1	6
Isopoda													
Munna boecki Krøyer	1	28	–	–	–	29	–	–	1	–	–	1	30
Amphipoda													
Aeginella spinosa Boeck	–	43	–	–	–	43	–	–	–	–	–	0	43
Amphitopsis longicaudata Boeck	–	12	–	–	–	12	–	–	–	–	–	0	12
Gitana abyssicola G. O. Sars	–	1	–	–	–	1	–	–	–	–	–	0	1
Ischyrocerus megacheir (Boeck)	–	1	–	–	–	1	–	–	–	–	–	0	1
Leucothoe spinicarpa (Abildgaard)	–	4	–	–	–	4	–	–	–	–	–	0	4
Metopa bruzelii (Goes)	–	297	–	–	–	297	–	–	–	–	1	1	298
T hemisto compressa Goes‡	2	1	–	>50	>50	>100	1	–	–	3	1	5	>100
Proboloides calcarata (G. O. Sars)	–	5	–	–	–	5	1	9	31	–	–	41	46
Stenopleustes malmgreni (Boeck)	–	229	–	1	–	230	6	–	34	–	–	40	270
Stenopleustes sp.	–	1	–	–	–	1	–	–	–	–	–	0	1
Juvenile indet.	–	–	1	–	–	1	–	–	–	–	–	0	1

Table 2. *(Continued)*.

	Samples from *Paragorgia arborea*						Samples from *Primnoa resedaeformis*						
Sample number	1-A	1-B	2-A	2-B	3-A	Sum	1-C	1-D	2-C	2-D	3-B	Sum	Total
Number of colonies	2	1†	1	2	1	7	1	2	2	1	2	8	15
Decapoda													
Pandalus propinquus (G. O. Sars)	1(7)	(7)	(5)	1(9)	(9)	2(37)	3(4)	4(7)	2(4)	(6)	(1)	9(22)	11(59)
Sergestes arcticus (Krøyer)‡	–	–	–	–	–	0	1	–	–	–	–	1	1
Euphausiacea													
Nematoscelis megalops (G. O. Sars)‡	–	–	–	–	30	30	–	–	–	–	–	0	30
Sum of individuals	239	782	8	150	124	1303	10	15	71	3	3	102	1405
Sum of species	4	13	2	3	2	16	3	4	5	1	2	7	17

Figures in parentheses are based on video observations. Sum of species and individuals excludes pelagic species.
†Coral colony with hydroids.
‡Species known to be pelagic.

The *Paragorgia arborea* fauna was richer in both numbers of individuals and species than the *Primnoa resedaeformis* fauna. A total of 1303 individuals belonging to 16 species was sampled from the seven *P. arborea* colonies (excluding 130 individuals from two pelagic species), whereas, only 102 individuals belonging to seven species (excluding six individuals from two pelagic species) came from the eight *P. resedaeformis* colonies. Thirteen of the species associated with *P. arborea* were mainly from hydroids attached to the coral.

Amphipods dominated the fauna in both species number (nine) and abundance (677 individuals). The two most common species were *Metopa bruzelii* (298 individuals) and *Stenopleustes malmgreni* (270 individuals), both having their main occurrence on hydroids attached to *P. arborea. Proboloides calcarata* and *Aeginella spinosa* also occurred in larger numbers, 46 and 43 individuals, respectively, the former mainly on *Primnoa resedaeformis* while the latter was only found together with hydroids. The isopod, *Munna boecki*, also occurred mainly on hydroids attached to *Paragorgia arborea.*

The species with the highest abundance (532 individuals) was a poecilostomatoid copepod belonging to the family Lichomolgidae (figure 2A). This species occurred in all samples from *P. arborea* with a mean of 76 individuals per colony while it was not found on *P. resedaeformis*. Another poecilostomatoid copepod, *Enalcyonium* cf. *olssoni* (figure 2B), was sampled only from *P. resedaeformis*, but in low numbers, having a mean of approximately one individual per colony. The ostracod *Synasterope abyssicola* only occurred on *P. arborea*. The largest crustacean species found on the corals was the Chirostylidae anomuran *Eumunida picta* Smith, 1883, and the shrimp *Pandalus propinquus.* Two specimens of *E. picta* were observed on two *P. resedaeformis* colonies at location No. 3. The specimens were orange-yellow coloured, with claws and outer parts of the pereopods strikingly white. Attempts to sample the specimens failed and the species was identified based on the video records.

Pandalus propinquus which occurred on both coral species was more frequent in the suction samples from *Primnoa resedaeformis* than from *Paragorgia arborea*, having a mean of one and 0.3 individual per colony, respectively. However, observations made during suction sampling (figures in parentheses, table 2) showed *P. propinquus* in much larger numbers on both coral species than indicated by the suction samples (e.g. figure 2C). The abundance was highest on *P. arborea* with a mean of five individuals per colony while a mean of two individuals per colony was observed for *P. resedaeformis*.

A total of 169 *Paragorgia arborea* colonies and 1524 *Primnoa resedaeformis* colonies were video-recorded at the three locations. In total, 63 and 92 individuals of *Pandalus propinquus* were observed on *P. arborea* and *P. resedaeformis*, respectively (table 3). In contrast to the observations made while suction sampling where shrimps were observed in all colonies, shrimps were seen only in 7.7% of all video-recorded *P. arborea* colonies, and 2.0% of all *P. resedaeformis* colonies. The average number of shrimps per colony for these observations was 4.8 for *P. arborea* and 3.1 for *P. resedaeformis*. On one occasion shrimps sitting on branches of *P. resedaeformis* were observed closely for a few minutes. These shrimps were not scared away by the light from the ROV, but stayed at the same spot or moved less than 2 cm. They continued their fast movements of the mouth-parts, probably searching for food among particles found on the coral surface.

The cirriped, *Ornatoscalpellum stroemii*, occurred on both coral species but was

Natural History *(gamma)* nah25420.3d 16/7/03 12:53:53 Rev 7.51n/W (Jan 20 2003)
The Charlesworth Group, Huddersfield 01484 517077

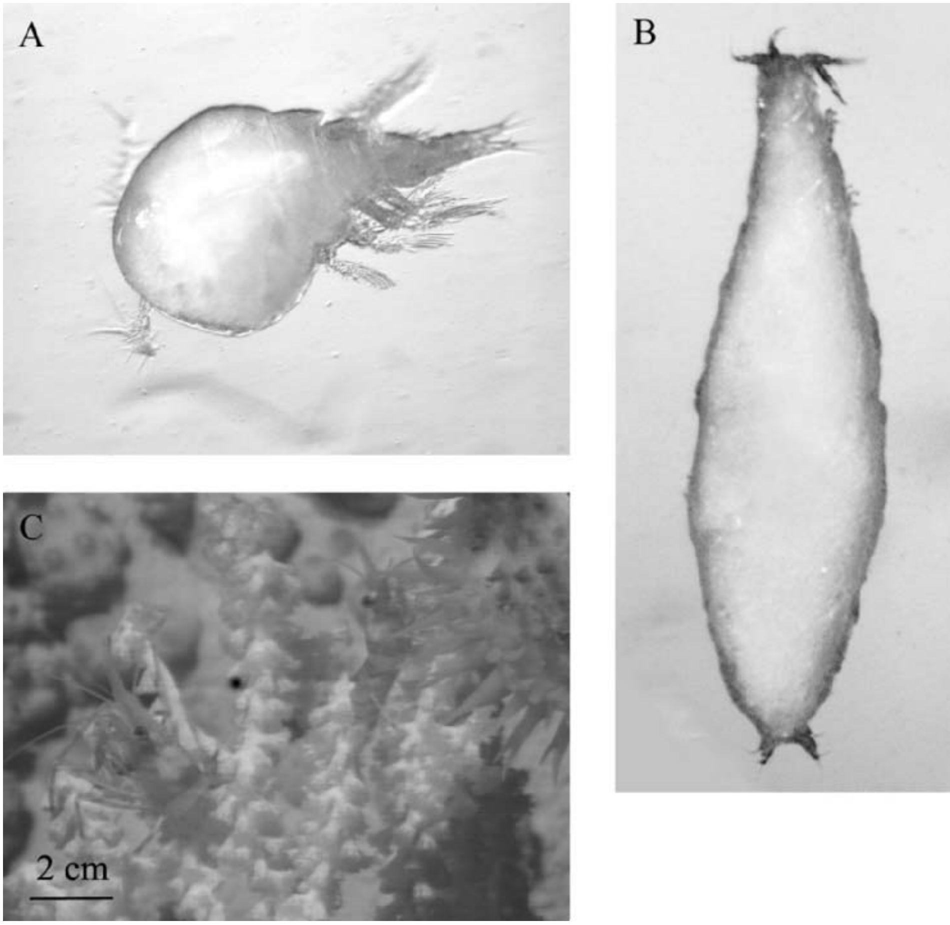

FIG. 2. Two parasitic poecilostomatid copepods and one decapod found on the gorgonian corals. (A) An unidentified species belonging to the family Lichomolgidae that was abundant on the surface of *Paragorgia arborea*. Total length = 1 mm. (B) *Enalcyonium* cf. *olssoni* belonging to the family Lamippidae was found on *Primnoa resedaeformis*, probably living inside the polyps. Total length = 1 mm. (C) *Pandalus propinquus* on branches of a *P. resedaeformis* colony frame grabbed from video records taken in the sampling area.

numerous only on *Paragorgia arborea*, with 133 individuals from one colony. This sample contained hydroids that had been attached to the coral and *O. stroemii* was mainly found on these hydroids. On the video records *Primnoa resedaeformis* with *O. stroemii* were observed quite frequently.

Discussion

Sampling method

The number of individuals and species collected from the deep-water gorgonians without hydroids was low. This could indicate that the gorgonian-associated crustaceans are few. However, it could also be due to the sampling equipment not collecting the mobile fauna in an adequate way. Manoeuvring the hose of a suction

Table 3. Number of shrimps observed on video records made during suction sampling of corals, collection of corals and transit between sampling locations.

		Observed during:					
		Suction sampling		Collection of corals		Transit	
Coral species	Location	Shrimps	Colonies	Shrimps	Colonies	Shrimps	Colonies
Paragorgia	1	14	3	0	2	19	157
arborea	2	14	3		0	7	3
	3	9	1		0		
Sum		37	7	0	2	26	160
Primnoa	1	11	3	15	6	14	1428
resedaeformis	2	10	3	20	7	11	48
	3	1	2	0	0	9	35
Sum		22	8	35	13	34	1511

sampler with a ROV arm in a controlled manner is hard and the efficiency of the sampling may differ between colonies.

The larger crustaceans, e.g. shrimps, can escape from the hose of the suction sampler. Another problem is that the movement of the hose can disturb nearby parts of a colony not yet sampled and scare away mobile fauna. Video-recordings made during sampling showed that many more shrimps occurred on the colonies than were captured by the suction sampler.

Smaller crustaceans such as amphipods and isopods may manage to cling to their host and avoid being sampled. However, when climbing on hydroids, which are more delicate and flexible, they are probably more easily captured, which may explain their high abundance in sample 1-B containing hydroids. On one occasion several specimens of the amphipod *Aeginella spinosa* was video-recorded clinging to hydroids attached to a *P. arborea* colony. The difference in size and morphology of the two coral species may also affect the sampling. The fauna of *P. resedaeformis* forming relatively small colonies with flexible branches is probably more efficiently suction sampled that the fauna of the larger tree-forming *P. arborea*.

Nevertheless, the presence of small copepods living inside or on the surface of the corals suggests that the suction power was strong enough to sample small crustaceans. On this basis we are convinced that the material sampled from colonies in the densest population of the two coral species on the Scotian shelf (Mortensen and Buhl-Mortensen, 2003) provides a reliable picture of their crustacean associates. When collecting whole coral colonies, first covering with a net will probably provide a better picture of the mobile associated fauna. This is, however, both technically a difficult procedure and destructive to the corals.

The fauna

The fauna of *Paragorgia arborea* was richer both in abundance and number of species than the *Primnoa resedaeformis* fauna, with 16 and seven species, respectively. There are significant differences in size and morphology of the two coral species (figure 3). *P. arborea* forms colonies that are tree-like with thick branches (2–4 cm in diameter) and with a maximum height of 2–3 m (Storm, 1901; Tendal, 1992). The more bush-like *P. resedaeformis* has thinner branches (1–1.5 cm

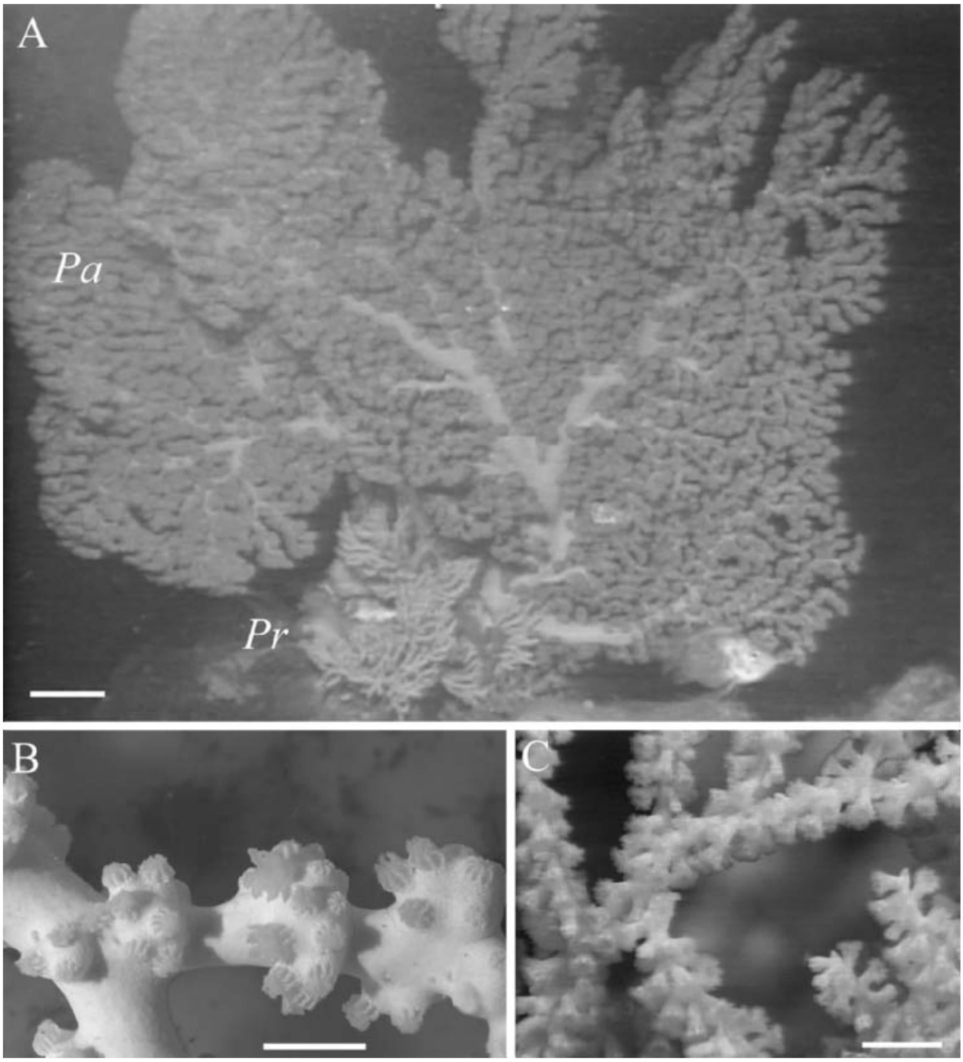

FIG. 3. The two gorgonian coral species suction sampled for associated crustaceans. (A) *Paragorgia arborea* (*Pa*) and *Primnoa resedaeformis* (*Pr*) frame grabbed from video records taken in the sampling area. Scale bar: 20 cm. Distance between the two laser dots on *P. arborea* is 10 cm. (B) Branch of *P. arborea*. Scale bar: 2 cm. Photographed in aquarium. (C) Branch of *P. resedaeformis*. Scale bar: 2 cm. Frame grabbed from video records taken in sampling area.

including the polyp houses) and a maximum height of 1 m (Carlgren, 1945). *P. arborea* also has a smoother surface between the polyps while *P. resedaeformis* has a scale-covered coenenchyme and closely packed polyps. *P. resedaeformis*, with its bushy morphology, may offer more hiding places between its branches while the taller *P. arborea* offers large areas of naked coenenchyme to parasites and stronger current regimes.

The amphipods dominated the fauna both in numbers of individuals and species. Of the four most common amphipods three have earlier been reported from coral habitats, *Stenopleustes malmgreni* on *P. arborea* (Sars, 1890–1895; Vader, 1969), *Aeginella spinosa* on *Paramuricea placomus* (L.) (Strømgren, 1970) and *Proboloides calcarata* has together with the former two been found in habitats with corals, hydroids and sponges (Storm, 1901; Buhl-Jensen, 1986, and literature cited therein). *S. malmgreni* and *P. calcarata* are new to Nova Scotia (P. Brunel, personal communication), which is not surprising since earlier studies in deep-water habitat in the area are scarce. *Metopa bruzelii* has to our knowledge not been reported previously as associated with corals. These amphipods are facultative symbionts and the corals together with their associated hydroids probably provide shelter against predators and a suitable substratum both for capturing and filtering particles from the water passing the coral.

Two parasitic poecilostomatoid were found on the corals. They did not co-occur but were confined each to their host species. The association between poecilostomatoid copepods and tropical gorgonians has been known for a long time (Zulueta, 1908 in Bayer, 1961), but there is no earlier record of copepods associated with either of the two coral species studied here. The copepod *Enalcyonium* cf. *olssoni* that occurred on *Primnoa resedaeformis* has been found parasitically in the octocoral *Alcyonium digitatum* L. (Stock, 1988). It belongs to the family Lamippidae that is exclusively endoparasitic in octocorals (Grygier, 1983; Stock, 1988). A copepod of the family Lichomolgidae was very common on *Paragorgia arborea* (a mean of 76 individuals per colony). This taxonomically difficult group of copepods is mainly associated with invertebrates and many species are known to be associated with gorgonians in tropical waters (Humes and Stock, 1973; Humes, 1993). The copepod was not identified to species level and may be a new species. It is probably strongly connected to *P. arborea* but may not be obligate on species level. Species of this family are often found on several gorgonian host species (Humes and Stock, 1973). The parasitic copepods are presumed to feed on the coenenchyme of their hosts (Patton, 1976). The large area of naked and smooth coenenchyme on *P. arborea* probably provides a better habitat for this surface living copepod than the scaled and rugged surface of *P. resedaeformis* on which it was not observed.

The shrimp *Pandalus propinquus* was common on both coral species and video observations indicated a mean of 4.8 individuals per *Paragorgia arborea* colony and 3.1 per *Primnoa resedaeformis* colony. These are conservative estimates since the shrimps are hard to discern on video records. It was during suction sampling, when they were disturbed and started moving, that the highest numbers were observed. The lower number of shrimps observed on *P. resedaeformis* is probably due to the higher architectural complexity of this coral compared to *P. arborea*. There is more sheltered space where shrimps can hide in a *P. resedaeformis* colony than the more fan-shaped *P. arborea*. This shrimp has been found clinging to branches of *P. arborea* (Storm, 1901) and is also common on the scleractinian deep-water coral *Lophelia pertusa* (L.) (Dons, 1944; Burdon-Jones and Tambs-Lyche, 1960; Jensen and Frederiksen, 1992; Fosså and Mortensen, 1998). The relation between *P. propinquus* and the corals is probably facultative and the branches of corals offers shelter against predators. It has also been suggested to be associated with the anthozoan *Bolocera tuediae* by Jonsson *et al.* (2001), however, in that study the video-recorded shrimps were not sampled and species identified. The shrimp may be beneficial to the coral by cleaning its surface from sedimenting particles. The cleaning function of shrimps in corals is well known from shallow water (Bruce, 1976; Hickson, 1906). However, we have few detailed observations and no direct evidence of such behaviour by *P. propinquus* on the corals, thus, this can only be speculation. The chirostylid anomuran *Eumunida picta* was observed twice on *P. resedaeformis* and even though the material is scarce this may indicate a relation between the two species. Associations between *Eumunida* species and corals has been documented previously from the Pacific Ocean (Saint Laurent and Macpherson, 1990; Saint Laurent and Poupin, 1994; Macpherson, personal communication). In the North Atlantic *Munidopsis serricornis* (Lovén, 1852) is often associated with the scleractinian *Lophelia perstusa* (Storm, 1901; Dons, 1944; Mortensen, 2001).

Several genera of cirripedes are known to be associated with tropical gorgonians (Goh *et al*., 1999). *Ornatoscalpellum stroemii* occurred on both coral species; however, it attached mainly to parts of the colonies that had already been colonized by hydroids. Little is known about the ecology of this deep-water cirripede but Nilsson-Cantell (1978) notes that 'It attaches to sponges, hydroids, gorgonians, octocorals etc.'. Our results fully agree with early observations by Storm (1901) who reported its association with hydroids on both *Primnoa resedaeformis* and *Paragorgia arborea*. This cirriped is a facultative symbiont using mainly exposed coral skeleton and associated hydroids as substratum for suspension feeding in a high current environment.

Communities associated with gorgonian corals

In a survey of the fauna associated with shallow-water gorgonians on coral reefs in Singapore, Goh *et al*. (1999) reported 73 crustaceans belonging to 11 species in samples taken by scuba divers over a period of 6 years from 16 gorgonian species (number of colonies are not given) (table 4). They found associated fauna only on 16 of 31 gorgonians. Goh *et al*. (1999) also present a general review of gorgonian associated fauna where they state that amphipods dominate numerically and that parasitic poecilostomatoid copepods are common and well-known associates of

Table 4. Abundance (No.) and species richness (Sp.) of gorgonian-associated crustacean taxa.

	Nova Scotia		Singapore		Review	
Taxa	No.	Sp.	No.	Sp.	No.	Sp.
Ostracoda	6	2	0	0	?	?
Copepoda	539	3	0	0	Many	Many
Cirripedia	136	1	20	1	Few	5
Isopoda	30	1	0	0	?	?
Amphipoda	677	9	23	2	Domin.	Many
Caridea	11 (59)	1	8	4	Many	Many
Anomura	0 (2)	0 (1)	21	3	Few	3
Brachyura	0	0	1	1	Few	2
Sum	1399 (61)	17 (1)	73	11		

Results from: this study (Nova Scotia) of 15 colonies of two coral species sampled with a suction sampler (numbers in parentheses from video observations); information from a study in Singapore based on 16 gorgonian species, number of colonies is not known, and; from a Review on gorgonian-associated fauna. The Singapore and Review data are from Goh *et al.* (1999).

tropical gorgonians. Our observations show that the associated fauna of the deep-water gorgonians resembles the fauna on shallow-water tropical gorgonians in amphipods, parasitic copepods being an important part of the fauna. The deep-water corals, however, had a richer and much more abundant crustacean fauna, with 1449 versus 72 specimens on the tropical gorgonians. It is also interesting that this fauna was from only two species of gorgonian corals in contrast to 16 tropical species. Another clear difference is that the rich decapod fauna on the tropical corals contrasts with only two species on the deep-water corals. Some of the differences in faunistic composition might be due to sampling methods. Sampling by scuba-diver in the tropics may have missed some of the smaller crustaceans. The richer decapod fauna in tropical waters in general can probably explain the larger numbers of associated decapods.

Interspecific obligate relationships are less common for high latitude biotopes in general, compared to the tropics (Karr, 1971; Rhode, 1978; Beaver, 1979). Many of the species associated with tropical corals are obligate while most species found on the deep-water corals are facultative symbionts. In contrast to the numerous examples of highly developed interspecific relationships in shallow-water tropical reefs (Patton, 1976, and references therein), there are very few examples of species found exclusively on deep-water corals (Burdon-Jones and Tambs-Lyche, 1960; Jensen and Frederiksen, 1992; Fosså and Mortensen, 1998). However, many of the species associated with the corals are much less common in other habitats. Several conditions of the North Atlantic deep-water coral habitat can be used to explain this general pattern, including time needed for development of such relationships, frequency of disturbance and variability of nutrient supply.

Acknowledgements

This study was funded by the Environmental Studies Research Fund (ESRF), Department of Fisheries and Oceans (DFO) and the National Science and Engineering Council (NSERC) in Canada. We thank Dr Anna Metaxas for organizing the cruise. The *ROPOS* team, and the CCGS *Martha Black* crew were very helpful in arranging for the sampling and video-recording at sea. We are indebted to Dr Enrique Macpherson for providing help with the identification of the galatheid anomuran. Dr Pierre Brunel and Dr Wim Vader provided valuable comments on the species list.

References

BAYER, F. M., 1961, *The Shallow Water Octocorallia of the West Indian Region. A Manual for Marine Biologists* (The Hague: Martinus Nijhoff).

BEAVER, R. A., 1979, Host specificity of temperate and tropical animals, *Nature*, **281**, 139–141.

BRUCE, A. J., 1976, Shrimps and prawns of coral reefs, with special reference to commensalism, in O. J. Jones and R. Endean (eds) *Biology and Geology of Coral reefs*, Vol. III (New York: Academic Press), pp. 37–94.

BUHL-JENSEN, L., 1986, The benthic amphipod fauna of the west-Norwegian continental shelf compared with the fauna of five adjacent fjords, *Sarsia*, **71**, 193–208.

BURDON-JONES, C. and TAMBS-LYCHE, H., 1960, Observations on the fauna of the North Brattholmen stone-coral reef near Bergen, *Årbok for Universitetet i Bergen, Matematisk-naturvitenskaplig Serie*, **4**, 1–24.

CARLGREN, O., 1945, Polypdyr (Coelenterata) III. Koraldyr, *Danmarks fauna*, **51**, 1–168.

CIMBERG, R. L., GERRODETTE, T. and MUZIK, K., 1981, Habitat requirements and expected distribution of Alaskan coral, *NOAA, OCSEAP Final Report*, **54**, 206–308.

DEICHMAN, E., 1936, The Alcyonaria of the western part of the Atlantic Ocean, *Harward University, Museum of Comparative Zoology Memoirs*, **53**, 1–317.

DONS, C., 1944, Norges korallrev, *Det Kongelige Norske Videnskabers Selskabs Forhandlinger*, **16**, 37–82.

FOSSÅ, J. H. and MORTENSEN, P. B., 1998, Artsmangfoldet på *Lophelia*-korallrev og metoder for overvåkning, *Fisken og havet*, **17**, 95 pp.

FOSSÅ, J. H., MORTENSEN, P. B. and FUREVIK, D. M., 2002, The deep-water coral *Lophelia pertusa* in Norwegian waters: distribution and fishery impacts, *Hydrobiologia*, **471**, 1–12.

GOH, N. K. C., NG, P. K. L. and CHOU, L. M., 1999, Notes on the shallow water gorgonian-associated fauna on coral reefs in Singapore, *Bulletin of Marine Science*, **65**, 259–282.

GRYGIER, M. J., 1983, An endoparasitic lamippid copepod in *Acanella* from the North Atlantic, *Crustaceana*, **45**(2), 178–182.

HICKSON, S. J., 1906, The Alcyonaria of the Maldives. Part I. The genera *Xenia*, *Telesto*, *Spongodes*, *Nephthya*, *Paraspongodes*, *Chironephthya*, *Siphonogorgia*, *Solenocaulon*, and *Melitodes*, in J. S. Gardiner (ed.) *The Fauna and Geography of the Maldive and Laccadive Archipelagoes* (Cambridge: Cambridge University Press), pp. 473–502, pls XXVI–XXVII.

HUMES, A. G., 1993, Copepoda associated with gorgonaceans (Cnidaria) in the Indo-Pacific, *Bulletin of Marine Science*, **53**, 1078–1098.

HUMES, A. G. and STOCK, H. J., 1973, A revision of the family Lichomolgidae Kossman, 1877, cyclopoid copepods mainly associated with marine invertebrates, *Smithsonian Contribution to Zoology*, **127**(i–v), 1–368.

JENSEN, A. and FREDERIKSEN, R., 1992, The fauna associated with the bank-forming deepwater coral *Lophelia pertusa* (Scleractinaria) on the Faroe shelf, *Sarsia*, **77**, 53–69.

JONSSON, L. G., LUNDÄLV, T. and JOHANNESSON, K., 2001, Symbiotic associations between anthozoans and crustaceans in temperate costal area, *Marine Ecology Progress Series*, **209**, 189–195.

KARR, J. R., 1971, Structure of avian communities in selected Panama and Illinois habitats, *Ecological Monographs*, **41**, 207–229.

KRIEGER, K. J., 2001, Coral (*P. resedaeformis*) impacted by fishing gear in the Gulf of Alaska, in J. H. M. Willison, J. Hall, S. E. Gass, E. L. R. Kenchington, M. Butler and P. Doherty (eds) *Proceeding of the First International Symposium on Deep-Sea Corals* (Halifax, Canada: Ecology Action Centre), pp. 106–116.

MADSEN, J. F., 1944, Octocorallia (Stolonifera—Telestacea—Xeniidea—Alcyonacea—Gorgonacea), *The Danish Ingolf-Expedition*, **V**(13), 65 pp.

MCCLOSKEY, L. R., 1970, The dynamics of the community associated with a marine Scleractinian coral, *International Revue ver Gesamten Hydrobiologie*, **55**(1), 13–81.

MORTENSEN, P. B., 2001, Aquarium observations on the deep-water coral *Lophelia pertusa* (L., 1758) (Scleractinia) and selected associated invertebrates, *Ophelia* **54**(2), 83–104.

MORTENSEN, P. B. and BUHL-MORTENSEN, L., 2003, Distribution, abundance, and morphology of deep-water gorgonian corals in the Northeast Channel, Nova Scotia, *Marine Biology* (submitted). 4

NILSSON-CANTELL, C.-A., 1978, Cirripedia Thoracica and Acrothoracica, *Marine Invertebrates of Scandinavia*, No. 5 (Oslo: Universitetsforlaget), pp. 1–135.

PATTON, W. K., 1976, Animal associates of living reef corals, in O. J. Jones and R. Endean (eds) *Biology and Geology of Coral Reefs*, Vol. III (New York: Academic Press), pp. 1–36.

PETRIE, B. and DEAN-MOORE, J., 1996, Temporal and spatial scales of temperature and salinity on the Scotian Shelf, *Canadian Technical Report of Hydrography and Ocean Sciences*, **177**, 45 pp.

RAMP, S. R., SCHLITZ, R. J. and WRIGHT, W. R., 1985, The deep flow through the Northeast Channel, Gulf of Main, *Journal of Physical Oceanography*, **15**, 1790–1808.

RHODE, K., 1978, Latitudinal differences in host-specificity of marine Monogenea and Digenera, *Marine Biology*, **47**, 125–134.

ROGERS, A. D., 1999, The biology of *Lophelia pertusa* (Linnaeus 1758) and other deep-water reef-forming corals and impacts from human activities, *International Revue ver Gesamten Hydrobiologie*, **84**, 315–406.

SAINT LAURENT, M. DE. and MACPHERSON, E., 1990, Crustacea Decapoda: le genre Euminida Smith, 1883 (Chirostylidae) dan les eaux néo-calédoniennes, in A. Crosnier (ed.) *Résultats des Campagnes MUSORSTOM*, Vol. 6, *Mémoire du Muséum national d'Histoire naturelle (A), (Paris)*, **145**, 227–288.

SAINT LAURENT, M. DE. and POUPIN, J., 1994, Crustacea, Anumura: les espéces indo-ouest pacifiques du genre Eumunida Smith, 1880 (Chorostylidae). Description de six espéces nouvelles, in A. Crosnier (ed.) *Résultats des Campagnes MUSORSTOM*, Vol. 15, *Mémoire du Muséum national d'Histoire naturelle, (Paris)*, **168**, 337–385.

SARS, G. O., 1890–1895, *Amphipoda. An Account of the Crustacea of Norway with Short Description and Figures of all the Species I* (Abs. Cammermeyer, Christiania), 711 pp., 248 pls.

SMITH, P. C. and SCHWING, F. B., 1991, Mean circulation and variability on the eastern Canadian continental shelf, *Continental Shelf Research*, **11**, 977–1012.

STOCK, J. H., 1988, Lamippidae (Copepoda: Siphonostomatidae) parasitic in *Alcyonium*, *Journal of the Marine Biological Association of the UK*, **68**, 351–359.

STORM, V., 1901, *Oversigt over Throndheimsfjordens fauna (med et kort)* (Trondheim: Trondhjems Biologiske Station, Meddelelser fra stationsanleggets arbeidskomite. H. Moe's Bog—Accidentstrykkeri).

STRØMGREN, T., 1970, Emergence of *Paramuricea placomus* (L.) and *P. resedaeformis* (Gunn.) in the inner part of Trondheimsfjorden (Western coast of Norway), *Det Kongelige Norske Videnskabers Selskabs Skrifter*, **4**, 1–6.

TENDAL, O. S., 1992, The North Atlantic distribution of the octocoral *P. arborea* (L., 1758) (Cnidaria, Anthozoa), *Sarsia*, **77**, 213–217.

VADER, W., 1969, Notes on a collection of Amphipoda from the Trondheimsfjord area, *Det Kongelige Norske Videnskabers Selskabs Skrifter*, **3**, 1–20.

WAINWRIGHT, S. A. and DILLON, J. R., 1969, On the orientation of sea fans (genus *Gorgonia*), *Biological Bulletin*, **136**, 130–139.

WAINWRIGHT, S. A. and KOEHL, M. A. R., 1976, The nature of flow and reaction of benthic Cnidaria to it, in G. O. Mackie (ed.) *Coelenterate Ecology and Behavior* (New York: Plenum Press), pp. 5–21.

ZIBROWIUS, H., 1980, Les Scléractiniaires de la Méditerranée et de l'Atlantique nord-oriental, *Memoires de l'Institut oceanographique*, No. 11.

Natural History *(gamma)* nah25420.3d 16/7/03 12:54:00 Rev 7.51n/W (Jan 20 2003)

The Charlesworth Group, Huddersfield 01484 517077

Authors Queries

Journal: **Journal of Natural History**
Title: **Crustaceans associated with the deep-water gorgonian corals *Paragorgia arborea* (L., 1758) and *Primnoa resedaeformis* (Gunn., 1763)**
Authors: **L. Buhl-Mortensen and P. B. Mortensen**

Dear Author
During the preparation of your manuscript for publication, the questions listed below have arisen. Please attend to these matters and return this form with your proof. Many thanks for your assistance

Query Reference	Query	Remarks
1	Frederiksen spelling changed to match reference list, OK?	
2	Mortensen 2000 changed to 2001 to match reference list throughout, OK?	
3	Buhl-Mortensen and Mortensen, in preparation, is there have any update? In press?	
4	Mortensen and Buhl-Mortensen 2003, submitted, is there have any update? In press?	