

Benthic Marine Fauna and Flora of Two Nearshore Coastal Locations in the Western and Central Canadian Arctic

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ABSTRACT. Baseline data on nearshore benthic macrofauna and flora assemblages are necessary for successful environmental monitoring in the Arctic, where major climate and industrial changes are underway, yet to date these environments remain understudied. This study used bottom video and benthic grab samples to compare shallow benthic marine (1–40 m) floral and faunal distribution and composition in two nearshore locations in the Canadian Arctic with different geomorphic settings. Sachs Harbour, located on southwestern Banks Island, has a submergent soft-sediment shoreline with locally rapid coastal erosion, while Gjoa Haven, located on southeastern King William Island, has an emergent shoreline dominated by coarse ice-contact Quaternary sediments with little to no coastal erosion. Gjoa Haven's sediment-starved, heterogeneous nearshore area contributes to a more diverse macroalgal flora than is found at Sachs Harbour, where a continuous supply of sand and mud from thermally driven coastal erosion and muddy runoff produces a more homogeneous nearshore environment. Seventy-four species (10 macroalgae, 64 macrofauna) were recorded from southwestern Banks Island and 65 species (26 macroalgae, 39 macrofauna) from southeastern King William Island. Species composition differed greatly among locations and varied significantly among substrate and depth classes for grab- and video-sampled biota at Gjoa Haven and among depth classes for bottom video biota at Sachs Harbour. Faunally barren, shallow, mobile sand sheets were the dominant habitat sampled in Sachs Harbour. Gjoa Haven's habitats differed significantly along a depth gradient, with sand and gravel substrates covered by *Fucus* sp. at depths shallower than 10 m and muddy substrates with filamentous green algae, *Coccolytus truncatus*, and cerianthid anemones inhabiting water down to 40 m.

Key words: Arctic, marine benthos, macroalgae, habitat, assemblages, coastal erosion, climate change, ecology, sedimentation

RÉSUMÉ. Les données de référence sur les assemblages de macrofaune et flore côtières sont nécessaires pour un suivi environnemental efficace en Arctique où d'importants changements climatiques et industriels sont en cours. Cependant, ces environnements particuliers restent peu étudiés. À l'aide de vidéos de fond et d'échantillons benthiques, cette étude compare la distribution et la composition de la faune et flore benthique peu profonde (de 1 à 40 m) entre deux zones littorales de l'Arctique canadien caractérisées par différents paramètres géomorphologiques. Le port de Sachs, situé au sud-ouest de l'île Banks, est caractérisé par une côte de submersion avec une érosion côtière locale rapide. Le site de Gjoa Haven, situé au sud-est de l'île du Roi-Guillaume, est caractérisé par une côte émergente, dominée par des sédiments de grosse taille du Quaternaire, avec peu voire pas d'érosion côtière. La zone côtière de Gjoa Haven, hétérogène et pauvre en sédiment, contribue à la présence d'une flore macroalgale diverse comparée au port de Sachs, environnement côtier plus homogène recevant des apports continus de sédiment suite à la thermo-érosion côtière et au ruissellement boueux. Soixante-quatorze espèces (10 macroalgues marines, 64 macrofaunes) ont été reportées au sud-ouest de l'île de Banks et 65 espèces (26 macroalgues marines, 39 macrofaunes) au sud-est de l'île du Roi-Guillaume. Au site de Gjoa Haven, les vidéos de fond et échantillons benthiques révèlent une composition d'espèces très différente en fonction des sites, substrats et profondeurs. Au port de Sachs, les vidéos de fond révèlent une différence dans la composition des espèces en fonction de la profondeur. Le principal type d'habitat échantillonné au port de Sachs est caractérisé par des bancs de sable mobiles dépourvus de faune. Les habitats du site de Gjoa Haven suivent un gradient de profondeur, avec *Fucus* sp. couvrant des fonds sableux ainsi que des graviers dans des eaux ayant une profondeur < 10 m, et des fonds boueux couverts d'algues marines vertes filamenteuses, *Coccolytus truncatus*. Les anémones cérianthides caractérisent les régions plus profondes jusqu'à 40 m.

Mots clés : Arctique, benthos marin, macroalgues, habitat, assemblage, érosion côtière, changement climatique, écologie, sédimentation

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INTRODUCTION

Arctic coasts are subject to rapid rates of geomorphic and biological change. Along sedimentary shorelines, accelerating climate change—including increased air and sea temperature, increased storm frequency and precipitation, global sea-level rise, and reduced sea-ice coverage—is accompanied by increased coastal erosion and sedimentation into Arctic nearshore environments (ACIA, 2005; Manson et al., 2005; Lantuit et al., 2009). These changes could alter marine benthic community structure (Snelgrove, 1998; ACIA, 2005; Piepenburg, 2005; Dunton et al., 2006; Reist et al., 2006; Anisimov et al., 2007). Benthic organisms are a critical component of the Arctic food chain, providing a food source for bottom-feeding fish, seabirds, and marine mammals (Frost and Lowry, 1984). They may be closely coupled to the pelagic system, consuming phytoplankton, transferring nutrients, and providing a link between pelagic organisms and species at upper trophic levels, including some species harvested by Inuit, such as grey whales, bearded seals, and ringed seals (Grebmeier and Barry, 1991; Hobson et al., 1995). Benthic infauna affect sediment microbiology, chemistry, and stability by breaking down detritus and reworking the upper 20 cm of the seabed (Snelgrove, 1998). Arctic benthic communities can host diverse and abundant macrofauna and flora composed of organisms that can be sensitive to environmental change (Conlan et al., 2008). If predictions of increased climate change and anthropogenic disturbance in the North hold true, Arctic nearshore environments may be greatly stressed.

Areas in the Western Canadian Arctic undergoing glacio-isostatic submergence, such as Tuktoyaktuk and Sachs Harbour, Northwest Territories (NWT), experience rapid coastal erosion and have been characterized as “highly sensitive” to sea-level rise (Shaw et al., 1998; Manson et al., 2005; Solomon, 2005; Dunton et al., 2006). Eustatic sea-level rise from thermal expansion and melting glaciers, combined with glacio-isostatic sea-level change, will likely lead to amplified relative sea-level rise in parts of the western Arctic (Manson et al., 2005; Belliveau, 2007). Coastal areas in the central and eastern Canadian Arctic such as Gjoa Haven, though dominantly emergent, are still subject to the effects of climate change and eustatic sea-level rise. Furthermore, many of these areas may be on the cusp of changing from glacio-isostatic emergence to submergence (Tarasov and Peltier, 2004). This change may result in relatively rapid relative sea-level rise, with possible attendant coastal erosion and sedimentation.

Detailed studies of nearshore benthic marine macrofauna and flora for the Canadian Arctic are relatively scarce, except for studies by Ellis (1960), Ellis and Wilce (1961), Lee (1973), Thomson (1982), Reimnitz et al. (1992), and Dale and Leontowich (2006) and some technical reports (Wacasey et al., 1979; Heath and Thomas, 1984; Thomson et al., 1986; Atkinson and Wacasey, 1989; Siferd, 2001). Most benthic studies in the Canadian Arctic have

concentrated on the benthic macrofauna inhabiting northern fiords (Curtis, 1972; Hunter and Leach, 1983; Dale, 1985; Aitken et al., 1988; Dale et al., 1989; Syvitski et al., 1989; Aitken and Fournier, 1993; Aitken and Gilbert, 1996) and along the Arctic continental shelf (Curtis, 1975; Stewart et al., 1985; Cusson et al., 2007; Conlan et al., 2008). In terms of baseline information about benthic species and communities, Arctic open-ocean and nearshore environments remain understudied in comparison with southern locations. Furthermore, researchers face the challenge of accessing the taxonomic skills and reference material required to provide a consistent and reliable inventory of species present in this region of Arctic Canada (Cusson et al., 2007). If future research can aim to fill the gaps in our knowledge of Arctic nearshore benthic ecology, we can establish a sound baseline that will help to track future changes brought on by climate change, sea-level rise, and industrialization.

In the summers of 2005 and 2006, we investigated the nearshore benthic macrofauna and flora of the southwestern coastline of Banks Island near Sachs Harbour and the southeastern coastline of King William Island near Gjoa Haven (Fig. 1). Our main goals were (1) to provide a baseline inventory and detailed description of the macrofauna and flora of the two study areas, and (2) to compare taxonomic composition at different locations, substrate types, and depths.

The shallow benthic environments in our two study locations have contrasting geomorphic settings. Sachs Harbour has a submergent, muddy-sandy shoreline with locally rapid coastal erosion, and Gjoa Haven has an emergent, gravelly shoreline with little to no coastal erosion. Both locations are the subjects of ongoing coastal geomorphic studies (Manson et al., 2005; Papadimitriou et al., 2006; Belliveau, 2007; Papadimitriou, 2007). Baseline information on the benthic macrofauna and flora is limited for the southwestern coastline of Banks Island (Sachs Harbour) (Siferd, 2001) and lacking for the southeastern coastline of King William Island (Gjoa Haven).

MATERIALS AND METHODS

Study Sites

Sachs Harbour (71°59' N, 125°14' W) is located on Amundsen Gulf along the exposed southwest coast of Banks Island, NWT, in western High Arctic Canada. Gjoa Haven (68°38' N, 95°52' W) is located on the southeastern coast of King William Island, in the Kitikmeot Region, Nunavut, in the central Canadian Arctic (Fig. 1). Coastal geomorphic processes influencing the nearshore environment in the two areas differ greatly, and this difference is enhanced by opposing trends in relative sea level. Sachs Harbour has a submergent shoreline with coastal erosion (Manson et al., 2005; Belliveau, 2007; Catto and Parewick, 2008). Exposed coastal bluffs to the west of the community

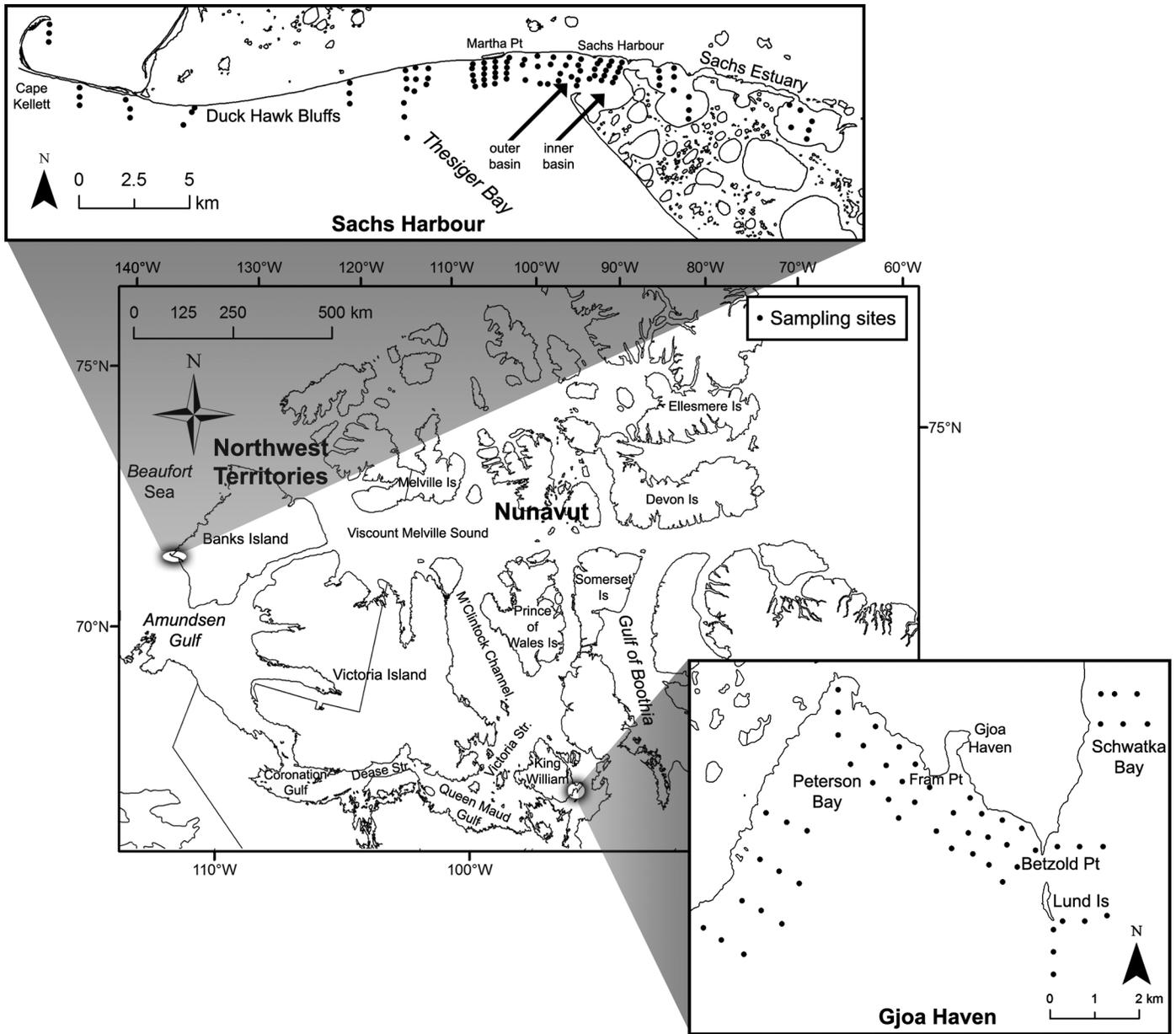


FIG. 1. Map showing the locations of Sachs Harbour on the southwestern coastline of Banks Island and Gjoa Haven on the southeastern coastline of King William Island. On the enlarged study area maps, dots indicate sampling sites.

are retreating at rates up to 3 m per year, and segregated ice lenses are common (Catto and Parewick, 2008). By contrast, Gjoa Haven exhibits an emergent (1 mm per year), low-energy shoreline underlain by coarse sand and gravel ice-contact Quaternary sediments (Papadimitriou, 2007; Catto and Parewick, 2008). Segregated ice lenses are rare, and thermokarst features are very shallow and present only in areas of anthropogenic disturbance (Catto and Parewick, 2008). The coarser surficial geology of Gjoa Haven is less susceptible to erosion than the ice-rich sandy sediments of Sachs Harbour. Tidal effects in both areas are assumed to be negligible because of low tidal range and coastal topography. The coastlines of both study areas are microtidal, with a mean tidal range of 0.25 m or less (DFO, 2007). The presence of coastal bluffs that are generally higher than

the tidal range along the southwestern coastline of Banks Island and raised beaches and emergent setting along the southeastern coast of King William Island minimize tidal influences. Both study areas are subject to ice scouring, especially during seasonal breakup and storm activities. Bathymetric surveys off Cape Kellett on the southwestern coastline of Banks Island showed evidence of extensive ice scour due to active sea-ice movement from the north (Belliveau, 2007).

The Sachs Harbour study area covers a 40 km length of coastline (Fig. 1). The southwestern coastline of Banks Island is composed mainly of unconsolidated sand and gravel sediments of the Miocene to Pliocene Beaufort Formation overlain by sandy Sachs Harbour till (Vincent, 1982; Vincent et al., 1983). The bluffs along this coastline



FIG. 2. (a) Erosion of coastal cliffs and ground ice along the southwestern shoreline of Banks Island (Person for scale: D. St. Hilaire, seated height = 122 cm). (b) Emergent coastline of raised beaches composed of sand, gravel, and cobbles, with some glacial erratic boulders, along the southeastern shoreline of King William Island; approximate height of raised beach is 1.2 m.

are interbedded silty sand, fine sand, and gravel with up to 25% excess ice and thin lenses and icy layers with excess ice ranging from 40% to 95% (French, 1975; Manson et al., 2005) (Fig. 2a). Massive ice, pore ice, and wedge ice are also present along the coast (French, 1975; Manson et al., 2005). The southwest coastline is a low-wave energy environment, with minimal wave interaction with coastal cliffs except during periods of high waves and water levels associated with storm events (Belliveau, 2007). Rapid coastal erosion along the southwestern coastline has been tied to long-term sea-level rise, abundant ground ice, and high storm frequency (mean 8 ± 4 storms per year, 1969–2005; Belliveau, 2007) during the open-water season (Solomon, 2001; Manson et al., 2005). Eroding cliffs of varying heights dominate much of the southwest coast and supply sand and some gravel to the nearshore environment (Manson et al., 2005). The depositional features (winged headlands, barrier beaches, curved spits, and the recurved coarse spit of Cape Kellett) present along this coastline indicate that sediment transport is an important depositional mechanism (Taylor and McCann, 1983; Belliveau, 2007). Previous studies have identified three major transport directions for sediment movement: 1) northward from the Sachs Lowlands supplying the Sachs Spit, 2) eastward along the shore to the Martha Point foreland and northwestward to the Sachs Harbour spit, and 3) westward along the Duck Hawk Bluffs to Cape Kellett (Harry et al., 1983; Manson et al., 2005; Belliveau, 2007) (Fig. 3). The beaches are prograding in many parts of the shoreline, and there is a net progradation in most areas of the Sachs Harbour community, except for Cape Kellett and the Duck Hawk Bluffs (Belliveau, 2007).

The coastal area south of the community of Sachs Harbour and inshore of the Sachs Harbour spit and in the Sachs Estuary is a gently sloping glacial outwash platform with

kettle lakes (French and Harry, 1988; Manson et al., 2005). These marine-inundated kettle lake basins have depths ranging from 40 to 50 m.

The Gjoa Haven study area is approximately 18 km in length, extending north of Betzold Point to the western coast of Peterson Bay (Fig. 1). King William Island has a uniformly low-gradient, regular coastline (Stewart and Bernier, 1983) that is subject to low wave energy and has no wave-cut bluffs more than 1 m high (Catto and Parewick, 2008). Among all the islands in the Arctic Archipelago, it is one of the lowest in elevation, never rising 100 m above sea level (Fraser and Henock, 1959). The southeastern coastline, around the Gjoa Haven area, is made up of Ordovician and Silurian dolomite and dolomitic sandstone overlain by Pleistocene ice-contact sediments composed mainly of sand and gravel (Blackadar, 1967; Helie, 1984). Glacial sediments, including basal till, ablation moraine, ice-rafted boulders, and silts, are present across the island (Fraser and Henock, 1959). The community of Gjoa Haven is built on flights of raised beaches, which are composed of wind-deflated sand, gravel, and cobbles, with some glacial erratic boulders, mixed with locally derived Silurian carbonates (Dyke and Dredge, 1989) (Fig. 2b). Hummocky terrain and tundra polygons are found throughout the Gjoa Haven area, and pore ice is the most dominant form of ground ice.

The coastal area south of Gjoa Haven and inshore of Peterson Bay is a gently sloping platform. Shoals are present to the north of Betzold Point and inshore of Schwatka Bay (Fig. 4). Sediment enters the marine system primarily from the river mouth located at the head of Peterson Bay (Fig. 4). Mud plumes from the river occur typically during spring thaw and occasionally after minor summer rain events (B. Porter, pers. comm. 2006).

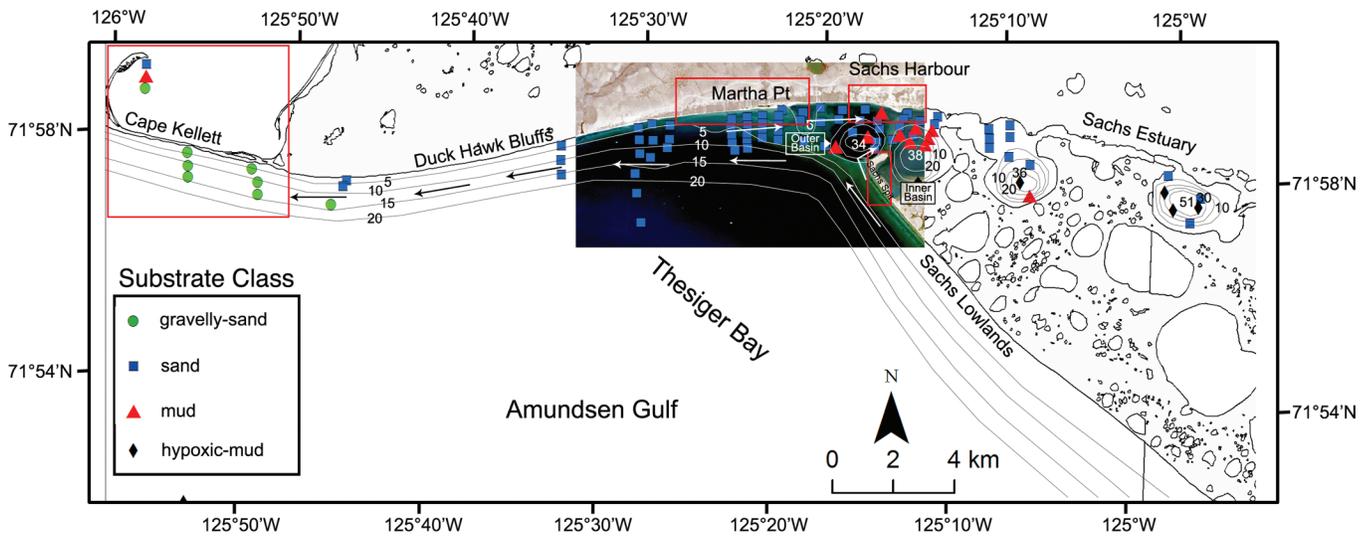


FIG. 3. Sachs Harbour study area, showing substrate classes and depth contours, depositional areas, and sediment transport for the southwest coastline of Banks Island. Coloured shapes refer to substrate class. Numbers refer to depth contours. Red boxes indicate depositional areas, and small arrows refer to movement of inferred sediment transport (Belliveau, 2007). (Modified from imagery © Digital Globe.)

Field and Laboratory Methods

In 2005 and 2006, 142 grab sample stations and 105 drop video transects were sampled in the nearshore area of the two study areas using a small open-deck speedboat piloted by a community member (Fig. 1, Table 1). Sampling sites were located 150 to 1200 m from the coast along transects perpendicular to shore at depths of 2 to 40 m. Generally, three sampling sites were sampled along each transect at approximately 200 m, 700 m, and 1200 m from shore. Transect locations and sample stations were selected to ensure a gradient in depth and maximize substrate and habitat variability. The location of each sample site was recorded using a Garmin ETrex hand-held GPS unit or WAAS-enabled Garmin 178C vessel-mounted GPS-depth sounder. To develop a bathymetric grid for each study area, we conducted sounding profiles using the Garmin GPS-MAP 178C sounder with WAAS-dGPS compatible sounder at 1–5 sec. intervals.

Biological sampling at each site included a single benthic grab sample and a drop video camera transect. Grab sample locations were sampled with a 17 × 15 cm (0.026 m²) Petit-Ponar grab, sieved on a 1.0 mm mesh screen, and preserved with 4% buffered formaldehyde solution. Time and logistical constraints and unfavourable weather precluded both the dedicated, five-replicate grab sample program recommended by Holme and McIntyre (1984) and actual measurement of grab sample volume, as suggested by Christie (1975). However, at each station we estimated the grab sample volume and took care to ensure that an adequate grab sample (no less than ~75% full; ≥ 0.0195 m²) was collected and sieved. Approximately 2% of the total volume of sediment collected from each grab sample was removed for grain-size analysis before the remainder was sieved. Because the grab cannot always penetrate to the

same depth when sampling different substrate types, the volume of substrate collected varied from station to station. If the sediment sample was too small, it was discarded and the sediment at that station re-sampled. Because of the variation in sample recovery and operational constraints, we analyzed grab sample data at the presence-absence level only (see *Data Analysis*, below).

The organisms were identified using various guides (Bousfield, 1960; Pettibone, 1963; Gosner, 1971; Macpherson, 1971; Abbott, 1974; Bernard, 1979; Appy et al., 1980; Lubinsky, 1980; Pocklington, 1989; Quijón, 2004; Gotshall, 2005). Benthic invertebrates were designated as carnivores, scavengers, suspension feeders, or deposit feeders using the classification scheme developed by Walker and Bambach (1974). The feeding guild of each organism was determined from information presented in Fauchald (1977), Fauchald and Jumars (1979), Barnes (1980), Kohn (1983), Morton (1983), and Rouse and Pleijel (2001).

Grain-size analysis of sediment samples used dry and wet sieving procedures, and sediments were classified according to the modified Udden-Wentworth grade scale (Krumbein, 1934). Dried sediment subsamples of 50–100 g, with grain sizes ranging from granules (2–4 mm) to coarse silt (0.031–0.0625 mm), were dry-sieved for 10 minutes on a mechanical sieve-shaker through a series of sieves, ranging in mesh size from -5 to +4 φ (32 mm–63 μm). Dried coarse silt and clay sediment (< 0.031 mm) were analyzed by wet-sieving, using masses of 5 grams. All visible shell debris and organic material were removed prior to analysis.

The video data were collected along video transects of approximately 3 min. duration using a SeaView Seaviewer 600 underwater drop video camera (SeaView Video Technology, Florida) or an Amphibico Dive Buddy underwater video housing. The underwater drop video camera was bolted into an aluminum cage with a fin, lowered to the

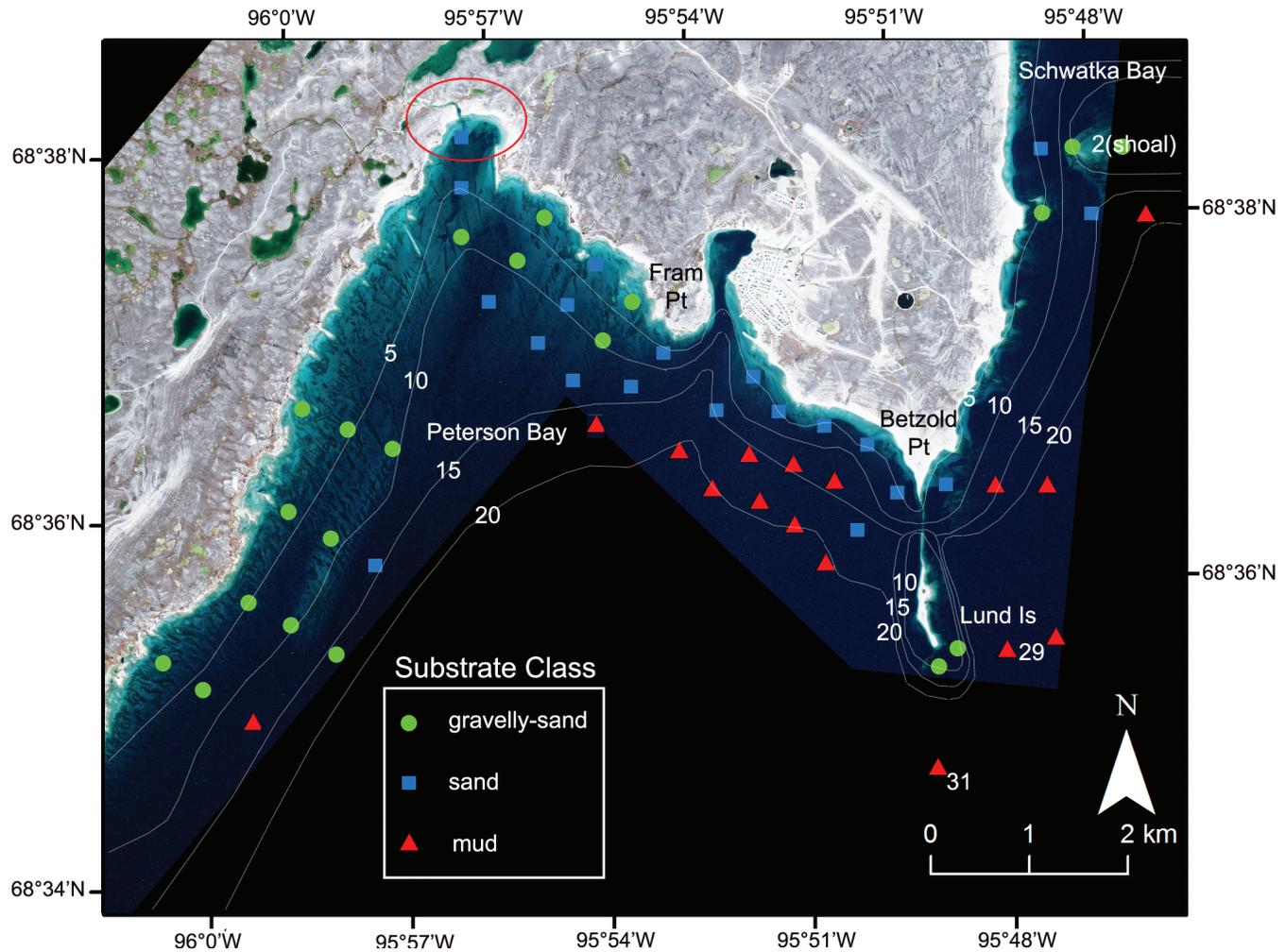


FIG. 4. Gjoa Haven study area showing substrate classes (coloured shapes) and depth contours (numbers). Red circle indicates the main source of sediment transported into the marine system. (Modified from imagery © Digital Globe.)

seafloor on a 45 m tether, and held approximately 0.5–1 m above the bottom. The view of the drop video camera was directly downward as the camera moved parallel to the bottom surface. The aluminum cage and fin helped keep the camera steady, preventing camera rotation, so that the camera could obtain a relatively stable image. We tried to maintain a constant speed of less than 5 km/h for each transect. The SeaView was powered with a 12-volt battery, and the video signal was recorded on a SONY TRV38 Digital “handycam” (Sony Corporation, Tokyo) with an LCD screen that doubled as a video monitor. Digital video was captured at 29.97 frames per second. The frame series for each transect was stored as an iMovie HD file, and digital enhancement (i.e., colour correction) was carried out where required to enhance clarity and contrast. Geographical position and depth were registered at the beginning and end of each transect using the Garmin 178C GPS-depth sounder. Laser beams provided a 15 cm scale for measuring approximate width of the video frame and size of the organisms and benthic features in the video images. We then viewed the video records of each transect and identified all macroalgae and fauna to the lowest possible taxon.

Video analysis was especially useful for the identification of megabenthos (~1–12 cm) and for substrates with dispersed cobbles or pebbles and boulders, which often yielded no recovery in grab samples.

Sachs Harbour video sampling stations covered depths between 1 m and 39 m, with an average transect duration of 3 minutes, 20 seconds per station (SD = 1 min. 30 sec.) and a total time for the video data of 2 hours and 33 minutes. Transects of the Gjoa Haven study area covered depths between 2 and 31 m, with an average duration of 2 min., 2 sec. (SD = 21 sec.) and a total time for the video data of 1 hour and 56 minutes. To sample approximately the same depth over the duration of each video transect, transects were planned to run parallel to bathymetric contours.

Two possible limitations complicate data interpretation of the seabed using a drop video camera. First, at sites dominated by macroalgae fronds and blades, it is difficult to locate fauna in the video. Second, the drop video camera was run at a constant speed for each transect; however, with daily changes in wave surface elevation, current, and wind speed and direction, the distance (and area) covered by a transect varied considerably. Video transect length ranged

TABLE 1. Substrate and depth class description and representation (number of grab stations and video transects sampled) in the Sachs Harbour and Gjoa Haven study areas.

Substrate class	Description	Sachs Harbour		Gjoa Haven	
		Grab	Video	Grab	Video
Gravelly sand	Sand with more than 20% dispersed pebbles and cobbles	8	7	16	20
Sand	Fine-, medium-, and coarse-grained sands	70	29	20	20
Mud	Fine sediments with more than 50% silt + clay	11	9	16	17
Hypoxic mud	Reduced sediments with more than 50% mud	1	3	0	0

Depth class	Description	Sachs Harbour		Gjoa Haven	
		Grab	Video	Grab	Video
< 10 m	Stations sampled 0 to 10 m below the surface	62	24	16	21
> 10 m	Stations sampled more than 10 m below the surface	28	24	36	36
Total no. of stations sampled		90	48	52	57

from 3 m to 138 m (mean: 31 m) in Sachs Harbour and from 2 m to 75 m (mean: 37 m) in Gjoa Haven.

Substrate and Depth Classes

Total sampling for the two study areas included 142 grab sample stations and 106 video transects classified into four substrate classes (gravelly sand, sand, mud, and hypoxic mud) and two depth classes (< 10 m and > 10 m). Table 1 outlines the characteristics used for classifying each substrate class from grain size and video analysis. The substrate classified as hypoxic mud was black and had a strong odour of hydrogen sulfide.

Data Analysis

Species-accumulation curves for taxa identified in each location and in each substrate class and depth zone within each location were generated by the species-accumulation functions in PRIMER. Two indices are shown: taxon counts (Sobs) and the first-order jackknife estimator. Curve calculations were based on individual grabs. The distribution of grab species richness between locations was examined using Kolmogorov-Smirnov two-sample tests. Because of the variable distance and area covered by video transects, we evaluated the effect of video transect length on the total number of species recorded in each transect, using a linear regression. To account for this variability, video transect data on species richness were normalized to transect length (number of species observed per meter multiplied by a hundred). Species richness indices for normalized video transect data between locations were compared by a one-way ANOVA.

Species richness and species composition analyses were carried out on presence/absence-transformed data (Clarke and Warwick, 2001) because of the geographical difference between the two locations and variability in sample size. Data gathered by the video and the grab sampler were analyzed separately (Kostylev et al., 2001). Bray-Curtis similarity among samples was calculated on the basis of species presence/absence among the sample sites (Clarke and

Warwick, 2001), using the PRIMER version 6.1.10 (Plymouth Routines Multivariate Ecological Research, PRIMER-E Ltd, Plymouth, UK). Each station was assigned to one of two locations (Sachs Harbour or Gjoa Haven), one of three substrate classes containing fauna (gravelly sand, sand, or mud; the hypoxic mud substrate was faunally barren), and one of the two depth classes. A two-way crossed analysis of similarity (ANOSIM) was conducted using the two factors (location and substrate + depth) on the similarity matrix to test for differences in taxonomic composition between the two locations. Creating the combined factor (substrate + depth) removes both substrate and depth effect when testing for a location effect. Differences in substrate type and depth were tested for significance using a two-way crossed ANOSIM, which removes one or two of the factors: depth or depth + location when testing for substrate type and substrate type or substrate + location when testing for depth. The pairwise R value (R statistic) obtained gave us a relative measure of how distinct the groups were on a scale of 0 (indistinguishable) to 1 (all similarities within groups are greater than similarities between groups) (Clarke and Warwick, 2001). Resemblances among location, sediment type, and depth were graphed using multidimensional scaling (MDS). A stress value tending towards zero (< 0.1) indicates that there is good separation between the groups (classes), with no real prospect of a misleading representation (Clarke and Warwick, 2001). We identified characteristic taxa (those found with consistent high frequency in most samples) by location, sediment type, and depth, using the SIMPER procedure.

RESULTS

Species Richness

In the Sachs Harbour study area, we identified 73 taxa, of which 47% were annelids, 29% molluscs, and 15% macroalgae. The remaining 9% comprised crustaceans, echinoderms, tunicates, and a sipunculid (see Appendix). In the Gjoa Haven study area, of the 66 taxa identified, annelids

accounted for 36%, macroalgae 41%, and molluscs 13%. The remaining 10% comprised crustaceans, echinoderms, tunicates, and a priapulid (see Appendix).

The estimated species-accumulation curves (first-order jackknife) for grab sample data for the two locations (based on counts and taxa from individual grabs at each location) were much greater than the curves for observed taxon counts, indicating that infaunal species may have been undersampled, and no asymptote was reached for estimated or observed, indicating an incomplete census of the infauna (Fig. 5a). By contrast, species-accumulation curves for the video data for both locations (based on counts and taxa from the individual video transects at each location) were able to define the richness of epifauna and algae reasonably well (Fig. 5a). Curves for the grab samples (composed primarily of infauna) indicated higher regional species richness in Sachs Harbour (Fig. 5a). By contrast, curves for the video transect data suggested higher species richness (greater number of epifauna and algae species) in Gjoa Haven (Fig. 5a).

Macrofauna were absent from 32% of the grab samples at Sachs Harbour, compared to only 13% of those at Gjoa Haven. One, two, or three species occurred in 47% of the grab samples at Sachs Harbour and 44% of those at Gjoa Haven. The remaining 21% of the samples at Sachs Harbour contained four to ten species, and the remaining 43% at Gjoa Haven, four to nine species (Fig. 6). Sampling sites yielded no recovery with the grab sampler at six stations in Sachs Harbour and five stations in Gjoa Haven. The distribution of per-grab-sample species richness indicated greater species richness per unit area in Gjoa Haven than in Sachs Harbour (Kolmogorov-Smirnov two sample test, $p = 0.022$).

Visible epifauna and macroalgae were absent from 47% of the Sachs Harbour video transects, but only 9% of the Gjoa Haven video transects. No relationship was found between video transect length and species richness in Gjoa Haven ($r^2 = 0.026$, $p = 0.310$); however, a weak positive relationship was found in Sachs Harbour ($r^2 = 0.286$, $p = 0.007$). Average length-normalized species richness among video transects was significantly greater in Gjoa Haven than in Sachs Harbour ($F = 8.55$, $p = 0.005$, $df = 1$) (Fig. 7).

Variation in Species Richness among Substrate and Depth Classes

The species-accumulation curves for substrate classes and depth zones derived from the macrofauna grab sample data for both locations did not stabilize toward an asymptotic value for observed data (Fig. 5b, c) or estimated data (not shown), indicating an incomplete census.

Species-accumulation results for substrate classes and depth zones derived from the macroflora and macrofauna video transect data for both locations suggest that sampling was reasonably able to define the epifauna and algae species richness for each substrate class and depth zone (Fig. 5b, c). The curves indicated that the substrate with greatest species richness at Sachs Harbour was sand, while at Gjoa Haven,

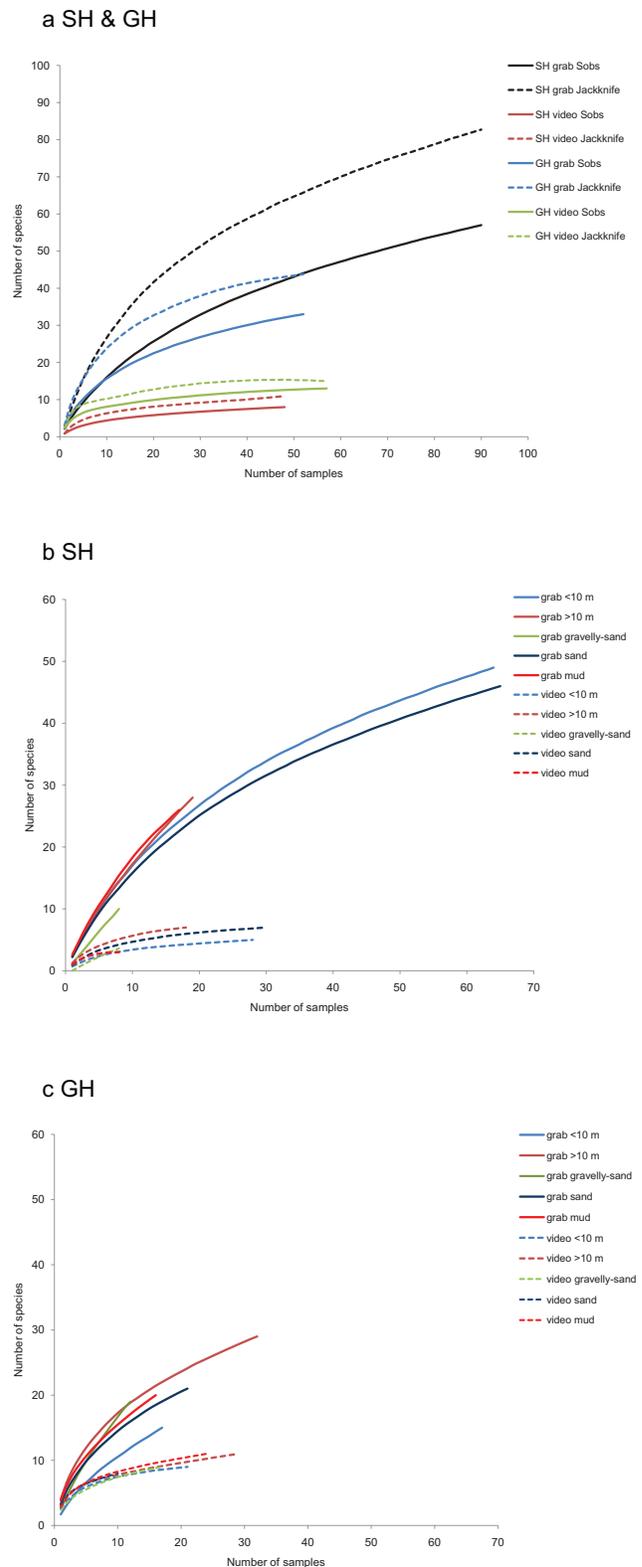


FIG. 5. Species-accumulation curves for biota sampled by grab (macrofauna) and video (macroflora and macrofauna) methods at two depths and three substrate classes for (a) Sachs Harbour and Gjoa Haven together, (b) Sachs Harbour, and (c) Gjoa Haven.

it was mud. For both sites, the curves indicated that species richness was greater at depths within 10 m of the surface.

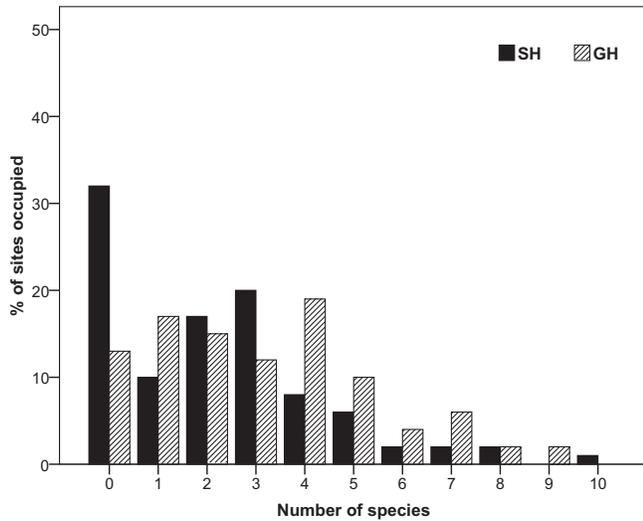


FIG. 6. Distribution of species richness among grab-sampled macrofauna. Distribution of species richness is the percentage of sites occupied by a number of species.

Characteristic Macroflora and Fauna of Sachs Harbour and Gjoa Haven

Macrobenthos differed significantly between the two study areas for both grab sample and video data (Table 2A; Fig. 8a, b). Among the grab samples, the most common macrofauna species found in the Sachs Harbour study area were carnivorous polychaetes (*Nephtys* sp., *Eumida* sp.), deposit-feeding bivalves (*Thyasira* sp., *Macoma calcarea*), and the predatory gastropod *Retusa obtusa* (Table 3). Algal mats consisting of brown (Phaeophyta) and green (Chlorophyta) algae (*Desmarestia aculeata*, *Sphacelaria* sp., *Chaetomorpha* sp.) identified from the video were the most common species of algae found within the area (Table 3). The scavenging crab (*Hyas coarctatus alutaceus*) and mats of red (Rhodophyta) macroalga, *Coccotylus truncatus*, were commonly identified in the video transects.

In Gjoa Haven, the most common species among the grab samples were a suspension-feeding bivalve (*Astarte montagui*), a deposit-feeding bivalve (*Yoldia hyperborea*), a deposit-feeding polychaete (*Scoloplos armiger*), and a carnivorous polychaete (*Aglaophamus neotenus*) (Table 3). The most common species among the video transects were brown (Phaeophyta), green (Chlorophyta) and red (Rhodophyta) macroalgae (*Fucus* sp., filamentous green algae, *Coccotylus truncatus*, *Sphacelaria* sp., *Laminaria saccharina*).

Many species collected at Sachs Harbour occurred very infrequently (one of each species) at a small number of stations, and many of the samples contained no macrobenthos (Fig. 6). Nearly all of the grab sample sites (90%) and video transects (91%) that were devoid of macrobenthos were found within the broad sand sheets that dominated Thesiger Bay. These sand sheets, apparently characterized by low floral and faunal density, were found along the nearshore area, extending from just west of the sill (approximately 2 m depth) that separates the Sachs River Estuary from Thesiger

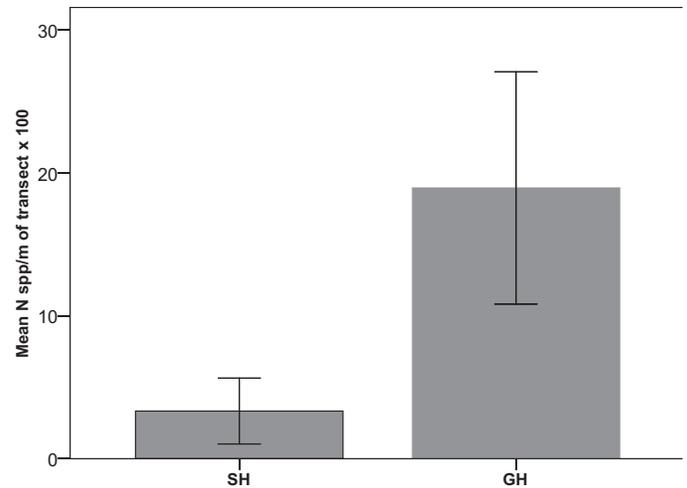


FIG. 7. Average species richness in video transects (macroflora and macrofauna) at Sachs Harbour and Gjoa Haven. Error bars are 95% CI.

Bay westward to Cape Kellett (Figs. 3, 9a). Carnivorous polychaetes (*Nephtys* sp., *Eumida* sp.), the predatory gastropod (*Retusa obtusa*), and the deposit-feeding bivalve (*Thyasira* sp.) dominated the fauna recovered from sand sheets. Sparse mats of algae were also found within this area. Very few epifauna and no macroalgae were recorded on the gravelly sand substrates south of Cape Kellett spit, and no macrobenthos were found on 50% of the gravelly sand transects (Fig. 3). To the northeast of the Cape Kellett spit, a gravelly sand bottom was present, with a diverse algal community dominated by red algae (*Coccotylus truncatus* and *Cerato-colax hartzi*) and a brown alga (*Scytosiphon* sp.). This area was dominated by deposit-feeding polychaetes (*Scoloplos armiger*, *Terebellides stroemi*) and *Thyasira* sp.

Beds of the tube anemone, *Cerianthus borealis*, were found in the deep (> 20 m) muddy substrates of the outer basin (Fig. 9b). The shallow perimeter of the inner basin was a sandy bottom covered with algal mats, consisting of Phaeophyta (*Scytosiphon* sp., *Stictyosiphon* sp., *Sphacelaria* sp., and *Desmarestia aculeata*) and Chlorophyta (*Chaetomorpha* sp.) (Fig. 9c), while the deepest parts of the inner basin consisted of a muddy bottom covered with algal mats and red algae *Coccotylus truncatus* (Fig. 9d). The carnivorous polychaete (*Nephtys* sp.) dominated the sandy substrates of the perimeter, while bivalves *Thyasira* sp. and *Macoma calcarea* dominated the deeper muddy substrates. The perimeters of the Sachs River Estuary basins were dominated by *Coccotylus truncatus*, suspension- and deposit-feeding bivalves (*Hiatella arctica*, *Macoma calcarea*) and the deposit-feeding polychaete (*Terebellides stroemi*) (Fig. 9e).

Hypoxic mud was found only in the Sachs Harbour study area, and only in the deep (> 40 m) submerged kettle lake basins of the Sachs Estuary (Fig. 10). Water and black mud taken from these basins smelled strongly of hydrogen sulfide, and numerous bubbles coming from the seabed were observed in the video. Flora and fauna were absent from these sampling stations. Acoustic profiling with the

TABLE 2. Results of two-way crossed ANOSIM tests comparing flora, fauna, and combined flora and fauna assemblages for (A) Sachs Harbour and Gjoa Haven together, by location, depth class, and substrate class; (B) Sachs Harbour and (C) Gjoa Haven separately, by depth and substrate classes. Data represent presence or absence, with R-value at left and *p*-value in parentheses. An asterisk (*) indicates significant difference ($\alpha = 0.05$).

Location	Sampling method	Number of sites	Biota	Substrate	Depth	Location
(A) SH & GH Combined	Grab	103	fauna	0.059 (0.193)	0.055 (0.150)	0.243 (0.002)*
	Video	78	flora/fauna	0.603 (0.001)*	0.398 (0.001)*	0.684 (0.001)*
	Video	67	flora	0.298 (0.001)*	0.288 (0.001)*	0.528 (0.001)*
	Video	37	fauna	0.205 (0.025)*	0.533 (0.001)*	0.433 (0.001)*
(B) Sachs Harbour	Grab	47	fauna	0.110 (0.100)	0.041 (0.370)	
	Video	26	flora/fauna	0.010 (0.448)	0.187 (0.028)*	
	Video	16	flora	-0.072 (0.660) ¹	-0.183 (0.778) ¹	
	Video	26	fauna	0.074 (0.274)	0.148 (0.219)	
(C) Gjoa Haven	Grab	44	fauna	0.16 (0.013)*	0.41 (0.001)*	
	Video	50	flora/fauna	0.273 (0.003)*	0.471 (0.001)*	
	Video	50	flora	0.286 (0.001)*	0.349 (0.001)*	
	Video	18	fauna	-0.167 (1.00) ²	1.00 (0.011)*	

¹ Large within-group dissimilarities compared with the between-group dissimilarities.

² Ten or fewer distinct permutations; a 1% level test is not possible, so data cannot be interpreted reliably.

Garmin 178C depth sounder in these basins showed an acoustically reflective pycnocline at about 20 m in these locations, which is likely linked to brine exclusion (Kvitek et al., 1998).

The video transects in Gjoa Haven were dominated by macroalgae and showed very few epifaunal taxa. Given the high rate of encountering macroalgae within the nearshore area (100% of the video stations), epifauna were likely hidden by the fronds and foliage of the macroalgae. Around Lund Island, a gravel bottom composed of gravelly sand and pebble cobble was present, with beds of *Saccharina longicuris*, *Fucus* sp., and *Coccotylus truncatus* (Fig. 9f). Beds of the tube anemone *Cerianthus borealis* and filamentous algae (Phaeophyta: *Sphacelaria* sp. and *Desmarestia* sp.; Rhodophyta: *Polysiphonia* sp. and *Rhodomela* sp.; Chlorophyta: *Ulothrix* sp.) (Fig. 9g) were found in offshore sampling sites (20–40 m depths) from around the shoal area near Betzold Point west to Fram Point. Shallow sites (< 10 m) within this region were composed of gravel and sand substrates with diverse macroalgae beds (*Coccotylus truncatus*, *Fucus* sp. and filamentous brown (Phaeophyta) algae: *Dictyosiphon* sp., *Petalonia* sp., *Pilayella littoralis*, *Sphacelaria* sp.) (Fig. 9h). The southwestern coastline of Peterson Bay was typically composed of sand, gravelly sand, and boulder-gravel with wide coverage of *Saccharina longicuris*, *Coccotylus truncatus*, and *Fucus* sp. Close to the river mouth, a sandy bottom was present with the tunicate *Molgula* sp. (Fig. 9i) and filamentous red algae (Rhodophyta: *Sphacelaria* sp. and *Rhodomela* sp.) and green algae (Chlorophyta: *Ulothrix* sp., *Cladophora* sp., *Spongomorpha* sp.), as well as gravelly sands with *Fucus* sp. beds.

Macroflora and Fauna Composition among Substrate and Depth Classes

Benthic macroflora and fauna species used in the ANOSIM, MDS, and SIMPER analyses are presented in the

Appendix. Species composition (Sachs Harbour and Gjoa Haven combined) differed significantly for substrate and depth classes observed in video data, but no significant differences were found in the grab sample data (Table 2A).

Species composition (flora and fauna) in Sachs Harbour sites was significantly different among depth classes for video-sampled data (Table 2B; Fig. 8c). Algal mats and *Coccotylus truncatus* dominated the shallow (< 10 m) nearshore environment, while the Arctic lyre crab (*Hyas coarctatus alutaceus*), northern cerianthid anemone (*Cerianthus borealis*), and algal mats dominated the deeper (> 10 m) areas (Table 3). Very few macrofauna observations were made in the shallow nearshore environment. Species composition did not differ significantly among depth classes for the grab sample data (Table 2B). Species composition among substrates showed no significant differences for grab or video data (Table 2B).

Species composition in Gjoa Haven sites was significantly different among substrate and depth classes for grab sampled data (Table 2C). Species composition of flora and of flora and fauna combined varied significantly among substrate and depth classes for video-sampled data (Table 2C). Faunal species composition varied significantly among depth classes, but not among substrate classes (Table 2C). Species composition (grab data) of sand substrates was variable, showing overlap with gravelly sand ($R = 0.317$, $p = 0.052$) and mud ($R = 0.069$, $p = 0.098$) substrates, while gravelly sand and mud substrates showed distinct separation between one another ($R = 0.415$, $p = 0.049$), with little to no overlap between the two classes (Fig. 8d). Species composition (video data) showed distinct separation across all three substrate classes ($G \neq M$: $R = 0.321$, $p = 0.015$; $G \neq S$: $R = 0.211$, $p = 0.044$; $M \neq S$: $R = 0.273$, $p = 0.012$) (Fig. 8f). Species composition (grab and video data) showed distinct separation between shallow (< 10 m) and deeper areas (> 10 m) (Table 2C; Fig. 8e, g). In the grab sampled data, the suspension-feeding bivalve *Astarte montagui* was

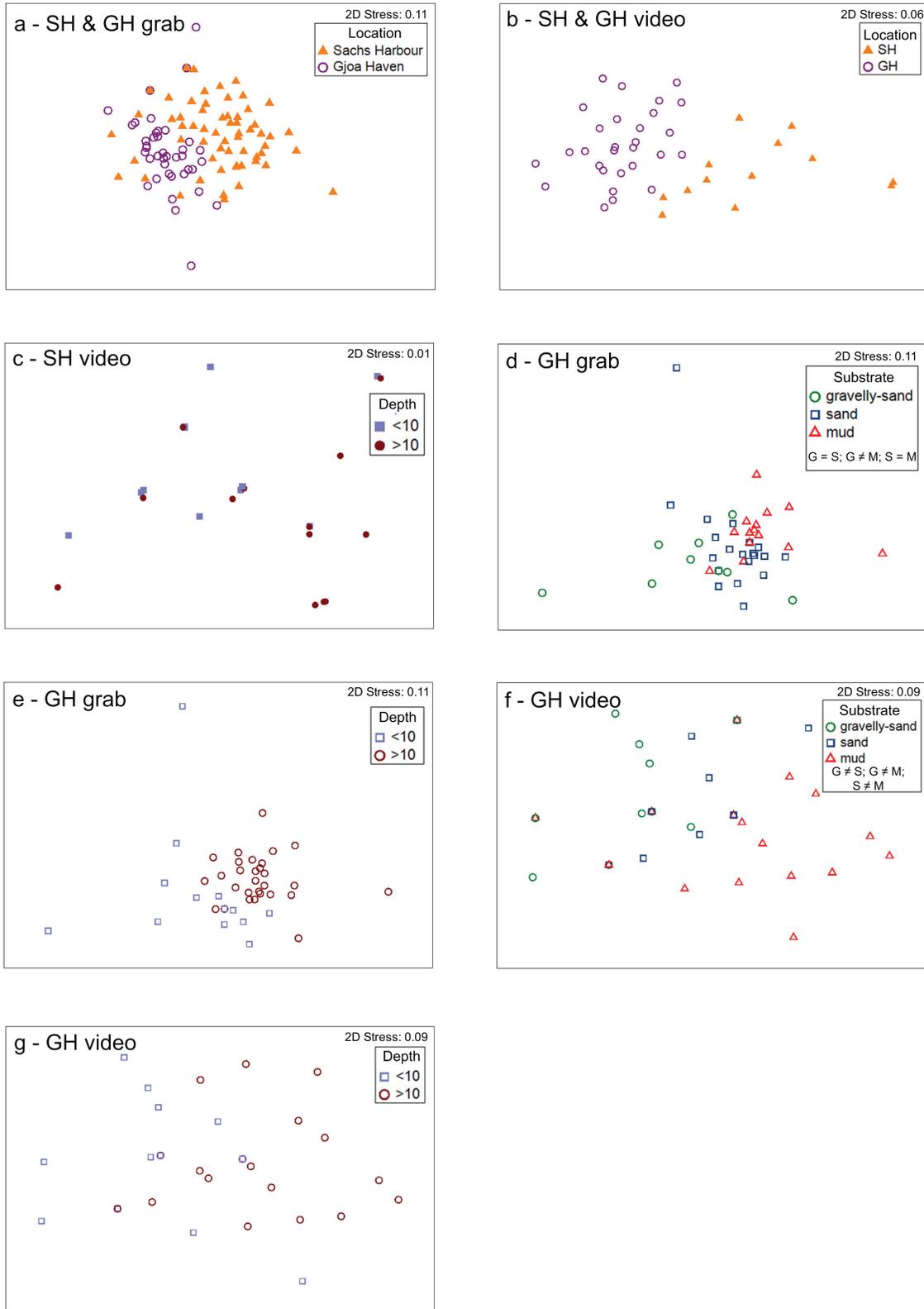


FIG. 8. Multidimensional scaling plots of taxa data from video and grab samples. Solid-coloured shapes represent Sachs Harbour (SH), and open shapes represent Gjoa Haven (GH). Depth zones: < 10 m and > 10 m; substrate classes: gravelly sand (G), sand (S), mud (M). Variation in species composition is shown among (a) SH and GH grab samples; (b) SH and GH video samples; (c) SH video flora and fauna; (d) GH grab fauna for substrate; (e) GH grab fauna for depth; (f) GH video flora and fauna for substrate; (g) GH video flora and fauna for depth.

a dominant species among all substrate and depth classes, while the deposit-feeding bivalve *Yoldia hyperborea* was

a characteristic species for deep (> 10 m) sand and mud (Table 3). The deposit-feeding polychaetes *Marenzelleria*

TABLE 3. Characteristic taxa in Sachs Harbour and Gjoa Haven for grab and video sampling methods, followed by characteristic taxa in substrate and depth classes for each study area. CTGS (Contribution to Total-Group Similarity, derived from SIMPER analysis) for each characteristic taxon is given as a percentage in parentheses. No characteristic taxa are shown for Sachs Harbour substrate classes, since no significant differences were found.

Sachs Harbour: Species (CTGS, feeding mode)		
	Grab analysis	Video analysis
Depth Class	<i>Nephtys</i> sp. (385, carnivore) <i>Thyasira</i> sp. (23%, deposit-feeder) <i>Eumida</i> sp. (8%, carnivore) <i>Retusa obtusa</i> (6%, predator) <i>Macoma calcarea</i> (5%, deposit-feeder)	Algal mats (50%) <i>Hyas coarctatus alutaceus</i> (39%) <i>Coccotylus truncatus</i> (7%)
< 10 m		Algal mats (81%) <i>Coccotylus truncatus</i> (9%)
> 10 m		<i>Hyas coarctatus alutaceus</i> (73%) <i>Cerianthus borealis</i> (12%) Algal mats (10%)
Gjoa Haven: Species (CTGS, feeding mode)		
Depth class	<i>Astarte montagui</i> (49%, suspension) <i>Yoldia hyperborea</i> (27%, deposit-feeder) <i>Scoloplos armiger</i> (6%, deposit-feeder) <i>Aglaophamus neotenus</i> (6%, carnivore) <i>Laminaria saccharina</i> (8%)	<i>Coccotylus truncatus</i> (27%) <i>Fucus</i> sp. (25%) filamentous green algae (18%) <i>Sphacelaria</i> sp. (14%)
< 10 m	<i>Astarte montagui</i> (36%) <i>Scoloplos armiger</i> (35%) <i>Retusa obtusa</i> (10%) <i>Marenzelleria viridis</i> (8%) <i>Saduria entomon</i> (6%)	<i>Fucus</i> sp. (82%) <i>Coccotylus truncatus</i> (9%)
> 10 m	<i>Astarte montagui</i> (39%) <i>Yoldia hyperborea</i> (34%) <i>Aglaophamus neotenus</i> (13%) <i>Praxillella gracilis</i> (2%) <i>Euclymene zonalis</i> (2%)	filamentous green algae (45%) <i>Cerianthus borealis</i> (21%) <i>Coccotylus truncatus</i> (21%) <i>Sphacelaria</i> sp. (8%)
Substrate class		
Gravelly-sand	<i>Astarte montagui</i> (55%) <i>Marenzelleria viridis</i> (18%) <i>Saduria entomon</i> (15%) <i>Retusa obtusa</i> (12%)	<i>Fucus</i> sp. (85%) <i>Coccotylus truncatus</i> (10%)
Sand	<i>Astarte montagui</i> (48%) <i>Yoldia hyperborea</i> (31%) <i>Scoloplos armiger</i> (8%)	<i>Coccotylus truncatus</i> (40%) <i>Sphacelaria</i> sp. (36%) <i>Laminaria saccharina</i> (16%)
Mud	<i>Yoldia hyperborea</i> (34%) <i>Astarte montagui</i> (28%) <i>Aglaophamus neotenus</i> (25%) <i>Praxillella gracilis</i> (5%)	filamentous green algae (49%) <i>Cerianthus borealis</i> (23%) <i>Coccotylus truncatus</i> (19%)

viridis and *Scoloplos armiger* were characteristic species for shallow (< 10 m) gravelly sand and sand substrates, respectively, while the carnivorous polychaete *Aglaophamus neotenus* was a characteristic species for deeper (> 10 m) mud environments (Table 3).

The video analysis, with macrofauna and flora species as attributes, was dominated by macroalgae (Table 3). *Fucus* sp. was the most dominant taxon observed in the gravelly sand substrate and shallow (< 10 m) depth class. The red

alga *Coccotylus truncatus* was a dominant species among all substrate and depth classes. Filamentous green algae and the northern cerianthid anemone (*Cerianthus borealis*) were characteristic of muddy substrates and depths greater than 10 m. The kelp *Laminaria saccharina* was most commonly found on sandy substrates with dispersed cobbles and pebbles (Table 3). The brown alga *Sphacelaria* sp. was characteristic of water depths greater than 10 m and sandy substrates (Table 3).

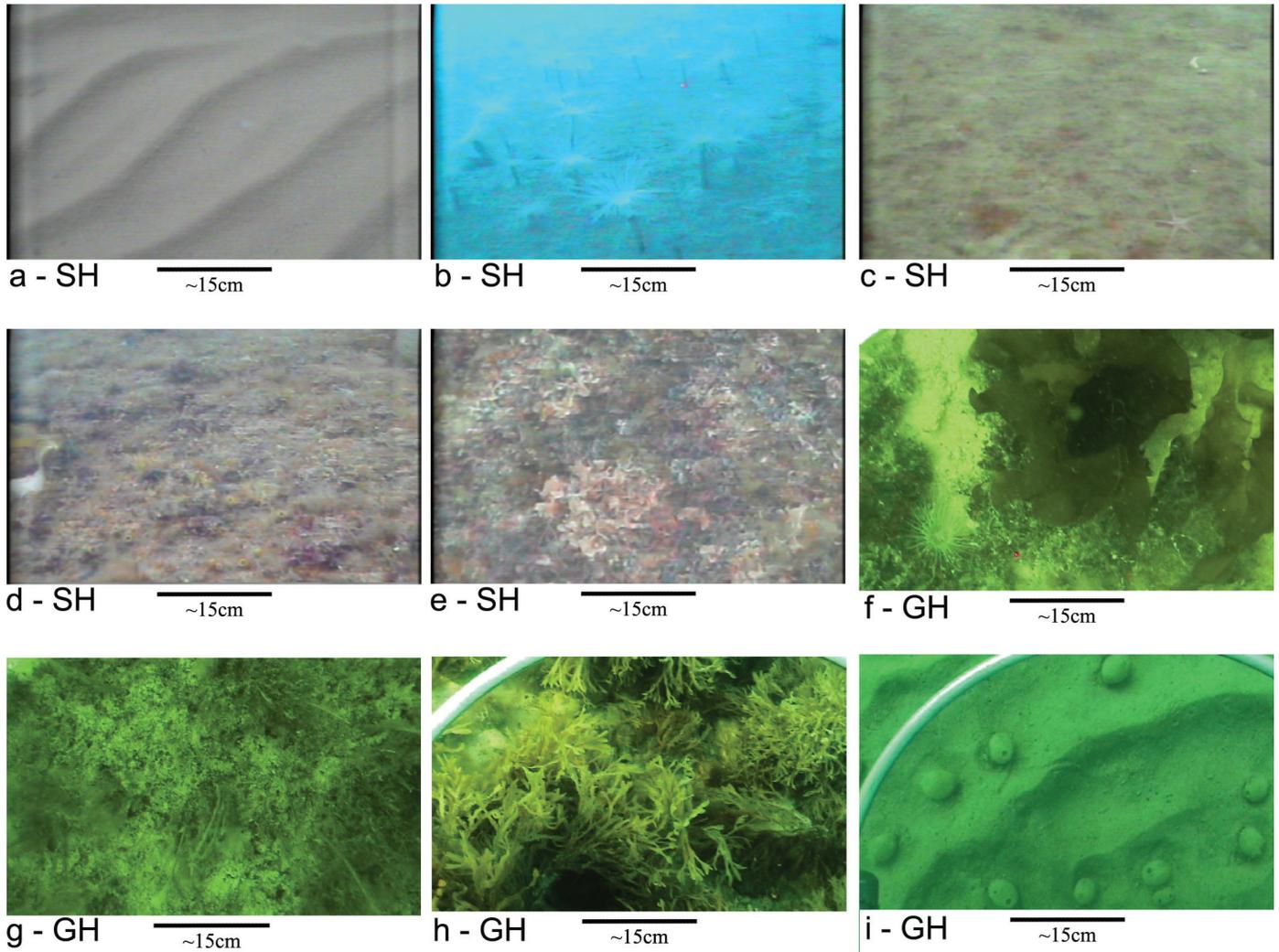


FIG. 9. Images of benthic environments for Sachs Harbour (a–e) and Gjoa Haven (f–i) from drop video transects: (a) shallow (< 10 m) rippled sands; (b) Cerianthid beds in deep (> 20 m) muddy substrates; (c) sandy substrates covered with algal mats; (d) muddy substrates with algal mats and red algae *Coccolytus truncatus*; (e) sandy substrates covered with red algae *Coccolytus truncatus*; (f) gravels and sands with diverse macroalgae beds; (g) deep (20–40 m) muddy substrates with filamentous algae; (h) shallow gravels (< 10 m) and sands with *Fucus* sp.; and (i) shallow (< 10 m) sands with *Molgula* sp.

DISCUSSION

Benthic marine macrofauna and flora for the Canadian Arctic nearshore environments remain relatively understudied, and fundamental knowledge on patterns of distribution in these environments is scarce. The present study is the most comprehensive investigation carried out along the nearshore area of these two coastlines. The only other benthic survey in Sachs Harbour (Siferd, 2001) collected epifauna along sampling transects using a drop video camera, SCUBA, and baited hooks and traps. Of the 26 species reported by Siferd, only nine were reported in this study, a discrepancy likely due to the variety of sampling methods used by Siferd. Earlier studies described benthic fauna collected from the southwest coast of Banks Island at the mouth of the Rufus River (Heath and Thompson, 1984) and at the tip of the Cape Kellett spit (Atkinson and Wacasey, 1989). Lee (1980) cataloged marine algae from various locations across the Canadian Arctic, including

some areas around Sachs Harbour and Peterson Bay, Gjoa Haven.

The present study recorded a total of 74 species (10 macroalgae, 64 macrofauna) from southwestern Banks Island (Sachs Harbour) and 65 species (26 macroalgae, 39 macrofauna) from southeastern King William Island (Gjoa Haven) (see Appendix). Polychaete worms and bivalve molluscs dominated the benthic fauna collected by grab sampling in both Sachs Harbour and Gjoa Haven. Among polychaetes and molluscs, deposit feeders had the greatest species richness for Sachs Harbour and Gjoa Haven, and polychaetes had the greatest species diversity of all higher taxa in both study areas. Similar observations have been made in other Arctic benthic nearshore fauna studies (Lalli et al., 1973; Wacasey et al., 1979; Heath and Thomas, 1984; Thomson et al., 1986; Atkinson and Wacasey, 1989; Leontowich, 2003; Dale and Leontowich, 2006). Despite the high number of samples collected in each location, the total species richness was still not captured, as indicated by

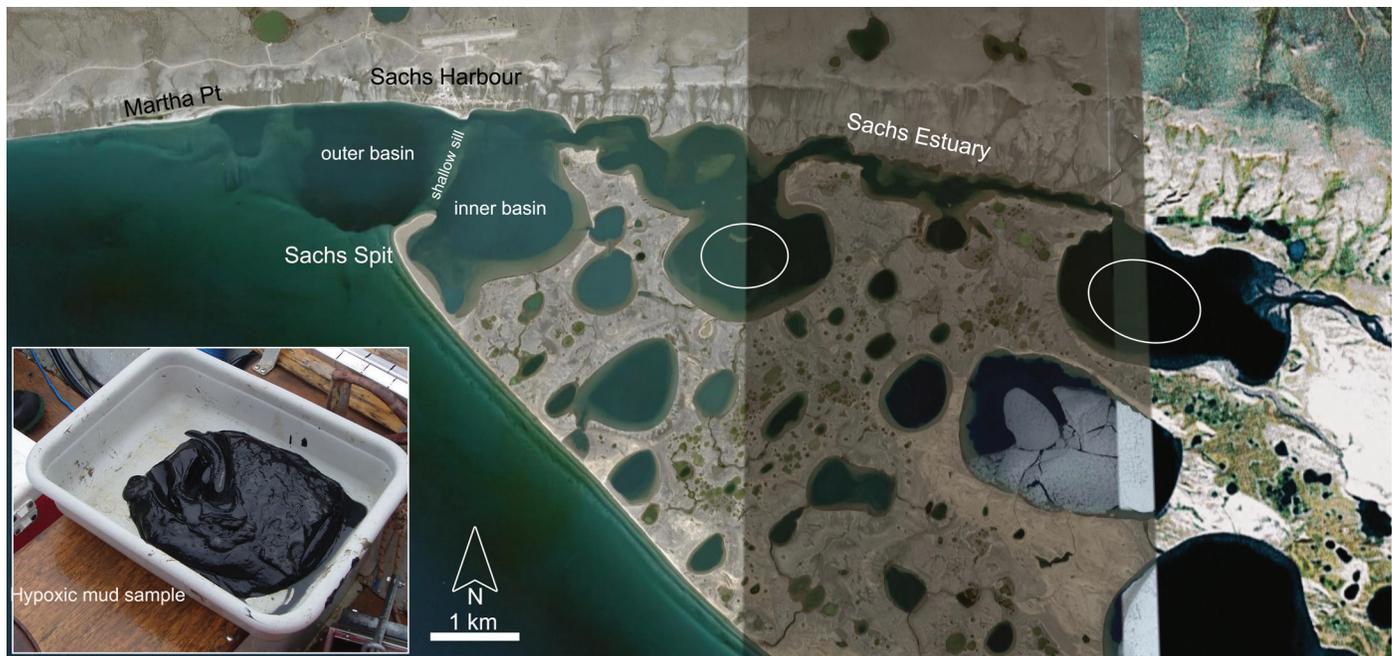


FIG. 10. Google Earth satellite image (accessed January 2009) of Sachs Harbour and the Sachs Estuary. Note the hypoxic mud basins (circled in white) located along the Sachs Estuary. Inset image: Hypoxic mud sample collected from the deep basin (> 40 m), located closest to the inner basin.

the species-accumulation curves, which did not stabilize towards asymptotic values. This failure was due to a high level of rarity within the very sparsely distributed fauna: many species were seen in only one sample, which was an artifact of undersampling. High proportions of rare species are often observed in benthic fauna and flora datasets, and thus region-specific and habitat-specific taxon accumulation curves fail to reach asymptotes (Ellingsen and Gray, 2002; Ferraro and Cole, 2007; Wlodarska-Kowalczyk et al., 2009). The assessment of the true species richness of marine benthos on habitat and regional scales is difficult to achieve even with extensive sampling (Gray, 2000). Nonetheless, the under-representation of rare species does not alter the primary taxonomic composition of the fauna and flora, which are determined by the most commonly occurring species.

Species composition differed significantly between the two study areas. Only one polychaete Family (Nephtyidae) was a characteristic taxon of both locations. *Nephtys* sp. was the predominant genus in Sachs Harbour and was most commonly found in the shallow sand environments. *Aglaophamus neotenus* was the dominant species in deeper muddy substrate environments in Gjoa Haven. Nephtyid polychaetes are opportunistic subsurface predators and typically inhabit sandy to muddy substrates (Rouse and Pleijel, 2001; Conlan et al., 2008). To our knowledge, only two other Arctic benthic studies have reported a nephtyid polychaete as a dominant species. Conlan et al. (2008) found *Micronephtys minuta* to be a characteristic species in the inshore fast ice and flaw lead regions of the Beaufort Shelf, while Dale and Leontowich (2006) found *Nephtys neotena* to be a prevalent species highly abundant in the subtidal zone of Turton Bay, Igloodik Island, northwest of

Foxe Basin. In Sachs Harbour, *Thyasira* sp. was the most common bivalve. This genus was a dominant taxon in depths greater than 100 m on the Beaufort Shelf and in the Amundsen Gulf, with no reported occurrences in the shallow flaw lead or fast ice regions of the Beaufort Sea (Conlan et al., 2008).

Given the distance between the two sites, some of the biogeographic differences observed at species level may be due to geographic position of the study area, proximity to the Arctic, Atlantic, and Pacific oceans, water mass origin, and relict distributions indicative of past environments (Ekman, 1953; Thorson, 1957; Lubinsky, 1980; Stewart et al., 1985).

Coastal geology and geomorphic processes likely contribute to some of the differences in species richness and species composition observed between the two sites. Coastal erosion and consequent sediment deposition or re-suspension, or both, can influence benthic ecosystems. After spring thaw and rain or storm events, the nearshore marine environment receives runoff from the land. Episodic or highly seasonal sedimentation can cause disturbance to benthos (Wlodarska-Kowalczyk and Weslawski, 2001; Wlodarska-Kowalczyk and Pearson, 2004; Wlodarska-Kowalczyk et al., 2005). Field observations indicate that the Sachs Harbour nearshore marine environment apparently receives greater amounts of sediment than Gjoa Haven.

Sachs Harbour's coastline is composed of unconsolidated sediments, ranging from silt and clays with vegetative debris to medium-to-coarse sands, and experiences thermally driven coastal erosion. During the Sachs Harbour 2005 field season, suspended particulate matter (SPM) concentrations at distances 100 m to 1000 m from shore

increased significantly after a minor wind-and-rain event along the southwest coast of Banks Island ($p = 0.03$; average SPM values: 29 mg/L before event, 43 mg/L after event; Brown et al., 2005; Belliveau, 2007). Areas sampled west of the community in locations of coastal retreat, with muddier coastal soils and higher ground ice content, showed the largest increase in SPM after the wind-and-rain event (24 mg/L before, 49 mg/L after) (Belliveau, 2007). The extensive mobile sand sheets in Thesiger Bay are likely derived from coastal erosion of the sandy Sachs till (Belliveau, 2007). Overall, the rippled sand sheets support a sparse community of benthic infaunal organisms (Fig. 5a), with potentially a large species richness occurring at very low abundance. Because of undersampling of this low-density environment, it was not possible to determine the total species richness of this habitat. Conlan et al. (2008) found similar variation in macrofauna abundance and diversity in the shallow fast ice (< 20 m depth) zone of the Beaufort Shelf, where species richness was relatively high with low abundance. Wave ripples commonly observed on the underwater video transects over the shallow sand sheets indicate active sediment transport, which produces a habitat relatively hostile to most macroalgae and benthic epifauna. This active sediment transport may explain the very low within-sample diversity of flora, epifauna, and infauna observed on the mobile sand sheets. Frequent disturbance by ice scour in the shallow nearshore environment can also affect benthic community structure (Conlan et al., 2008). Muddy substrates were restricted to the deeper basins within the Sachs Estuary, and to very deep sites offshore (Siferd, 2001).

Gjoa Haven, by contrast, has a coastline composed of sand mixed with cobbles and pebbles, along with some glacial erratics, and is not experiencing coastal erosion. Here the river mouth located at the head of Peterson Bay is the main source of sediment into the marine system. Local observers in 2006 commented that mud plumes from the river occur typically during spring thaw and sometimes following minor summer rain events (B. Porter, pers. comm. 2006). The higher epibenthic species richness in Gjoa Haven than in Sachs Harbour is consistent with patterns described in northern fiord environments (Dale et al., 1989). Environments with reduced sedimentation rates and more stable substrate surfaces generally support a more stable benthic population and often have the highest densities of epibenthos (Dale et al., 1989). Although absolute abundance was not statistically comparable between Sachs Harbour and Gjoa Haven, the vast number ($n = 52$) of Sachs Harbour grab- and video-sampled sites with no biota suggests that benthic fauna and flora at this location are sparse, with many depauperate sites. Siferd (2001) also suggested that the Sachs Harbour nearshore environment (depths 0–57 m) was largely devoid of macroinvertebrates and that macrobenthos were sparse.

One principal difference between the benthos in the two locations was the presence of abundant and diverse macroalgae attached to gravel substrates to depths of 25 m and beyond in Gjoa Haven. This area demonstrated the presence

of diverse macroalgae beds throughout, while in Sachs Harbour, sparse algal mats and small beds of *Coccotylus truncatus* were found only in the inner basin and Sachs Estuary. The different macroalgae presence and diversity observed in the two study areas is most likely the result of substrate and local environmental conditions. The lack of pebbles and cobbles in the shallow sand sheets and deeper muds in the nearshore environment of Sachs Harbour restricts macroalgae species requiring firm substrates, whereas the gravelly sand substrate located south of Cape Kellett spit was epifaunally bare, with no macroalgae, probably because the area is exposed to harsh conditions and subject to ice scouring and push ice. This area is wide open to the Beaufort Sea and showed signs along Cape Kellett spit of ice push (Belliveau, 2007). By contrast, pebbles and cobbles were frequently observed dispersed throughout Gjoa Haven's finer substrates, providing an attachment surface for macroalgae species. Although macroalgal diversity is generally low in Arctic areas, the numerous macroalgal species found on Gjoa Haven's mud and sandy substrata with pebbles and cobbles have been documented in other Arctic shallow coastal areas with coarse-grained sediments (Lee, 1973, 1980; Lüning, 1990; Borum et al., 2002; Hop et al., 2002).

Depth and substrate are two important factors that can affect small-scale distributions and composition of species (Wilson, 1953; Thomson, 1982; Etter and Grassle, 1992; Kostylev et al., 2001). Variation in species composition within the Gjoa Haven study area appeared to be influenced by depth and substrate for both grab samples and video-derived data. Gjoa Haven's habitats aligned along a gradual depth gradient, with *Fucus* sp. covered sand and gravel substrates at the shoreline, to muddy substrates with filamentous green algae, *Coccotylus truncatus*, and cerianthid anemones inhabiting the deeper areas.

By contrast, Sachs Harbour showed little to no statistically significant relationship between species composition and depth or substrate factors. The only significant difference found was between species composition and depth for the video-derived data. One explanation is that 47% of the sites were faunally barren, and many sites with biota contained very low species abundance, yielding an undersampled flora and fauna, especially for the grab sample data. The majority of stations sampled at Sachs Harbour were on the barren, homogeneous sand sheets that dominated the nearshore environment. Numerous sites (~ 40%) sampled within this area contained no biota, and therefore a large percentage of these sites could not be included in the species composition analyses. There was also a high level of rarity within the fauna. The lack of grab replicates at each station and the narrow range of substrates and depths sampled at Sachs Harbour may also be a reason for the lack of a statistically significant substrate or depth effect on community composition. The greatest species richness in both Sachs Harbour and Gjoa Haven occurred at the deepest sites with the finest sediments. Deeper, muddy environments are likely to be more stable and subject to less disturbance by sea ice and coastal erosion effects, compared to

the shallow (< 10 m) depth zone. Nonetheless, the nature of the habitats sampled reflects the nature of the physical environment surrounding Sachs Harbour.

The lack of macrobenthos in the two innermost basins in the Sachs River Estuary is likely due to the hypoxic conditions at the seafloor in those basins. This study sampled hypoxic substrate (black mud smelling strongly of hydrogen sulfide) and observed numerous bubbles coming up from the seabed during the drop video transects. Siferd (2001) reported that water samples 20 m and below were much more saline than the surface water, which suggests that the process of brine exclusion had taken place. Seafloor brine pools have been reported from bays and shallow continental shelves in the Arctic (Lewis, 1981). The formation of the evaporate mineral mirabilite ($\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$) by brine exclusion was also observed in the deep basins around Sachs Harbour, which indicates that winter formation of sea ice had cut off tidal circulation, producing a hyper-concentrated saline water body (Smith et al., 2007). In the absence of mixing, the saline water bodies could go anoxic in approximately 15 days, creating inhospitable conditions and leading to the death of benthic species (Kvitek et al., 1998). This is the only documented finding of mirabilite in the Arctic; however, mirabilite has been found in Antarctic saline and ice shelf lakes (Smith et al., 2007). The Sachs River Estuary out to the mouth of Sachs Harbour is a series of four deep basins (> 35 m), with very shallow sills (1–2 m) between each basin (Siferd, 2001). This structure greatly affects the circulation and can alter species distribution in the area. The hypoxic and most likely anoxic condition at the bottom of these basins is the result of a naturally occurring process, and given the topography of the basins, has likely existed for hundreds of years (Siferd, 2001).

This study provides a detailed description of the nearshore benthic community composition of Sachs Harbour and Gjoa Haven and provides a foundation for further research on nearshore benthic ecology and community structure in Arctic marine nearshore environments at depths shallower than 40 m. More research is required in nearshore Arctic environments to establish a baseline that can be used to detect future climate and anthropogenic changes to the benthic communities. If climate-warming predictions hold true, coastal erosion and resultant sedimentation into the nearshore environment would be expected to increase in Sachs Harbour. Climate warming and eustatic sea-level rise could push Gjoa Haven from emergent to submergent conditions, leading to limited coastal erosion and increased runoff during spring melt. Climate warming may allow the Northwest Passage to become a viable shipping route. If this occurs, anthropogenic impacts (e.g., petroleum pollution, tourism pollution, and the introduction of invasive species) will likely increase along Arctic coasts. Biotic consequences of these various impacts could result in change or loss of benthic species and habitat in vulnerable areas of the Canadian Arctic.

CONCLUSION

Shallow, mobile, and faunally barren sand sheets dominate the nearshore habitats of Sachs Harbour. Deep submerged kettle lake basins along the Sachs Estuary are hypoxic at depth and devoid of macrobenthos. Species richness was highest in the inner and outer basins of Sachs Harbour. Pockets of *Coccolytus truncatus* and algal mats were found along the shallow nearshore seabed of the Sachs Estuary and inner and outer basin. Variations in the physical and biological characteristics of the nearshore environment are likely due to the geological setting and dynamic coastal geomorphic processes, such as submergent coastline with rapid coastal erosion, complex longshore sediment transport patterns, restricted tidal circulation due to submerged kettle lake basins, and accompanying substrate and depth characteristics.

Gjoa Haven's nearshore area is characterized as a low-wave energy, microtidal, and sediment-starved environment. The nearshore environment is defined by substrate surfaces that are coarser and more stable than at Sachs Harbour, and it most likely supports a more stable benthic population. Gjoa Haven's nearshore macrobenthos varied along a depth gradient, grading from *Fucus* sp. covered sand and gravel substrates at the shoreline to muddy substrates with filamentous green algae, *Coccolytus truncatus*, and cerianthid anemones inhabiting the deeper areas. Variation between depth zones was greater than variation among substrate types.

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APPENDIX: Benthic flora and fauna occurring within the nearshore area of southwestern Banks Island (BI) (Sachs Harbour = SH) and southeastern King William Island (KWI) (Gjoa Haven = GH). New species reported for the areas are indicated.

VIDEO TRANSECTS	Feeding Mode	GH	SH	New species	
				KWI	BI
Macroalgae					
Chlorophyceae					
Filamentous green algae	autotroph	X			
Phaeophyceae					
<i>Fucus</i> sp.	autotroph	X	X	X	
<i>Laminaria saccharina</i>	autotroph	X	X		
<i>Scytosiphon</i> sp.	autotroph		X		X
<i>Sphacelaria</i> sp.	autotroph	X	X		
<i>Stictyosiphon</i> sp.	autotroph	X	X	X	X
Rhodophyceae					
Algal mats	autotroph		X		
<i>Coccotylus truncatus</i>	autotroph	X	X	X	X
<i>Rhodomela</i> sp.	autotroph	X			
Macrofauna					
Crustacea					
<i>Hyas coarctatus alutaceus</i> (Brandt)	scavenger		X		
<i>Saduria entomon</i> (Linnaeus)	scavenger	X	X		
Tunicata					
<i>Molgula</i> sp.	suspension	X	X		X
Cnidaria					
<i>Cerianthus borealis</i> (Verrill)	suspension	X	X		
Echinodermata					
<i>Echinarachnius parma</i> (Lamarck)	deposit	X	X		X
<i>Leptasterias littoralis</i>	carnivore	X			X
Ophiuroidea	carnivore	X			
<i>Pontaster tenuispinus</i>	carnivore		X		
<i>Strongylocentrotus droebachiensis</i> (Muller)	omnivore		X		
BENTHIC GRAB SAMPLES					
Macroalgae					
Chlorophyceae					
<i>Chaetomorpha</i> sp.	Autotroph	X	X		
<i>Cladophora</i> sp.	Autotroph	X		X	
<i>Percursaria</i> sp.	Autotroph	X		X	
<i>Rhizoclonium</i> sp.	Autotroph	X		X	
<i>Spongomorpha</i> sp.	Autotroph	X		X	
<i>Ulothrix</i> sp.	Autotroph	X			
<i>Urospora</i> sp.	Autotroph	X		X	
Phaeophyceae					
<i>Desmarestia aculeata</i>	Autotroph	X	X	X	
<i>Dictyosiphon</i> sp.	Autotroph	X		X	
<i>Fucus</i> sp.	Autotroph		X	X	X
<i>Laminaria saccharina</i>	Autotroph	X	X		
<i>Petalonia</i> sp.	Autotroph	X		X	
<i>Pilayella littoralis</i>	Autotroph	X		X	
<i>Saccorhiza</i> sp.	Autotroph	X		X	
<i>Scytosiphon</i> sp.	Autotroph	X	X		X
<i>Sphacelaria</i> sp.	Autotroph	X	X		
<i>Stictyosiphon</i> sp.	Autotroph	X	X	X	X
Rhodophyceae					
<i>Audouinella</i> sp.	Autotroph	X		X	
<i>Ceratocolax hartzi</i>	Autotroph		X		
<i>Coccotylus truncatus</i>	Autotroph	X	X	X	X
<i>Hildenbrandia rubra</i>	Autotroph	X		X	
<i>Odonthalia dentata</i>	Autotroph	X			
<i>Pantoneura</i> sp.	Autotroph	X			
<i>Polysiphonia</i> sp.	Autotroph	X			
<i>Rhodomela</i> sp.	Autotroph	X			
<i>Scagelia</i> sp.	Autotroph	X			
Macrofauna					
Crustacea					
<i>Acanthostepheia malmgreni</i> (Göes)	Scavenger	X	X	X	
<i>Diastylis rathkei</i> (Krøyer)		X		X	
<i>Gammarus</i> sp.	Scavenger	X	X	X	
<i>Saduria entomon</i> (Linnaeus)	Scavenger	X		X	
Echinodermata					
<i>Amphipholis squamata</i> (Delle Chiaje)	deposit-feeder		X		
<i>Echinarachnius parma</i> (Lamarck)	deposit-feeder		X		

APPENDIX: Benthic flora and fauna occurring within the nearshore area of southwestern Banks Island (BI) (Sachs Harbour = SH) and southeastern King William Island (KWI) (Gjoa Haven = GH). New species reported for the areas are indicated – continued:

BENTHIC GRAB SAMPLES	Feeding Mode	GH	SH	New species	
				KWI	BI
Bivalvia					
<i>Astarte montagui</i> (Dillwyn)	suspension	X	X	X	
<i>Clinocardium ciliatum</i> (Fabricius)	suspension		X		
<i>Cumingia tellinoïdes</i> (Conrad)	suspension		X		X
<i>Ennucula tenuis</i> (Montagu)	deposit-feeder	X	X	X	X
<i>Hiatella arctica</i> (Linnaeus)	suspension	X	X	X	
<i>Macoma calcarea</i> (Gmelin)	deposit-feeder		X		X
<i>Macoma moesta</i> (Deshayes)	deposit-feeder	X	X	X	X
<i>Musculus discors</i> (Linnaeus)	suspension	X	X	X	X
<i>Mysella planulata</i> (Stimpson)	suspension		X		X
<i>Nucula bellotti</i> (Adams)	deposit-feeder		X		X
<i>Nucula proxima</i> (Say)	deposit-feeder		X		X
<i>Tellina</i> sp.	deposit-feeder		X		X
<i>Thyasira</i> sp.	deposit-feeder		X		X
<i>Turtonia minuta</i> (Fabricius)	suspension		X		X
<i>Yoldia hyperborea</i> (Gould)	deposit-feeder	X	X	X	X
Gastropoda					
<i>Lacuna vineta</i> (Montagu)	herbivore		X		X
<i>Odostomia</i> sp.	parasite		X		X
<i>Oenopota turricula</i> (Montagu)	carnivore		X		X
<i>Retusa obtusa</i> (Montagu)	predator	X	X	X	
<i>Volutopsius</i> sp.			X		X
Polychaeta					
<i>Aglaophamus neotenus</i> (Noyes)	carnivore	X	X	X	X
<i>Ancistrosyllis groenlandica</i> (McIntosh)	carnivore		X		X
<i>Apistobanchus tullbergi</i> (Levinsen)	deposit-feeder		X		X
<i>Capitella capitata</i> (Fabricius)	deposit-feeder		X		
<i>Cossura longocirrata</i> (Webster & Benedict)	deposit-feeder		X		X
<i>Enipo</i> sp.	carnivore	X	X	X	X
<i>Eteone</i> sp.	carnivore	X	X	X	
<i>Euclymene zonalis</i> (Verrill)	deposit-feeder	X		X	X
<i>Eumida</i> sp.	carnivore		X		X
<i>Eunice</i> sp.	carnivore		X		X
<i>Fabricia sabella</i> (Ehrenberg)	suspension		X		X
<i>Goniada gigantea</i> (Verrill)	carnivore		X		X
Goniadidae	carnivore				X
<i>Harmothoe extenuata</i> (Grube)	carnivore	X	X	X	X
<i>Laonice cirrata</i> (Sars)	deposit-feeder	X		X	X
<i>Magelona</i> sp.	deposit-feeder		X		X
<i>Marenzelleria viridis</i> (Verrill)	deposit-feeder	X		X	X
<i>Naineris</i> sp.	deposit-feeder	X	X	X	X
<i>Nephtys</i> sp.	carnivore	X	X	X	
<i>Nereis</i> sp.	suspension	X		X	X
<i>Nereis zonata</i> (Malmgren)	suspension	X	X	X	X
<i>Ophelina</i> sp.	deposit-feeder		X		
<i>Ophelina acuminata</i> (Ørsted)	deposit-feeder		X		X
<i>Paralacydonia</i> sp.	unknown		X		X
<i>Pectinaria gouldii</i> (Verrill)	deposit-feeder	X		X	X
<i>Phylo ornatus</i> (Verrill)	deposit-feeder		X		X
<i>Polycirrus medusa</i> (Grube)	deposit-feeder		X		X
<i>Potamilla</i> sp.	suspension		X		X
<i>Praxillella gracilis</i> (Sars)	deposit-feeder	X		X	
<i>Protodorvillea kefersteini</i> (McIntosh)	carnivore	X	X	X	X
<i>Rhodine loveni</i> (Malmgren)	deposit-feeder	X	X	X	X
<i>Sabellides</i> sp.	suspension		X		X
<i>Scalibregma inflatum</i> (Rathke)	carnivore	X	X	X	X
<i>Scoloplos armiger</i> (Müller)	deposit-feeder	X	X	X	X
<i>Sternaspis scutata</i> (Ranzani)	unknown		X		X
<i>Streblospio benedicti</i> (Webster)	deposit-feeder	X		X	X
<i>Terebellides stroemi</i> (Sars)	deposit-feeder	X	X	X	
<i>Tharyx acutus</i> (Webster & Benedict)	deposit-feeder	X	X	X	X
<i>Travisia</i> sp.	deposit-feeder		X		
Sipuncula					
<i>Phascolosoma</i> sp.	deposit-feeder		X		X
Priapulida					
<i>Priapulid</i> sp.	carnivore	X		X	X
Nematoda					
Agglutinated foraminifera	deposit-feeder	X	X	X	