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Walrus foraging marks on the seafloor in Bristol Bay, Alaska: a reconnaissance survey

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Abstract A reconnaissance sidescan sonar survey in Bristol Bay, Alaska revealed extensive areas of seafloor with features related to walrus foraging. They are similar to those seen in areas such as the outer Bering Sea and Chukchi Sea. Two types of feature were observed: (a) small ($\ll 1$ m diameter) shallow pits, often in clusters ranging in density from 5 pits per hectare to 35 pits per hectare; and, (b) more abundant, narrow, sinuous furrows, typically 5 to 10 m long with some reaching 20 m or more. Most foraging marks were in less than 60 m water depth in areas of sandy seafloor that were smooth, hummocky or characterized by degraded bedforms; the absence of foraging marks in other areas may be related, in part, to their more dynamic nature. The distribution of foraging marks was consistent in a general way with walrus locations from satellite telemetry studies.

Introduction

Marine mammals are known to create a variety of seafloor features as they forage for food, significantly reworking large areas of the continental shelf (Nelson et al. 1987; Nelson and Johnson 1987; Nelson et al. 1994). In particular, impacts of the California gray whale and Pacific walrus (*Odobenus rosmarus divergens*) have been investigated in the northern Bering and Chukchi Seas (Nelson et al. 1987) where they create abundant pits and elongate seafloor depressions as they forage for invertebrates (Fay et al. 1977; Fay and Lowry 1981). In this study we document the occurrence of pits and depressions in Bristol Bay, Alaska and interpret their occurrence in relationship to walrus foraging patterns. The aim of the investigation was to determine if such features occur in the area, how well they are preserved and their relationship to what is known about the distribution of walruses based on satellite telemetry and other studies (Jay et al. 2001). This work is reconnaissance in nature, based on widely spaced sidescan sonar transects with limited seabed towed video and grab sampling groundtruth. The study was part of the National Oceanic and Atmospheric Administration (NOAA)-funded "Next Generation Tools" project undertaken by the National Marine Fisheries Service.

In summer, thousands of adult male walruses reside in Bristol Bay while females and young migrate northward into the Chukchi Sea (Fay 1982). A population survey in the mid-1980s indicated approximately 7% of the total population (roughly 230,000) summered in the Bristol Bay area (Gilbert 1989). Despite the obvious significance of the Bristol Bay region for walruses, relatively little is known about predator–prey interactions, impacts of foraging on benthic productivity, and possible relationships between local population size and food availability. This reconnaissance study is the first attempt to relate foraging activity, as evidenced by seafloor morphology, to observations of walrus at sea in the area (Fig. 1).

While walruses can feed in water depths up to 100 m, most feeding occurs in waters less than 80 m deep (Fay and Burns 1988), in areas of muddy sand to gravel (Phillips and Colgan 1988). Nelson et al. (1994) recorded feeding marks over much of the eastern Chukchi Sea shelf, which consists primarily of water depths less than 60 m. Four tagged animals in Bristol Bay foraged mostly in depths less than 50 m, but with a paucity of

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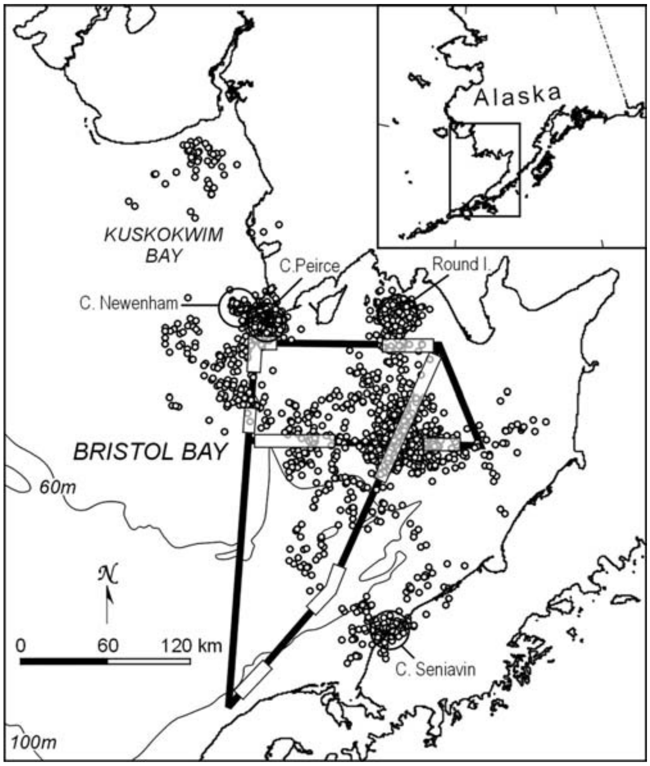

Fig. 1 Location map of sidescan sonar survey in Bristol Bay, Alaska (*gray line*). Seafloor areas where walrus foraging marks were observed in sidescan sonar records are indicated (*open rectangles*; zones A and D from Fig. 2 have been merged in this map). Locations of tagged walruses, and principal haul-outs, from Jay and Hills (2005) are shown

foraging between 10 m to 35 m for unknown reasons (Jay et al. 2001). Prey selection is accomplished primarily through tactile exploration from the mystacial vibrissae which are extremely sensitive, having the ability to identify different shapes with surface areas as small as 0.4 cm^2 (Kastelein and van Gaalen 1988). For deeper burrowing bivalves, such as Mya, the walrus "roots" through the seafloor with its snout and jets water out through its mouth to excavate the clam (Oliver et al. 1983; Kastelein and Mosterd 1989). Walruses thus disturb significant areas of seafloor, leaving characteristic marks of two types: (1) furrows, on average 47 m long (10–200 m), 0.40 m wide and about 0.10 m deep (Nelson et al. 1987); and (2) small pits 0.14–0.30 m in diameter (Oliver et al. 1983). Furrows have been mapped using 100 kHz sidescan sonar on the Bering shelf (Nelson et al. 1987), but pits were not identified. Walrus feeding marks have unique characteristics (Nelson et al. 1987) and can be readily distinguished from other seabed features such as trawl marks or gray whale excavations (Phillips and Colgan 1988; Klaus et al. 1990).

In the Chukchi Sea, Nelson et al. (1994) estimated, based on sidescan sonographs, that between 24% and 36% of the seafloor was reworked by walrus foraging. Thus they concluded that the entire seafloor is reworked every 3 years. No such studies of sediment reworking intensity have been undertaken in Bristol Bay. There may, however, be important differences between Bristol Bay and the Bering and Chukchi Seas since mostly adult males remain in Bristol Bay during the summer and animals haul-out at fixed terrestrial sites from which they move to feed at sea.

Study area

Bristol Bay (Fig. 1) is a broad, flat, shallow shelf, generally less than about 70 m deep, and characterized by a low-relief sandy and muddy sand seafloor (McDonald et al. 1981; Johnson 1983; Marlow et al. 1999; Smith and McConnaughey 1999) with only minor amounts of gravel. Exposures of bedrock are rare within the bay, except close to islands. Mobile sand is abundant over much of the region, and manifested in active bedforms, lineations, and lenses (bars) (Marlow et al. 1999). In many parts of northernmost Bristol Bay, the seafloor consists of a mixture of sediment types, generally a lag pavement of pebbles, cobbles, and scattered boulders with thin patches of sandy sediments ranging from a few to many tens of meters in extent. Seafloor morphologies include: smooth, featureless muddy sands; hummocky or broadly undulating muddy sands with minor ($<$1–2 m) relief; symmetrical, low-amplitude sandwaves (15–20 m wave lengths) (Collinson and Thompson 1982; Marlow et al. 1999); asymmetrical low-relief ($<$0.5 m) sandwaves; and, narrow (10–40 m wide), thin sand lineations or ribbons, some of which have superimposed orthogonal ripples/sandwaves (wave lengths of 20 cm to 5 m).

Tidal currents in Bristol Bay are oriented NE-SW and can reach speeds of about 50 cms^{-1}, though average much less (Hebard 1961; Kinder and Schumacher 1981; Schumacher and Kinder 1983). Storm waves can affect the seafloor over large areas of Bristol Bay (Quayle and Fulbright 1975; Marlow et al. 1999) moving sandy sediments over most of the study area producing the observed symmetrical ripples and sand waves.

Materials and methods

Over one thousand kilometres of sidescan sonar data were collected from Bristol Bay (Figs. 1, 2) by using a Klein 5410 455 kHz sidescan operated at a 150 m swath width. Navigation was by GPS.

Video imagery and grab sampling were acquired using a drop camera at eight localities throughout the region and provided groundtruth for the sidescan sonographs (Fig. 2). The grab sampler was a 0.1 m^2 van Veen. The camera system was a Watec 902H module with a Computar f0.8 lens.

Walrus furrows and pits are distinct morphologies that can be readily distinguished from other seabed features such as trawl marks (which generally occur as pairs of broad, long, parallel traces on the seafloor) or gray whale foraging marks (shallow, oval pits several

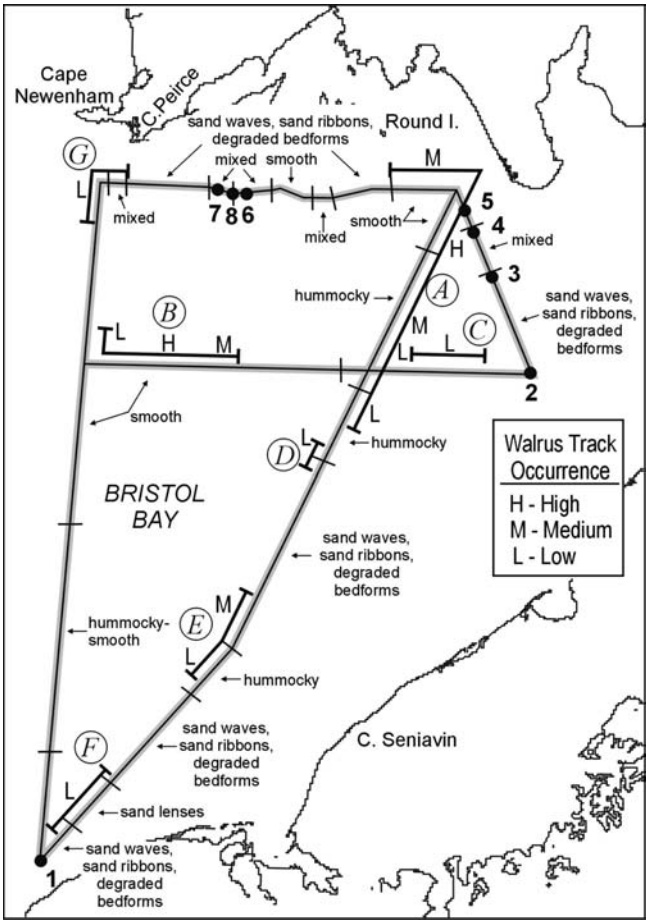

Fig. 2 Sidescan sonar trackline showing seafloor morphology and zones of walrus foraging marks (*circled letters* A through G). The intensity of seafloor reworking by walruses is indicated. The *numbered black dots* are locations of grab samples and drop video camera stations

meters across) which are much larger than those produced by walruses (Nelson et al. 1994).

The concentration of foraging marks throughout the area was difficult to quantify precisely, so in places where they occurred, they were classified qualitatively as High, Medium, and Low. Areas of high concentration were those in which at least half of the surveyed seafloor was covered with foraging marks. In this class, the density of marks could locally be so high that marks completely merged with one another and covered the entire seafloor. Areas classified ''Low'' had only a few foraging marks per 0.1 km^2 (approximate size of the individual sidescan files analysed).

The concentration of foraging marks in the bay was compared to walrus locations derived from a separate study (Jay and Hills, 2005). In that study, tracking data were collected from 57 adult males using satellite-linked radio transmitters attached to the tusk of each animal. The transmitters were deployed during the periods 1987–1990 and 1995–1999, at four principal haul-out sites: Cape Seniavin (CS), Round Island (RI), Cape Peirce (CP), and Cape Newenham (CN). Most transmitters were deployed either at CS and RI in May and early June or at CP in August. Only three transmitters were deployed at CN. The operational life of the transmitters varied considerably among animals, spanning spring through late autumn. Many animals used all four haul-out sites during this time. Furthermore, many of the location data were collected in years prior to collection of the sidescan data in the current study (summer 2002). Therefore, the locations are used here as supportive evidence of foraging and non-foraging in particular areas, but are not necessarily fully representative of the distribution of walruses that occurred during the collection of the sidescan data.

Results

Features interpreted as walrus foraging marks occurred throughout much of the bay (Fig. 2), although in varying concentrations on the seafloor. For convenience, in referring to specific features in the following text, the zones where these features were noted were designated A through G (Fig. 2).

Based on video imagery and grab samples from eight locations (Fig. 2), as well as from regional maps of sediment types (Fig. 3), most of the seafloor is dominated by sandy sediments (>93 % sand with minor mud). Exceptions are areas of ''mixed sediments'' (sites 3, 4 and 8) where samples at the same sites can range from 25% to 47% gravel (site 8) or from 0% to 18% gravel (sites 3 and 4) with less than 8% mud.

As in previous studies, the seafloor features interpreted as walrus foraging marks were of two basic types:

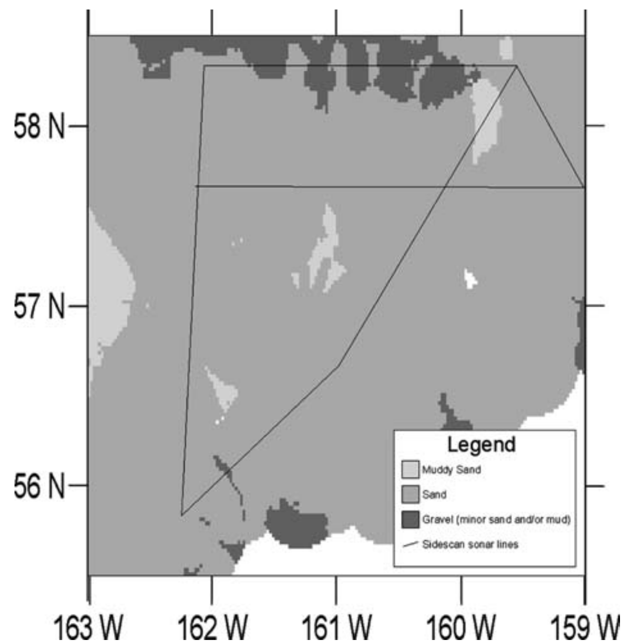

Fig. 3 Grain size distribution for the study area within Bristol Bay. Coverage was interpolated from data contained in the surficial sediment database (Smith and McConnaughey 1999)

(1) small (≪1 m diameter), very shallow pits (Fig. 4); and (2) elongate (<20 m), sinuous or irregular furrows (Fig. 5). Furrows were found to be considerably more abundant than pits, although this may be, in part, related to our ability to detect them more readily in the sidescan sonographs. Pits observed in this study are quite small features, usually occurring in clusters of many tens of pits in irregular to oval patches ranging from 20 m^2 to 400 m^2. Typical pit densities in these patches range from 5 per 100 m^2 to 35 per 100 m^2 with most lying between 10 per 100 m^2 and 15 per 100 m^2.

Pits occurred throughout much of the study area, but tended to have a highly aggregated distribution. The highest concentrations of pits were found at the west end of zone B (Fig. 2) in an area of smooth seafloor as very clearly defined patches of 90 to 250 m^2 with average densities of about 10 per 100 m^2 ; pits were also common in zone C, marked by degraded sand waves (Fig. 2), and in zone F in a region of sand lenses, broad, irregular patches of mobile sand (Fig. 2). They were completely absent from Zone E and were not well defined in the southern part of Zone A. These two areas are characterized by evident sandwaves (Fig. 6) to degraded bedforms and seafloor lineations or sand ribbons.

Furrows typically ranged in length from about 5 m to 10 m, with some reaching 15 m and occasionally more than 20 m long. The longest recorded furrow was 30 m long, which occurred in Zone A. The highest concentration of furrows was found in Zone B where most of the area was classed as medium to very high density. This area was characterized by a smooth to hummocky or broadly undulating seafloor devoid of bedforms. The only other area of high furrow concentration was the northern part of Zone A where concentrations were generally medium to high. This area was typified by degraded bedforms and by ''mixed sediments'', i.e., highly patchy seafloor consisting of broad (>30 m diameter) zones of smooth sand and of gravel-cobble-boulder. Elsewhere, furrow concentrations were low with a small area of medium density in the northernmost part of Zone E. The areas of low furrow density were characterized by fresh to degraded asymmetrical bedforms and symmetrical sand waves, sediment lineations or ribbons, or broad, irregular, thin sand lenses.

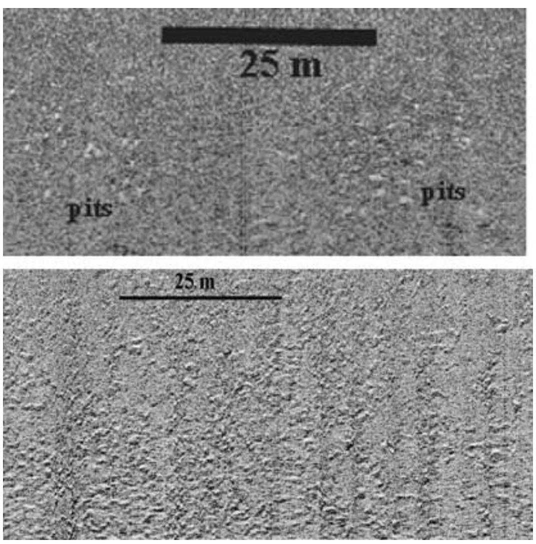

Fig. 4 **a** Clusters of shallow pits (*light dots*) in muddy sand in Bristol Bay, Alaska. The features are generally much less than 1 m in diameter and about 30–50 cm deep. **b** Cluster of somewhat larger oblong pits (light ''spots'')

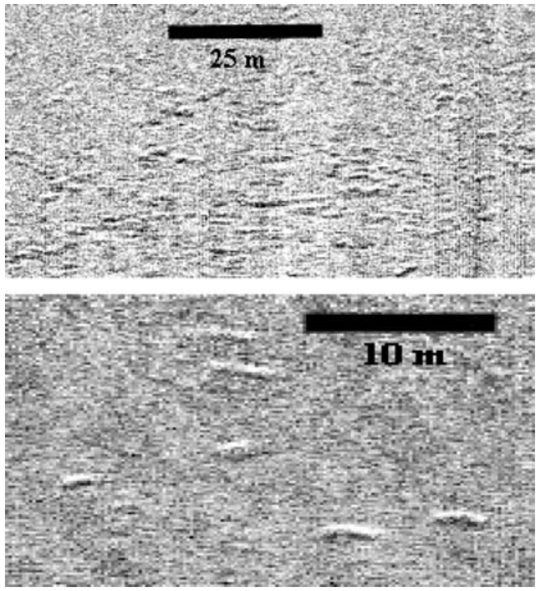

Fig. 5 **a** Elongate narrow furrow, across lower part of the image, with abundant surrounding shorter furrows. **b** Short (3–5 m), furrows in muddy sand in Bristol Bay, Alaska. Furrow lengths range from about 4 m to 12 m on average with some as long as 20 m

The distribution of foraging marks was in reasonable agreement with the walrus locations at sea from Jay and Hills (2005) (Fig. 1), although it must be remembered that the locations were sampled unevenly among animals (some of the location clusters are from only a few animals) and were derived during different years than the data derived from the current study. Most of the foraging marks were located in the northern third of the study area, with the highest concentrations located there (Zones A and B), corresponding to many walrus locations observed about 100 km south and midway between CP and RI and within about 75 km southeast of RI. Foraging marks occurred in low abundance from the southern part of Zone E through Zone F, and did not overlap with observed walrus locations.

Almost all of the foraging marks observed from the sidescan sonar were from less than 60 m water depth. This includes most of the long N–S survey line along the western edge of the study area. The absence of features in deep water along this N–S survey line is in good agreement with the absence of walrus locations at sea in this area (Figs. 1, 2). Most of the seafloor along this N-S survey line is smooth to slightly hummocky, devoid of

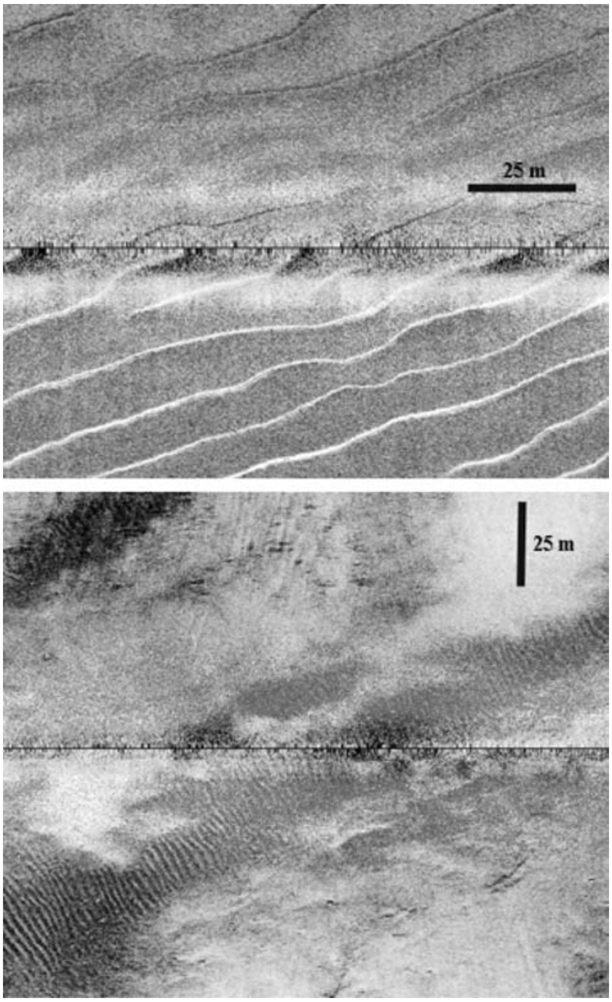

Fig. 6 Seafloor features and bedforms in Bristol Bay, Alaska. **a** Extensive areas of asymmetrical, low amplitude (<0.5 m) sandy bedforms with wave lengths from 8 m to 15 m occur over large areas of Bristol Bay. **b** Sand ribbons, often exhibiting symmetrical to asymmetrical bedforms (wave lengths <5 m) occur commonly superimposed on hummocky seafloor or in areas of mixed sediments (sands and gravels)

bedforms, and would likely preserve foraging marks if they were produced. An interesting occurrence was the medium density of foraging marks found in the northern part of Zone E (Fig. 2), where the water depth is greater than 60 m.

Discussion and conclusions

Many marine animals, including invertebrates, fish and seabirds, are capable of creating similar surface disruptions to the seabed to those observed in Bristol Bay (e.g., Steinbeck 1951; Cook 1971; Flemming 1977; Cadée 2001). Because of water depths and the absence of specific types of organisms in the area, however, and the similarity with walrus foraging marks elsewhere in Alaskan waters (e.g., Nelson et al. 1987), it is highly doubtful that the observed features were produced by these other animals. The purple orange sea star (*Asterias amurensis*) does occur in the region and is often found within observed pits; these sea stars, however, are capable of creating only very shallow pits (<10 cm deep; Fukuyama and Oliver 1985) and typically are found in pits only where walrus are also abundant. The interpretation is that the sea stars are attracted to the discarded bivalves from walrus foraging (Oliver et al. 1985) and do not, themselves, create the observed pits and furrows in which they are found.

The distribution of walrus foraging marks in Bristol Bay was consistent, in a general way, with walrus locations from the satellite telemetry study. The marks, both small pits and longer sinuous furrows, were readily detected using sidescan sonar and were most abundant in water depths of less than 60 m, consistent with previous sidescan sonar studies (Nelson et al. 1987, 1994), although most previous work was undertaken in less than 60 m water depth. Abundant foraging marks were in seafloor areas characterized by hummocky or smooth relief (i.e., an absence of bedforms). The absence of foraging marks in some areas where they would otherwise be expected to occur is probably related to seafloor mobility: migrating bedforms may simply obliterate walrus tracks or appropriate prey species are absent in such a dynamic seafloor environment. It may also be possible, as pointed out by Nelson et al. (1987), that detection of furrows may be reduced on sidescan sonographs if they are oriented normal to the vessel track; in general, however, these sinuous features appear to have sufficient variation in direction to be observed in most areas.

While confirmation must await further more detailed studies, it can be conjectured that the internal structures associated with these features will consist of locally truncated sandy and muddy sand strata to a depth of about 30 cm and up to 50 cm wide, with zones of homogenized collapsed sediments around the edges of the depressions. It is probable that, in many instances, infilling of these depressions will be by somewhat finer sediments than those characterizing the surrounding seafloor although Nelson et al. (1987, 1994) have suggested that seafloor currents, in some instances, could actually scour and enlarge walrus feeding traces. Locally, concentrations of excavated bivalve shells will be present associated with zones of foraging marks. The preservation potential for such features in the geologic record is estimated to be low; active seafloor processes at many sites will obliterate the marks and intense foraging of the seafloor could result in a completely homogenized zone to depths of about 30 cm. Nelson et al. (1994), for example, have estimated that approximately 24% of the Chukchi seafloor is disturbed annually by walrus foraging and that "the entire Chukchi sea floor ... may be disturbed every three years".

The haul-outs closest to areas of highest density foraging marks were CP and RI, and therefore may correspond primarily to walrus foraging trips that originated at these sites. Similarly, the medium density foraging marks observed northwest of CS (northern part of Zone E) may be mainly from walrus foraging trips originating from this haul-out.

The absence of any foraging features along most of the long N–S survey line at the western edge of the study area is in good agreement with the radio telemetry locations. Despite an apparently suitable smooth to hummocky sandy and muddy sand seafloor in this region, no foraging marks were observed, nor were locations observed in the vicinity of the southerly three-quarters of this survey line (Fig. 1). It is interesting that the occurrence of foraging marks in the southernmost corner of the survey area (Zone F) did not correspond with any nearby walrus locations. The origin of the walruses that created these features is unknown at present, although walruses have been known in the past to haul-out at Port Moller and Amak Island, about 50 km and 210 km southwest of CS (Frost et al. 1982).

A major difference in the results of this investigation and those of previous researchers (e.g., Nelson et al. 1987) is in the length of the narrow sinuous foraging marks. In this study the maximum observed length was about 30 m while the average length in the outer Bering Sea was 47 m with a 37 m standard deviation. In the Chukchi Sea, however, Nelson et al. (1994) found that furrows ranged from 2 m to 6 m long, averaging 2.46 m; they deduced that this much shorter length was a result of cross-cutting furrows that made the features appear shorter than when they were produced. While this may also be the explanation for the much shorter features in Bristol Bay, other possibilities could include variations in foraging strategy based on the concentration of prey (e.g., discontinuous short furrow segments versus continuous long furrows), obliteration of some of the marks by seafloor processes, or age/sex differences in feeding behaviour (the area is occupied by mostly mature males throughout the summer; females and young migrate into the Chukchi Sea).

Further, more localized, detailed investigations in Bristol Bay are required to assess such aspects of walrus foraging as: (a) intensity of seafloor disturbance; (b) relationships among sediment type, prey abundance, and foraging intensity; (c) rates of obliteration of foraging marks on a mobile seabed; and, (d) differences in foraging marks and intensity by animals from the various haul-outs in the region. These investigations should proceed with sidescan sonar, seabed video observations, and large-volume sampling together with walrus surveys or further telemetry studies. Box cores could also be used to elucidate the internal sedimentary structures associated with these features.

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