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Robert L. Rausch
University of Washington, rausch@uw.edu

John C, George
Department of Wildlife Management, North Slope Borough, Alaska

Harry K. Brower
Department of Wildlife Management, North Slope Borough, Alaska

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Effect of Climatic Warming on the Pacific Walrus, and Potential Modification of Its Helminth Fauna

Robert L. Rausch, John C. George*, and Harry K. Brower*, Department of Comparative Medicine, School of Medicine, University of Washington, Box 357190, Seattle, Washington 98195-7190; *Department of Wildlife Management, North Slope Borough, P.O. Box 69, Barrow, Alaska 99723. *e-mail: rausch@u.washington.edu*

ABSTRACT: The decreasing extent of sea-ice in the arctic basin as a consequence of climatic warming is modifying the behavior and diets of pagophilic pinnipeds, including the Pacific walrus, *Odobenus rosmarus divergens* Illiger, the species emphasized here. Mammals such as the walrus and bearded seal, *Erignathus barbatus* (Erxleben), cannot remain associated with the sea-ice, and continue to feed on their usual diet of benthic invertebrates inhabiting coastal waters to a depth of approximately 100 m, when the northwestward retreating ice reaches deep waters beyond the margins of the continental shelf. With reduction of their customary substrate (ice), the walrus has become more pelagic and preys more often on ringed seals, *Phoca hispida* Schreber. Dietary changes, with modifications of helminth faunas, may be induced by various factors. Increased consumption of mammals or their remains by walruses may lead to a higher prevalence of trichinellosis in them and to more frequent occurrence in indigenous peoples inhabiting the arctic coasts. To assess predicted effects on the composition of helminth fauna of the walrus, we recommend systematic surveys of their helminths as part of research on effects of climatic warming.

Compared with temperate and tropical ecosystems, those of the Arctic and Subarctic have been less disrupted by the impact of rapidly increasing human populations and associated phenomena. In recent years, as a consequence of anthropogenic factors, warming of the climate of the Arctic (defined as the region north of the mean 10 C isotherm for the warmest month of the year) is predicted to have severe to disastrous effects on pagophilic mammals and other organisms in the arctic basin. Here, we briefly consider the observed influence of climatic warming on pagophilic marine mammals of 4 species that occur in the Chukchi and Beaufort seas bordering the north coasts of Alaska: polar bear, *Ursus maritimus* L.; Pacific walrus, *Odobenus rosmarus divergens* Illiger; bearded seal, *Erignathus barbatus* (Erxleben); and ringed seal, *Phoca hispida* Schreber. Especially, we stress the effects of climatic warming on the Pacific walrus and the potential modification of the composition of its helminth fauna. Its fauna is not so diverse in species as those of the other pinnipeds, and according to our observations, the polar bear has few helminths—only *Trichinella nativa* Britov et Boev, 1972, and rarely, the intestinal nematode *Pseudoterranova decipiens* (Krabbe, 1878).

After having greatly depleted the population of the bowhead whale, *Balaena mysticetus* L., commercial whalers in the Arctic turned their attention to the Pacific walrus in about 1859, and by the 1870s, ''. . . virtually the entire fleet was hunting walruses'' (Bockstoce, 1986, p 131). An estimated 150,000 walruses were killed by whalers, about 85% having been taken in 1869–1878 (Bockstoce, 1986, p 135). After commercial whaling ceased, walruses increased in numbers. Fay (1982, p 240) stated that the world population numbered about 200,000 by 1978, of which, during the warmer months, about 80% occurred in the Bering-Chukchi region.

The polar bear also has been an important resource for the indigenous peoples inhabiting the Alaskan arctic coast and elsewhere. During at least about 2 decades preceding 1972, hunting of bears by nonindigenous persons, usually with the use of aircraft, removed many bears along the arctic coast. Although reliable data are unavailable, evidently polar bears have increased in the Bering and Chukchi seas since the Marine Mammals Protection Act of 1972 restricted the taking of marine mammals except by indigenous people for subsistence purposes (Amstrup and DeMaster, 1988).

Numbers of 2 species of pagophilic pinnipeds, the bearded seal and the ringed seal, seem to have persisted at near natural levels. The bearded seal, like the walrus, feeds mainly on benthic invertebrates in the relatively shallow waters over the continental shelf, and it is not so discriminating in selecting type of sea-ice (Kelley, 1988); they maintain breathing-holes in the ice in winter. The ringed seal feeds on invertebrates as well as on fishes. It is closely associated with sea-ice, and it also makes breathing-holes in winter. The young are born in subnivean lairs in pack-ice or shorefast ice.

Notwithstanding the early exploitation of marine mammals, mainly during the 19th century, only one species in the far north is known to have become extinct during historical time. Steller's sea cow, *Hydrodamalis gigas* (Zimmermann), existed in some numbers around the Komandorskie Islands (Bering and Mednyi) in the northern Bering Sea. It was first observed by Europeans in 1741, by the remaining crew of the ship *Saint Peter* of the Bering Expedition, which overwintered on the island later named for Bering. The ship grounded there, and on the following day, Georg Wilhelm Steller observed in the surrounding shallow waters along shore a large marine mammal (up to 30 feet in length, with a weight estimated by Steller at 3 tons) that he recognized as a sirenian (Stejneger, 1936, pp 318 and 354). Steller (1753, p 75) provided a description of the anatomy of a female specimen and noted also (p 75) the presence of a large nematode in the stomach and upper duodenum: ''Die innere tunica des Magens war von weissen Würmern (lumbricis) die einen halben fuss Länge hatten, durchfressen, auch war der gantze Magen, dessen Pförtner (pylorus) und der zwölfFingerdarm damit angefüllet.'' The sea cow had disappeared from around Mednyi Island by 1754, and the last individual of the species was killed on Bering Island in 1768 (Forsten and Youngman, 1982). The gastric nematode, probably host specific, was never recorded again, and we have no doubt that it became extinct along with its host.

As a result of climatic warming, the eventual extinction—conceivably relatively soon—of other arctic sea mammals is now a frequent suggestion. That the extent of sea-ice in arctic and subarctic regions has been decreasing for nearly 50 yr has been reported by Vinnikov et al. (1999). Maslanik et al. (1999) reported that 7% of the arctic basin that had been perennially ice covered was free of ice in 1998 and that the distance to the edge of the pack-ice north of Barrow, Alaska (ca. 71°23′N, 156°28′W), in September 1998 was 46% greater than in the record years 1954 and 1958 (568 km vs. 390 km) and that freeze-over of the sea did not occur until the second week of November. (In autumn 2006, it was observed [J.C.G. and H.K.B.] that the sea along the arctic coast off Barrow had not yet frozen by the end of November.) According to Arctic Climate Impact Assessment (2004, p 25), arctic sea-ice was at its lowest concentration on record in September 2002. The decrease in sea-ice during recent years has been sufficient to indicate that climatic warming may have a devastating effect on pagophilic mammals throughout the Arctic.

In the central Arctic, mammals of the aforementioned 4 species have already been affected to a lesser or greater degree by reduction of sea-ice during the warmer months of the year. Ringed seals often establish dens for their young in shorefast ice (Kelly, 1988), a zone that now is subject to unpredictable disruption (George et al., 2004). That seal also is the major prey of the polar bear, which requires a firm (ice) substrate for successful hunting. Increasing duration of the ice-free period in the eastern Arctic, at least, prevents hunting of seals, and this increase is expected to cause nutritional stress and deteriorated physical condition of the bears (Stirling and Derocher, 1993; Stirling and Parkinson, 2006). The bearded seal frequented the southern margins of the pack-ice, which now annually retreats northward beyond the northern edge of the continental shelf. Although the behavior of all species of pagophilic marine mammals is influenced by climatic warming, we focus here the effects of this warming on the Pacific walrus, with consideration of consequent conditions that may modify the composition of its helminth fauna.

The pattern of seasonal migrations and diet of the Pacific walrus as

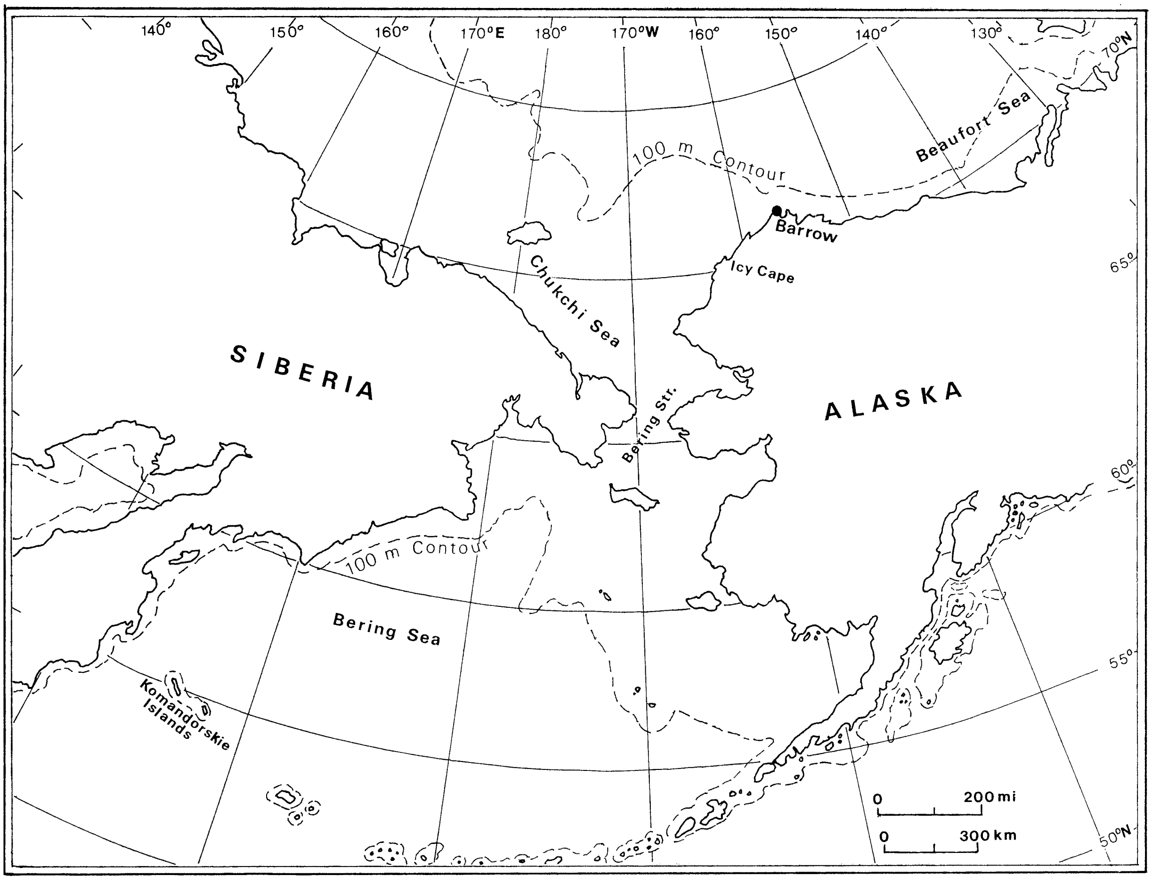

FIGURE 1. Map, Bering Strait and surrounding region. The 100-m contour line represents approximately the edge of the continental shelf to the north and south of Alaska.

were typical until about the early 1980s has been described by Fay (1982), from whose work most of the following details have been taken. The walrus winters in the northern Bering Sea. In spring, the greater part of the population migrates northward through the Bering Strait into the adjacent seas (Fig. 1). Part of the population, mostly males, remains in the Gulf of Anadyr' and in Bristol Bay during the warmer months (Fay, 1982, p 14). According to Fay (1982, p 8), >90% of the seas north of Bering Strait were covered by ". . . a relatively stable, heavy ice during the month of January"; in February, northern winds continued to drive the sea-ice southward in the Bering Sea until it reached nearly the southern margin of the continental shelf (far to the south of the Bering Strait). As ice in the Bering Sea began to melt in spring, northward migration of walruses toward Bering Strait was evident in April. By May, a large part of the population had passed through the Bering Strait, and some had reached the western Chukchi Sea. Dispersion northeastward continued through July, and by August many of the animals were present on ice-floes along the arctic coast between Icy Cape and Barrow, where they were available to Iñupiaq hunters (Fig. 2). (At present, the Iñupiat at Barrow hunt walruses in June, when they are closer to shore.) As noted by Fay (1982, p 21), walruses are transported northward on ice-floes by southerly winds and sea currents, requiring little effort on their part. The condition of the surfaces of ice-floes transporting groups of walruses is indicative of a long period of occupation. Few of the animals dispersed eastward beyond ca. 150°W (Fay, 1982).

During September and October, most of the animals had migrated southwestward and southward, through Bering Strait. A few, mostly adult males, sometimes winter in the ice-covered seas north of Bering Strait, where they often preyed on ringed seals (Fay, 1960; Rausch, 1970). By September, ice in the central Chukchi Sea had attained its minimal extent, its southern margin being at about 74°N, but its edge to east and west was farther south (Fay, 1982, p 17). Such conditions evidently prevailed for many centuries, nor does the traditional knowledge of the Iñupiat suggest any deviation. While in the Chukchi Sea, walruses formerly remained south of the 100-m isobath, where they characteristically fed in waters no deeper than 80 m (Vibe, 1950).

As has been long known, the composition of helminth faunas depends mainly on the diet of the host (cf. Dogiel [Dogel'], 1963, p 281]: "Es kann gar kein Zweifel daran bestehen, dass die Zusammensetzung eines Schmarotzerkomplexes in bestimmten Masse von der Art der Nahrung des Wirtes abhängt." Now, as an effect of climatic warming, with consequent retraction of pack-ice northward beyond the northern margins of the continental shelf during the warmer months, the feeding habits of the walrus have been substantially altered. As has been observed by Iñupiaq hunters along the arctic coast of Alaska, walruses have become more pelagic in habit, and they are feeding more often on ringed seals, and, perhaps, bearded seals.

Lowry and Fay (1984) reported that remains of seals of 3 species were present in the stomachs of 5 of 364 walruses in the region of Bering Strait during 1952–1982. They found that in 1983, the remains of ringed seals were present in the stomachs of 5 of 44 walruses from the western Chukchi Sea, and they concluded that predation on seals had increased by the late 1970s. Remains of seals had been present in the stomachs of 8.6% of 35 walruses in the 1960s, with an increase to 11.4% of 44 animals by 1983 (Lowry and Fay, 1984).

Continuing warming in the Arctic predictably will modify the composition of the helminth faunas of pagophilic animals, due to the consequent changes in feeding habits and of diets, because warming of the seas and reduced salinity can be expected to bring about changes in the species composition of pelagic and benthic invertebrate faunas. Also to be expected is a northward shift in the distribution of fishes of various species, already observed in the North Sea (Perry et al., 2005).

According to Fay (1982), the helminth fauna of the Pacific walrus consisted of about 16 species: 7 species of trematodes (including 5

FIGURE 2. Walruses on pack-ice near Barrow, Alaska.

species of the genus *Orthosplanchnus* Odhner, 1905); 3 species of cestodes of the genus *Diphyllobothrium* Cobbold, 1858 (a fourth species of that genus was added by Rausch [2005]); an acanthocephalan, *Corynosoma validum* Van Cleave, 1953; and 2 species of nematodes, *Trichinella nativa* and *Pseudoterranova decipiens*. A more carnivorous diet, greater consumption of fishes, and changes in the species composition of the benthic fauna, as noted, may modify the diversity and prevalence of helminth species that are able to persist in walruses.

Although the pattern of transmission of *T. nativa* in marine mammals is not understood (Rausch, 1970), the occurrence of that nematode probably would increase in walruses with their added consumption of such mammals as prey or carrion. If so, trichinellosis in indigenous peoples in the Arctic also could become more frequent. Roth (1949) reported an epidemic of trichinellosis among Iñuit in western Greenland in April 1947, involving >300 people, and Roth attributed this epidemic to consumption of the meat of walruses; the nematode at that time was designated *Trichinella spiralis* (Owen, 1835). Most outbreaks since that time have involved fewer people. For example, 26 clinical cases were diagnosed at Barrow in 1975 (Margolis et al., 1979). In the eastern Arctic, the prevalence of *T. nativa* seems to be higher (4%) in walruses in waters adjacent to Nunavik, Quebec, Canada, than in waters bordering Alaska (Simard, pers. comm.). In Nunavik, 13 outbreaks of trichinellosis in people have been documented by the public health authorities since 1982, 9 outbreaks of which, involving 1 to 41 cases, had walrus as a source (Proulx, pers. comm.). The large size of walruses (males average 1,200 kg; Fay, 1982) favors sharing the flesh among numerous families. Although by tradition the Iñupiat always cook the flesh of polar bears, in which typically the prevalence of larvae of *T. nativa* is high, they evidently thought unnecessary to cook the flesh of walruses.

The larvae of *T. nativa* are adapted for survival in the arctic-subarctic environment. Larvae (designated *T. spiralis*) from the subarctic were found to tolerate several months of storage at subfreezing temperatures without loss of vitality (Brandly and Rausch, 1950). Britov (1972) distinguished the cold-adapted taxon as *T. spiralis* var. *nativa*, and it was elevated to the rank of species by Britov and Boev (1972). Its ability to tolerate low temperatures has been confirmed by several investigators. Dick and Belosovich (1978) found that larvae from muscle of a polar bear, obtained at Churchill, Manitoba, Canada, remained infective after 12 mo at −15 C. The larvae also are long lived, and they are able to remain infective for several years in carnivores. In a black bear, *Ursus americanus* Pallas, larvae introduced experimentally were recovered after 10 yr, exhibiting little calcification of the capsule, and they were still transmissible to rodents (Rausch, 1970). In a polar bear thought to have been exposed before capture as a wild cub, larvae were infective after 20 yr (Kumar et al., 1990). The scavenging by walruses on carrion of marine mammals (Freuchen, 1935, p 244) may be important in transmitting *T. nativa*; freezing of such carrion would merely preserve the larvae.

Although modifications of diet caused by effects of altered climate may be expected to produce changes in the composition of the helminth fauna of marine mammals in the Arctic, the relationship has not yet been discerned. However, such changes have been observed in helminth faunas, brought about by adaptation of an arctic mammal to atypical habitat, or when dietary modifications are induced by depletion of a major component of the normal diet. Examples of adaptation to a non-arctic habitat are exhibited by the Caspian seal, *Phoca caspica* Gmelin, and by the Baikal seal, *Phoca sibirica* Gmelin, which are considered to be derived from populations of ringed seals, ''. . . that evolved in isolation'' (Jefferson et al., 1993, p 264). In the Caspian Sea, wherein salinity is less than half that of arctic seas, the Caspian seal harbors a helminth fauna consisting of about 13 species (Kurochkin, 1972): 6 species of trematodes, 2 species of cestodes (including 1 species of *Diphyllobothrium*, evidently host specific), 1 acanthocephalan, and 4 species of nematodes. By contrast, the ringed seal in arctic-subarctic habitat has a helminth fauna of ca. 21 species (Deliamure, 1955; Deliamure et al., 1976): 3 species of trematodes, 6 species of cestodes, 5 species of acanthocephalans, and 7 species of nematodes. *Phoca caspica* and *P. hispida* have only 2 species of helminths in common: a trematode, *Pseudamphistomum truncatum* (Rudolphi, 1819), and the acanthocephalan *Corynosoma strumosum* (Rudolphi, 1802). Those, with *Opisthorchis felineus* (Rivolta, 1884), in the Caspian seal, are not only in marine mammals but also in terrestrial hosts. We are unable to find recent information about the helminths in the Baikal seal, in freshwater habitat, but only a single species of nematode was listed from this species by Deliamure (1955).

The apparent modification of a helminth fauna by depletion of an important component of the typical diet was induced by overpopulation in sea otters, *Enhydra lutris* L., around Amchitka Island (Aleutian Islands). After near extinction of this mammal in Alaskan waters by Russian promyshlenniki and by American hunters, the sea otter survived as only a vestigial population, but eventual protection permitted increase in their numbers. Sea otters around Amchitka rose to a maximum observed density in the 1940s (Kenyon, 1969, fig. 74), and as a consequence of overpopulation and perhaps other factors, the sea urchin *Strongylocentrotus droebachiensis* (Mueller), an important component of their diet, was depleted (Kenyon, 1969, p 129). Thus, the otters increased their consumption of fishes and hermit crabs, *Pagurus hirsutiusculis* (Dana), in which, respectively, the larval stages of the nematode *Pseudoterranova decipiens* and of metacercariae of the trematode *Microphallus pirum* (Afanas'ev, 1941) occurred (Schiller, 1954). The death of many otters was attributed to the effects of intestinal perforation by the larval nematodes and of severe enteritis caused by massive infections by the trematode (Rausch, 1953).

Reduction of sea-ice in the arctic basin and temporal changes in its seasonal presence have thus modified the habitat and behavior of some pagophilic pinnipeds and of the polar bear. Increasing warming of the Arctic is predicted to affect severely the patterns of nutrition, reproduction, and migration of those mammals and the physical condition of the mammals themselves. Modifications of helminth faunas, an indication of dietary changes, could be determined by means of systematic surveys, which we strongly recommend as an integral part of investigations to assess consequences of climate change at high northern latitudes. The walrus would seem to be well suited for such surveys, to be undertaken in cooperation with the indigenous people. Its helminth fauna is well known, involving a moderate number of species, of which at least 1 species, *T. nativa*, is of interest for public health.

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