

The Dynamics of Hookworm Disease in Northern Fur Seals

by
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Northern fur seals (*Callorhinus ursinus*) breed on the Pribilof Islands and Bogoslof Island in the eastern Bering Sea, the Commander Islands in the western Bering Sea, the Kurile Islands in the western North Pacific, Robben Island in the western Okhotsk Sea, and Southeast Farallon and San Miguel Islands off California in the eastern Pacific. Hookworm disease has been recognized in northern fur seals since 1896 when F. A. Lucas described the worm from the intestine of a 3-month-old dead fur seal pup in the Pribilof Islands. The fur seal hookworm was subsequently described as *Uncinaria lucasi* by C.W. Stiles in 1901. From the time of their description until the early 1980s, hookworms were highly prevalent in fur seal pups and were responsible for a substantial amount of pup mortality in the Pribilof Islands.

Hookworms are intestinal parasites that suck blood, and if the intensity of the infection (number of worms/individual seal) is great enough, pups develop anemia that leads to mortality. Currently, there is virtually no mortality associated with hookworms in Pribilof Island fur seal pups, although hookworm disease continues to cause pup mortality in several rookeries on Bering and Medney Islands in the Commander Islands. Hookworm disease is not a significant cause of mortality among fur seals on the Kurile Islands or Robben Island apparently because of a marked difference in rookery habitat on those islands. However, on San Miguel Island in the California Channel Islands, hookworm disease has become a major source of pup mortality. This article provides an overview of the biology of hookworms, discusses the change in hookworm disease prevalence in the Pribilof Islands, and reviews a recent experiment in which fur seal pups were treated with drugs to control the disease on San Miguel Island.

Biology

Hookworms infect a wide variety and number of vertebrates including man and pinnipeds. A generalized life cycle is as follows. Infective larvae live in soil, penetrate the skin of an appendage, and migrate into the circulatory system. They are transported via the blood to the lungs where they exit the

blood and enter the bronchi of the lungs. There they are coughed up through the trachea into the throat and swallowed. This is referred to as the pulmonary route of infection and historically had been considered the only route of hookworm infection. In the small and large intestine the worms attach to the wall of the intestine and suck blood, mature, and lay eggs, which pass out with the feces and are deposited in soil. The eggs hatch and release infective larvae that repeat the infection process. It has been known for many years that in fur seals and sea lions only pups died of hookworm infections, but it was not understood why. This became the source of an interesting case study in which a young researcher made an exciting discovery.

Historical Background

In 1951, a renowned parasitologist named O. Wilford Olsen from Colorado State University began studying hookworm disease in northern fur seals on St. Paul Island in the Pribilof Islands. His research, lasting several years, focused on how pups became infected. His findings indicated that infective larvae overwintered in the soil but seemed to disappear from the soil at about the time fur seal pup births began in June, with the larvae not reoccurring in the soil until sometime in August. The vexing question for Dr. Olsen was, Where were larvae coming from that infected newborn pups?



Figure 1. Reproductive territories of northern fur seals on Adams Cove beach, San Miguel Island, July 2006.

He was unable to discover how the infectious process occurred.

A decade after initiating his study, Olsen brought the doctoral graduate student Gene Lyons to St. Paul Island. Lyons spent the summer of 1960 there conducting research on hookworms and exhausted the possibility that hookworm infections were occurring prenatally. Lyons knew that transplacental infection of some parasitic worms was known to occur, and this became a logical avenue of investigation for him. During a second field season on St. Paul, Lyons had his day of discovery on 4 July 1961. He found hookworm larvae in ingested milk from a pup's stomach; remarkably the animal was only 2 hours old. Lyons subsequently discovered that larvae moved from the blubber in the pregnant female into the mammary tissue sometime prior to birthing and were ingested upon the pup's first feeding. This was the first case in parasitology where transmammary transmission of a parasite had been demonstrated.

Gene Lyons was excited with the discovery but also was aware that his work would face extreme scrutiny. He spent the following year conducting field research addressing the final details of the infectious process. I met Gene Lyons in 1962 while he was working on St. Paul Island, the same year that marked my introduction to fur seals and marine mammal research. I came to St. Paul Island as an undergraduate student working as a biological aid for the summer. Lyons' dedication, meticulous investigative habits, and raw stamina for his work were astounding. He was frequently still in the laboratory at 10:00 pm, already having worked 14 hours, and he maintained that schedule 7 days a week. Lyons completed his doctoral program in 1963 and accepted a position as a research parasitologist in the Department of Veterinary Sciences at the University of Kentucky.

During the 80 years since their discovery until the late 1970s, hookworms killed thousands of fur seal pups on St. Paul Island in the Pribilofs. In 1957 up to 56% of 1,727 pups examined at necropsy by Professor Leo Doyle had died of hookworm infections, and as late as 1979, 18% of 204 pups necropsied by Dr. Mark Keyes had died of hookworm infections. Then, from 1986 to 2006, Dr. Terry Spraker found only 0.6% of 2,735 fur seal pups examined at necropsy had hookworm infections. Because the intensity of infections was very low in all but one case, hookworms were not classified as the cause of death. (The exception was a pup that had hookworm infections and was anemic at the time of death.) Clearly,

some change occurred in the late 1970s or early '80s that caused fur seals in the Pribilof Islands to become nearly free of hookworm infections, but what exactly that change was remains a mystery today.

In a recent review, Gene Lyons and coauthors suggest that the decline in prevalence of hookworm infections corresponds to a decline in the fur seal population on the Pribilof Islands, raising the possibility that the prevalence of infection is a density-dependent response. The authors also point out that most pups there are currently born on rookeries which have rocky substrate which is not good hookworm habitat. As the number of breeding fur seals has declined on all rookeries in the Pribilof Islands their distribution has become restricted to rocky habitat. (Recall that infective larvae live in soil and apparently are not found on cobble or bedrock beaches.) An alternative hypothesis is that Pribilof Island fur seals have, after a long period of exposure, evolved a population immune response to hookworms. It is not entirely clear how this might work, but the leading hypothesis has to do with the major histocompatibility complex (MHC) genes that control immune function. If there are MHC haplotypes which confer survival advantages to fur seal pups infected with hookworms, they would be selected for and emerge in animals that survive hookworm infections. Then, gradually, the MHC haplotypes which generate resistance to hookworm would become dominant in the population, thereby providing resistance to infection by the worms.

In Russia, during the 1980s and 1990s hookworm disease was a dominant cause of mortality on single rookeries on Bering and Medney Islands in the Commander Islands. The disease remains an important cause of pup mortality there today, despite the fact that large numbers of pups were treated with antiparasitic drugs during the 1990s. Although I have heard oral reports of some of this work, I have not been successful in finding the relevant papers or having them translated; consequently, I do not know the details of these studies. However, it was reported that following treatment of several thousand pups there the mortality rate of pups declined for several years but then increased to more than 35% annually on those rookeries. Normal fur seal pup mortality rates range from 8% to 15%. It is noteworthy that each of the Commander Island rookeries where hookworm disease is prevalent are on beaches with sandy and cobble substrates. Hookworm disease became apparent in dead pups on San Miguel Island in the California Channel