Bacteria and fungi of marine mammals: A review

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Abstract — A list of the different bacterial and fungal agents isolated from marine mammals in different parts of the world is presented. Importance is given to some of the most recently identified bacterial agents, including *Actinobacillus delphinicola, A. scotiae,* and *Brucella* spp. A list, in alphabetical order, of bacteria recovered from different tissues or organs from marine mammals is presented for the integumentary, respiratory, digestive, genitourinary, and reticuloendothelial systems. Infectious bacterial agents associated with abscesses and with cases of septicemia are also listed. Information about the different fungal agents recovered from marine mammals is summarized. A section covering some of the zoonotic infectious agents recovered from marine mammals is included.

Résumé — Agents infectieux d'origine bactérienne et fongique chez les mammifères marins : revue de sujet. Cet article présente une liste des différents agents infectieux, bactériens et fongiques, rencontrés chez les mammifères marins dans différentes parties du monde. L'emphase est mise sur certains des plus récents agents infectieux identifiés chez ces animaux, tels *Actinobacillus delphinicola, A. scotiae, Brucella* sp. et autres. Des tableaux présentent la liste, par ordre alphabétique, des bactéries identifiées dans les tissus ou organes des systèmes tégumentaire, respiratoire, digestif, génito-urinaire et réticulo-endothélial, ainsi que dans les cas d'abcès et de septicémie. Une liste des agents fongiques retrouvés chez les différentes espèces de mammifères marins est aussi présentée. Enfin, une section du texte est consacrée aux agents infectieux retrouvés chez les mammifères marins et susceptibles de causer des zoonoses.

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Introduction

Information concerning bacterial and fungal infectious agents of marine mammals is dispersed in the scientific literature. The degree of identification given by the different authors is extremely varied, some organisms being identified to exacting standards and others simply being attached to the closest convenient known organism by using sources primarily dedicated to human clinical isolates. Each year, new bacterial species are discovered in cetaceans and pinnipeds, and some of them, such as *Brucella* spp., have the potential to infect people in contact, directly or indirectly, with these animals.

Some bacteria and fungi may be part of the normal flora in some marine mammals and are present in their environment. Some are opportunistic, causing disease when the animal is in some way compromised. For many, their clinical significance is unknown, since essential data, such as clinical history, clinical manifestations, and macroscopic and microscopic lesions, are not available.

In this document, some bacterial and fungal agents isolated from marine mammals are presented in more detail because of their recent identification, or because of their importance as pathogens in cetaceans and pinnipeds, and, in some cases, because of their importance as potential zoonotic agents. A list, in alphabetical order, of bacteria recovered from different tissues or organs from marine mammals is presented for each of the following systems: integumentary, respiratory, digestive, genitourinary, and reticuloendothelial. Infectious bacterial agents associated with abscesses and cases of septicemia are also listed. The aim of this review is to provide useful information to persons involved in the diagnosis and control of infectious diseases in marine mammals, as well as people interested in the zoonotic aspect of some infections diagnosed in these animals.

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Bacterial agents

Actinobacillus spp.

Actinobacillus delphinicola, a rod-shaped bacterium with phenotypic characteristics consistent with identification as a member of the family *Pasteurellaceae,* was reported for the first time in 1996. Isolates were recovered from cetaceans around the Scottish coastline; until now, this bacterium has not been found in other marine mammals. On the basis of the results of phylogenetic analyses and phenotypic criteria, the name *A. delphinicola* was proposed for this newly identified bacterium (1).

In 1998, Foster et al (2) reported the characterization of a second, new *Actinobacillus* sp., *A. scotiae*. The nearest phylogenetic relative of *A. scotiae* is *A. delphinicola* (1). These 2 microorganisms can be distinguished from each other by the fact that, unlike *A. delphinicola, A. scotiae* produces β-galactosidase, urease, and acid from lactose. Both species are oxidase-positive, catalase-negative, and do not grow on MacConkey's agar. Assignment of these cetacean bacterial agents to the genus *Actinobacillus* is, therefore, considered a placement of convenience, and their position may have to be changed in the future (1,2).

Cetaceans

Actinobacillus delphinicola has been isolated from various tissues (lungs, cervix, uterus, intestine) by Foster et al (1): the stomach and intestinal contents of harbor porpoises (*Phocoena phocoena*); the lungs, gastric and mandibular lymph nodes, and intestinal content of a striped dolphin (*Stenella coeruleoalba*); and the lungs of a Sowerby's beaked whale (*Mesoploden bidens*). Interestingly, no genotypic differences among strains according to their host species (*Phocoena* and *Stenella* species) were found. In their paper, devoted mostly to the description of the newly characterized bacterial agent, Foster et al did not discuss pathological lesions in sea mammals and mentioned that the pathological significance of this organism is not yet clear.

Actinobacillus scotiae was also isolated from various tissues of 3 harbor porpoises stranded on the Scottish coastline (2): one of the *A. scotiae* isolates appeared to be involved as a cause of septicemia in a stranded animal, while other isolates, although recovered from different tissues (spleen, liver, lymph nodes, intestines) from the 2 other porpoises, were not definitely incriminated in the pathological process.

Pinnipeds

Foster et al (1) attempted but failed to isolate *A. delphinicola* from a large number of common seals (*Phoca vitulina*), grey seals (*Halichoerus grypus*), hooded seals (*Cystophara cristata*), and harp seals (*Phoca groenlandica*), and suggested that the bacterium may be adapted to cetaceans. In 1999, off the Hudson Bay coastline, a bacterium similar to an *Actinobacillus* sp. was isolated from the lungs and lymph nodes of 5 dead ringed seals (*Phoca hispida*). Preliminary data indicate that the isolates are biochemically identical one to another and that they do not belong to either of the *Actinobacillus* species mentioned above (Foster G, personal communication, 1999). Although the bacterium was isolated in pure culture, no macroscopic and microscopic lesions were detected that could explain the death of the animals.

Brucella spp.

Brucella spp. that differed from the recognized members of the genus were first isolated in 1994 from marine mammals off the coast of Scotland (3). Evidence of the presence of this bacterium in a bottlenose dolphin (*Tursiops truncatus*) was also reported in 1994 in California (4). The first presumptive evidence of *Brucella* infection in marine mammals off Arctic Canada was reported in 1996 by Nielsen et al (5). Later reports of the isolation of *Brucella* spp. from marine mammals were again from Scotland (6,7) and California (8), and from Washington state (9). Procedures for the isolation of *Brucella* spp. have been described; they can be separated into 2 groups based on their carbon dioxide dependency and the host species (7).

In 1997, Jahans et al (10) mentioned that *Brucella* spp. isolates recovered from seals, porpoises, and dolphins, including a Californian seal isolate, form a relatively homogenous group that differs from each of the known species in at least 2 of the major differentiating characteristics. They proposed that these strains should be assigned to a new species to be called *Brucella maris* and that this species be subdivided into 3 biovars corresponding to their CO_2 requirement, metabolic activity on galactose, dominant antigen, and animal host.

In 1998, Clavareau et al (11) reported the phenotypic and molecular characterization of a *Brucella* strain isolated from a minke whale. The authors did not compare their isolate with *Brucella* isolates from other marine mammals, but indicated that it could not be classified within the known species of the genus.

Cetaceans

Serological studies and bacteriological isolations carried out on sera collected from fresh cetacean carcasses found stranded along the Scottish coastline between 1991 and 1993 have indicated the presence of *Brucella* sp. infection in harbor porpoise and common dolphin and common seal populations (6).

The presence of a *Brucella* sp. was reported in 1994 in several tissues from an aborted fetus of a captive bottlenose dolphin (4). The isolation of a *Brucella* sp. from subcutaneous lesions, spleen, and mammary glands of harbor porpoises was reported by Ross et al in 1996 (6). In one of these porpoises, all tissues that yielded growths of *Brucella,* with the exception of one subcutaneous lesion, showed no significant pathological changes. Ross et al also isolated the bacterial agent from subcutaneous lesions in a common dolphin (*Delphinus delphis*). They mentioned it as being the first published report of the isolation of this bacterium in free-living cetaceans (6).

In 1996, another report mentioned the isolation of *Brucella* sp. from marine mammals in Scotland (7). Isolates were recovered from subcutaneous lesions in porpoises, common dolphins, and striped dolphins; the spleens of porpoises and striped dolphins; the gastric lymph nodes of an Atlantic white-sided dolphin (*Lagenorhynchus acutus*); the mammary gland of porpoises and striped dolphins; the mandibular lymph node of a striped dolphin; the blood and the uterus of porpoises; and the sublumbar lymph node of a striped dolphin. Finally, a *Brucella* sp. was isolated from the spleen and the liver of a minke whale (*Balaenoptera acutorostrata*) that had been caught during commercial whaling off the Norwegian coast in 1995; the presence of any particular lesions in this animal was not mentioned (11).

Pinnipeds

A *Brucella* sp. was isolated from gastric lymph nodes, internal iliac lymph nodes, and the spleen of common

seals (6). Antibodies against this bacterium were also detected in common seals and grey seals (6). All sera from Lake Baikal seals (*Phoca sibirica*), a landlocked species unlikely to have been exposed to infections of the marine environment, were negative for antibodies to *Brucella* sp. (6).

Another report described the isolation of *Brucella* spp. from the spleen, gastric lymph nodes, mandibular lymph nodes, and external and internal iliac lymph nodes of common seals; the testes of a grey seal; and the spleen and the colorectal, external iliac, and gastric lymph nodes of a hooded seal (*C. cristata*) (7).

In Canada, blood samples from 248 ringed seals and 59 Atlantic walruses (*Odobenus rosmarus rosmarus*), obtained from 8 locations in the Canadian Arctic between 1987 and 1994, were tested for the presence of antibodies against *Brucella* spp; approximately 4% of the seals and 12% of the walruses tested positive. A relationship between these serological results and clinical disease could not be established (5).

In the United States in 1997, reports mentioned the isolation of a *Brucella* sp. from the mesenteric, sublingual, subclavicular, and supraclavicular lymph nodes of harbor seals (*Phoca vitulina richardsi*) (8). One of these animals was infested with *Parafilaroides* lungworms and it was suggested that transmission of brucellosis to pinnipeds by infected lungworms is possible (9). If *Parafilaroides* infection has a commensal relationship with *Brucella,* it seems that *Brucella* infections might be endemic in some populations of harbor seals.

Erysipelothrix rhusiopathiae

It is generally believed that marine mammals acquire *Erysipelothrix rhusiopathiae* from the fish in their diet (12).

Cetaceans

Cetaceans are the most susceptible of marine mammals to erysipelas. Two forms of the disease have been reported, an acute septicemic form and a dermatologic form (13). The septicemic form ordinarily results in death (12). This form was reported in 3 bottlenose dolphins and 1 Atlantic spotted dolphin (*Stenella plagiodon*) (14). Later, the disease was diagnosed in an Atlantic white-beaked dolphin (*Lagenorhynchus albirostris*) (15). A beluga whale in the same system was later diagnosed as having a chronic, ulcerative, suppurative, multifocal dermatitis due to *E. rhusiopathiae* (13). Suer and Vedros (12) have cited reports of this disease in bottlenose dolphins, Atlantic spotted dolphins, Risso dolphins (*Grampus griseus*), and Pacific white-sided dolphins (*Lagenorhynchus obliquidens*). Geraci et al (16) have reported 4 cases of septicemia due to *E. rhusiopathiae* in trained, captive bottlenose dolphins. The dermatologic form has been reported in an 18-month-old bottlenose dolphin that presented well-defined cutaneous plaques on its ventrolateral side. Immediately beneath the plaques, the subcutaneous fat was erythematous (17). Considerable controversy exists as to the appropriate vaccination regimen to prevent erysipelas in captive marine mammals. Some institutions reject the idea of vaccination because of side effects from the bacterin or its administration (13).

Pinnipeds

According to Suer and Vedros (12), there are only scattered reports of erysipelas in pinnipeds. The same authors cited cutaneous lesions, resembling those of swine erysipelas, in hooded seals, harp seals, and ringed seals, and they reported the isolation of *E. rhusiopathiae* from the tooth/gum margin of 2 of 10 northern fur seals (*Callorhinus ursinus*) and 2 of 20 northern elephant seals (*Mirounga augustirostus*). All isolates belonged to one or other of serotypes 2, 5, 9, 16, and 21 of *E. rhusiopathiae*). Another report indicated that erysipelas was not an important clinical problem in pinnipeds (18).

Leptospira interrogans

Leptospirosis is a worldwide disease caused by different serovars of pathogenic leptospires, most of them in the species *Leptospira interrogans.* The disease has been recognized in a variety of domestic and wild animals. The first report of leptospirosis in marine mammals was published in 1971; since then, several reports of this infection in pinnipeds have been published (19). Until now, there has been no report of leptospirosis in cetaceans (13).

Pinnipeds

Epizootics of leptospirosis due to serovar *pomona* occurred several times between 1970 and 1994 in sea lions (*Zalophus californianus*) in California; they were more common in the autumn and typically affected juvenile males (20). The disease associated with serovar *pomona* was also diagnosed in northern fur seals (21). It was suggested that the disease was responsible for reproductive failure in adults and a multiple hemorrhagic syndrome in fetuses and neonates (21). Other manifestations of the disease included depression, extreme thirst, reluctance to use the rear limbs, fever, and, on occasion, icterus (19,22). In 1998, a report by Stamper et al (23) mentioned the presence of renal lesions in Pacific harbor seals that were attributed to serovar *grippotyphosa* on the basis of serological data.

Prevalence of leptospirosis was determined in sea lions stranded live along the central California coast between January 1981 and December 1994. Clinical signs of renal disease were seen in 764 (33%) of the 2338 animals examined; 71% of these died, with similar gross lesions of nephritis. *Leptospira interrogans* serovar *pomona* genotype kennewicki was cultured from 4 kidney samples in 1991 (20). It was speculated that domestic animals and wild rodents could contaminate fresh water and be the source of the spread of the leptospires into the pinniped population (22).

Mycobacterium spp.

The presence of *Mycobacterium* spp. in marine mammals is not very well documented and appears to be limited to pinnipeds.

Pinnipeds

Tuberculosis was diagnosed in 6 cases of strandings in Argentina between March 1989 and December 1992, involving 2 otariid species: 1 southern sea lion (*Otario flavescens*) and 5 South American fur seals

(*Arctocephalus australis*) (24). In all cases, granulomatous lesions were observed in the prescapular and hepatic lymph nodes. Lesions were also seen in the lungs, pleura, liver, spleen, and peritoneum. The *Mycobacterium* isolates were identified as belonging to the *M. tuberculosis* complex but had unique characteristics. This was the first time tuberculosis had been diagnosed in wild seals from the southwestern Atlantic coast. In 1991, tuberculosis had been diagnosed in an Australian sea lion (*Neophora cinerae*) and in a New Zealand fur seal (*Arctocephalus forsteri*) (25). Cutaneous mycobacteriosis due to *Mycobacterium* spp. has been reported in a harbor seal (26). Finally, other members of the genus such as *M. marinum,* present in water, can be found in the oral cavity of marine mammals and can possibly be involved in human infections following a bite (27).

Mycoplasma spp.

The isolation of *Mycoplasma* spp. has been reported only in pinnipeds. No other marine mammal has been mentioned as host for these bacteria.

Pinnipeds

In 1979 and 1980, an epizootic of pneumonia killed at least 445 harbor seals along the New England seaboard of the northeastern United States (28,29). An influenza virus was isolated from the lungs of these seals and *Mycoplasma* strains were isolated from the lungs, trachea, bronchi, and cardiac muscle. The *Mycoplasma* isolates appeared to be different from those of the known *Mycoplasma* species. They were characterized and designated as a new species, *M. phocidae* (30).

In 1988, mass mortality spread among the harbor seals of the Baltic Sea and the North Sea. More than 18 000 seals died because of an acute disease associated with a morbillivirus and characterized by pneumonia, skin lesions, diarrhea, polyarthritis, nervous signs, and abortions in pregnant females. The resulting immunosuppression favored infection by a wide variety of opportunistic microorganisms. In addition to several viruses, *Mycoplasma* was isolated, mainly from the respiratory tract, from a large number of these animals (31). The *Mycoplasma* isolates did not belong to the *M. phocidae* species, or to any of the other known *Mycoplasma* species. They were characterized and classified into 2 new species, *M. phocarhinis* and *M. phocacerebrale.* Even if these mycoplasmas were not the primary cause, they might have been involved in the production of pathological changes and in the general disease, leading to the deaths of the seals (31).

Salmonella spp.

Salmonellosis is a major problem in domestic animals, mainly because of the effect on public health. *Salmonella* sp. serotype Typhimurium DT104 is clearly emerging in different animal species in several countries (32).

Cetaceans

Salmonella spp. have been isolated from various species of cetaceans including killer whale (*Orcinus orca*), bottlenose dolphin, and an unspecified species of pilot whale (33). In 1999, isolation of a monophasic group B *Salmonella* was reported in harbor porpoises in Scottish coastal waters. Lung was the tissue from which the bacterium was most frequently recovered (33 out of 36 attempted isolations), in appreciably higher numbers than from intestine and other tissues sampled (34). The same authors also reported the isolation of *Salmonella* Typhimurium DT12 from a porpoise.

Pinnipeds

Salmonella spp. have been found in pneumonic lungs of northern elephant seals, as well as in California sea lions (33). Systemic salmonellosis was also diagnosed in California sea lions and in northern elephant seals. On San Miguel island, 33% of the fur seal pups and 40% of the sea lion pups were carriers of *Salmonella* spp. and 3 different serotypes, Newport, Heidelberg, and Oranienburg, were detected (35). Serotype Typhimurium DT104 was isolated from a grey seal (*H. grypus*) (36), serotype Tennessee from a common seal (*P. vitulina*), and serotype Bovismorbificans from 2 grey seals (34). *Salmonella* spp. and other Enterobacteriaceae accounted for 75% of the gram-negative isolates from various sites of inflammation in California sea lions, harbor seals, and northern elephant seals (37). In that study, 9 different *Salmonella* serotypes were isolated from 49 animals, with serotype Newport being the most common.

Staphylococcus delphini

Cetaceans

In 1988, a new species of coagulase-positive staphylococci, *Staphylococcus delphini,* was described in dolphins (38). Contrary to *S. aureus, S. delphini* does not produce a heat-stable DNAse and does not produce acid from trehalose. Isolates belonging to this species were isolated from purulent material taken from dolphins living in an aquarium. The animals were suffering from multiple suppurating skin lesions and recovered quickly after antibiotic treatment. The authors indicated that a particular order of marine mammals, such as cetaceans, has not previously been described as hosting any *Staphylococcus* strain or species. Indeed, in their study on beluga whales, De Guise et al did not mention any isolations of *Staphylococcus* spp. (39).

Streptococcus spp.

Cetaceans

In 1980, a case of bronchopneumonia caused by *Streptococcus equi* was reported in a North Atlantic pilot whale (*Globicephala melaena*) in the St. Lawrence estuary (40). This was the first reported isolation of this equine pathogen in marine mammals. Well-circumscribed clusters of necrosis were disseminated throughout the left lung. *Streptococcus equi* was isolated in pure culture from the lung parenchyma, pharynx, and pericardial fluid (40). Numerous previous reports had mentioned the isolation of β-hemolytic streptococci from marine mammals, but most of them were not biochemically identified or serogrouped.

Pinnipeds

In European seals, *Streptococcus* spp. are the organisms most commonly found (41). These organisms constitute one of the major groups of bacteria that inhabit the

respiratory system. Isolation of streptococcal species (α-hemolytic, β-hemolytic, or non-hemolytic) from seals with pneumonia or septicemia has been reported several times. Authors have described isolates that resemble those of *S. canis* (42,43), *S. zooepidemicus* (42), and β-hemolytic streptococci without any further identification (44,45). In accordance with several studies, β-hemolytic streptococci seem to be major pathogens causing septicemia, abscesses, or bronchopneumonia in harbor porpoises and have sometimes been isolated in pure culture (46).

In 1994, a new streptococcal species, *S. phocae,* was isolated from undetermined species of seals (45). This is a β-hemolytic streptococcus. Isolates were recovered from seals suffering from pneumonia, and some had septicemia (45).

Authors have investigated 35 β-hemolytic streptococcal isolates from 16 harbor porpoises of the North and Baltic seas on a comparative basis. Among the 35 isolates recovered from various organs (lungs, kidneys, liver, spleen, lymph nodes, and intestines), 9 were in pure culture and 16 predominated. All 35 isolates could be classified in Lancefield's serological group L and could be identified as *S. dysgalactiae* subsp. *dysgalactiae* (46). In 1992, other authors had reported the association of group L streptococci with pneumonia in harbor porpoises (47).

Fungal agents

Aspergillus spp.

Aspergillosis is commonly caused by *Aspergillus fumigatus,* and less commonly by *A. niger* and *A. terreus.* These fungi are abundant in nature, and the disease occurs worldwide and generally affects the respiratory system (48). Avian species are most commonly affected and the respiratory tract is the principal site of infection. Abortions have been reported in different animal species. *Aspergillus* spp. account for the majority of pulmonary mycoses causing pneumonia in marine mammals (49).

Cetaceans

Aspergillosis has been diagnosed in captive Atlantic bottlenose dolphins (48,49). Large granulomatous lesions in the lungs and a large nodule protruding on the mucosal surface of the trachea were observed. Some animals had a granulomatous pneumonia (48).

Pinnipeds

Aspergillosis has been reported in pinnipeds (50).

Blastomyces spp.

North American blastomycosis is caused by *Blastomyces dermatitidis,* a dimorphic fungus. Infection occurs as a result of inhalation of spores that proliferate as saprophytes in nature. In infected animals, a primary lesion develops in the lungs, with subsequent metastases to various organs, including the skin. The disease has been reported in several animal species (48). In marine mammals, cases have been seen in captive animals.

Cetaceans

Blastomycosis has been reported in a subadult Atlantic bottlenose dolphin held in captivity for 6 mo in Hawaii (50). No mention was made of the anatomic location or the severity of the lesions. Other cases have also been reported in this species (51).

Pinnipeds

Blastomycosis has been reported in a captive 8-year-old Steller's sea lion (*Eumetopias jubata*), with disseminated lesions in lungs, lymph nodes, spleen, liver, thyroid, and kidneys (52).

Coccidioides spp.

Coccidioides immitis is a free-living, soil-dwelling, dimorphic fungus that survives in saline soil and in sea water. It is endemic in certain southwest states of the United States. It is also found in Mexico and parts of South America.

Table 1. List of bacterial agents isolated from the integumentary system in marine mammals

Agent	Species	Reference
Acinetobacter spp.	Bowhead whale	81
Actinomyces viscosus	Harbor seal	33
Aeromonas hydrophila	Beluga whale	39, 82
	Bottlenose dolphin	83
Brucella spp.	Harbor porpoise	7
	Striped dolphin	7
	Common dolphin	7
Clostridium perfringens	Bottlenose dolphin	84
Corynebacterium spp.	California sea lion	33
	Bowhead whale	81
Dermatophilus congolensis	South American sea lion	48
Edwardsiella spp.	California sea lion	33
Erysipelothrix rhusiopathiae	Hooded seal	12
	Beluga whale	12
	Harp seal	12
	Ringed seal	12
Escherichia coli	Beluga whale	84
Moraxella spp.	Bowhead whale	81
Morganella morganii	Bottlenose dolphin	84
Mycobacterium spp.	Atlantic bottlenose dolphin	33
	Harbor seal	26
Nocardia brasiliensis	Pacific bottlenose dolphin	48
Photobacterium (Vibrio) damselae	Bottlenose dolphin	85, 86
Proteus mirabilis	Bottlenose dolphin	84
Pseudomonas pseudomallei	Undetermined	33
Pseudomonas spp.	California sea lion	33
Staphylococcus aureus	Harp seal	84
	Pacific bottlenose dolphin	84
	Bottlenose dolphin	84
Staphylococcus delphini	Captive dolphins	38
Staphylococcus hyicus	Bottlenose dolphin	84
Staphylococcus spp. (hemolytic)	California sea lion	33
Streptococcus spp. (β-hemol.)	Northern elephant seal	33
	California sea lion	33
Vibrio alginolyticus	Bottlenose dolphin	84
	Atlantic bottlenose dolphin	87

Table 2. List of bacterial agents isolated from the respiratory system in marine mammals

Agent	Species	Reference
Acinetobacter spp.	Beluga whale	88
Actinobacillus delphinicola	Harbor porpoise	1
	Striped dolphin	1
	Sowerby's beaked whale	1
Aeromonas hydrophila	Beluga whale	39, 82
	Beluga whale	88
	Bottlenose dolphin	83
Aeromonas salmonicida	Beluga whale	88
Arcanobacterium phocae	Common seal	89
	Grey seal	89
Arizona spp.	California sea lion	33
Bordetella bronchiseptica	Common seal	90, 91
Citrobacter freundii	Beluga whale	88
Clostridium tertium	Beluga whale	39
Corynebacterium equi	Lake Baikal seal	92
Corynebacterium spp.	California sea lion	33
	Beluga whale	88
	Northern elephant seal	33
	Harbor seal	33
Corynebacterium phocae	Common seal	93
Edwardsiella spp.	Beluga whale	39, 82
	California sea lion	33
	Northern elephant seal	33
	Harbor seal	33
	Killer whale	33
	Common dolphin	33
	Pacific white-sided dolphin	33
Enterobacter aerogenes	Beluga whale	88
Escherichia coli	Beluga whale	39
	Beluga whale	88
	California sea lion	33
Kingella kingae	Beluga whale	39
Klebsiella pneumoniae	Beluga whale	39
	Beluga whale	88
	California sea lion	33
	Pacific white-sided dolphin	33
	Common dolphin	33
Klebsiella spp.	Beluga whale	88
Micrococcus spp.	Beluga whale	88
Mycoplasma phocarhinis	Harbor seal	31
Mycoplasma phocacerebrale	Harbor seal	31
Mycoplasma phocidae	Harbor seal	30
Mycoplasma spp.	California sea lion	33
Mycobacterium spp.	Atlantic bottlenose dolphin	33
	Southern sea lion	24
	South American fur seal	24
	Australian sea lion	25
	New Zealand fur seal	25
Nocardia asteroides	Pilot whale	48
	Pacific bottlenose dolphin	48
	Killer whale	48
	Spinner dolphin	48
	Harbor porpoise	48
Nocardia brasiliensis	Pacific bottlenose dolphin	48

Table 2. ***(Concluded)***

Agent	Species	Reference
Nocardia caviae	Pacific bottlenose dolphin	48
Nocardia spp.	Pygmy sperm whale	48
Pasteurella multocida	Beluga whale	88
Proteus mirabilis	Bottlenose dolphin	84
Pseudomonas aeruginosa	Beluga whale	88
Pseudomonas spp.	Beluga whale	39, 82
	Beluga whale	88
	California sea lion	33
	Northern elephant seal	33
	Harbor seal	33
	Killer whale	33
	Pilot whale	33
	Pacific white-sided dolphin	33
	Common dolphin	33
Salmonella spp.	California sea lion	33
	Northern elephant seal	33
Staphylococcus aureus	Bottlenose dolphin	84
Staphylococcus epidermidis	Beluga whale	88
Staphylococcus hyicus	Beluga whale	88
Staphylococcus spp.	Beluga whale	88
	California sea lion	33
	Northern elephant seal	33
	Pacific white-sided dolphin	33
Streptococcus mitis	Beluga whale	88
Streptococcus phocae	Common seals	45
Streptococcus spp. (β-hemolytic)	California sea lion	33
	Northern elephant seal	33
	Killer whale	33
	Pacific white-sided dolphin	33
	Harbor porpoise	46
Vibrio alginolyticus	Beluga whale	88
	Bottlenose dolphin	84, 87
Vibrio fluvialis	Beluga whale	88

Cetaceans

The first case of coccidioidomycosis in a cetacean was reported in 1998. A stranded bottlenose dolphin succumbed to a pulmonary infection due to *C. immitis*. At necropsy, caseous nodules were observed throughout the lungs and perihilar lymph nodes (53).

Pinnipeds

Seven cases of coccidioidomycosis have been described in free-ranging California sea lions (54). The authors cited published reports concerning a captive California sea lion in an Arizona Zoo and a wild California sea lion in San Diego. Multiple suppurative granulomatous lesions were found throughout the liver and spleen (48).

***Cryptococcus* spp.**

Cryptococcosis is caused by an encapsulated yeast, *Cryptococcus neoformans*, which occurs as a saprophyte in nature. A high correlation was noted between *C. neoformans* and nests and droppings of birds, principally pigeons (48). Cryptococcosis has a worldwide distribution and has been reported in many animal

species (48). In marine mammals, cases have been diagnosed in captive cetaceans.

Cetaceans

The first case was a 7-year-old Atlantic bottlenose dolphin in which a firm subpleural nodule, due to *C. neoformans,* was found in the left lung. Although the source of the *C. neoformans* was not determined, many seabirds were observed roosting near the compound where the dolphin was kept in captivity (55). Pulmonary cryptococcosis has also been reported in a captive female Pacific white-sided dolphin (*L. obliquidens*) (48).

Other yeasts associated with infections in marine mammals

Infections caused by *Candida* spp. appear to be more common in marine mammals than are other fungal infections. They have been a problem in marine mammals in seaquariums. The clinical disease may be associated with prolonged use of antibiotics and corticosteroids, overtreatment of the water for purity, or both (50). Among the members of the genus *Candida, C. albicans* is seen more frequently than other species. *Torulopsis* spp., *Trichosporon* spp., and *Malassezia* spp. have also been reported in marine mammals (56,57).

Cetaceans

Candida albicans is known to occur in captive, but not in wild, populations of dolphins. In captive cetaceans, reports are numerous. *Candida* infection was diagnosed on the skin of freshwater dolphins (*Soulignenia geoffrenis*) in Germany and in the terminal esophagus of Atlantic bottlenose dolphins in the United States (48). Systemic lesions of candidiasis have also been reported in 2 killer whales (*O. orca*); visceral lesions were found in many organs including heart, kidneys, and lymph nodes (48). Cetaceans with candidiasis often show evidence of gastric or esophageal distress, reluctance to swallow food that has been mouthed, vomiting, head shaking, and retching (13). This infection has also been reported in an Atlantic bottlenose dolphin, a beluga whale (*Delphinapterus leucas*), a juvenile harbor porpoise (*P. phocoena*), and a pilot whale (58); recommendations were made for prevention and diagnosis of the disease.

Candida guiliermondii and *C. lambica* have been isolated from the blowhole of captive beluga whale (*D. leucas*) (56). *Candida ciferrii, C. guiliermondii,* and *C. pseudotropicalis* were isolated from anal swabs of the same belugas. *Torulopsis candida* and *Trichosporon cataneum,* from the blowhole and from anal swabs of captive beluga whales, are among other yeasts isolated from cetaceans (56).

Pinnipeds

Candidiasis in phocids is characterized by inflammation at mucocutaneous junctions, especially the commissures of the mouth, and the periocular, perivulvar, and perianal areas. In many animals, the hind flippers become inflamed; isolated skin lesions have also been observed (13). Multiple large areas of alopecia and erythema of the eyelids, lips, limbs, and abdomen were associated with candidiasis in a male harbor seal in a zoological park in Japan (59). Similar lesions were reported in elephant seals (*Mirounga leonina*) in a zoo in Germany (60). Dunn et al (61) have reported on candidiasis in captive pinnipeds and discussed the diagnosis, treatment, and pathogenesis of this infection in captive pinnipeds, such as grey seals, harbor seals, California sea lions, and northern elephant seals.

Dermatitis caused by *Malassezia pachydermatis,* a lipophilic yeast, was reported in 1998 in a California sea lion (57). The diagnosis was supported by histopathologic findings, mycological cultures, and response to antifungal treatment. The authors mentioned that the only other report of finding this fungus was in a clinically normal ear of a sea lion (57).

Table 3. List of bacterial agents isolated from the digestive system in marine mammal

Agent	Species	Reference
Acinetobacter spp.	Beluga whale	88
Actinobacillus delphinicola	Harbor porpoise	1
	Striped dolphin	1
	Sowerby's beaked whale	1
Aeromonas hydrophila	Beluga whale	88
	Beluga whale	88
Arcanobacterium phocae	Grey seal	89
	Common seal	89
Cetobacterium ceti	Harbor porpoise	95
	Minke whale	95
Clostridium perfringens	Beluga whale	88
Citrobacter freundii	Beluga whale	88
Edwardsiella tarda	Beluga whale	39
	Bottlenose dolphin	84
Enterobacter aerogenes	Beluga whale	88
Enterobacter agglomerans	Beluga whale	88
Enterobacter cloacae	Beluga whale	88
Enterococcus faecalis	Bottlenose dolphin	84
Erysipelothrix rhusiopathiae	Northern elephant seal	12
	Northern fur seal	12
Escherichia coli	Beluga whale	84
Klebsiella pneumoniae	Beluga whale	88
Morganella morganii	Beluga whale	39, 88
Nocardia paraguayensis	Atlantic bottlenose dolphin	48
Pasteurella multocida	Beluga whale	88
Plesiomonas shigelloides	Beluga whale	39
Proteus mirabilis	Beluga whale	88
	Bottlenose dolphin	84
Proteus vulgaris	Beluga whale	88
Providencia spp.	Bottlenose dolphin	84
Pseudomonas putrefaciens	Beluga whale	39, 88
Pseudomonas spp.	Beluga whale	88
Serratia spp.	Beluga whale	88
Salmonella spp.	Grey seal	34, 36
Staphylococcus aureus	Beluga whale	88
Staphylococcus epidermidis	Bottlenose dolphin	84
Staphylococcus hyicus	Bottlenose dolphin	84
Staphylococcus spp.	Beluga whale	88
Vibrio alginolyticus	Beluga whale	88
Vibrio fluvialis	Beluga whale	88
Vibrio parahaemolyticus	Beluga whale	39

Dermatophytes

Reports of dermatophytosis in marine mammals are relatively rare. The fungi responsible for dermatophytosis

Table 4. List of bacterial agents isolated from the genitourinary system in marine mammals

Agent	Species	Reference
Actinobacillus delphinicola	Harbor porpoise	1
	Striped dolphin	1
	Sowerby's beaked whale	1
Aeromonas spp.	Beluga whale	39, 88
Brucella spp.	Grey seal	6, 7
	Porpoise	6, 7
Escherichia coli	Beluga whale	39
Edwardsiella spp.	California sea lion	33
Leptospira spp.	California sea lion	20–23
	Northern fur seal	20–23
Morganella morganii	Beluga whale	39
Pseudomonas spp.	Beluga whale	39
	California sea lion	33
Salmonella spp.	California sea lion	34–36
Staphylococcus spp.	California sea lion	33

Table 5. List of bacterial agents isolated from the reticuloendothelial system in marine mammals

Agent	Species	Reference
Actinobacillus delphinicola	Striped dolphin	1
Brucella spp.	Atlantic white-sided dolphin	3–10
	Hooded seal	3–10
	Grey seal	3–10
	Pacific harbor seal	3–10
	Ringed seal	3–10
	Atlantic walrus	3–10
	European otter	3–10
Mycobacterium spp.	Southern sea lion	24
	South American fur seal	24
	Australian sea lion	25
	New Zealand fur seal	25
Plesiomonas shigelloides	Beluga whale	39

parasitize the keratinized layer of the epidermis, hair, feathers, and horn of animals. The deeper tissues generally remain unaffected (48).

Cetaceans

The isolation of *Trichophyton* spp. from nodules on the trunk of a captive Atlantic bottlenose dolphin was reported from Japan (62).

Pinnipeds

The isolation of several dermatophytes from northern fur seals (*Callorhinus ursinus*) has been reported, including a *Trichophyton* sp. in cutaneous lesions (63). *Epidermophyton floccosum* was implicated with numerous erosions on the skin of the nose, face, flippers, and tail of a captive manatee (*Trichechus* sp.) (64). *Microsporum canis* was isolated from cutaneous lesions in a harbor seal (65).

Fusarium spp.

Fusariomycosis is caused by the genus *Fusarium,* which is a common soil inhabitant and considered to be saprophytic (48). Reports of this disease in animals and humans are rare. Predisposing factors remain undetermined, but the onset of the disease may be associated with some factor related to captivity.

Cetaceans

Mycotic dermatitis associated with *Fusarium* spp. was diagnosed in an Atlantic white-sided dolphin (*L. acutus*) and a pygmy sperm whale (*Kogia breviceps*) (66). Gross examination revealed raised, firm, erythematous, cutaneous nodules that were most prominent on the heads, trunks, and caudal portions of the bodies. All animals had been stressed by such factors as being stranded on a beach, transported long distances, etc. Microbial culturing of the lesions yielded fungal isolates characteristic of *Fusarium* spp. Hyphae were also seen on histologic examination. The dermatitis resolved in animals treated with ketoconazole. *Fusarium* spp. may be opportunistic invaders of the skin of marine mammals that have decreased immunocompetence (66).

Pinnipeds

Fusariomycosis in California sea lions and grey seals caused severe proliferative dermatitis. Lesions were firm, raised papules found mainly on the face, trunk, and flippers (48). Similar lesions have been reported in harbor seals (66).

Histoplasma spp.

Histoplasmosis is caused by *Histoplasma capsulatum,* a dimorphic fungus that grows in soil enriched by bird or bat droppings. The usual route of entry of the organism is the respiratory tract with the primary lesions in the lungs, from which dissemination may occur to other parts of the body. The disease has a worldwide distribution and has been reported in a wide variety of animal species (48).

Pinnipeds

Histoplasmosis was diagnosed in an adult captive female harp seal. Two large submandibular masses and multiple nodules in the lungs were found (67). Whether the sea gulls contributed to the source of infection remains unknown.

Loboa spp.

Lobomycosis, also known as keloidal blastomycosis, is caused by *Loboa loboi.* Since the lesions are restricted to the skin with no evidence of dissemination to the regional lymph nodes or other organs, it is believed that infection follows abrasion or traumatization of the skin (48). This disease had only been reported in humans in the forests of South and Central America. No other animal species has been involved with this disease, except dolphins, 1 captured in the estuary of the Surinam River and the others along the coast of Florida (48). How they contracted the disease is unknown.

Cetaceans

All dolphins affected with lobomycosis were Atlantic bottlenose dolphin (68), except one, a Guiana dolphin (*Sotalia guianensis*) (69). The gross lesions were multiple, elevated, whitish, crusty, nodular growths on the skin, similar to those found in human cases. Lesions were

found on the head, flippers, abdomen, fins, back, tail stocks, and flukes (48).

Sporothrix spp.

Sporotrichosis is caused by *Sporothrix schenckii,* a dimorphic fungus that is a ubiquitous saprophyte. Several cases have been diagnosed in different animal species and in humans; only a single report of the disease exists for a marine mammal, a Pacific white-sided dolphin of undetermined age that had been in captivity for about 3 y at Sea World in Orlando, Florida. Lesions were cutaneous lacerations over the body, enlarged and hemorrhagic respiratory lymph nodes, and hemorrhagic lesions in the lungs and oral mucous membrane. The origin of the infection was undetermined (70).

Zygomycetes

Zygomycosis is the term now used to describe the diseases formerly called mucormycosis, phycomycosis, or hyphomycosis. It includes a diverse group of mycoses caused by a variety of fungi, including the genera *Absidia, Rhizopus, Mucor,* and *Mortierella* (48). These organisms are ubiquitous soil inhabitants and opportunistic organisms; infection may result from predisposing factors, such as traumatic damage to the tissue or suppression of the immune system. The lesions in some of the diseases are confined to the skin and subcutaneous tissue, while in others, systemic infection occurs (48).

Cetaceans

Zygomycosis was diagnosed in a young, southern right whale (*Eubalaena australis*) in South Africa. Several suppurative granulomatous lesions containing nonseptate hyphal organisms, similar to the genus *Mucor,* were found in the left epaxial muscle (71). Other cases were reported in captive cetaceans in an Atlantic bottlenose dolphin in Florida (72), and in a killer whale in Vancouver (48). In the latter case, there was a mycotic invasion of the blood vessels of many organs, including the gastrointestinal tract, lungs, heart, and skeletal muscles, resulting in thrombosis, embolism, and infarction (48).

Pinnipeds

A granulomatous pneumonia caused by a member of the genus *Mucor* was diagnosed in a captive female harp seal (73).

Zoonotic infectious agents associated with marine mammals

Brucella spp.

Members of this genus found in nonmarine mammals are known to infect humans; the health implications of this potential zoonotic infection should now be taken into account by all those involved in marine mammal research or rehabilitation (6). It is a potential source of exposure for native American people who use harbor seals as food source (8).

Erysipelothrix rhusiopathiae

Erysipelothrix rhusiopathiae has been isolated from 12 of 116 bite wounds in handlers of marine mammals (12).

Table 6. List of bacterial agents associated with septicemia or isolated from several tissues in marine mammals

Agent	Species	Reference
Abiotrophia balaenopterae	Minke whale	98
Actinobacillus scotiae	Harbor porpoise	2
Actinomyces bovis	Atlantic bottlenose dolphin	33
Aeromonas spp.	California sea lion	33
	Pacific white-sided dolphin	33
Aeromonas hydrophila	Steller sea lion	33, 48
Arcanobacterium phocae	Grey seal	89
Arizona spp.	California sea lion	33
Bordetella bronchiseptica	Seals (undetermined)	90, 91
Citrobacter spp.	Northern elephant seal	33
Clostridium perfringens	Bottlenose dolphin	84
Corynebacterium spp.	California sea lion	33
	Northern elephant seal	33
	Harbor seal	33
Edwardsiella tarda	Beluga whale	39, 88
Edwardsiella spp.	California sea lion	33
	Northern elephant seal	33
	Harbor seal	33
	Pilot whale	33
	Pacific white-sided dolphin	33
Erysipelothrix rhusiopathiae	Pilot whale	33
	Bottlenose dolphin	33
	Pacific white-sided dolphin	33, 97
	Hooded seal	12
Escherichia coli	Beluga whale	39, 88
	California sea lion	33
Klebsiella pneumoniae	Pilot whale	33
Nocardia spp.	Beluga whale	88
	Risso's dolphin	84
Pasteurella haemolytica	California sea lion	33
Pasteurella multocida	California sea lion	88
	Northern fur seal	88
Plesiomonas shigelloides	Beluga whale	88
Proteus vulgaris	Beluga whale	88
Pseudomonas putrefaciens	Beluga whale	88
Pseudomonas spp.	California sea lion	33
	Northern elephant seal	33
	Pacific white-sided dolphin	33
Salmonella spp.	California sea lion	33
	Northern elephant seal	33, 96
	Killer whale	33
	Bottlenose dolphin	33
Serratia marcescens	Beluga whale	88
Staphylococcus aureus	Bottlenose dolphin	88
Staphylococcus spp.	California sea lion	33
	Harbor seal	33
	Bottlenose dolphin	33
Streptococcus spp.	Bottlenose dolphin	88
	California sea lion	33
	Northern elephant seal	33
	Harbor seal	33
Streptococcus phocae	Seals (undetermined)	45
Vibrio alginolyticus	Undetermined	13, 88
Vibrio cholerae	Beluga whale	88
Vibrio parahaemolyticus	Beluga whale	88

Table 7. List of bacterial agents isolated from abscesses in marine mammals

Agent	Species	Reference
Actinomyces viscosus	Harbor seal	33
Arcanobacterium pyogenes	Harbor seal	89
Corynebacterium spp.	California sea lion	33
Escherichia coli	California sea lion	33
Nocardia asteroides	Harbor porpoise	48
	Leopard seal	48
Nocardia spp.	Beluga whale	82
Pseudomonas spp.	California sea lion	33
	Harbor seal	33
	Common dolphin	33
Rhodococcus equi	Common seal	33
Salmonella spp.	California sea lion	33
	Pilot whale	33
Streptococcus spp. (α-hemol.)	California sea lion	33
Streptococcus spp. (β-hemol.)	California sea lion	33
	Pacific white-sided dolphin	33

Leptospira interrogans

Epizootics of leptospirosis have been reported frequently in pinnipeds (19–23). This disease can be transmitted to humans by contaminated water, urine, or organs, namely kidneys.

Mycobacterium marinum

Human infection due to *Mycobacterium marinum* is possible after a bite from a marine mammal (27).

Mycoplasma spp.

In 1990, it was suggested that the disease called seal finger (74) was associated with a *Mycoplasma* sp., first isolated from seals in 1980 (75). *Mycoplasma phocacerebrale* was isolated from the finger of a young female trainer who had been bitten, and from the front teeth of the seal that had bitten her at the New England Aquarium in Boston (76). Clinically, the seal finger syndrome is characterized by acute pain, swelling, discharge, and, frequently, by arthritis of long duration (75). However, the direct implication of mycoplasmas in seal finger syndrome remains to be confirmed. The syndrome has to be differentiated from other conditions, such as erysipeloid caused by *Erysipelothrix rhusiopathiae* (77). Finally, seals and, possibly, polar bears are the only known carriers of the causative agent of seal finger (78).

Salmonella spp.

Outbreaks of salmonellosis in humans have been associated with eating meat from whales and dolphins (79,80).

Other zoonotic infectious agents

If one considers the possibility of human infections due to marine mammal bites, or wound infections following close contact with marine mammals, the list of potential infectious agents should include most of the bacterial agents listed in tables presented in this article. In spite of their species specificity, some bacteria, such as *Actinobacillus* spp., could be isolated from bites or wound infections in humans. Dermatomycoses or other mycoses are possibly also transmitted to humans after close contact with marine mammals.

Bacterial agents isolated in different species of marine mammals

A list, in alphabetical order, of bacterial agents isolated from different species of marine mammals is presented, according to the system involved, in Tables 1 to 7. CVJ

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