A Review of Potential Infectious Disease Threats to Southern Resident Killer Whales (*Orcinus orca*)

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ABSTRACT

The southern resident killer whale (*Orcinus orca*) population, also called the eastern North Pacific southern resident stock of killer whales, is declining. The Canadian Committee for the Status on Endangered Wildlife in Canada (COSEWIC) recently listed this stock as endangered. The U.S. National Oceanic & Atmospheric Administration Fisheries (NOAA Fisheries) has formally initiated a status review for this population under the U.S. Federal Endangered Species Act. Reasons for the decline in this population since 1996 are unknown, but high tissue contaminant levels, decreased prey abundance, and increased vessel traffic have been suggested. Information about the role that infectious diseases may play in this population's decline is not available, nor is information regarding the threat that infectious diseases may play in the long-term viability of this small population. Fifteen infectious agents reported in free-ranging killer whales and captive killer whales were identified using available databases and reference literature. Also identified were 28 infectious agents not specifically reported in killer whales, but reported in free-ranging and captive odontocetes sympatric to southern resident killer whales. Although more research is necessary before the potential role of these agents in the decline of this population can be determined, marine *Brucella* spp. and cetacean poxvirus were identified as pathogens that could be playing a role in the neonatal mortality seen in the southern resident population. Herpesviruses and morbilliviruses were identified as pathogens that could potentially influence the long-term viability of the southern resident killer whale population. Efforts need to continue in order to learn more about infectious diseases of free-ranging southern resident killer whales and sympatric odontocetes. Regardless of the pathogens involved, the small population size, social structure, and the potential for high polychlorinated biphenyl concentrations to increase susceptibility to infectious diseases suggest that infectious diseases have the potential to threaten the long-term viability of the southern resident killer whale population.

INTRODUCTION

Killer whales (*Orcinus orca*) are distributed in marine waters worldwide, and distinct populations and sub-populations or stocks, are well defined by morphometric, photographic, and molecular techniques (Dalheim and Heyning, 1999). Data suggest that the typical social organization among these marine predators is along matrilines that result in life-long kinship bonds; these groups tend to specialize with respect to dietary preference and habitat utilization. In the Pacific Northwest, there are kinship groups that are more or less "resident" and feed primarily on salmon; others are more "transient" and feed on marine mammals (Ford et al., 1998). One resident stock that ranges extensively throughout the inland marine waters of Washington State and southern British Columbia, known as the southern resident killer whale population, is declining. This population, also called the eastern North Pacific southern resident stock of killer whales, has numbered 100 or more but has declined to less than 80 individuals in the last 7 years. The Canadian Committee for the Status on Endangered Wildlife in Canada (COSEWIC) recently listed this stock as endangered. The U.S. National Oceanic & Atmospheric Administration Fisheries (NOAA Fisheries) has formally initiated a status review for southern resident killer whales under the U.S. Federal Endangered Species Act.

Annually since 1976, the Center for Whale Research (Friday Harbor, WA) has made an absolute count (census) of southern resident killer whales, and since 1996, this population has been in decline. Reasons for the decline are unknown, but high tissue contaminant levels (Ross et al., 2000), decreased prey abundance, and increased vessel traffic have been suggested as reasons for the decline. Information about the role that infectious diseases may be playing in this population's decline is not available, nor is information regarding infectious diseases that may threaten the long-term viability of this small population. This paper discusses the potential for infectious diseases (bacteria, viruses, or fungi) to be involved in the decline in the southern resident killer whale population or to threaten the long-term viability of this population. We identify pathogens that have been reported in free-ranging and captive killer whales, as well as those reported in free-ranging and captive odontocetes sympatric to southern resident killer whales. Infectious agents are then evaluated for their potential to be involved in the decline of southern residents or to threaten the long-term viability of this small population.

MATERIALS AND METHODS

Infectious agents (bacteria, viruses, and fungi) reported in free-ranging and captive killer whales were identified using available databases and reference literature. Also listed were infectious agents not specifically reported in killer whales, but reported in free-ranging and captive odontocetes sympatric to southern resident killer whales, particularly common dolphins (*Delphinus delphis*), Dall's porpoises (*Phocoenoides dalli*), false killer whales (*Pseudorca crassidens*), harbor porpoises (*Phocoena phocoena*), northern right whale dolphins (*Lissodelphis borealis*), bottlenose dolphins *(Tursiops*

truncatus), white-sided dolphins (*Lagenorhynchus obliquidens*), Risso's dolphins (*Grampus griseus*), short-finned pilot whales (*Globicephala macrorhynchus*), and striped dolphins (*Stenella coeruleoalba*).

Photographic identification census data compiled by the Center for Whale Research on the southern resident killer whale population were examined for mortality trends. Trends were graphically assessed by year and by age at death. The following groupings were used for age classification: animals 0-3 years old were classified as infants, 4-11 year olds as juveniles, 12-17 year olds as adolescents, >18 year olds as adults. Animals that died at less than a year of age were evaluated for trends in birth order. Infectious agents identified in killer whales and sympatric odontocetes were evaluated for their potential to cause identified mortality patterns.

Pathogens identified also were examined for their ability to cause disease, morbidity, or mortality at the population level. Each pathogen was qualitatively evaluated based on reported ability for the pathogen to cause disease in an individual animal and at the population level. Pathogens were assigned a virulence rating of 1, 2, 3, or unknown, with pathogens rated one (1) as being those that were considered highly virulent and capable of causing epizootics in killer whales or sympatric odontocetes. Rated as two (2) were pathogens reported to cause mortality in individual animals, but not believed to be capable of causing epizootics. A rating of three (3) was given to pathogens reported to cause insignificant lesions. Pathogens for which virulence and potential population impact were unknown were labeled "unknown." All infectious agents assigned a virulence rating of 1 were considered to have the potential to impact the long-term viability of the southern resident population.

RESULTS AND DISCUSSION

Pathogens identified

We identified 43 pathogens reported from captive and free-ranging killer whales or sympatric odontocetes, including 20 bacteria, 8 viruses, and 15 fungi. Of these, 2 infectious agents were reported in free-ranging killer whales (table 1), 13 from captive killer whales (table 2), and 11 and 17 from free-ranging (table 3) and captive (table 4) odontocetes, respectively, that are sympatric to southern resident killer whales.

Pathogens potentially involved in population decline

Since the annual census was started in 1974, 78 southern resident killer whales have died. When evaluated by the number of deaths per year, death counts were the highest in 1998 and 2000, however no obvious epizootic patterns were noted (Fig. 1). Of the 78 deaths, 26% (n=20) were infants, 14% (n=11) were juveniles, 4% (n=3) were adolescents, and 56% (N=44) were adults (Fig. 2). When age class was separated out into age in years at death, only animals dying at less than 1 year old were over-represented (n=11). Southern resident killer whale calves dying in the first year of life were evaluated by birth order to see if calves born to nulliparous, premiparous, or multiparous females were over-represented, but no apparent trends were noted.

Many wild animal populations experience highest mortality in the first year age class. High mortality in this age class does not necessarily mean that infectious agents are

responsible, but the possibility exists. From the list of 43 potential infectious disease agents identified, two have high potential to cause neonatal mortality in the southern resident population. These pathogens, marine *Brucella* and cetacean poxvirus, were assigned level 2 and unknown virulence ratings.

Marine *Brucella* spp. are Gram negative bacteria closely related to better known terrestrial pathogens in the genus *Brucella* (Cloeckaert et al., 2001)). Infection by *Brucella* has been documented to cause abortion in captive bottlenose dolphins (Miller et al., 1999); however, the clinical and pathologic significance of infection by these organisms in other marine mammals, including *Orcinus orca*, is not well understood. It is not known if marine *Brucella* infection occurs in southern resident killer whales, although antibodies to *Brucella* spp. have been identified in a free-ranging killer whale (Jepson et al., 1997) and were detected in a female transient killer whale stranded within the range of southern resident killer whale population (CA 189; January 2002, Dungeness Spit, Washington; pers. comm., S. Raverty). It is possible that killer whales within the southern resident population could be infected with marine *Brucella*, and the potential exists for this pathogen to cause abortion and neonatal calf mortality. More research is necessary before this pathogen can be fully evaluated for its potential to cause abortion and neonatal mortality in the southern resident killer whale population.

Cetacean poxviruses typically cause cutaneous lesions referred to as tattoo and ring skin lesions (Van Bressem et al., 1999). Reported clinical and epidemiological data do not suggest poxvirus infection causes high mortality in cetaceans (Geraci, et al., 1979). It has been suggested, however, that poxvirus infection could cause neonatal and calf mortality in immunologically naïve cetaceans (Van Bressem et al., 1999). Cetacean poxvirus has been documented to cause cutaneous lesions in killer whales (Van Bressem et al., 1999), however, it is not know if the virus occurs within the southern resident population. More data are necessary before the role this virus plays in causing neonatal death in the southern resident killer whale population can be determined.

Potential long-term viability threats

No infectious agent known to infect free-ranging or captive killer whales was assigned the highest virulence rating (level 1), however, such pathogens were identified in sympatric odontocetes and may have the potential to threaten the long-term viability of the small southern resident population. Morbilliviruses (dolphin and porpoise) and herpesviruses were considered infectious disease threats that have the highest potential to affect the long-term viability of the southern resident killer whale population. Mycotic infections have been reported as a major cause of mortality in captive killer whales (Greenwood and Taylor, 1985; Ridgway, 1979), but were not ranked as level 1 pathogens because they were not considered capable of causing epizootics in free-ranging killer whales. Some consider mycotic infections in captive cetaceans uncommon in animals kept in open air, natural sea water systems (Greenwood and Taylor, 1985); their importance as a mortality factor in captive killer whales is more likely associated with captive conditions. Fungal infections often result from an environmental point source, are poorly transmitted between animals, and rarely result in epidemics (Reidarson et al., 1999). All fungal pathogens, therefore, were assigned a virulence rating of 2; they could potentially cause mortality in individual southern resident killer whales, but it is unlikely that they represent a population threat.

Porpoise and dolphin morbilliviruses are antigenically and genetically similar (Barrett et al., 1993) and are generally considered strains of the same viral species, cetacean morbillivirus (Kennedy-Stoskopf, 2001). Although precise mortality rates are unknown for these viruses, they have caused large-scale epizootics in bottlenose dolphins in the Western Atlantic (Lipscomb et al., 1994a) and the Gulf of Mexico (Lipscomb et al., 1996b), and in striped dolphins in the Mediterranean Sea (Forcada et al., 1994). Antibodies to morbilliviruses have been found in free-ranging common dolphins in the northeastern Pacific Ocean (Reidarson et al., 1998b) and may occur within the range of the southern resident killer whale population, yet it is not known if killer whales are susceptible to infection by cetacean morbillivirus. It has been hypothesized that cetacean morbillivirus infection may be enzootic among short-finned and long-finned (*Globicephala melas*) pilot whales in the western Atlantic Ocean (Duignan et al., 1995). Southern resident killer whales are sympatric with short-finned pilot whales. Because cetacean morbilliviruses have a history of being highly virulent in some odontocetes, because antibodies have been found in free-ranging common dolphins in the northeast Pacific Ocean, and because short-finned pilot whales, a possible reservoir host for these viruses, could potentially transmit these viruses to southern resident killer whales, morbilliviruses represent a potential threat to the long-term viability of the southern resident killer whale population. If cetacean morbillivirus occurs or is introduced into the range of southern resident killer whales and if morbilliviruses are highly virulent in killer whales, an epizootic within the population could have catastrophic consequences and could threaten to the long-term viability of this population.

Historically, herpesviruses were thought to cause cutaneous (Van Bressem and Van Waerbeek, 1996) and mucosal (Lipscomb et al., 1996b) lesions in odontocetes. More recently they have been documented to cause severe encephalitis in harbor porpoises (Kennedy et al., 1992b; Blanchard et al., 2001) in the eastern Atlantic Ocean, and systemic disease in bottlenose dolphins (Blanchard et al., 2001) in the western Atlantic Ocean. Very little is known about the epidemiology of these viruses, and reports of herpesviruses causing fatal disease may represent recrudescence of latent infections, infection in immunologically naïve hosts, or atypical infections in aberrant hosts. Similar viruses have not been identified in the northeast Pacific Ocean and there is no evidence that killer whales would be susceptible to infection by these viruses if they were present, but the possibility exists. Because herpesviruses have been reported to cause severe disease in two species of free-ranging odontocetes, herpesviruses may have the ability to cause large-scale mortality in the southern resident killer whale population. Surveillance for herpes viruses in odontocetes from the northeast Pacific Ocean should continue. Continued research on the epidemiology of these pathogens is warranted.

Caveats

There are potential flaws in assuming that southern resident killer whales are equally susceptible to infection by pathogens known to cause epizootics in sympatric odontocetes. It is not known if pathogens that cause epizootics and/or severe disease in individual sympatric odontocetes will similarly affect killer whales. Conversely, we cannot be certain that infectious agents in sympatric odontocetes classified as less virulent might not be more virulent in killer whales. High total polychlorinated biphenyls (PCB) concentrations in tissues of southern resident killer whales make them among the

most contaminated cetaceans in the world (Ross et al., 2000). Although age may be a confounding factor, it has been suggested that there is an association between cetacean exposure to PCBs and mortality due to infectious diseases (O'Hara and O'Shea, 2001). For example, Jepson et al. (1999), found that harbor porpoises that died from infectious diseases had higher chlorobiphenyl concentrations than those that died from physical trauma. Also it has been suggested that the high mortality seen in a morbillivirus epizootic in striped dolphins in the Mediterranean Sea may have been related to high PCB concentrations (Domingo et al., 1992; Aguilar and Borrell, 1994). If high PCB levels in southern resident killer whales reduce host susceptibility to infectious agents, pathogens that are not documented to cause severe disease in other odontocetes may be more virulent in this population of killer whales.

CONCLUSION

It is recognized that infectious diseases have the potential to negatively impact wild animal populations (Scott, 1988; Gulland, 1995; Deem et al., 2001). Unfortunately, information about infectious diseases in free-ranging killer whales is sparse, making identification of potentially important pathogens difficult. Marine *Brucella* and cetacean poxvirus could be playing a role in the neonatal mortality documented in the southern resident population; more research is necessary before the significance of marine *Brucella* and cetacean poxvirus can be determined.

In order to speculate on the threat that infectious disease may have on the long-term viability of the southern resident killer whale population we were required to make assumptions based on limited available information about infectious diseases in sympatric odontocetes. If killer whales are susceptible to infection, morbilliviruses have the potential to threaten the long-term viability of the southern resident population. Much less is known about herpesviruses in odontocetes, however they appear to have the ability to be highly virulent in at least two species and may represent a potential threat to the southern resident population. Potential infectious disease threats other than morbilliviruses and herpesviruses also may exist but have not been documented at this time.

Infectious disease risk assessment should be regularly re-evaluated based on new findings within the field of marine mammal medicine. Investigation into the potential for parasites to threaten the long-term viability of the southern resident killer whales was not addressed in this paper, but warrants evaluation. Protozoal pathogens such as *Toxoplasma gondii* and *Sarcocystis* sp., once thought to be only a disease of terrestrial animals, have been reported to cause fatal encephalitis in some marine mammals (Dailey, 2001) and could represent a threat to the fecundity or long-term viability of the southern resident killer whale population.

Regardless of which pathogens are involved, infectious diseases could be a threat to the long-term viability of the southern resident killer whale population. The small size of the population, its highly social structure, and the potential for high PCB levels to increase susceptibility to pathogens, increase this possibility. Efforts need to continue in order to learn more about infectious diseases of free-ranging southern resident killer whales and sympatric odontocetes. For this reason it is imperative that when possible,

complete postmortem evaluations (including analyses to detect presence/absence of infectious agents) should be performed on all odontocetes stranded or accidentally caught in fishing gear throughout the range of the southern resident killer whale population.

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ACKNOWLEDGEMENTS

We thank K. Gilardi and S. Raverty for reviewing the manuscript. Financial support for this work was provided by the Marine Ecosystem Health Program of the UC Davis School of Veterinary Medicine's Wildlife Health Center.

Figure 1: Southern resident killer whale mortality data by year (1976-2002)

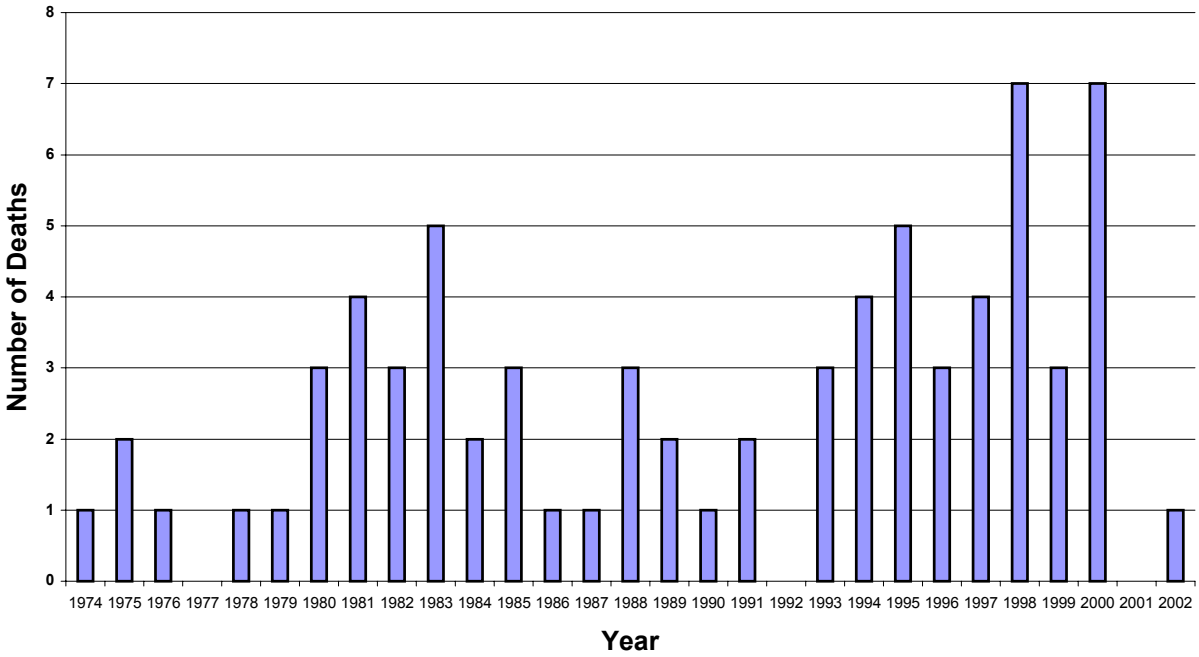

Figure 2: Southern resident killer whale mortality data by age class (1976-2002; n=78 mortalities)

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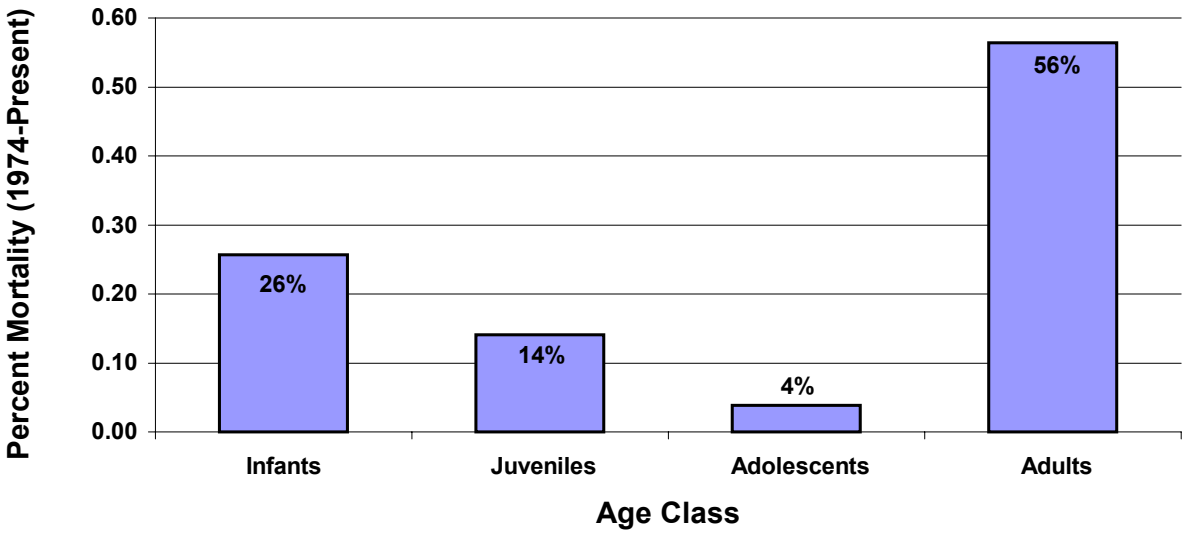

Table 1: Known infectious diseases of free-ranging killer whales

Pathogen	Reference	Virulence	Ocean
Bacteria			
Brucella spp.	Jepson et al., 1997	2; Unknown	Northeast Atlantic
Viruses			
Cetacean pox virus (Orthopoxvirus)	Van Bressem et al., 1999	3, Unknown	Unknown

Virulence rating: 1 = highly virulent, potential to cause population impact
2 = moderately virulent, causes impact on individual animal
3 = low virulence, insignificant disease at individual level

Table 2: Known infectious diseases of captive killer whales

Pathogen	Reference	Virulence
Bacteria		
Burkholderia pseudomallei	Hicks et al., 2000	2
Clostridium perfringens	Walsh et al., 1994	2
Erysipelothrix rhusiopathiae	Bossart et al., 1988	Unknown
Nocardia asteroides	Sweeney et al., 1976	2
Nocardia otitidiscaviarum	Dunn et al., 2001	2
Salmonella sp.	Ridgway, 1979	2
Streptococcus sp., beta-hemolytic	Greenwood and Taylor, 1985	2
Viruses		
Hepatitis-B like virus	Bossart et al., 1990	3
Influenza (suspected; no virus isolated)	Ridgway, 1979	2
Cutaneous papilloma virus	Bossart et al., 1996	3
Fungi		
Aspergillus fumigatus	Reidarson et al., 1999	2
Candida alibicans	Greenwood and Taylor, 1985; Ridgway, 1979; Sweeney et al., 1976	2
Saksenaea vasiformis	Reidarson et al., 1999	Unknown

Virulence rating: 1 = highly virulent, potential to cause population impact
2 = moderately virulent, causes impact on individual animal
3 = low virulence, insignificant disease at individual level

Table 3: Infectious diseases of free-ranging sympatric odontocetes not reported in killer whales

Pathogen	Species	Reference	Virulence	Ocean
Bacteria				
Actinomyces bovis	Bottlenose dolphin	Sweeney et al., 1976	2	Gulf of Mexico
Helicobacter sp.	1. White-sided dolphins 2. Common Dolphin	Harper et al., 2000	Unknown	Northwest Atlantic
Vibrio alginolyticus	1. Bottlenose dolphin 2. Striped dolphins	Buck and Spotte, 1986	Unknown	
Vibrio parahaemolyticus	Bottlenose dolphin	Buck and Spotte, 1986	Unknown	Unknown
Viruses				
Herpesviruses	1. Bottlenose dolphin 2. Harbor porpoise 3. Harbor porpoise	1. Blanchard, et al., 2001 2. Kennedy et al., 1992b 3. Lipscomb et al, 1996b	1. 1 2.1 3. 3	1. Western Atlantic 2. Western Atlantic 3. Western Atlantic
Morbillivirus, Dolphin	1. Bottlenose dolphin 2. Striped dolphins 3. Short-finnedPilot whales 4. Harbor porpoise 5. Striped dolphin 6. Risso's dolphin 7. Common dolphin	1. Lipscomb at al., 1994a and b; Taubenberger et al., 1996; Van Bressem et al., 2001 2. Domingo et al., 1992 3. Duignan, 1995 4. Van Bressem et al., 2001 5. Van Bressem et al., 2001 6. Van Bressem et al., 2001 7. Reidarson et al., 1998b	1 1 1 1 1 1 1	1. Western Atlantic; Gulf of Mexico 2. Mediterranean Sea 3. Western Atlantic 4. N. E. Atlantic, North Sea 5. Mediterranean Sea 6. Mediterranean Sea 7. Northeast Pacific

Morbillivirus, Porpoise	1. Harbor porpoise	1. McCullough et al., 1991; Visser et al., 1993	1	1. Northeastern Atlantic, North Sea
	2. Bottlenose dolphin	2. Taubenberger et al., 1996	1	2. Western Atlantic
	3. Common porpoise	3. Kennedy et al, 1992a	1	3. Eastern Atlantic
Fungi				
Coccidioides immitis	Bottlenose dolphin	Reidarson et al., 1998a	2	Northeastern Pacific
Cryptococcosis neoformans	Striped dolphin	Gales et al., 1985	2	South Pacific
Loboa loboi	Bottlenose dolphin	Caldwell et al., 1975	3	Western Atlantic
Rhizopus sp.	Harbor porpoise	Wunschmann et al., 1999.	2	Baltic Sea

Virulence rating: 1 = highly virulent, potential to cause population impact
2 = moderately virulent, causes impact on individual animal
3 = low virulence, insignificant disease at individual level

Table 4: Infectious diseases of captive sympatric odontocetes not reported in free-ranging odontocetes nor in free-ranging or captive killer whales

Pathogen	Species	Reference	Virulence
Bacteria			
Edwardsiella tarda	Bottlenose dolphin	Sweeney and Ridgway, 1975	3
Nocardia braziliensis	Bottlenose dolphin	Sweeney et al., 1976	Unknown
Nocardia caviae	Bottlenose dolphin	Sweeney et al., 1976	Unknown
Nocardia paraguayensis	Bottlenose dolphin	Jasmin et al., 1972	3
Pasteurella hemolyticum	Bottlenose dolphin	Sweeney and Ridgway, 1975	2
Pasteurella multocida	Bottlenose dolphin Common dolphin	Sweeney and Ridgway, 1975	2
Pseudomonal pseudomallei	Bottlenose dolphin	Sweeney, 1986	2
Staphlococcus aureus	Bottlenose dolphin	Ketterer and Rosenfeld, 1974	2
Viruses			
Caliciviruses	Bottlenose dolphin	Smith, A. W., 1983	3
Fungi			
Apophysomyces elegans	Bottlenose dolphin White-sided dolphin	Reidarson et al., 1999	Unknown
Aspergillus flavis	Bottlenose dolphin	Sweeney et al., 1976	Unknown
Blastomyces dermatitidus	Bottlenose dolphin	Cates et al., 1986	2
Cladophialophora bantiana	Harbor porpoise	Reidarson et al., 1999	Unknown
Histoplasma capsulatum	Bottlenose dolphin	Jensen et al., 1998	2
Mucor sp.	Bottlenose dolphin	Sweeney et al., 1976	Unknown
Sporothrix schenckii	Pacific white-sided dolphin	Migaki et al., 1978	2
Trichophyton sp.	Bottlenose dolphin	Hoshina and Sigiura in Sweeney and Ridgway, 1975	3

Virulence rating: 1 = highly virulent, potential to cause population impact
2 = moderately virulent, causes impact on individual animal
3 = low virulence, insignificant disease at individual level