

Wildlife reservoirs of brucellosis: *Brucella* in aquatic environments

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Summary

Neurobrucellosis and osteomyelitis are common pathologies of humans and cetaceans infected with *Brucella ceti* or *B. pinnipedialis*. Currently, 53 species of marine mammal are known to show seropositivity for brucellae, and *B. ceti* or *B. pinnipedialis* have been isolated or identified in polymerase chain reaction assays in 18 of these species. Brucellae have also been isolated from fish and identified in lungworm parasites of pinnipeds and cetaceans. Despite these circumstances, there are no local or global requirements for monitoring brucellosis in marine mammals handled for multiple purposes such as capture, therapy, rehabilitation, investigation, slaughter or consumption. Since brucellosis is a zoonosis and may be a source of infection to other animals, international standards for *Brucella* in potentially infected marine mammals are necessary.

Keywords

Brucella ceti – *Brucella pinnipedialis* – Marine brucellosis – Marine mammals – Surveillance – Zoonosis.

Introduction

The potential hosts of *Brucella* in aquatic environments include 130 species of marine mammal that live and feed in lakes, rivers and oceans. Among these, 86 species are cetaceans in the suborders Odontoceti and Mysticeti, which include dolphins, porpoises and whales, and 36 species are pinnipeds, including the Otariidae (sea lions, fur seals), Odobenidae (walrus) and Phocidae (true seals). In addition, sea otters (*Enhydra lutris*), marine otters (*Lutra felina*), polar bears (*Ursus maritimus*), manatees (*Trichechus* spp.) and dugongs (*Dugong dugon*) are included as marine mammals (52).

The study of brucellosis in marine mammals began in 1994, when a *Brucella* sp. was isolated from an aborted fetus of an Atlantic bottlenose dolphin (*Tursiops truncatus*) held in captivity in California in the United States (USA) (32). In the same year, brucellae were isolated from the carcasses of a harbour seal (*Phoca vitulina*), a harbour porpoise

(*Phocoena phocoena*) and a common dolphin (*Delphinus delphis*) stranded along the coast of Scotland (87). These marine mammal strains were initially named *B. maris* (50); however, later studies showed that there were at least two *Brucella* species, one affecting cetaceans (*B. delphinidae*) and another affecting pinnipeds (*B. pinnipediae*) (22). In 2007, these species were renamed *B. ceti* and *B. pinnipedialis*, respectively (36). Currently, these two marine species of *Brucella* are divided into several subgroups reflecting heterogeneity in molecular genotyping (10, 12, 13, 20, 21, 22, 30, 44, 50, 53, 58, 100, 103, 104).

Marine mammals and brucellosis serology

At least 53 species of marine mammal have been described as seropositive for brucellae using conventional brucellosis diagnostic tests, such as enzyme-linked immunosorbent

assays (ELISAs), primarily designed for ruminants (45, 54, 69, 70, 92, 96, 98). A competitive ELISA has been developed especially for cetaceans and pinnipeds (62) and an indirect ELISA for odontocetes (48). Unlike these two last assays, the conventional tests have not been standardised and validated for diagnosis of *Brucella* infections in marine mammals, leading to caution when interpreting the serological results (45, 48). Despite this, positive reactions in these tests have been described in 35 species of cetacean, 14 species of pinniped, two subspecies of sea otter, one species of freshwater otter and the polar bear. There are no reports of isolation of brucellae or seropositivity in manatees, dugongs or river dolphins (45). Among the species that have been reported as seropositive, 33 cetacean and nine pinniped species are consumed by humans worldwide (Table I).

Brucella ceti

Brucellae have been demonstrated in isolates or in polymerase chain reaction assays in cetaceans belonging to the families Phocoenidae (porpoises), Delphinidae (dolphins), Monodontidae (narwhals, belugas), Balaenidae

(right whales, bowhead whales) and Balaenopteridae (rorquals). In total, 11 species have been confirmed as infected with brucellae, including the harbour porpoise (24, 28, 51, 77, 78, 79, 87, 88), Atlantic bottlenose dolphin (29, 32, 63), common dolphin (34, 77, 87, 88), striped dolphin (*Stenella coeruleoalba*) (26, 34, 42, 43, 47, 65, 77), Atlantic white-sided dolphin (*Lagenorhynchus acutus*) (25, 77), white-beaked dolphin (*Lagenorhynchus albirostris*) (77), killer whale (*Orcinus orca*) (81) and Hector's dolphin (*Cephalorhynchus hectori maui*) (17). *Brucella* DNA has been detected in the narwhal (*Monodon monoceros*) (82), Southern right whale (*Eubalaena australis*) (18) and minke whale (*Balaenoptera acutorostrata*), from which the bacteria were also cultured (20, 96).

Most of these isolates of brucellae were obtained from cetaceans that were naturally stranded on the Atlantic Ocean shores of the Americas and Europe, and also on shores of the south-western and eastern sides of the Pacific Ocean. The isolates in Europe were obtained from animals on coasts of the North Atlantic and North Sea in Scotland, Spain, England and Wales. In the Americas, isolates have been obtained from animals in the Atlantic Ocean on the



I: *Brucella* isolated in at least one animal of a specific species
 P: pathologies associated with *Brucella* spp.
 A: DNA of *Brucella* spp.
 o: one individual studied

‡ 102: number of sera from harbour porpoise (*Phocoena phocoena*) in coastal areas of Scotland (this number is given to enable readers to estimate the number of sera in each sector of each circular graph)

Fig. 1
Distribution of cetaceans seropositive for *Brucella* infection
 References to each species as in Table I

southern coasts of New England and in the Gulf of Mexico along the USA coastline. *Brucella ceti* has also been isolated from animals in the Eastern Tropical Pacific along the coastline of Costa Rica and from New Zealand in the south-western Pacific Ocean (Fig. 1). Cetacean isolates have been found in captive animals in the USA and Europe (45, 63).

Pathology associated with *Brucella* infection in cetaceans

Brucella ceti has been isolated from the central nervous system of cetaceans presenting macroscopically with hyperaemia of the meninges and brain; microscopically, the same animals also had severe nonsuppurative meningoencephalomyelitis. There are also descriptions of secondary hydrocephalus resulting from infiltration of mononuclear cells (especially lymphocytes, plasma cells, macrophages), and moderate to severe fibrosis in the meninges and surrounding the ventricular system (23, 42, 43, 47, 88).

In the cetacean respiratory system, brucellae have been cultured from clinically normal lungs (35), whereas some dolphins with neurobrucellosis had interstitial pneumonia, bronchopneumonia, microcalcifications, hyperaemia and leukocyte aggregates in the peribronchial connective tissue (43, 45). The formation of brucellae-associated lung abscesses has also been reported in dolphins (15). Furthermore, a relationship between lung inflammation and the presence of nematodes (from which brucellae have been isolated) has been established (28, 51, 78).

Brucellae have also been recovered from the reticuloendothelial system, specifically from samples of mandibular, pulmonary, mesenteric and gastric lymph nodes, as well as from the spleen and liver (34, 87, 88). Pathologies have included hepato- and splenomegaly, enlarged lymph nodes, and necrotic foci and inflammation in the liver, spleen and lymph nodes (43).

In the cardiovascular system, brucellae have been cultured from blood and pericardial fluid and, using immunohistochemical methods, *B. ceti* has been demonstrated in a vegetative nodule in the mitral valve of an animal with neurobrucellosis (43, 45). This cardiac lesion has also been described in humans infected with other species of *Brucella* (7, 16). There are descriptions of abscesses and steatitis of the cetacean integument caused by *Brucella*, in and beneath the blubber (subcutaneous fat layer), mainly near the dorsal fin (29, 35, 82), and in some animals there have been skin ulcerations (51).

In the musculoskeletal system, *B. ceti* has been isolated from discospondylitis (25, 35, 37, 43) and fibrinopurulent

osteoarthritis of the shoulder joint in an animal with neurobrucellosis (43). The bacterium has also been isolated from the atlanto-occipital joint (25), spine and vertebrae (58). In the urinary system, brucellae have been cultured from cetaceans with congested kidneys (25). As in terrestrial animals, brucellae have been isolated from the female reproductive system, mammary glands, milk and placenta, causing placentitis, necrotising endometrial granulomas, endometritis and abortion (32, 35, 43, 47, 51, 63, 75, 81). The bacteria have been demonstrated by direct fluorescence in milk, umbilical cord, amniotic and allantoic fluids and in multiple fetal organs that had no associated pathology (47). In males, brucellae cause epididymitis and orchitis with granulomas, mineralisation, and abscesses with caseous necrosis (24, 74, 75).

Brucella pinnipedialis

Brucellae have been isolated from true seals (phocids) and otariids. The isolations from phocids have been made in six species of seal: the hooded seal (*Cystophora cristata*) (34, 35, 77, 96), ringed seal (*Pusa hispida*) (33), harp seal (*Pagophilus groenlandicus*) (33, 60), grey seal (*Halichoerus grypus*) (33, 79), Pacific harbour seal (*Phoca vitulina richardii*) (38) and common seal (*Phoca vitulina*) (60, 79, 88, 102). The bacterium has also been isolated from a California sea lion (*Zalophus californianus*) (41). Isolates have been obtained from animals in the North Atlantic Ocean (Northern Ireland, New England, Canada), North Sea (Scotland, Germany) and the Pacific Ocean (California, USA) (Fig. 2).

Pathology associated with *Brucella* infection in pinnipeds

Unlike cetaceans, in which the largest numbers of isolates were obtained from sick or stranded animals, most isolates from pinnipeds have been recovered from clinically healthy animals or animals hunted in the wild, with no reported *Brucella*-associated pathology (70). The bacteria were isolated mainly from seals, from the respiratory system (lungs or lung parasites) related to bronchopneumonia (79) and from the reticuloendothelial system in lymph nodes, spleen and liver. Brucellae have also been isolated from the digestive tract, kidneys and testes, and from placenta associated with abortion in otariids (41, 70).

Treatment of brucellosis in marine mammals

Classic antibiotic treatments for brucellosis have occasionally been attempted in captive dolphins (15), but

Table 1
Seroprevalence of brucellosis in marine mammals and human consumption between 1970 and 2009
 Adapted from Robards and Reeves, 2011 (85)

Common name (Species) (IUCN status)	Estimated population	Seroprevalence Pos./total	Human consumption	Reference (serology)	Common name (Species) (IUCN status)	Estimated population	Seroprevalence Pos./total	Human consumption	Reference (serology)
Southern right whale (<i>Eubalaena australis</i>) (LC)	8,000	1/31	Yes (1970–1989)	(18)	Pygmy killer whale (<i>Feresa attenuata</i>) (DD)	39,000 ^(a)	1/3	Yes	(48)
Fin whale (<i>Balaenoptera physalus</i>) (End.)	140,000	12/108	Yes	(96)	Rough-toothed dolphin (<i>Steno bredanensis</i>) (DD)	150,000	12/23	Yes	(48)
Sei whale (<i>B. borealis</i>) (End.)	80,000	7/49	Yes	(96)	Dusky dolphin (<i>Lagenorhynchus obscurus</i>) (DD)	Unknown	21/27	Yes	(98)
Bryde whale (<i>B. brydei</i>) (DD)	40,000	4/43	Yes	(74)	White-beaked dolphin (<i>L. albirostris</i>) (LC)	100,000	2/10	Yes	(77)
Mink whale (<i>B. acutorostrata</i>) (NT)	180,000	32/256	Yes	(75, 96)	Atlantic white-side dolphin (<i>L. acutus</i>) (LC)	150,000	4/12	Yes	(77)
Grey whale (<i>Eschrichtius robustus</i>) (CE)	20,000 ^(b)	1/1	Yes	(81)	Risso's dolphin (<i>Grampus griseus</i>) (DD)	330,000	8/11	Yes	(48)
Sperm whale (<i>Physeter macrocephalus</i>) (V)	360,000	1/9	Yes	(77)	Bottlenose dolphin (<i>Tursiops truncatus</i>) (DD)	>600,000	60/349	Yes	(5, 29, 48, 54, 63, 77, 98)
Pygmy sperm whale (<i>Kogia breviceps</i>) (LC)	Unknown	6/22	Yes	(48, 73)	Pacific bottlenose dolphin (<i>T. aduncus</i>) (DD)	Unknown	17/74	Yes	(92)
Narwhal (<i>Monodon monoceros</i>) (DD)	50,000	5/77	Yes	(69)	Black Sea bottlenose dolphin (<i>T. truncatus ponticus</i>) (DD)	Unknown	40/133	Yes	(4, 5)
Beluga whale (<i>Delphinapterus leucas</i>) (CE, V)	150,000	38/635	Yes	(4, 69)	Pantropical spotted dolphin (<i>Stenella attenuata</i>) (CD)	>2,000,000	1/6	Yes	(45)
Cuvier's beaked whale (<i>Ziphius cavirostris</i>) (DD)	110,000	1/2	Yes	(45)	Spinner dolphin (<i>S. longirostris</i>) (CD)	800,000	7/7	Yes	(45, 48)
Sowerby's beaked whale (<i>Mesoplodon bidens</i>) (DD)	Unknown	1/3	No	(77)	Striped dolphin (<i>S. coerulealba</i>)	>1,000,000 ^(a)	46/64	Yes	(26, 42, 43, 47, 48, 54, 65, 98)
Killer whale (<i>Orcinus orca</i>) (CD)	90,000	8/9	Yes	(54, 77, 81)	Common dolphin (<i>Delphinus delphis</i>) (LC)	>3,500,000	14/39	Yes	(54, 77, 81, 87, 88)
Long-finned pilot whale (<i>Globicephala melas</i>) (LC)	990,000	3/25	Yes	(45, 54, 77)	Long-beaked common dolphin (<i>D. capensis</i>) (LC)	>60,000	3/6	Yes	(98)

Table 1
Seroprevalence of brucellosis in marine mammals and human consumption between 1970 and 2009 (cont.)

Common name (Species) (IUCN status)	Estimated population	Seroprevalence Pos./total	Human consumption	Reference (serology)	Common name (Species) (IUCN status)	Estimated population	Seroprevalence Pos./total	Human consumption	Reference (serology)
Fraser's dolphin (<i>Lagenodelphis hosei</i>) (DD)	280,000 ^(a)	5/24	Yes	(48)	Pacific harbour seal (<i>P. vitulina richardii</i>) (LC)	Unknown	47/101	Yes	(38, 105)
Northern right whale dolphin (<i>Lissodelphis borealis</i>) (LC)	>80,000	1/1	Yes	(81)	Ringed seal (<i>Pusa hispida</i>) (LC)	>2,500,000	22/925	Yes	(68, 69, 96)
Maui's dolphin (<i>Cephalorhynchus hectori mauii</i>) (CE)	<100	1/3	No	(17)	Harp seal (<i>Pagophilus groenlandicus</i>) (LC)	>6,000,000	28/1319	Yes	(60, 69, 77, 96)
Hector's dolphin (<i>C. hectori</i>) (End.)	7,300	1/1	No	(17)	Grey seal (<i>Halichoerus grypus</i>) (LC)	380,000	50/473	Yes	(54, 69, 77, 81, 87, 88)
Dall's porpoises (<i>Phocoenoides dallii</i>) (CD)	>1,200,000	2/6	Yes	(81)	Hawaiian monk seal (<i>Monachus schauinslandii</i>) (End.)	1,400	28/144	No	(67)
Harbour porpoise (<i>Phocoena phocoena</i>) (V)	>675,000	200/808	Yes	(28, 54, 66, 77, 81, 87, 88)	Hooded seal (<i>Cystophora cristata</i>) (LC)	>350,000	68/372	Yes	(69, 77, 95, 96)
Burmeister's porpoise (<i>P. spinipinnis</i>) (DD)	Unknown	5/25	Yes	(98)	Leopard seal (<i>Hydrurga leptonyx</i>) (LC)	>220,000	1/3	No	(30)
Steller sea lion (<i>Eumetopias jubatus</i>) (End.)	100,000	1/197	Yes	(14)	Weddell seal (<i>Leptonychotes weddellii</i>) (LC)	>500,000	6/13	No	(2, 9, 83)
Australian sea lion (<i>Neophoca cinerea</i>) (LC)	12,500	9/12	No	(27)	Alaskan sea otter (<i>Enhydra lutris kenyoni</i>) (End.)	73,000	6/102	No	(77)
Antarctic fur seal (<i>Arctocapaliaus gazella</i>) (LC)	>3,000,000	14/167	No	(1, 8, 83)	Southern sea otter (<i>E. lutris nereis</i>) (End.)	>3,000	4/68	No	(46)
Australian fur seal (<i>A. pusillus doriferus</i>) (LC)	60,000	207/498	Yes	(27, 55)	European otter (<i>Lutra lutra</i>) (End.)	>10,000	8/74	No	(77)
Atlantic walrus (<i>Odobenus rosmarus rosmarus</i>) (LC)	200,000	12/229	Yes	(68, 69)	Polar bear (<i>Ursus maritimus</i>) (V)	>22,000	69/1,072	Yes	(72, 80, 94)
Harbour seal (<i>Phoca vitulina</i>) (LC)	>300,000	423/1,937	Yes	(38, 53, 58, 68, 76, 86, 87)					

a) estimates for the Eastern Tropical Pacific only
 b) estimates for the Northern Pacific only
 CD: conservation dependent
 CE: critically endangered
 DD: data deficient
 End.: endangered
 ETP: Eastern Tropical Pacific
 LC: least concern
 NT: near threatened
 Pos: positive
 V: vulnerable

IUCN: International Union for Conservation of Nature
 LC: least concern
 NT: near threatened
 Pos: positive
 V: vulnerable

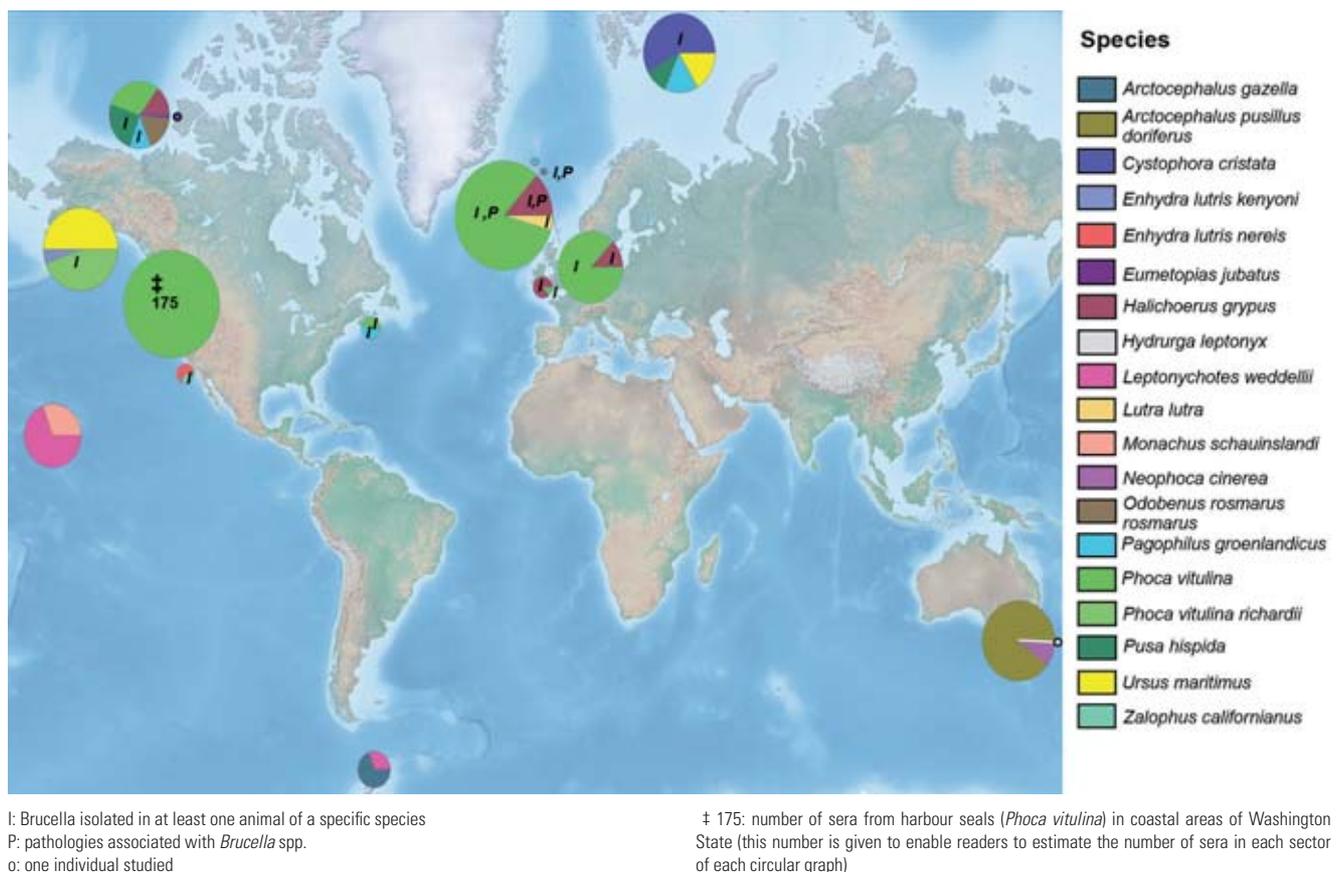


Fig. 2
Distribution of pinniped, otter and polar bear seropositive for *Brucella* infection
 References for each species as in Table I

no successful treatment has been documented in marine mammals. Thus, because of the long-term intracellular survival of brucellae and the risk that infected animals represent to other animals and to humans, euthanasia should be considered in specific cases, especially in those with clinical complications. Isolation of the bacterium should be attempted in seropositive animals, in addition to regular tests for changes in antibody titres or appearance of symptoms.

Transmission of brucellosis in marine mammals

Sea water characteristics such as gradients of temperature, salinity, density, oxygen and nutrients, combined with sea water's capacity for absorption of light and heat, create complex physical, chemical and biological oceanographic dynamics (93). Members of the genus *Brucella* are non-motile and do not survive long in adverse conditions (64), therefore the survival of marine strains outside their hosts may be affected by oceanographic characteristics. Dilution

of the bacteria below the infective dose could also hinder transmission (45).

The mode of transmission of brucellosis in marine mammals is not yet established, but it has been suggested that, in cetaceans, the infection could spread horizontally between individuals through sexual contact or by contact with aborted fetuses or placental tissues (45, 47). In addition, infection may be transmitted vertically from the mother to the fetus or neonate (41, 43, 45, 47, 58, 63, 70). In pinnipeds, the mode of transmission is even less understood, but the close contact of these animals living in groups along coastlines may favour transmission of infection following the manner of transmission in terrestrial mammals (64, 70).

Lungworms have been proposed as possible vectors of brucellosis in marine environments. In cetaceans, brucellae have been identified in the uterus of a lung nematode (*Pseudalius inflexus*) in the airway of a stranded harbour porpoise. The life cycle of this parasite is unknown (28, 78). In pinnipeds, *Brucella* spp. have been demonstrated in the uterus and intestinal lumen of female *Parafilaroides* lungworms (38). In the life cycle of this parasite, the larvae migrate up the respiratory tree

of a sea lion, following which they are swallowed and pass into the environment through the faeces. The green fish (*Girella nigricans*) and other intermediary coprophagic fish eat the contaminated faeces, and when the fish are subsequently eaten by sea lions the larvae are released into the gastrointestinal tract of the pinniped. After the larvae mature, they migrate to the lungs to continue the cycle (49). The isolation of brucellae from the faeces of seals suggests another possibility of transmission, via coprophagic fish to pinnipeds (84).

Brucella and fish

Study of the serological and bacteriological responses in Nile catfish (*Clarias gariepinus*) after experimental subcutaneous infection with *B. melitensis* (biovar 3) demonstrated the development of antibodies seven days post inoculation, with maintenance of positive titres for five weeks (89). The bacterium was subsequently isolated from various organs and the authors concluded that fish are susceptible to brucellosis.

Brucella melitensis (biovar 3) has been isolated from internal organs and skin swabs of seropositive Nile catfish (*C. gariepinus*) naturally infected in the delta region of the Nile in Egypt (31). Animal waste is commonly deposited in water channels of the region, and the river may have been contaminated with brucellae. It is not known what role the fish may have in transmission or as reservoirs of infection in aquatic environments. However, marine brucellae have been identified in cases of brucellosis in humans who frequently consume raw seafood (56, 91).

Marine *Brucella* infecting humans

Despite the global distribution in terrestrial mammals of this zoonotic disease, fewer than 10% of human cases of brucellosis are clinically recognised, treated and reported (57). These infections are usually associated with consumption of unpasteurised dairy products contaminated with brucellae. Brucellosis is also considered an occupational disease for laboratory, veterinary and farm personnel, as well as meat industry workers and hunters, who inhale the organism or become infected by contact with fetal tissues or contaminated fluids (57). Relapses of the infection are well documented in patients, even with adequate protocols for the treatment of brucellosis (57, 76).

Occupational exposure was responsible for the first reported case of human marine brucellosis in a laboratory worker in 1999 (11). The patient had mild symptoms,

including headaches, fatigue and severe sinusitis, and showed seroconversion. The bacterium was isolated from a blood culture and identified as a marine strain. Three other cases of marine brucellosis in humans have been tentatively reported as naturally acquired: two from Peru and one from New Zealand (56, 91). The two Peruvian cases were described in 1985 and 2001 but the strains were not clearly characterised; both cases showed severe symptoms with intracerebral neurobrucellosis and granulomas. These patients regularly consumed fresh cheese, unpasteurised milk (cow, goat) and raw seafood, and swam in the Pacific Ocean, but none reported direct contact with marine mammals. The two Peruvian isolates were preliminarily classified as *B. melitensis*; however, conventional molecular tests later excluded *B. melitensis*, *B. suis* and *B. abortus* biovar 1, and confirmed the isolates to be of marine origin by amplification of gene *bp26* (91).

The New Zealand patient presented with spinal osteomyelitis and did not report exposure to marine mammals. This individual fished regularly and had contact with raw fish and bait fish, and frequently consumed raw snapper. The isolate was initially reported as *B. suis* but, because the profile was not a perfect match, it was sent to four reference laboratories where it was identified as *B. suis* or *B. melitensis* (56). Further studies reported all three human isolates to have genotypic characteristics that most closely matched *B. pinnipedialis*. However, later studies found that the New Zealand isolate had a unique genotype corresponding to a strain of marine *Brucella* but different from isolates obtained from pinnipeds and cetaceans (104, 106). Whether this strain really belongs to a parasite of a marine mammal remains undetermined.

Two more human cases with a presumptive diagnosis of marine brucellosis have been reported in Peru (97). The first patient was a researcher who performed hundreds of necropsies on fresh dead cetaceans during the period that the clinical symptoms developed. The other case was of a woman who distributed whale meat in Pucusana market. The symptoms consisted of loss of consciousness, severe myalgia, back pain, intermittent fever, profuse night sweats, headaches, chronic fatigue, anorexia and weight loss. Despite several tests, no definitive diagnoses were made.

There are at least three patterns of intracellular behaviour of marine brucellae in human macrophages (THP-1 cell line) (59). The bacterium isolated from the human case in New Zealand, and two other groups of strains of *B. ceti* and *B. pinnipedialis*, were all able to infect THP-1 cells with the same virulence as *B. melitensis* 16 M and *B. suis* 1330, both reported to be virulent human strains. Other strains of *B. ceti* and *B. pinnipedialis* were able to invade THP-1 cells – much like the classic *Brucella* strains – but were eliminated after 48 hours. A third pattern of infection was demonstrated in an isolate from hooded seals that was unable to enter

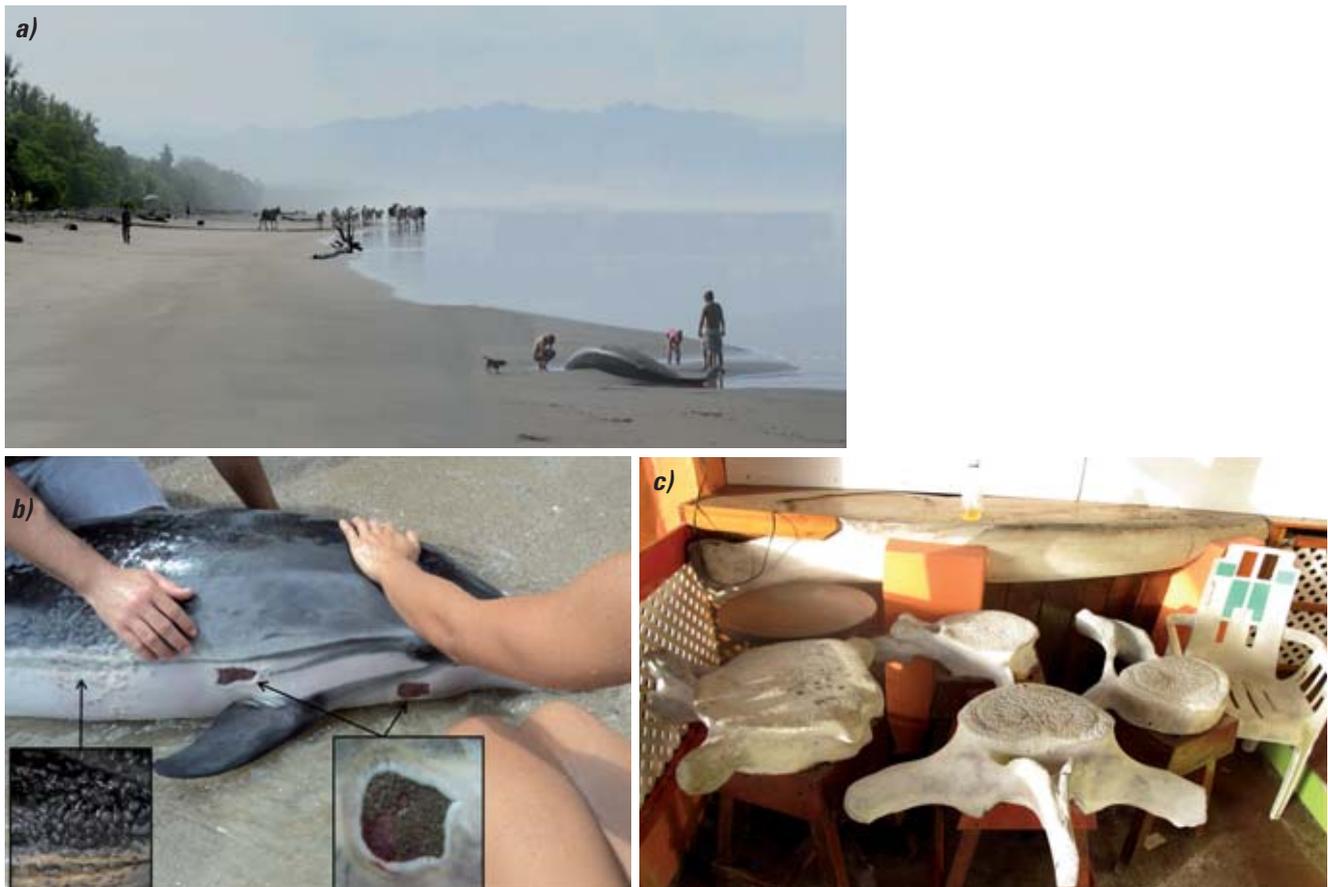


Fig. 3

The impact of stranded marine mammals in coastal areas

a) Stranded pregnant Cuvier's beaked whale (*Ziphius cavirostris*) with positive *Brucella* serology in Playa Matapalo, Costa Rica (11 April 2009). Humans, dogs and domestic animals such as cattle (in the background) use the beach to move between farms

b) Living striped dolphin (*Stenella coeruleoalba*) with neurobrucellosis, also showing lesions of unknown cause, handled by inhabitants of Playa Guiones, Costa Rica (24 August 2011)

c) Vertebrae and jaw used as seats and table in a restaurant in Bequia Island in St Vincent and the Grenadines. Photo by Cristina Sánchez of the Keto Foundation (28 July 2011)

or infect THP-1 cells. These results suggest variation in virulence of *Brucella* strains from marine mammals; thus, infected marine animals may display differences in severity of disease.

Marine *Brucella* in other animals

Cattle experimentally infected with a *Brucella* sp. isolated from a harbour porpoise demonstrated seroconversion and abortion under experimental conditions (85). In another study, *B. ceti* was less virulent than ruminant brucellae in cows and rodents (78). Seals are an important part of the diet of polar bears (61), the latter showing *Brucella* seroprevalence between 5% and 10% in the Arctic (72, 80, 94). Seroprevalences of 3% to 8% in the Alaskan sea otter (*Enhydra lutris kenyoni*) and 6% in the southern sea otter (*E. lutris nereis*) have been reported (46).

Discussion

After almost two decades of investigation, strains of *Brucella* from marine mammals are now recognised as being globally distributed. People from numerous countries have frequent contact with marine mammals and, in at least 114 countries, consumption of meat and other products from one or more of 87 species of marine mammal is relatively common (86). Despite this, there is no systematic surveillance of marine brucellosis and the possible resulting infections in humans and domestic animals. In several countries, there is no system of veterinary inspection of marine mammal meat or organs and, in some cases, whaling station personnel have sole responsibility for determining the quality of material intended for consumption. Furthermore, freshly killed marine mammals are frequently handled without hygienic precautions (3, 6, 19, 40, 71, 97, 99). Both *B. ceti* and *B. pinnipedialis* are smooth-type brucellae equipped with

all known virulence factors and, as with their terrestrial counterparts, have their preferred hosts but are able to infect other species (45).

Brucellosis in free-living or stranded marine animals is not routinely recorded. Nevertheless, early recognition of seropositive animals could be achieved using simple screening tests, such as the Rose Bengal agglutination test, under field conditions (47, 48). Worldwide, there are therapeutic programmes involving captive cetaceans in contact with children and adults, but there are no regulations preventing contact between infected or seropositive animals with either immunocompetent or with naturally or medically immunosuppressed humans (e.g. pregnant women, patients receiving corticosteroid therapy or other drug therapies for hydrocephalus, post-operative brain tumours, tetra- and hemiplegia, autism or spina bifida) (3). Marine facility staff, researchers, wildlife officers, government agencies and the public who are in direct contact with potentially infected species should be made fully aware of the potential risks and the need for primary protection to avoid exposure to brucellae, especially if aerosol-generating procedures are in operation.

The potential impact of marine brucellae in coastal areas where stranded cetaceans may come into contact with domestic animals, scavenging animals or humans should be investigated. In some coastal regions, the skulls, vertebrae and other skeletal parts from dead cetaceans, which may serve as fomites for transmission, are commonly collected as souvenirs without knowledge of the cause of stranding (Fig. 3). Marine mammals infected with brucellae are more likely to have reproductive problems. In populations that are specially endangered, specific conservation policies should therefore consider the infection rates, lower birth rates and described pathologies of this disease that are known to impact reproductive and population success. Marine mammals that are wild-caught and maintained in captive facilities may be susceptible to infection resulting from immunosuppression associated with the stress of captivity or unnatural close contact with other marine mammal species (3). It is therefore important to develop comprehensive studies to determine the prevalence of brucellosis in captive marine mammals and to establish global standards

to protect both human and animal health. Moreover, marine mammals are generally at the top trophic level of a complex food chain and are known to bioaccumulate pollutants, which have a possible immunosuppressive role and increase predisposition to infection with emerging diseases (90, 101). Research and worldwide monitoring of marine brucellosis and other zoonotic infections in marine mammals are still necessary for a better understanding of diseases and mortalities affecting the recovery of their populations.

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Réservoirs sauvages de la brucellose : *Brucella* dans les environnements aquatiques

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Résumé

Chez l'homme comme chez les cétacés, l'infection à *Brucella ceti* et à *B. pinnipedialis* se manifeste principalement par des pathologies telles que la neurobrucellose et l'ostéomyélite. À ce jour, la présence d'anticorps antibrucelliques a été recensée chez 53 espèces de mammifères marins. *Brucella ceti* ou *B. pinnipedialis* ont été isolées ou détectées par amplification en chaîne par polymérase chez 18 de ces espèces. La bactérie a également été isolée de poissons et de vers présents dans les poumons de pinnipèdes et de cétacés. Malgré ces observations, aucune mesure n'est imposée au niveau local ou mondial pour assurer le suivi de la brucellose chez les mammifères marins qui sont manipulés en vue de leur capture, de leur sauvetage ou de leur réhabilitation ou à des fins de recherche, d'abattage ou de consommation humaine. La brucellose étant une zoonose potentiellement transmissible à d'autres espèces animales, il est indispensable que le risque d'infection à *Brucella* chez les mammifères marins fasse l'objet de normes internationales.

Mots-clés

Brucella ceti – *Brucella pinnipedialis* – Brucellose marine – Mammifère marin – Surveillance – Zoonose.



Reservorios de la brucelosis en la fauna salvaje: *Brucella* en medios acuáticos

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Resumen

La neurobrucelosis y la osteomielitis son patologías comunes en personas y cetáceos infectados por *Brucella ceti* o *B. pinnipedialis*. En la actualidad se conocen 53 especies de mamíferos marinos que muestran seropositividad ante las brucelas, y en 18 de esas especies se han aislado organismos *B. ceti* o *B. pinnipedialis* o se ha detectado su presencia por reacción en cadena de la polimerasa (PCR). También se han aislado brucelas en peces y se ha observado su presencia en vermes que parasitan los pulmones de pinnípedos y cetáceos. Pese a todo ello, ni a escala local ni a escala mundial existen requisitos de control de la brucelosis en los mamíferos marinos manipulados con fines de captura, tratamiento, rehabilitación, investigación, sacrificio o consumo. Dado que la brucelosis es una infección zoonótica y puede contagiarse a otros animales, se precisan normas internacionales referentes a la posible brucelosis en mamíferos marinos.

Palabras clave

Brucella ceti – *Brucella pinnipedialis* – Brucelosis marina – Mamífero marino – Vigilancia – Zoonosis.



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