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Salmonella infections in Antarctic fauna and island populations of wildlife exposed to human activities in coastal areas of Australia

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SUMMARY

Salmonella infections in Antarctic wildlife were first reported in 1970 and in a search for evidence linking isolations with exposure to human activities, a comparison was made of serovars reported from marine fauna in the Antarctic region from 1982–2004 with those from marine mammals in the Northern hemisphere. This revealed that 10 (83 %) *Salmonella enterica* serovars isolated from Antarctic penguins and seals were classifiable in high-frequency (HF) quotients for serovars prevalent in humans and domesticated animals. In Australia, 16 (90 %) HF serovars were isolated from marine birds and mammals compared with 12 (86 %) HF serovars reported from marine mammals in the Northern hemisphere. In Western Australia, HF serovars from marine species were also recorded in humans, livestock, mussels, effluents and island populations of wildlife in urban coastal areas. Low-frequency *S. enterica* serovars were rarely detected in humans and not detected in seagulls or marine species. The isolation of *S.* Enteritidis phage type 4 (PT4), PT8 and PT23 strains from Adélie penguins and a diversity of HF serovars reported from marine fauna in the Antarctic region and coastal areas of Australia, signal the possibility of transient serovars and endemic *Salmonella* strains recycling back to humans from southern latitudes in marine foodstuffs and feed ingredients.

Key words: Antarctica, epizootics, salmonellosis, wildlife, zoonoses.

INTRODUCTION

During the past century, sealing and whaling activities in the Southern Ocean, the use of dogs on expeditions to Antarctica, and introduction of rodents, rabbits, reindeer and domesticated animals to sub-Antarctic islands [1] have created man-made opportunities for the spread of exotic pathogens from the Northern hemisphere to marine fauna in previously isolated natural regions. Bay whalers from Europe and North America were active in southern coastal areas of Western Australia prior to settlement by the British in 1826, and this relatively recent translocation of humans and domesticated food animals to temperate

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coastal areas of the state provides an opportunity to gauge the impact of human activities on the indigenous fauna.

In recent decades the impact from sealing and whaling, has been replaced by the establishment of some 43 Antarctic bases operated by 18 countries, shore visits from cruise ships by tourists [2, 3], the harvesting and processing of Antarctic krill [4] (*Euphausia superba*), exposure to sewage effluent [5], food wastes and exotic pathogens [6] with the capacity to cause epizootics in wild birds [7]. The risk of acquiring enteric infections from humans is greatest during the Austral summer when peak activities coincide with the group behaviour of marine species such as penguins and seals in coastal habitats and feeding areas. The need for studies designed to establish whether *Salmonella enterica* forms part of the normal microbial flora of colonies of penguins and seals located close to permanent bases is thus manifest [8].

Salmonella infections in Antarctic wildlife were first reported in 1970 [9], and serovars *S*. Blockley, *S*. Infantis, *S*. Johannesburg and *S*. Panama were isolated from Adélie penguins (*Pygoscelis adélie*) and *S*. Blockley and *S*. Typhimurium from south polar skuas (*Catharacta maccormicki*) at Cape Crozier on Ross Island. In studies in sub-Antarctica [10], *S*. Enteritidis phage type 4 (PT4), PT35, and PT4-like, *S*. Havana, *S*. Newport and *S*. Typhimurium were variously isolated from gentoo penguins (*Pygoscelis papua*), fur seal pups (*Arctocephalus gazella*) and a black-browed albatross (*Thalassarche melanophrys*). In studies on the sub-Antarctic Auckland islands [11], *S*. Cerro, *S*. Derby, *S*. Enteritidis PT4, PT8, and *S*. Newport were isolated from New Zealand sea lions (*Phocarctos hookeri*). *S*. Cerro and *S*. Newport were also isolated from feral pigs quarantined after removal from the islands [12].

In a comparison of *S*. *enterica* and *Edwardsiella tarda* isolates over a 30-year period from human effluents and indigenous fauna in tropical and temperate latitudes of Western Australia [13], we proposed that serovars predominant in the epidemiology of salmonellosis in urban areas are strains mostly of European origin [14] and have spilled over to the indigenous fauna on coastal islands causing public health problems [15]. Serovars classed as exotic were not isolated from indigenous species in pristine areas of the state [16]. Comparison of *S*. *enterica* and *E*. *tarda* infections in terrestrial and marine fauna in Australia with isolates from marine fauna in Antarctica and sub-Antarctica, provides an adjunct to more definitive biogeographical studies and assessments of the epidemiological significance of zoonotic infections translocated from the Northern hemisphere to geographically isolated natural regions.

The diversity of *S*. *enterica* serovars and phage types reported from Antarctic fauna conflicts with the principle of reduced natural biodiversity in polar and sub-polar latitudes, and with the exception of *S*. Antarctica [17], a new serovar isolated from an emperor penguin (*Aptenodytes forsteri*), and *S*. Johannesburg isolated from Adélie penguins on Ross Island, it was observed that *Salmonella* serovars reported from Antarctic fauna are listed in high-frequency (HF) quotients computed by Kelterborn [18], for serovars prevalent in humans and domesticated animals. We have used regional comparisons of *Salmonella* frequencies previously in defining naturally occurring reservoirs of infection in remote tropical areas of Australia [13], and the isolation of serovars classed in HF quotients from marine fauna in the Antarctic region, prompted this review of isolates and comparison of serovar frequencies with those recorded from humans, effluents and island population of wildlife in southern coastal areas of Australia.

The aims of this study were (1) to document the occurrence of *Salmonella enterica* infections in wildlife living in Antarctica and sub-Antarctic islands and to classify them as naturally occurring, or acquired as a consequence of exposure to humans and exotic animals; (2) to compare and contrast these data with samples taken from marine and terrestrial fauna occupying islands off the West Australian coast where both naturally occurring and exotic *Salmonella* infections are known to occur [14].

METHODS

Collection of samples in Antarctica

Samples were collected by a number of workers over a period of 4 years from 1982 to 1986 involving two expeditions to Cape Denison in eastern Antarctica and six expeditions to four sub-Antarctic islands and regular trips to coastal islands in Western Australia. For logistic reasons it was not always possible to use the same sample preservation methods and the use of single and pooled swab samples collected in different transport media was adopted in expectation of low rates of *Salmonella* infection and for detection of *E*. *tarda* in a separate study [19]. Single swabs and pools of up to four cloacal samples collected from different penguins at Cape Denison in eastern Antarctica and on four sub-Antarctic islands were transported without freezing in combinations of Robertson's cooked meat medium (RCM) and strontium chloride B (SCB) [20]. A total of 502 adult Adélie penguins were sampled over consecutive breeding seasons at Cape Denison (67° 0′ S, 142°40′ E) near the site of Mawson's Hut. Faecal samples and occasionally swabs from sleeping animals were also collected from 19 Weddell seals (*Leptonychetes weddelli*) and duplicate swabs were preserved in both RCM and SCB. A total of 718 samples from five other species of penguins (royal penguins, *Eudyptes schlegeli*, gentoo penguins *Pygoscelis papua*, king penguins *Aptenodytes patagonicus*, macaroni penguins *Eudyptes chrysolphus* and rockhopper penguins *Eudyptes chrysocome*), were collected in sub-Antarctica at locations on Macquarie Island (54° 37′ 53″ S, 158° 52′ 15″ E), Heard Island (73° 30′ E, 53° 05′ S), Kerguelen Island (49° 20′ S, 70° 20′ E) and Îles Crozet (45° 95′ to 46° 50′ S, 50° 33′ to 52° 58′ E). Faecal samples were also collected from elephant seals (*Mirounga leonina*) and mud wallow samples near Port-aux-Français on Kerguelen Island (49° 21′ S, 70° 13′ E). Samples from penguins were also collected at Pointe Molloy, Cape Cotter and Cape Ratmanoff (49° 13′ 58″ S, 70° 33′ 4″ E) The majority of samples collected in Antarctica were examined 1–2 months after collection.

Collection of samples from birds and marine life in coastal areas of Western Australia

In southern coastal areas of Western Australia, a total of 2550 single cloacal swabs were collected in SCB broth from eight species of marine birds at island breeding colonies bordering on the Southern and Indian Oceans. The sampling locations comprised the disturbed Carnac Island (32° 7′ 22″ S, 115° 39′ 49″ E), Rottnest Island (32° 0.5′ S, 115° 30.1′ E) and Penguin Island (32° 18′ 21″ S, 115° 41′ 27″ E) and Boullanger Island (30° 18′ 59″ S, 115° 00′ 20″ E) habitats close to urban coastal areas and the less disturbed, Sandy Island, Bald Island (34° 55′ 07″ S, 118° 27′ 44″ E), Abrolhos Island (28° 28′ 03″ S, 113° 13′ 12″ E) and Barrow Island (20° 47′ 57″ S, 115° 24′ 18″ E). The combined total of 947 cloacal swabs and 1537 droppings from silver gulls (*Larus novaehollandiae*) were collected from birds at mainland forage sites in Perth and Fremantle, and nearby breeding colonies of Carnac, Rottnest and Penguin islands. Gull droppings included samples from birds feeding on offal at a remote whaling station (closed since this study) during the flensing of sperm whales (*Phyceter macrocephalus*) captured in the Southern Ocean. Samples of mussels (*Mytilus edulis*) exposed to coastal effluents were examined prior to closing of abattoir facilities and resiting of sewage outfalls. Species of marine birds comprised little penguins (*Eudyptes minor-novaehollandiae*), flesh-footed shearwaters (*Puffinis carneipes*), wedge-tailed shearwaters (*Puffinis pacificus*), crested terns (*Sterna bergeii*), sooty terns (*Sterna fuscata*), bridled terns (*Sterna anaethetus*), white-faced storm petrels (*Pelagodroma marina*), lesser noddys (*Anous tenuirostris*) and common noddys (*Anous stolidus*). Marine mammals comprised Australian sea lions (*Neophoca cinerea*), false killer whales (*Phoecaena crassidens*) and bottlenose dolphins (*Tursiops truncatus.*) Sea snakes (*Hydrophis major*) were collected in nets during prawning operations in the Indian Ocean and cloacal samples were collected from them in the laboratory. Samples from marine mammals comprised fresh droppings from Australian sea lions, rectal swabs and intestinal content from stranded false killer whales and rectal samples from bottlenose dolphins. Samples from stranded marine mammals were transported in SCB and RCM to the laboratory.

Collection of samples from terrestrial fauna of islands in Western Australia

Samples collected in Western Australia from island populations of terrestrial fauna close to urban coastal areas comprised king skinks (*Egernia kingii*) and tiger snakes (*Notechis scutatus*) on Carnac Island, king skinks on Penguin Island, king skinks, bobtail lizards (*Tiliqua rugosa*), dugite snakes (*Pseudonaja affinis*) and marsupial quokkas (S*etonix brachyurus*) on Rottnest Island and skinks (*Egernia multiscutata, Egernia pulchra, Ctenotus fallens*), the marsupial dunnart (*Sminthopsis griseoventor*) and dibbler (*Parantechinus apicalis*) on Boullanger Island close to the Jurien Bay townsite. Samples from reptiles and marsupials were also collected on the less disturbed Wallabi Islands in the Abrolhos group and Barrow Island.

Collection of fishmeal samples

Commencing in 1985 and continuing sporadically until 1991, samples of imported fishmeal from producers in South America and the South Pacific region, were examined for evidence of *Salmonella* contamination prior to blending with locally produced meat meals.

Cultivation of samples and identification of serovars

Cloacal swabs from Antarctic birds and faeces from seals were pre-enriched in buffered peptone water (BPW) for 24 h at 37 °C and subcultured in SCB enrichment broth incubated for 48 h at 43 °C, with 37 °C as a control. After enrichment, samples were plated onto deoxycholate citrate agar (DCA) and bismuth sulphite agar (BSA) at 24 h and 48 h. Selected samples from each batch were plated after pre-enrichment onto McConkey agar as a guide to the survival of target and indicator organisms prior to testing. Suspect colonies were screened in a single-tube Glissuda biochemical test medium (Iveson's medium), a single-tube method developed in our laboratory. This method detects glucose, lactose, sucrose, sorbose and dulcitol fermentation as well as the production of urea and hydrogen sulphide. After 14–16 h, tubes showing negative reactions are discarded and growth on the Glissuda slope is used for slide agglutination. The medium was developed for the economical and rapid screening of suspect colonies and provides a unique colour reaction indicating the presence of pathogenic Enterobacteriaceae. Other methods used for the isolation of *S. enterica* from humans, animals, waters and effluents and selected data used in this paper have been reported previously [13, 20]. Notifications of *S. enterica* isolations from marine fauna in other states of Australia by the National Enteric Pathogens Surveillance Scheme (NEPSS) are included with the permission of the editors.

RESULTS

A total of nine isolates of *S. enterica* serovar Enteritidis were recorded from 94 cloacal swabs collected in RCM and two from swabs collected in SCB. These PT4, PT8 and PT23 strains were recorded from 298 (3%) Adélie penguins during the first visit to Cape Denison in January 1985. No *Salmonella* isolates were recorded from 204 penguins sampled at the same site in December of that year. *S.* Oranienburg was isolated from one sample of pooled cloacal swabs collected from 80 king penguins sampled on Îles Crozet in February 1986.

Plesiomonas shigelloides was identified in eight (7.5%) cloacal swab samples collected in Stuart's transport medium (STM) from penguins on Macquarie Island. No isolates of *S. enterica* were recorded from samples collected in STM.

S. enterica serovars isolated from seagulls, marine birds and marine mammals in urban and non-urban coastal areas of Western Australia are presented in Table 1. Infection rates in urban areas averaged 17.85%, compared with only 2·61% in non-urban areas, the difference being highly statistically significant ($\chi^2 = 227{\cdot}42$, $P < 0{\cdot}0001$). *Salmonella* isolates from marine fauna in the Antarctic region, the Northern hemisphere and Australia; international frequency quotients, somatic groups and isolates common to humans, domesticated food animals, sewage, effluents, and coastal mussels in Western Australia are presented in Table 2. *Salmonella* serovars classed in HF groups identified in reptiles and marsupials cohabiting with marine fauna on coastal islands are presented in Table 3, and *S. enterica* serovars classed as naturally occurring in low-frequency quotients, are presented in Table 4. *Salmonella* isolates from marine birds and mammals in coastal areas are listed in Table 5.

A total of 20 HF *Salmonella* serovars classed in HF quotients were isolated from 22 (52%) samples of imported fishmeal processed in the Southern Ocean and South Pacific region. Serovars comprised *S.* Anatum, *S.* Binza, *S.* Cerro, *S.* Cubana, *S.* Derby, *S.* Havana, *S.* Infantis, *S.* Johannesburg, *S.* Mbandaka, *S.* Montevideo, *S.* Muenster, *S.* Orion, *S.* Ohio, *S.* Oranienburg, *S.* Schwarzengrund, *S.* Senftenberg, *S.* Singapore, *S.* Stanley, *S.* Tennessee and *S.* Thomasville.

DISCUSSION

In recent decades, increases in the volume of effluent from Antarctic bases and the harvesting and pelagic processing of fin fish and krill has expanded human activities impacting on coastal habitats and feeding areas and increased the risk of the marine food chain becoming involved in the epidemiology of salmonellosis. The isolation of *S.* Enteritidis PT4, PT8 and PT23 strains from Adélie penguins at Cape Denison preceded the pandemic of PT4 infections traced in many countries to reservoirs of infection in poultry flocks [21]. The subsequent isolation of *S.* Enteritidis PT4 from gentoo penguins on Bird Island, South Georgia was reported in a note by Olsen *et al.* [22]. The isolation of the previously rare *S.* Johannesburg

Table 1. Salmonella *isolations from seagulls, marine birds and marine mammals in urban and non-urban coastal areas of Western Australia*

	Urban areas			Non-urban areas			
Salmonella serovar	Seagulls	Marine birds	Marine mammals	Seagulls	Marine birds	Marine mammals	Totals
Adelaide	26	0	1	1	4	0	32
Agona	1	0	0	0	0	0	1
Anatum	38	0	0	0	0	0	38
Bahrenfeld	0	0	0	1	0	0	1
Bovismorbificans	6	1	0	0	22	0	29
Chester	14	0	0	0	0	0	14
Coleypark	24	0	0	0	0	0	24
Derby	105	1	3	0	2	0	111
Give	27	0	0	0	0	0	27
Havana	53	0	0	0	1	0	54
Infantis	5	0	0	0	1	0	6
Javiana	1	0	0	0	0	0	1
Litchfield	3	0	0	0	0	0	3
Livingstone	10	0	0	0	0	0	10
Muenchen	30	0	1	0	0	0	31
Newington	2	0	0	0	0	0	2
Newport	21	0	0	0	0	0	21
Ohio	3	0	0	0	0	0	3
Oranienburg	18	0	0	11	0	0	29
Orion	14	0	0	0	0	0	14
Panama	0	0	0	0	1	5	6
Saintpaul	11	1	1	0	1	0	14
Senftenberg	13	0	1	0	0	0	14
Singapore	5	0	0	0	0	0	5
Tennessee	8	0	0	0	0	3	11
Typhimurium	63	1	1	0	1	0	66
II Wandsbek	0	0	0	1	0	0	1
4,12:d:-	6	0	0	0	0	0	6
Total isolations	507	4	8	14	33	8	574
Total samples	2456	429	22	28	2021	60	5016

from penguins on Ross Island [10] also preceded isolates from samples of poultry feed and chicks in Canada [23], poultry products in the United Kingdom [24], and a major outbreak of human infection in Hong Kong over the period 1971–1974 [25].

Australia was not included in the list of countries directly associated with the *S*. Enteritidis pandemic [21], and the majority of *S*. Enteritidis PT4 infections in Western Australia in the 1980s were reported from travellers and immigrants arriving from Asian countries. *S*. Johannesburg isolates reported by NEPSS in Australia at this time were mainly from pigs, pig meats, the milk-processing industry and occasionally from fishmeal imported from South America and South Pacific countries. Occasional non-human isolates of *S*. Enteritidis in Western Australia have been reported from rodents, reptiles and coastal sewage effluent [13].

No event or food vehicle linking *S*. Enteritidis infections in Adélie penguins at Cape Denison with the history of human activities in the Terre Adélie region has been established and, apart from brief visits by survey parties, occasional cruise ships and the collection of samples during the Operation Blizzard Conservation project, the Commonwealth Bay area has remained free from major human disturbance since Cape Denison served as an operations base for Mawson and his sledge-dogs during the 1911–1914 Australian Antarctic Expedition.

A permanent base was established at Dumont d'Urville some 50 km from Commonwealth Bay in 1956 [26], and during the summer breeding season the

Table 2. Salmonella *serovar frequency quotients, somatic groups and isolations from humans, marine fauna, livestock and coastal effluents*

						Western Australia					
Salmonella serovar	Somatic group	Antarctic and sub-Antarctica	Australia	Northern hemisphere	Human	Sewage effluents	Cattle	Sheep	Pigs	Poultry	Frequency quotient
Adelaide	0	—	5	3	151	266	38	43	22	125	F
Anatum	E_1	—	2*	—	221	436	39	23	84	27	MF
Antarctica	D_1	1	—	—	—	—	—	—	—	—	VR
Blockley	C_2	14	—	—	14	25	—	—	—	—	MF
Bovismorbificans	C_2	—	23 (14)	19	207	177	12	304	68	15	F
Cerro	K	2†	—	—	14	8	—	—	—	—	F
Chester	B	—	1* (6)	—	455	442	40	9	58	68	F
Derby	B	3†	6 (44)	—	197	446	16	242	265	1	MF
Dublin	D_1	—	—	1	1	2	—	—	—	—	MF
Enteritidis	D_1	22	1*	15	16	17	—	—	1	—	MF
Hadar	C_2	—	—	2	4	1	—	—	—	—	U
Havana	G	17	1 (30)	—	140	367	19	264	38	17	F
Heidelberg	B	—	—	1	15		—	—	—	—	MF
Infantis	C_1	1	1 (12)	—	98	138	4	2	9	1095	MF
Johannesburg	R	4	—	—	2	—	—	—	—	—	U
Montevideo	C_1	—	—	2	5	10	—	—	—	—	MF
Muenchen	C_1	—	1	3	906	433	18	5	56	541	MF
Newport	C_2	25†	(1)	28	108	97	5	27	34	—	MF
Oranienburg	C_1	1	3* (6)	1	78	127	9	—	4	2	MF
Panama	D_1	1	6	—	11	3	—	—	—	—	MF
Saintpaul	B	—	2 (11)	2	251	133	17	—	16	329	MF
Senftenberg	E_4	—	1 (23)	—	144	357	—	—	13	—	F
Tennessee	C_2	—	3 (3)	1	43	101	—	3	24	—	F
Typhimurium	B	2	2 (30)	6	2359	761	179	926	219	620	MF
Wangata	D_1	—	9*	—	—	—	—	—	—	—	R
4,12:a:-	B	—	—	39	—	—	—	—	—	—	VR
9,12:b:z_{57}	D1	—	9	—	—	—		—	—	—	VR
Totals		93	76 (180)	123	5440	4344	396	1848	911	2840	16221

* NEPSS Notifications, Annual Reports (ed. Powling J, Lightfoot D) [28].
† Fenwick *et al*. [12].
Isolates from coastal mussels given in parentheses; F, frequent; MF, most frequent; U, uncommon; VR, very rare.

Table 3. Salmonella *serovars, high-frequency quotients and isolations from reptiles* (*R*) *and marsupials* (*M*) *on coastal islands in Western Australia*

Salmonella serovar	Rottnest Island		Carnac Island (R)	Penguin Island (R)	Abrolhos Islands (R)	Barrow Island		Boullanger Island		Serovar frequency quotients
	R	M				R	M	R	M	
Adelaide	5	246	33	4	1	3	3	3	2	F
Agona	—	—	1	—	—	—	—	—	—	F
Anatum	—	21	37	3	—	—	—	—	—	F
Bovismorbificans	—	7	11	4	—	—	—	5	3	MF
Chester	5	88	2	—	1	8	12	—	1	MF
Derby	—	2	37	1	—	—	—	1	—	F
Enteritidis	—	—	2	—	—	—	—	—	—	MF
Give	1	2	7	5	—	1	—	—	—	MF
Havana	—	—	19	6	1	1	1	3	1	F
Infantis	—	2	4	1	—	—	—	1	1	F
Javiana	1	81	—	—	—	—	—	—	—	MF
Livingstone	—	—	5	—	—	—	—	—	—	F
Montevideo	—	—	1	—	—	—	—	—	—	MF
Muenchen	8	405	34	—	—	—	—	—	—	F
Newington	6	301	10	—	—	—	—	—	—	F
Newport	—	4	7	—	—	—	—	—	—	MF
Oranienburg	2	93	4	—	—	4	7	—	—	MF
Orion	2	28	4	1	5	1	4	—	—	F
Saintpaul	—	1	9	2	—	—	—	—	—	MF
Senftenberg	—	—	1	6	—	—	—	—	—	F
Tennessee	—	—	5	1	—	—	—	—	—	F
Typhimurium	2	79	63	7	—	—	—	5	5	MF
Total	32	1360	296	41	8	18	27	18	13	1813
Samples	80	4668	220	102	106	173	241	89	36	5715

F, Frequent; MF, most frequent.

Table 4. Salmonella *serovars, somatic groups, frequency quotients, and isolations from reptiles* (*R*) *and marsupials* (*M*) *on coastal islands in Western Australia*

Salmonella serovar		Somatic groups	Rottnest Island		Carnac Island (R)	Penguin Island (R)	Abrolhos Islands (R)	Barrow Island		Boullanger Island		Frequency quotients
			R	M				R	M	R	M	
II	Alsterdorf	R	4	4	1	—	1	9	11	1	—	VR
	Bahrenfeld	H	3	38	1	1	1	11	23	—	—	R
II	Bleadon	J	—	7	—	—	3	13	13	—	—	R
	Birkenhead	C1	—	4	—	—	—	—	—	—	—	VR
	Blukwa	K	3	2	—	—	—	—	—	—	—	VR
	Bootle	X	3	9	—	4	—	7	9	—	—	VR
	Bullbay	F	—	—	—	—	21	—	—	—	—	VR
II	Bunnik	U	7	1	—	—	—	—	—	—	—	VR
	Carnac	K	—	—	1	3	1	—	—	1	—	VR
	Charity	H	—	—	5	—	—	—	—	—	—	R
	Decatur	C_1	4	8	—	—	—	—	—	—	—	VR
	Fitzroy	Y	—	—	—	—	—	1	—	—	—	VR
II	Fremantle	T	—	9	35	—	2	1	1	2	16	R
IV	Houten	U	2	—	11	—	1	—	—	1	1	R
	Hvittingfoss	I	—	—	—	—	—	5	—	—	—	U
	Litchfield	C_2	—	—	2	—	—	—	—	—	—	VR
	Merseyside	I	—	—	6	18	—	—	—	—	—	R
	Orientalis	I	4	83	3	—	—	—	—	—	—	U
	Poona	G	—	—	2	6	—	2	—	—	—	U
	Potsdam	C1	—	2	—	—	—	—	—	1	18	V
	Rottnest	G	5	40	—	—	—	1	3	2	—	VR
	Rubislaw	F	—	—	1	—	11	6	10	—	2	VR
	Treforest	(51)	—	—	—	—	—	5	—	—	—	VR
	Waycross	S	3	82	1	—	—	—	—	—	—	U
II	Wandsbeck	L	7	138	30	5	5	5	5	—	—	R
II	Zeist	K	—	—	1	—	—	—	—	—	—	VR
II	$53{:}d{:}z_{42}$	(53)	2	1	—	—	—	—	—	—	—	VR
IIIb	Diarizonae		35	89	109	9	4	11	7	—	—	VR
Totals			82	517	209	46	50	77	82	8	37	1168
Samples			80	4668	220	102	106	173	241	89	36	5715

R, Rare; U, uncommon; VR, very rare.

Table 5. Salmonella *isolations from marine mammals and birds in Western Australia*

Location	Marine species	Samples	*Salmonella* serovar	Isolations
Cape Le Grande	Australian sea lions	16	Panama	5
Cape Leeuwin	False killer whales	28	Tennessee	3
Carnac Island	Australian sea lions	22	Adelaide	1
			Derby	3
			Senftenberg	1
			Typhimurium	2
	Little penguins	18	Derby	1
			Muenchen	1
			Saintpaul	1
Sandy Island	Flesh-footed shearwaters	412	Adelaide	4
			Bovismorbificans	19
			Derby	2
			Havana	1
			Infantis	1
Bald Island	Little penguins	2	Panama	1
Lancelin Island	Bridled terms	112	Bovismorbificans	1
			Typhimurium	1
Pelsart Island	Common noddys	428	Bovismorbificans	1
			Saintpaul	1
	Lesser noddys	355	Bovismorbificans	1
	Sooty terns	323	Bovismorbificans	1
Totals		1716		52

convergence of penguins and seals feeding on Antarctic krill presents opportunities for the recruitment and foodborne spread of *S. enterica* and *E. tarda* infections carried by species exposed more directly to human activities. Antarctic krill has the capacity to act as an intermediate host for pathogenic organisms [4] and krill swarms exposed to factory ships and convergent wildlife provide a marine staging post and vehicle for the spread of *Salmonella* infections to penguin chicks and seal pups during the breeding season. Infections with *Salmonella* serovars adapted to the breeding cycle of Antarctic birds may also remain dormant for long periods in carrier hosts, and transfer internally via the reproductive system from infected parent bird to chick embryo, thereby avoiding the external route as demonstrated by *S.* Enteritidis PT4 infections in poultry flocks [27].

The possibility of host-adapted *Salmonella* infections in Antarctic penguins exhibiting a winter breeding cycle is suggested by the isolation of *S.* Antarctica, a new O group D1 serovar related antigenically to *S.* Enteritidis from an emperor penguin [17]. Other somatic group D1 serovars isolated from marine species in Australia reported by NEPSS, comprise *S.* Enteritidis PT1 from an Australian fur seal in Victoria (*Arctocephalus pusillus doriferis*) [28], and *S. Wangata* from little penguins in New South Wales also reported by NEPSS. In Western Australia, *S.* Panama, a serovar rare in Australia, was isolated from little penguins on Bald Island [29], sea lions examined during an oil spill off the southern coast of Western Australia, and *S.* 9,12:b:z_{57} isolated from sea snakes.

Salmonella enterica infections in Adélie penguins were not detected over consecutive breeding seasons at Cape Denison. Failure to isolate salmonellae during the second visit may reflect the small sample quota in a single rookery, or a fall in the number of orga isms excreted by carrier birds to below the level critical for their isolation by the swab procedure [29]. Cloacal rinse samples have been shown to increase *Salmonella* isolations from seagulls [30], and in coastal areas of Australia 21% of isolations were recorded from gull droppings, compared with 8% of gulls positive by the single cloacal swab procedure. The utilization of molecular biology techniques, such as PCR, could be appropriate in such circumstances.

The isolation of three *S*. Enteritidis phage types from nine infected penguins in a single rookery at Cape Denison suggests birds may act as both silent carriers and intermittent excretors during the breeding season in other colonies in the Commonwealth Bay area. Increases in infection rates may occur as a response to population stress induced by adverse conditions or an epizootic triggered by parent birds exposed to processing effluents and unregulated wastes from ships discharged in feeding areas.

The diversity of commonly occurring serovars isolated from fishmeal produced in southern latitudes was a surprise finding and warrants further study of fish offal and krill processed for use as animal feed. The possibility that an unsuspected vehicle or new technology has in recent decades selected for the emergence and international spread of virulent *S*. Enteritidis PT4 strains has been considered [31]. Sealing, whaling and fishing activities have impacted on the Antarctic food chain for over a century and selected serovars and strains may be a legacy of past exposure to the insanitary practices of sealers and whalers, and in recent decades, to factory ships observed on krill swarms in feeding areas used by tagged seals [32].

A cause-and-effect relationship between *Salmonella* infections in marine species and exposure to shipping activities has not been established. In the Northern hemisphere, food and waterborne disease outbreaks due to contamination with *S*. Typhi, *S*. Enteritidis and other HF serovars have occurred in passengers and crew on cruise ships [33], and it is possible that, during outbreaks, pathogens may spill over to the marine environment during the unregulated discharge of contaminated wastes. In Australia, *S*. Typhi infections were notified by NEPSS in passengers on a cruise ship returning from Papua New Guinea and *S*. Enteritidis PT21 from air crew arriving in Australia after a stopover in Sri Lanka.

In Western Australia, birds and marine mammals frequenting port facilities, coastal waters and feeding areas, are exposed to ships transporting livestock to countries in the Middle East and Asia. Evidence suggesting exposure to wastes, and sheep carcases discarded offshore into the marine environment, was provided by the isolation of *S*. Adelaide, *S*. Bovismorbificans, *S*. Derby, *S*. Havana and *S*. Typhimurium from marine birds feeding in shipping lanes and in the wake of ships. *Salmonella* isolates from clinical cases and sheep fatalities were recorded during on-board veterinary investigations [34] and *S*. Bovismorbificans, the major isolate from sheep, was present in island populations of flesh-footed shearwaters, common noddys, lesser noddys, bridled terns, sooty terns, seagulls, pelicans and green sea turtles (*Chelonia mydas*). In 1986 about 76 000 sheep died during loading and transportation [35]. Disposal of carcases, feed and droppings overboard exposes marine birds, and whales during seasonal migrations, to serovars causing clinical infections and fatalities in livestock.

Marine mammals have been implicated in the epidemiology of salmonellosis, and in Japan, *S*. Enteritidis was isolated from humans consuming meat products prepared from a sick bottlenose whale (*Hyperaodon rostratum*) [36]. Whale meat was implicated in a major outbreak of *S*. Enteritidis infections in an Eskimo community in Alaska [37]. *Salmonella* serovars active in the epidemiology of salmonellosis in humans and livestock were also isolated from imported whale meals in the United Kingdom [38] and from imported fishmeal contaminated with *S*. Agona implicated in an international outbreak of salmonellosis in humans and livestock [39].

Isolations of *S*. Enteritidis recorded from marine mammals in the Northern hemisphere include fur seals (*Callorhinus ursinus*) in Alaska [40] and on San Miguel Island in California [41]. *S*. Enteritidis PT7, PT8, *S*. Newport, and *E*. *tarda* were isolated during post mortems on seals in California [42] and from stranded sea lions (*Zalophus californianus*) near Los Angeles [43]. *S*. Enteritidis was implicated in a fatal case of meningoencephalitis in a northern fur seal on St George Island, Alaska [44]. Other commonly occurring serovars variously reported from pinnipeds in the United Kingdom [45], Hawaii, Japan and New Zealand [46] comprise *S*. Adelaide, *S*. Bovismorbificans, *S*. Havana, *S*. Newport and *S*. Typhimurium. All these serovars were variously isolated from humans, effluents, domesticated animals and island populations of wildlife in urban coastal areas of Australia.

An exception to the close relationship between salmonellae in humans, livestock, coastal effluents and marine fauna, was provided by the isolation of *S*. 4,12:a,:- from the tissues of stranded and deceased harbour porpoises (*Phocaena phocaena*) in coastal areas of Scotland [47]. Infections were restricted to harbour porpoises and the majority of isolates were recorded from lung tissues infested with nematodes. It was suggested that parasites may act selectively as intermediate hosts and vehicles maintaining circles of

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infection in seal family groups. It is also possible that other hosts not previously tested may be involved in maintaining infections. Trematodes have been linked with long-term *Salmonella* infection in humans, and episodes of bacteraemia [48].

Seals foraging in coastal habitats in Antarctica and sub-Antarctica may contribute to numbers of faecal indicator organisms in seawater and effluents from Antarctic bases [49]. Testing of sewage effluent and kitchen wastewaters for *S. enterica* and *E. tarda* using Moore swab samples collected and cultured in SCB broth alongside routine procedures, may assist in defining input levels from marine fauna (mammals and birds) with access to coastal waters receiving sewage effluent and kitchen waste waters from coastal bases.

Public health problems associated with sewage disposal, contaminated surface melt waters and processing of crustaceans, have been reported from Arctic settlements in Greenland [50], and similar problems may follow in the wake of expanding human activities in the Antarctic region. Further regulations limiting ship-to-shore excursions by tourists, discharge of wastes from ships, pelagic processing of marine foodstuffs in feeding areas south of the Antarctic convergence, and testing of coastal effluents during the Austral summer [51, 52] are measures consistent with maintaining biological integrity in the Antarctic food web. Such measures are needed in order to limit the spill-over of *Salmonella* serovars active in the global epidemiology of salmonellosis to penguin and seal colonies.

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DECLARATION OF INTEREST

None.

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