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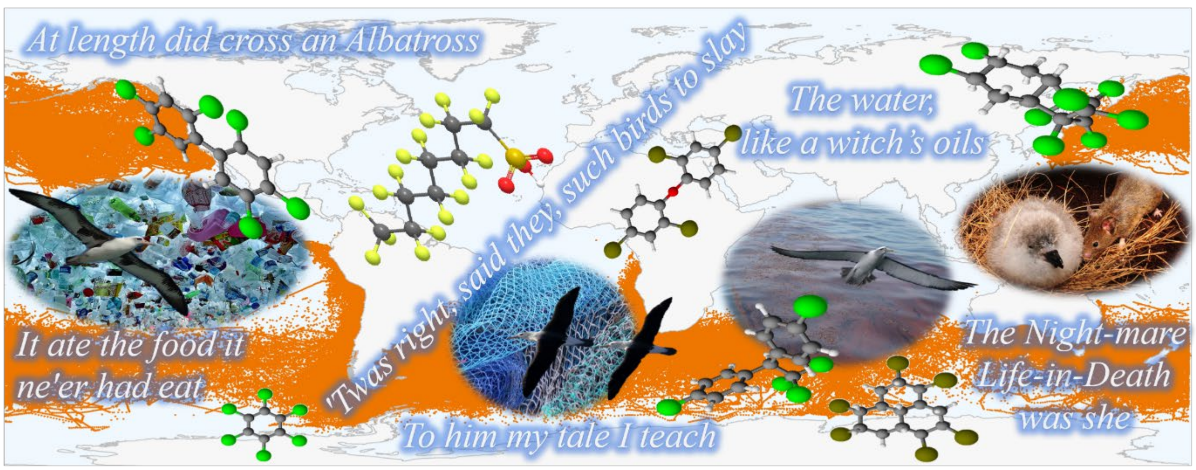
The Albatross About Our Neck: The State of our Oceans Revealed through the Family Diomedeidae



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Preface

In 2010, the 111th U.S. Congress directed NIST "to expand its capabilities and resources in the Pacific region through a Pacific Islands component of NIST and … to expand its biodiversity storage capabilities in the region." The Seabird Tissue Archival and Monitoring Project (STAMP) component of the NIST Biorepository was expanded under this directive to include collections of albatross eggs from the Hawaiian Islands. As there was not an easy way to compare contaminant results, the Albatross Species Chemical Database and Annotated Bibliography (ASCDAB) was created. Literature searches for contaminants in albatross and other perils were undertaken up to the year 2015. The key results are provided here set against Samuel Taylor Coleridge's epic poem "The Rime of the Ancient Mariner" for what I hope is an enjoyable and informative read.

Abstract

Albatross (Family Diomedeidae) are long-lived seabirds that inhabit most of the world's oceans coming ashore only to breed. Most of the species are listed as at least vulnerable by the IUCN and have been tracked during breeding and non-breeding seasons. This review set against Samuel Taylor Coleridge's epic poem "The Rime of the Ancient Mariner" summarizes and examines the current threats to albatross including fisheries, plastic ingestion, oil pollution, climate change, and chemical contamination while demonstrating how albatross may serve as a biomonitor for the state of our oceans.

Key words

Biomonitoring; Climate Change; Contaminants; Environment; Fisheries; Oil Pollution; Plastics.

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1. Introduction

1.1 At length did cross an Albatross
Through the fog it came
As if it had been a Christian soul,
We hailed it in God's name.

Albatross (Family Diomedeidae) have been revered by sailors for centuries as epitomized by Samuel Taylor Coleridge's epic poem "The Rime of the Ancient Mariner" [1] in which a seafarer recounts his story of killing an albatross. While the poem is pervasive in popular movies, TV, games, music, literature and sports [2]; have we really learned its lessons? Humans have continued to inflict numerous harms on the albatrosses.

While the exact number and names of albatross species are debated, the International Union for Conservation of Nature (IUCN) recognizes 22 species of albatross with 15 listed as vulnerable to critically endangered ([3] Table 1). Chambers et al. [4] used phylogenetic analysis of mitochondrial DNA to distinguish 24 species, which will be used throughout this manuscript with the abbreviations listed in Table 1. Albatross are found in every ocean except the North Atlantic (Fig. 1 with breeding locations listed in Table 2) so they can be used as a nearly global biomonitor as they also meet the criteria for biomonitoring as outlined previously [5]. Specifically, albatross are easy to collect and monitor as

1. they return to shore to breed, usually to the same location as hatching,
2. are long-lived upper trophic level consumers so have chemical profiles that are able to be measured, and
3. most species have well understood foraging and wintering areas.

This review focuses on the numerous issues facing albatross and examines the use of albatross as sentinel species for our oceans set against Coleridge's poem.

Table 1. Albatross species with population status, threats, number of records in the Albatross Species Chemical Database and Annotated Bibliography (ASCDAB) and tracking data.

Abbreviation Used	Names of Albatrosses: Common[1]	Scientific[1]	Previously used[2]	Threats[2]	Status[3]	Population Trend[3]	Records in ASCDAB	Tracked: Breeding (B), Non-breeding (N) All year (A)
	Genus *Phoebastria* :							
ST	Short-tailed	*P. albatrus*	Steller's[4]; *D. albatrus*	Volcanic islands, plastic, fisheries	Vulnerable D2	Increasing	377	N[5,6]
Wv	Waved	*P. irrorata*	Galápagos[4]; *D. irrorata*	Introduced goats; climatic effects; possibly fisheries	Critcally Endangered B2ab(v)	Decreasing	0	B[7-9]
La	Laysan	*P. immutabilis*	Laysan; *D. immutabilis*	Fisheries among many others	Near Threatened	Stable	1014	B[9-11]
BF	Black-footed	*P. nigripes*	Black-footed; *D. nigripes*	Habitat degredation; Fisheries	Near Threatened	Increasing	1550	B[9-12] N[5]
	Genus *Diomedea* :							
SR	Southern royal	*D. epomophora*	Southern royal; *D. epomophora epomophora*	Longline fishing	Vulnerable D2	Stable	93	B[13]
NR	Northern royal	*D. sanfordi*	Northern royal; *D. epomophora sanfordi*	Human harvesting, habitat degredation, climatic changes, longline fishing	Endangered A4bc;B2ab(iii,v)	Decreasing	759	A[14]
Tr	Tristan	*D. dabbenena*	(Gough[4]) Wandering; *D. exulans dabbenena*	Human persecution, plastics, longline	Critically Endangered A4ade	Decreasing	32	B[15]
An	Antipodean	*D. a. antipodensis*	(Antipodes[4]) Wandering; *D. exulans antipodensis*	Longline fishing	Endangered A4bde	Decreasing	2	A[14,16]
Gi	Gibson's	*D. a. gibsoni*	(Auckland[4]) Wandering; *D. exulans gibsoni*	Introduced pests, longline fishing			2	A[16]
Am	Amsterdam	*D. amsterdamensis*	Amsterdam wandering; *D. exulans amsterdamensis*[4]	Habitat degredation; Introduced predation; Longline fisheries	Critically Endangered B2ab(v); C2a(ii)	Decreasing	2	
Wa	Wandering	*D. exulans*	Wandering; D. exulans exulans	Longline fishing	Vulnerable A4bd	Decreasing	216	A[14] B[17-19] N[20]
	Genus *Phoebetria* :							
So	Sooty	*P. fusca*	None	Longline fishing	Endangered A4bd	Decreasing	38	B[21]
LM	Light-mantled	*P. palpebatra*	None	Longline fishing	Near Threatened	Decreasing	205	B[22]
	Genus *Thalassarche* :							
IYN	Indian yellow-nosed	*T. carteri*	Yellow-nosed; *D. chlorohynchos bassi* ; Eastern Yellow-nosed; *T. bassi*[4]	Fisheries; Viral disease	Endangered A4bde	Decreasing	59	B[21,23]
AYN	Atlantic yellow-nosed	*T. chlororhynchos*	(Western[4]) Yellow-nosed; *D. chlorohynchos chlorohynchos*	Fisheries	Endangered A4bd;B2ab(v)	Decreasing	79	
GH	Grey-headed	*T. chrysostoma*	Grey-headed; *D. chrysostoma*	Fisheries	Endangered A4bd	Decreasing	255	B[21,24] N[25]
Ca	Campbell	*T. impavida*	(New Zealand) Black-browed*; D. melanophrys impavida*	Predation & Longline fishing	Vulnerable D2	Increasing	2	B[21]
BB	Black-browed	*T. melanophris*	Black-browed; *D. melanophrys*	Fisheries	Least Concern	Increasing	359	B[21,24,26]
Bu	Buller's	*T. b. bulleri*	(Southern) Buller's*; D. bulleri bulleri*	Fisheries	Near Threatened	Stable	25	B[27]
Pa	Pacific	*T. b. platei*	(Northern) Buller's; *D. bulleri platei*	Unknown, but longline suspected			10	
Ch	Chatham	*T. eremita*	Shy; *D. cauta eremita*	Habitat loss from storms and climatic change; fisheries	Vulnerable D2	Increasing	50	B[28]
Sa	Salvin's	*T. salvini*	Shy (or Salvin's); *D. cauta salvini*	Unknown, but longline possible	Vulnerable D2	Unknown	19	
Sh	Shy	*T. cauta*	(Tasmania[4]) Shy; *D. cauta cauta*	Viral disease; Fisheries	Near Threatened	Unknown	63	N[29] B[30]
WC	White-capped	*T. steadi*	(Aukland[4]) Shy; *D. cauta steadi*	Habitat destruction; fisheries	Near Threatened	Decreasing	68	B[31]

[1][4]; [2][6]; [3][3]; [4][7]; [5][8]; [6][9]; [7][10]; [8][11]; [9][12]; [10][13]; [11][14]; [12][15]; [13][16]; [14][17]; [15][18]; [16][19]; [17][20]; [18][21];[19][22]; [20][23]; [21][24]; [22][22]; [23][25]; [24][26]; [25][27]; [26][25]; [27][28]; [28][29]; [29][30]; [30][31]; [31][32]

Table 2. Locations with the number of records in the Albatross Species Chemical Database and Annotated Bibliography (ASCDAB). See Table 1 for the species full names.

Location	Ocean	Latitude	Longitude	Records	Records by Species
Albatross Island	South Pacific	-40.4	144.6	28	Sh n=28
Antipodes Islands	South Pacific	-49.7	178.8	2	An n=2
Auckland Islands	South Pacific	-41.3	174.8	90	Gi n=2; SR n=11; Wa n=30; Bu n=17; n=11; Sh n=11; GH n=3; BB n=11; Sa n=3; WC n=2
Bounty Islands	South Pacific	-47.8	179.0	2	Sa n=2
Campbell Island	South Pacific	-52.5	169.2	4	GH n=2; Ca n=2
Chatham Islands	South Pacific	-43.6	-176.8	194	NR n=134; Pa n=10; Ch n=50
Falkland Islands	South Atlantic	-51.0	-59.0	1	BB n=1
Gough island	South Atlantic	-40.3	-9.9	74	Tr n=2; Wa n=19; So n=28; IYN n=2; AYN n=23
Heard Island	Indian	-53.1	73.5	2	BB n=2
Ile Amsterdam	Indian	-37.8	77.6	6	Am n=2; So n=2; IYN n=2
Iles Kerguelen	Indian	-49.4	70.3	25	Wa n=5; LM n=5; BB n=15
Isla de Guadalupe	North Pacific	29.1	-118.3	18	La n=18
Isles Crozet	Indian	-46.5	51.8	68	Wa n=48; So n=6; LM n=14
Macquarie Island	South Pacific	-46.5	159.0	4	LM n=4
Marion Island	Indian	-46.9	37.8	10	Wa n=4; So n=2; LM n=2; GH n=2
Midway Atoll	North Pacific	28.2	-177.4	1149	La n=735; BF n=411; La & BF n=3
North Pacific Ocean	North Pacific	34.8	179.9	1061	La n=241; BF n=818; La & BF n=2
Snares Islands	South Pacific	-48.0	166.6	4	Bu n=2; Sa n=2
South Atlantic Ocean	South Atlantic	-28.0	-29.3	158	Tr n=30; SR n=4; Wa n=32; LM n=10; Sh n=10; AYN n=34; GH n=4; BB n=34
South Georgia	South Atlantic	-54.0	-38.0	200	Wa n=63; LM n=8; BB n=64
South Pacific Ocean	South Pacific	-31.2	179.9	154	SR n=6; Wa n=11; NR n=2; LM n=17; Bu n=6; GH n=22; BB n=67; Sa n=12; WC n=11
Southern Indian Ocean	Indian	-50.0	75.0	689	SR n=72; Wa n=4; LM n=145; Sh n=12; IYN n=55; AYN n=22; GH n=157; WC n=55; BB n=165
Taiaroa Head	South Pacific	-45.8	170.7	623	NR n=623
Tasmania	South Pacific	-41.0	145.0	2	Sh n=2
Tern Island	North Pacific	23.9	-166.3	28	La n=18; BF n=312
Torishima	North Pacific	30.5	140.3	688	ST n=377; BF n=311

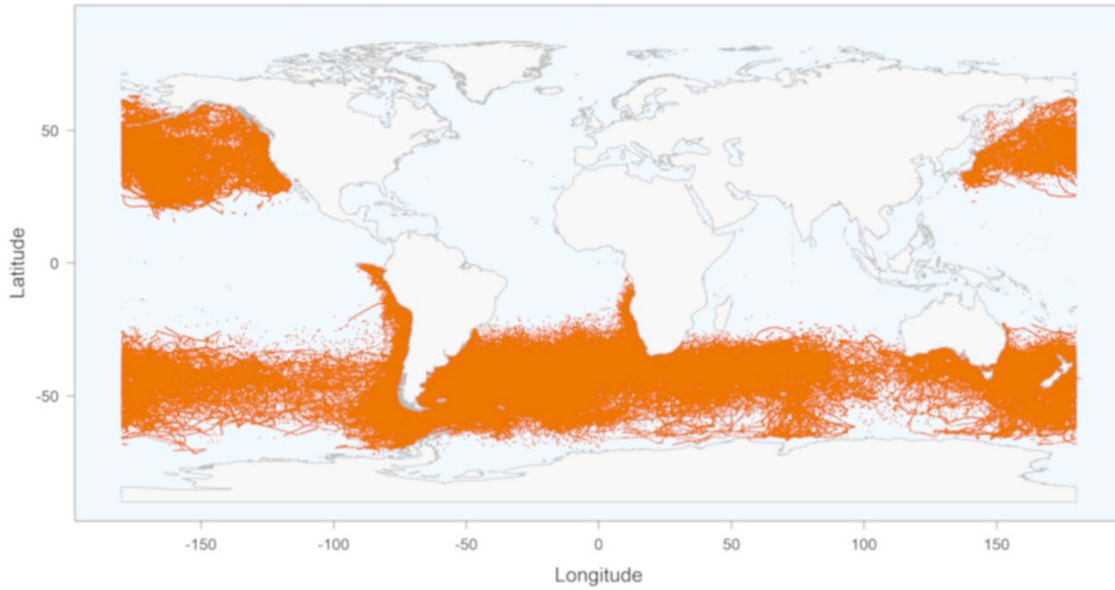


Fig. 1. World-wide distributions of albatross from tracking locations. Adapted from [33] and used with permission.

2.1. The Albatross did follow, And every day, for food or play, Came to the mariners' hollo!

Albatross traverse thousands of kilometers (km), even during the breeding season for foraging (e.g., see [14, 20, 33]). Most albatross species have been tracked during breeding and non-breeding seasons (see Table 1) and these tracks (see Fig. 1) indicate how often albatross would have been observed by sailors on their long flight patterns. These data are also useful in determining the regions where albatross may encounter specific hazards (e.g., contaminants and industrial fishing).

3. Albatross Perils

3.1. 'Twas right, said they, such birds to slay, That bring the fog and mist.

3.1.1. Human consumption

Although sailors in theory revered albatross, Captain Cook noted that his men enjoyed catching and eating albatross even when they had fresh mutton. Numerous other accounts of sailors, explorers and locals enjoying albatross meals into the late 1970s exist [34].

3.1.2. Other perils

Additional threats from humans include killing albatross for feathers or because they were viewed as a nuisance which is not as much of a threat now due to international protections, introduced predators and animals that destroyed habitats (along with human development), plastic ingestion, fisheries interactions, and climatic effects. Volcanic eruptions, viruses, and habitat loss from storms also threaten albatross (see review by Gales [6], and Table 1 for more information).

3.2. It ate the food it ne'er had eat,
And round and round it flew.
Water, water (Food, food) everywhere, nor any drop (bite) to drink (eat)

3.2.1. Fisheries interactions

What happens when commercial fisheries target the same prey as albatross? Albatrosses may benefit from additional food provided by fisheries (bycatch and offal discards) and reduced competitors, but overfishing may detrimentally reduce the availability of a particular fish species that is important to the birds and baited hooks also capture and drown birds. For instance, detrimental fisheries effects were noted in the population of Black-Browed Albatross (*Thalassarche melanophris*; BB) along the Patagonian shelf [35, 36], but mixed effects were observed in Black-Browed tracked from Kerguelen Islands in the Southern Indian Ocean with some benefitting from fisheries and others harmed [37], and no evidence of impact was noted from legal tuna longlining on Indian Yellow-Nosed Albatross (*T. carteri*; IYN) from Amsterdam Island in Subtropical Indian Ocean [38]. Antipodean (*Diomedea antipodensis antipodensis;* An) and Gibson's Albatross (*D. a. gibsoni,* Gi) in the New Zealand subantarctic are differentially impacted by fisheries with 36 % less overlap with foraging area for Antipodean, but 61 % more deaths associated with fisheries [19]. White-Capped Albatross (*T. steadi*; WC) significantly altered foraging behaviors by slowing speeds and travelling in straight lines when associated with fishing vessels based on GPS tracking and fishing effort distribution data in subantarctic New Zealand [32]. While scavenging from drift nets, the food habits of Black-Footed (*Phoebastria nigiripes*, BF) and Laysan Albatross (*P. immutabilis*, La) are nearly identical, with net-caught neon flying squid and Pacific pomfret forming the major part of their diets. Mass-balance equations predict that diets of Laysan feeding from drift nets (DRD) are trophically quite different feeding mostly on flying squid from those of birds not feeding from drift nets (NDRD) feeding mostly on fish. In contrast, these equations indicate that for Black-Footed, the DRD and NDRD are trophically similar [39]. Thus, the effect of commercial fisheries on albatross is dependent on the species, location, and type of fishery where mitigation measures may reduce the threat to albatrosses [40].

3.2.2. Plastics

Plastics were never an issue for the albatrosses of Coleridge's era as plastic was not created until the early 1900s. However in 2015, there were nearly 5000 metric tons of plastic as waste in landfills and the natural environment [41], now causing a major concern for albatrosses. The concerns with ingestion of plastic are:

1. dehydration and starvation due to lack of nutrition of plastic and the weight and volume contributing to a lack of space for nutrient-rich food,
2. tearing or blockage of the intestinal tracts, and
3. exposure to persistent pollutants associated with the plastic production or absorbed from the environment that may cause toxicological issues [42].

Pollutants are discussed in section 3.4. Plastics may also lead to death by entanglement leading to strangulation, drowning, and reduction of feeding efficiency [42].

Determining the exact amount of plastic debris in the oceans is extremely difficult, but monitoring ingestion in seabirds is relatively easy [43]. Plastic ingestion may be noted through necropsy, stomach pumping, or boluses that chicks regurgitate before fledging. Anecdotal evidence of plastic ingestion in Grey-Headed (*T. chrysostoma*, GH) and Wandering Albatross (*D. exulans,* Wa) from South Africa (Furness, 1983), Wandering in Australia [44], Wandering and Southern Royal Albatross (*D. epomophora*, SR) from New Zealand [45] and in Laysan and Black-Footed Albatross from the Northwest Hawaiian Islands [46, 47] occurred as early as the mid-1970s to early-1980s. While plastic was not found in a single Laysan collected from Alaska collected sometime between 1969-1977 [48] nor in three Light-Mantled Albatross (*Phoebetria palpebatra*, LM) collected from Australia between 1968-1975 [44]. Kenyon and Kridler [49] studied Laysan in 1966 from Pearl and Hermes Reef in the Northwest Hawaiian Islands and found 74 % incidence of ingestion with 241 pieces weighing 183 g total in 100 birds. The incidence of plastic ingestion in albatross from published literature are summarized in Table 3. The differences in reporting methods between total number of pieces, mass, volume, and ingestion incidence makes pure comparisons difficult. Location may play a role in plastic ingestion amounts as demonstrated by Young et al. [50]. Laysan chick boluses from Kure Atoll in the Northwest Hawaiian Islands had nearly ten times more plastic by pieces, mass and volume compared to those on Oahu in the Main Hawaiian Islands, while prey remnants were not significantly different from either location.

Table 3. Plastic ingestion in Albatross species. See Table 1 for the species full names.

Species	Location	Age	Study Date	Plastic #	Plastic Mass (g)	Plastic volume (cc)	Ingestion Incidence %	N	Reference
LM	Macquarie Island, Australia	NS	1968-1975				0	3	Slip et al. 1990
Wa	Macquarie Island, Australia	NS	1974				100	1	Slip et al. 1990
Wa	Bird Island, South Georgia	Chick	1993-1994	11[a]				1329	Huin and Croxall, 1996
La	Pearl and Hermes Reef, Hawaiian Islands	NS	1966	241[a]	183[a]		74	100	Kenyon and Kridler 1969
La	Alaska	Adult	1969-1977				0	1	Day 1980
La	Midway Atoll, Hawaiian Islands	Chick	1982-1983		1-175	1-188	90	50	Fry et al. 1987
La	Midway Atoll, Hawaiian Islands	NS	1986			1-186		45	Sileo et al 1990
La	Midway Atoll, Hawaiian Islands	Adult	1986				35	31	Sileo et al 1990
La	Midway Atoll, Hawaiian Islands	Chick	1986				94	78	Sileo et al 1990
La	Laysan Island, Hawaiian Islands	Chick	1986				92	24	Sileo et al 1990
La	Tern Island, Hawaiian Islands	Chick	1986				92	12	Sileo et al 1990
La	Midway Atoll, Hawaiian Islands	NS	1987			5-20		76	Sileo et al 1990
La	Midway Atoll, Hawaiian Islands	Chick	1987				98	43	Sileo et al 1990
La	Pearl and Hermes Reef, Hawaiian Islands	Chick	1987				91	35	Sileo et al 1990
La	Laysan Island, Hawaiian Islands	Chick	1987				100	35	Sileo et al 1990
La	Tern Island, Hawaiian Islands	Chick	1987				67	6	Sileo et al 1990
La	Central North Pacific	Adult	1990-1991	14			93	167	Robards et al. 1997
La	North Pacific Ocean	Adult	1990-1991			298[a]	93.5	154	Gould et al. 1997
La	Midway Atoll, Hawaiian Islands	Chick	1994-1995		0-136.3		96.7	249	Auman et al. 1997
La	Tern and Laysan Islands, Hawaiian Islands	Chick	2001-2008			8.05 ± 1.11		61	Henry, 2011
La	Guadalupe Island, E. Pacific Ocean	Chick	2001-2008			3.8 ± 0.62		77	Henry, 2011
La	Hawaiian Islands	Adult	2006-2008			0.998 ± 2.244	83.3	18	Gray et al 2012
La	Kure Atoll, Hawaiian Islands	Chick	2006-2007	70.6 ± 11.5	38.03 ± 5.32	53.67 ± 6.38	100	15	Young et al 2009
La	Oahu, Hawaiian Islands	Chick	2006-2007	17.4 ± 5.5	4.37 ± 2.10	5.26 ± 2.50	100	8	Young et al 2009
BF	Midway Atoll, Hawaiian Islands	NS	1986			0-198		25	Sileo et al 1990
BF	Midway Atoll, Hawaiian Islands	Chick	1986				89	28	Sileo et al 1990
BF	Laysan Island, Hawaiian Islands	Chick	1986				79	56	Sileo et al 1990
BF	Tern Island, Hawaiian Islands	Chick	1986				0	1	Sileo et al 1990
BF	Midway Atoll, Hawaiian Islands	NS	1987			5-165		18	Sileo et al 1990
BF	Midway Atoll, Hawaiian Islands	Chick	1987				100	18	Sileo et al 1990
BF	Pearl and Hermes Reef, Hawaiian Islands	Chick	1987				97	35	Sileo et al 1990
BF	Laysan Island, Hawaiian Islands	Chick	1987				92	36	Sileo et al 1990
BF	Tern Island, Hawaiian Islands	Chick	1987				89	35	Sileo et al 1990
BF	Nihoa Island, Hawaiian Islands	Chick	1987				86	21	Sileo et al 1990
BF	NE Pacific Ocean	Adult	1987	2-11			100	3	Blight and Burger 1997
BF	North Pacific Ocean	Adult	1990-1991			27.1[a]	53.8	93	Gould et al. 1997
BF	Central North Pacific	Adult	1990-1991				45	110	Robards et al. 1997
BF	Hawaiian Islands	Adult	2006-2008			0.130 ± 0.286	51.7	29	Gray et al 2012
AYN	Southern Brazil	NS	1991-2008				8	13	Colabuono et al 2010
AYN	Southern Brazil	NS	1994-2005	3			7	27	Colabuono et al 2009
BB	Southern Brazil	NS	1991-2008				6	31	Colabuono et al 2010
BB	Southern Brazil	NS	1994-2005	1			12	59	Colabuono et al 2009
BB	Rio Grande do Sul, Southern Brazil	NS	1997-1998	7[a]			20	35	Petry et al 2007
BB	Rio Grande do Sul, Southern Brazil	NS	1994-2007	3[a]			100	2	Tourinho et al. 2010
GH	Bird Island, South Georgia	Chick	1993-1994	6[a]				3397	Huin and Croxall, 1996
Sh	Albatross Island, Tasmania	Chick	1994-1998				0.9	540	Hedd and Gales 2001

[a] Total for all birds

3.3. ***About, about, in reel and rout***
The death-fires danced at night;
The water, like a witch's oils,
Burnt green, and blue and white.

While burning oil spills like the Deepwater Horizon and Gulf Oil Spill may be conjured by Coleridge's lines, chronic oil seepage from natural sources and ship operations may be more hazardous to albatross. Tank washings, which may release more oil than spills, were found to pose greatest threat to offshore seabird species including Short-Tailed Albatross (*Phoebastria albatrus*, ST) and Black-Footed Albatross [51]. However, anecdotal evidence of unknown source oil spots on plumage of two breeding Wandering Albatross at Bird Island, South Georgia was noted without ill effect on breeding success [52]. Atlantic Yellow-Nosed Albatross (*T. chloroyhynchos*, AYN) were also observed oiled from the Oliva spill off Nightingale Island, Tristan da Cunha Group in 2011 with unreported effects [53]. Albatrosses have a moderate oil vulnerability index (OVI) compared to other seabirds and may be affected by damage to the feathers, skin, eyes and toxic effects of polycyclic aromatic hydrocarbons (PAHs) exposure which may affect health, reproductive success and survival [54].

3.3.2. Climate change

As climates change and more vessels are entering polar waters, albatrosses may have more interactions with oil seepage and fisheries while also dealing with shifting prey structures, temperature changes and loss of breeding habitat. As with fisheries, the climate change effects are species dependent. Light-Mantled Albatross were negatively affected by warming sea surface temperatures (SST) while feeding south of the polar front, while Wandering and Sooty Albatross (*Phoebetria fusca*, So) foraging north of the front had enhanced breeding success and Black-Browed Albatross were not affected [55]. In one of the rarest species of albatross, Amsterdam (*D. amsterdamensis*, Am), a negative Indian Ocean Dipole (IOD) not only warms the SST, but also lowers the winds providing less prey and higher energetic costs to fly with possible negative impacts on survival and breeding success, but fisheries may play a larger role in Amsterdam Albatross survival success [56]. Likewise Black-Browed Albatross in the Southern Indian Ocean were more likely to be affected by fisheries than climate variability, where positive SST anomalies during breeding period increased breeding success, but warmer SST at the wintering grounds reduced breeding success and survival was significantly decreased by tuna longlining efforts [37]. Indian Yellow-Nosed Albatross at Amsterdam Island in the sub-tropical Indian Ocean had no demographic impact from tuna longlining, but had lower hatching success during El Niño years and chick mortality was affected by avian cholera [38]. Sea level rise and increased storm surges are also major issues for breeding in low-lying islands such as the Northwest Hawaiian Islands [57].

***3.4. Instead of the cross, the Albatross
About my neck was hung.
Her lips were red, her looks were free,
Her locks were yellow as gold:
Her skin was as white as leprosy,
The Night-mare Life-in-Death was she,
Who thicks man's blood with cold.***

3.4.1. Contaminants

Is there a greater harm than death? According to Coleridge, it is the living dead. Some effects of chemical contaminants are visible, such as easily crushed eggshells from dichlorodiphenyltrichloroethane (DDT) and other organochlorine pesticides and drooped wing from lead poisoning. Other effects may not be so immediately visible such as impaired immune, reproductive, and nervous system functions caused by an onslaught of environmental contaminants [58].

3.4.2. Albatross Species Chemical Database and Annotated Bibliography (ASCDAB)

In order to assess levels of chemical contaminants in albatross, the Albatross Species Chemical Database and Annotated Bibliography (ASCDAB) was created and is available online at: https://doi.org/10.18434/mds2-2304. ASCDAB contains 5284 records entered from 781 collection events (unique species, location, date; Table S1) from 170 manuscripts (Table S2; supplemental materials are available at: https://data.nist.gov/od/ds/mds2-2304/Albatross%20Species%20Chemical%20Database%20and%20Annotated%20Bibliograpy%20results.xlsx). The ASCDAB metadata provides information on where the majority of effort has been placed and highlights information needs. No chemical data was found for the Galapagos Islands with the next fewest records (437) in South Atlantic. The Indian Ocean and South Pacific had a moderate number of records with 800 and 1103, respectively. The North Pacific had the most data with 2944 records with Midway Atoll alone containing 1149 records, amounting to 21.7 % of the total database (see Table 2 for individual locations and Fig. S1 for the locations and URL of the interactive map). Not surprisingly, the species breeding on Midway Atoll, the Black-Footed and Laysan Albatross were also studied the most frequently with 1550 and 1014 records or 29.3 % and 19.2 % of the total database, respectively (Table 1). The Antipodes, Amsterdam, Campbell Albatross (*T. impavida*, Ca), and Gibson's had only 2 records each (all for stable isotopes in feathers by Cherel et al. [59]). Males and females were equally analyzed (530 records each) where sexes were known, but there were 925 records where sexes were combined and 2239 records or 42.4 % of the total database (after subtracting for all egg compartments) where sexes were not known or listed. As diet and metabolism may differ between the sexes, this is important information that should be included in the studies to allow for proper interpretation of the results. Liver was the most common tissue type examined, followed by eggs, feathers, and muscle (Table 4). If all the blood compartments (blood, plasma and serum) are combined, there are 490 records making it the fifth most analyzed tissue. If all the egg compartments (egg, egg with embryo, eggshell, and egg yolk) are combined, egg becomes the most analyzed tissue with 1060 records or 20 % of the total. Sampling non-lethal tissues is very important for future contaminant monitoring, especially considering the tenuous population statuses of most albatross species. Metals were most frequently analyzed with 1915 records or 36.2 % of the total database (with mercury the most common individual compound with 378 records) followed by polychlorinated biphenyls (PCBs) with 1179 records (Table 5). Providing all the data from the database is not logistically feasible here, but a few trends from tissues are presented where more data was available. Results are displayed as interactive maps (Table S3).

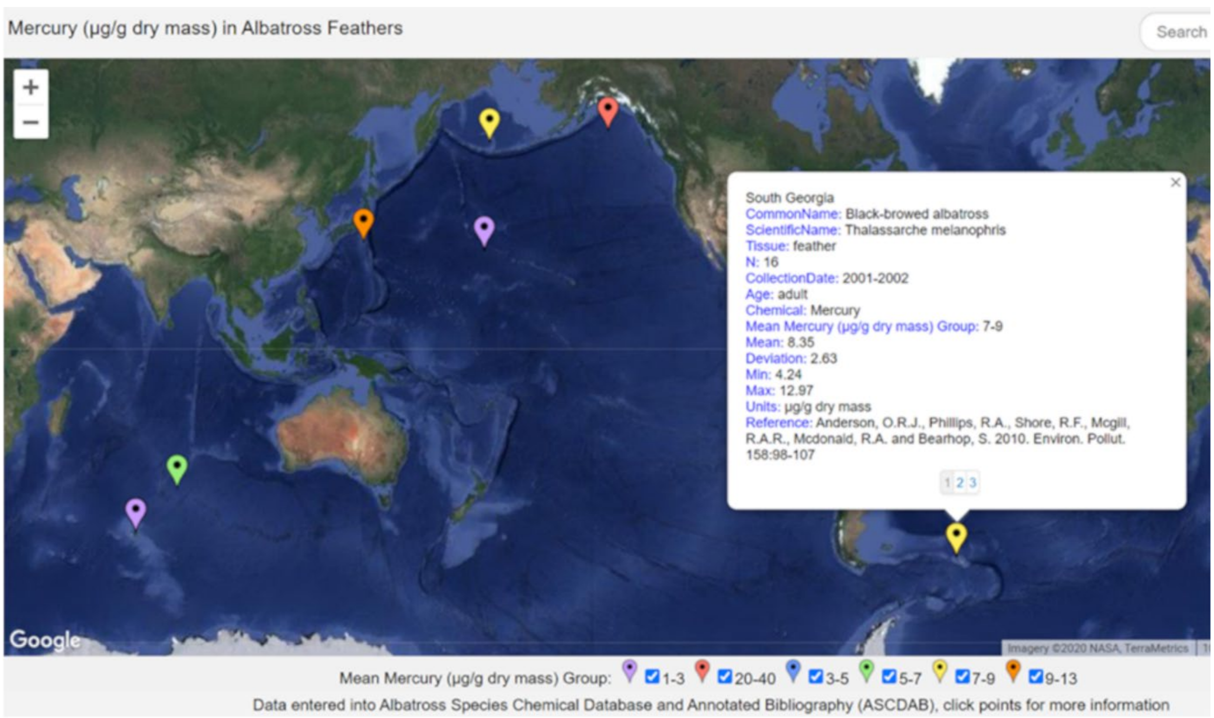
Table 4. Tissue types with the number of records in the Albatross Species Chemical Database and Annotated Bibliography (ASCDAB).

Tissue	Records
liver	857
egg	798
feather	788
muscle	560
subcutaneous fat	248
plasma	234
blood	217
egg with embryo	216
kidney	195
whole body	195
breast muscle	193
fat	177
down	80
stomach contents	80
pectoral muscle	60
serum	39
eggshell	36
bone	26
lung	21
visceral fat	20
brain	18
gallbladder	18
gizzard	18
heart	18
intestinal contents	18
intestine	18
pancreas	18
spleen	18
stomach	18
uropygial gland	18
head and neck	12
internal organs	12
skin	12
egg yolk	10
ovary	9
testis	9

Chemical Type	Records
Metals	1915
PCBs	1179
Organochlorine Pesticides	659
Furans	383
Isotopes	318
Dioxins	294
Toxicology	175
PFCs	166
PBDEs	108
Other (Ratios)	48
PAHs	24
Phenols	15

3.4.3. Mercury (Hg)

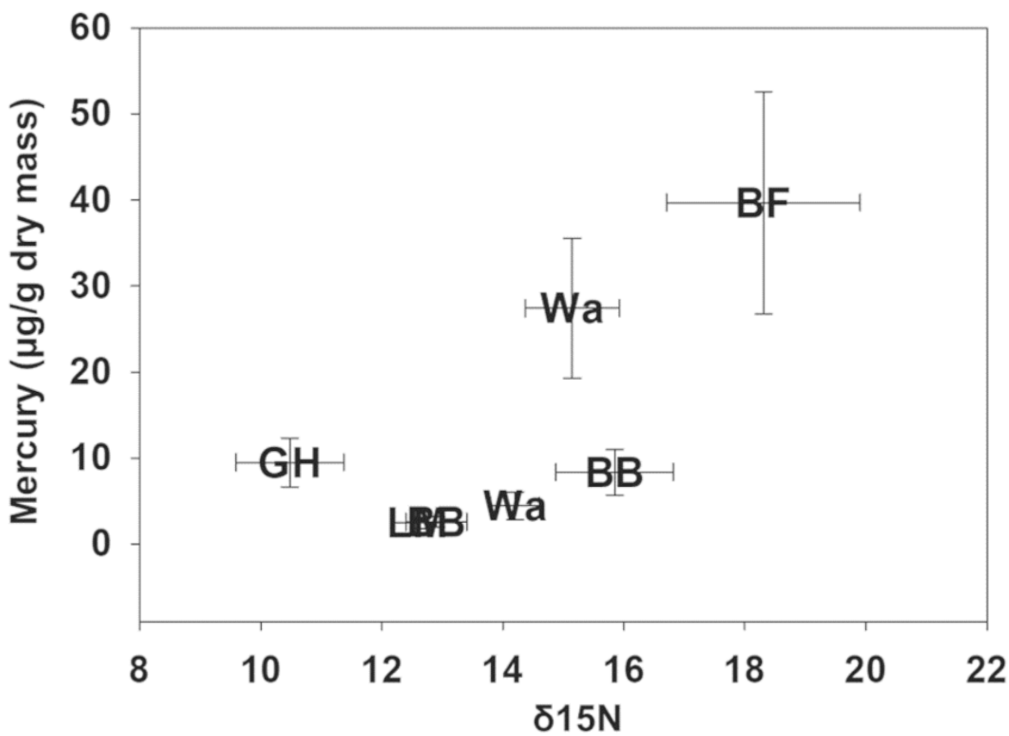
Hg is a nonessential heavy metal that may cause neurological and kidney damage, reduced vision, impaired mental faculties, decreased breeding success, and even death [60]. In albatross feathers, Hg levels ranged from 1.5 µg/g dry mass in Black-Browed and Light-Mantled Albatross chicks on Iles Kerguelen in the Southern Ocean in 2005 [61] to 66 µg/g dry mass in Black-Footed adults collected from the North Pacific Ocean in 1985 [62] (Fig. 2 and Table S4).



https://www.easymapmaker.com/map/HgAlbatrossFeathers

Unfortunately, insufficient data was available to examine temporal trends in species from the same locations, except in a single study Vo et al. [63] examined temporal trends in feathers of Black-Footed Albatross stored in museums. This study did find an increase in methylHg over time, but due to potential inorganic Hg contamination from preservation techniques, these data were not included in the figure or table. In livers, the levels of Hg ranged from 6.2 µg/g dry mass in Indian Yellow-Nosed Albatross collected from the Southern Indian Ocean in 1994 [64] to 1800 µg/g dry mass in Wandering adult females (gender differences were observed with females having significantly higher Hg levels than males) collected from the

Southern Indian Ocean in 1990-1994 [65] (Table S5). In general Wandering and Black-Footed Albatross had the highest Hg levels ([2.2 to 66] µg/g dry mass in feathers and [31 to 1800] µg/g dry mass in liver) and were potentially at a level of concern for toxicological endpoints based on review by Thompson [60], but species specific information is not available. Many of the feather samples also had complementary $\delta^{15}N$ (a measure of trophic level based on ratios of the stable isotope of nitrogen) data available. There was no complementary $\delta^{15}N$ data for the Black-Footed Albatross feathers, but the museum samples of Black-Footed feathers from across the North Pacific Ocean collected between 1977 and 2002 analyzed by Vo et al. [63] were used as a proxy. The Wandering and Black-Footed adults did generally have higher $\delta^{15}N$ values, but the Black-Browed adults also had relatively high $\delta^{15}N$ values indicating higher trophic level, but much lower Hg levels (Fig. 3). The Wandering and Black-Browed chicks from Iles Kerguelen in the Southern Indian Ocean had lower $\delta^{15}N$ indicating lower trophic level and Hg levels than adults of those species from South Georgia in the South Atlantic Ocean [59, 61, 63, 66-73]. This may be related to either diet differences between adults and chicks or reflective of food web differences in these regions. Lock et al. [74] examined Hg in livers on a wet mass basis in adults and chicks from the same colony and, except for White-Capped Albatross which were nearly identical between the ages, the chicks had less than half of the Hg of the adults.



3.4.4. Cadmium (Cd)

Cd is another toxic heavy metal that may bind to metallothioneins and damage the kidneys [75]. Albatross livers had mean levels of Cd ranging from 7.7 µg/g dry mass in Shy Albatross (*T. cauta*, Sh) collected from Auckland Islands in 1995-1996 [76] to 125 µg/g dry mass in Black-Footed collected from the North Pacific Ocean in 1998 [77] (Table S6). On a wet mass basis, mean levels ranged from 0.3 µg/g in fledgling Buller's Albatross (*T. bulleri bulleri*, Bu) collected from the South Pacific Ocean before 1983 [74] to 32 µg/g in adult Wandering Albatross collected from Gough Island in 1983 [75] (Table S7). Other studies did not observe Cd in liver causing effects up to 45 µg/g wet mass as reviewed by [78], so it is unlikely for Cd to have an effect on albatross and none were noted in these studies either. For feathers, Torishima Island in 2002 had both extremes and ranged from 31 ng/g dry mass Cd in Short-Tailed to523 ng/g dry mass in Black-Footed Albatross [79] (Table S8).

3.4.5. Lead (Pb)

Pb in feathers was extremely variable with values below the detection limit of 237 ng/g dry mass in Black-Browed, Grey-Headed, and Wandering Albatross collected form South Georgia Island in 2001-2002 [70], to a mean ± standard deviation of (3350 ± 2250) ng/g dry mass in female Black-Browed collected from the Patagonia shelf in the South Pacific Ocean in 2005 [80] (Table S9). Laysan chicks on Midway Island in the North Pacific Island in 1997 exhibiting droop-wing syndrome had the highest levels of Pb with a mean ± standard error of (40 200 ± 6070) ng/g dry mass measured in their down, while those that appeared normal had (2410 ± 370) ng/g dry mass [81]. Finkelstein, Gwiazda, & Smith [82] observed similar effects associated with blood levels in chicks from reference sites at (6.0 ± 4.2) µg/dL and those with drop-wing at (440 ± 310) µg/dL. Droop-wing syndrome is attributed to the ingestion of Pb paint flaking from buildings.

3.4.6. Dichlorodiphenyltrichloroethane (DDT)

Metabolites of DDT, the pesticide that was the impetus for Rachel Carson's book *Silent Spring,* were measured in albatross eggs. The major metabolite, *p,p'*-dichlorodiphenyldichloroethylene (DDE) was found to range in eggs from a mean ± standard deviation of (32.3 ± 17) ng/g wet mass in Northern Royal Albatross (*D. sanfordi*, NR) collected from Chatham Islands in 1996 [83] to (1550 ± 250) ng/g wet mass in Black-Footed collected from Midway Atoll in 1992-1993 [84] (Table S10). Eggshell thinning was found in Golden Eagles (*Aquila chrysaetos*) at 100 ng/g wet mass of DDE in egg contents, However Black Duck (*Anas rubripes*) did not exhibit eggshell thinning until 144 000 ng/g wet mass of DDE in egg contents. Levels above 1000 ng/g wet mass may be associated with impaired reproductive success as previously reviewed [85] so it is difficult to determine without empirical tests if albatross are affected by DDE.

3.4.7. Hexachlorobenzene (HCB)

HCB, a persistent organic fungicide banned under the Stockholm Convention on Persistent Organic Pollutants (POPs), has been measured in albatrosses but no effect is expected given the low levels found. HCBs ranged from 2.36 ng/g wet mass in Pacific Albatross eggs collected from Chatham Island in 1996 [83] to 12.2 ng/g wet mass in Black-Footed eggs collected from Midway Atoll in 1994-1995 [86] (Table S11). Reproduction and chick survival was normal in American Kestrels (*Falco sparverius*), Canadian Geese (*Branta canadensis*), and Japanese Quail (*Coturnix japonica*) with levels above 2400 ng/g wet mass in eggs as previously reviewed [87].

3.4.8. Polychlorinated Biphenyls (PCBs)

PCBs were widely used in electrical equipment and banned by the Stockholm Convention on POPs. There is potential for reproductive harm to albatrosses from PCB's considering the levels that have been found. In albatross eggs, levels ranged from 19.4 ng/g wet mass in Pacific Albatross (*T. b. platei*, Pa) collected from Chatham Islands in 1996 [83] to 3800 ng/g wet mass in Black-Footed collected from Midway Atoll in 1992-1993 [84] (Table S12). Threshold level of PCBs in eggs for reproductive success ranged from 1000 ng/g wet mass in Chickens to 35 000 ng/g wet mass in American Kestrels and 142 000 ng/g wet mass in Herring Gulls (*Larus argentatus*) as previously reviewed [88]. The levels of PCBs found in Laysan and Black-Footed Albatross from Midway Atoll (3800 ng/g wet mass in Black-Footed) are within the range where reproductive harm could result if albatross are on the sensitive side of the scale.

3.4.9. Contaminant trends

Overall, it appears that albatross species in the Southern Ocean have lower chemical contaminant levels than Laysan and Black-Footed Albatross in the North Pacific. This may be due to 88 % of the world population living in the Northern Hemisphere [89] and thus more contaminants are released from the Northern Hemisphere. There are also differences in land masses and global distillation of chemicals between Northern and Southern hemispheres which are consistent with other studies [90]. The effects of contaminants, other than lead from paint. in albatross have not been well studied. Synergistic studies are especially lacking, although Finkelstein and colleagues [91] studied Black-Footed on Midway and found significant associations between organochlorine contaminants and mercury and altered immune function.

4. Conclusion

4.1. I have strange power of speech;
That moment that his face I see,
I know the man that must hear me:
To him my tale I teach.

Despite our treatment of albatross, they still have a story to teach us about our oceans. By integrating information from regions of the North and South Pacific. South Atlantic, Indian and Southern Oceans, we can use albatross caught in fisheries, along with minimally invasive measurements (blood, feathers, or abandoned eggs) to examine plastic and contaminant levels. Observing prey items brought to chicks and dissecting boluses regurgitated near the end of the breeding season to assess fish and plastics abundance will also provide valuable information that can be used to learn about the state of our oceans.

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Appendix A: Supplemental Materials

The Albatross Species Chemical Database and Annotated Bibliography (ASCDAB) and supplemental tables and figures as results are available for download free of charge from: https://doi.org/10.18434/mds2-2304