Appendix A. Supplementary material

A systematic review of aquatic contamination biomarkers in seabirds and their potential for ocean health monitoring

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Table S1. Criteria for inclusion or exclusion of studies in the systematic review, based on the PICO framework (**P**opulation, **I**ntervention, **C**omparison, **O**utcome) and additional parameters relevant to global ecotoxicological research on seabirds.

PICO	**Inclusion Criteria** QUALIFY the study for inclusion in the systematic review	**Exclusion Criteria** DISQUALIFY the study for inclusion in the systematic review (or qualify it for exclusion)
Population	Seabirds Highlights: "sea bird" OR “seabird” OR “seabirds” OR “pelagic birds” OR “oceanic birds” OR “marine bird” OR "marine birds".	Terrestrial wild birds and domestic birds; Poultry; Migratory shorebirds; Freshwater wild aquatic birds (inland species).
Intervention	Anthropogenic contaminants Highlights: Pollutant OR pollutants OR pollution OR polluted OR contaminant OR contaminated OR contaminants OR contamination OR metal OR metals OR organic OR organics OR xenobiotic OR xenobiotics.	Publications on natural contaminants and toxins.
Comparison	Association between contaminants and biomarkers in correlational or hypothesis-driven studies.	Descriptive studies with levels of contaminants, but without any biomarkers relations.
Outcome	Biomarkers at the biochemical, molecular or	Epidemiological studies involving specific diseases and/or pathogens.

	cellular level measured to assess aquatic contamination; publications involving classical or candidate biomarkers for environmental contamination monitoring should be included, even in the absence of direct associations with contaminants or chemical analyses.	
Additional criteria (type, date, language, nationality, authorship, etc.)	Only original peer-reviewed articles were accepted in this systematic review. No restrictions were applied regarding language, publication date, geographic area, or authors' nationality; restrictions were applied only to the type of publication. During title/abstract screening we must include *review/chapter/book* with similar scope (population, intervention and results) of our review. This will facilitate the reference checking process, avoiding the loss of important documents.	Exclude review articles, conference abstracts, monographs, dissertations, thesis, books and book chapters, or any other type of record that does not constitute an original peer-reviewed article. However, during the screening phase, include reviews, chapters, and books to facilitate the process of checking for potentially missing references.

Contextualization of the research problem:
Seabirds have dominated the skies above the oceans for millions of years. However, they have not experienced similar success in recent centuries due to human activities, which have proven devastating for many seabird species, both directly and indirectly. More recently, bycatch in industrial fisheries, marine pollution, and climate change have become the main threats to this group. These impacts have the potential to reduce population sizes, which is particularly impactful for seabirds given their life-history traits: long lifespans (up to 70 years), low fecundity (as low as one egg every two years), strong reproductive philopatry (returning to the same breeding sites), monogamy, and therefore a limited capacity for population recovery in the face of acute and chronic impacts. Among current threats, ocean pollution adversely affects the health and survival of seabirds. Aquatic contamination biomarkers can provide early indication of exposure or toxic effects of pollutants in seabirds. In this context, there is a clear need to compile the aquatic contamination biomarkers currently being studied worldwide that indicate exposure or toxic effects in seabirds. This will enable the guidance of future research efforts, strengthen the scientific evidence of impact, and bring insights to practical and safe management to be implemented within the scope of environmental biomonitoring and public policies aimed at conservation of the oceans and its biodiversity.

Scientific literature research question:
"*What biomarkers of aquatic contamination were studied or are currently under investigation, and how do they reflect exposure to or toxic effects of ocean pollution in seabirds globally*?"

Objectives of the systematic review:

General objective:
To systematically and quantitatively present the available research on aquatic contamination biomarkers in seabirds.

Specific objectives:

- ✓ To compile scientific articles investigating changes in gene expression, protein levels, and enzyme activity related to biotransformation and oxidative stress systems in response to exposure to anthropogenic contaminants;
- ✓ To compile scientific articles investigating endocrine disruption, immunosuppression, and cyto- and genotoxicity as consequences of exposure to anthropogenic contaminants;
- ✓ To identify different assay conditions used for biomarkers related to biotransformation and oxidative stress in seabirds;
- ✓ To identify the biological materials used in research on aquatic contamination biomarkers in seabirds;
- ✓ To critically analyse the use of aquatic contamination biomarkers in seabirds and propose future research efforts based on gaps and results identified in studies on aquatic contamination biomarkers in seabirds.

Observations: Metals and metalloids were considered contaminants in this review. Monitoring in ecotoxicology, as adopted in our review, refers to the collection of data on contamination, exposure, and/or effects at one or more sites over an extended period (temporal evolution of the analysed variables). It is a crucial component of environmental management because the data are used to estimate trends in contaminant concentrations, assess effects and potential remediation performance, and even predict future changes through extrapolation or modelling.

Sources:

- Vizuete, J., Hernández-Moreno, D., López-Beceiro, A., Fidalgo, L. E., Soler, F., Pérez-López, M., & Míguez-Santiyán, M. P. (2022). Heavy metals and metalloid levels in the tissues of yellow-legged gulls (*Larus michahellis*) from Spain: sex, age, and geographical location differences. *Environmental Science and Pollution Research*, *29*(36), 54292-54308. https://doi.org/10.1007/s11356-022-19627-8
- DiFilippo, E., Tonkin, M., & Huber, W. (2023). Use of Censored Multiple Regression to Interpret Temporal Environmental Data and Assess Remedy Progress. *Groundwater*, 61(6), 846-864. https://doi.org/10.1111/gwat.13315
- Monitoramento da biodiversidade para conservação dos ambientes marinhos e costeiros [electronic book] / ICMBIO. – Brasília, DF: Instituto Chico Mendes - ICMBio, 2024.

PICO tool. Adapted from **https://libguides.umsl.edu/ebp/pico#s-lg-box-22621413** and PICOT Question Template, Ellen Fineout-Overholt, 2006. https://libguides.umsl.edu/ebp/pico#s-lg-box-22621413

Table S2. Search strategy for each database.

Database	Field	Keyword and Boolean operator
Scopus	Title, abstract and key-words	TITLE-ABS-KEY("sea birds" OR "sea bird" OR seabird OR seabirds OR "pelagic birds" OR "pelagic bird" OR "oceanic birds" OR "oceanic bird" OR seafowl OR seafowls OR "marine bird" OR "marine birds") AND TITLE-ABS-KEY(Biomarkers OR Biomarker OR "Biological Marker" OR "Biological Markers" OR "Biologic Marker" OR "Biologic Markers" OR "Immune Markers" OR "Immunologic Markers" OR "Immune Marker" OR "Immunologic Marker" OR Bioindicator OR Bioindicators OR "Biological Indicator" OR "Biological Indicators" OR "Biological Monitoring" OR "Biologic Monitoring" OR "Bio Monitoring" OR biomonitoring OR biotransformation OR "metabolic detoxification" OR detoxification OR "oxidative stress" OR genotoxicity OR "endocrine disrupting" OR immunosuppression OR toxic OR toxics OR toxicology OR effect OR effects OR cytotoxicity) AND TITLE-ABS-KEY(contamination OR contaminations OR contaminants OR contaminant OR contaminated OR pollutant OR pollutants OR pollution OR polluted OR xenobiotic OR xenobiotics OR metal OR metals OR organic OR organics)
Web of Science and Embase	All fields	TS=("sea birds" OR "sea bird" OR seabird OR seabirds OR "pelagic birds" OR "pelagic bird" OR "oceanic birds" OR "oceanic bird" OR seafowl OR seafowls OR "marine bird" OR "marine birds") AND TS=(Biomarkers OR Biomarker OR "Biological Marker" OR "Biological Markers" OR "Biologic Marker" OR "Biologic Markers" OR "Immune Markers" OR "Immunologic Markers" OR "Immune Marker" OR "Immunologic Marker" OR Bioindicator OR Bioindicators OR "Biological Indicator" OR "Biological Indicators" OR "Biological Monitoring" OR "Biologic Monitoring" OR "Bio Monitoring" OR biomonitoring OR biotransformation OR "metabolic detoxification" OR detoxification OR "oxidative stress" OR genotoxicity OR "endocrine disrupting" OR immunosuppression OR toxic OR toxics OR toxicology OR effect OR effects OR cytotoxicity) AND TS=(contamination OR contaminations OR contaminants OR contaminant OR contaminated OR pollutant OR pollutants OR pollution OR polluted OR xenobiotic OR xenobiotics OR metal OR metals OR organic OR organics)
PubMed (Medline)	All fields	("sea birds" OR "sea bird" OR "seabird" OR "seabirds" OR "pelagic birds" OR "pelagic bird" OR "oceanic birds" OR "seafowl" OR "marine bird" OR "marine birds") AND (Biomarkers OR Biomarker OR "Biological Marker" OR "Biological Markers" OR "Biologic Marker" OR "Biologic Markers" OR "Immune Markers" OR "Immunologic Markers" OR "Immune Marker" OR "Immunologic Marker" OR Bioindicator OR Bioindicators OR "Biological Indicator" OR "Biological Indicators" OR "Biological Monitoring" OR "Biologic Monitoring" OR "Bio Monitoring" OR biomonitoring OR biotransformation OR "metabolic detoxification" OR detoxification OR "oxidative stress" OR genotoxicity OR "endocrine disrupting" OR immunosuppression OR toxic OR toxics OR toxicology OR effect OR effects OR cytotoxicity) AND (contamination OR contaminations OR contaminants OR contaminant OR contaminated OR pollutant OR pollutants OR pollution OR polluted OR xenobiotic OR xenobiotics OR metal OR metals OR organic OR organics)
SciELO	All fields	("sea birds" OR "sea bird" OR seabird OR seabirds OR "pelagic birds" OR "pelagic bird" OR "oceanic birds" OR "oceanic bird" OR seafowl OR seafowls OR "marine bird" OR "marine birds" OR "Aves marinhas" OR "ave marinha" OR "pájaros

		marinos" OR "ave marina" OR "pájaro de mar") AND (biomarkers OR biomarker OR "Biological Marker" OR "Biological Markers" OR "Biologic Marker" OR "Biologic Markers" OR "Immune Markers" OR "Immunologic Markers" OR "Immune Marker" OR "Immunologic Marker" OR bioindicator OR bioindicators OR "Biological Indicator" OR "Biological Indicators" OR "Biological Monitoring" OR "Biologic Monitoring" OR "Bio Monitoring" OR biomonitoring OR biotransformation OR "metabolic detoxification" OR detoxification OR "oxidative stress" OR genotoxicity OR "endocrine disrupting" OR immunosuppression OR toxic OR toxics OR toxicology OR effect OR effects OR cytotoxicity OR biomarcador OR biomarcadores OR bioindicador OR "Indicador Biológico" OR "Indicadores Biológicos" OR "Monitoramento Biológico" OR biomonitoramento OR "Monitoreo Biológico" OR "vigilancia biológica" OR "monitorización biológica") AND (contamination OR contaminations OR contaminants OR contaminant OR contaminated OR pollutant OR pollutants OR pollution OR polluted OR xenobiotic OR xenobiotics OR metal OR metals OR organic OR organics OR contaminação OR contaminación OR contaminantes OR contaminante OR contaminado OR poluente OR poluentes OR polutantes OR poluição OR poluído OR polución OR xenobiótico OR xenobióticos OR metal OR metais OR metales OR organico OR orgânicos)
Lilacs	Tittle, abstract and subject	("sea birds" OR "sea bird" OR seabird OR seabirds OR "pelagic birds" OR "pelagic bird" OR "oceanic birds" OR "oceanic bird" OR seafowl OR seafowls OR "marine bird" OR "marine birds" OR "Aves marinhas" OR "ave marinha" OR "pájaros marinos" OR "ave marina" OR "pájaro de mar") AND (biomarkers OR biomarker OR "Biological Marker" OR "Biological Markers" OR "Biologic Marker" OR "Biologic Markers" OR "Immune Markers" OR "Immunologic Markers" OR "Immune Marker" OR "Immunologic Marker" OR bioindicator OR bioindicators OR "Biological Indicator" OR "Biological Indicators" OR "Biological Monitoring" OR "Biologic Monitoring" OR "Bio Monitoring" OR biomonitoring OR biotransformation OR "metabolic detoxification" OR detoxification OR "oxidative stress" OR genotoxicity OR "endocrine disrupting" OR immunosuppression OR toxic OR toxics OR toxicology OR effect OR effects OR cytotoxicity OR biomarcador OR biomarcadores OR bioindicador OR "Indicador Biológico" OR "Indicadores Biológicos" OR "Monitoramento Biológico" OR biomonitoramento OR "Monitoreo Biológico" OR "vigilancia biológica" OR "monitorización biológica") AND (contamination OR contaminations OR contaminants OR contaminant OR contaminated OR pollutant OR pollutants OR pollution OR polluted OR xenobiotic OR xenobiotics OR metal OR metals OR organic OR organics OR contaminação OR contaminación OR contaminantes OR contaminante OR contaminado OR poluente OR poluentes OR polutantes OR poluição OR poluído OR polución OR xenobiótico OR xenobióticos OR metal OR metais OR metales OR organico OR orgânicos) AND (db:("LILACS"))
Google scholar	All fields	("sea bird" OR Seabird) AND (Biomarkers OR biotransformation OR xenobiotics) AND (pollutant OR contamination OR metal OR organics)

Table S3. List of seabird species and number of publications considered in the current systematic review. The classification into Coastal and Pelagic is based on Dias et al. (2019).

Order	Scientific name	Common name	Pelagic / Coastal	Number of papers
Anseriformes	*Bucephala islandica*	Barrow's Goldeneye	Coastal	2
Anseriformes	*Clangula hyemalis*	Long-tailed Duck	Coastal	2
Anseriformes	*Histrionicus histrionicus*	Harlequin Duck	Coastal	3
Anseriformes	*Melanitta fusca*	Velvet Scoter	Coastal	1
Anseriformes	*Melanitta perspicillata*	Surf Scoter	Coastal	4
Anseriformes	*Somateria fischeri*	Spectacled Eider	Coastal	1
Anseriformes	*Somateria mollissima*	Common Eider	Coastal	14
Charadriiformes	*Alca torda*	Razorbill	Pelagic	5
Charadriiformes	*Alle alle*	Little Auk	Pelagic	3
Charadriiformes	*Cepphus columba*	Pigeon Guillemot	Pelagic	3
Charadriiformes	*Cepphus grille*	Black Guillemot	Pelagic	11
Charadriiformes	*Cerorhinca monocerata*	Rhinoceros Auklet	Pelagic	3
Charadriiformes	*Fratercula arctica*	Atlantic Puffin	Pelagic	8
Charadriiformes	*Fratercula cirrhata*	Tufted Puffin	Pelagic	2
Charadriiformes	*Fratercula corniculata*	Horned Puffin	Pelagic	2
Charadriiformes	*Ptychoramphus aleuticus*	Cassin's Auklet	Pelagic	1
Charadriiformes	*Synthliboramphus antiquus*	Ancient Murrelet	Pelagic	1
Charadriiformes	*Chroicocephalus genei*	Slender-billed Gull	Coastal	1
Charadriiformes	*Chroicocephalus ridibundus*	Black-headed Gull	Coastal	4
Charadriiformes	*Ichthyaetus audouinii*	Audouin's Gull	Coastal	3
Charadriiformes	*Larus argentatus*	European Herring Gull	Coastal	27
Charadriiformes	*Larus atlanticus*	Olrog's Gull	Coastal	3
Charadriiformes	*Larus canus*	Mew Gull	Coastal	1
Charadriiformes	*Larus crassirostris*	Black-tailed Gull	Coastal	2
Charadriiformes	*Larus delawarensis*	Ring-billed Gull	Coastal	4
Charadriiformes	*Larus dominicanus*	Kelp Gull	Coastal	4
Charadriiformes	*Larus fuscus*	Lesser Black-backed Gull	Coastal	7
Charadriiformes	*Larus heermanni*	Heermann's Gull	Coastal	1
Charadriiformes	*Larus hyperboreus*	Glaucous Gull	Coastal	12
Charadriiformes	*Larus marinus*	Great Black-backed Gull	Coastal	3
Charadriiformes	*Larus michahellis*	Yellow-legged Gull	Coastal	13
Charadriiformes	*Leucophaeus atricilla*	Laughing Gull	Coastal	3
Charadriiformes	*Pagophila eburnea*	Ivory Gull	Coastal	1
Charadriiformes	*Rissa tridactyla*	Black-legged Kittiwake	Coastal	27
Charadriiformes	*Rynchops niger*	Black Skimmer	Coastal	1
Charadriiformes	*Stercorarius antarcticus*	Brown Skua	Pelagic	2
Charadriiformes	*Stercorarius maccormicki*	South Polar Skua	Pelagic	4
Charadriiformes	*Stercorarius parasiticus*	Arctic Jaeger	Pelagic	1
Charadriiformes	*Stercorarius skua*	Great Skua	Pelagic	5
Charadriiformes	*Gelochelidon nilotica*	Common Gull-billed Tern	Coastal	1
Charadriiformes	*Hydroprogne caspia*	Caspian Tern	Coastal	1

Charadriiformes	*Sterna dougallii*	Roseate Tern	Coastal	1
Charadriiformes	*Sterna forsteri*	Forster's Tern	Coastal	1
Charadriiformes	*Sterna hirundo*	Common Tern	Coastal	20
Charadriiformes	*Sterna paradisaea*	Arctic Tern	Coastal	2
Charadriiformes	*Thalasseus maximus*	Royal Tern	Coastal	2
Charadriiformes	*Uria aalge*	Common Murre	Pelagic	14
Charadriiformes	*Uria lomvia*	Thick-billed Murre	Pelagic	9
Pelecaniformes	*Pelecanus occidentalis*	Brown Pelican	Coastal	4
Phaethontiformes	*Phaethon lepturus*	White-tailed Tropicbird	Pelagic	1
Procellariiformes	*Ardenna carneipes*	Flesh-footed Shearwater	Pelagic	4
Procellariiformes	*Ardenna gravis*	Great Shearwater	Pelagic	1
Procellariiformes	*Ardenna pacifica*	Wedge-tailed Shearwater	Pelagic	1
Procellariiformes	*Ardenna tenuirostris*	Short-tailed Shearwater	Pelagic	1
Procellariiformes	*Calonectris borealis*	Cory's Shearwater	Pelagic	2
Procellariiformes	*Calonectris diomedea*	Scopoli's Shearwater	Pelagic	3
Procellariiformes	*Calonectris leucomelas*	Streaked Shearwater	Pelagic	1
Procellariiformes	*Daption capense*	Cape Petrel	Pelagic	1
Procellariiformes	*Diomedea exulans*	Wandering Albatross	Pelagic	2
Procellariiformes	*Phoebastria immutabilis*	Laysan Albatross	Pelagic	1
Procellariiformes	*Phoebastria nigripes*	Black-footed Albatross	Pelagic	3
Procellariiformes	*Thalassarche chrysostoma*	Grey-headed Albatross	Pelagic	1
Procellariiformes	*Thalassarche melanophris*	Black-browed Albatross	Pelagic	1
Procellariiformes	*Fulmarus glacialis*	Northern Fulmar	Pelagic	12
Procellariiformes	*Macronectes giganteus*	Southern Giant Petrel	Pelagic	3
Procellariiformes	*Macronectes halli*	Northern Giant Petrel	Pelagic	3
Procellariiformes	*Hydrobates furcatus*	Fork-tailed Storm-petrel	Pelagic	1
Procellariiformes	*Hydrobates leucorhous*	Leach's Storm-petrel	Pelagic	3
Procellariiformes	*Pagodroma nivea*	Snow Petrel	Pelagic	4
Procellariiformes	*Procellaria aequinoctialis*	White-chinned Petrel	Pelagic	1
Procellariiformes	*Pterodroma baraui*	Barau's Petrel	Pelagic	1
Procellariiformes	*Pterodroma macroptera*	Great-winged Petrel	Pelagic	
Procellariiformes	*Puffinus puffinus*	Manx Shearwater	Pelagic	1
Procellariiformes	*Puffinus lherminieri*	Audubon's Shearwater	Pelagic	1
Procellariiformes	*Puffinus opisthomelas*	Black-vented Shearwater	Pelagic	1
Sphenisciformes	*Aptenodytes forsteri*	Emperor Penguin	Pelagic	1
Sphenisciformes	*Eudyptes chrysocome*	Southern Rockhopper Penguin	Pelagic	1
Sphenisciformes	*Eudyptula minor*	Little Penguin	Pelagic	2
Sphenisciformes	*Pygoscelis adeliae*	Adélie Penguin	Pelagic	8
Sphenisciformes	*Pygoscelis antarcticus*	Chinstrap Penguin	Pelagic	5

Sphenisciformes	*Pygoscelis papua*	Gentoo Penguin	Pelagic	8
Sphenisciformes	*Spheniscus demersus*	African Penguin	Pelagic	1
Sphenisciformes	*Spheniscus humboldti*	Humboldt Penguin	Pelagic	3
Sphenisciformes	*Spheniscus magellanicus*	Magellanic Penguin	Pelagic	4
Suliformes	*Fregata magnificens*	Magnificent Frigatebird	Pelagic	3
Suliformes	*Morus bassanus*	Northern Gannet	Pelagic	4
Suliformes	*Nannopterum auritum*	Double-crested Cormorant	Coastal	20
Suliformes	*Nannopterum brasilianus*	Neotropical Cormorant	Coastal	1
Suliformes	*Phalacrocorax aristotelis*	European Shag	Coastal	5
Suliformes	*Phalacrocorax carbo*	Great Cormorant	Coastal	13
Suliformes	*Sula dactylatra*	Masked Booby	Pelagic	1
Suliformes	*Sula leucogaster*	Brown Booby	Pelagic	2
Suliformes	*Sula nebouxii*	Blue-footed Booby	Pelagic	3
Suliformes	*Sula sula*	Red-footed Booby	Pelagic	1

Table S4. Glossary of Contaminant Groups, Acronyms, and Definitions. Standardized terminology and definitions for contaminant classes referenced in this review, harmonizing groupings and acronyms according to current ecotoxicological conventions (adapted from Xie et al., 2022 and Li et al., 2024).

Contaminant Group / Acronym	Definition	Examples / Notes
Legacy contaminants	Long-regulated contaminants with well-documented environmental persistence, bioaccumulation, and toxic effects.	PCBs, OCPs (DDT/DDE, HCB), PBDEs, metals/metalloids (Hg, Pb, Cd).
Emerging contaminants	Compounds of current or increasing concern for which environmental distribution and toxicological effects are not fully understood.	PFASs (PFOS, PFOA), novel flame retardants (NBFRs), pharmaceuticals and personal care products (PPCPs), plastic-related chemicals (phthalates, BPA).
Organic contaminants *(broad category)*	Anthropogenic carbon-based chemicals that contaminate marine ecosystems through industrial, agricultural, or urban sources. They include persistent, bioaccumulative compounds (legacy contaminants) as well as recently recognized emerging contaminants.	POPs, PCBs, OCPs, PBDEs, PFASs, petroleum hydrocarbons (crude oil), triclosan, plastic-related additives.
POPs – Persistent Organic Pollutants	Organic contaminants resistant to degradation, with long-range transport and biomagnification potential.	OCPs, PCBs, PBDEs.
OCPs – Organochlorine Pesticides	Chlorinated pesticides historically used in agriculture and vector control.	Dichlorodiphenyltrichloroethane / Dichlorodiphenyldichloroethylene (DDT/DDE), aldrin, dieldrin, endosulfan, hexachlorobenzene (HCB).
PCBs – Polychlorinated Biphenyls	Industrial chemicals widely used in transformers and capacitors; persistent and strongly lipophilic.	Dioxin-like and non-dioxin-like congeners.
PBDEs – Polybrominated Diphenyl Ethers	Flame retardants used in plastics, textiles, and electronics; persistent in marine food webs.	BDE-47, BDE-99, BDE-209.
HAHs – Halogenated Aromatic Hydrocarbons	Aromatic compounds with halogen substitutions.	Dioxins, furans, some PCB congeners.
PFASs – Per- and Polyfluoroalkyl Substances (formerly **PFCs**)	Highly stable fluorinated compounds used in industrial and consumer products. Some are bioaccumulative and toxic.	PFOS, PFOA, fluorotelomer sulfonates (FTSs).
HPPs – Hydrophobic Persistent Pollutants	Lipophilic contaminants with strong biomagnification potential due to environmental persistence.	PCBs, PBDEs, selected OCPs.

Contaminant Group / Acronym	Definition	Examples / Notes
Metals and metalloids	Elements capable of inducing toxicity, oxidative stress, and biomarker responses.	Hg, Pb, Cd, As, Cr; essential metals such as Zn and Cu at elevated levels.
Plastic-related chemicals	Additives or monomers associated with plastic production and degradation.	Phthalates, bisphenol A (BPA), styrene derivatives.
Biotoxins *(excluded)*	Naturally occurring biological toxins; excluded because this review focuses on anthropogenic contaminants.	Algal toxins (e.g., domoic acid).

Reference of concepts presented within this Table were adapted from: Li, X., Shen, X., Jiang, W., Xi, Y., & Li, S. (2024). Comprehensive review of emerging contaminants: Detection technologies, environmental impact, and management strategies. *Ecotoxicology and Environmental Safety*, *278*, 116420. https://doi.org/10.1016/j.ecoenv.2024.116420 and Xie, Z., Zhang, P., Wu, Z., Zhang, S., Wei, L., Mi, L., ... & Mi, W. (2022). Legacy and emerging organic contaminants in the polar regions. Science of the Total Environment, 835, 155376. https://doi.org/10.1016/j.scitotenv.2022.155376

Table S5. Biomarkers related to the general health conditions of seabirds, screened in studies published between 1976 and 2025. The number of articles (*n*) that investigated each biomarker is shown. Associations between biomarkers and contaminants are represented by positive correlations (+), negative correlations (-), or by increases (↑) or decreases (↓) in biomarkers compared to a control group. NF (Not Found) indicates the absence of significant associations between biomarkers and contaminants, whereas NA (Not Applicable) refers to articles that did not directly investigate associations between biomarkers and contaminants. Gene names are in italics.

Biomarker	*n*	Association with contaminant(s) (+/-, ↑/↓)	Species	Reference
Albumin (alb)	3	(NF) organic (PAHs), and inorganic (As, Ba, Cd, Cu, Fe, Mn, Mo, Ni, Pb, Rb, Se, Sn, Sr, V and Zn) contaminants	*Morus bassanus*	(Champoux et al., 2020)
		(NF) PBDEs and other flame retardants (PBEB, dechlorane 602 and dechlorane plus)	*Fulmarus glacialis*	(Mortensen et al., 2022)
		(NF) plastic ingestion	*Ardenna carneipes*	(de Jersey et al., 2025)
Albumin (plasma)	10	(NF) organic contaminants (oil)	*Cepphus columba*	(Seiser et al., 2000)
		(↑) aviation fuel – JP-1, polar diesel	*Pysgoscelis adeliae*	(Najle et al., 2006)
		(+) organic contaminants (PCBs, DDTs, HCB, CHLs, Mirex)	*Stercorarius skua*	(Sonne et al., 2013)
		(NF) organic contaminants (oil)	*Nannopterum auritum*, *Leucophaeus atricilla*	(Dean et al., 2017b)
		(↓) organic contaminants (oil)	*Nannopterum auritum*	(Dean et al., 2017a)
		(NF) organic (HPAs) and inorganic (As, Ba, Cd, Cu, Fe, Mn, Mo, Ni, Pb, Rb, Se, Sn, Sr, V and Zn) contaminants	*Morus bassanus*	(Champoux et al., 2020)
		(NF) Hg	*Somateria mollissima*	(Ma et al., 2020)
		NA	*Larus atlanticus*	(García et al., 2023)
		(-) THg	*Stercorarius antarcticus*	(Ibañez et al., 2024)
		NA	*Cerorhinca monocerata*	(Lee et al., 2024)
Alpha-actinin-2 (ACTN2)	1	(-) HCH (β-hexachlorocyclohexane)	*Nannopterum auritum*	(King et al., 2025)
α-Amino-β-carboxymuconate-ε-semialdehyde Decarboxylase (ACMSD)	1	(+) PCBs	*Nannopterum auritum*	(King et al., 2025)

Alpha-hydroxybutyrate dehydrogenase (α-HBD)	1	(NF) organic contaminants (oil)	*Cepphus grille*	(Peakall et al., 1980)
Alpha-tocopherol (α-tocopherol or vitamin E)	7	(+) PCB-74, -66, -118, -153, -105, -138; (NF) PCB-74, -66, -118, -153, -105, -138 (nestlings de Kongsfjorden); (NF) PCB-28, -52, -47, -101, -99, - 149, -114, -137, -187, -183, - 128, -156, -157, -180, -170, -189, -194, PBDE-28, -47, -99, -100, -153, -154, HBCD, HCB, β-HCH, Oxichlordane, p,p'-DDE, Mirex	*Rissa tridactyla*	(Murvoll et al., 2006)
		(-) PBDE-28	*Phalacrocorax aristotelis*	
		(-) HCB, oxichlordane, p,p′-DDE; (NF) PCB-28, -52, -47, -74, -66, -101, -99, -149, -118, -114, -153, -105, -137, -138, -187, -183, -128, -156, -157, -180, -170, -189, -194, β-HCH, Mirex, PBDE-28, -47, -99, -100, -153, -154, HBCD	*Uria lomvia*	(Murvoll et al., 2007)
		(+) PCBs, β-HCH e oxichlordane; (NF) HCB, p,p'-DDE, Mirex, PBDE-28, -47, -99, -100, -153, -154, HBCD	*Somateria mollissima*	
		(NF) PCB-28, -52, -47, -74, -66, -101, -99, -149, -118, -114, -153, -105, -137, -138, -187, -183, -128, -156, -157, -180, -170, -189, -194, HCB, β-HCH, p,p'-DDE, Mirex, PBDE-28, -47, -99, -100, -153, -154, oxichlordane and HBCD	*Uria lomvia*, *Somateria mollissima*	
		(NF) PCB-105,-118,-138,-153,-180, p,p′-DDE, HCB, HCE, oxichlordane, Parlar 26, Parlar 50	*Phalacrocorax aristotelis*	(Jenssen et al., 2010)
		(↑) organic contaminants (oil)	*Larus michahellis*	(Pérez, Lores and Velando, 2010)
		(-) organic contaminants - p,p′-DDE, oxichlordane, trans-nonachlor, PCB-28, -47, -66, -74, -99, -101, -105, -114, -118, -128, -137, -138, -141, -149, -153, -156, -157, -170, -180, -183, -187, -189, -194, -196 e -206, hexabromocyclododecane [∑α-, β- e γ-HBCD], (NF) Hg	*Pagophila eburnea*	(Miljeteig et al., 2012)
		NA	*Sterna hirundo*	(Oudi et al., 2019)
		(-) dicyclohexyl phthalate (DCHP)	*Larus argentatus*	(Allen et al., 2021)
Amylase	4	(-) organic contaminants (HCHs)	*Stercorarius skua*	(Sonne et al., 2013)
		(+) plastic ingestion	*Ardenna carneipes*	(Lavers, Hutton and Bond, 2019)
		(NF) Hg	*Somateria mollissima*	(Ma et al., 2020)
		NA	*Cerorhinca monocerata*	(Lee et al., 2024)
Basal metabolic rate (BMR)	2	(-) organic contaminants (CHL - chlordane, PCB, DDT)	*Larus hyperboreus*	(Verreault et al., 2007)
		(-) CHL – females and males; (+) PFTrA - females; (NF) Hg, PCBs, p,p′-DDE, β-HCH, HCB, PFOSlin, PFNA, PFDcA, PFUnA e PFDoA.	*Rissa tridactyla*	(Blévin et al., 2017a)
Basophil count (haematology)	5	(NF) organic contaminants (oil)	*Cepphus columba*	(Seiser et al., 2000)

		(+) PCBs and DDE	*Sterna caspia*	(Grasman and Fox, 2001)
		(NF) DDTs, PCBs, HCB, α-endosulfan, β-endosulfan	*Pygoscelis antarcticus*	(Jara-Carrasco et al., 2015)
		NA	*Pygoscelis papua*, *P. adeliae*	(D'Amico et al., 2016)
		NA	*Larus atlanticus*	(García et al., 2023)
Biliverdin	1	(-) ∑DDTs	*Gelochelidon nilotica*	(Pérez de Vargas et al., 2020)
Calcium (plasma)	10	(↓) organic contaminants (oil)	*Cepphus columba*	(Seiser et al., 2000)
		(+) ∑PAHs, in nestlings	*Larus michahellis*	(Alonso-Alvarez, Pérez and Velando, 2007)
		(-) organic contaminants (HCHs)	*Stercorarius skua*	(Sonne et al., 2013)
		(↓) organic contaminants (oil)	*Nannopterum auritum*	(Dean et al., 2017a)
		(↓) organic contaminants (oil)	*Nannopterum auritum*	(Dean et al., 2017b)
		(-) plastic ingestion	*Ardenna carneipes*	(Lavers, Hutton and Bond, 2019)
		(-) organic contaminants (1-Metilnaf)	*Morus bassanus*	(Champoux et al., 2020)
		(NF) Hg	*Somateria mollissima*	(Ma et al., 2020)
		NA	*Cerorhinca monocerata*	(Lee et al., 2024)
		(NF) plastic ingestion	*Ardenna pacifica*	(Mejia et al., 2024)
Caspase-1 (CASP1)	1	(+) HCH (β-hexachlorocyclohexane)	*Nannopterum auritum*	(King et al., 2025)
Carbon dioxide (serum)	2	NA	*Cerorhinca monocerata*	(Lee et al., 2024)
		(NF) plastic ingestion	*Ardenna pacifica*	(Mejia et al., 2024)
Cardiac isoform of troponin I (cTnI)	1	NA	*Nannopterum auritum*	(Daigneault et al., 2017)
Carotenoids (astaxanthin, zeaxanthin, lutein, cryptoxanthin)	1	(+) organic contaminants (PFAS); (NF) Hg	*Rissa tridactyla*	(Costantini et al., 2022)
Carotenoids (other)	2	(+) PCB-99, -118, -138, -153, -170 and -180; (NF) HCB, β-HCH, oxichlordane and p,p'-DDE	*Larus marinus*	(Bustnes, Kristiansen and Helberg, 2007)
		(-) organic contaminants (oil)	*Larus michahellis*	(Pérez, Lores and Velando, 2010)
CCAAT enhancer-binding protein beta (CEBPB)	1	(-) PCBs	*Nannopterum auritum*	(King et al., 2025)

Chloride (plasma or serum)	2	NA	*Cerorhinca monocerata*	(Lee et al., 2024)
		(NF) plastic ingestion	*Ardenna pacifica*	(Mejia et al., 2024)
Cholesterol	11	(↓) ∑PAHs	*Larus michahellis*	(Alonso-Alvarez, Pérez and Velando, 2007)
		(NF) organic contaminants	*Stercorarius skua*	(Sonne et al., 2013)
		NA	*Pygoscelis papua*, *P. adeliae*	(D'Amico et al., 2016)
		(NF) organic contaminants (oil)	*Nannopterum auritum*, *Leucophaeus atricilla*	(Dean et al., 2017b)
		(↓) organic contaminants (oil)	*Nannopterum auritum*	(Dean et al., 2017a)
		(+) plastic ingestion	*Ardenna carneipes*	(Lavers, Hutton and Bond, 2019)
		(NF) organic (PAHs), and inorganic (As, Cu, Fe, Ni, Rb, Se, V, Zn in blood; As, Ba, Cd, Cu, Fe, Mn, Mo, Pb, Rb, Se, Sn, Sr, V and Zn in feathers) contaminants	*Morus bassanus*	(Champoux et al., 2020)
		(NF) Hg	*Somateria mollissima*	(Ma et al., 2020)
		NA	*Larus atlanticus*	(García et al., 2023)
		NA	*Cerorhinca monocerata*	(Lee et al., 2024)
		(NF) THg	*Stercorarius antarcticus*	(Ibañez et al., 2024)
Creatine	1	(NF) plastic ingestion	*Ardenna pacifica*	(Mejia et al., 2024)
Creatine phosphokinase (CPK)	7	(NF) organic contaminants (oil)	*Cepphus columba*	(Seiser et al., 2000)
		(↑) organic contaminants (oil)	*Nannopterum auritum*	(Dean et al., 2017a)
		(↑) organic contaminants (oil)	*Nannopterum auritum*	(Dean et al., 2017b)
		(NF) organic contaminants (oil)	*Leucophaeus atricilla*	(Horak et al., 2017)
		(NF) organic (PAHs) and inorganic (As, Ba, Cd, Cu, Fe, Mn, Mo, Ni, Pb, Rb, Se, Sn, Sr, V and Zn) contaminants	*Morus bassanus*	(Champoux et al., 2020)
		(NF) organic contaminants (PAHs)	*Pelecanus occidentalis*	(Jodice et al., 2023)
		NA	*Cerorhinca monocerata*	(Lee et al., 2024)
Creatinine	6	(↓)∑PAHs (only adults)	*Larus michahellis*	(Alonso-Alvarez, Pérez and Velando, 2007)
		(NF) organic contaminants	*Stercorarius skua*	(Sonne et al., 2013)

		(NF) organic contaminants (oil)	*Nannopterum auritum*, *Leucophaeus atricilla*	(Dean et al., 2017b)
		(↑) organic contaminants (oil)	*Nannopterum auritum*	(Dean et al., 2017a)
		(NF) Hg	*Somateria mollissima*	(Ma et al., 2020)
		NA	*Cerorhinca monocerata*	(Lee et al., 2024)
Early growth response gene 1 (EGR1)	1	(+) PCBs	*Nannopterum auritum*	(King et al., 2025)
Eosinophil count (haematology)	6	(NF) organic contaminants (oil)	*Cepphus columba*	(Seiser et al., 2000)
		(NF) organic contaminants (OCs, PCBs, PCDDs, PCDFs, PBDEs, PAHs)	*Melanitta perspicillata*	(Wilson et al., 2010)
		(-) DDTs and PCBs; (NF) HCB, α-endosulfan, β-endosulfan	*Pygoscelis antarcticus*	(Jara-Carrasco et al., 2015)
		NA	*Pygoscelis papua*, *P. adeliae*	(D'Amico et al., 2016)
		(NF) organic contaminants (oil)	*Nannopterum auritum*	(Dean et al., 2017b)
		NA	*Larus atlanticus*	(García et al., 2023)
Erythrocyte sedimentation rate - ESR (Pi)	3	(-) Hg, Se, (NF) As, Cd, Co, Cr, Cu, Fe, Hg, Mn, Ni, Pb, Sn, Sr, Zn)	*Larus michahellis*, *Ichthyaetus audouinii*, *Calonectris borealis*	(dos Santos et al., 2024)
		(NF) PBDE - polybrominated diphenyl ethers - BDE99 (plasticizer)	*Larus michahellis*, *L. fuscus*	(Veríssimo et al., 2024a)
		(-) PBDE, MeO-BDEs	*Larus michahellis, Ichthyaetus audouinii*	(Veríssimo et al., 2024b)
Fibroblast growth factor 19 (FGF19)	1	(-) total mercury (THg)	*Cerorhinca monocerata*	(King et al., 2023)
Ferritin (FT)	1	(+) PAHs	*Uria aalge*	(Troisi et al., 2007)
Fructosamine	2	(-) organic contaminants (PBDEs)	*Stercorarius skua*	(Sonne et al., 2013)
		(NF) Hg	*Somateria mollissima*	(Ma et al., 2020)
Gastrokine-2 (GKN2_1)	1	(NF) plastic ingestion	*Ardenna carneipes*	(de Jersey et al., 2025)
Glucose	12	(↓) ∑PAHs (only adults)	*Larus michahellis*	(Alonso-Alvarez, Pérez and Velando, 2007)
		(NF) organic contaminants	*Stercorarius skua*	(Sonne et al., 2013)
		NA	*Spheniscus magellanicus*	(Carabajal et al., 2016)

		NA	*Pygoscelis papua*, *Pygoscelis adeliae*	(D'Amico et al., 2016)
		(↓) organic contaminants (oil)	*Nannopterum auritum*	(Dean et al., 2017a)
		(↓) organic contaminants (oil)	*Nannopterum auritum*	(Dean et al., 2017b)
		(NF) organic (PAHs) and inorganic (As, Ba, Cd, Cu, Fe, Mn, Mo, Ni, Pb, Rb, Se, Sn, Sr, V and Zn) contaminants	*Morus bassanus*	(Champoux et al., 2020)
		(NF) Hg	*Somateria mollissima*	(Ma et al., 2020)
		NA	*Larus atlanticus*	(García et al., 2023)
		(NF) THg	*Stercorarius antarcticus*	(Ibañez et al., 2024)
		NA	*Cerorhinca monocerata*	(Lee et al., 2024)
		(NF) plastic ingestion	*Ardenna pacifica*	(Mejia et al., 2024)
Glutamate dehydrogenase (GLDH)	1	(↑) organic contaminants (oil)	*Nannopterum auritum*	(Dean et al., 2017a)
Haptoglobin (HP)	4	(NF) organic contaminants (oil)	*Cepphus columba*	(Prichard et al., 1997)
		(-) PAHs	*Uria aalge*	(Troisi et al., 2007)
		(NF) organic contaminants (oil)	*Nannopterum auritum*, *Leucophaeus atricilla*	(Dean et al., 2017b)
		NA	*Cerorhinca monocerata*	(Lee et al., 2024)
Haptoglobin (HP)	1	(NF) organic contaminants	*Phalacrocorax carbo*	(Nakayama et al., 2006)
Haematocrit or packed cell volume (PCV)	21	(-) p,p'-DDE	*Larus argentatus*	(Grasman, Scanlon and Fox, 2000)
		(NF) organic contaminants (oil)	*Cepphus columba*	(Seiser et al., 2000)
		(NF) organic contaminants (PCBs and 21 pesticides)	*Sterna caspia*	(Grasman and Fox, 2001)
		(+) ∑PAHs (nestlings)	*Larus michahellis*	(Alonso-Alvarez, Pérez and Velando, 2007)
		(NF) organic (PCBs, DDTs, Clordanos, HCB), and (NF) inorganic (Ag, Cd, Sn, Pb, Cr, Ni, Cu, Zn, As, Se and total Hg) contaminants	*Phoebastria nigripes*	(Finkelstein et al., 2007)
		(+) Hg	*Larus atlanticus*	(La Sala et al., 2011)
		(↓) organic contaminants (oil)	*Sterna hirundo*	(Nisbet, Tseng and Apanius, 2013)
		(NF) organic contaminants (oil)	*Spheniscus magellanicus*	(Romero et al., 2015)
		NA	*Spheniscus magellanicus*	(Carabajal et al., 2016)
		NA	*Pygoscelis papua*, *P. adeliae*	(D'Amico et al., 2016)

		(+) organic contaminants (oil)	*Uria aalge*	(Duerr, Ziccardi and Massey, 2016)
		(↓) organic contaminants (oil)	*Nannopterum auritum*	(Dean et al., 2017b)
		(↓) organic contaminants (oil)	*Nannopterum auritum*	(Harr et al., 2017)
		(NF) organic contaminants (oil)	*Leucophaeus atricilla*	(Horak et al., 2017)
		(NF) organic (PAHs) and inorganic (oil) (As, Cu, Fe, Ni, Rb, Se, V, Zn in blood; As, Ba, Cd, Cu, Fe, Mn, Mo, Pb, Rb, Se, Sn, Sr, V and Zn in feathers) contaminants	*Morus bassanus*	(Champoux et al., 2020)
		(↓) organic contaminants (oil)	*Rynchops niger*, *Pelecanus occidentalis*	(Fallon et al., 2020)
		NA	*Larus atlanticus*	(García et al., 2023)
		(-) THg	*Stercorarius antarcticus*	(Ibañez et al., 2024)
		(NF) organic contaminants (PAHs)	*Pelecanus occidentalis*	(Jodice et al., 2023)
		(NF) plastic ingestion	*Ardenna pacifica*	(Mejia et al., 2024)
		(-) PFAS, PFOS in females, (+) PFAS, PFOS in males	*Eudyptula minor*	(Wells et al., 2024)
Haemoglobin	6	(NF) organic contaminants (oil)	*Cepphus columba*	(Seiser et al., 2000)
		(NF) organic contaminants (oil)	*Nannopterum auritum*, *Leucophaeus atricilla*	(Dean et al., 2017b)
		(↓) organic contaminants (oil)	*Rynchops niger*, *Pelecanus occidentalis*	(Fallon et al., 2020)
		(NF) plastic ingestion	*Ardenna pacifica*	(Mejia et al., 2024)
		(NF) inorganic contaminants (Hg, Se, As, Cd, Co, Cr, Cu, Fe, Hg, Mn, Ni, Pb, Sn, Sr, Zn)	*Larus michahellis*, *Ichthyaetus audouinii*, *Calonectris borealis*	(dos Santos et al., 2024)
		(+) PBDE, MeO-BDEs	*Larus michahellis, Ichthyaetus audouinii*	(Veríssimo et al., 2024b)
Hemopexin (HPX)	2	(-) organic contaminants (PCBs)	*Nannopterum auritum*	(King et al., 2025)
		(+) Chlordane compounds (CHLs) - males; (NF) organic contaminants - females	*Phalacrocorax carbo*	(Nakayama et al., 2006)
Heat shock protein (HSP70)	4	(-) organic contaminants (PFCs; DRCs)	*Phalacrocorax carbo*	(Nakayama et al., 2008)
		NA	*Eudyptes chrysocome*, *Pygoscelis papua*	(Bowen et al., 2022)
		(NF) THg, methyl mercury (Me–Hg)	*Nannopterum auritum*	(Gibson et al., 2014)

		(NF) organic contaminants (PAHs, PCBs, DDTs, HCB, Drins, Mirex)	*Puffinus puffinus*	(Serafini et al., 2024)
Heinz bodies in red blood cells	5	(NF) organic contaminants (oil)	*Nannopterum auritum*, *Leucophaeus atricilla*	(Dean et al., 2017b)
		(↑) organic contaminants (oil)	*Nannopterum auritum*	(Harr et al., 2017)
		(+) organic contaminants (oil)	*Leucophaeus atricilla*	(Horak et al., 2017)
		(↑) organic contaminants (oil)	*Rynchops niger*, *Pelecanus occidentalis*	(Fallon et al., 2020)
		(+) PAHs	*Uria aalge*	(Troisi et al., 2007)
Heterophil count	13	(+) p,p'-DDE	*Larus argentatus*	(Grasman, Scanlon and Fox, 2000)
		(NF) organic contaminants (oil)	*Cepphus columba*	(Seiser et al., 2000)
		(+) OCs	*Larus hyperboreus*	(Bustnes et al., 2004)
		(+) organic contaminants (organochlorines), (NF) inorganic contaminants (Ag, Cd, Sn, Pb, Cr, Ni, Cu, Zn, As, Se e Hg total.)	*Phoebastria nigripes*	(Finkelstein et al., 2007)
		(+) organic contaminants (PCBs)	*Melanitta perspicillata*	(Wilson et al., 2010)
		(+) DDTs e PCBs; (NF) HCB, α-endosulfano, β-endosulfano	*Pygoscelis antarcticus*	(Jara-Carrasco et al., 2015)
		(-) organic contaminants (oil)	*Sterna hirundo*	(Nisbet et al., 2015)
		NA	*Pygoscelis papua*, *P. adeliae*	(D'Amico et al., 2016)
		(NF) organic contaminants (oil)	*Nannopterum auritum*, *Leucophaeus atricilla*	(Dean et al., 2017b)
		NA	*Pygoscelis adeliae*	(Olmastroni et al., 2019)
		(-) organic (PAHs), and (NF) inorganic (As, Cu, Fe, Ni, Rb, Se, V, Zn in blood; As, Ba, Cd, Cu, Fe, Mn, Mo, Pb, Rb, Se, Sn, Sr, V and Zn in feathers) contaminants	*Morus bassanus*	(Champoux et al., 2020)
		NA	*Larus atlanticus*	(García et al., 2023)
		(NF) organic contaminants (PAHs)	*Pelecanus occidentalis*	(Jodice et al., 2023)
Highly carboxylated porphyrins	2	(+) PCBs	*Larus argentatus*	(Kennedy et al., 1998)
		(+) PCBs - adults; (NF) PCBs - nestlings	*Larus argentatus*	(Grasman, Scanlon and Fox, 2000)
Hydroxymethylbilane synthase (hMBS_2)	1	(NF) plastic ingestion	*Ardenna carneipes*	(de Jersey et al., 2025)
Immature erythrocyte counts (IE)	2	(+) inorganic (Hg, Se), (NF) inorganic (As, Cd, Co, Cr, Cu, Fe, Hg, Mn, Ni, Pb, Sn, Sr, Zn)	*Larus michahellis*, *Ichthyaetus audouinii*, *Calonectris borealis*	(dos Santos et al., 2024)

		(+) PBDE, MeO-BDEs	*Larus michahellis*, *Ichthyaetus audouinii*	(Veríssimo et al., 2024b)
Laminin gamma-3 (LAMC3)	1	(-) PCBs	*Nannopterum auritum*	(King et al., 2025)
Liver Basic Fatty Acid Binding Protein (lbfabp)	2	(-) THg	*Cerorhinca monocerata*	(King et al., 2023)
		(↓) organic contaminants (52 polycyclic aromatic compounds - PACs)	*Cepphus grylle*	(Zahaby et al., 2025)
Lipase	1	NA	*Cerorhinca monocerata*	(Lee et al., 2024)
Lymphocyte count	13	(+) PCBs	*Larus argentatus*	(Grasman, Scanlon and Fox, 2000)
		(↑) organic contaminants (oil)	*Cepphus columba*	(Seiser et al., 2000)
		(+) OCs	*Larus hyperboreus*	(Bustnes et al., 2004)
		(+) organic (organochlorines), and (NF) inorganic (Ag, Cd, Sn, Pb, Cr, Ni, Cu, Zn, As, Se and total Hg) contaminants	*Phoebastria nigripes*	(Finkelstein et al., 2007)
		(-) organic contaminants (PCBs)	*Melanitta perspicillata*	(Wilson et al., 2010)
		NA	*Pygoscelis papua*	(Barbosa et al., 2013)
		(-) DDTs e PCBs; (NF) HCB, α-endosulfan, β-endosulfan	*Pygoscelis antarcticus*	(Jara-Carrasco et al., 2015)
		(+) organic contaminants (oil)	*Sterna hirundo*	(Nisbet et al., 2015)
		NA	*Pygoscelis papua*, *P. adeliae*	(D'Amico et al., 2016)
		(NF) organic contaminants (oil)	*Nannopterum auritum*, *Leucophaeus atricilla*	(Dean et al., 2017b)
		(+) organic (PAHs), and (NF) inorganic (As, Cu, Fe, Ni, Rb, Se, V, Zn in blood; As, Ba, Cd, Cu, Fe, Mn, Mo, Pb, Rb, Se, Sn, Sr, V and Zn in feathers) contaminants	*Morus bassanus*	(Champoux et al., 2020)
		NA	*Larus atlanticus*	(García et al., 2023)
		(+) organic contaminants (PAHs)	*Pelecanus occidentalis*	(Jodice et al., 2023)
Magnesium (plasma or serum)	3	(-) HCHs, (+) CHLs	*Stercorarius skua*	(Sonne et al., 2013)
		(NF) Hg	*Somateria mollissima*	(Ma et al., 2020)
		NA	*Cerorhinca monocerata*	(Lee et al., 2024)
Malic enzyme activity in liver	1	(NF) organic contaminants (PCBs)	*Cepphus grylle*	(Kuzyk et al., 2003)
Mean Cell Volume (MCV)	1	(↓) organic contaminants (oil)	*Cepphus columba*	(Seiser et al., 2000)

Mean corpuscular haemoglobin concentration (MCHC)	1	(NF) organic contaminants (oil)	*Cepphus columba*	(Seiser et al., 2000)
Methylation and hydroxymethylation	1	(NF) Organic (PAHs)	*Nannopterum auritum*	(Wallace et al., 2018)
Monocyte count	7	(-) PCBs and DDE	*Sterna caspia*	(Grasman and Fox, 2001)
		(NF) organic (PCBs, DDTs, Clordanos, HCB), and (NF) inorganic (Ag, Cd, Sn, Pb, Cr, Ni, Cu, Zn, As, Se and total Hg) contaminants	*Phoebastria nigripes*	(Finkelstein et al., 2007)
		(NF) organic contaminants (OCs, PCBs, PCDDs, PCDFs, PBDEs, PAHs)	*Melanitta perspicillata*	(Wilson et al., 2010)
		(NF) DDTs, PCBs, HCB, α-endosulfan, β-endosulfan	*Pygoscelis antarcticus*	(Jara-Carrasco et al., 2015)
		NA	*Pygoscelis papua*, *P. adeliae*	(D'Amico et al., 2016)
		(↑) organic contaminants (oil)	*Nannopterum auritum*	(Dean et al., 2017b)
		NA	*Larus atlanticus*	(García et al., 2023)
Monoenols	1	(-) ∑OCs	*Sterna hirundo*	(Mateo et al., 2004)
Na^+/K^+-ATPase activity (nasal gland – in vitro)	1	(↓) DDE.	*Cepphus grylle*, *Fratercula arctica*	(Miller et al., 1976)
Na^+/K^+-ATPase activity (nasal gland – in vivo)	1	(NF) DDE	*Cepphus grylle*	(Miller et al., 1976)
		(↓) DDE.	*Fratercula arctica*	
Omega-3 polyunsaturated fatty acids (n-3 PUFAs)	1	(+) ∑OC	*Sterna hirundo*	(Mateo et al., 2004)
Ovotransferrin	1	(NF) organic contaminants	*Phalacrocorax carbo*	(Nakayama et al., 2006)
Peptidylarginine deiminases (PADs) and extracellular vesicles (EVs)	1	NA	*Diomedea exulans*, *Thalassarche chrysostoma*, *T. melanophris*, *Macronectes halli*, *M. giganteus*, *Procellaria aequinoctialis*, *Stercorarius antarcticus*, *S. maccormicki*	(Phillips, Kraev and Lange, 2020)
Phenylalanine hydroxylase (PAH)	1	(NF) organic contaminants (52 polycyclic aromatic compounds - PACs)	*Cepphus grylle*	(Zahaby et al., 2025)
Phosphorus (plasma)	5	(NF) organic contaminants (oil)	*Cepphus columba*	(Seiser et al., 2000)
		(NF) organic contaminants (oil)	*Nannopterum auritum*, *Leucophaeus atricilla*	(Dean et al., 2017b)
		(↑) organic contaminants (oil)	*Nannopterum auritum*	(Dean et al., 2017a)

		(-) organic contaminants (1-Metilnaph)	*Morus bassanus*	(Champoux et al., 2020)
		NA	*Cerorhinca monocerata*	(Lee et al., 2024)
Plasma-blood lipid content (%)	1	(NF) organic contaminants	*Stercorarius skua*	(Bustnes et al., 2015)
Plasma inorganic phosphate	2	(-) organic contaminants (PBDEs)	*Stercorarius skua*	(Sonne et al., 2013)
		(NF) Hg	*Somateria mollissima*	(Ma et al., 2020)
Plasma osmolarity (electrolytes)	1	(NF) DDE	*Cepphus grylle*, *Fratercula arctica*	(Miller et al., 1976)
Plasma proteome - proteins of interest labeled as BdnF, AlB, GAPdh, hMGB1, pepsinogen A5 (PGA5) (29) and gastrokine- 2 (GKN2)	1	(+) plastic ingestion	*Ardenna carneipes*	(de Jersey et al., 2025)
Potassium (plasma or serum)	7	(NF) organic contaminants	*Stercorarius skua*	(Sonne et al., 2013)
		(NF) organic contaminants (oil)	*Nannopterum auritum*, *Leucophaeus atricilla*	(Dean et al., 2017b)
		(↑) organic contaminants (oil)	*Nannopterum auritum*	(Dean et al., 2017a)
		(+) organic contaminants (1-Metilnaph)	*Morus bassanus*	(Champoux et al., 2020)
		(NF) Hg	*Somateria mollissima*	(Ma et al., 2020)
		NA	*Cerorhinca monocerata*	(Lee et al., 2024)
		(NF) plastic ingestion	*Ardenna pacifica*	(Mejia et al., 2024)
Poikilocytosis	1	NA	*Larus dominicanus*	(Frixione et al., 2022)
Porphyrins (copro-, uro-, proto-)	9	(+) PCB-118; (NF) Oxichlordane, p,p'-DDE, p,p'-DDT, HCB, Mirex, PCB-28, -52, -99, -101, -138, -153, -170 and -180	*Larus hyperboreus*	(Henriksen et al., 2000)
		NA	*Pelecanus occidentalis thagus*, *Nannopterum brasilianum*, *Larus dominucanus*	(Casini, 2001)
		(NF) organic contaminants (PCBs)	*Cepphus grylle*	(Kuzyk et al., 2003)
		(NF) organic contaminants (OCs, PCBs, PCDDs, PCDFs, PBDEs, PAHs)	*Melanitta perspicillata*	(Wilson et al., 2010)
		(+) Hg, Pb; (NF) As, Cd.	*Pygoscelis papua*	(Celis et al., 2012)
		(+) As, Pb e Cu; (-) Zn; (NF) Hg and Cd	*Spheniscus humboldti*	(Celis et al., 2014)
		(+) organic contaminants (PAHs)	*Nannopterum auritum*	(Crump et al., 2017)
		(+) organic contaminants (PCBs, DDTs)	*Pygoscelis adeliae*, *P. antarcticus*, *P. papua*	(Jara-Carrasco et al., 2017)

		(-) ∑DDTs	*Gelochelidon nilotica*	(Pérez de Vargas et al., 2020)
Pyruvate dehydrogenase kinase 4 (PDK4)	1	(↓) Chlorpyrifos in 4,0μg/g	*Nannopterum auritum*	(Desforges et al., 2021)
Red blood cell (RBC) count or total erythrocyte count	4	(↓) organic contaminants (oil)	*Rissa tridactyla*	(Walton et al., 1997)
		(NF) organic contaminants (oil)	*Cepphus columba*	(Seiser et al., 2000)
		(↓) organic contaminants (oil)	*Rynchops niger*, *Pelecanus occidentalis*	(Fallon et al., 2020)
		NA	*Larus atlanticus*	(García et al., 2023)
Regucalcin (RGN)	1	(NF) organic contaminants (52 polycyclic aromatic compounds - PACs)	*Cepphus grylle*	(Zahaby et al., 2025)
Reticulocyte count	3	(↑) organic contaminants (oil)	*Rissa tridactyla*	(Walton et al., 1997)
		(↑) organic contaminants (oil)	*Nannopterum auritum*	(Harr et al., 2017)
		(↑) organic contaminants (oil)	*Rynchops niger*, *Pelecanus occidentalis*	(Fallon et al., 2020)
Retinyl palmitate	9	(+) organic contaminants (PAHs, PCBs, PCDFs and PCDDs)	*Sterna hirundo*	(Murk et al., 1994)
		(NF) Oxichlordane, p,p'-DDE, p,p'-DDT, HCB, Mirex, PCB-28, -52, -99, -101, -118, -138, -153, -170 and -180	*Larus hyperboreus*	(Henriksen et al., 2000)
		(-) organic contaminants (PCBs) - females	*Cepphus grylle*	(Kuzyk et al., 2003)
		(NF) PCB-28, -52, -47, -74, -66, -101, -99, - 149, -118, -114, -153, -105, -137, -138, -187, -183, -128, -156, -157, -180, -170, -189, -194, PBDE-28, -47, -99, -100, -153, -154, HBCD, HCB, β-HCH, Oxichlordane, p,p'-DDE and Mirex	*Rissa tridactyla*	(Murvoll et al., 2006)
		(NF) organic contaminants (PCBs, PBDEs, HBCD and OCPs)	*Phalacrocorax aristotelis*	(Murvoll et al., 2006)
		(NF) PCB-28, -52, -47, -74, -66, -101, -99, -149, -118, -114, -153, -105, -137, -138, -187, -183, -128, -156, -157, -180, -170, -189, -194, HCB, β-HCH, p,p'-DDE, Mirex, PBDE-28, -47, -99, -100, -153, -154, oxichlordane and HBCD	*Uria lomvia*, *Somateria mollissima*	(Murvoll et al., 2007)
		(NF) organic contaminants	*Fulmarus glacialis*	(Helgason et al., 2010b)
		(+) OCs	*Fulmarus glacialis*	(Verreault et al., 2013)
Retinyl palmitate / retinol	1	(+) organochlorines (HCB, ΣPCB, ΣPCDD)	*Fulmarus glacialis*	(Verreault et al., 2013)
Retinol (vitamin A)	17	(NF) organic contaminants (PAHs, PCBs, PCDFs and PCDDs)	*Sterna hirundo*	(Murk et al., 1994)
		NA	*Sterna hirundo*	(Murk et al., 1996)
		(+) PCBs	*Phalacrocorax aristotelis*	(Murvoll et al., 1999)

		(NF) Oxichlordane, p,p'-DDE, p,p'-DDT, HCB, Mirex, PCB-28, -52, -99, -101, -118, -138, -153, -170 and -180	*Larus hyperboreus*	(Henriksen et al., 2000)
		(-) organic contaminants (PCBs)	*Cepphus grylle*	(Kuzyk et al., 2003)
		(-) organic contaminants (PCBs and OCPs)	*Phalacrocorax aristotelis*	(Murvoll et al., 2006)
		(NF) PCB-28, -52, -47, -74, -66, -101, -99, - 149, -118, -114, -153, -105, -137, -138, -187, -183, -128, -156, -157, -180, -170, -189, -194, PBDE-28, -47, -99, -100, -153, -154, HBCD, HCB, β-HCH, Oxichlordane, p,p'-DDE, Mirex	*Rissa tridactyla*	(Murvoll et al., 2006)
		(+) inorganic (Cd and Zn); and (NF) organic contaminants	*Melanitta perspicillata*	(Harris et al., 2007)
		(NF) PCB-28, -52, -47, -74, -66, -101, -99, -149, -118, -114, -153, -105, -137, -138, -187, -183, -128, -156, -157, -180, -170, -189, -194, HCB, β-HCH, p,p'-DDE, Mirex, PBDE-28, -47, -99, -100, -153, -154, oxichlordane and HBCD	*Uria lomvia*, *Somateria molissima*	(Murvoll et al., 2007)
		(NF) PCB-105,-118,-138,-153,-180, p,p′-DDE, HCB, HCE, oxichlordane, Parlar 26, Parlar 50	*Phalacrocorax aristotelis*	(Jenssen et al., 2010)
		(NF) organic contaminants	*Fulmarus glacialis*	(Helgason et al., 2010b)
		(+) PCBs and organochlorine pesticides - dieldrin, PCDDs, PCDFs, PCBs	*Fulmarus glacialis*	(Braune et al., 2011)
		(NF) organic contaminants and Hg	*Pagophila eburnea*	(Miljeteig et al., 2012)
		(-) organochlorides (except ΣCHL)	*Fulmarus glacialis*	(Verreault et al., 2013)
		(↓) Radionuclide	*Calonectris leucomelas*	(Uematsu et al., 2014)
		NA inorganic contaminants (metals)	*Sterna hirundo*	(Oudi et al., 2019)
		(NF) organic (PAHs) and inorganic (As, Ba, Cd, Cu, Fe, Mn, Mo, Ni, Pb, Rb, Se, Sn, Sr, V, Zn) contaminants	*Morus bassanus*	(Champoux et al., 2020)
Serum amyloid A (SAA)	2	(NF) organic contaminants (oil)	*Nannopterum auritum*, *Leucophaeus atricilla*	(Dean et al., 2017b)
		NA	*Cerorhinca monocerata*	(Lee et al., 2024)
Sodium (plasma or serum)	8	(NF) organic contaminants (oil)	*Cepphus columba*	(Prichard et al., 1997)
		(NF) organic contaminants (oil)	*Cepphus columba*	(Seiser et al., 2000)
		(+) organic contaminants (HCB)	*Stercorarius skua*	(Sonne et al., 2013)
		(↓) organic contaminants (oil)	*Nannopterum auritum*	(Dean et al., 2017b)
		(-) organic contaminants (1-Metilnaph)	*Morus bassanus*	(Champoux et al., 2020)
		(NF) Hg	*Somateria mollissima*	(Ma et al., 2020)

		NA	*Cerorhinca monocerata*	(Lee et al., 2024)
		(NF) plastic ingestion	*Ardenna pacifica*	(Mejia et al., 2024)
Total fatty acids (FAs)	2	(NF) plastic ingestion	*Ardenna tenuirostris*, *A. carneipes*	(Puskic et al., 2019)
		(NF) plastic ingestiona	*Larus michahellis*, *L. fuscus*	(Lopes et al., 2022)
Total concentrations of hepatic DNA, RNA, and proteins	1	(NF) DDE, DDT, dieldrin, heptachlor epoxide, oxychlordane, cis-chlordane, trans-nonachlor, toxaphene, Mirex, polychlorinated styrenes and PCBs	*Sterna hirundo*	(Hoffman, Smith and Rattner, 1993)
Total protein (plasma or serum)	18	(NF) organic contaminants (oil)	*Cepphus columba*	(Prichard et al., 1997)
		(↓) organic contaminants (oil)	*Cepphus columba*	(Seiser et al., 2000)
		(↑) TMT; (↓) aviation fuel – JP-1, Polar Diesel	*Pygoscelis papua*, *P. adeliae*	(Najle et al., 2006)
		(↓) ∑PAHs (adults)	*Larus michahellis*	(Alonso-Alvarez, Pérez and Velando, 2007)
		(+) ΣOH-PCB and ΣPBDE	*Larus hyperboreus*	(Verreault et al., 2007)
		(+) organic contaminants (PCBs, DDTs, HCHs, HCB, CHLs)	*Stercorarius skua*	(Sonne et al., 2013)
		NA	*Spheniscus magellanicus*	(Carabajal et al., 2016)
		(+) organic contaminants (oil)	*Uria aalge*	(Duerr, Ziccardi and Massey, 2016)
		NA	*Pygoscelis papua*, *P. adeliae*	(D'Amico et al., 2016)
		(↓) organic contaminants (oil)	*Nannopterum auritum*	(Dean et al., 2017a)
		(↓) organic contaminants (oil)	*Nannopterum auritum*	(Dean et al., 2017b)
		(NF) organic (HPAs) and inorganic (As, Ba, Cd, Cu, Fe, Mn, Mo, Ni, Pb, Rb, Se, Sn, Sr, V and Zn) contaminants	*Morus bassanus*	(Champoux et al., 2020)
		(NF) Hg	*Somateria mollissima*	(Ma et al., 2020)
		NA	*Larus atlanticus*	(García et al., 2023)
		(NF) THg	*Stercorarius antarcticus*	(Ibañez et al., 2024)
		(+) organic contaminants (PAHs)	*Pelecanus occidentalis*	(Jodice et al., 2023)
		NA	*Cerorhinca monocerata*	(Lee et al., 2024)
		(-) PFAS, PFOS in females, (+) PFAS, PFOS in males	*Eudyptula minor*	(Wells et al., 2024)
Total transcriptome comparative analysis	1	(NF) plastic ingestion	*Ardenna pacifica*	(Mejia et al., 2024)

(*P2ry2, Slc9a3r2, Ssbp3, Slc29a1, CALBOR_R11618_mrna, Znf518a, Golgb1_1, Golga4, Cep290, Morc3, N4bp1, Rb1cc1, Rtfdc1, Arhgap5* - males; females - *Usp48, Rps23_1, Irf8, Grin2d*).				
Total transcriptome comparative analysis (differential gene expression related to stress, immune, and inflammatory responses: e.g. *CTSL, ABCG2, ARL4A*)	1	(+) organic contaminants (oiled birds)	*Uria aalge*	(Esperanza et al., 2024)
Total transcriptome comparative analysis (differential gene expression of immune-related genes, such as *ANXA2,LY96,* and *LY86*; as well as *MAPK12, PI4KB, LRRC34*)	1	(-) organic contaminants (oiled birds)	*Uria aalge*	(Esperanza et al., 2024)
ToxChip array - 27 target genes analysed/significant differential transcription for: *CYP3A37, CYP1A4, UGT1A9, SULT2B1, DIO1, VTG2, MT4, thioredoxin (TXN*)	1	(+) organohalogen flame retardants (OFRs)	*Larus argentatus*	(Porter et al., 2013)
ToxChip array - 27 target genes analysed/ significant differential transcription for: *IGF1, THRSP*	1	(-) organohalogen flame retardants (OFRs)	*Larus argentatus*	(Porter et al., 2013)
ToxChip array - 27 target genes analysed - significant diferential transcription for: *CYP1A4, UGT1A9, fibroblast growth factor 19 (FGF19)*		(+) mix of chemicals: bisphenol S (BPS), bisphenol A (BPA), tris(methylphenyl) phosphate (TMPP), tris(2-butoxyethyl) phosphate (TBOEP), triethyl phosphate (TEP), tris(2,3-dibromopropyl) isocyanurate (TBC), allyl 2,4,6-tribromophenyl ether (ATE), 1,2-dibromo-4-(1,2- dibromoethyl)-cyclohexane (DBE-DBCH), PCB 126, BDE 209, tetradecabromo-1,4-diphenoxybenzene (TeDB-DiPhOBz); tris (1-chloro-2-propyl) phosphate (TCIPP), tris(1,3-dichloro-2-propyl) phosphate (TDCIPP), TCDD	*Nannopterum auritum*	(Crump et al., 2016)
ToxChip array - 27 target genes analysed - significant differential transcription for *IGF1*		(-) mix of chemicals: bisphenol S (BPS), bisphenol A (BPA), tris(methylphenyl) phosphate (TMPP), tris(2-butoxyethyl) phosphate (TBOEP), triethyl phosphate (TEP), tris(2,3-dibromopropyl) isocyanurate (TBC), allyl 2,4,6-tribromophenyl ether (ATE), 1,2-dibromo-4-(1,2- dibromoethyl)-cyclohexane (DBE-DBCH), PCB 126, BDE 209, tetradecabromo-1,4-diphenoxybenzene (TeDB-DiPhOBz); tris (1-chloro-2-propyl) phosphate (TCIPP), tris(1,3-dichloro-2-propyl) phosphate (TDCIPP), TCDD	*Nannopterum auritum*	(Crump et al., 2016)
ToxChip array - 27 AhR-related genes analysed: significant differential transcription for: *CYP1A4,*		(+) Organic (PAHs)	*Nannopterum auritum*	(Crump et al., 2017)

pyruvate dehydrogenase kinase 4 (PDK4)				
ToxChip array - 27 AhR-related genes analysed: significant differential transcription for *THRSP, IGF1, TTR*		(-) Organic (PAHs)	*Nannopterum auritum*	(Crump et al., 2017)
ToxChip array - 43 toxicity genes analysed: significant diferential transcription for *ALAS1, CYP1A4*		(+) 10 organic flame retardants (OFRs)	*Nannopterum auritum*	(Pagé-Larivière et al., 2018)
ToxChip array - 43 toxicity genes analysed: significant differential transcription for *IGF1*		(-) 10 organic flame retardants (OFRs)	*Nannopterum auritum*	(Pagé-Larivière et al., 2018)
ToxChip array analysis - 44 toxicity genes analysed - significance for biotransformation genes mostly	1	(+) organic contaminants (PAHs)	*Nannopterum auritum*	(Mundy et al., 2019)
ToxChip array - 47 toxicity genes analysed: significance on *CYP1A4, LBFABP*, and *MT4*	1	(+) organic contaminants (PCBs, PBDEs)	*Nannopterum auritum*	(Xia et al., 2020)
ToxChip array - toxicity genes analysed: *LIPC, DNA polymerase kappa (POLK), frizzled-related protein (FRZB), LBFABP, TTR*	1	(-) replacement compounds to bisphenol A (BPA): 4,4′-propane-2,2-diyl) diphenol - BPA, bis 4-hydroxyphenyl methane - BPF, bis 3-allyl-4-hydroxyphenyl sulfone - TGSH, 7-bis 4-hydroxyphenylthio-3,5-dioxaheptane - DD-70, 2,2-bis 4-hydroxyphenyl) hexafluoropropane- BPAF, 4-hydroxyphenyl 4-isoprooxyphenylsulfone – BPSIP	*Nannopterum auritum*	(Sharin et al., 2021)
ToxChip array - toxicity genes analysed: *MT4, fibroblast growth factor* *19 (FGF19), cytochrome* *P450 A 37 (CYP3A7),* *Aldehyde dehydrogenase 1 family member A1* *(ALDH1A1)*	1	(+) replacement compounds to bisphenol A (BPA): 4,4′-propane-2,2-diyl) diphenol - BPA, bis 4-hydroxyphenyl methane - BPF, bis 3-allyl-4-hydroxyphenyl sulfone - TGSH, 7-bis 4-hydroxyphenylthio-3,5-dioxaheptane - DD-70, 2,2-bis 4-hydroxyphenyl) hexafluoropropane- BPAF, 4-hydroxyphenyl 4-isoprooxyphenylsulfone - BPSIP	*Nannopterum auritum*	(Sharin et al., 2021)
Transcription of multiple genes related to inflammation and health *(RGN, IGFBP1, IL16, LBFABP, ACSL5, ORM2, POLK, APOB, LSS, CD36, FOX1A, PDK4, PAH, FRZB, FABP3, ALDH1a1, MDM2, RPL4, EEF1A1)*	1	(NF) Hg, As, Cd, Pb, Se, and 53 polycyclic aromatic hydrocarbons (PAHs)	*Uria lomvia*, *Cepphus grylle*	(Zahaby et al., 2021)
Transcription of multiple genes related to inflammation and health (*RGN, IGFBP1, IL16, LBFABP, ACSL5,*	1	(NF) Hg, As, Cd, Pb, Se, and 53 polycyclic aromatic hydrocarbons (PAHs)	*Uria lomvia*, *Cepphus grylle*	(Zahaby et al., 2021)

CDKN1A, POLK, APOB, LSS, MGMT, FOXA1, PDK4, PAH, FRZB, SLCO1A2, ALDH1a1, MDM2, RPL4, EEF1A1)				
Transferrin (Tf)	1	(↓) MeHg, 0,4μg/g or more	*Leucophaeus atricilla*	(Jenko et al., 2012)
Triglycerides	3	NA	*Larus atlanticus*	(García et al., 2023)
		NA	*Pygoscelis papua*, *P. adeliae*	(D'Amico et al., 2016)
		NA	*Cerorhinca monocerata*	(Lee et al., 2024)
Triacylglicerols	1	(NF) THg	*Stercorarius antarcticus*	(Ibañez et al., 2024)
Tumor rejection antigen 1 (TRA1)	1	(-) PFCs; DRCs	*Phalacrocorax carbo*	(Nakayama et al., 2008)
Tumour-suppressing P53 pathway regulation genes: *MDM2*	1	(-) organic contaminants (PAHs)	*Nannopterum auritum*	(Wallace et al., 2018)
Tumour-suppressing P53 pathway regulation proteins: P53, P53R2; DNA repair and tumour-suppressing P53 pathway genes: *P53, OGG1, P21*		(NF) organic contaminants (PAHs)	*Nannopterum auritum*	(Wallace et al., 2018)
Urea	6	(-) HCHs, (+) PBDEs	*Stercorarius skua*	(Sonne et al., 2013)
		(↑) organic contaminants (oil)	*Nannopterum auritum*	(Dean et al., 2017a)
		(NF) organic contaminants (oil)	*Nannopterum auritum*, *Leucophaeus atricilla*	(Dean et al., 2017b)
		(NF) Hg	*Somateria mollissima*	(Ma et al., 2020)
		(NF) plastic ingestion	*Ardenna pacifica*	(Mejia et al., 2024)
		NA	*Cerorhinca monocerata*	(Lee et al., 2024)
Uric acid	9	(NF) organic contaminants (oil)	*Cepphus columba*	(Seiser et al., 2000)
		(NF) organic contaminants	*Stercorarius skua*	(Sonne et al., 2013)
		(↑) organic contaminants (oil)	*Nannopterum auritum*	(Dean et al., 2017a)
		(↑) organic contaminants (oil)	*Nannopterum auritum*	(Dean et al., 2017b)
		(+) plastic ingestion	*Ardenna carneipes*	(Lavers et al., 2019)
		(NF) organic (PAHs) and inorganic (As, Cu, Fe, Ni, Rb, Se, V, Zn -blood; As, Ba, Cd, Cu, Fe, Mn, Mo, Pb, Rb, Se, Sn, Sr, V and Zn - feathers) contaminants	*Morus bassanus*	(Champoux et al., 2020)
		NA	*Larus atlanticus*	(García et al., 2023)
		NA	*Cerorhinca monocerata*	(Lee et al., 2024)

		(NF) THg	*Stercorarius antarcticus*	(Ibañez et al., 2024)
Vascular endothelial growth factor (VEGFA)	1	NA	*Eudyptes chrysocome, Pygoscelis papua*	(Bowen et al., 2022)
3-Methylhistidine	2	(+) organic contaminants (oil)	*Leucophaeus atricilla*	(Horak et al., 2017)
		(↑) organic contaminants (oil)	*Nannopterum auritum*	(Dean et al., 2017b)
δ-aminolevulinic acid dehydratase (ALAD) activity	1	(-) Pb	*Diomedea immutabilis*	(Work and Smith, 1996)

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