PFAS in Birds: Data Gaps and Challenges for Ecological Risk Assessment

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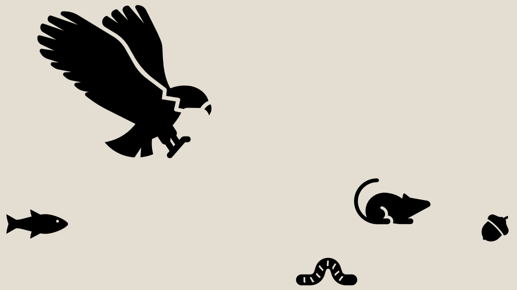
Definitions

- **Bioaccumulation** = build up of contaminant in an organism over time
  - **Bioconcentration** = process by which an organism absorbs and retains a substance from the surrounding medium - in terrestrial organisms from air through respiration. Does not include diet.
- **Biomagnification** = increase in a contaminant (chemical potential, fugacity, or activity) in the consumer compared to that in its diet
- **Trophic magnification** = general increase in animals of a food web relative to their increasing trophic positions
  - successive biomagnification events; BMF that averages all the trophic interactions across a food web.



Effects

Apical

- Mortality
- Development
- Growth
- Reproduction
- Organosomatic

Non-apical

- Histopathological
- Endocrine
- Immune
- Metabolic
- Biochemical

Environmental Toxicology and Chemistry—Volume 00, Number 00—pp. 1–42, 2020
Received: 20 July 2020 | Revised: 13 August 2020 | Accepted: 31 August 2020

Critical Review

Assessing the Ecological Risks of Per- and Polyfluoroalkyl Substances: Current State-of-the Science and a Proposed Path Forward

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Pressing Needs

1) development of empirical physicochemical property data to support testing and development of predictive models;

2) identification of susceptible species and toxicity endpoints as a basis for selecting appropriate in vitro and in vivo assays/toxicity tests;

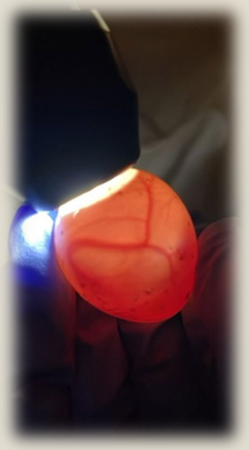
3) development of effects-based toxicity endpoint values (e.g., screening levels, benchmarks, criteria) in different matrices (water, sediment, soil, tissue);

4) identification of methods to efficiently measure or predict the bioaccumulation and biomagnification potential of PFAS.

Ankley et al., 2020

Laboratory Studies

	# References	# Species	In vitro	In vivo	Egg Injection
Laboratory	74	11	19	55	30

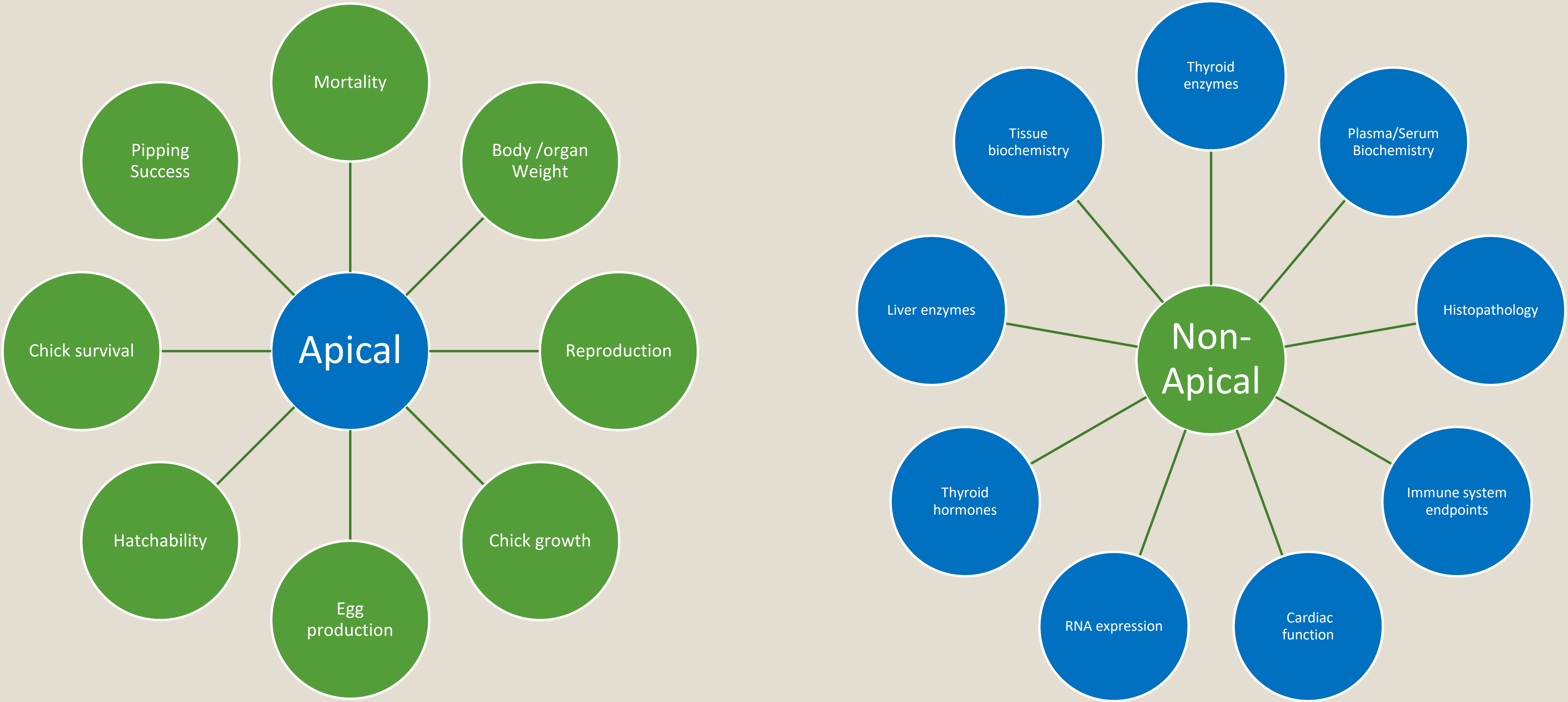


Laboratory Studies

Scientific Name	Common Name	# Studies
Haliaeetus leucocephalus	Bald Eagle	1
Caracara plancus	Crested Caracara	1
Anser anser ssp. domesticus	Domestic Goose	1
Phalacrocorax auritus	Double-Crested Cormorant	1
Columba livia	Rock Dove	1
Anser cygnoides	Swan Goose	1
Larus argentatus	Herring Gulls	2
Coturnix japonica	Japanese Quail	3
Anas platyrhynchos	Mallard Duck	7
Colinus virginianus	Northern Bobwhite Quail	10
Gallus gallus	Chicken	52

Galliformes 81%

Laboratory Studies

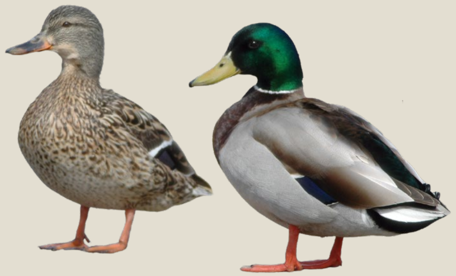


Lab Studies Results - Acute

PFAS	Species	NOEC (mg/kg)	LC50 (mg/kg)	LD50 (mg/kg bw/d)	Duration	Reference
PFBS	Bobwhite Quail	>10,000	>10,000	>2,304	5 d	Newsted et al. 2008
	Mallard	>10,000	>10,000	>3,974	5 d	Newsted et al. 2008
PFOS	Bobwhite Quail	70.3	212(158-278)	61 (48-77)	5 d	Newsted et al. 2006
	Mallard	141	603 (431-938)	150 (117-201)	5 d	Newsted et al. 2006
	Japanese Quail	91	351 (275–450)	38 (34–43)	5 d	Bursian et al. 2020
PFOA	Japanese Quail	162	496 (427–575)	68 (63–74)	5 d	Bursian et al. 2020
PFOS + PFOA	Japanese Quail	74 + 79	398 (339–468)	55 (51–59)	5 d	Bursian et al. 2020
PFOS in 3M -AFFF	Japanese Quail	73	467 (390–559)	130 (103–164)	5 d	Bursian et al. 2020
6:2 FtTAoS (Ansul AFFF)	Japanese Quail	1,118	>1,118	>257	5 d	Bursian et al. 2020

Adapted from Ankley et al., 2020

- sulfonates > carboxylates
- 8-C PFAS > shorter chain PFAS



Lab Studies Results - Chronic

- sulfonates > carboxylates
- 8-C PFAS > shorter chain PFAS
- Co-exposure of PFAS influences hatching success
- Exposure via water more toxic than via food

PFAS	Species	Endpoint	NOAEL (mg/kg bw/d)	LOAEL (mg/kg bw/d)	Duration	Reference
PFOS	Mallard	Mortality	1.48	6.36	21 weeks	Newsted et al. 2007
		Body Weight	1.48			
		Reproduction	1.48			
	Bobwhite Quail	Mortality	0.77	2.64	21 weeks	Newsted et al. 2007
		Body Weight	0.77			
		Chick growth		0.77		
	Japanese Quail	Body Weight (female)		0.28	20 weeks	Bursian et al. 2021
		Egg production		0.28		
		Hatchability	0.55	1.1		
		Chick survival	0.55	1.1		
PFOS in 3M -AFFF	Japanese Quail	Body Weight	2.5	3.4	20 weeks	Bursian et al. 2021
		Egg production	1.4	2.5		
		Hatchability	1.4	2.5		
		Chick Survival	0.66	1.4		
PFBS	Bobwhite Quail	Body weight	87.7		21 weeks	Newsted et al. 2008
		Egg production	87.7			
		Hatchability	87.7			
PFHxA (water)	Bobwhite Quail	Weight		1.49E-05	90 d	Dennis et al. 2021
		Growth Rate		1.49E-05		
PFOS:PFHxA (2.7:1) (Water)	Bobwhite Quail	Hatching success	8.00E-05	0.00445	90 d	Dennis et al. 2021
		Survival	8.00E-05	0.00445		
		Growth	8.00E-05	0.00445		
		Weight		8.20E-06		
PFOS (water)	Bobwhite Quail	Hatching success		2.45E-03		
PFOS:PFHxS (water)	Bobwhite Quail	Weight		3.10E-03	90 d	Dennis et al. 2020

Adapted from Ankley et al., 2020

Toxicity Reference Values (TRVs)

Reference	NOAEL (mg/kg bw/d)	LOAEL (mg/kg bw/d)
Newsted et al. 2005	0.021	0.77
Beach et al. 2006	0.021	0.77
Giesy et al. 2010	0.032	0.77
Gobas et al. 2020	0.02	
McCarthy et al. 2017		0.77
Zodrow et al. 2021	0.079	0.79

Field Studies

Field studies >> lab studies

Uptake

whole body, plasma/serum, other tissues, eggs

Non – Apical Effects

immune system, thyroid, oxidative stress, plasma/serum biochemistry

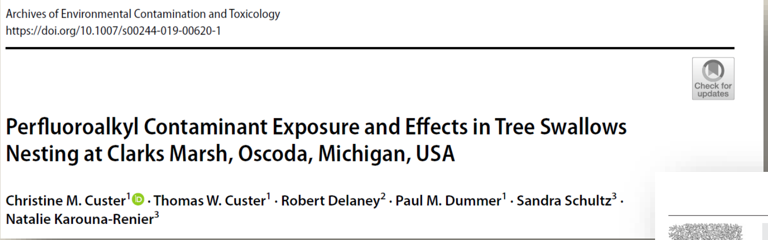
Apical Effects

Egg production, hatching success, body condition

Food webs

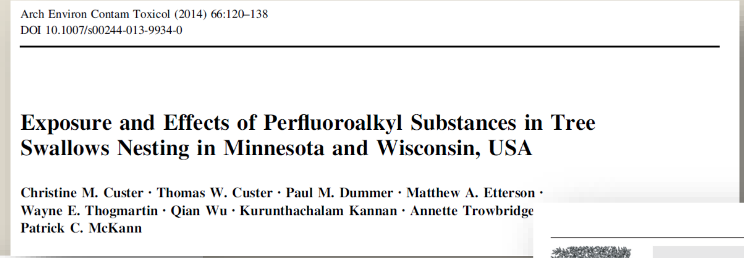
Field Studies

- Effects on reproduction (inconsistent)
  - e.g. Custer et al. 2019 vs Custer et al. 2012, 2014
- Effects on /relationships with a variety of non-apical endpoints
  - mechanism-based quantitative linkages between exposure and effect have not yet been established
  - additional research is needed to relate changes in these endpoints to apical endpoints


Archives of Environmental Contamination and Toxicology
https://doi.org/10.1007/s00244-019-00620-1

Perfluoroalkyl Contaminant Exposure and Effects in Tree Swallows Nesting at Clarks Marsh, Oscoda, Michigan, USA

Christine M. Custer[1] · Thomas W. Custer[1] · Robert Delaney[2] · Paul M. Dummer[1] · Sandra Schultz[3] · Natalie Karouna-Renier[3]


Arch Environ Contam Toxicol (2014) 66:120–138
DOI 10.1007/s00244-013-9934-0

Exposure and Effects of Perfluoroalkyl Substances in Tree Swallows Nesting in Minnesota and Wisconsin, USA

Christine M. Custer · Thomas W. Custer · Paul M. Dummer · Matthew A. Etterson · Wayne E. Thogmartin · Qian Wu · Kurunthachalam Kannan · Annette Trowbridge · Patrick C. McKann


Reproductive Toxicology 33 (2012) 556–562

Contents lists available at ScienceDirect

Reproductive Toxicology

journal homepage: www.elsevier.com/locate/reprotox

ELSEVIER

Exposure and effects of perfluoroalkyl compounds on tree swallows nesting at Lake Johanna in east central Minnesota, USA

Christine M. Custer[a,*], Thomas W. Custer[a], Heiko L. Schoenfuss[b], Beth H. Poganski[b], Laura Solem[c]


Science of the Total Environment 652 (2019) 718–728

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

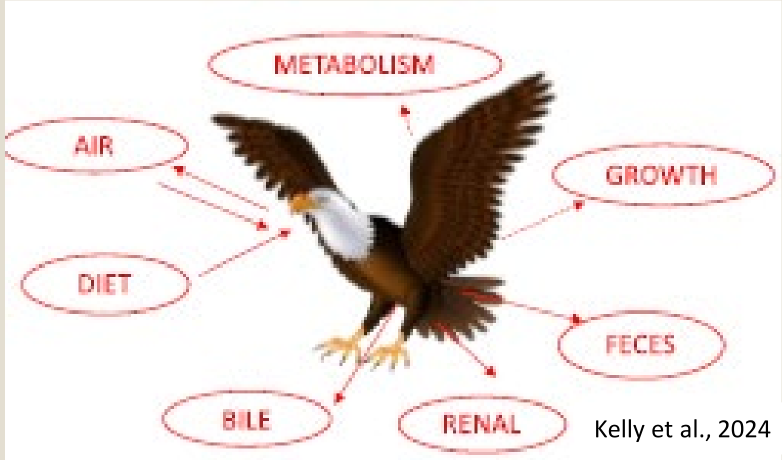
ELSEVIER

Limited reproductive impairment in a passerine bird species exposed along a perfluoroalkyl acid (PFAA) pollution gradient

Thimo Groffen[a,*,1], Robin Lasters[a,1], Ana Lopez-Antia[b], Els Prinsen[c], Lieven Bervoets[a], Marcel Eens[b]

Properties in terrestrial species

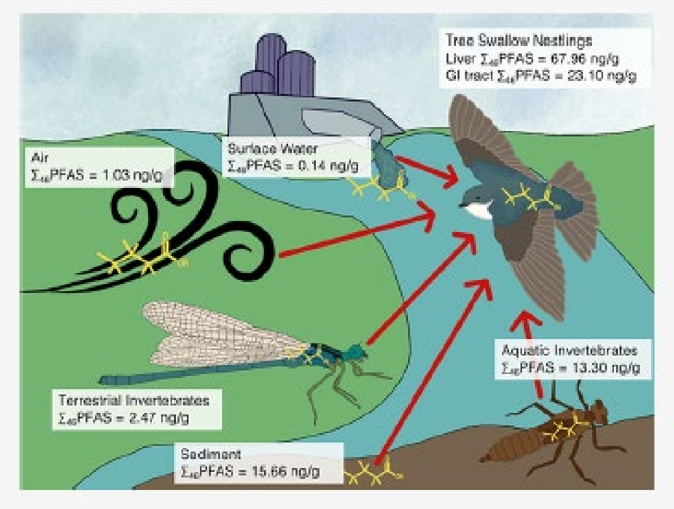
- Generally oleophobic = do not readily accumulate in lipid-rich tissues
- Relatively high affinity for albumin, transporter proteins and phospholipids
  - Distributed in biofluids and tissues such as plasma, liver, kidney and brain
- Elimination via feces, renal, biliary, maternal transfer and metabolism
- Respiratory uptake and respiratory elimination only of neutral (nonionized) PFAS e.g. FTOHs, perfluorooctane sulfonamidoethanols (MeFOSE and EtFOSE)



Kelly et al., 2024

Food Web Studies

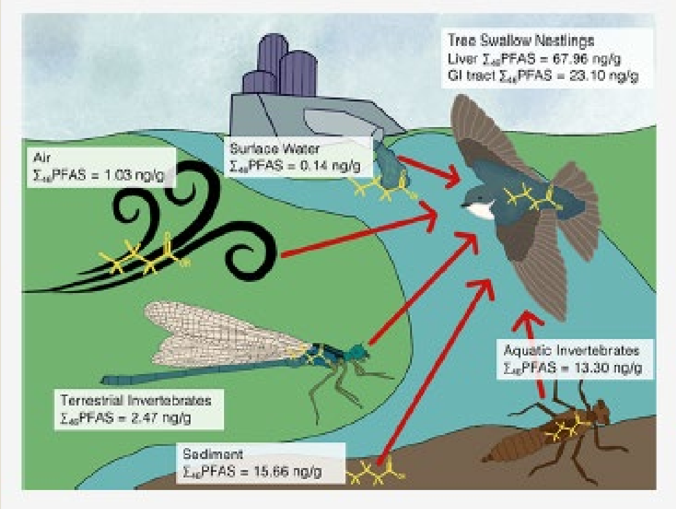
- Fremlin et al. (2023) – invertebrates → songbirds → Cooper's hawk eggs
  - TMFs revealed that PFNA, PFDA, PFUnDA, PFDoDA, PFTrDA, PFTeDA, PFOS, and PFDS biomagnified
  - PFOA, PFHxDA, and PFHxS did not appear to biomagnify; PFBS biodiluted
  - PFCA C8−C11 and PFSA C4−C8 predominantly occurred in albumin > polar lipids > structural proteins > neutral lipids and insignificant amounts in water
  - longer-chained PFAS (i.e., C12−C16) in polar lipids > albumin > structural proteins > neutral lipids > water
- Hopkins et al. (2023) – macroinvertebrates → tree swallows
  - PFAS profiles of air, terrestrial invertebrates, and swallows dominated by PFOS
  - PFOS and long-chain PFCAs (PFNA, PFDA, PFTrDA) and precursors are most bioaccumulative > PFOA
  - short-chain and other long-chain PFCAs bioaccumulated less or not at all



From: Hopkins et al. (2023)

Food Web Studies

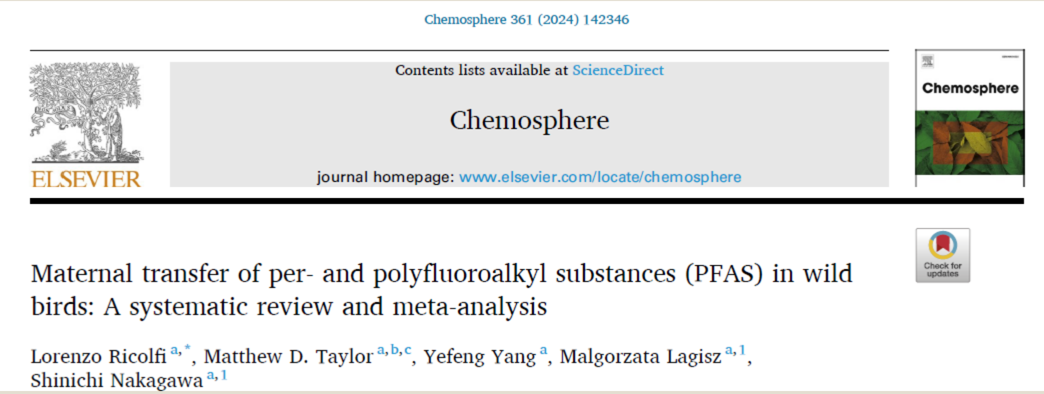
- Ecke et al. (2024) - Bank vole → Tengmalm's owl (blood and eggs)
  - PFOS dominant
  - Most PFAS (except PFOA, PFDA) concentrations were higher in owls than in voles
  - PFNA, PFTeDA, and PFOS showed biomagnification from voles to owl blood
  - PFNA, PFDA, PFTeDA, and PFOS showed biomagnification from voles to owl eggs
- Heimstadt et al. (2024) – earthworm → fieldfare eggs → tawny owl and sparrowhawk eggs
  - PFOS and the long chain PFCAs were the most dominating compounds in all samples
  - 8:2 FTS found in earthworms, fieldfare eggs, sparrowhawk eggs
  - Biomagnification of PFDoDA > PFTrDA > PFUnDA > PFD˜A PFTeDA > 8:2 FTS > PFOS ~ PFNA
  - PFHxS and PFOA showed trophic dilution



From: Hopkins et al. (2023)

Meta-analysis

- Ricolfi et al. (2024) reviewed 13 studies on 16 bird species (mostly seabirds) and 25 compounds
  - Examined maternal transfer and sources of variation
- Offspring have ~40% higher PFAS than mother*
- Carbon chain length and molecular weight positively correlated with increased PFAS transfer to egg/offspring
- Larger clutch size was associated with decreased PFAS transfer
- Piscivorous birds and those with opportunistic/diverse diets transfer rate > insectivores
- PFAS in yolk > albumen; VLDL
- Body weight, egg weight, and the functional group did not affect maternal PFAS transfer



Chemosphere 361 (2024) 142346

Contents lists available at ScienceDirect

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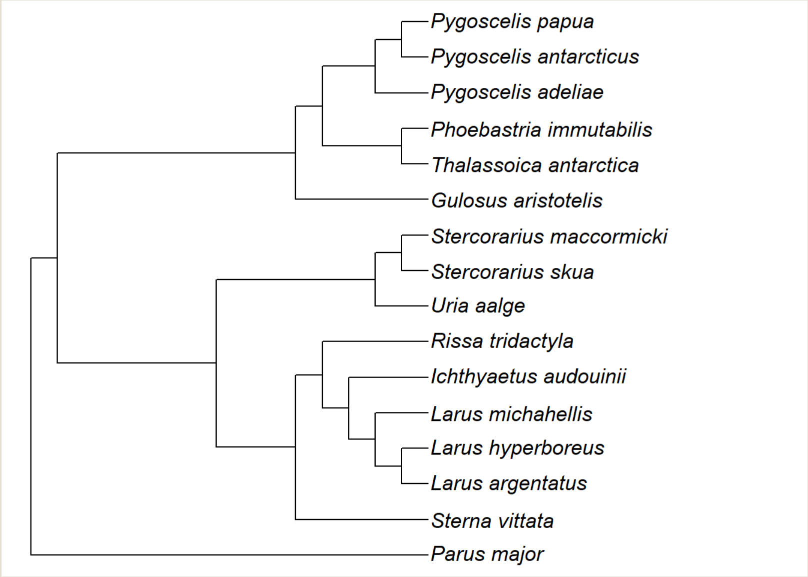
journal homepage: www.elsevier.com/locate/chemosphere

ELSEVIER

Maternal transfer of per- and polyfluoroalkyl substances (PFAS) in wild birds: A systematic review and meta-analysis

Lorenzo Ricolfi [a,*], Matthew D. Taylor [a,b,c], Yefeng Yang [a], Malgorzata Lagisz [a,1], Shinichi Nakagawa [a,1]

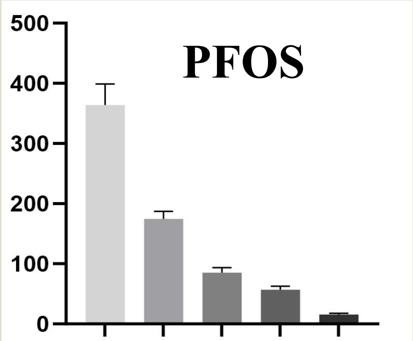


Current limitations for Risk Assessment

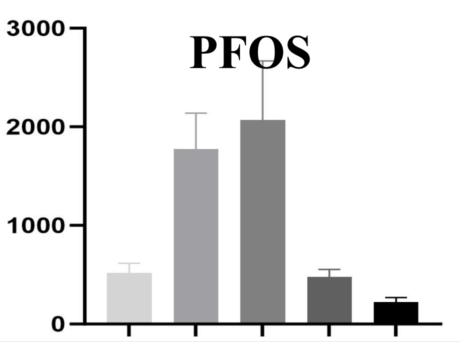
- So many PFAS, so little time/data
- Extensive toxicity data for PFOS and PFOA
  - Limited or no *in vivo* effects data for most other PFAS
- Limited established thresholds for PFAS effects
- Interspecies variability in tissue distribution and clearance rates
- Species differences in sensitivity
  - Precocial vs Altricial birds
- Sex-specific differences in elimination
- Variability in biological persistence (bioaccumulation) between species
  - larger airbreathing organisms having slower rates of depuration
  - trophic position affects biomagnification

Data Gaps

- Better integration of laboratory studies with environmental/field studies
- Move from single PFAS chemicals or constructed mixtures to those reflecting the environment
  - Adverse effects at environmentally relevant concentrations
- PFAS interactions with other contaminants and stressors to which organisms are exposed in the environment
- Empirical data on the uptake, tissue distribution, and excretion of a range of PFAS in organisms other than those frequently tested are needed for model development and validation
- Emphasis not just on the apical endpoints needed for risk assessment but on biochemical, physiological, and histological responses indicative of the chemical's mechanism of action
- Chronic effects data gap



Site 1



Site 2

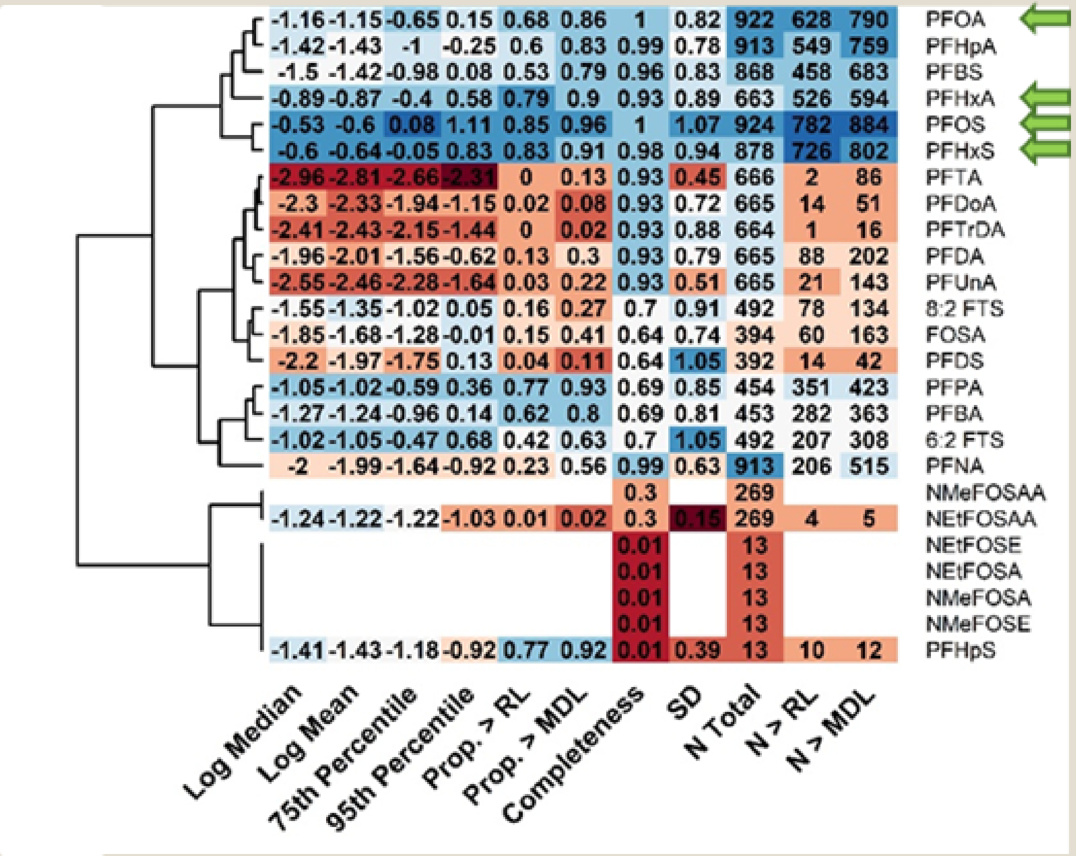
Options

- Can we use data from new approach methods (NAMs) or short-term in vivo tests with pathway-specific molecular/biochemical endpoints, and bioinformatic/ computational models?
- Quantitative structure–activity relationships (QSARs) to predict specific bioactivities
- Focus testing on PFAS based on production volume, use patterns, potential for persistence and bioaccumulation, and anticipated biological activity
- Prioritize PFAS for more focused *in vivo* characterization based on structural classification i.e. increase testing of other than PFCAs and PFSAs to help reduce risk assessment uncertainties
- Identify of a suite of "model" PFAS that represent ecologically relevant profiles for generation of baseline toxicity data for ecologically relevant species

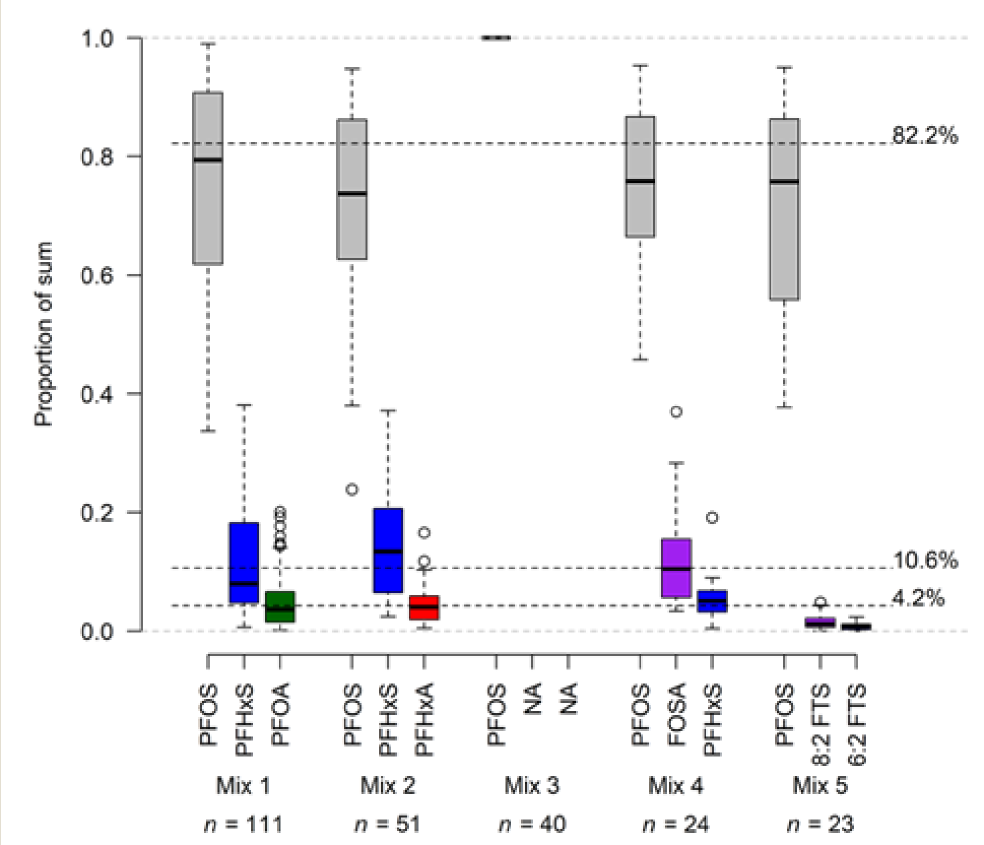
Ankley et al. 2020

Identifying Ecologically Relevant Profiles

Surface Water



Soil



East et al. 2020

Body Compartment Partitioning and Ecological Effects of PFAS Mixtures in a Multi-Species System

- Trophic transfer from rodents to avian species
  - uptake, tissue distribution and body burden profiles of PFAS mixtures in mice
- Environmentally relevant PFAS mixture profile identified by East et al. (2020) and based on mouse whole body burdens
- Doses based on 5x avian TRV derived for PFOS, approximate PFOS TRV, and 1/5 TRV, which captures (unpublished) high field values.

Sample Size	5 pairs	5 pairs	5 pairs		5 pairs
ΣPFAS	5 mg/kg-d[a]	1 mg/kg-d[b]	0.2 mg/kg-d[c]	%[d]	Control
PFOS	3	0.6	0.12	60	0
PFHxS	1.4	0.28	0.056	28	0
PFOA	0.6	0.12	0.024	12	0
PFHxA	0.00125	0.00025	0.00005	0.025	0
Anticipated effects	Reduction in hatching rate[e]	→	Suborganismal effects		
Anticipated exposure	Toxicologically relevant exposure	←	Environmentally relevant exposure quantification		

DCPH-A
Defense Centers for Public Health – Aberdeen
(formerly U.S. Army Public Health Center)

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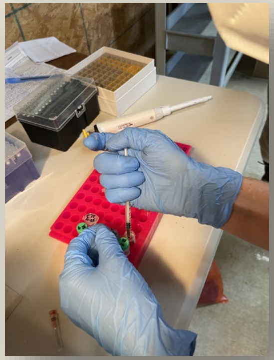
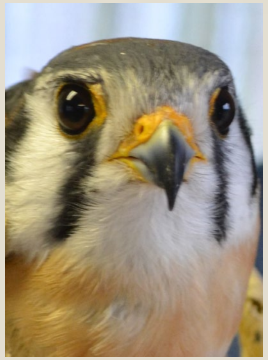
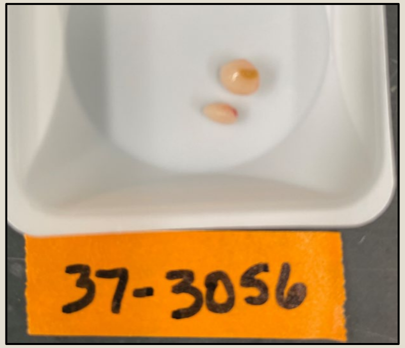
Body Compartment Partitioning and Ecological Effects of PFAS Mixtures in a Multi-Species System

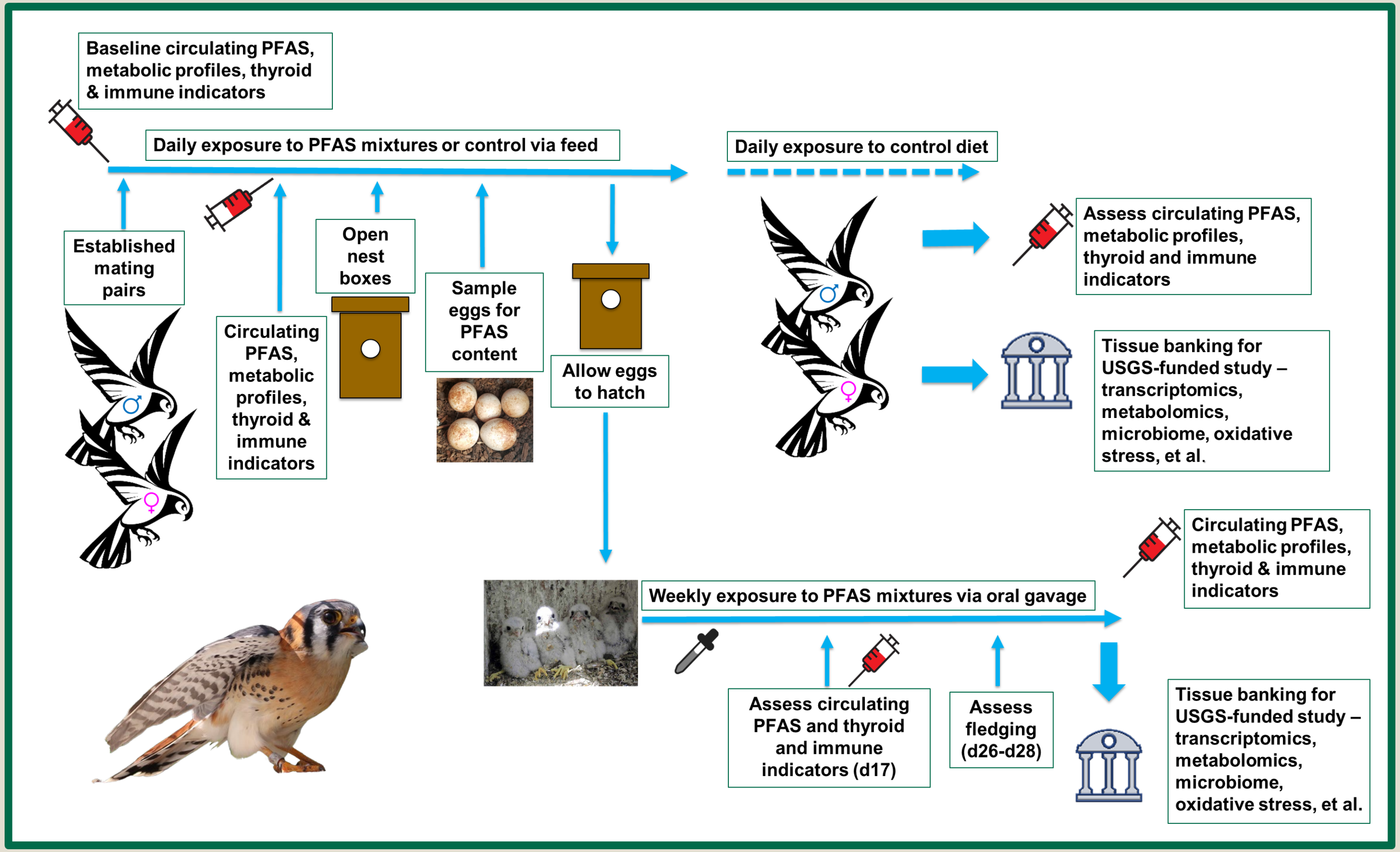
- Dietary and *in ovo* exposures of American kestrels to environmentally relevant concentrations
- Tissue partitioning, cumulative effect modeling
- Importance of trophic transfer and life stage for exposure assessment
- Apical – Mortality, reproduction, growth



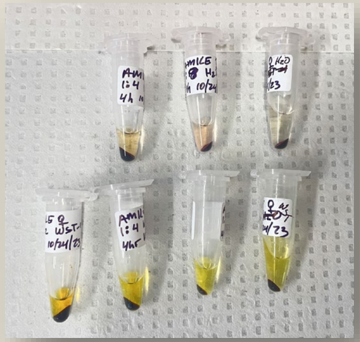




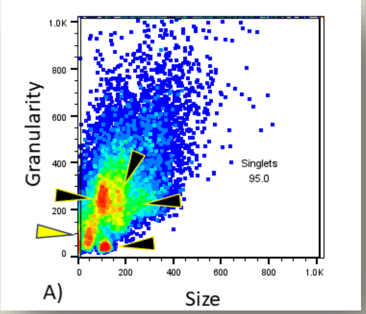
Body Compartment Partitioning and Ecological Effects of PFAS Mixtures in a Multi-Species System



Non-Apical



- endocrine, immune, clinical chemistry, oxidative stress, testicular biomarkers, microbiome, transcriptomic and metabolomic effects



Indicator	Physiological component	Function
Bactericidal assay	Acquired immunity	Indicative of individual's susceptibility to bacterial infection
Hemolysis/ hemagglutination	Innate immunity	Hemolytic activity and natural antibody titers
Leukocyte differentials	Innate immunity	Concentrations of phagocytes and lymphocytes
Immunoglobulin Y	Aquired immunity	Concentrations of immunoglobulins in plasma
Lysozyme	Innate immunity	Antimicrobial enzyme indicative of innate immune activity
Haptoglobin	Innate immunity	Acute-phase protein induced by inflammatory cytokines
Plasma clinical chemistry	AST, BA, CK, UA, GLU, CA++, PHOS, TP, ALB, GLOB, K+, Na+	Plasma analytes for determination of health status/ pathologic conditions
T3, T4	Thyroid system	Thyroid hormones regulate metabolism, reproduction, development, immune system, nervous system, et al.
GSH, CAT, SOD, GPx, ROS	Oxidative stress	Indicative of imbalance of free radicals and antioxidants that can lead to cell and tissue damage
Metabolomics	Various metabolites	Examination of metabolites produced by extrinsic and intrinsic contributors
Transcriptomics	Gene expression	Examination of gene expression patterns structured by extrinsic and intrinsic factors

Uptake and potential health effects of PFAS in apex predators

- Birds of prey and other large waterbirds are particularly vulnerable to accumulation and maternal transfer of persistent organic pollutants
- PFAS accumulation and possible effects
- Prevalence of PFAS in apex avian predators, such as raptors and pelicans and other avian species from across the U.S.
- Does PFAS exposure and accumulation affect immune system, thyroid and other health indicators in these birds?
  - Immune system and thyroid axis effects, plasma clinical chemistry, transcriptomics, and metabolomics to evaluate potential health effects
- Pelicans, bald eagles, vultures, gulls, osprey
- Chesapeake Bay; Cape Fear Estuary, NC; Delaware River and Bay; Charleston Harbor, SC; Great Lakes Region; New England

Acknowledgements

➢ Funding provided by the USGS Environmental Health Program; SERDP

Questions / Comments?