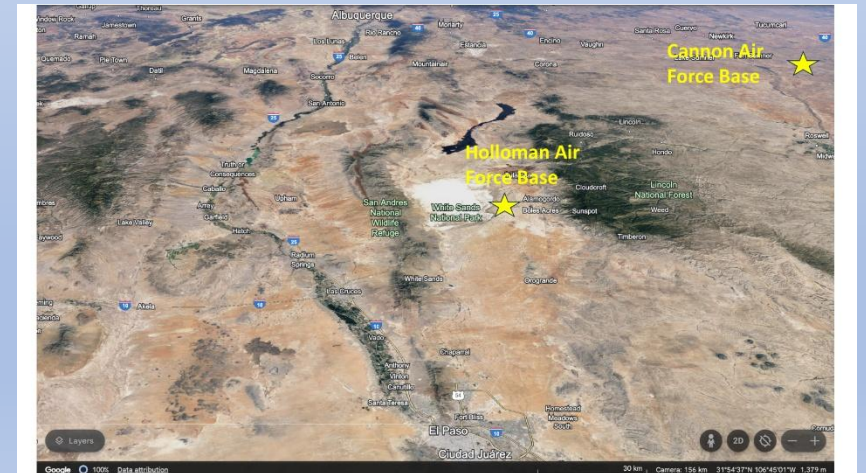
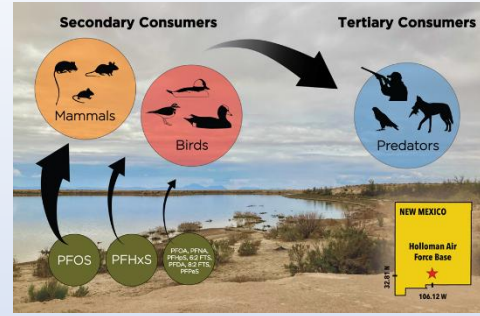
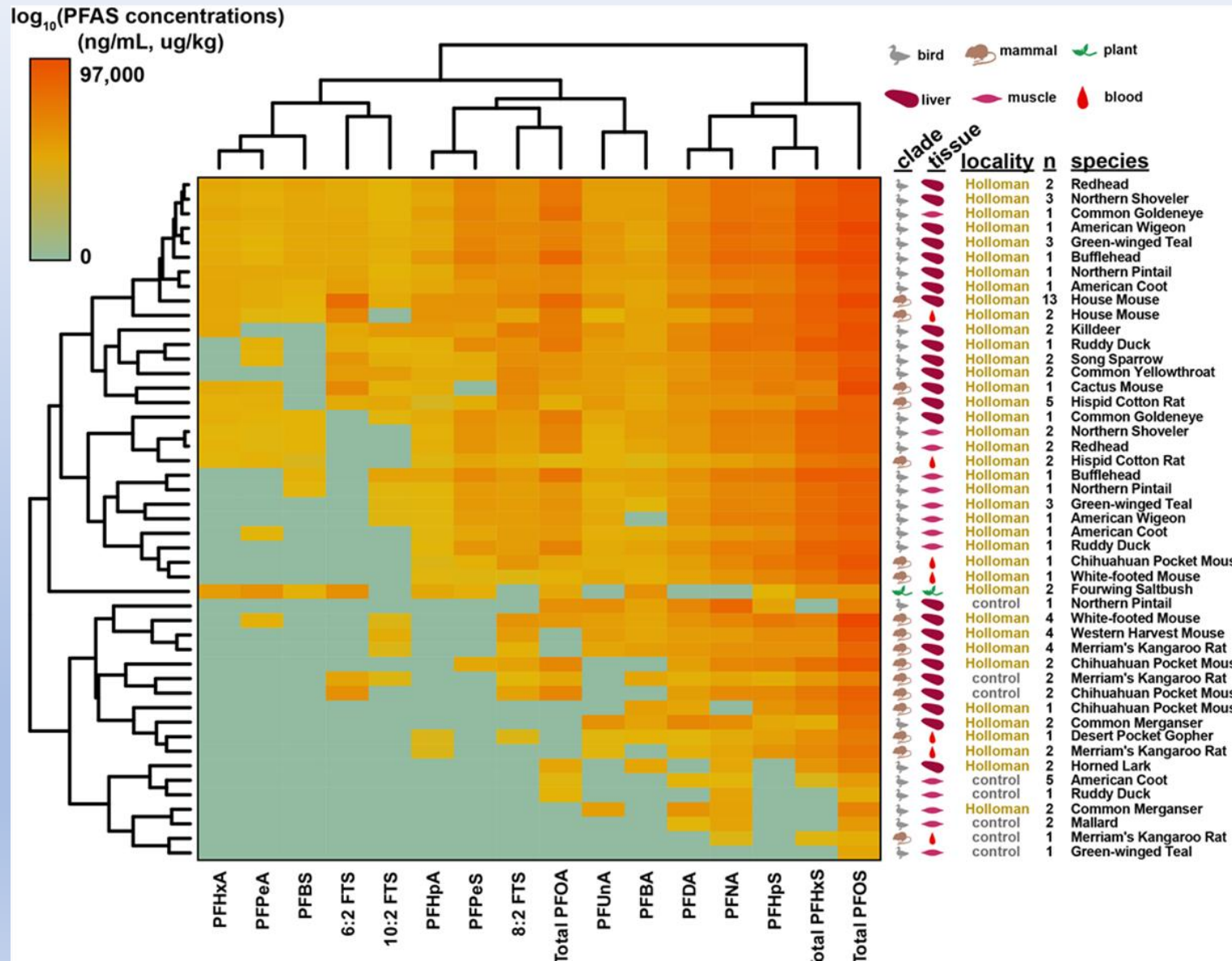


PFAS Exposure Pathways and Ecological Toxicity: Current Knowledge and Research Funding Priorities in New Mexico

Jean-Luc E. Cartron, Ph.D., M.D.
Department of Biology
University of New Mexico



Extraordinary PFAS contamination levels in Holloman Lake wildlife



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Extraordinary levels of per- and polyfluoroalkyl substances (PFAS) in vertebrate animals at a New Mexico desert oasis: Multiple pathways for wildlife and human exposure

Christopher C. Witt^{a,b,*}, Chauncey R. Gadek^{a,b,c}, Jean-Luc E. Cartron^{a,b,d}, Michael J. Andersen^{a,b}, Mariel L. Campbell^{a,b}, Marilejandra Castro-Farías^{a,b}, Ethan F. Gyllenhaal^{a,b}, Andrew B. Johnson^{a,b}, Jason L. Malaney^{a,c}, Kyrana N. Montoya^{a,b}, Andrew Patterson^e, Nicholas T. Vinciguerra^{a,b}, Jessie L. Williamson^{a,b,f}, Joseph A. Cook^{a,b}, Jonathan L. Dunnum^{a,b}

^a Museum of Southwestern Biology, University of New Mexico, Albuquerque, NM, 87131, USA
^b Department of Biology, University of New Mexico, Albuquerque, NM, 87131, USA
^c Environmental Health Laboratory, Los Alamos, NM, 87545, USA
^d Daniel B. Stephens & Associates, Inc., 6020 Academy Road NE, Suite 100, Albuquerque, NM, 87109, USA
^e New Mexico Museum of Natural History and Science, Albuquerque, NM, 87104, USA
^f Pacific Environmental Testing America, West Sacramento, CA, 95605, USA
^{*} Corresponding author. Museum of Southwestern Biology, University of New Mexico, Albuquerque, NM, 87131, USA. E-mail address: cwitt@unm.edu (C.C. Witt).

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ABSTRACT

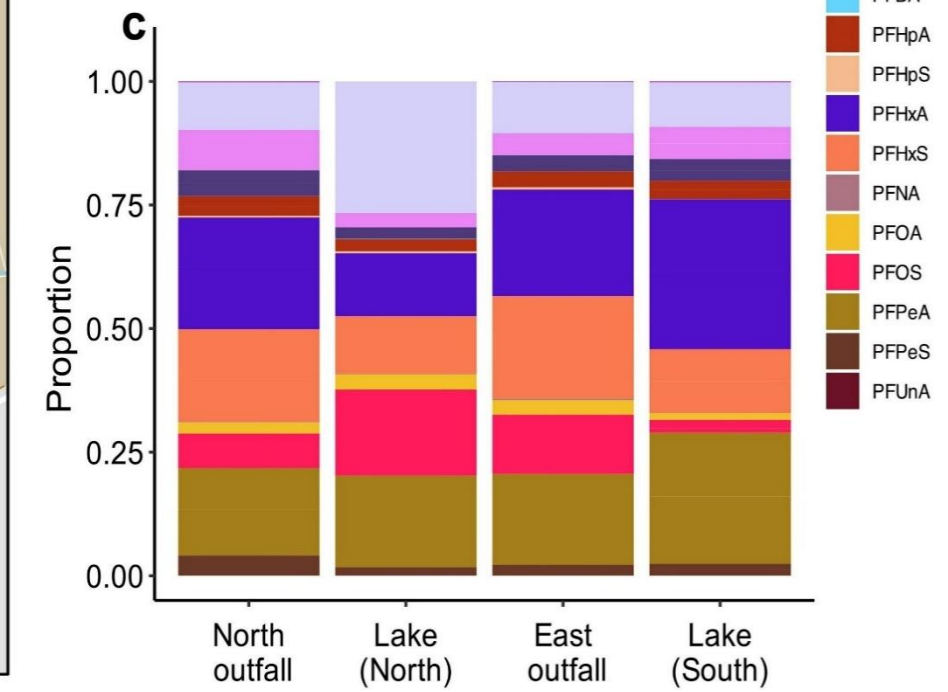
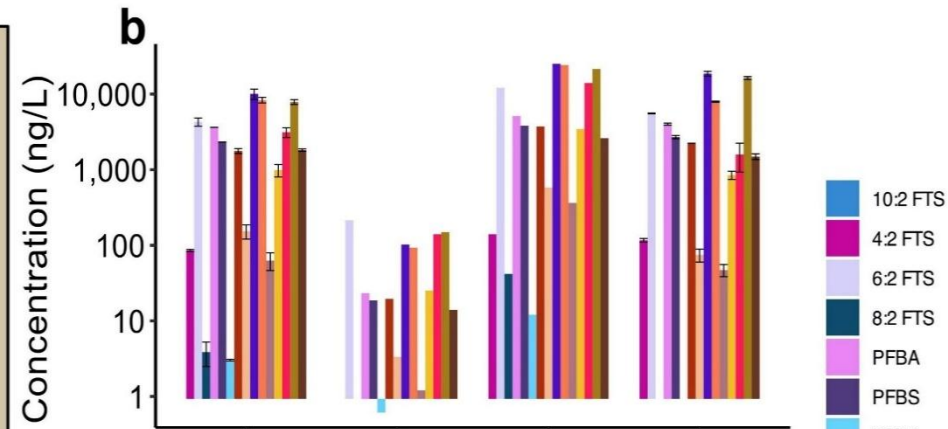
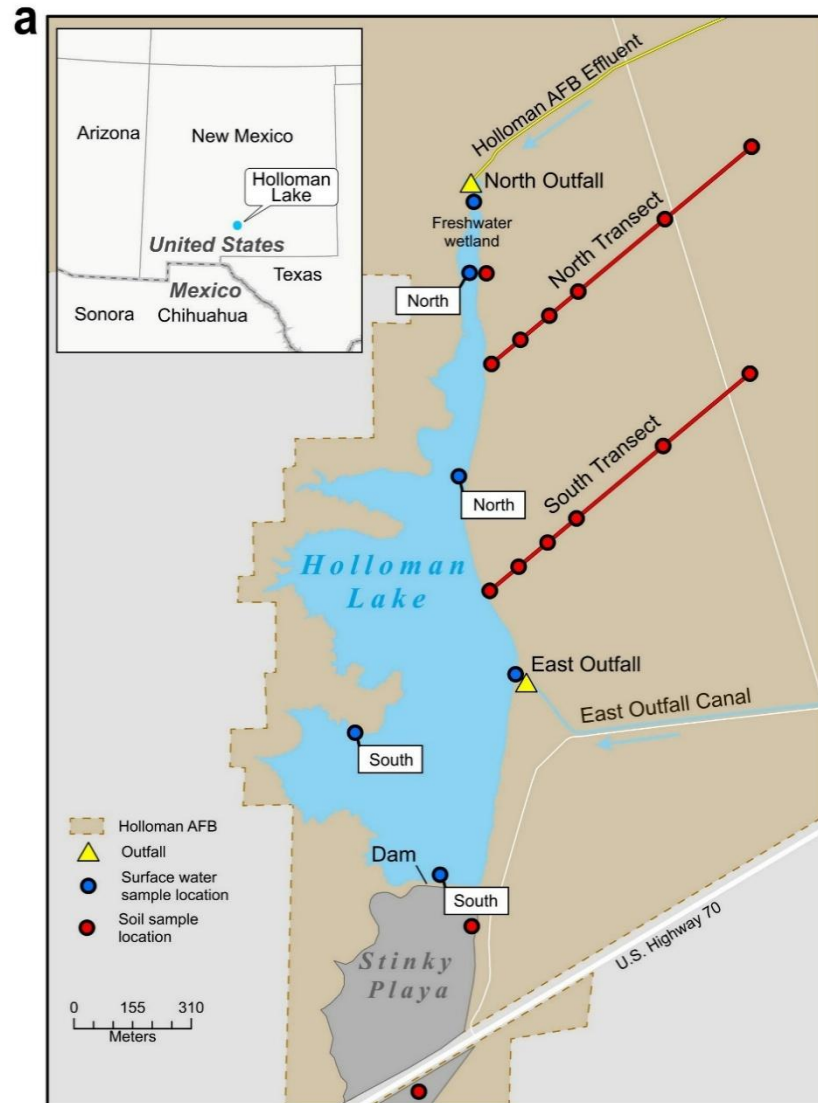
Per- and polyfluoroalkyl substances (PFAS) in the environment pose persistent and complex threats to human and wildlife health. Around the world, PFAS point sources such as military bases expose thousands of populations of wildlife and game species, with potentially far-reaching implications for population and ecosystem health. But few studies shed light on the extent to which PFAS permeate food webs, particularly ecologically and taxonomically diverse communities of primary and secondary consumers. Here we conducted >2000 assays to measure tissue-concentrations of 17 PFAS in 23 species of mammals and migratory birds at Holloman Air Force Base (AFB), New Mexico, USA, where wastewater treatment lakes form biodiverse oases. PFAS concentrations were among the highest reported in animal tissues, and high levels have persisted for at least three decades. Twenty of 23 species sampled at Holloman AFB were heavily contaminated, representing middle trophic levels and wetland to desert microhabitats, implicating pathways for PFAS uptake: ingestion of surface water, sediments, and soil; foraging on aquatic invertebrates and plants; and preying upon birds or mammals. The hazardous long carbon-chain form, perfluorooctanoic acid (PFOS), was most abundant, with liver concentrations averaging >16,000 ng/g wet weight (ww) in birds and mammals, respectively, and reaching as high as 97,000 ng/g ww in a 1994 specimen. Perfluorohexanoic acid (PFHxS) averaged thousands of ng/g ww in the livers of aquatic birds and littoral-zone house mice, but one order of magnitude lower in the livers of upland desert rodent species. Prey items and upland desert songbirds were relatively uncontaminated. At control sites, PFAS levels were strikingly lower on average and differed in composition. In sum, major PFAS at this desert oasis have permeated local aquatic and terrestrial food webs across decades, severely contaminating populations of resident and migrant animals, and exposing people via game meat consumption and outdoor recreation.

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Chemical	Proposed MCL
PFOA	4 ppt
PFOS	4 ppt
PFNA	1.0 (unitless)
HFPO-DA (GenX)	Hazard index
PFHxS	
PFBS	



PFAS are pervasive throughout the entire Holloman Lake ecosystem



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Ecosystem-wide PFAS characterization and environmental behavior at a heavily contaminated desert oasis in the southwestern U.S.

Jean-Luc E. Carton^{a,b,c,d}, Chauncey R. Gadek^{a,b,c,d}, Jonathan L. Dunning^{a,b,c}, Christopher C. Witt^{a,b,c}, Mariel L. Campbell^{a,b,c}, Samuel J. Romero^{a,b}, Andrew B. Johnson^{a,b}, Julie Kutz^a, Christopher Wolf^a, Sarah J. Choyke^a, Joseph A. Cook^{a,b,c}

^a Museum of Southwestern Biology, University of New Mexico, Albuquerque, NM 87131, USA
^b Department of Biology, University of New Mexico, Albuquerque, NM 87131, USA
^c David B. Sighner & Associates, Inc., Albuquerque, NM, 87116, USA
^d Environmental Toxicology, Los Alamos National Laboratory, Los Alamos, NM, 87545, USA
^e EarthLife Environment Testing, Denver, CO, 80202, USA

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ABSTRACT
 Recent high PFAS contamination levels were reported in birds and small mammals from Holloman Lake, a high-salinity wastewater oasis located in southern New Mexico, USA. We expanded the PFAS screening to surface water, soils, algae, invertebrates, fish, reptiles, and a larger number of plants, birds, and mammals to examine the fate, transport, and bioaccumulation of PFAS in the ecosystem and generate contamination profiles across both the water land interface and multiple trophic levels. C2 and C6 perfluorooctanoic acids, both of them known degradation products of C8 PFAS, were the dominant PFAS in surface water in the lake. In contrast, perfluorooctanoic acid (PFOS) was the main PFAS found in sediments along the shoreline, with the number of fluorescent carbons in the alkyl chain and clay minerals both appearing to play a key role in soil sorption. High soil PFAS concentrations up to 960 ng from the edge of the water could not be explained by air transport of contaminated dust and instead seemed related to past inundation events involving contaminated water. Higher PFAS concentrations along the main body of the lake included an extraordinary 30,000 ng/g wet wt of PFOS recorded for a composite subsolar (Tamarix sp.) tissue sample. Bioaccumulation provided the ecosystem's food web and trophic levels, with PFAS detection in all species and all types of animal tissue (blood, liver, muscle, and bone). Contamination involved mainly PFOS, followed by perfluorobenzamide acid (PFBA), with the observed concentrations of PFAS increasing concomitantly among tissue types but the liver bioaccumulating at a faster rate.

1. Introduction

There is growing concern over the issue of global environmental contamination and associated risks to human health, much of it related to the widespread use of per- and polyfluorinated substances (PFAS), also known as "forever chemicals" (e.g., Anagnostis et al., 2020; Booth et al., 2010; Rankin et al., 2014; Wei and Aziz, 2023; Aherne and Gosnell et al., 2024; Garfield et al., 2025). PFAS are synthetic compounds with one or more carbon-fluorine bonds conferring both high environmental persistence and strong resistance to degradation by conventional methods (Curren et al., 2022). With increasing frequency, PFAS have been detected in the world's oceans (Sun et al., 2013), drinking water

(Ho et al., 2016; Guo et al., 2024), ambient soils (Struyver et al., 2012; Rankin et al., 2014; Brønnum et al., 2020), indoor dust (Tao et al., 2014; Brønnum (Struyver et al., 2018), foodstuffs, fish, and wildlife (e.g., Gull-litter et al., 2022; Stubbö et al., 2022; Hodgson et al., 2023; Vaughan et al., 2023; Wells et al., 2024; Pickard et al., 2024), and even human serum and breast milk (Ostert et al., 2012; Zhang et al., 2012; Foglietti et al., 2024; Hiron et al., 2024; Lyu et al., 2024). In many cases, PFAS are found at relatively low levels ranging from pg/g to ng/g in wild countries and from low ng/L to tens of ng/L in aqueous solutions (e.g., Clari et al., 2016; Indaleno et al., 2018; Brønnum et al., 2020; Page et al., 2024; Wells et al., 2024). In areas near point sources, however, observed contamination levels can be higher by several orders of magnitude.

^{*} Corresponding author. Museum of Southwestern Biology, University of New Mexico, Albuquerque, NM, 87131, USA.
 E-mail address: jcarton@unm.edu (J.-L.E. Carton).
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Ongoing Research: Risk/Damage Assessment

1. Study of PFAS contamination in ducks and geese at the scale of New Mexico (funded by NMED through 2024, with additional private funds)

2. Study of PFAS contamination in oryx (in partnership with the New Mexico Department of Game and Fish)

Ongoing Research: Risk/Damage Assessment

3. PFAS contamination
of regional playas
(Maki Foundation
grant; BLM assistance)

4. PFAS contamination
along Tijeras Arroyo
(UNM Graduate
Studies grant)

Ongoing Research: Risk/Damage Assessment

5. Study of metabolic and immune toxicity in Holloman Lake wildlife (T&E Foundation grant)

6. Developmental toxicity in shorebirds at Holloman Lake (with Audubon Society)

Functioning ecosystem?



Animal PFAS toxicity

Toxicity = f (Exposure, Toxicodynamics)
Exposure = f (Dose, Time)

Liver, hormonal, reproductive, developmental, metabolic, and immune toxicity; liver, pancreatic, and testicular tumors in lab animal studies

120,000 ng/g (liver)

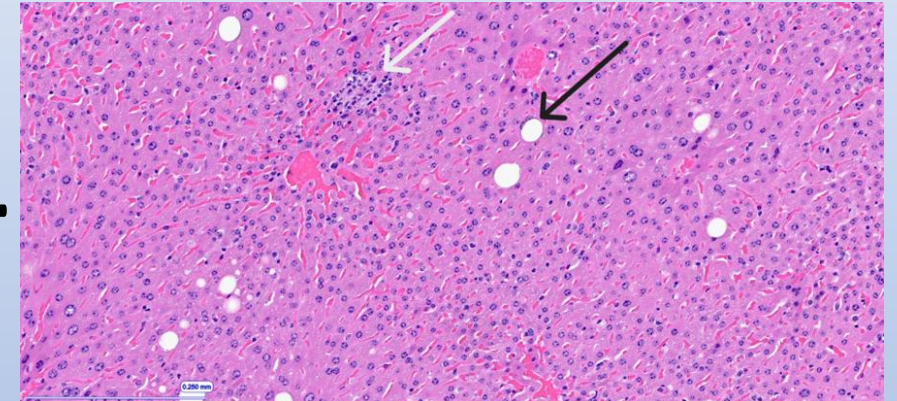
1000s-10,000s ng/g

100s ng/g (egg)

ng/g (liver)

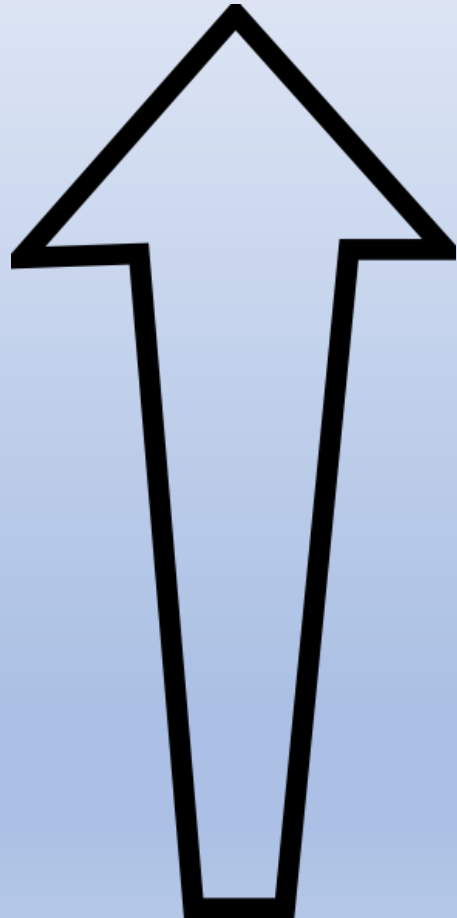


+



20 percent decrease in hatching success (tree swallows)

Disruptions of amino acid and lipid metabolism, energy production, and oxidative stress response; altered egg composition; hatchling deformities (turtles)



With T&E Foundation funding, in collaboration with VDS



Animal Necropsies
Histopathology
Lipidomics
PFAS Testing

Control, blind study
Three Groups of rodents:
Holloman Lake
Control Group
PFAS-free Site

Two rodent species

Metabolic and Immune Toxicity

In collaboration with the Audubon Society



Developmental toxicity

Nest searches and remote camera monitoring

Necropsies

Histopathology

Lipidomics

Thank you!!

For more information, please contact me:

Jean-Luc E. Cartron, Ph.D., M.D.

Research Professor

Department of Biology

MSC03 2020

1 University of New Mexico

Albuquerque, NM 87131-0001

Cell: 505-977-7716

Email: jlec@unm.edu

