

PEER-REVIEWED ARTICLE

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A Survey of the Levels of 16 Per- and Polyfluoroalkyl Substances in Meat, Chicken, and Siluriformes Fish, 2019 to 2023

ABSTRACT

The United States Department of Agriculture (USDA) Food Safety and Inspection Service (FSIS) conducted exploratory sampling of 16 per- and polyfluoroalkyl substances (PFAS) from 2019 to 2023. FSIS found that PFAS compounds are rarely detected in meat, poultry, and farm raised Siluriformes at a detection level of 0.5 ng/g or ppb. Less than 0.2% of beef, chicken, and farm raised Siluriformes, and less than 0.3% of pork samples contained detections of PFAS. Wild-caught domestic Siluriformes were frequently shown to contain at least one PFAS compound (48%; 110/228), though at lower levels compared to other surveys of freshwater fish in the U.S. The most detected PFAS compound in all samples was perfluorooctanesulfonic acid (PFOS). FSIS plans to expand its method to include more PFAS compounds and lower its minimum limit of applicability (MLA) and will continue to regularly monitor for PFAS as part of the National Residue Program. FSIS will continue to aid state regulatory partners with analyses on a case-by-case basis.

INTRODUCTION

Per- and polyfluoroalkyl substances (PFAS) are a class of thousands of man-made chemicals produced since the 1940s that are used in a broad range of consumer products and industrial applications. Dubbed “forever chemicals” in popular media, PFAS compounds have strong, stable carbon-fluorine (C-F) bonds that make them resistant to hydrolysis, photolysis, microbial degradation, and metabolism and, therefore, they are environmentally persistent (2). PFAS compounds have hydrophobic and lipophobic properties, giving them desirable characteristics for over 200 applications, such as coatings, aqueous film-forming foams, enhanced oil recovery, cleaning products, electronics processing, electroplating, paper, mining, photographic films, pesticide application, and other uses (3, 9). Many products contain PFAS, including coatings on wires and other surfaces, indoor and outdoor paints, food packaging, surfactants, cleaning solutions, refrigerants, and polymer processing aids (11). Available information shows that PFAS compounds can be widely dispersed in water, air, and soil and, as a result, are sometimes found in the food supply (7). Known sources of PFAS to the environment

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are production plants, wastewater treatment plants, landfill release, incineration, and biosolid application (7).

Government agencies in the U.S. and abroad routinely test food items for the presence of PFAS. The U.S. Food and Drug Administration (FDA) has tested food collected as part of the FDA's Total Diet Study since 2019 to better understand the occurrence of PFAS in foods, determine if targeted sampling assignments are necessary for certain foods, and help inform future surveillance efforts (20). No PFAS were detected in 97% (701 out of 718) of the fresh and processed foods tested from the Total Diet Study. However, it is noted that meat and fish products were among the positive detections. Method detection limits for the samples analyzed in the Total Diet Study range from 0.01 ng/g to 0.6 ng/g, depending on the PFAS analyte measured. (18, 19). In freshwater fish monitoring conducted by the Environmental Protection Agency (EPA), detectable levels of PFAS were found in 348 of the 349 freshwater fish samples analyzed in the 2013–2014 EPA National Rivers and Streams Assessment, and all 152 fish samples in the 2015 EPA Great Lakes Human Fish Fillet Tissue Study had detectable levels of PFAS (1). The EPA studies had a method detection limit of 0.043 ng/g to 0.63 ng/g, depending on the PFAS analyte measured. The more recently published EPA National Rivers and Streams Assessment 2018–2019 shows a small decrease in the number of fish containing perfluorooctanesulfonic acid (PFOS), at 91%, with a method detection limit for PFOS of 0.35 ng/g (17). In contrast, samples of retail seafood purchased in grocery stores and analyzed by FDA showed significantly lower mean and median concentrations of PFAS compared to the freshwater fish samples collected by EPA (1). Additionally, in a 2012 report, the European Food Safety Authority (EFSA) reported that the food groups with the most observations of PFAS detections were “Fish and other seafood,” and “Meat and meat products” (5). In a subsequent 2018 report, EFSA noted that PFOS is usually the PFAS that is present at the highest concentration in fish and shellfish, with concentrations ranging from <0.5 to 23 µg/kg where there is no apparent contamination incident, and that farmed fish and shellfish samples usually have lower concentrations of PFOS compared to wild fish. The 2018 EFSA report also identifies high PFOS and perfluorooctanoic acid (PFOA) detections in the “meat and meat products” category as mainly derived from detections in wild boar liver in Germany over several years. When offal detections from both game and farm animals are left out of the calculations in the “meat and meat products” category, the PFOS and PFOA levels in this category drop from lower bound/upper bound (LB/UB) levels of 215/215 µg/kg to 0.55/0.75 µg/kg for PFOS and LB/UB levels of 1.10/789 µg/kg to 0.10/0.34 µg/kg for PFOA (6).

The U.S. Department of Agriculture (USDA) Food Safety and Inspection Service (FSIS) has conducted exploratory sampling of sixteen PFAS compounds in beef, swine, chicken and Siluriformes fish since 2019 as a part

of the National Residue Program (NRP). The NRP is an interagency testing program administered by FSIS to control and regulate residues such as veterinary drugs, pesticides, and environmental contaminants in meat, poultry, egg products, and Siluriformes fish. FSIS coordinates with the EPA and the FDA on NRP testing priorities. FSIS issues an Annual Sampling Plan and publishes residue data quarterly on its website (8, 12). This paper provides the results of PFAS exploratory sampling from 2019 to 2023. FSIS's PFAS method analyzes sixteen PFAS compounds (Table 1).

MATERIALS AND METHODS

FSIS started exploratory testing of PFAS in 2019 with the quantitation of sixteen PFAS compounds in beef muscle and blood plasma. In 2020, FSIS expanded the method to chicken, swine, and Siluriformes fish muscle. Exploratory monitoring of PFAS in beef, chicken, swine, and Siluriformes fish muscle samples was incorporated into the NRP in 2021. Also in 2021, to increase screening efficiency and decrease turnaround times, the FSIS method was extended to use bovine muscle as a universal muscle quality control tissue. In 2023, FSIS began publishing PFAS data in quarterly residue reports on the FSIS website (12).

Because there are no U.S. regulatory levels for PFAS in FSIS-regulated products, tested carcasses are not held pending PFAS test results and no routine regulatory actions are taken with respect to individual carcasses in response to PFAS test results. FSIS actively monitors and reviews PFAS results to evaluate whether additional actions are necessary. FSIS PFAS data is used to measure typical PFAS levels in meat, chicken, and Siluriformes products, and to identify areas of concern.

PFAS concentrations are determined in skeletal muscle tissue samples collected as part of the NRP. Under this program, FSIS inspectors collect samples from randomly selected pork, chicken and Siluriformes fish carcasses at slaughter establishments and ship the samples to one of three FSIS Field Service Laboratories (FSL) for analysis.

Under the NRP, the beef samples analyzed for PFAS are derived from inspector-generated samples that were found to be positive for the presence of antibiotics through use of the kidney inhibition swab (KIS) test and condemned by FSIS inspection personnel. Inspector-generated samples are expected to be unbiased with regards to PFAS prevalence, *i.e.*, there is no reason to expect that inspector-generated samples would be more or less likely to contain PFAS than any other beef samples. Additionally, inspector-generated sampling provides a mixture of different bovine production classes. Generally, for beef, pork, and chicken samples, FSIS inspection personnel collect two pounds of skeletal muscle for NRP surveillance samples and one pound of skeletal muscle for inspector-generated samples (15), which are sent via cold packing to the FSL. The samples are taken from less expensive cuts of meat that are not overly fatty.

TABLE 1. Name and structure of PFAS analytes analyzed by CLG-PFAS2

Analyte	Name	Structure	CAS Number	Bovine Muscle Screening MLA ^a (ng/g)
PFPeA	Perfluoropentanoic Acid	CF ₃ (CF ₂) ₃ COOH	2706-90-3	0.50
PFHxA	Perfluorohexanoic Acid	CF ₃ (CF ₂) ₄ COOH	307-24-4	0.50
PFHpA	Perfluoroheptanoic Acid	CF ₃ (CF ₂) ₅ COOH	375-85-9	0.50
PFOA	Perfluorooctanoic Acid	CF ₃ (CF ₂) ₆ COOH	335-67-1	0.50
PFNA	Perfluorononanoic Acid	CF ₃ (CF ₂) ₇ COOH	375-95-1	0.50
PFDA	Perfluorodecanoic Acid	CF ₃ (CF ₂) ₈ COOH	335-76-2	0.50
PFUnA	Perfluoroundecanoic Acid	CF ₃ (CF ₂) ₉ COOH	2058-94-8	0.50
PFDoA	Perfluorododecanoic Acid	CF ₃ (CF ₂) ₁₀ COOH	307-55-1	0.50
PFTriA	Perfluorotridecanoic Acid	CF ₃ (CF ₂) ₁₁ COOH	72629-95-8	0.50
PFTeA	Perfluorotetradecanoic Acid	CF ₃ (CF ₂) ₁₂ COOH	376-06-7	0.50
PFHxDA	Perfluorohexadecanoic Acid	CF ₃ (CF ₂) ₁₄ COOH	67905-19-5	1.25
PFODA	Perfluorooctodecanoic Acid	CF ₃ (CF ₂) ₁₆ COOH	16517-11-6	0.50
PFBS	Perfluorobutanesulfonic Acid	CF ₃ (CF ₂) ₃ SO ₃ H	375-73-5	0.50
PFHxS	Perfluorohexanesulfonic Acid	CF ₃ (CF ₂) ₅ SO ₃ H	355-46-4	0.50
PFOS	Perfluorooctanesulfonic Acid	CF ₃ (CF ₂) ₇ SO ₃ H	1763-23-1	0.50
PFDS	Perfluorodecanesulfonic Acid	CF ₃ (CF ₂) ₉ SO ₃ H	335-77-3	0.50

^aMinimum Level of Applicability (MLA). FSIS defines the MLA as the lowest level at which a method has been successfully validated for a residue in a matrix. For quantitative methods, it is the minimum level at which regulatory results are reported. The MLA is also the lowest level at which laboratory analysts are expected to maintain proficiency. The MLA is greater than the method limit of detection and greater than or equal to the method limit of quantitation. This table lists the bovine muscle screening MLAs; other screening and confirmation MLAs are available in CLG-PFAS2 (13).

FSIS inspection personnel collect random Siluriformes samples from FSIS-regulated slaughter and processing facilities. The Siluriformes fish may have been farm-raised or caught in the wild prior to slaughter. At the time of sampling, FSIS inspection personnel note on the sample collection form whether the fish sampled was farm-raised or wild-caught. For Siluriformes samples, FSIS inspection personnel collect one pound of fish product in the final package, which is shipped to a FSL (16).

Once received at the laboratory, samples are frozen at -10°C if they cannot be prepared on the day of receipt. Muscle samples are prepared for analysis by removing fat and connective tissue and are then homogenized in a food processor. Thawed muscle tissue (0.5 g) is placed into 15 mL polypropylene centrifuge tubes.

As described in FSIS method CLG-PFAS 2.04 (13), PFAS residues are extracted through a protein precipitation extraction through use of methanol and stored in a freezer to aid precipitation. Protein precipitation is an extraction

technique that results in solid material being left at the bottom of an extraction vessel with the extract or liquid layer containing the analyte. The liquid layer can be separated out for further analysis. The extracted residues are examined using Ultra-High Performance Liquid Chromatography Coupled with Tandem Mass Spectrometry (UHPLC-MS-MS). The FSIS method CLG-PFAS 2.04 contains a listing of equipment, instruments, and reference materials used (13).

Prior to extraction, all samples are thawed at room temperature for 30 minutes. A methanolic extraction through protein precipitation is used to extract the PFAS analytes by adding 2.20 mL of methanol to the tubes. Samples are then centrifuged. The supernatant (500 uL) is transferred to vials and analyzed by UPLC-MS-MS in negative electrospray ionization (ESI) mode. The FSIS method detects 16 PFAS compounds of various chain lengths (4-carbon to 16-carbon) (Table 1). The analytical range of the method is 0.25-125 ng/g. The minimum level of applicability (MLA) of the method is 0.50-12.5 ng/g, depending on the PFAS analyte,

TABLE 2. FSIS samples analyzed per poultry, swine, and bovine production classes from 2019 to 2023

Production Class	Number of Samples Analyzed
Poultry	792
Young chicken	792
Swine	1,206
Feral swine	128
Market swine	542
Sow	536
Bovine	4,011
Beef cow	416
Bob veal	173
Bull/Stag	61
Dairy cow	2,601
Formula-fed veal	2
Heavy calf	9
Heifer	275
Non formula-fed veal	12
Steer	462

species, and matrix. FSIS defines the MLA as the lowest level at which a method has been successfully validated for a residue in a matrix. For quantitative methods, it is the minimum level at which regulatory results are reported. The MLA is also the lowest level at which laboratory analysts are expected to maintain proficiency. The MLA is greater than the method limit of detection and is greater than or equal to the method limit of quantitation (14).

RESULTS

Chicken, Swine, and Bovine Results.

FSIS analyzed chicken, swine, and bovine samples for PFAS from 2019 to 2023. [Table 2](#) shows the number of samples analyzed per production class.

Chicken, swine, and bovine samples containing PFAS detections > MLA are provided in [Table 3](#).

From 2020 to 2023, FSIS FSL analyzed 792 chicken samples for PFAS compounds. One young chicken sample (1/792, 0.13%) contained PFPeA at an estimated value of 0.70 ng/g. Due to the characteristics of the method, the PFPeA detection was not able to be confirmed. No other PFAS analytes were detected in the samples.

FSIS analyzed 1,206 pork samples for PFAS compounds from 2020 to 2023. Three samples had detections above the MLA (3/1,206, 0.25%). A market swine sample contained PFHpA at 0.68 ng/g, a feral swine sample contained PFOS

at 1.30 ng/g and PFBS at 1.27 ng/g, and another feral swine sample contained PFOS at 3.88 ng/g.

FSIS analyzed 4,011 beef samples for PFAS compounds from 2019 to 2023. Seven samples contained PFOS detections above the MLA (7/4,011, 0.17%). No other PFAS analytes were detected in bovine samples. Two steer samples contained PFOS at 0.66 ng/g and 0.83 ng/g, three beef cow samples contained PFOS at 0.74 ng/g, 0.90 ng/g, and 1.78 ng/g, and two dairy cow samples contained PFOS at 2.0 ng/g and 3.13 ng/g.

Siluriformes Results.

From 2020 to 2023, FSIS FSL analyzed 805 Siluriformes samples for PFAS compounds, of which 112 samples contained PFAS above the MLA of 0.5 ng/g (112/805, 13.9%) ([Table 4](#)). Of the 112 samples with detections above the MLA, 111 samples contained PFOS, fourteen samples contained PFUnA, twelve samples contained PFDA, seven samples contained PFDS, six samples contained PFDoA, and two samples contained PFTriA (see [Table 4](#)). Multiple PFAS were found in 21 samples.

Of the 805 Siluriformes samples measured by FSIS FSL, 423 (53%) were samples from imported Siluriformes and 382 (47%) were samples from domestic Siluriformes ([Figure 1](#)). There were no detections of PFAS above the MLA (0%; 0/423) in imported Siluriformes samples. Of the domestic

TABLE 3. FSIS chicken, swine, and bovine detections > MLA from 2019 to 2023

Collection Date	Production Class	PFOS (ng/g)	PFPeA (ng/g)	PFHpA (ng/g)	PFBS (ng/g)
Poultry					
08/30/2022	Young Chicken	ND	0.70	ND	ND
Swine					
06/23/2021	Market Swine	ND	ND	0.68	ND
10/12/2022	Feral Swine	1.30	ND	ND	1.27
12/19/2022	Feral Swine	3.88	ND	ND	ND
Bovine					
12/23/2019	Steer	0.83	ND	ND	ND
01/21/2020	Beef Cow	0.74	ND	ND	ND
03/05/2020	Steer	0.66	ND	ND	ND
06/16/2021	Beef Cow	1.78	ND	ND	ND
04/27/2022	Beef Cow	0.90	ND	ND	ND
03/01/2023	Dairy Cow	3.13	ND	ND	ND
07/12/2023	Dairy Cow	2.00	ND	ND	ND

TABLE 4. Summary of FSIS PFAS detections in Siluriformes from 2020 to 2023

	PFOS	PFUnA	PFDA	PFDS	PFDoA	PFTrIA
Number of detections > MLA / Total number of samples; (Percent of Siluriformes samples containing compound)	111/805; (13.8%)	14/805; (1.7%)	12/805; (1.5%)	7/805; (0.87%)	6/805; (0.74%)	2/805; (0.25%)
Maximum detection (ng/g)	21.2	3.71	3.46	2.04	2.66	0.73
Minimum detection (ng/g)	0.52	0.53	0.53	0.53	0.84	0.61
Average of detections > MLA (ng/g)	2.94	1.28	1.17	1.03	1.75	0.67

Siluriformes samples, 29% (112/382) contained detections above the MLA. Of the 112 samples containing PFAS above the MLA, all but two were from wild-caught fish, as opposed to a farm-raised fish or fish of unknown origin (110/112, 98% wild-caught). There were 228 domestic wild-caught Siluriformes samples analyzed, and 48% (110/228) of these contained PFAS detections > MLA. One of the Siluriformes samples containing PFAS above the MLA was in a farm-raised fish (0.4%; 1/228) and one positive Siluriformes sample was of unknown origin (0.4%; 1/228). A complete list of FSIS Siluriformes samples containing PFAS above the MLA is available in the Supplemental Material.

No statistical analyses were performed for this article.

DISCUSSION

FSIS exploratory PFAS data shows that there are very few detections of PFAS in beef, pork, chicken, and farm-raised Siluriformes samples at levels above the MLA of 0.5 ng/g. Less than 0.2% of beef, chicken, and farm-raised Siluriformes, and less than 0.3% of pork samples contained detections of PFAS. While there have been isolated incidents of PFAS contamination impacting certain livestock producers (10), FSIS exploratory data shows that PFAS contamination is not a widespread issue in the nation's beef, pork, chicken, and farm-raised Siluriformes supply at currently measured levels.

The most detected PFAS in Siluriformes was PFOS, with detections ranging from 0.52 to 21.2 ng/g, and a mean of

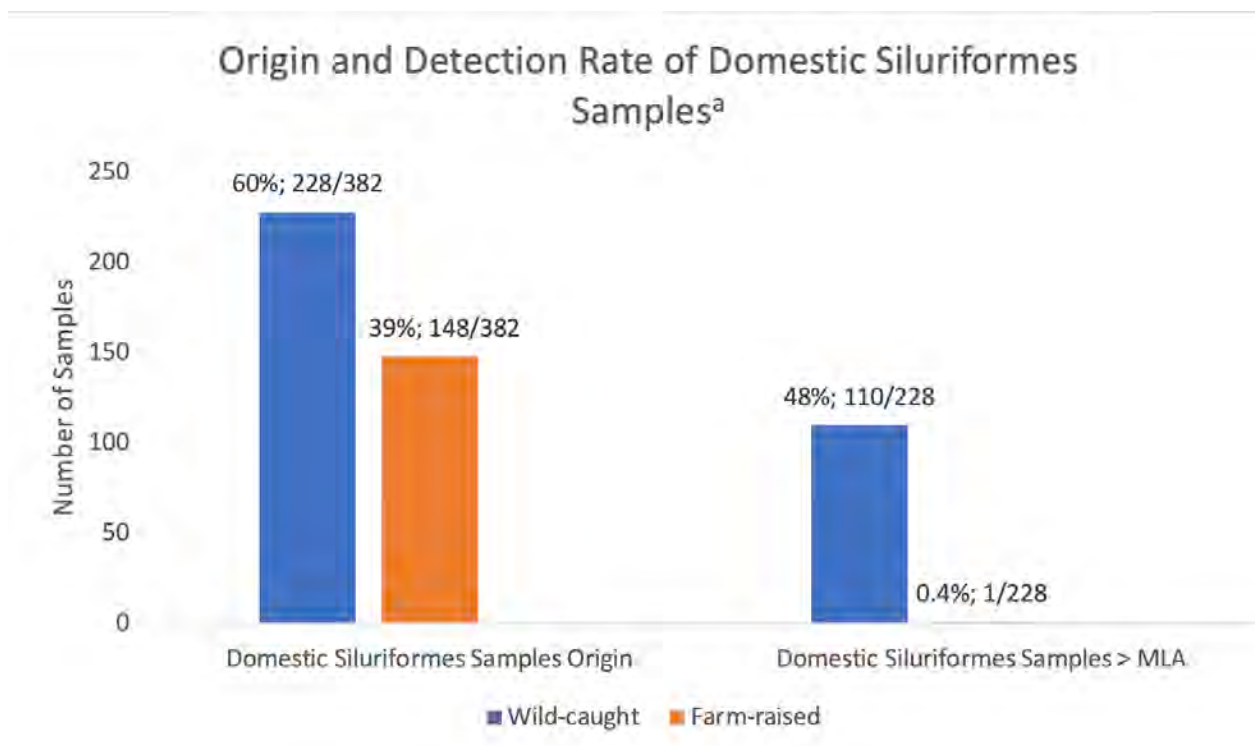


FIGURE 1. Origin and detection rate of domestic Siluriformes samples.
 *One Siluriformes sample with a detection > MLA was of unknown origin.

2.94 ng/g. FSIS does not have geographic data indicating where fish were caught, but does record the establishment where the sampled fish were processed. PFAS Siluriformes detections greater than the MLA were found in samples collected in a wide geographical area including 11 states.

FSIS exploratory data shows that PFAS compounds, particularly PFOS, are more commonly found in wild-caught Siluriformes fish than farm-raised Siluriformes. Of the 805 Siluriformes samples tested between 2020 to 2023, 112, or 13.9%, contained PFAS. Of the 112 samples containing PFAS above the MLA, 110, or 98%, were wild-caught Siluriformes. Additionally, 111 out of the 112 Siluriformes samples containing PFAS above the MLA, or 99%, contained the analyte PFOS.

FSIS regulates Siluriformes slaughter and processing establishments. The majority of Siluriformes product produced in the U.S. originates from farming operations, however, there is a proportion of Siluriformes product that is wild-caught (4). These wild-caught Siluriformes are generally thought to be from the vicinity of the processing establishment, but the exact body of water from which any given wild-caught Siluriformes is obtained is unknown.

U.S. EPA samples freshwater fish for PFAS, as shown in the 2013–2014 U.S. EPA National Rivers and Streams Assessment and the 2015 U.S. EPA Great Lakes Human

Health Fish Fillet Tissue Study. These studies analyzed a variety of freshwater fish species, with channel catfish (*Ictalurus punctatus*), smallmouth bass (*Micropterus dolomieu*), largemouth bass (*Micropterus salmoides*), yellow perch (*Perca flavescens*), and walleye (*Sander vitreus*) being the most frequently analyzed species. Of the 501 samples analyzed in these studies, 500 contained measurable levels of PFAS, with PFOS being the most detected PFAS analyte. The mean of total PFAS detected in freshwater fish in these studies was 20.8 ng/g. The 25th–75th percentile total PFAS was 5.69 ng/g to 25.9 ng/g. The mean of PFOS detected in these studies was 16.26 ng/g, and the 25th–75th percentile of PFOS was 3.79 ng/g to 20.0 ng/g (1).

FSIS Siluriformes samples contain fewer detections of PFAS at lower concentrations compared to other wild freshwater fish in the U.S. While 99% (500/501) of samples in the 2013–2014 U.S. EPA National Rivers and Streams Assessment and the 2015 U.S. EPA Great Lakes Human Health Fish Fillet Tissue Study contained PFAS compounds, 48% (110/228) of FSIS wild-caught Siluriformes samples contained PFAS compounds. The FSIS MLA for most PFAS compounds in fish tissue is 0.5 ng/g, while the quantitation limit in the EPA studies ranged from 0.25 ng/g to 1.25 ng/g. With a lower MLA, FSIS would likely detect more samples containing PFAS. Additionally, FSIS Siluriformes samples

contain lower levels of PFOS, with an average level of 2.94 ng/g for samples with detections > MLA, compared to a mean level of 16.26 ng/g in the EPA studies of wild-caught fish of a variety of species. Nearly all (98%, 110/112) of the FSIS Siluriformes samples with a detection above the MLA were from wild-caught catfish processed at an FSIS-regulated facility, as compared to farm-raised Siluriformes samples. The results of this paper add to the evidence that PFAS are commonly detected in wild-caught freshwater fish, including fish of the order Siluriformes, in the U.S.

FSIS is currently collaborating with the FDA and the USDA Agricultural Research Service (ARS) to expand the number of analytes in its method and to lower the MLA for the method. The current FSIS method measures 16 PFAS analytes. It is anticipated that the expanded method will include 32 PFAS analytes and lower the MLA from 0.50 ng/g to 0.05 ng/g to align methods with FDA and USDA ARS. With an expanded method, it is reasonably likely that additional PFAS analytes will be detected at lower levels than in FSIS-regulated products than is currently measured.

CONCLUSION

From analyses conducted as a part of its NRP from 2019 to 2023, FSIS found that PFAS compounds are rarely detected

in meat, chicken, and farm-raised Siluriformes at the method MLA of 0.5 ng/g. Wild-caught Siluriformes were frequently shown to contain at least one PFAS compound, though at lower levels compared to other surveys of freshwater fish in the U.S. FSIS plans to expand its method to include more PFAS compounds and lower the MLA and will continue to monitor for PFAS as part of the NRP.

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USE OF AI-ARTIFICIAL INTELLIGENCE

Generative AI was not used in any way in the creation of this article.

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IAFP's Business Meeting will be held Tuesday, July 29 at IAFP 2025.

As required by the Association's Constitution and Bylaws, **we are notifying IAFP Members that amendments to the Constitution and Bylaws will be presented for a vote at this year's Business Meeting.**

Visit the IAFP website to view the proposed changes. Look under the "About" dropdown, click "Governance" and scroll down. For questions, contact Lisa Garcia, IAFP Executive Director.