Food Safety and Inspection Service:
S68: The National Antimicrobial-resistance Monitoring System - Twenty Years of Vigilance

NARMS at the USDA: Monitoring Antimicrobial Resistance in Food Animals at Slaughter and Processing

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Office of Public Health Science, FSIS, USDA
Established in 1996 as a collaborative public health surveillance program to monitor susceptibility of enteric bacteria to antimicrobial agents used in human and veterinary medicine.
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NARMS at USDA: A Collaborative Program – Program Transition

ARS → FSIS

- 1996: FSIS PR/HACCP verification sampling begins
- 1997: FSIS PR/HACCP verification sampling begins
- 2012: Cecal sampling begins - culture, subtyping, and AST conducted by FDA/CVM
- 2013: NARMS antimicrobial susceptibility testing (AST) on PR/HACCP isolates conducted by ARS
- 2014: FDA - Whole Genome Sequencing (WGS) for Salmonella isolates from cecal samples
- 2015: FSIS begins WGS for all Salmonella and Campylobacter
- 2016: FSIS - WGS for all Salmonella and Campylobacter
- 2017: FSIS - WGS for all Salmonella and Campylobacter
Animal Arm of NARMS officially launched in 1996
- Began as a research project in ARS – 1995 under the leadership of Dr. Paula Cray working with frozen cultures from NVSL and ARS
- Approached by FDA in 1996 to join NARMS

ARS’s Bacterial Epidemiology and Antimicrobial Resistance Research Unit (BEAR) formed in 2006 and housed the Animal Arm of NARMS until 2013
- Methodological development and data analysis
- Provided genotypic and phenotypic data on foodborne pathogens and commensals for over 15 years
- Monitoring program successfully transitioned to FSIS ~ 2012-2013
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NARMS at ARS: History – Animal Arm Reporting and VetNet

Established in 2003 by ARS-FSIS in collaboration with CDC

Objectives:

- Use PFGE analysis of *Salmonella* isolates from food animals to assist in food borne illness outbreak
- Modeled after PulseNet USA
- Use comparative data for surveillance
- Assist at the farm level through study of clonal dissemination of isolates
  - Investigate animal illness outbreaks
- 23K entries as of June, 2013

Development of Interactive Dashboards by ARS in collaboration with FDA and CDC

- Improved ease of access of NARMS data
- From Static to Interactive!
Significant Contributions:

- Critical role in FDAs withdrawal of enrofloxacin for use in poultry
- Developed the first genus and species specific multiplex PCR for identification of enterococci
- First in the U.S. to find the \textit{mcr-1} gene in the intestine of livestock
- Conduct AMR Research
To address gaps in the AMR monitoring - AMR profiles identified through NARMS and on farm
   - FDA supported four on-farm pilot studies in poultry, swine, beef, and dairy cattle (2011-2015)

- Data collection
  - Animal drug use
  - Resistance results on-farm
  - Logistical challenges and costs
  - Feasibility of gathering drug use information with the biological samples

- Emphasis was on collecting on-farm samples and comparing them to cohort animals at slaughter
Some Findings/Observations

- Logistics of data and sample collection
- Adding an on-farm sampling component to NARMS surveillance
- Cecal sampling at slaughter
Reduce the prevalence and spread of Antimicrobial Resistance (AMR) across the food animal production and processing continuum by

- AMR and biocide resistance
- AMR in production and processing environments
- Stakeholders collaborations
FSIS is the public health agency in the U.S. Department of Agriculture responsible for ensuring that the nation's commercial supply of meat, poultry, and egg products is safe, wholesome, and correctly labeled and packaged.

**Inspection and Testing**
- About 6400 Establishments
- > 7350 Inspection Personnel
- Over 100 K Samples
- Over 233K Micro Analysis
- 3.4 million Scientific Analysis

**Our Authority**
- Federal Meat Inspection Act (FMIA), 1906
- Agricultural Marketing Act (AMA), 1946
- Poultry Products Inspection Act (PPIA), 1957
- Humane Methods of Slaughter Act (HMSA), 1958
- Egg Products Inspection Act (EPIA), 1970
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**NARMS at FSIS: Two Sources of Samples**

<table>
<thead>
<tr>
<th>FSIS Sampling Sources</th>
<th>Cecal Sampling Program (2013-Present)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pathogen Reduction/Hazard Analysis and Critical Control Point (PR/HACCP) Program (1997-Present)</strong></td>
<td><strong>Salmonella - Campylobacter</strong></td>
</tr>
<tr>
<td><strong>Cecal Sampling Program</strong></td>
<td><strong>Salmonella – Campylobacter – E.coli – Enterococcus</strong></td>
</tr>
</tbody>
</table>

Samples are collected from federally inspected slaughter and processing plants throughout the United States.
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NARMS at USDA: A Collaborative Program – Program Transition

ARS  -  FSIS

1996
FSIS PR/HACCP verification sampling begins

1997

NARMS antimicrobial susceptibility testing (AST) on PR/HACCP isolates conducted by ARS

2012  2013
Cecal sampling begins - culture, subtyping, and AST conducted by FDA/CVM

2014
FDA - Whole Genome Sequencing (WGS) for Salmonella isolates from cecal samples

2015
FSIS begins WGS on selected cecal Salmonella and Campylobacter

2016
FSIS - WGS for all Salmonella and Campylobacter from cecal samples

2017

FSIS- WGS for all Salmonella and Campylobacter
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NARMS at FSIS: Cecal Sampling Program

Joint FSIS-FDA *non-regulatory* project for collecting cecal samples at FSIS regulated establishments

- *Salmonella, Campylobacter, E. coli* and *Enterococcus* isolates are collected from cecal contents from federally inspected slaughter and processing plants
- Cattle samples (dairy cows, beef cows, steers, and heifers)
- Poultry (young chicken and turkey)
- Swine (market swine and sows)

Results not used for enforcement but to understand AMR microflora in FSIS products
III. ESTABLISHMENT ELIGIBILITY FOR THE FSIS NARMS SAMPLING PROGRAM

A. Livestock and poultry slaughter establishments are eligible for the NARMS sampling program based on data in PHIS: by establishment size; the animal classes slaughtered; and annual slaughter volumes. Sampling tasks for the NARMS sampling program will be assigned at the following frequencies, using the previous 12 months of slaughter data:

<table>
<thead>
<tr>
<th>Slaughter Volume</th>
<th>Maximum number of sampling tasks per month per sampling project</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top 25% of Slaughter Establishments</td>
<td>4</td>
</tr>
<tr>
<td>Second 25% of Slaughter Establishments</td>
<td>2</td>
</tr>
<tr>
<td>Lowest 50% of Slaughter Establishments</td>
<td>1</td>
</tr>
</tbody>
</table>

B. PHVs at these establishments will receive sampling tasks through PHIS and are to order supplies for each sampling event from the EL (see Section VI). PHVs are to respond to each sampling task using the instructions provided in this directive.

V. SAMPLING TASK ASSIGNMENT

A. Notification of sampling tasks will be in the form of an alert in PHIS. The sampling tasks will be directed tasks on the establishment task list with one or more of the following sampling project codes:

<table>
<thead>
<tr>
<th>Project Code</th>
<th>Slaughter Class To Sample</th>
</tr>
</thead>
<tbody>
<tr>
<td>NARMS_YC</td>
<td>Young Chicken</td>
</tr>
<tr>
<td>NARMS_YT</td>
<td>Young Turkey</td>
</tr>
<tr>
<td>NARMS_DC</td>
<td>Dairy Cow</td>
</tr>
<tr>
<td>NARMS_BC</td>
<td>Beef Cow</td>
</tr>
<tr>
<td>NARMS_ST</td>
<td>Steer</td>
</tr>
<tr>
<td>NARMS_HF</td>
<td>Heifer</td>
</tr>
<tr>
<td>NARMS_MS</td>
<td>Market Swine</td>
</tr>
<tr>
<td>NARMS_SW</td>
<td>Sow</td>
</tr>
</tbody>
</table>
# Food Safety and Inspection Service

## NARMS at FSIS: Sampling and Results – Focus on *Salmonella* Isolates

<table>
<thead>
<tr>
<th></th>
<th>2014</th>
<th>2015</th>
<th>2016&lt;sup&gt;1&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No. Samples</td>
<td>No. Isolates</td>
<td>Percent Positive</td>
</tr>
<tr>
<td><strong>HACCP</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chickens</td>
<td>10,446</td>
<td>936</td>
<td>9.0%</td>
</tr>
<tr>
<td>Turkey</td>
<td>3,374</td>
<td>299</td>
<td>8.9%</td>
</tr>
<tr>
<td>Cattle</td>
<td>16,720</td>
<td>344</td>
<td>2.1%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>30,540</td>
<td>1,579</td>
<td></td>
</tr>
<tr>
<td><strong>Ceca</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chickens</td>
<td>575</td>
<td>103</td>
<td>17.9%</td>
</tr>
<tr>
<td>Turkey</td>
<td>264</td>
<td>45</td>
<td>17.0%</td>
</tr>
<tr>
<td>Beef</td>
<td>1,798</td>
<td>104</td>
<td>5.8%</td>
</tr>
<tr>
<td>Dairy</td>
<td>1,069</td>
<td>217</td>
<td>20.3%</td>
</tr>
<tr>
<td>Swine</td>
<td>1,295</td>
<td>606</td>
<td>46.8%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>5,001</td>
<td>1,075</td>
<td>21.5%</td>
</tr>
</tbody>
</table>

<sup>1</sup>Preliminary 2016 Data
NARMS at FSIS: Focus on *Salmonella* Isolates

![Bar chart showing the number of *Salmonella* isolates from different types of meat and data years: 2014, 2015, and preliminary 2016 data.](chart)

1Preliminary 2016 Data
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NARMS at FSIS: Focus on MDR *Salmonella* in Cattle

**Percent of *Salmonella* isolates MDR - resistant to ≥ 3 antimicrobial classes**

- **Cecal MDR:**
  - > 90% R to Str, Sul, Tet
  - >70% R to Amp
  - 57% R to Ceftriaxone (C)

- **HACCP MDR:**
  - > 90% R to Str, Sul, Tet
  - >70% R to Amp, Chl
  - 60% R to Ceftriaxone (C)

<table>
<thead>
<tr>
<th>Year</th>
<th>Beef cow (cecal)</th>
<th>Dairy (cecal)</th>
<th>Heifer (cecal)</th>
<th>Steer (cecal)</th>
<th>HACCP</th>
</tr>
</thead>
<tbody>
<tr>
<td>2014</td>
<td>15</td>
<td>217</td>
<td>42</td>
<td>47</td>
<td>344</td>
</tr>
<tr>
<td>2015</td>
<td>31</td>
<td>233</td>
<td>45</td>
<td>50</td>
<td>291</td>
</tr>
<tr>
<td>2016</td>
<td>29</td>
<td>218</td>
<td>47</td>
<td>74</td>
<td>285</td>
</tr>
</tbody>
</table>

1 Preliminary 2016 Data
S. Dublin from ceca: n=5 (2014-2016)
S. Dublin is included in ‘Others’ category

1Preliminary 2016 Data
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NARMS at FSIS: Focus on MDR *Salmonella* in Cattle – Serotype Distribution (without S. Dublin!)

**Percent of *Salmonella* isolates MDR - resistant to ≥ 3 antimicrobial classes**

- **Beef cow (cecal)**
  - 2014 n=15
  - 2015 n=31
  - 2016 n=29

- **Dairy (cecal)**
  - 2014 n=217
  - 2015 n=233
  - 2016 n=218

- **Heifer (cecal)**
  - 2014 n=42
  - 2015 n=45
  - 2016 n=47

- **Steer (cecal)**
  - 2014 n=47
  - 2015 n=50
  - 2016 n=74

- **HACCP**
  - 2014 n=313
  - 2015 n=260
  - 2016 n=258

*Preliminary 2016 Data*
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NARMS at FSIS: Focus on MDR *Salmonella* in Cattle – HACCP Dublin

### Preliminary 2016 Data

**S. Dublin Ceftriaxone-R vs. S. Dublin in Cattle**

- **No. Cattle Isolates**: 24, 284, 1610, 1388, 893, 1008, 670, 607, 329, 21, 14, 15, 30, 30, 13, 19, 40, 53, 21, 41, 38, 30, 21, 31, 31, 27

- **No. S. Dublin**: 0, 1, 26, 21, 14, 15, 30, 30, 13, 19, 40, 53, 21, 41, 38, 30, 21, 31, 31, 27

2014-2016: 56% of Dublin isolates were resistant to:

- AMC
- AMP
- FOX
- CRO
- CHL
- STR
- SOX
- TCY

*S. Dublin from ceca: n=5 (2014-2016)*
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NARMS at FSIS: Focus on MDR Salmonella in Chicken

Percent of Salmonella isolates MDR - resistant to ≥3 antimicrobial classes

<table>
<thead>
<tr>
<th>Year</th>
<th>HACCP n</th>
<th>Cecal n</th>
</tr>
</thead>
<tbody>
<tr>
<td>2014</td>
<td>936</td>
<td>103</td>
</tr>
<tr>
<td>2015</td>
<td>1491</td>
<td>130</td>
</tr>
<tr>
<td>2016</td>
<td>1857</td>
<td>133</td>
</tr>
</tbody>
</table>

Cecal Chicken – MDR Serotypes

- Typhimurium: 54%
- Kentucky: 15%
- Infantis: 10%
- Heidelberg: 5%
- Schwarzengrund: 3%
- Others: 2%

HACCP Chicken – MDR Serotypes

- Kentucky: 37%
- Typhimurium: 28%
- Infantis: 15%
- Heidelberg: 9%
- Enteritidis: 5%
- Schwarzengrund: 3%
- I 4,[5],12:i:-: 1%
- Others: 2%

1Preliminary 2016 Data
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NARMS at FSIS: Focus on MDR Salmonella in Turkeys

Percent of Salmonella isolates MDR - resistant to ≥ 3 antimicrobial classes

HACCP Turkey – MDR Serotypes

Cecal Turkey – MDR Serotypes

1Preliminary 2016 Data
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**NARMS at FSIS: Focus on MDR *Salmonella* in Swine**

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**Percent of *Salmonella* isolates MDR - resistant to ≥ 3 antimicrobial classes**

- **Market Swine (Cecal)**
  - 2014: 280
  - 2015: 216
  - 2016: 307

- **Sow (Cecal)**
  - 2014: 328
  - 2015: 278
  - 2016: 312

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**Cecal Market Swine – MDR Serotypes**

- Derby: 33%
- I 4,[5],12:i:-: 25%
- Typhimurium: 17%
- Agona: 17%
- Johannesburg: 14%
- Brandenburg: 12%
- Infantis: 3%
- Others: 6%

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**Cecal Sow – MDR Serotypes**

- Derby: 32%
- I 4,[5],12:i:-: 17%
- Typhimurium: 17%
- Agona: 17%
- Johannesburg: 14%
- Brandenburg: 12%
- Infantis: 3%
- Others: 6%

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1Preliminary 2016 Data
## NARMS at FSIS: Focus on *Campylobacter jejuni* and *Campylobacter coli*

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Species</th>
<th>2014 n</th>
<th>2015 %</th>
<th>2016 1 n</th>
<th>2016 1 %</th>
<th>HACCP 2014 n</th>
<th>2015 %</th>
<th>2016 1 n</th>
<th>2016 1 %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>2014</td>
<td>2015</td>
<td>2016</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chickens</td>
<td>Jejuni</td>
<td>8</td>
<td>11%</td>
<td>2</td>
<td>4%</td>
<td>12</td>
<td>20%</td>
<td>418</td>
<td>73%</td>
</tr>
<tr>
<td></td>
<td>Coli</td>
<td>62</td>
<td>89%</td>
<td>51</td>
<td>96%</td>
<td>47</td>
<td>80%</td>
<td>156</td>
<td>27%</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>70</td>
<td>100%</td>
<td>53</td>
<td>100%</td>
<td>59</td>
<td>100%</td>
<td>574</td>
<td>100%</td>
</tr>
<tr>
<td>Turkeys</td>
<td>Jejuni</td>
<td>1</td>
<td>6%</td>
<td>2</td>
<td>18%</td>
<td>2</td>
<td>13%</td>
<td>19</td>
<td>44%</td>
</tr>
<tr>
<td></td>
<td>Coli</td>
<td>15</td>
<td>94%</td>
<td>9</td>
<td>82%</td>
<td>13</td>
<td>87%</td>
<td>24</td>
<td>56%</td>
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<td></td>
<td>Total</td>
<td>16</td>
<td>100%</td>
<td>11</td>
<td>100%</td>
<td>15</td>
<td>100%</td>
<td>43</td>
<td>100%</td>
</tr>
<tr>
<td>Beef Cow</td>
<td>Jejuni</td>
<td>574</td>
<td>76%</td>
<td>500</td>
<td>73%</td>
<td>452</td>
<td>69%</td>
<td>395</td>
<td>88%</td>
</tr>
<tr>
<td></td>
<td>Coli</td>
<td>180</td>
<td>24%</td>
<td>181</td>
<td>27%</td>
<td>200</td>
<td>31%</td>
<td>55</td>
<td>12%</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>754</td>
<td>100%</td>
<td>681</td>
<td>100%</td>
<td>652</td>
<td>100%</td>
<td></td>
<td></td>
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<tr>
<td>Dairy Cow</td>
<td>Jejuni</td>
<td>395</td>
<td>88%</td>
<td>375</td>
<td>83%</td>
<td>364</td>
<td>85%</td>
<td>395</td>
<td>88%</td>
</tr>
<tr>
<td></td>
<td>Coli</td>
<td>55</td>
<td>12%</td>
<td>76</td>
<td>17%</td>
<td>66</td>
<td>15%</td>
<td>55</td>
<td>12%</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>450</td>
<td>100%</td>
<td>451</td>
<td>100%</td>
<td>430</td>
<td>100%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Market</td>
<td>Swine</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Not tested</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Swine</td>
<td>Jejuni</td>
<td>9</td>
<td>5%</td>
<td>8</td>
<td>7%</td>
<td>9</td>
<td>6%</td>
<td>148</td>
<td>48%</td>
</tr>
<tr>
<td></td>
<td>Coli</td>
<td>174</td>
<td>95%</td>
<td>102</td>
<td>93%</td>
<td>139</td>
<td>94%</td>
<td>160</td>
<td>52%</td>
</tr>
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<td></td>
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<td>148</td>
<td>100%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sow</td>
<td>Jejuni</td>
<td>148</td>
<td>48%</td>
<td>134</td>
<td>48%</td>
<td>136</td>
<td>49%</td>
<td>148</td>
<td>48%</td>
</tr>
<tr>
<td></td>
<td>Coli</td>
<td>160</td>
<td>52%</td>
<td>143</td>
<td>52%</td>
<td>141</td>
<td>51%</td>
<td>160</td>
<td>52%</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>308</td>
<td>100%</td>
<td>277</td>
<td>100%</td>
<td>277</td>
<td>100%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1 Preliminary 2016 Data
Food Safety and Inspection Service
NARMS at FSIS: Focus on MDR *Campylobacter jejuni* and *Campylobacter coli*

**Cecal - Percent of C. coli isolates MDR - resistant to ≥ 3 antimicrobial classes**

![Graph showing percent of C. coli isolates MDR-resistant to ≥ 3 antimicrobial classes across different commodities.](image)

**HACCP - Percent of C. coli isolates MDR - resistant to ≥ 3 antimicrobial classes**

![Graph showing percent of C. coli isolates MDR-resistant to ≥ 3 antimicrobial classes for Chickens and Turkeys.](image)

MDR in *C. Jejuni* was <2% for all commodities in both HACCP and Cecal

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1Preliminary 2016 Data

*Please note the difference in y-axis scale*
Food Safety and Inspection Service:
NARMS at FSIS: Focus on *Salmonella* MDR 1997-2016

<table>
<thead>
<tr>
<th></th>
<th>HACCP</th>
<th>Ceca (2013)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total No. of Isolates Tested</td>
<td>41,145</td>
<td>4,319</td>
</tr>
<tr>
<td>Total No. of MDR</td>
<td>7643</td>
<td>548</td>
</tr>
<tr>
<td>Total Percent MDR</td>
<td>18.6%</td>
<td>12.7%</td>
</tr>
</tbody>
</table>

1 Preliminary 2015 & 2016 data
Food Safety and Inspection Service
Application of Whole Genome Sequencing to NARMS

Genotypic screening for antimicrobial resistance using whole genome sequencing (WGS)

2015
*Salmonella* and *Campylobacter* from *ceca* with R > 1 antimicrobial

2016
All *Salmonella* and *Campylobacter* from *ceca*

2017
All *Salmonella* and *Campylobacter* from both *ceca* and HACCP + AMR *E. coli* and *Enterococcus*
Food Safety and Inspection Service
FSIS WGS Update: WGS Milestones and NCBI Uploads

**Milestone Dates**
- July 2014: *Salmonella* and *Listeria monocytogenes*
- December 2014: STECs
- February 2015: *Campylobacter*
- May 2015: Capability to directly upload WGS files to NCBI

**As of 6/30/2017: 8,822 FSIS isolates have been sequenced and uploaded to NCBI**

<table>
<thead>
<tr>
<th></th>
<th>Listeria monocytogenes</th>
<th>STEC</th>
<th>Salmonella</th>
<th>Campylobacter</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Routine/Special Projects</td>
<td>377</td>
<td>431</td>
<td>2774</td>
<td>778</td>
<td>4360</td>
</tr>
<tr>
<td>NARMS Cecal Sampling</td>
<td></td>
<td></td>
<td>2025</td>
<td>2437</td>
<td>4462</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>377</td>
<td>431</td>
<td>4799</td>
<td>3215</td>
<td>8822</td>
</tr>
</tbody>
</table>
Metadata and sequence data is immediately available for upload to NCBI

- Product/Source type (Ready to eat product, raw meat/poultry, environmental swab, etc.)
- Year sample was collected
- State where sample was collected
- Subtyping information when available
  - *Salmonella* – serovar
  - Adulterant STECs – O-group
  - *Campylobacter* – species
Food Safety and Inspection Service
FSIS Update: WGS Applications to AMR

- Ability to rapidly identify new genes of concern
  - Work with NARMS and other partners in a real-time to identify the presence, magnitude and impact of undesirable gene(s)
  - Proactively work with stakeholders to start taking the necessary actions
- Examples of WGS application to novel gene detection and actions
  - ESBL \( bla_{\text{CTX-M-65}} \)
  - Colistin Resistance
  - Quinolone Resistance
  - Linezolid Resistance
  - Daptomycin Resistance
Cecal sampling has further strengthened NARMS surveillance by adding another sampling point and additional ~ 5000 samples.

Continuation of WGS and timely sequence uploads into NCBI.

Work with NARMS partners to monitor Resistome and Mobilome.

Develop a mechanism to inform regulated industry of new findings of concern.

FSIS NARMS Webpage and publications.
Food Safety and Inspection Service

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