

# The Realities of Chemical Recycling and the Plastic Pollution Crisis

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28.02.2024



## Academic background

- Environmental Sciences (University of Valencia)
  - University of Rome “La Sapienza”
- MsC Environmental pollution and toxicology (University of Valencia)
- PhD Chemistry (University of Valencia and Polytechnic's University of Valencia)
  - University of Athens
  - University of Eastern Finland

## Professional experience

- Helmholtz-Center for Environmental Research (2019-)
  - University of Gothenburg
  - University of Goethe (Frankfurt)
  - RWTH University of Aachen



# The plastic challenge

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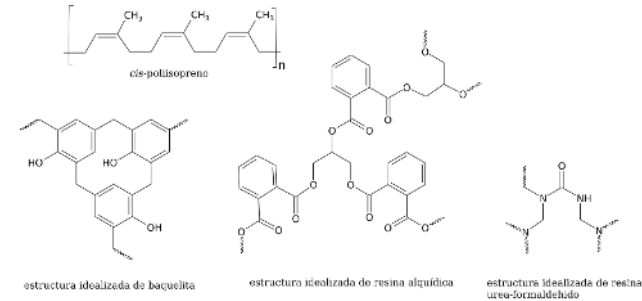
In which century do we date the use of the first polymers that gave rise to today's plastics?

- A 14<sup>th</sup> A.C.
- B 16<sup>th</sup> B.C.
- C 3<sup>rd</sup> A.C.
- D 19<sup>th</sup> A.C.

# The plastic challenge

In which century do we date the use of the first polymers that gave rise to today's plastics?

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- C** 3<sup>rd</sup> A.C.
- D** 19<sup>th</sup> A.C.



# The plastic challenge

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Which company(s) developed the first vulcanization of rubber giving rise to today's plastics?

- A Goodyear
- B Hancock
- C Michelin
- D A and B are correct

# The plastic challenge

---

Which company(s) developed the vulcanization of rubber giving rise to today's plastics?

A Goodyear

B Hancock

C Michelin

**D A and B are correct**

# The plastic challenge

---

How much plastic was produced in 2022 worldwide?

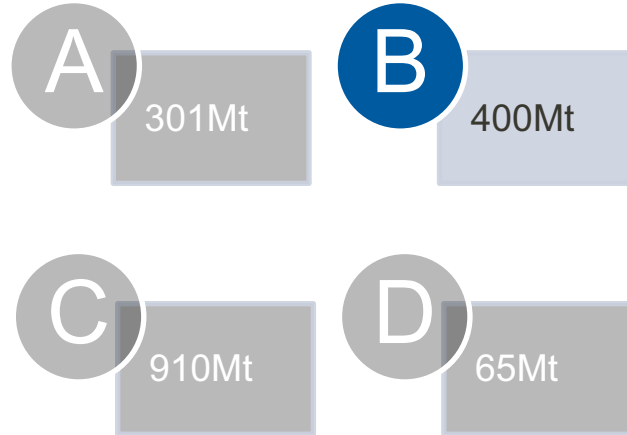
- A 301Mt
- B 400Mt
- C 910Mt
- D 67Mt



# The plastic challenge

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How much plastic was produced in 2022 worldwide?

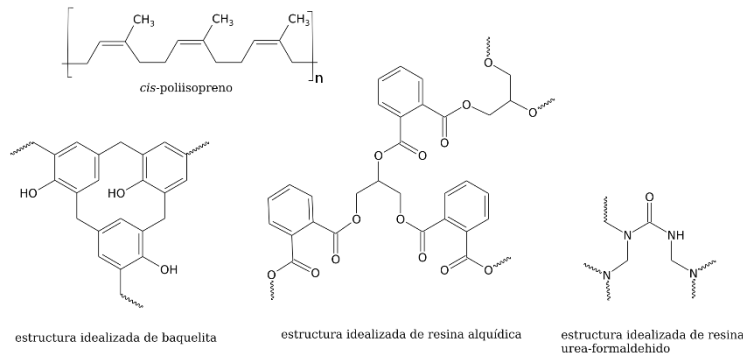


# History of plastics

The use of polymers dates back to the 16th century BC, when ancient Mesoamerican cultures first processed natural rubber into solid objects. Ancient Mesoamericans obtained the raw material for making rubber objects from latex produced by the tree *Castilla elastica*.

In 1839, Goodyear in the USA and Hancock in England developed the vulcanisation of rubber, i.e. the hardening of rubber and its increased resistance to cold, in parallel.

The plastics industry began with the development of the first thermosetting plastics by Baekeland in 1909. Baekeland produced the first synthetic polymer and also developed the plastic moulding process, which enabled him to produce various articles of commerce. These early plastics were named Bakelite after their discoverer. Bakelite is formed by a condensation reaction of phenol with formaldehyde.



# History of plastics



PET



HDPE



PVC



LDPE



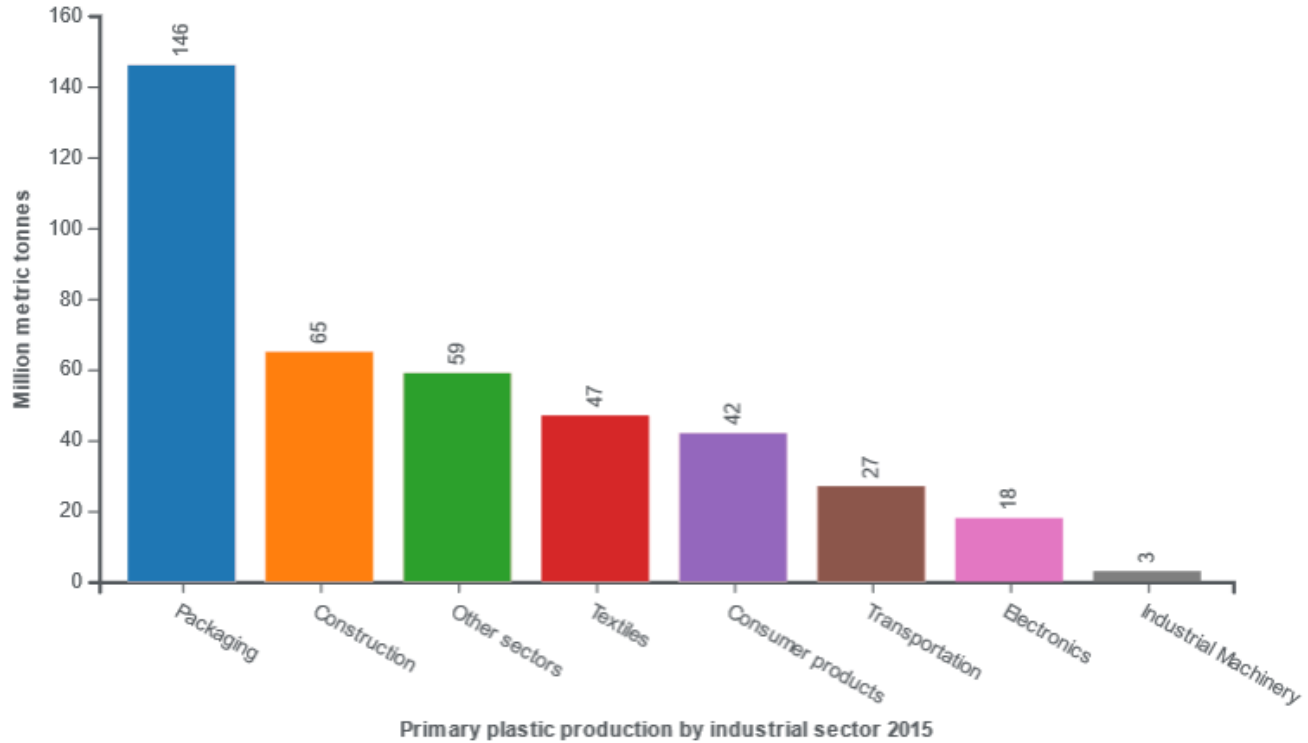
PP



PS

| Polymer                          | Production (Mt) | Percentage of all plastics | Polymer type           | Thermal character |
|----------------------------------|-----------------|----------------------------|------------------------|-------------------|
| polypropylene (PP)               | 68              | 16.70%                     | Polyolefin             | Thermoplastic     |
| Low-density polyethylene (LDPE)  | 64              | 15.70%                     | Polyolefin             | Thermoplastic     |
| PP&A Fibers                      | 59              | 14.50%                     | Condensation           | Thermoplastic     |
| High-density polyethylene (HDPE) | 52              | 12.80%                     | Polyolefin             | Thermoplastic     |
| Polyvinyl chloride (PVC)         | 38              | 9.30%                      | Halogenated            | Thermoplastic     |
| Polyethylene terephthalate (PET) | 33              | 8.10%                      | Condensation           | Thermoplastic     |
| Polyurethane (PUR)               | 27              | 6.60%                      | Condensation           | Thermo            |
| Polystyrene (PS)                 | 25              | 6.10%                      | Unsaturated polyolefin | Thermoplastic     |
| Additives                        | 25              | 6.10%                      | -                      | -                 |
| All Others                       | 16              | 3.90%                      | Various                | Varies            |
| <b>Total</b>                     | <b>407</b>      | <b>100.00%</b>             | -                      | -                 |

# Use of plastics

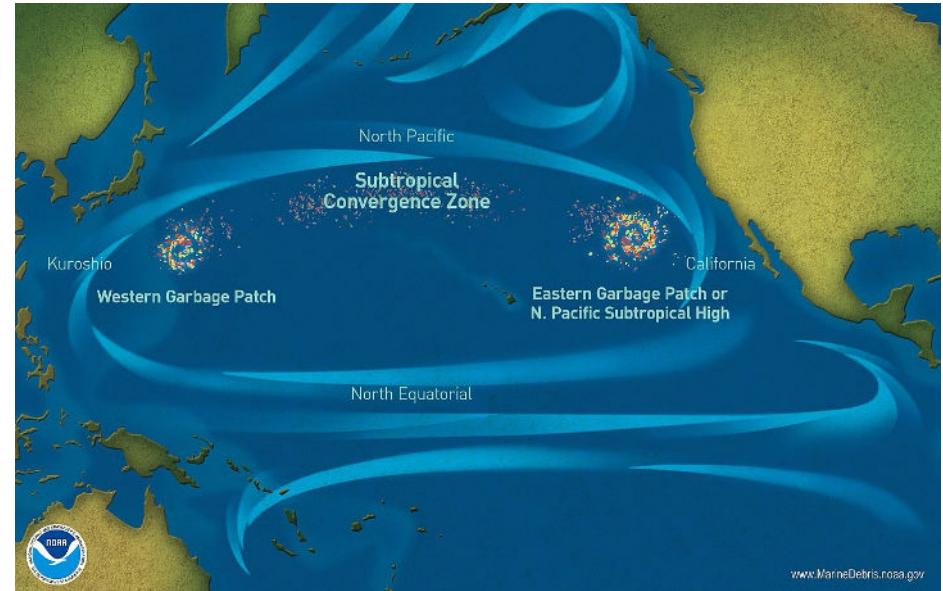
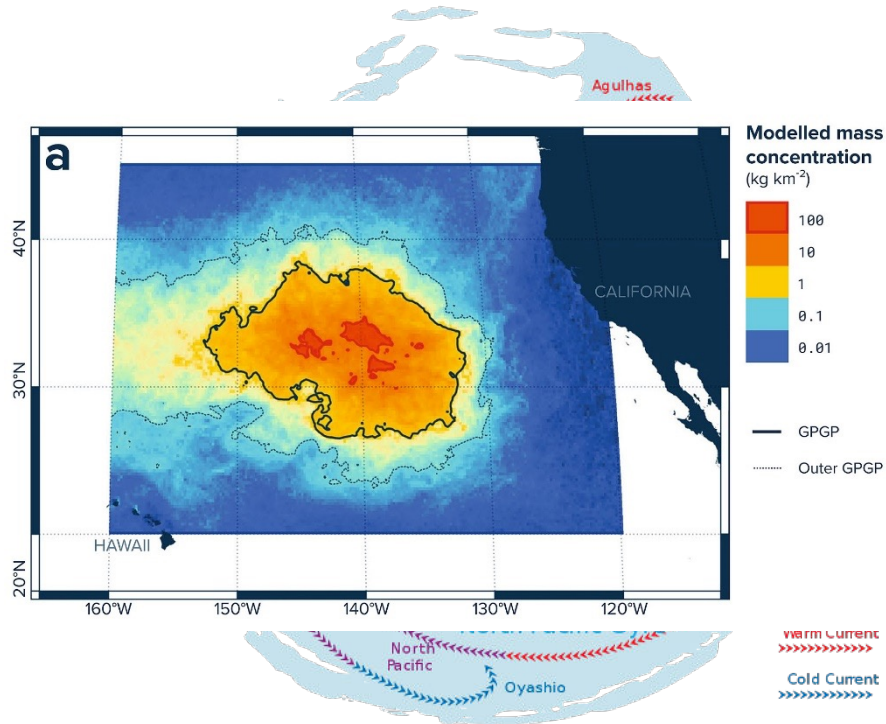


## Use of plastics



# Environmental problems

## The plastic island



# Environmental problems

## *The life of plastic*



# The solutions





Data in Brief 51 (2023) 109740



Contents lists available at [ScienceDirect](https://www.sciencedirect.com)

Data in Brief

journal homepage: [www.elsevier.com/locate/dib](https://www.elsevier.com/locate/dib)

Data Article

## A dataset of organic pollutants identified and quantified in recycled polyethylene pellets

Eric Carmona<sup>a,b,\*</sup>, Elisa Rojo-Nieto<sup>c</sup>, Christoph D. Rummel<sup>c</sup>,  
Martin Krauss<sup>a</sup>, Kristian Syberg<sup>d</sup>, Tiffany M Ramos<sup>d</sup>, Sara Brosche<sup>e</sup>,  
Thomas Backhaus<sup>a,f</sup>, Bethanie Carney Almroth<sup>a,\*</sup>



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**Dangerous chemicals found in recycled plastics, making them unsafe for use – experts explain the hazards**

P.MedSci January 10, 2024;14(2):S107

# The study



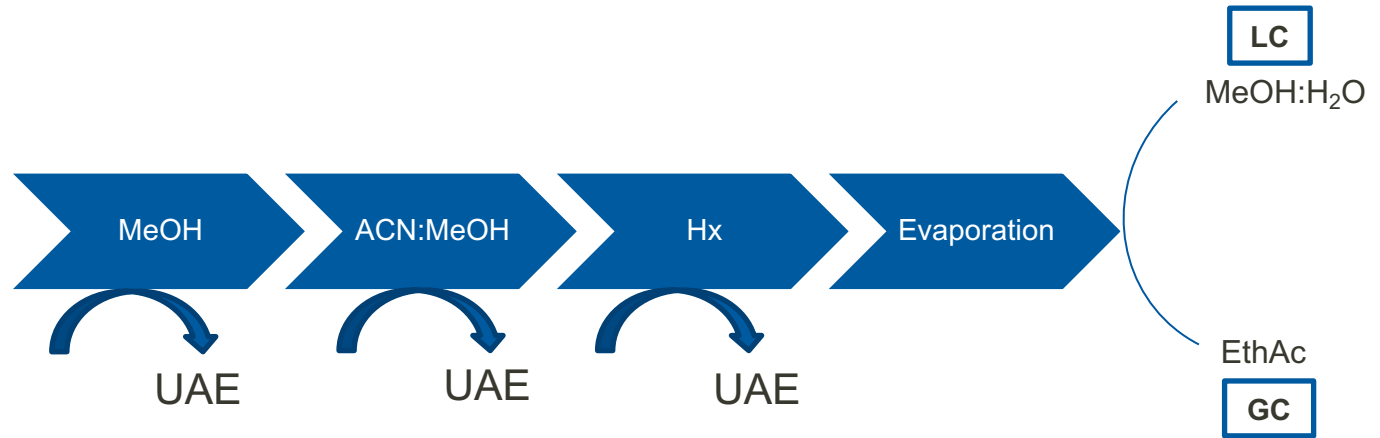
Samples coming from:

- Argentina
- Cameroon
- India
- Indonesia
- Malaysia
- Mauritius
- Nepal
- Nigeria
- Serbia
- Taiwan
- Tanzania
- Thailand
- Togo

29 samples

# The analysis

Extraction of compounds: UAE



# The analysis

*Instrumental analysis: LC-MS*

## LC-HRMS



**Thermo Ultimate 3000 LC system**

**Thermo QExactive Plus MS**

ESI+ and ESI-

Target analysis: >600 compounds

Retrospective analysis: ~200  
compounds

# The analysis

*Instrumental analysis: GC-MS*



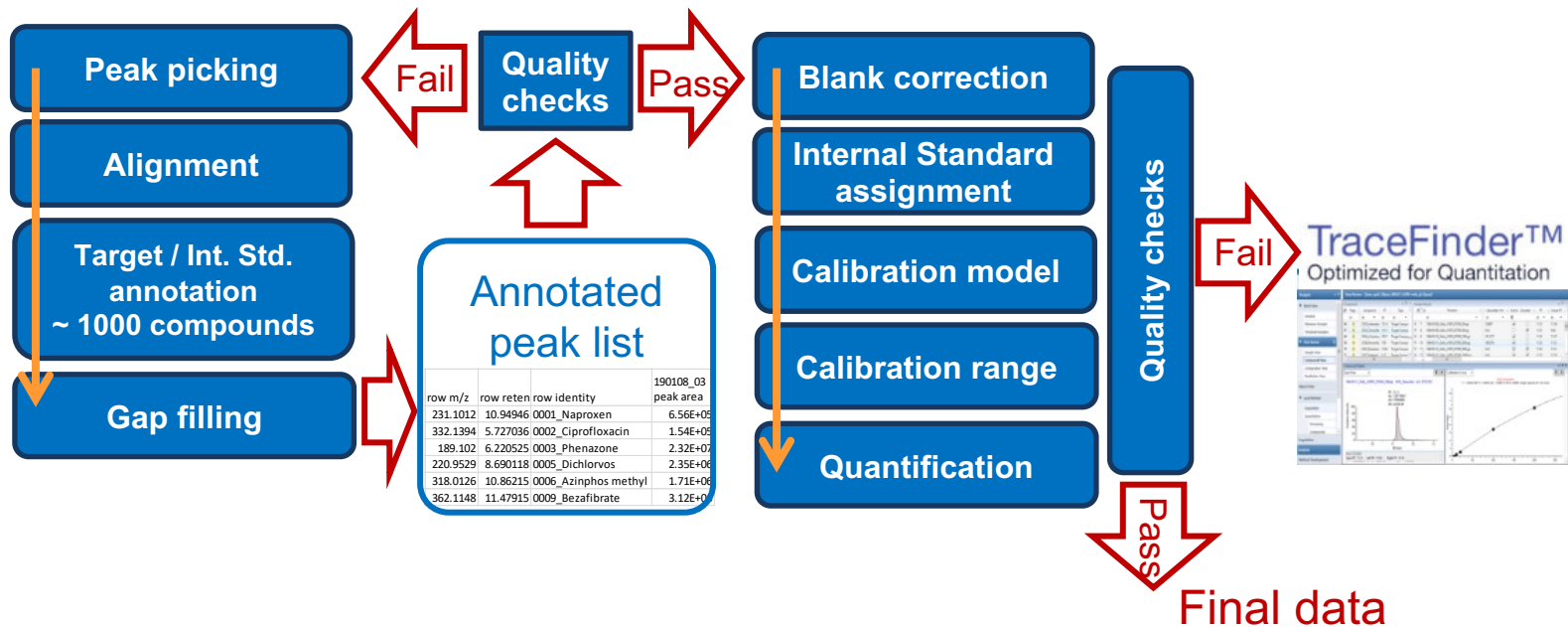
## Thermo GC QExacte MS

Target analysis: >150 compounds

# The analysis

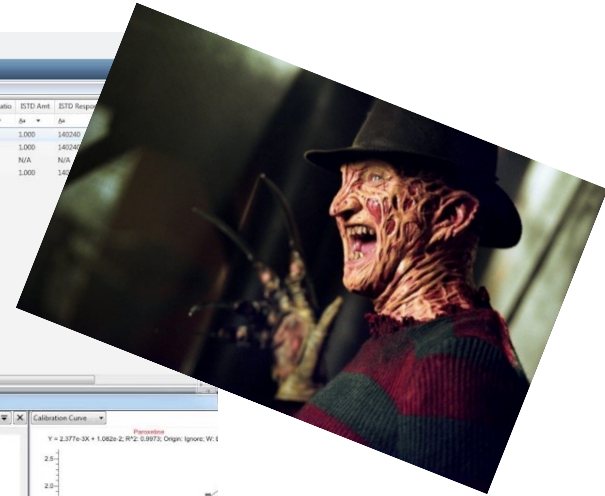
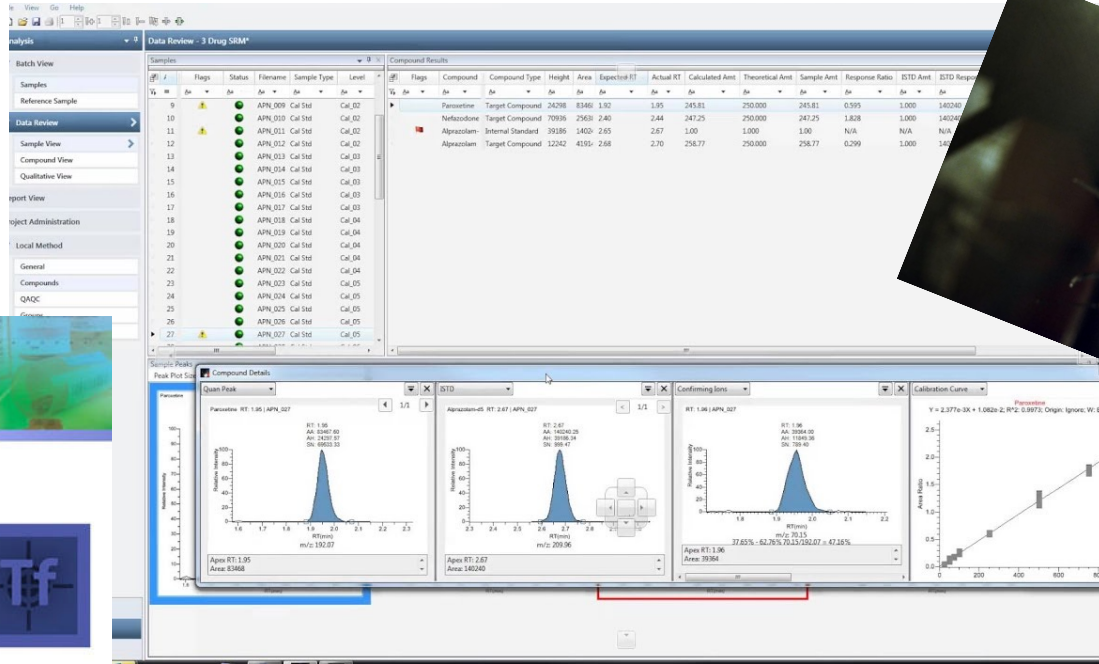
Data analysis: LC-MS

## Automated R-based workflow



# The analysis

## Data analysis: GC-MS

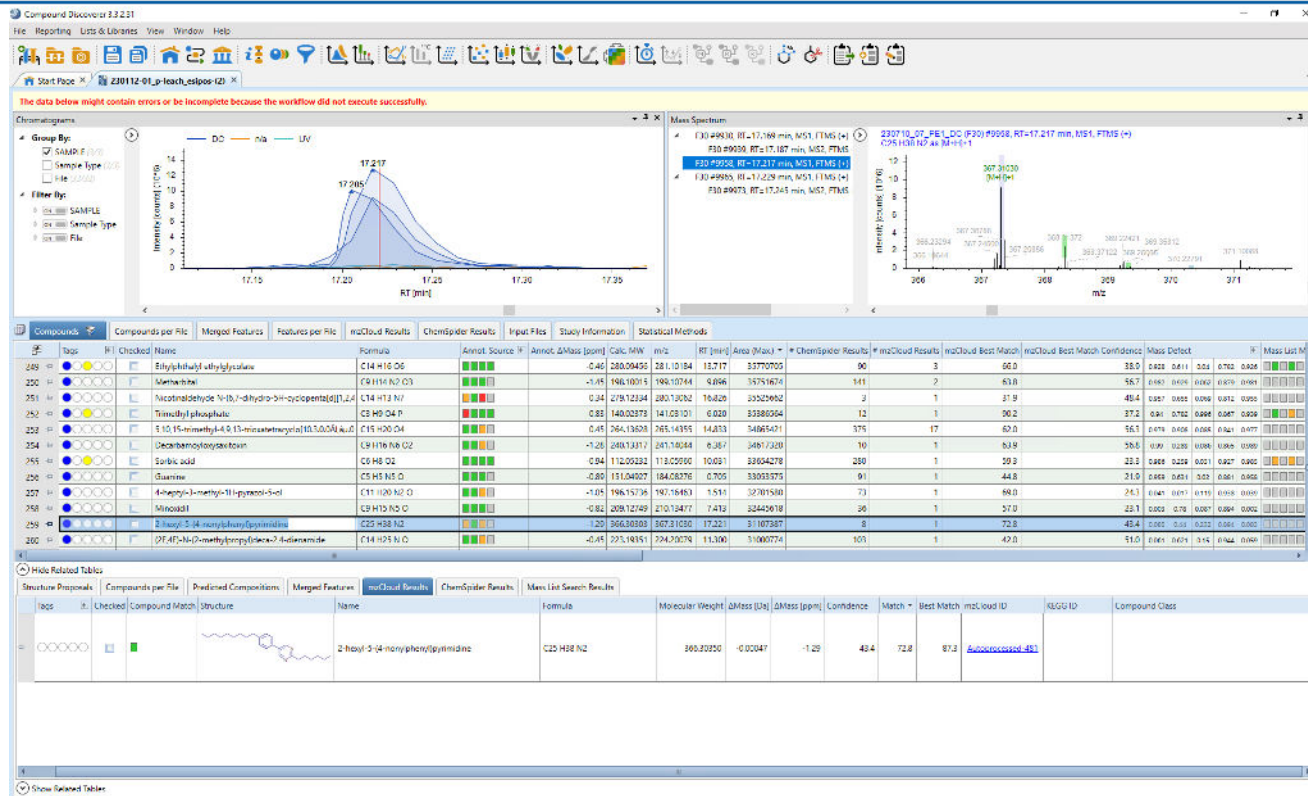


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# The analysis

## Data analysis: Non-Targeted Screening

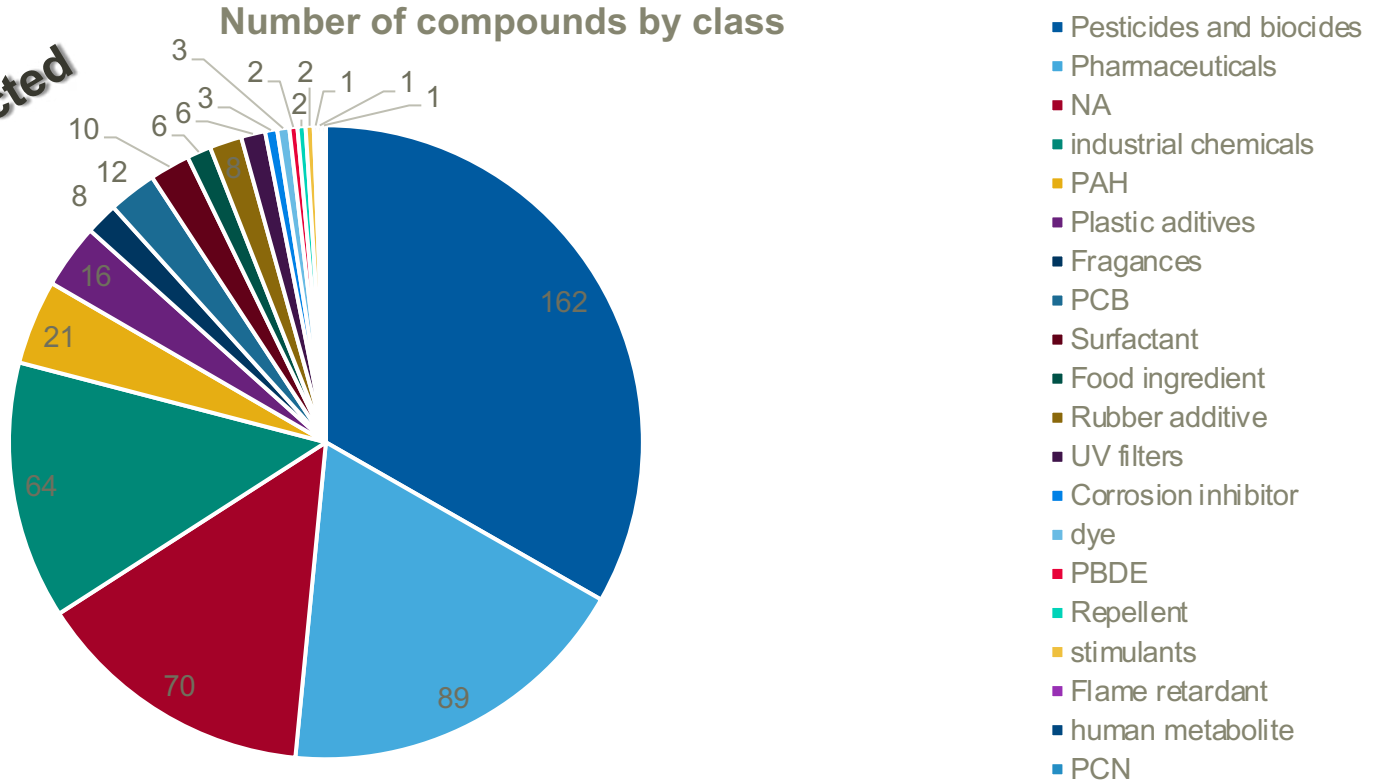




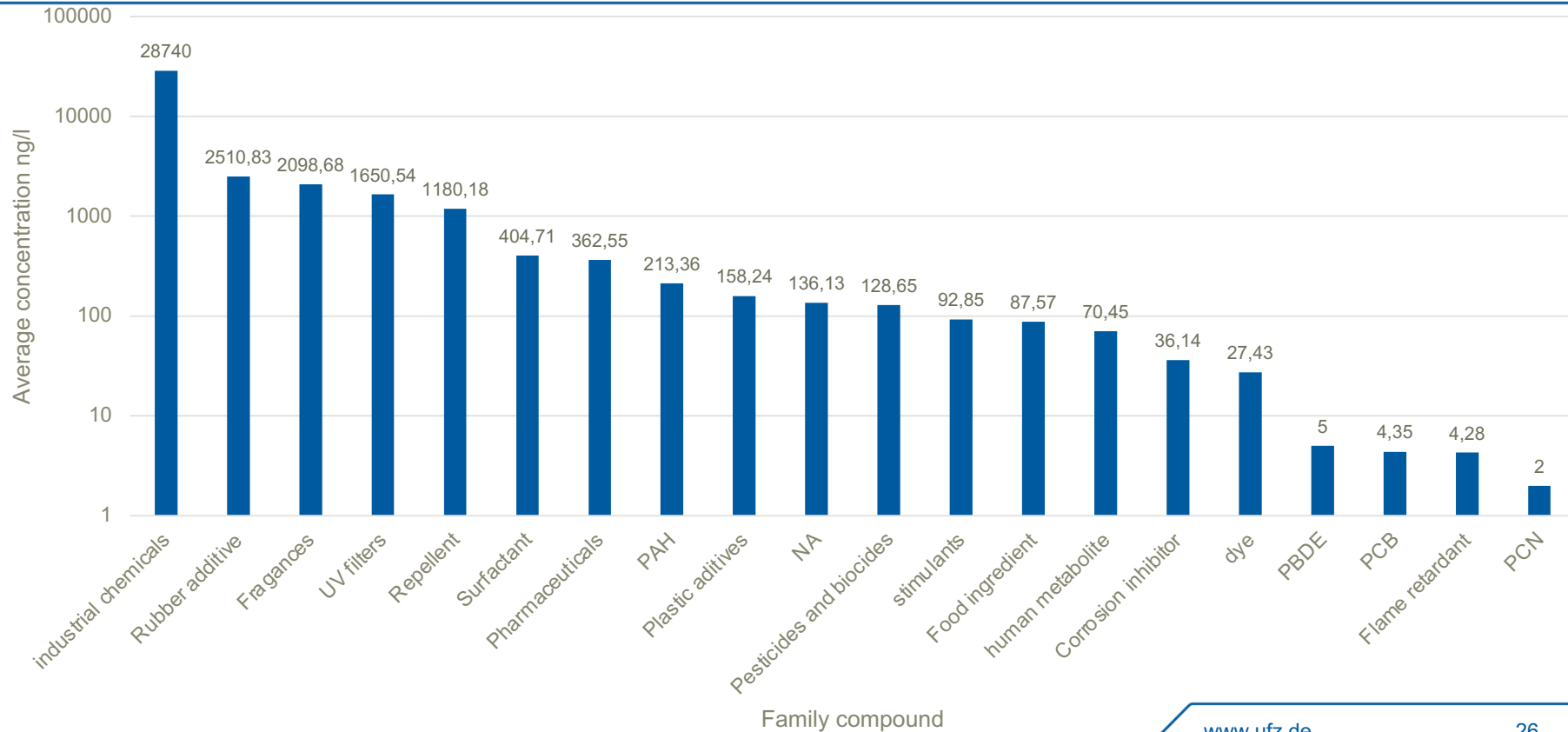
# The results

492 chemicals detected

Number of compounds by class



# The results



# The results

| Compound   | Compound.class  | n  | Average<br>ng/l | Min<br>ng/l | Max<br>ng/l |
|--|-----------------|----|-----------------|-------------|-------------|
| N-Ethyl-o-toluenesulfonamide                               | industrial      | 29 | 861389.83       | 2764        | 24019657    |
| N,N-Dimethyl-p-phenylenediamine                            | rubber additive | 26 | 10497.27        | 427         | 77463       |
| ISO E Super  | fragrance       | 15 | 9833.87         | 512         | 57885       |
| Octyl-methoxycinnamate                                     | UV filter       | 16 | 7667.25         | 36          | 42576       |
| Gabapentin-Lactam  | pharmaceutical  | 5  | 5998.20         | 2           | 29968       |
| Disulfoton   | insecticide     | 3  | 5021.00         | 431         | 10460       |
| Fluoranthene   | PAH             | 13 | 4719.15         | 193         | 25900       |
| 4-Hydroxy-1-(2-hydroxyethyl)-2,2,6,6-tetramethylpiperidine | industrial      | 29 | 4013.62         | 22          | 56272       |
| p-Toluenesulfonamide                                       | industrial      | 28 | 3458.39         | 604         | 7230        |
| TMDD   | industrial      | 29 | 2854.17         | 338         | 9060        |
| Tramadol   | pharmaceutical  | 4  | 2825.00         | 8           | 11221       |
| Flumioxazin  | pesticide       | 3  | 2709.00         | 700         | 5342        |
| DCOIT  | biocide         | 3  | 2395.33         | 844         | 5468        |
| Efavirenz  | pharmaceutical  | 15 | 2120.80         | 1           | 27986       |
| Benzophenone-3   | UV filter       | 29 | 1859.90         | 31          | 12844       |
| DEET   | repellent       | 29 | 1567.55         | 19          | 18160       |
| Fluconazole  | pharmaceutical  | 1  | 1548.00         | 1548        | 1548        |
| Melamine   | industrial      | 29 | 1522.79         | 87          | 14372       |
| Adiponitrile   | industrial      | 19 | 1312.37         | 248         | 4130        |
| Losartan   | pharmaceutical  | 1  | 1257.00         | 1257        | 1257        |
| Tetrabutylammonium_M+                                      | NA              | 1  | 1241.00         | 1241        | 1241        |

# The results

## PubChem N-Ethyl-O-toluenesulfonamide (Compound)

### 11 Patents



#### 11.1 Depositor-Supplied Patent Identifiers



1,560 items [View More Rows & Details](#)

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| SORT BY <span>Priority Date</span> |   |               |            |
|------------------------------------|---|---------------|------------|
| Publication Number                 | Title   | Priority Date | Grant Date |
| <a href="#">CN-111333943-A</a>     | Preparation method of HDPE corrugated pipe material for sewage pipe | 2020-04-14    |            |
| <a href="#">US-2021190742-A1</a>   | Intelligent compositions, packaging, and methods thereof            | 2019-12-19    |            |
| <a href="#">WO-2021123922-A1</a>   | Intelligent compositions, packaging, and methods thereof            | 2019-12-19    |            |
| <a href="#">US-2021171739-A1</a>   | Cellulose Ester Composition Containing Other Bio-Based Polymers     | 2019-12-10    |            |
| <a href="#">US-2021171740-A1</a>   | Impact-Modified Biodegradable Polymer Compositions                  | 2019-12-10    |            |

< Previous 1 **2** 3 4 ... 312 Next >

# The results

| ID:   | Average  |      | m/z:                              | RT:     | Identity:  | 0368                               |                       |      |                                      |        |
|-------|----------|------|-----------------------------------|---------|------------|------------------------------------|-----------------------|------|--------------------------------------|--------|
| ID    | m/z      | RT   | Identity                          | Comment | Peak shape | 210512_16_Recyc_BLK_210504.mzML    | 210512_17_ARG-R-03G.n |      |                                      |        |
|       |          |      |                                   |         |            | Status                             | Height                | Area | Status                               | Height |
| 11031 | 200.0739 | 8.85 | 0368_N-Ethyl-o-toluenesulfonamide |         |            | <span style="color: red;">●</span> |                       |      | <span style="color: green;">●</span> | 3.9E8  |

#11031 200.0739 m/z @8.85 0368\_N-Ethyl-o-toluenesulfonamide

Windows

**0368\_N-Ethyl-o-toluenesulfonamide**  
#11031 200.0739 m/z @8.85

| File Name                | Mass     | RT   | Height | Area   |
|--------------------------|----------|------|--------|--------|
| 210512_27_NEP-R-03R.mzML | 200.0739 | 8.83 | 9.3E8  | 8.3E9  |
| 210512_33_SER-R-02P.mzML | 200.0739 | 8.85 | 1.5E9  | 1.5E10 |
| 210512_25_MAU-R-02B.mzML | 200.0738 | 8.86 | 1.1E9  | 1.2E10 |
| 210512_28_NEP-R-04.mzML  | 200.0739 | 8.84 | 1.8E9  | 1.8E10 |
| 210512_21_DN-R-01W.mzML  | 200.0738 | 8.85 | 8.8E8  | 7.9E9  |
| 210512_32_NIG-R-05L.mzML | 200.0739 | 8.84 | 1.1E9  | 1.1E10 |
| 210512_40_TAI-R-06W.mzML | 200.0739 | 8.85 | 8.9E8  | 8.5E9  |
| 210512_42_TAI-R-06B.mzML | 200.0739 | 8.85 | 1.6E9  | 1.7E10 |
| 210512_31_NIG-R-04Y.mzML | 200.0739 | 8.85 | 1.5E9  | 1.5E10 |
| 210512_19_CAM-R-02R.mzML | 200.0738 | 8.85 | 1.1E9  | 1.1E10 |

Mass spectrum

# The results

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| Octyl-methoxycinnamate                                     | UV filter       | 16 | 7667.25         | 36          | 42576       |
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| Losartan   | pharmaceutical  | 1  | 1257.00         | 1257        | 1257        |
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# The results

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|-------------------------------|----------------|---|---------|-------------|-------------|
| N-Ethyl-o-toluenesulfonamide  |                |   |         | 2764        | 24019657    |
| N,N-Dimethyl-p-phenylenedia   |                |   |         | 427         | 77463       |
| ISO E Super                   |                |   |         | 512         | 57885       |
| Octyl-methoxycinnamate        |                |   |         | 36          | 42576       |
| Gabapentin-Lactam             |                |   |         | 2           | 29968       |
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| 4-Hydroxy-1-(2-hydroxyethyl)- |                |   |         | 22          | 56272       |
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| TMDD                          |                |   |         | 338         | 9060        |
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| Flumioxazin                   |                |   |         | 700         | 5342        |
| DCOIT                         |                |   |         | 844         | 5468        |
| Efavirenz                     |                |   |         | 1           | 27986       |
| Benzophenone-3                |                |   |         | 31          | 12844       |
| DEET                          |                |   |         | 19          | 18160       |
| Fluconazole                   |                |   |         | 1548        | 1548        |
| Melamine                      |                |   |         | 87          | 14372       |
| Adiponitrile                  |                |   |         | 248         | 4130        |
| Losartan                      |                |   |         | 1257        | 1257        |
| Tetrabutylammonium_M+         | NA             | 1 | 1241.00 | 1241        | 1241        |



# The results

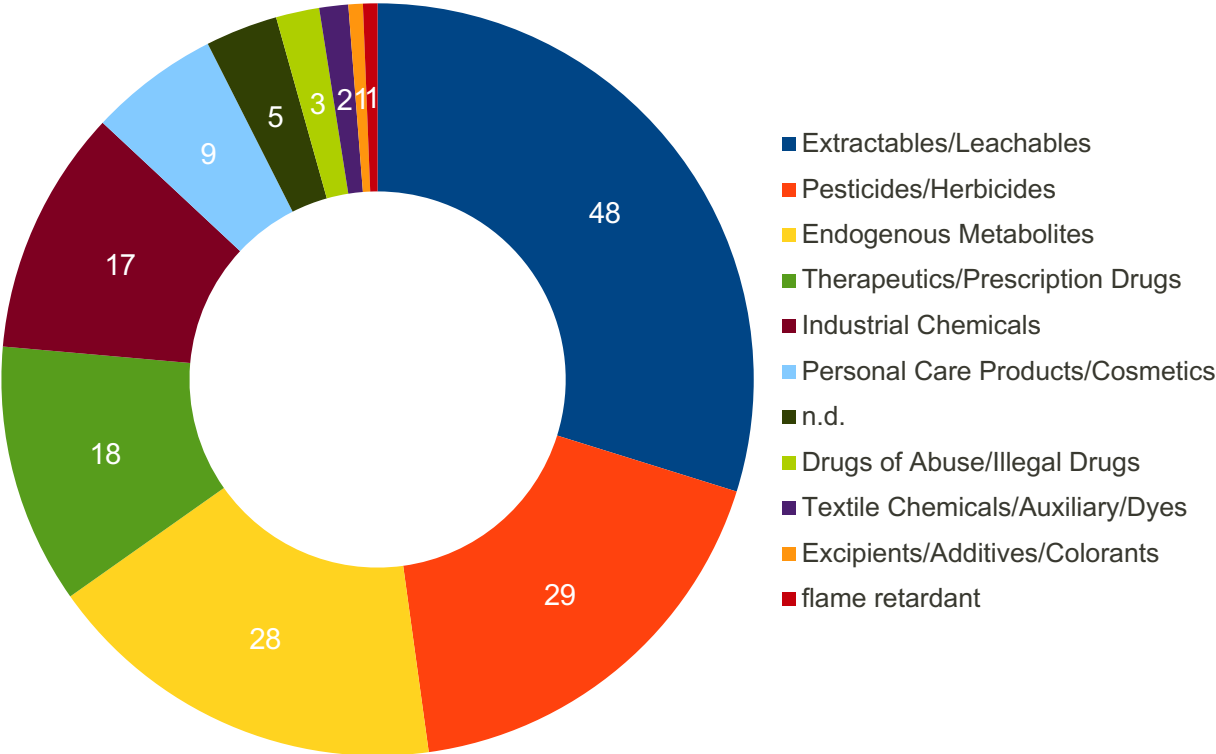
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| Sample   | n   | Average   | Min  | Max      |
|----------|-----|-----------|------|----------|
| NIG_03G  | 226 | 108321.82 | <LOD | 24019657 |
| IDN_01Y  | 212 | 1467.58   | <LOD | 105099   |
| NEP_04   | 199 | 924.12    | <LOD | 58017    |
| IND_02B  | 256 | 812.88    | <LOD | 37156    |
| NIG_04Y  | 237 | 700.13    | <LOD | 49962    |
| CAM_02R  | 141 | 669.04    | <LOD | 56272    |
| TOG_01W  | 179 | 643.32    | <LOD | 49053    |
| MAU_02B  | 196 | 627.66    | <LOD | 48334    |
| TAN_04W  | 204 | 596.15    | <LOD | 46095    |
| IDN_02N  | 189 | 583.37    | <LOD | 30263    |
| ARG_02Y  | 148 | 538.91    | <LOD | 41275    |
| SER_02P  | 222 | 537.00    | <LOD | 37470    |
| TAI_06W  | 167 | 517.00    | <LOD | 49264    |
| TAI_03B  | 205 | 486.09    | <LOD | 36681    |
| THA_02G  | 193 | 468.48    | <LOD | 37338    |
| SER_03R  | 154 | 433.84    | <LOD | 34538    |
| ARG_03Y  | 175 | 425.86    | <LOD | 23849    |
| TAI_07BL | 218 | 402.17    | <LOD | 35245    |
| TAI_05BR | 169 | 384.89    | <LOD | 37958    |
| TAI_04BR | 173 | 379.15    | <LOD | 40972    |
| NEP_03P  | 203 | 371.44    | <LOD | 22271    |
| TOG_02P  | 189 | 352.70    | <LOD | 39930    |
| NIG_05L  | 164 | 342.61    | <LOD | 30409    |
| TAI_06B  | 143 | 333.87    | <LOD | 32206    |
| NIG_02B  | 132 | 332.02    | <LOD | 25848    |
| TAI_02W  | 209 | 257.50    | <LOD | 33255    |
| MAL_03W  | 130 | 246.75    | <LOD | 17178    |
| MAL_02G  | 124 | 210.22    | <LOD | 16107    |
| TAN_04G  | 143 | 208.84    | <LOD | 11259    |

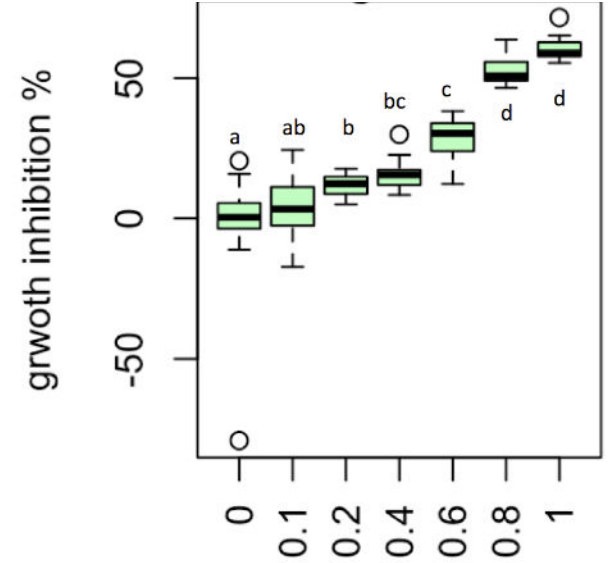
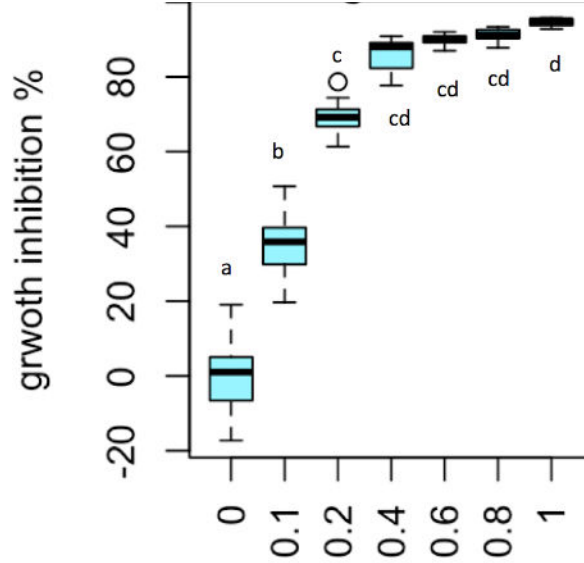
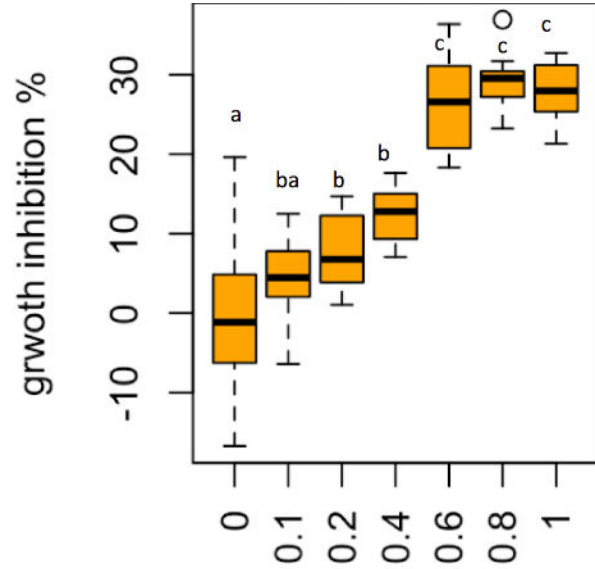


# The results

## Non-Targeted Screening



# The results



Growth inhibition of algae

## Questions to solve

- Are these plastics suitable for food packaging?
- Can have harmful effects in the environment/human health?
- Is the N-Ethyl-o-toluenesulfonamide a compound to monitor? Could be the driver of the pollution?
- Is there a way to remove the chemicals that are at the recycled plastics?



## Possible solutions

- Reducing consumption of plastics.
- Reduction of number of chemicals.
- Regulation of the toxicity.
- Investigation to improve the recycle processes.



# Thank you!

Eric Carmona Martínez

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