UNIVERSITY OF AMSTERDAM

Inspectie Leefomgeving en Transport
Ministerie van Infrastructuur en Milieu

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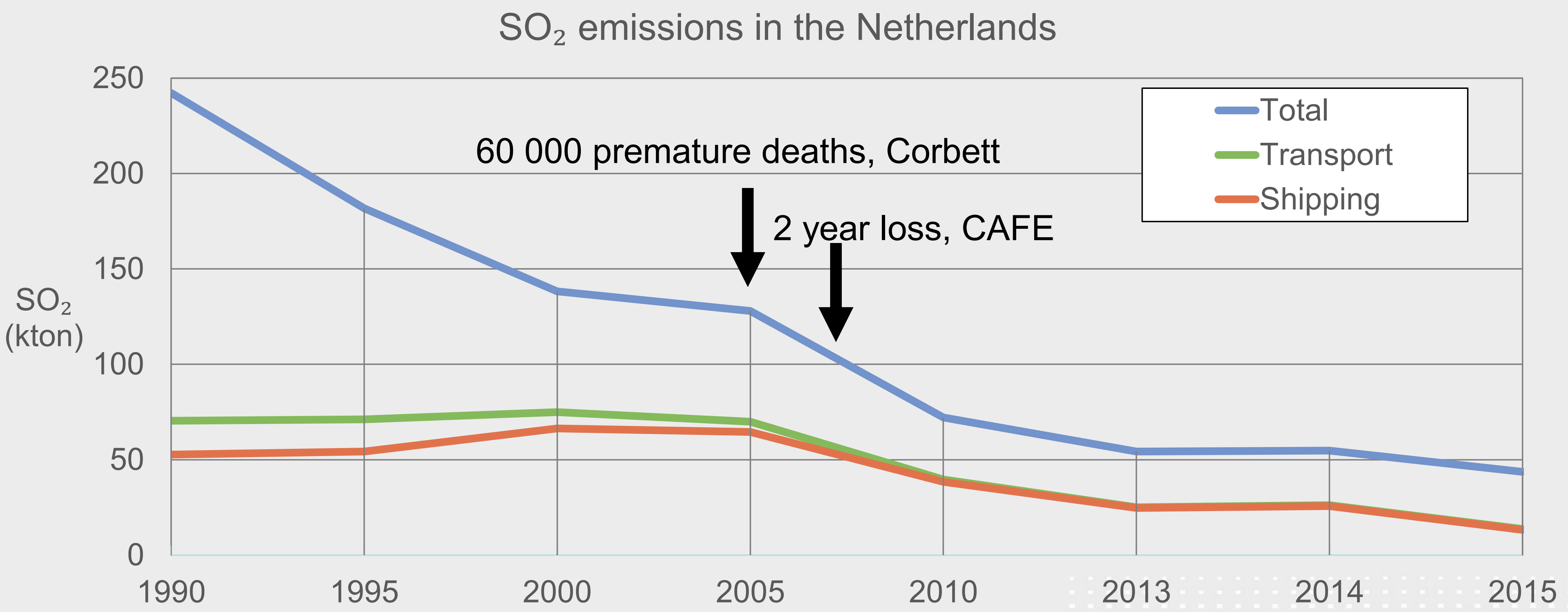
Efficient compliance monitoring:

Comparison of both airborne and landside sniffing and spectrometric methods to provide direct control on the sulfur emission of ships.

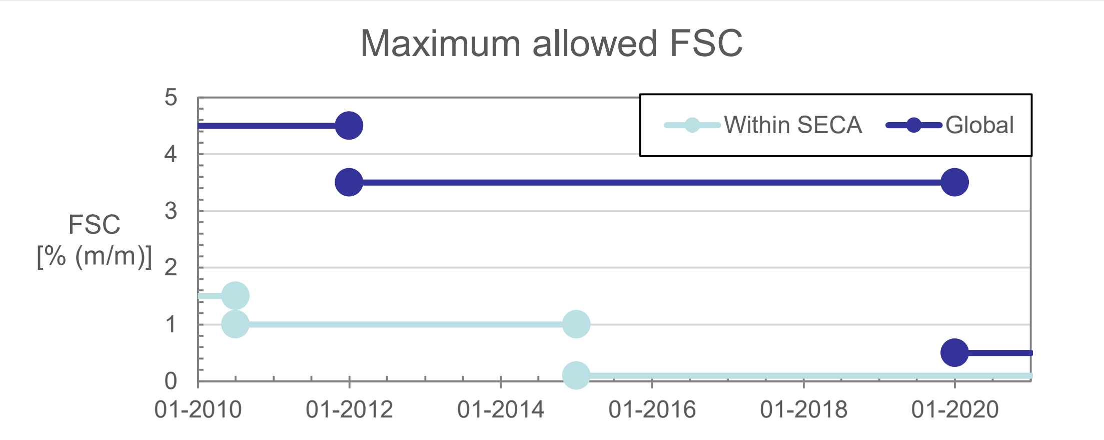
Contents

- Introduction
- Aim
- Analytical techniques
- Statistical techniques
  - Classification with linear boundary
  - Classification using Z-score
  - EM algorithm
- Outlook

The emission of SO_2 over time.



Left: Image courtesy of D.J. Oostwoud Wijdenes and National Geographic Society.



$ 40 000 day⁻¹

Fuel Sulfur Content

- $\text{FSC} = \frac{\text{weight of sulphur}}{\text{weight of fuel}}$
- $\text{FSC} = \frac{\frac{16}{64.066} \times M(\text{S}) \times \int \left([\text{SO}_2] - [\text{SO}_2]_{\text{bg}} \right) dt}{\frac{12}{44} \times (M(\text{C})/0.87) \times \int \left([\text{CO}_2] - [\text{CO}_2]_{\text{bg}} \right) dt}$
- $\text{FSC} = 0.232 \, \frac{\int \left([\text{SO}_2] - [\text{SO}_2]_{\text{bg}} \right) dt}{\int \left([\text{CO}_2] - [\text{CO}_2]_{\text{bg}} \right) dt}$

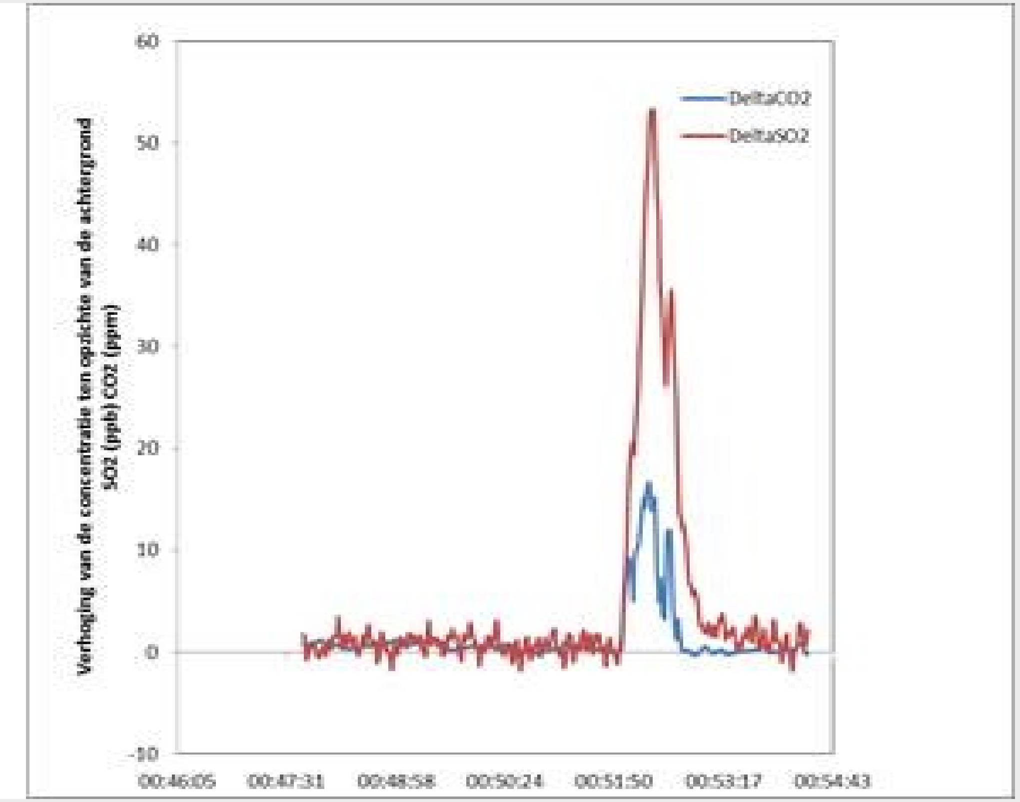


Image courtesy of ILT.

Aim

- Compare different techniques and operators for future use for the inspectorate.
- Explore the measurements performed so far by all inspectorates in Northern Europe.
  - What are the compliance rates?
- What are the type I and type II errors? *I.e.* how sure are we that a ship is (non-)compliant?

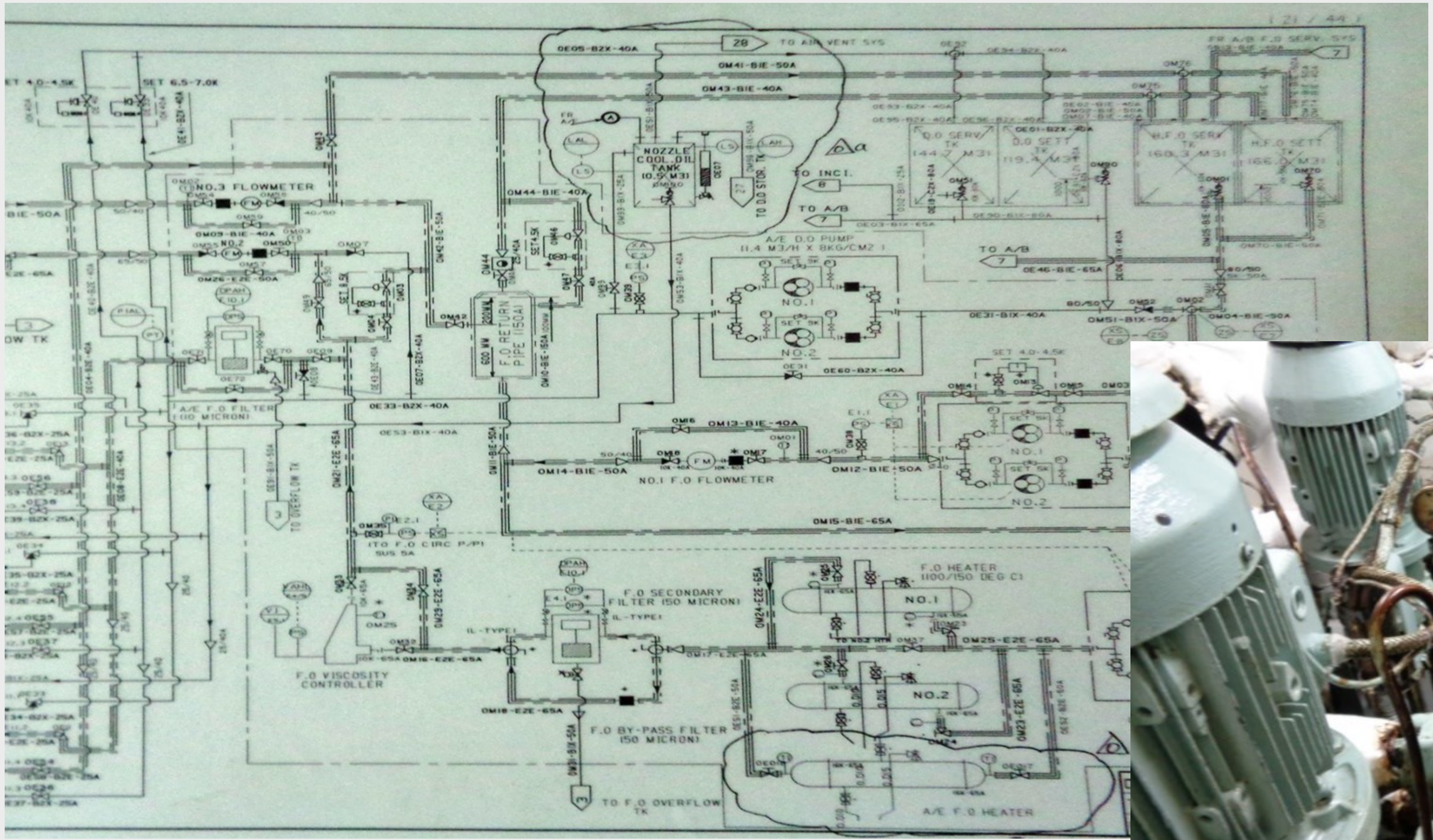


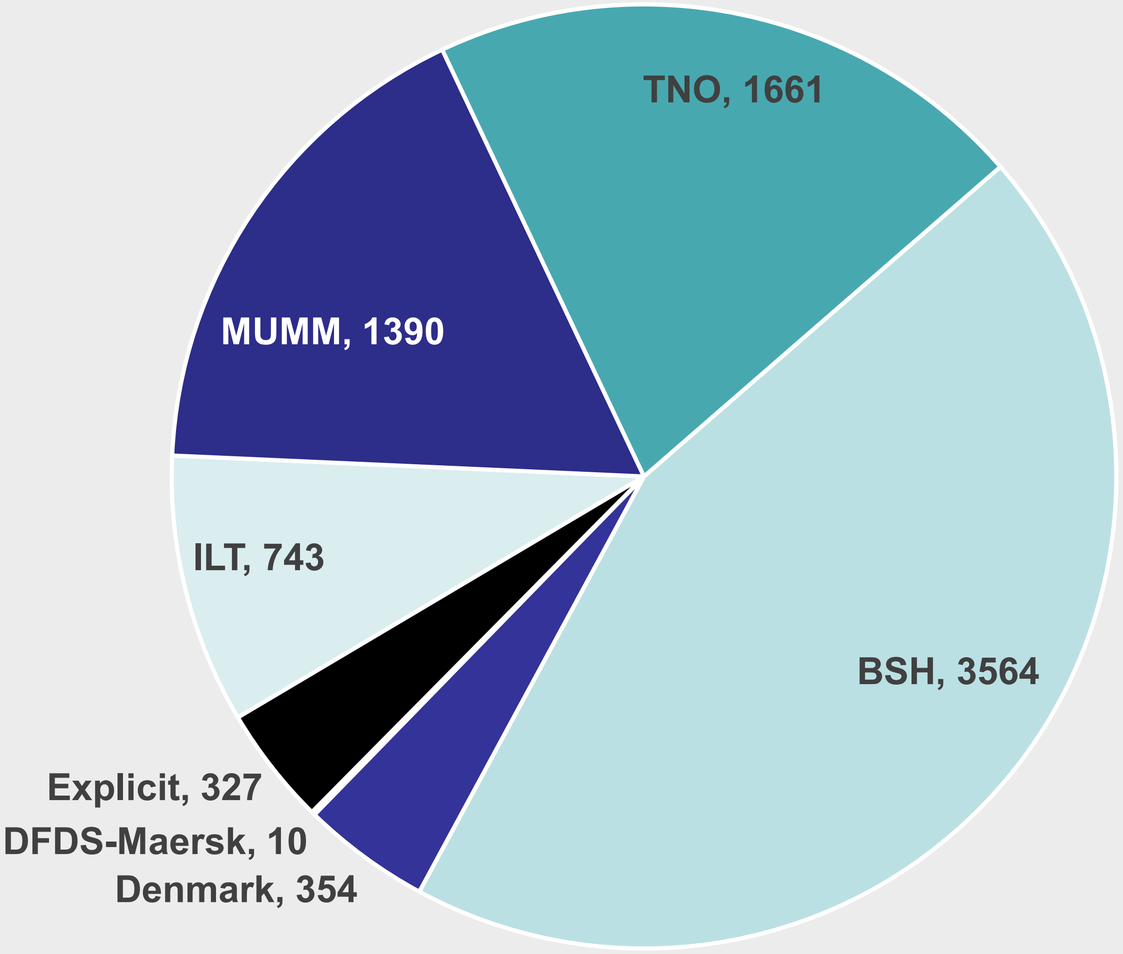
Image courtesy: ILT

Image courtesy: ILT

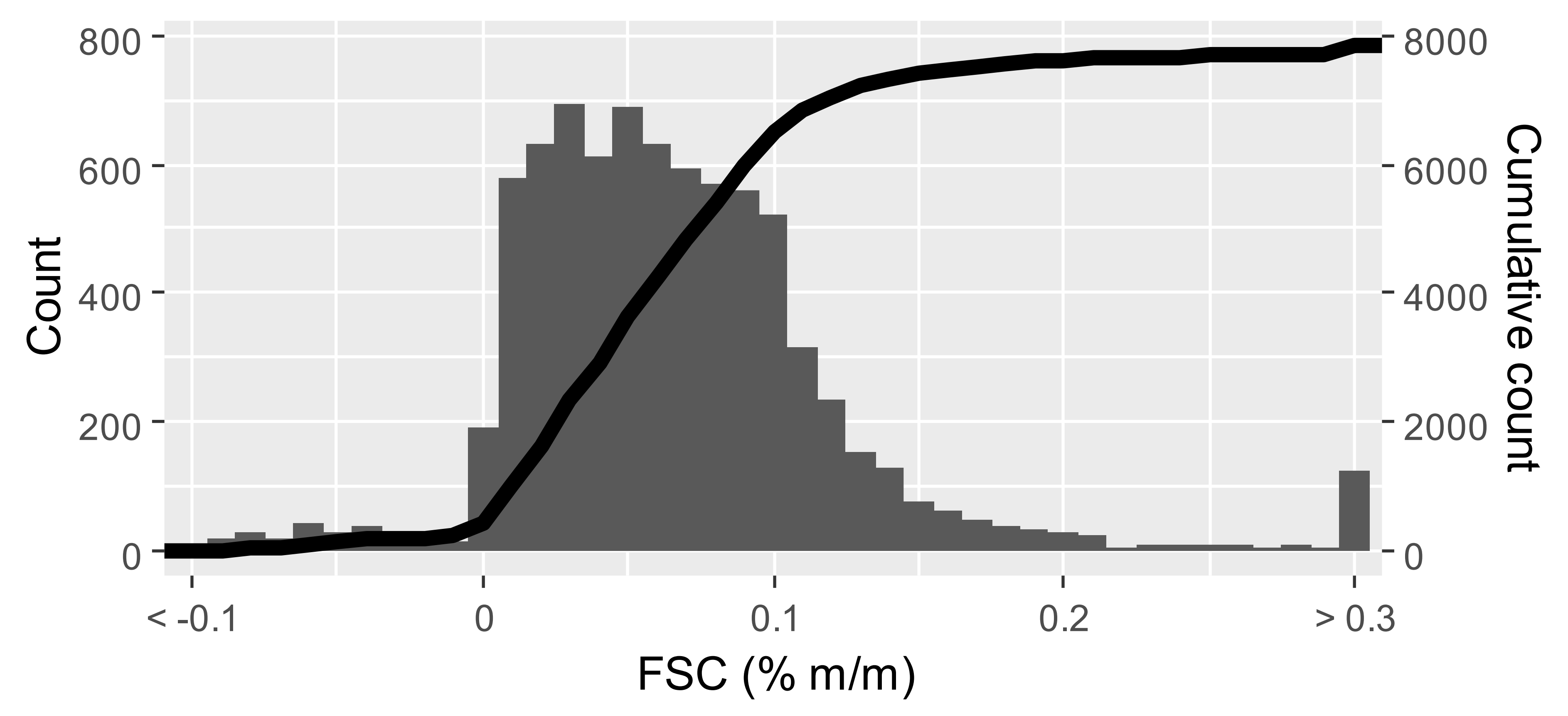
TNO/ ILT sniffer

Image courtesy: ILT

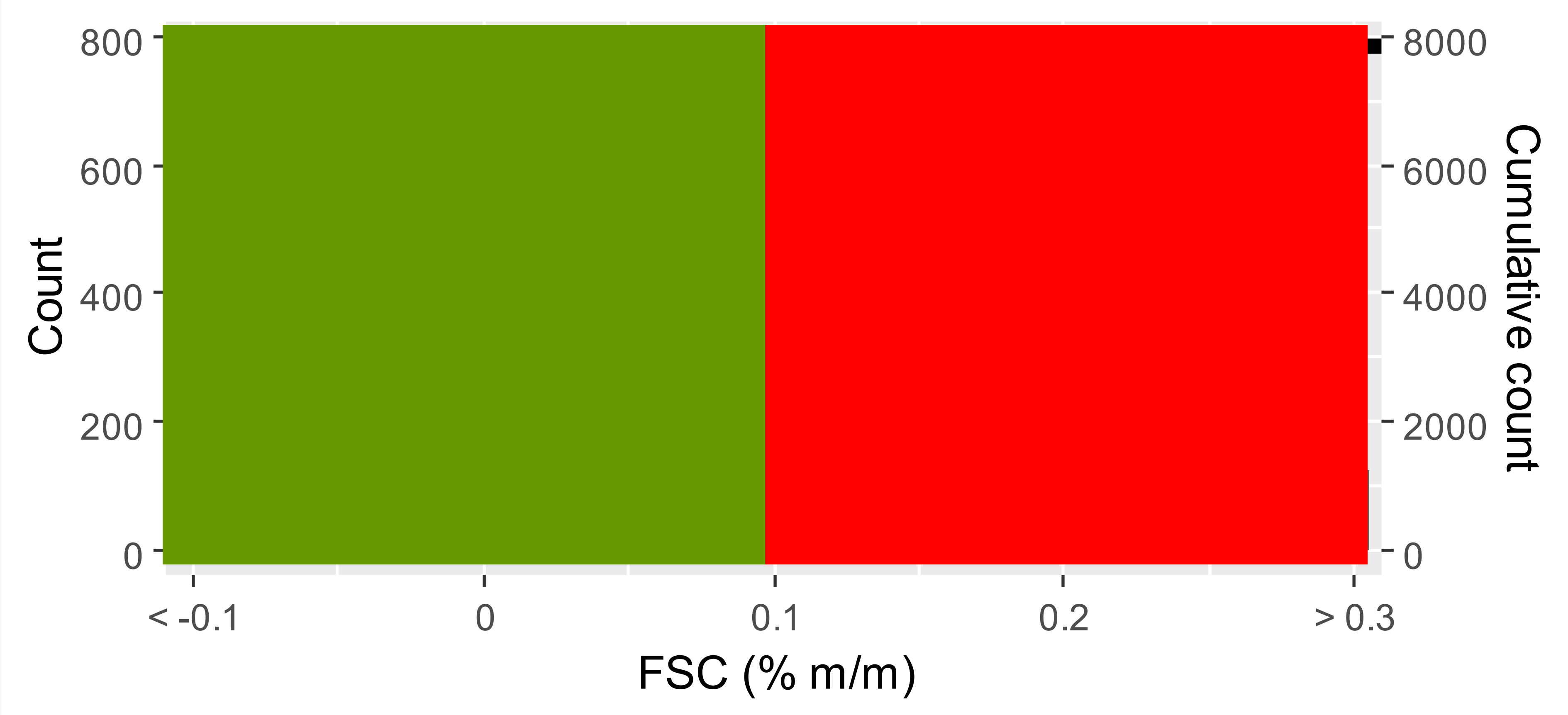
N = 8049


TNO, 1661
MUMM, 1390
ILT, 743
BSH, 3564
Explicit, 327
DFDS-Maersk, 10
Denmark, 354

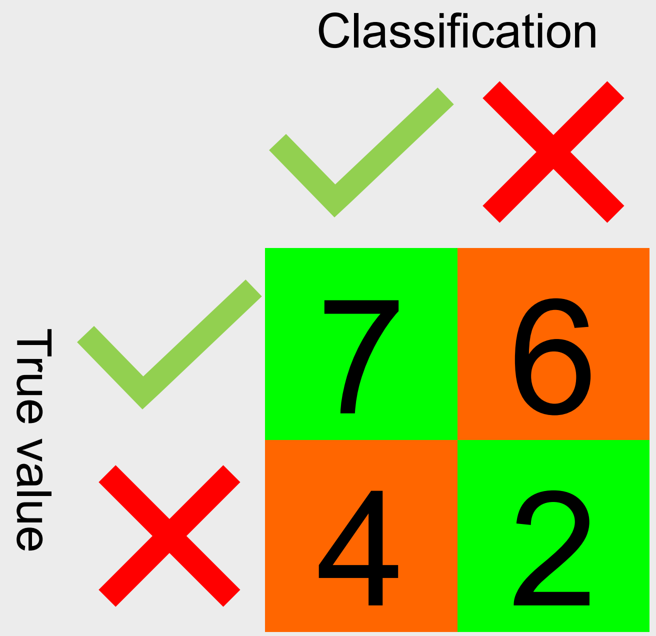
What fraction is non-compliant?



What fraction is non-compliant?

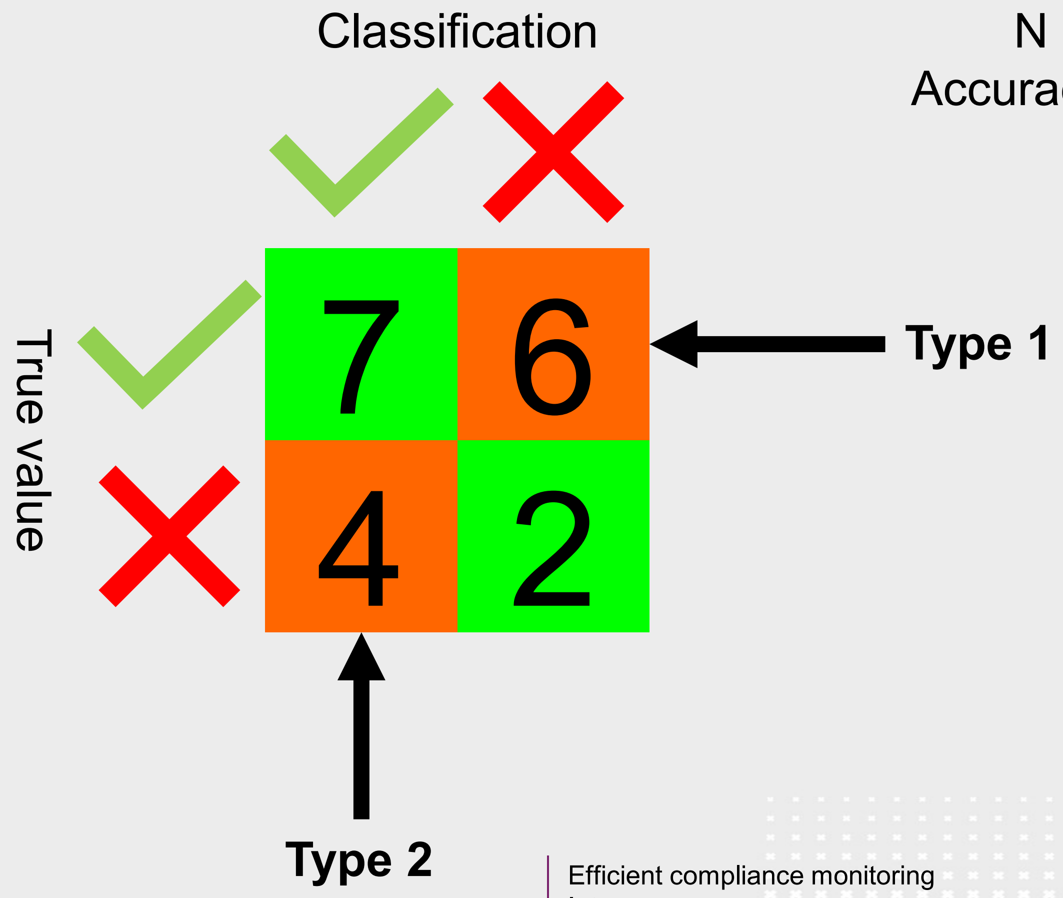


What fraction is non-compliant?



N = 19
Accuracy = 47%

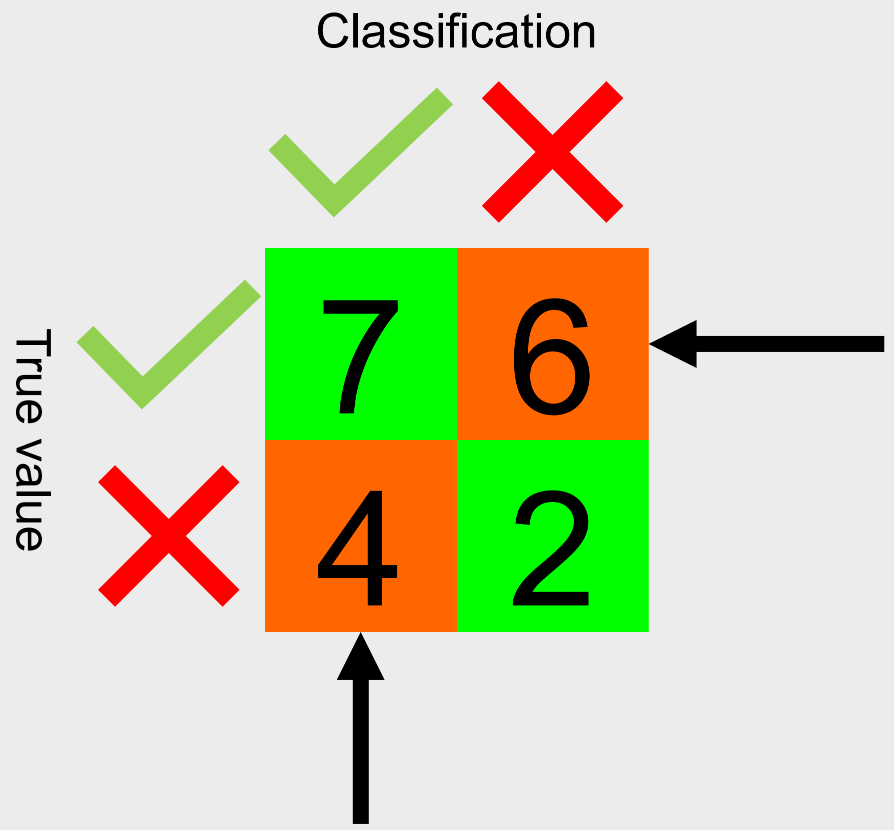
Intermezzo – type I and type II errors



N = 19
Accuracy = 47%

Intermezzo – type I and type II errors

N = 19
Accuracy = 47%

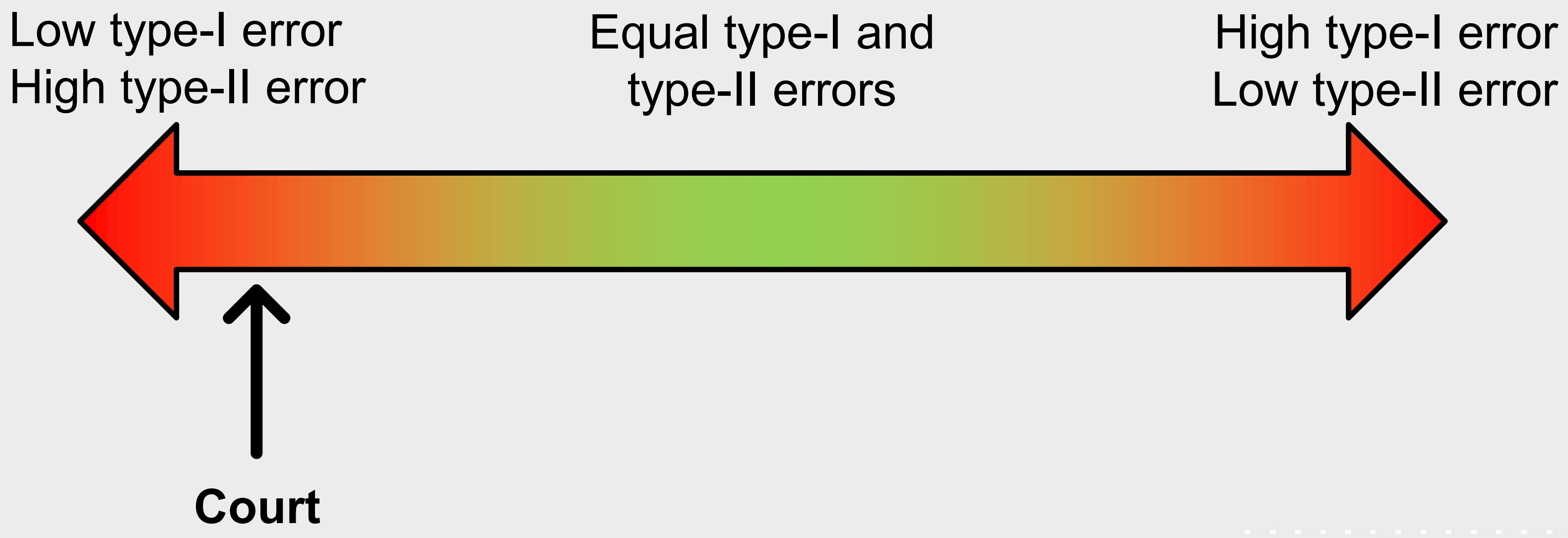


Type 1: wrongly accusing

Type 2: overlooking non-compliance

Intermezzo – type I and type II errors

- What do we want?



Intermezzo – type I and type II errors

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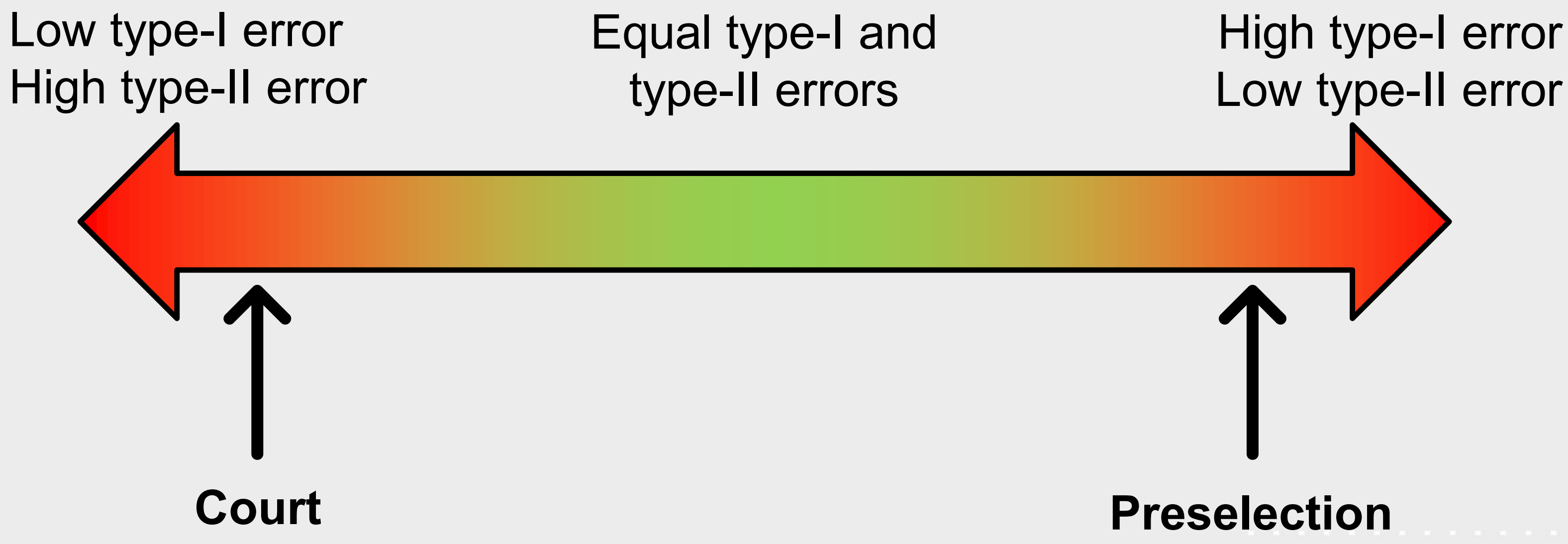
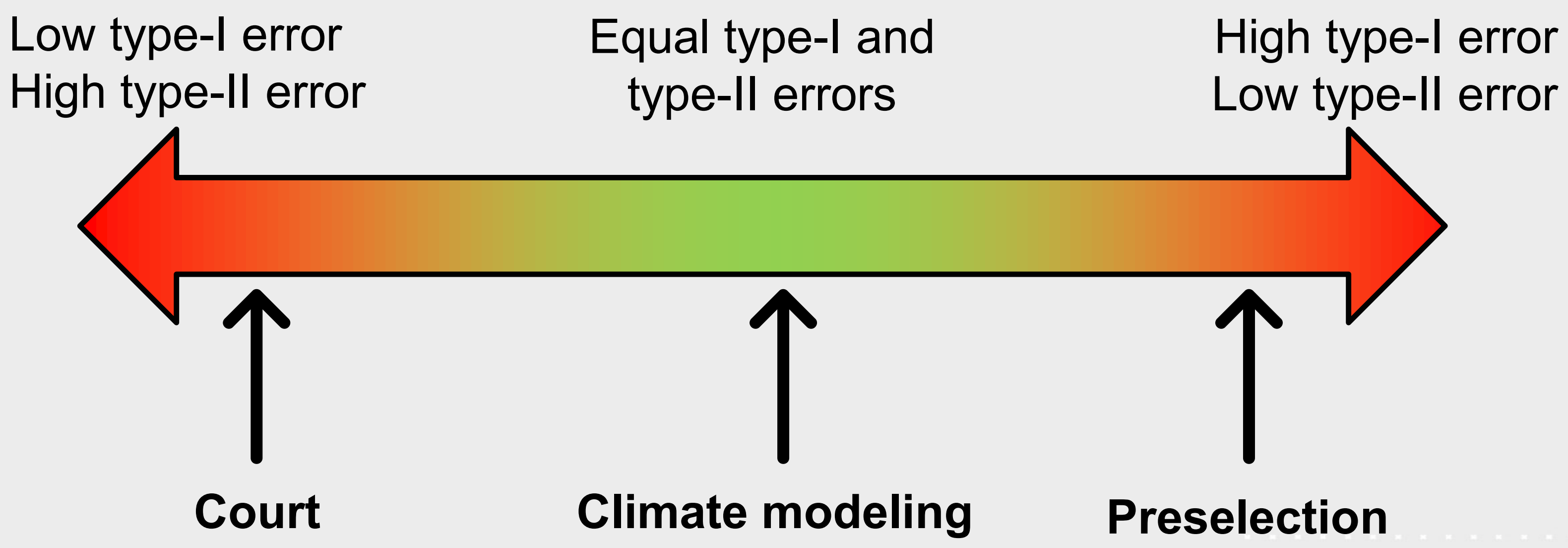


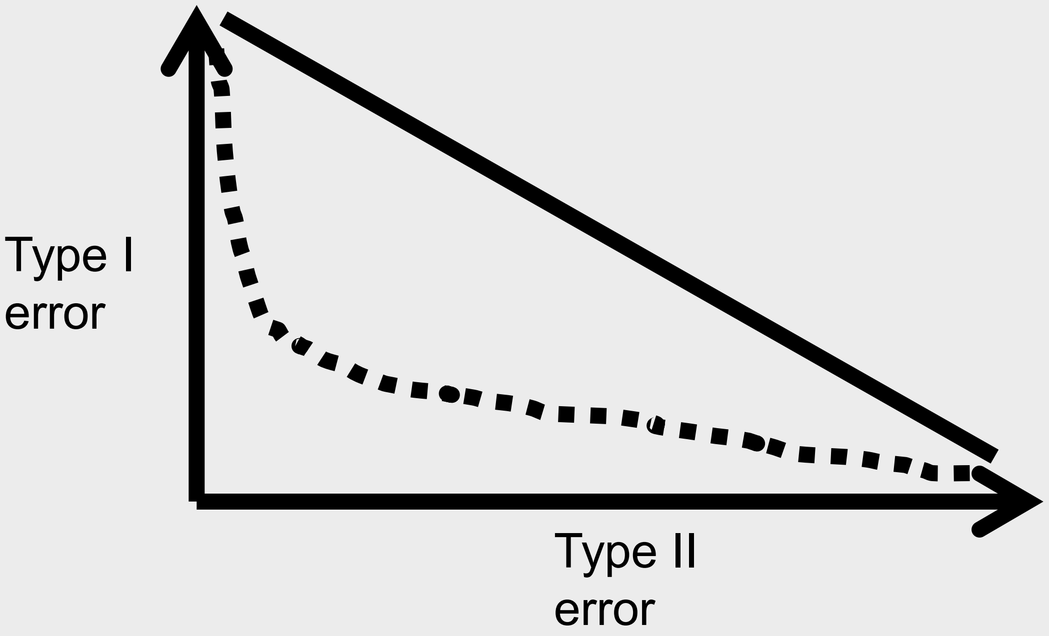
Intermezzo – type I and type II errors

- What do we want?

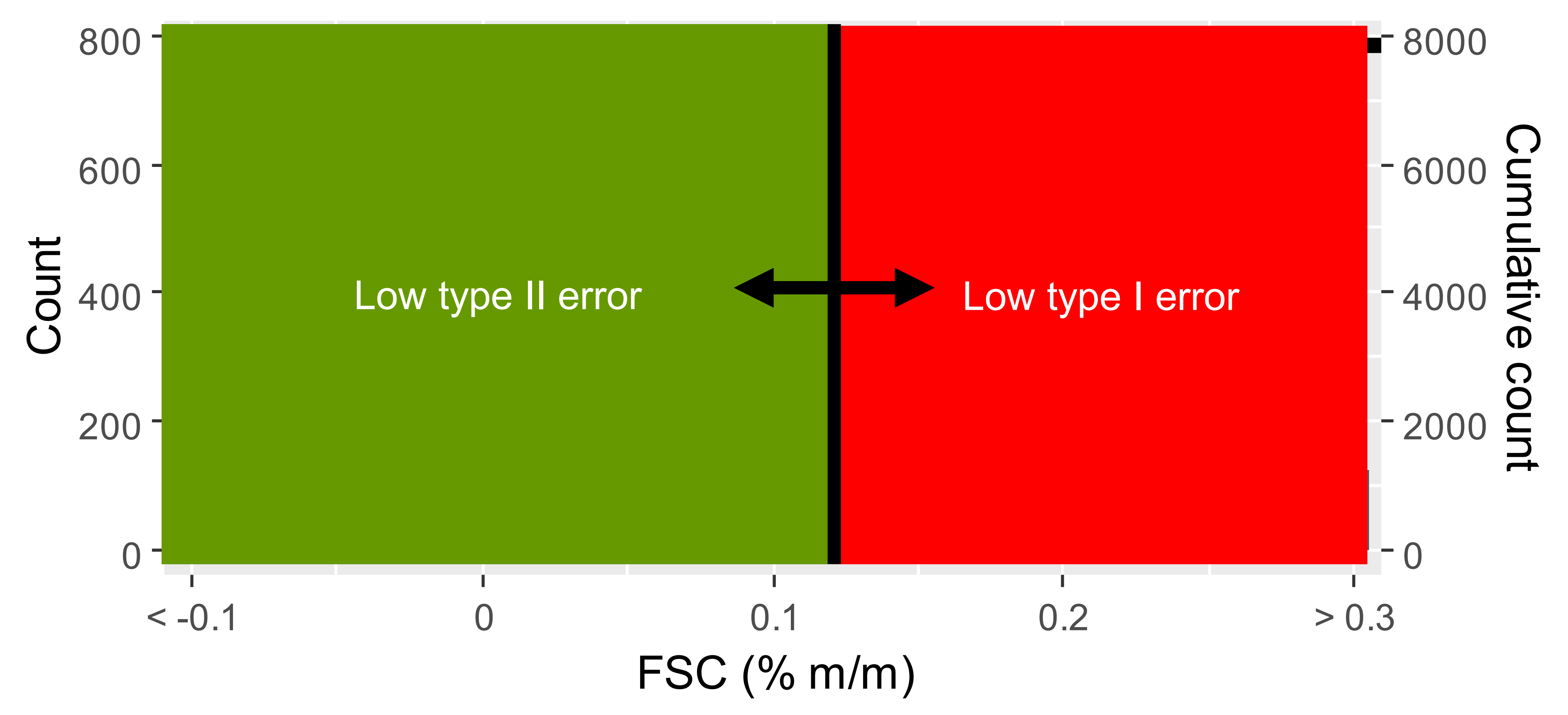


Intermezzo – type I and type II errors

- What do we want?



What fraction is non-compliant?



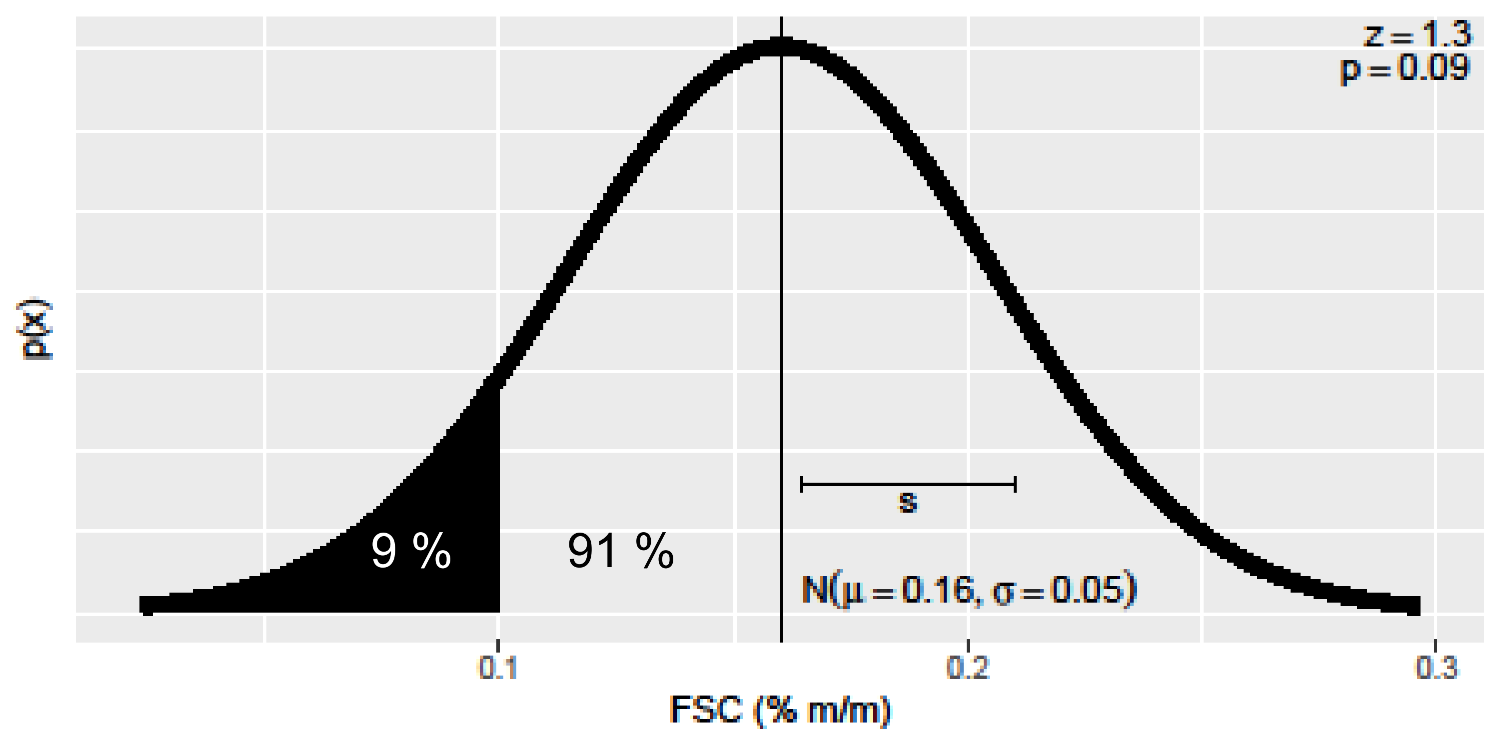
Z-score

N = 5552 (69%)

- H_0: The ship has a FSC of 0.1 wt. % or less.
- H_1: The ship has a higher FSC than 0.1 wt. %.

- $z = \frac{\bar{x} - \mu_0}{s_x / \sqrt{n}}$
- Z-score can be calculated to p-value with a significance level

Z-score with $\alpha = 0.05$



Z-score with $\alpha = 0.05$

Classification

True value	✓	✗
✓	11	2
✗	4	2

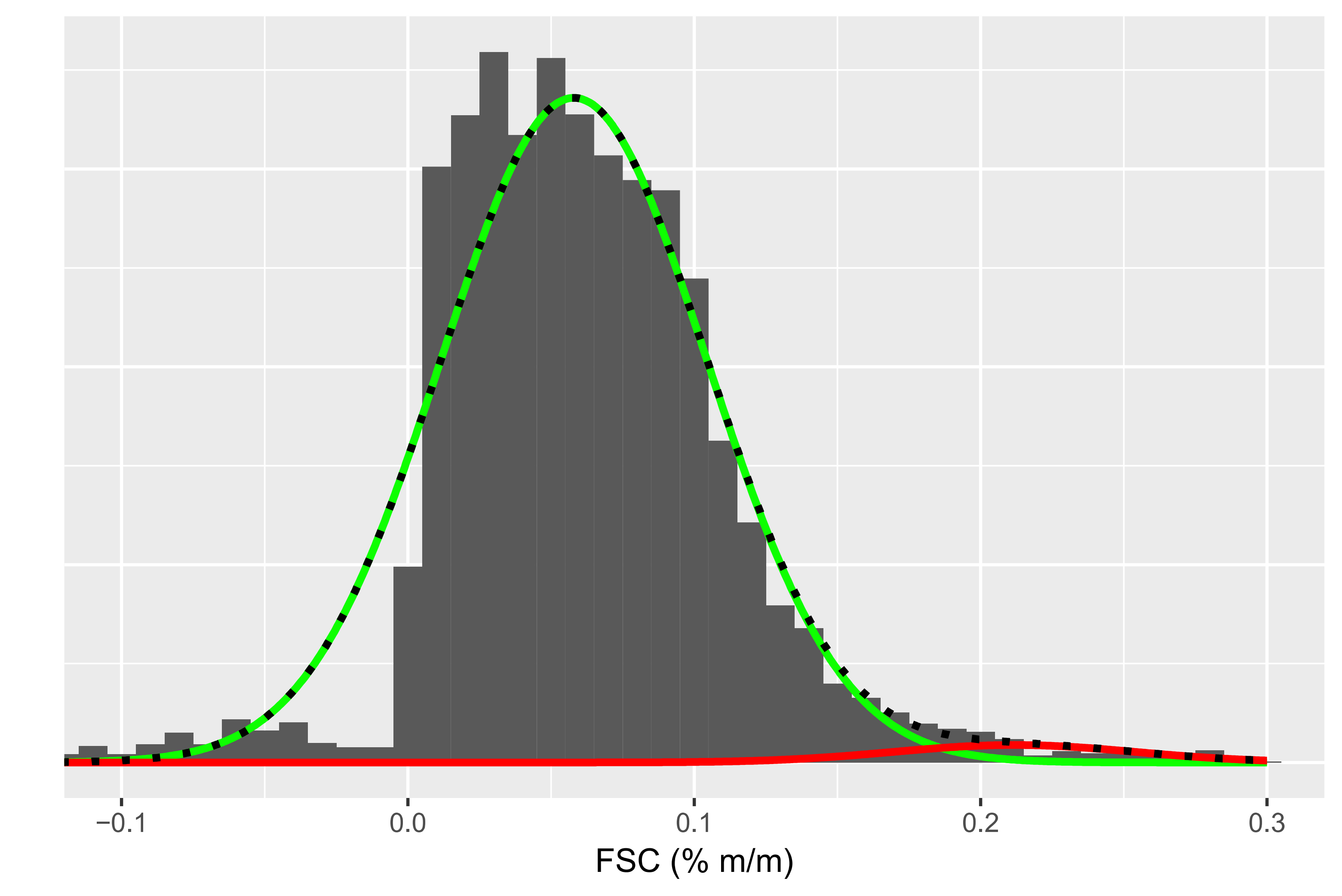
N = 19
Accuracy = 68%

Another approach

What fraction is non-compliant?

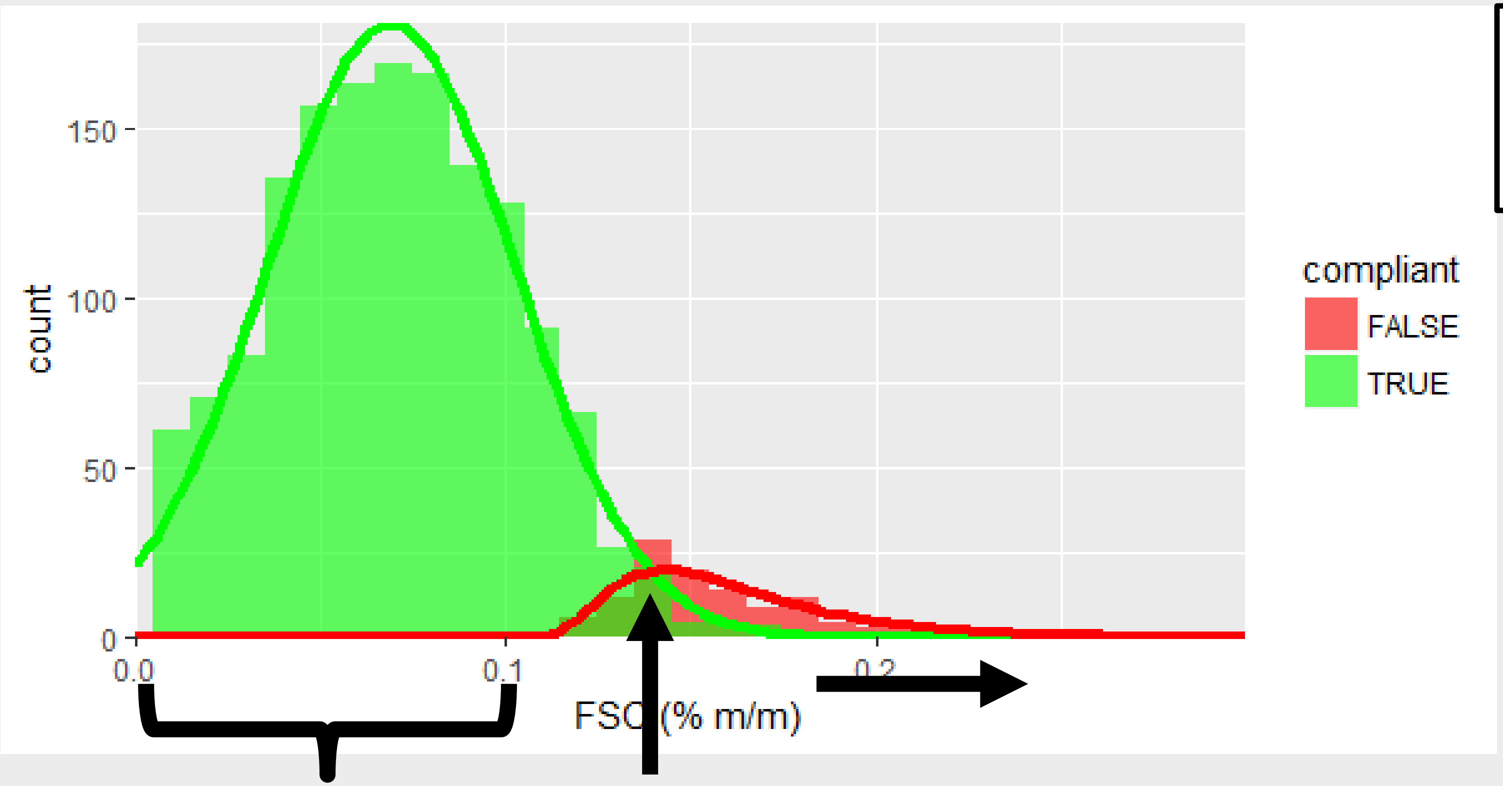
- How many port state controls should take place?
- How reliable are climate modellings assuming 100% compliance?
- What is the catch rate?

EM-algorithm



EM algorithm

- Guess initial parameters
- Calculate responsibility
- Maximize likelihood of all parameters



$$\gamma_{i,0} + \gamma_{i,1} = 1$$

For each datapoint i

$\gamma_{i,0} = 1$
$\gamma_{i,1} = 0$

$\gamma_{i,0} = 0.5$
$\gamma_{i,1} = 0.5$

$\gamma_{i,0} = 0$
$\gamma_{i,1} = 1$

EM algorithm

- Guess initial parameters
- Calculate responsibility
- Maximize likelihood of all parameters

$$\widehat{\mu_k} = \frac{1}{n_k} \sum_{i \in k}^{n_k} x_i$$

$$\widehat{\sigma_k} = \frac{1}{n_k} \sum_{i \in k}^{n_k} (x_i - \mu_k)^2$$

EM algorithm

- Guess initial parameters
- Calculate responsibility
- Maximize likelihood of all parameters

$$\widehat{\mu_k} = \frac{1}{n_k} \sum_{i \in k}^{n_k} x_i$$

$$\widehat{\sigma_k} = \frac{1}{n_k} \sum_{i \in k}^{n_k} (x_i - \mu_k)^2$$

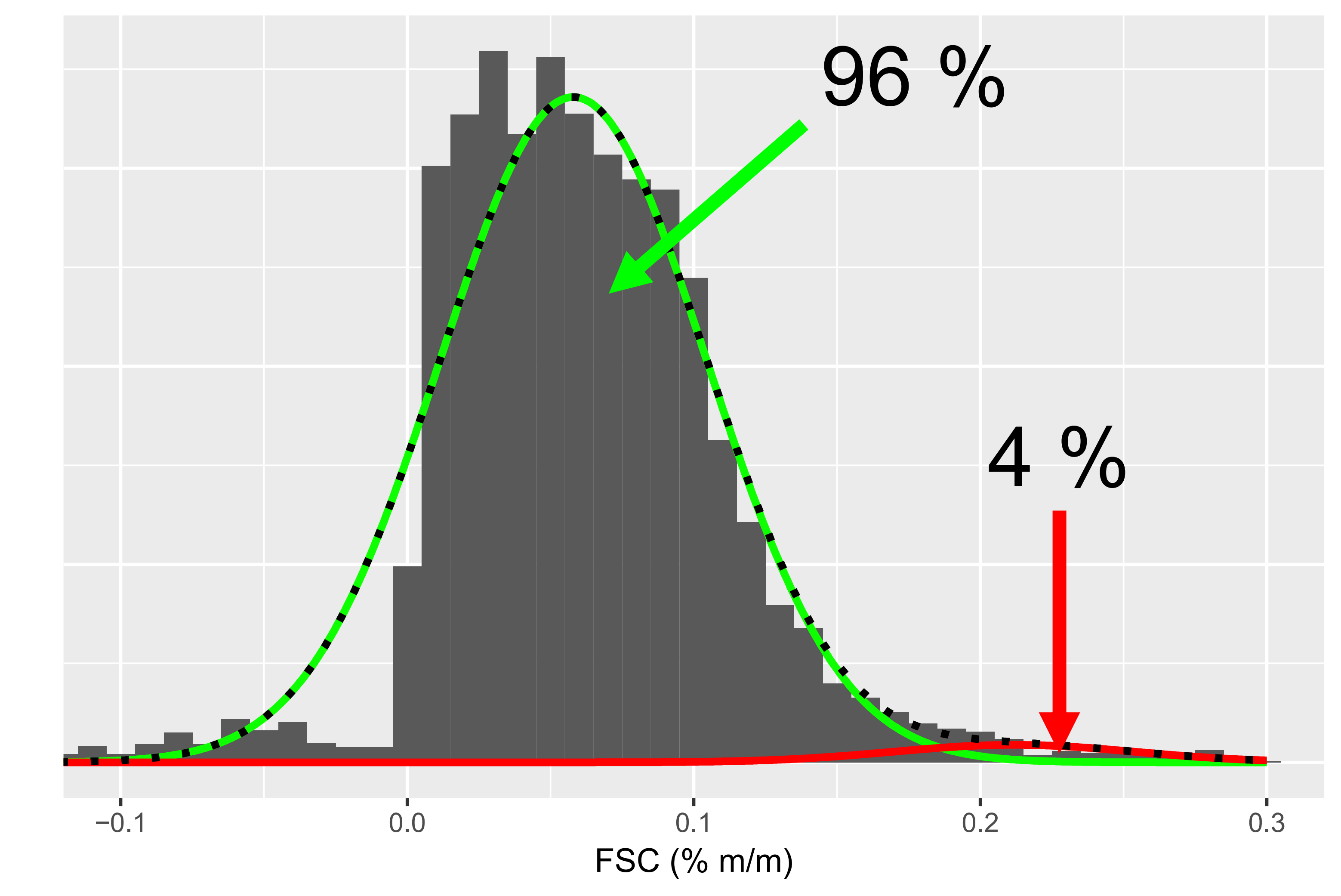
EM algorithm

- Guess initial parameters
- Calculate responsibility
- Maximize likelihood of all parameters

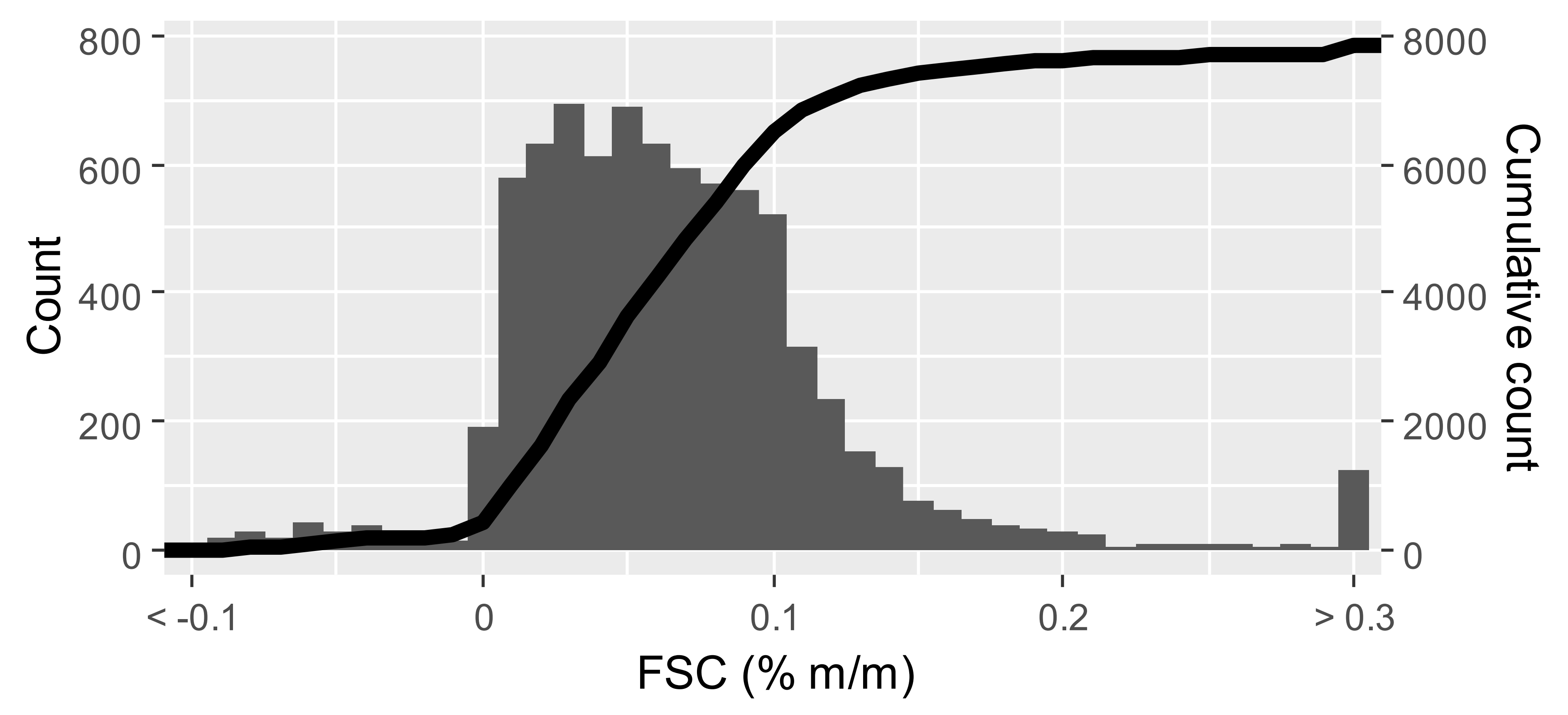
Iterate until convergence

EM-algorithm

N = 5552 (69%)
$\mu_1 = 0.06$ wt−%
$\sigma_1 = 0.04$ wt−%
$\mu_2 = -1.1$ wt−%
$\sigma_2 = 0.8$ wt−%



What fraction is non-compliant?



EM algorithm

- Guess initial parameters
- Calculate responsibility

$$\widehat{\gamma_{i,k}} = \frac{\overbrace{\widehat{\pi_k}}^{\text{prior}} \overbrace{\mathcal{N}(x_i \mid \widehat{\mu_k}, \widehat{\sigma_k}^2)}^{\text{likelihood}}}{\underbrace{\pi_1 \mathcal{N}(x_i \mid \widehat{\mu_1}, \widehat{\sigma_1}^2) + \pi_2 \text{Lognormal}(x_i - 0.1 \mid \widehat{\mu_2}, \widehat{\sigma_2}^2)}_{\text{evidence}}}$$

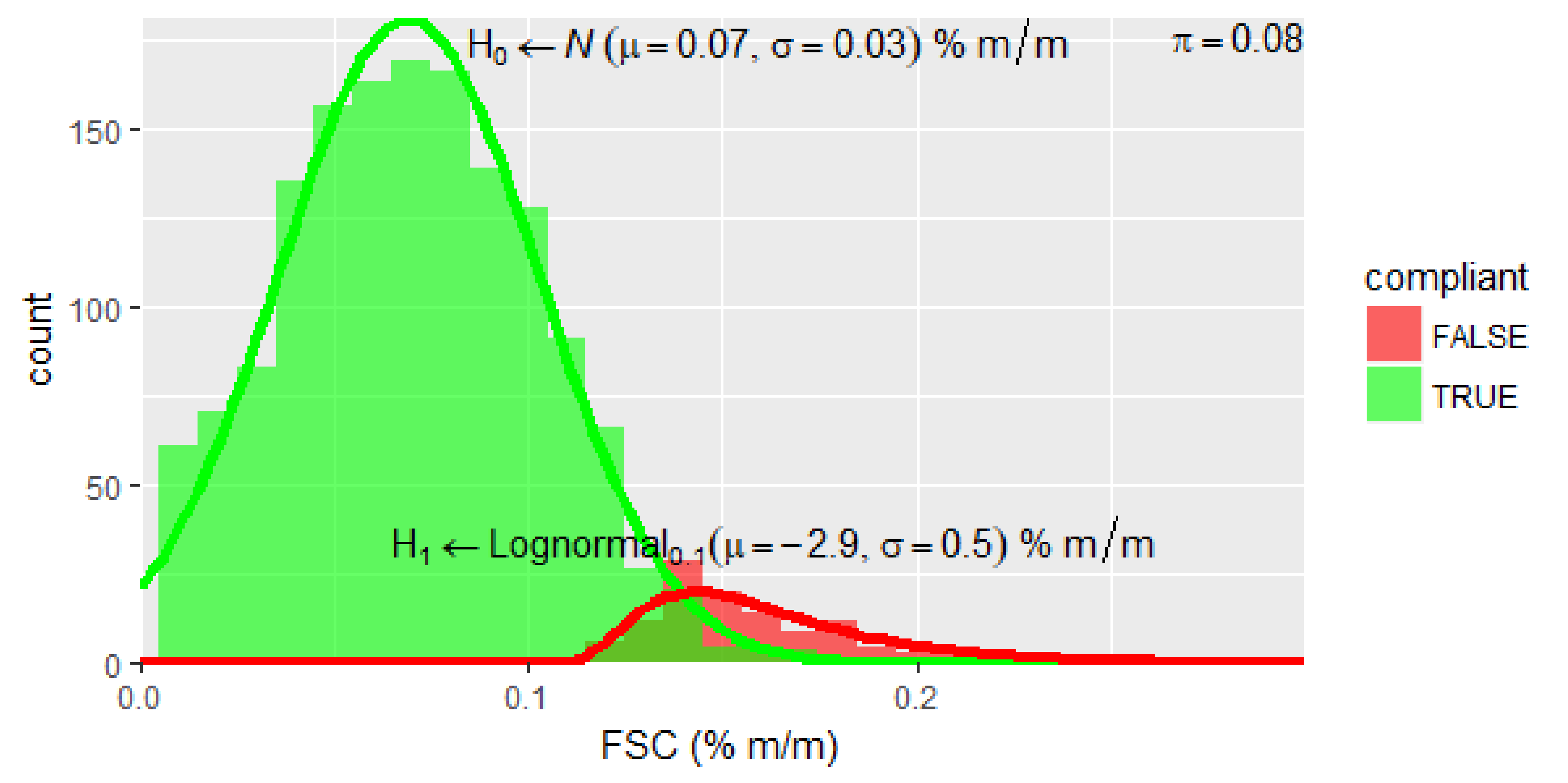
- Maximize likelihood

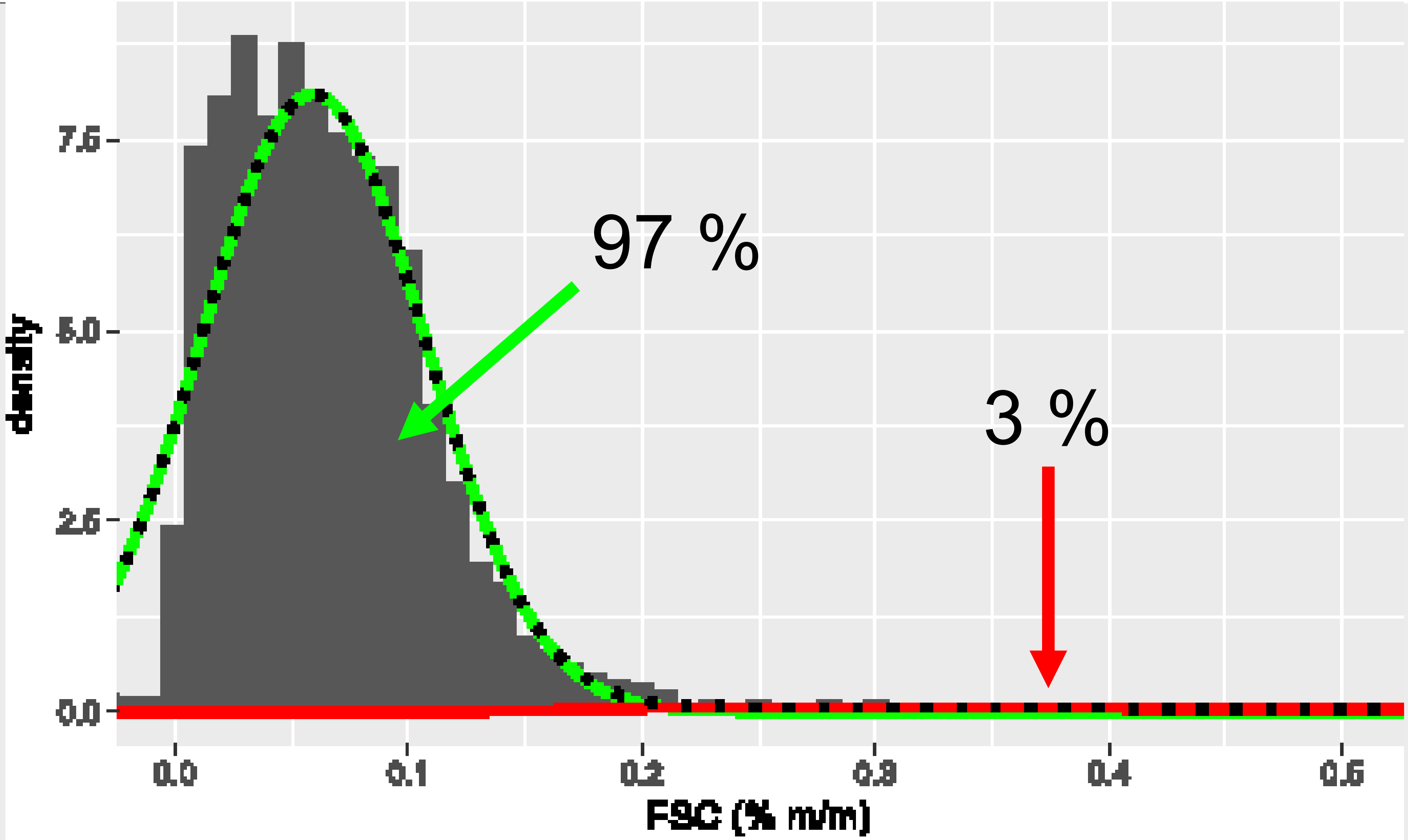
$$\widehat{\mu_c} = \frac{\sum_{i\in c}^{n_k} x_i}{N_c}$$

$$\widehat{\sigma_c} = \frac{\sum_{i\in c}^{n_k} (x_i - \mu_c)^2}{N_c}$$

$$\widehat{\mu_{nc}} = \frac{1}{N_{nc}} \sum_{i\in nc}^{n_k} \log(x_i - 0.1)$$

$$\widehat{\sigma_{nc}} = \frac{1}{N_{nc}} \sum_{i\in nc}^{n_k} (\log(x_i - 0.1) - \mu_{nc})^2$$


$H_0 \leftarrow N\,(\mu = 0.07,\ \sigma = 0.03)\ \%\ m/m$
$\pi = 0.08$
$H_1 \leftarrow \text{Lognormal}_{0.1}(\mu = -2.9,\ \sigma = 0.5)\ \%\ m/m$
150
100
50
0
count
0.0
0.1
0.2
FSC (% m/m)
compliant
FALSE
TRUE


97 %
3 %
density
7.5
5.0
2.5
0.0
0.0
0.1
0.2
0.3
0.4
0.5
FSC (% m/m)

Outlook

- Determine the relation between type I and type II errors more precisely.
- Better instruments will result in better accuracy.
- Better validation makes the introduction of supervised methods possible.