Examples of use of ERA and biomarker-EIA

Study cases on ERA for E&P offshore activities; Examples on how biomarkers are used as a tool for environmental impact assessment

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ERA & Biomarker-EIA

- Use in different phases of field development
  - Pre-operational phase
    - ERA input to assessment of environmental consequences
      - Plan for Development and Operation (in Norway: 'PUD')
      - Regional plans for environmental consequences
    - Biomarker-EIA: Baseline monitoring study
  - During operation
    - ERA for environmental optimization
      - example: minimizing chemical hazards and produced water discharges
    - Biomarker-EIA: Environmental Effect Monitoring to control that environmental goals are achieved
  - After operation
    - Biomarker-EIA: Environmental Effect Monitoring to control that the field is redelivered in good environmental conditions after decommissioning

First example

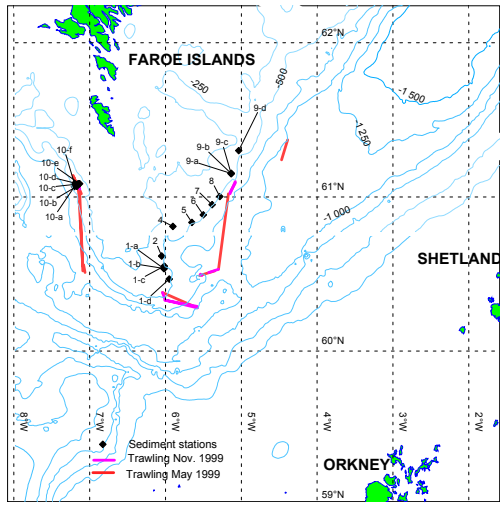
use of ERA & Biomarker-EIA

- Pre-operational phase
  - Biomarker-EIA: Baseline monitoring study

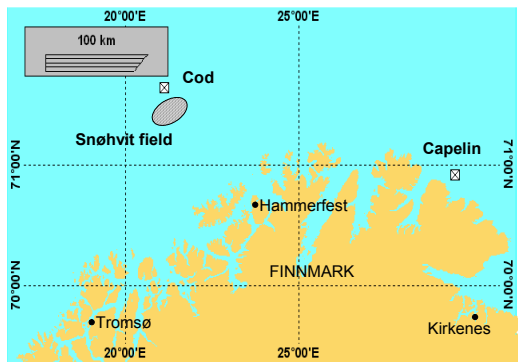
Biomarker-EIA:
Baseline monitoring study

- **Baseline:**
  Background levels and impacts before e&p activity start

  - Faroes
    (G.E.M. program)



  - Snøhvit field
    (Barents sea)
    Operator: Statoil



Biomarker-EIA:
Baseline monitoring study

- Biomarker based baseline studies
  - Faroe Islands
    - G.E.M. program
  - Snøhvit field
    - Statoil

Greenland halibut

Objective:

Background levels of biomarkers
- in Greenland halibut (Faroe Islands)
- In Cod and Capelin (Barents Sea)

Cod

Capelin

Biomarkers included:

PAH metabolites
EROD
DNA adducts
Vitellogenin (Vtg)
Zona radiata protein (ZRP)
Reference material
histology

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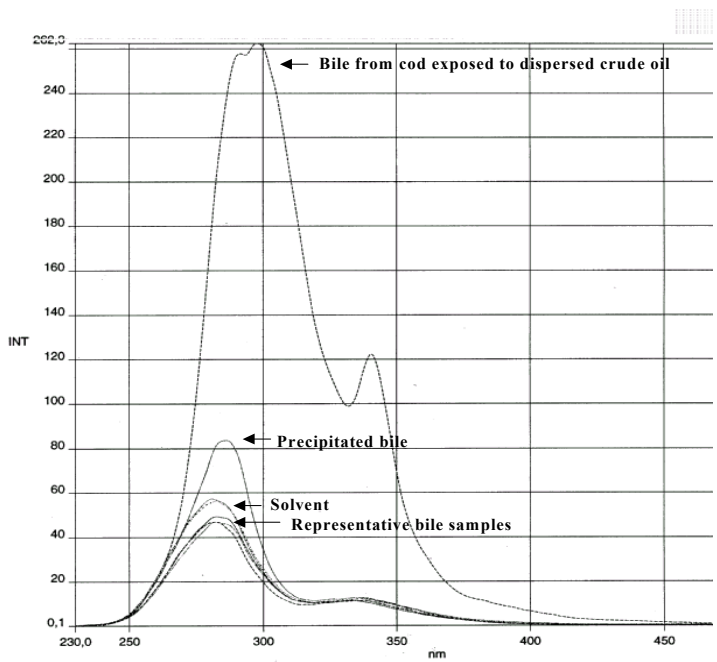
Faroes baseline - example results

- Overall result - low signals

Sex	N	Sampling time	EROD (pmol/min/mg protein)
Male	24	May -99	2,2 ± 0,8
Female	25	May -99	1,5 ± 0,7
Male	20	Nov -99	0,4 ± 0,4
Female	21	Nov -99	0,3 ± 0,3



EROD

Low basal levels

probably first time measured in Greenland halibut

similar level as in cod

Bile metabolites

similar results as for EROD

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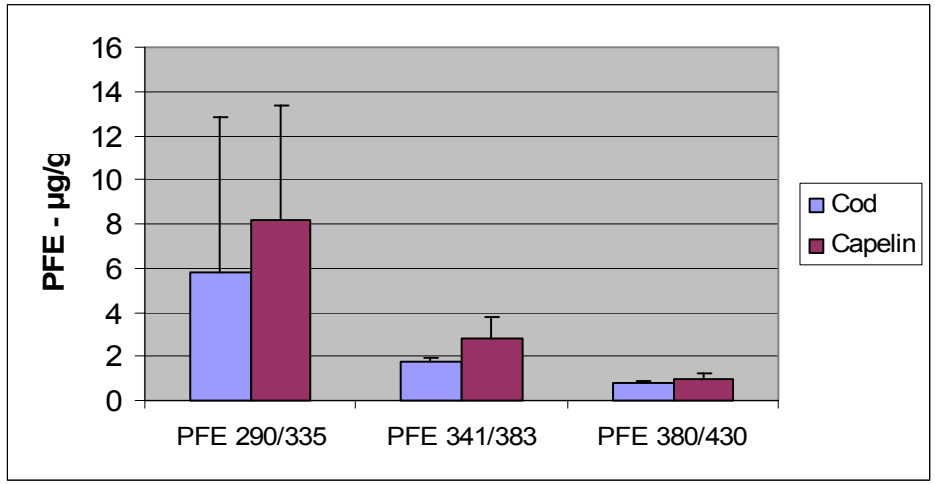
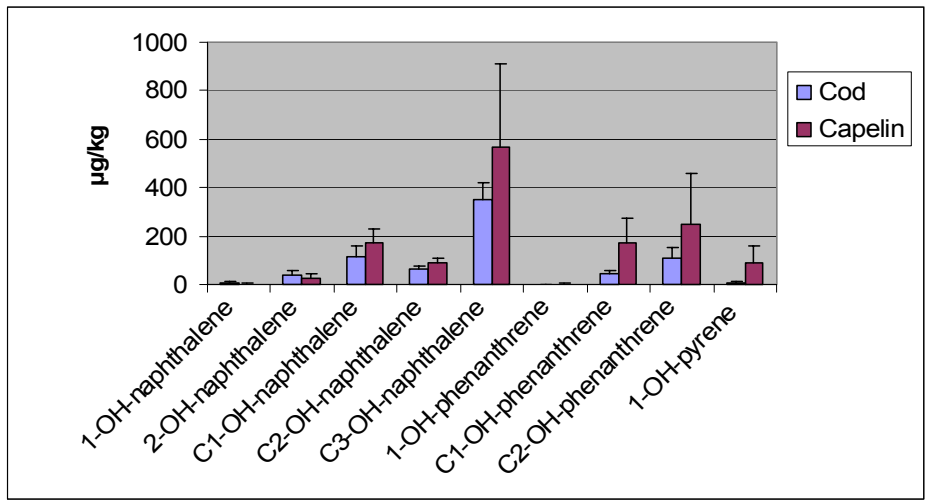
Snøhvit baseline - example results

- PAH metabolites in bile

Fluorescense (FF)

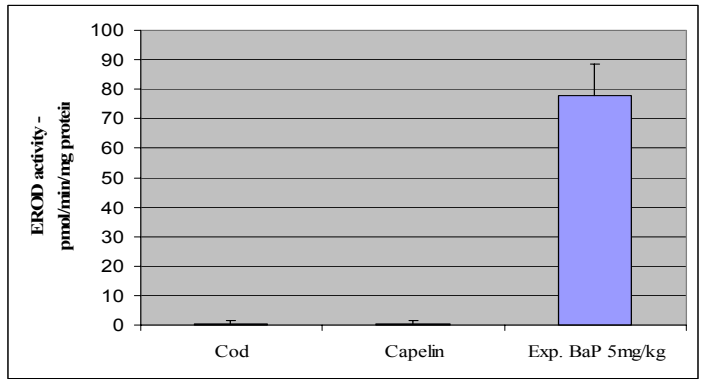


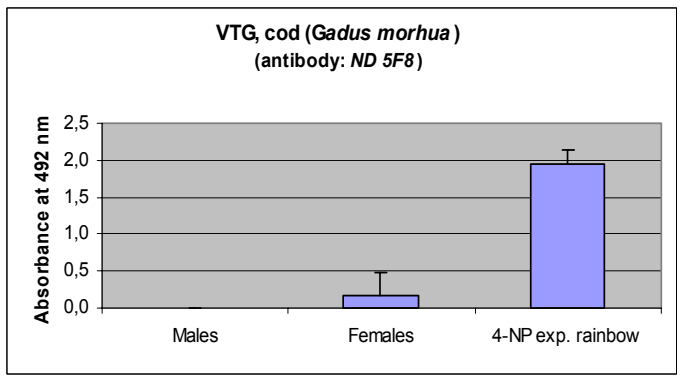
GC-MS SIM

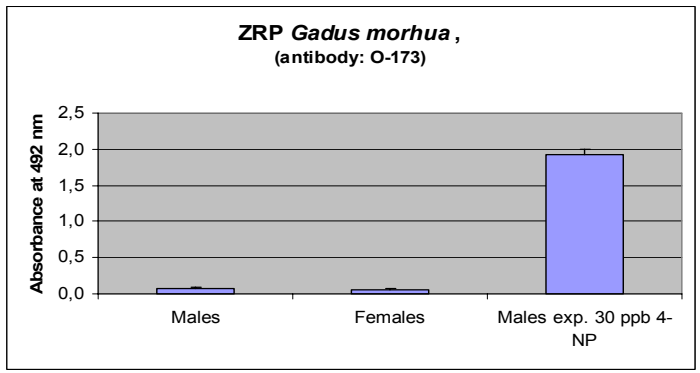


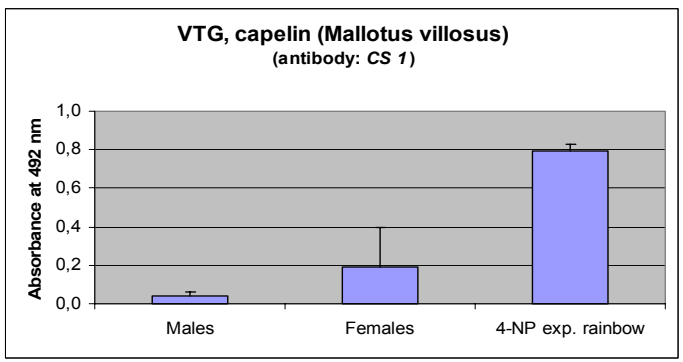
Snøhvit baseline - example results

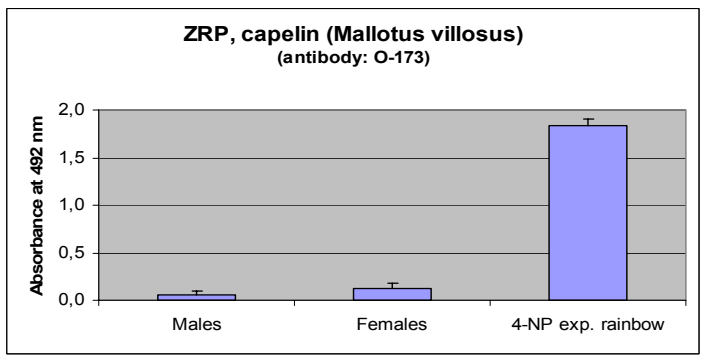
- EROD
- Vitellogenin (Vtg)
- Zona Radiata (Zrp)





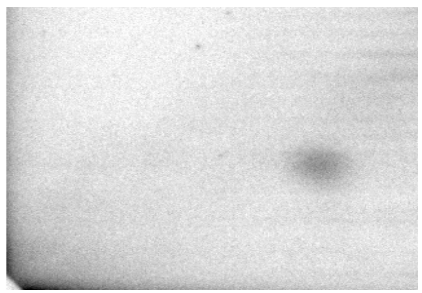


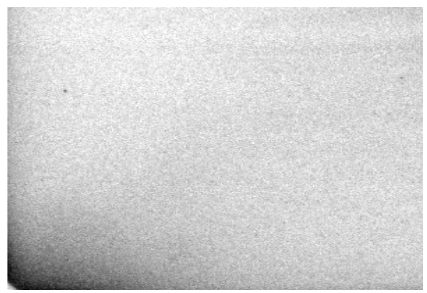




Snøhvit baseline - example results

- DNA adducts



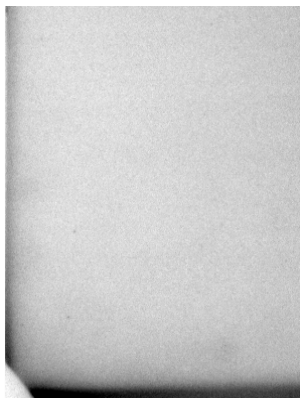


Cod

Capelin

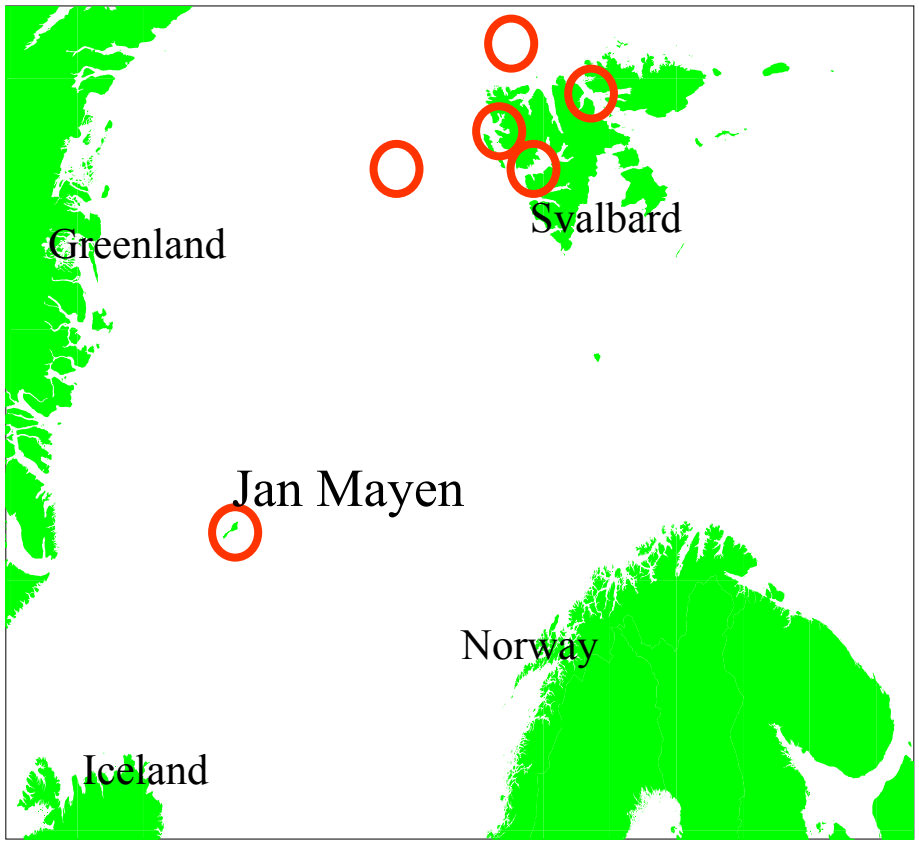
Arctic Baseline

- DNA adducts
  - Background level in the Arctic
  - Positive control

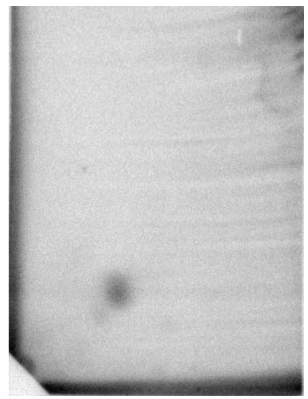


Autoradiogram non exposed polar cod

Similar in 6 other species



Sampling sites



Autoradiogram BaP exposed polarcod

Example

use of ERA & Biomarker-EIA

- During operation
  - ERA for environmental optimization
    - example:
      minimizing chemical hazards and produced water discharges
    - Risk assessment of discharges of Alkylated phenols

Example use of ERA

Risk Assessment of reproductive effects of alkyl phenols in produced water on fish stocks in the North Sea

- Preliminary results from
  - Environmental risk simulations and fish stock estimation

- Project client:
  - Norwegian Oil Industry Association ('OLF')
- Cooperation RF-Akvamiljø and IMR

ERA- *Alkyl phenols*
Background and objectives

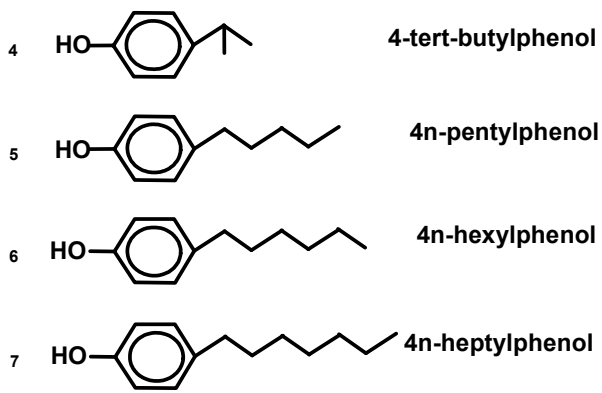
- Background
  - effects in low concentrations of Alkyl phenols found in experiments carried out at IMR and later toxicokinetic study by RF-Akvamiljø

- Objective
  - compile the most relevant data and
  - assess the environmental risk of alkyl phenol discharges in produced water on fish stocks in the North Sea

- To use the best currently available methods and tools in risk assessment (ERA tool: DREAM)

ERA- *Alkyl phenols*
Introduction

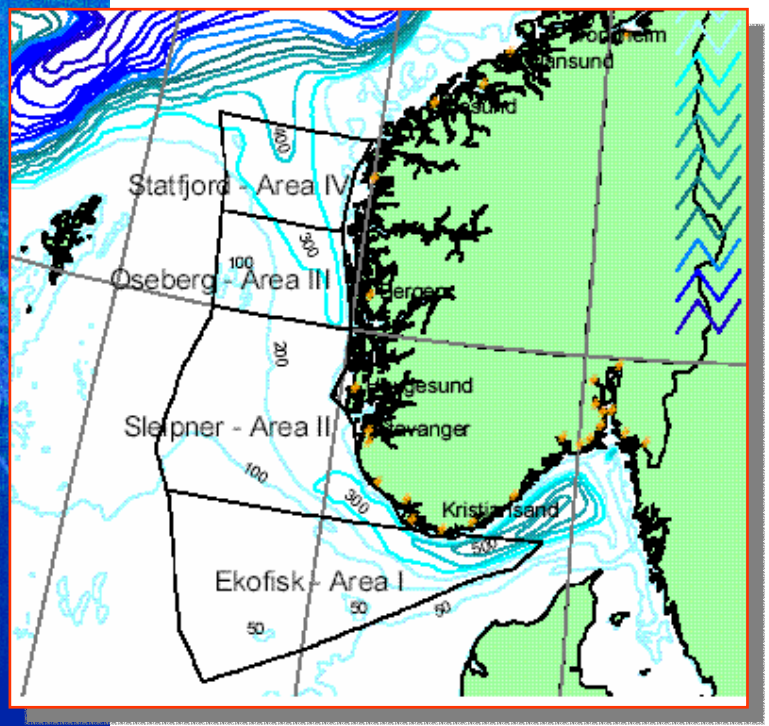
- Experiments conducted by IMR (Meier *et al.* 2002)
  - revealed the lowest effect doses reported, namely 20 ppb body burden.
  - converted to water concentration using a BCF=500 this gives an input NOEC to simulations (*LOEC*) of **40 ng/L** (0,04 ppb)



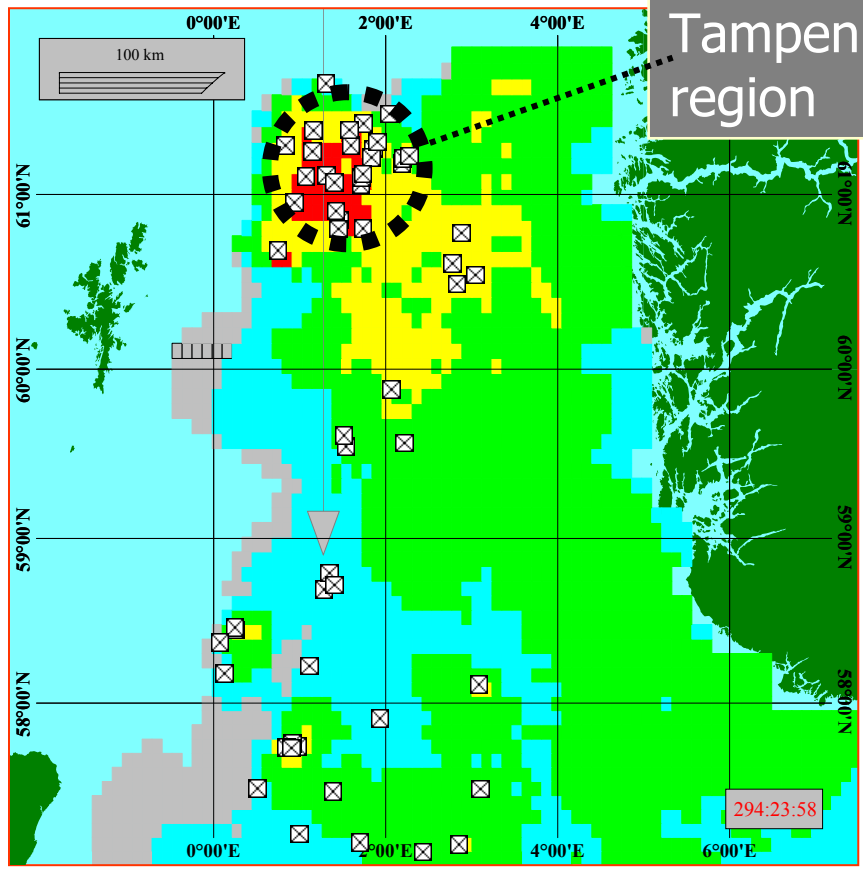
- Later studies
  - show that the absorption efficiency of the AP compounds over the gut wall is only about 10% (Pickford *et al.* 2003; Sundt and Baussant 2003).
  - This suggests an even lower PNEC of **4 ng/l**

(regarded as a very conservative estimate)

The North Sea recipient



Oil production regions in the Norwegian sector



> 1 ppb oil hydrocarbons

Model data (1996) - SINTEF

RF-Akvamiljø

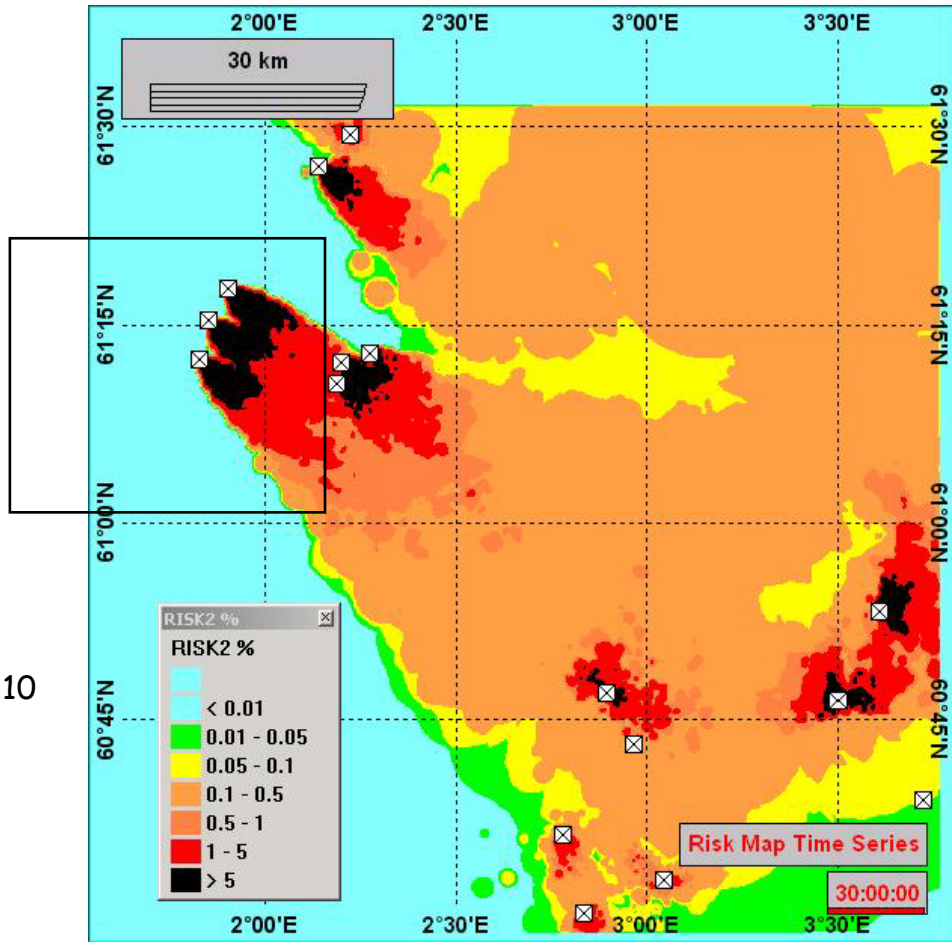
ERA- *Alkyl phenols*

Simulation of different North Sea regions

- Tampen region
- PNEC 4 ng/l

Using PEC:PNEC approach

- Sum of risk area over 30 days
- # cells in concentration grid: 400 * 400 * 10
- Output interval: 12 hours
- Time step: 60 min
- Size of habitat area: 110 * 120 km



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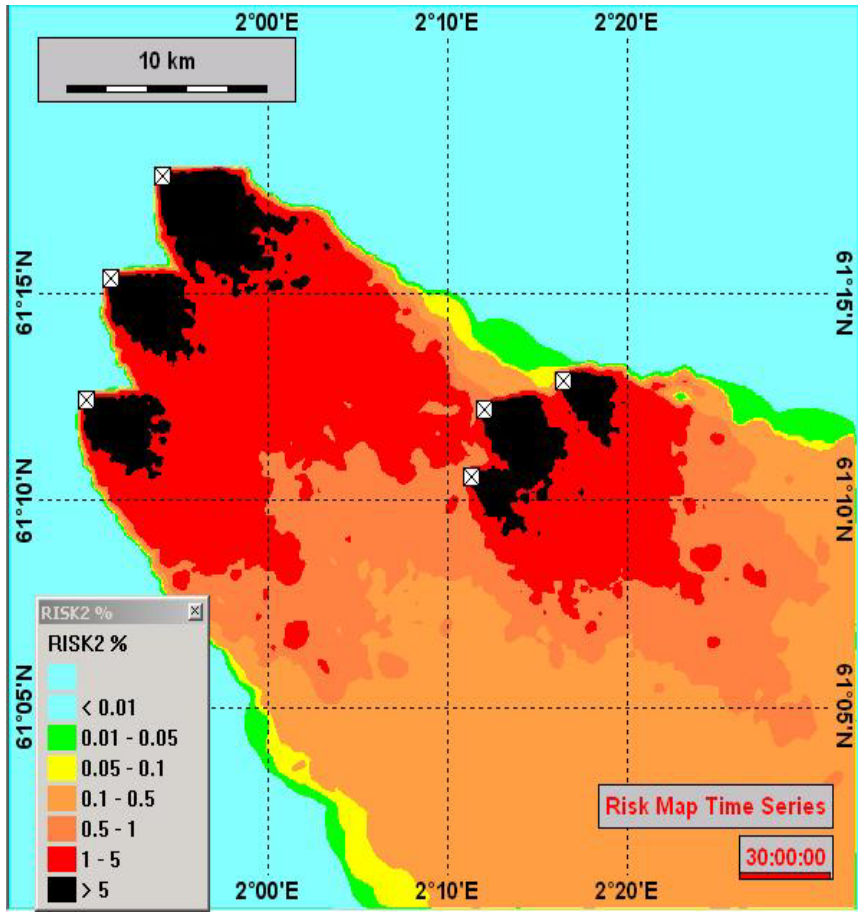
ERA- *Alkyl phenols*
Simulation of Tampen sub region

- Close up at
- Statfjord/Gullfaks
- PNEC 4 ng/l

Using PEC:PNEC approach

- Sum of risk area over 30 days
- # cells in concentration grid: 300 * 300 * 10
- Output interval: 6 hours
- Time step: 20 min
- Size of habitat area: 46 * 42 km



ERA- *Alkyl phenols*

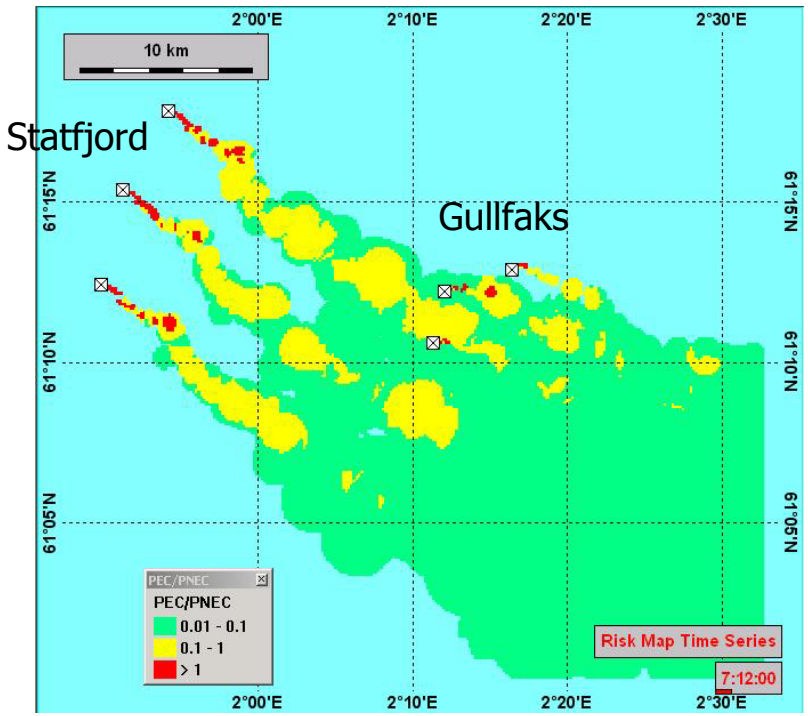
Estimation of risk area

(PEC:PNEC approach)

Sub region Statfjord/Gullfaks

PNEC 4 ng/l

Estimated actual risk area



Installation	Number of squares with PEC/PNEC >1,0	Area, 1 square 0,021 km²
Statfjord A	54	1,134 km²
Statfjord B	61	1,281 km²
Statfjord C	71	1,491 km²
Gullfaks A, Gullfaks B Gullfaks C	42	0,882 km²
Total		4,788 km²

RF-Akvamiljø

ERA- *Alkyl phenols*

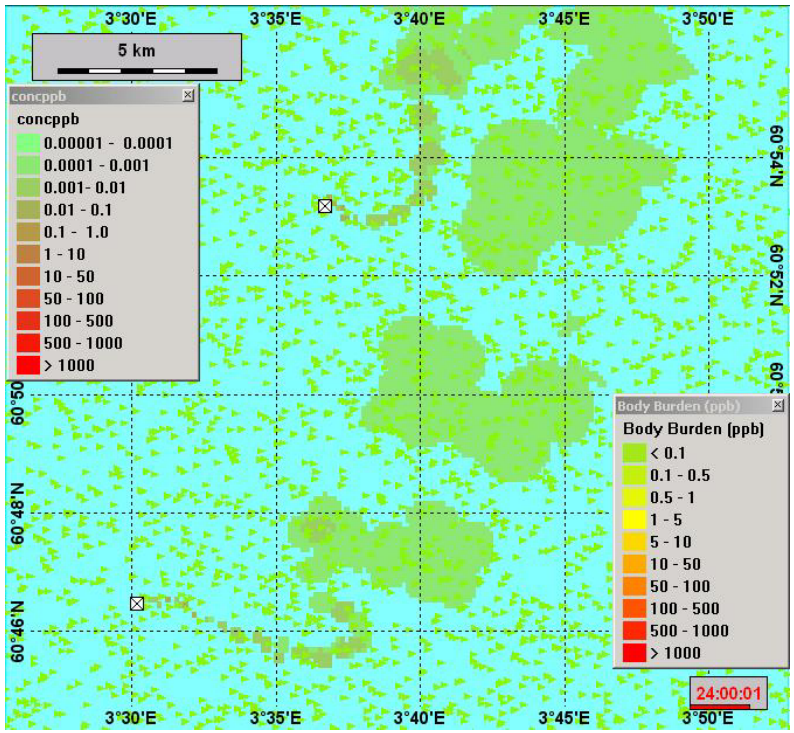
Simulation of body burdens -> effects

(Dose related approach)

Field: Troll

CBB 2 ppm (equivalent to 4 ng/l NOEC)

DREAM simulated body burdens



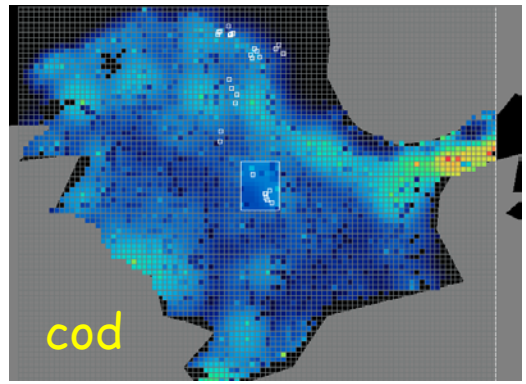
ERA- *Alkyl phenols*
Fish distributions

North Sea

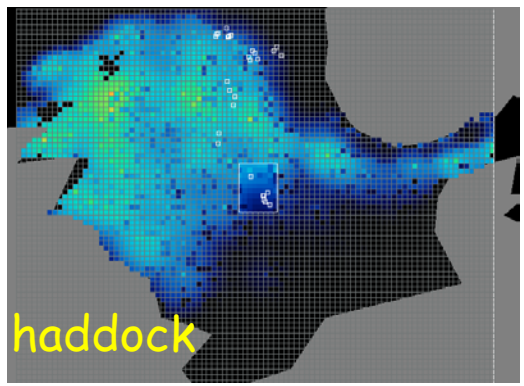
Cod, Haddock, Saithe

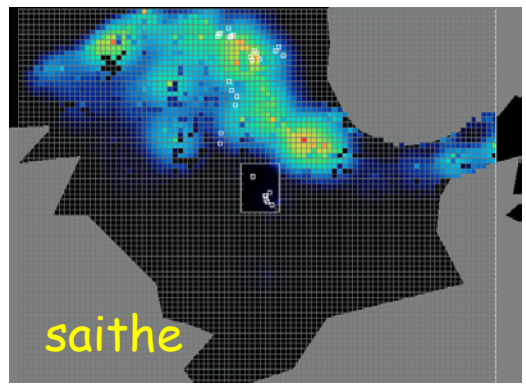
(1+3q 2002; ICES)

Data processed and prepared for ERA by IMR



In the risk assessment the amount of fish exposed to alkyl phenols over the critical body burden was combined with the fish abundance data provided by IMR





ERA- *Alkyl phenols*
Results

Tampen area

Cod, Haddock, Saithe

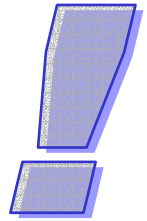
Percentage Risk of Reproductive effect (unsuccessful spawning)

(F_{risk} * 35) / 100 = potential percentage of the fish stocks with unsuccessful spawning that year

Tampen	NOEC	F_{risk} Cod	F_{risk} Saithe	F_{risk} Haddock	Cod	Saithe	Haddock
2002	40 ng/l	0,0000	0,0001	0,00002	0,000007	0,000045	0,000007
	4 ng/l	0,0011	0,0085	0,00132	0,000416	0,003003	0,000462
2006	40 ng/l	0,0000	0,0000	0,00001	0,000003	0,000021	0,000003
	4 ng/l	0,0008	0,0059	0,00092	0,000287	0,002079	0,000322

Percentages of the fish stocks of Cod, Saithe and Haddock that have unsuccessful spawning.

ERA- *Alkyl phenols*
Conclusions



- Conclusion after ERA using DREAM
  - There is insignificant risk of reproductive effects on the population levels of cod, saithe and haddock in the North Sea as a result of alkyl phenol discharges in produced water
  - It is reasonable to believe that effects may occur on individual level in the close vicinity of the discharges, but effects on individual level would not influence the populations
  - it is still important that the alkyl phenols discharges will be followed up with monitoring as soon as the methods for this are sufficiently developed

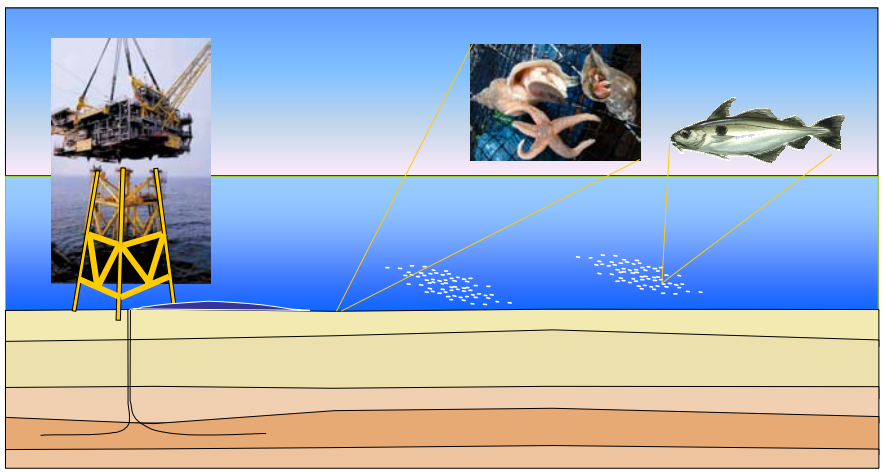
Example

use of ERA & Biomarker-EIA

- After operation
  - Biomarker-EIA:
    - Environmental Effect Monitoring to control that the field is redelivered in good environmental conditions after decommissioning

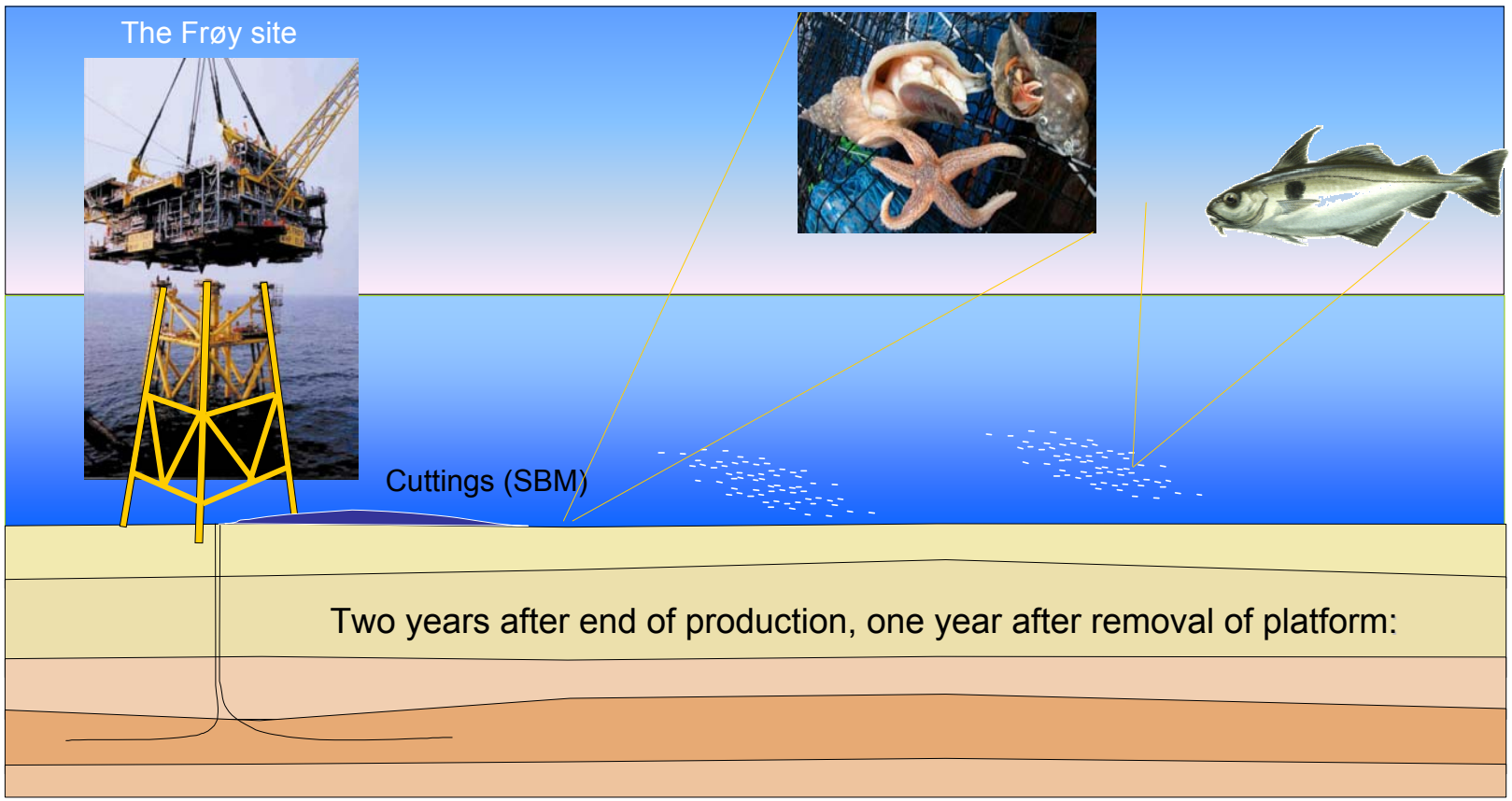
Biomarker tools in sediment monitoring after decommission

Experience from the 2003 survey at the Frøy field
(in Frigg area, North Sea)



RF-Akvamiljø & TOTAL E&P Norge AS

Study issue and study subjects

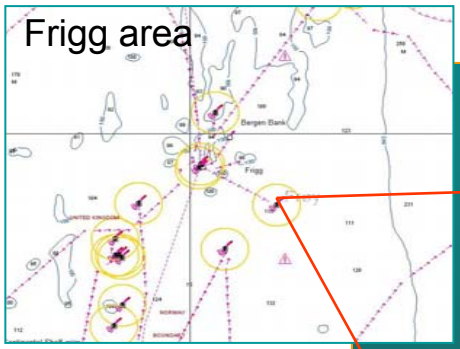


Are biomarker levels in fish and invertebrates at the Frøy site different from the background levels?

Other objectives of Frøy study

- To assess the use of biomarkers as a tool to study environmental effects from cuttings in fish and invertebrates by using the decommissioned Frøy site
- To field validate biomarkers that could be included in future offshore oil industry EIA studies
- To provide additional knowledge to the 2000 cuttings survey and the regular sediment surveys

Study locations: Frøy site + reference



Trawl paths

Station 3
(ref site)
10 km NE

Frøy rig site X

Station 1

Areas for
operation of
fish and
invertebrate
traps

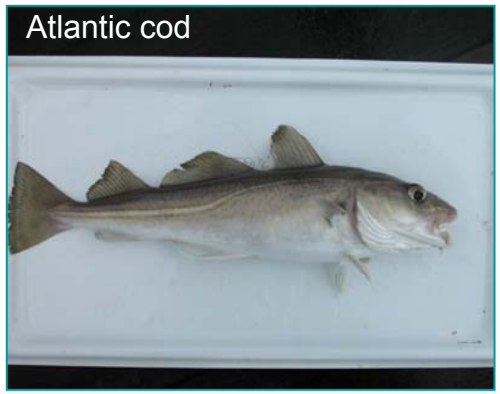
Station 2

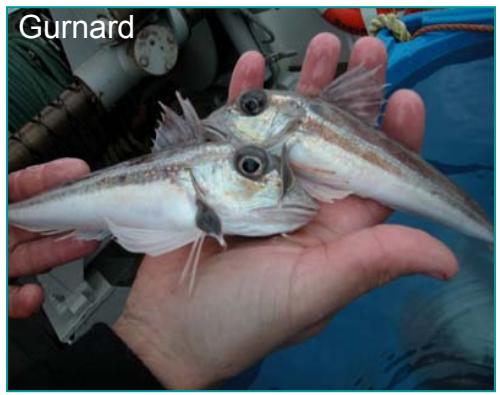
N

1000 m

The survey vessel

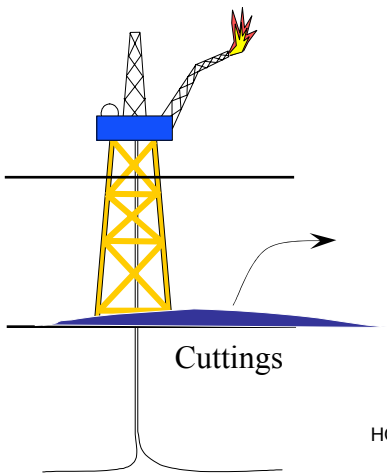
Fish study species



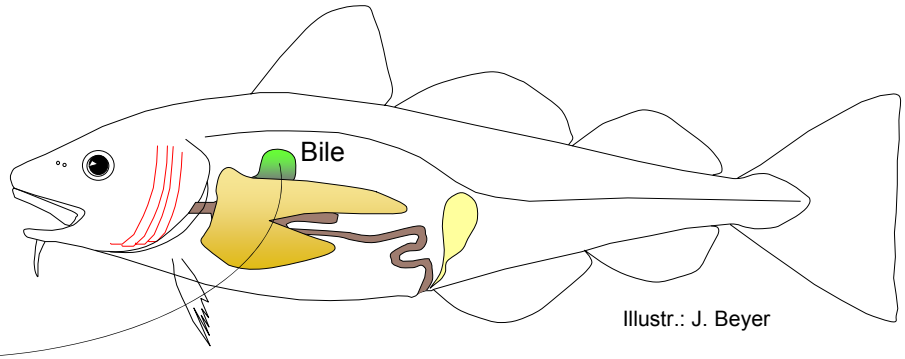


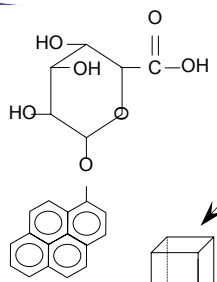
Invertebrate study species

3 Methods for bile PAH detection



Exposure ?

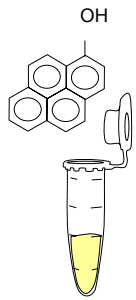




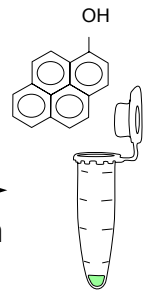
storage in freezer

+ solvent (methanol)

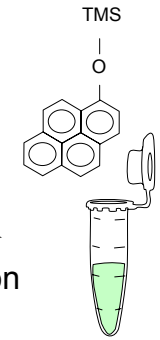
Hydrolysis



Extraction



Derivatization



Diluted bile sample

Hydrolysed bile sample

Extracted bile sample

Derivatized bile sample

FF, SFS & HPLC-F detection

HPLC-F detection

GC-MS SIM detection

Semi-quantitative assays

Quantitative assays

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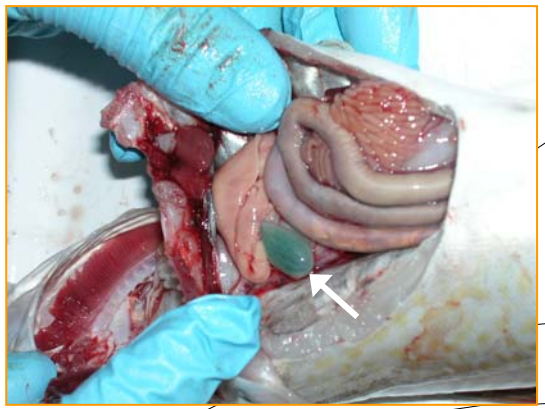
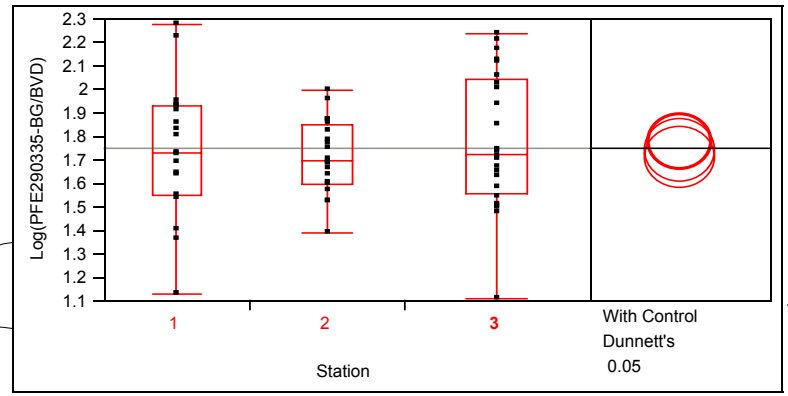
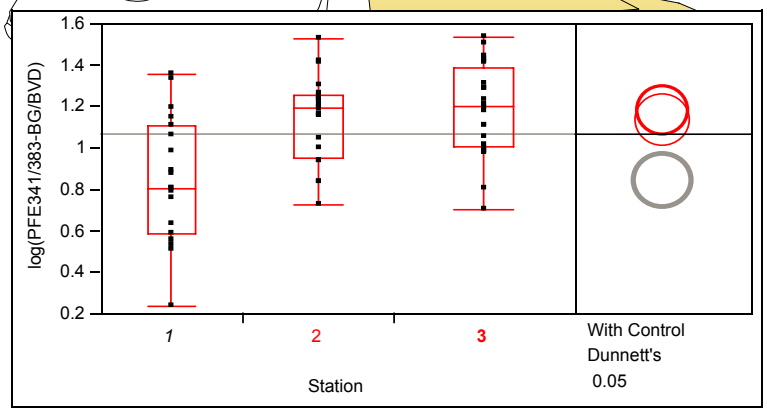
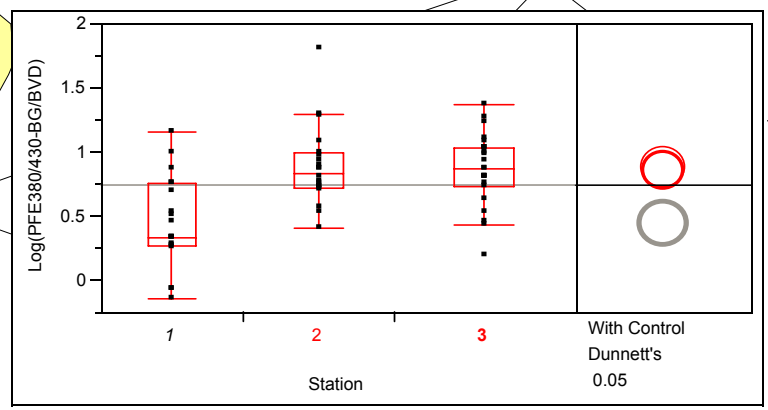
PAH exposure biomarker in haddock bile

2&3-ring PAH metabolite signal









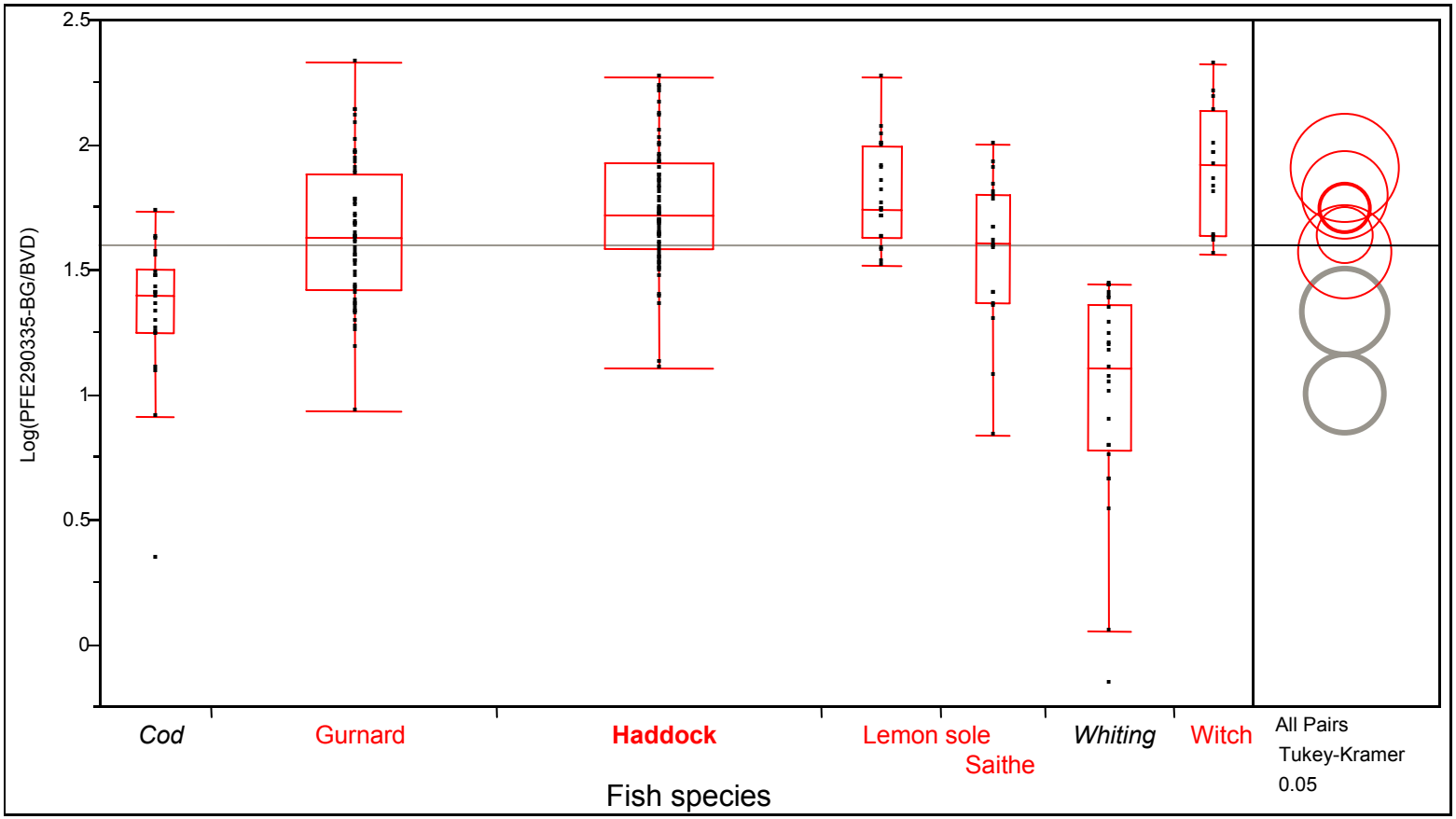
4-ring PAH metabolite signal

5-ring PAH metabolite signal

Oneway Analysis By Station

RF-Akvamiljø

PAH exposure biomarker – species effect



2&3-ring PAH metabolite signal in fish bile

One way analysis by species

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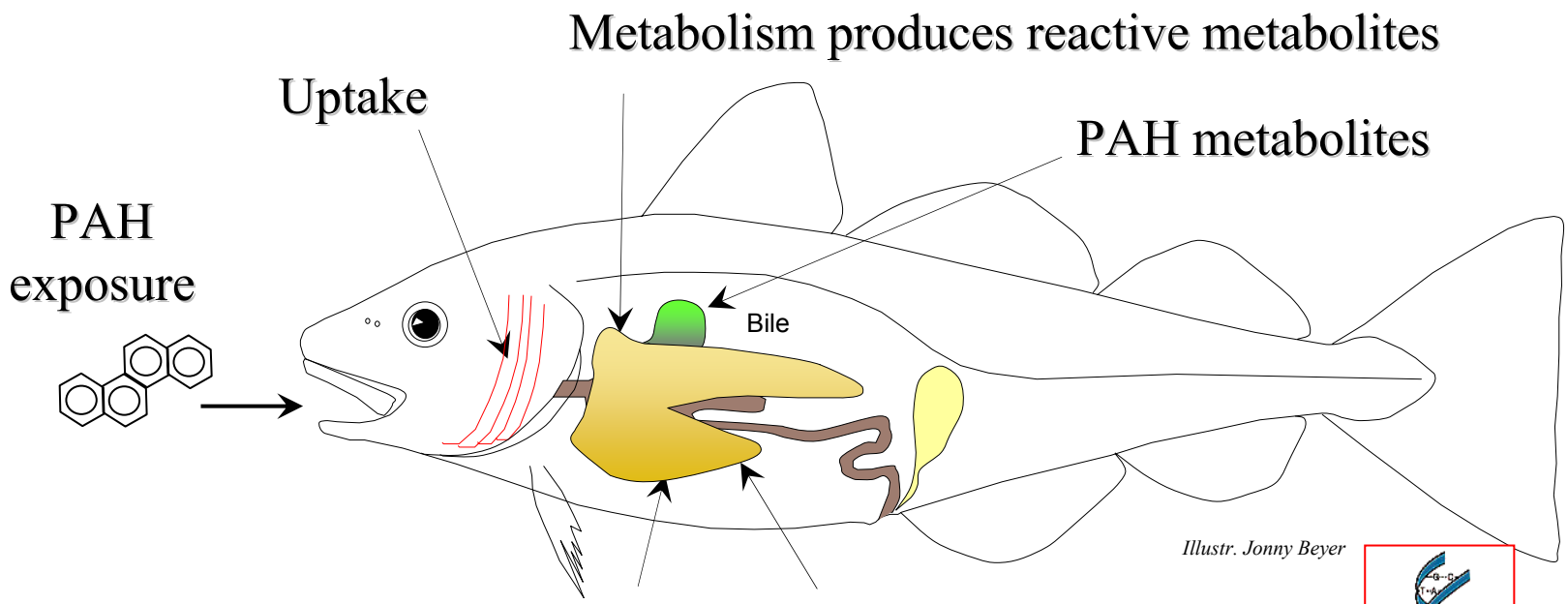
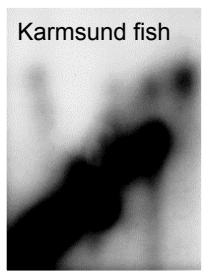
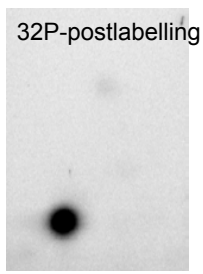
DNA adduct formation - a biomarker of potential genotoxic effects

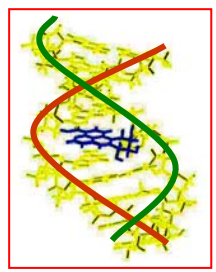


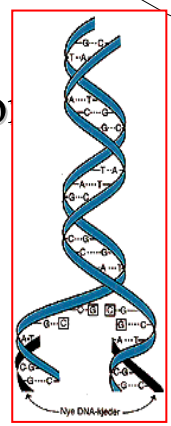
Cellular and tissue

PAH-DNA adduct formatio









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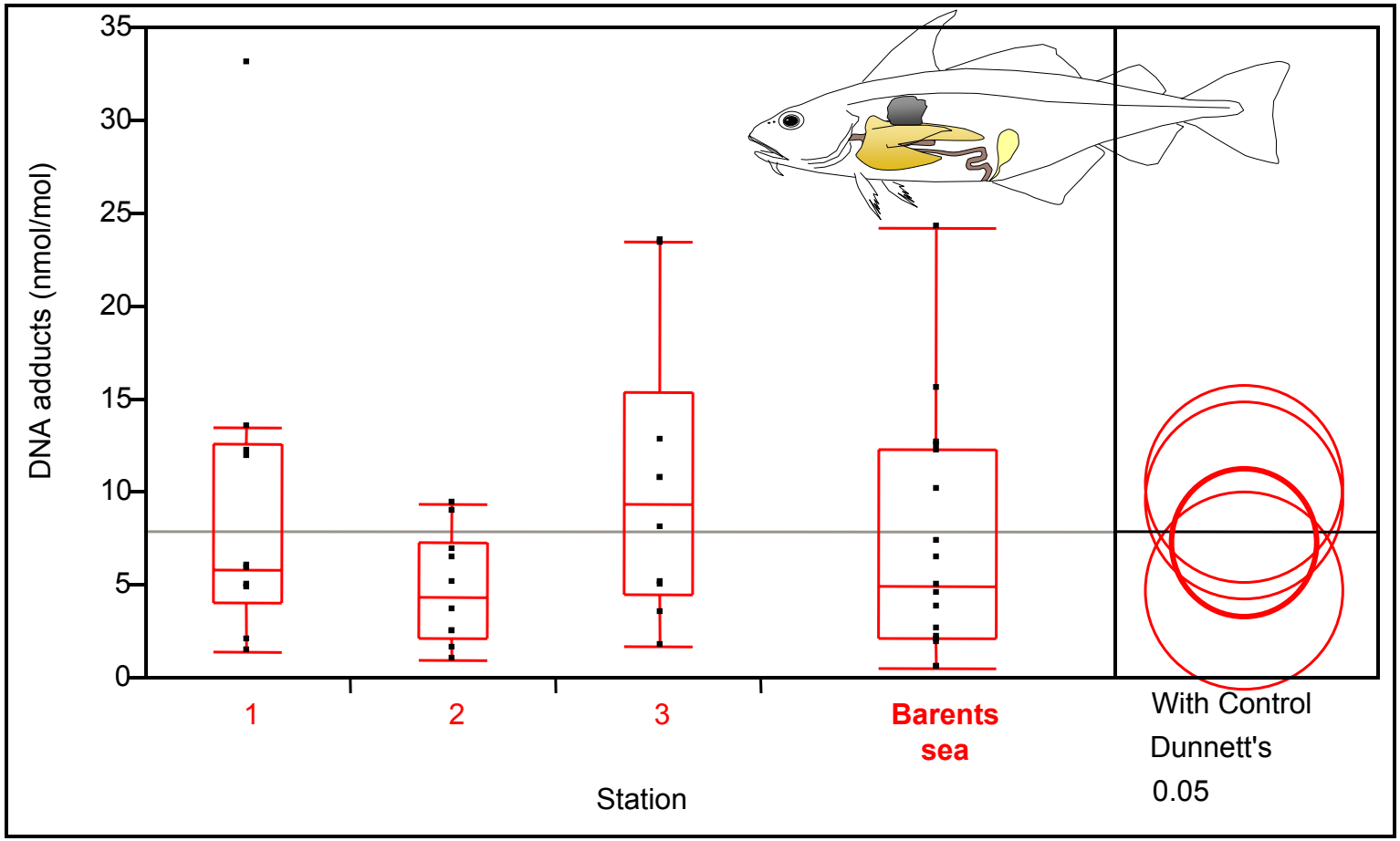
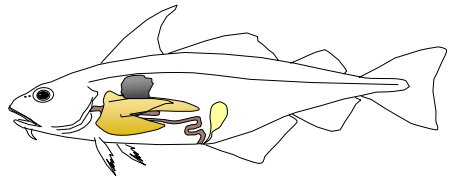
DNA adducts in haddock liver

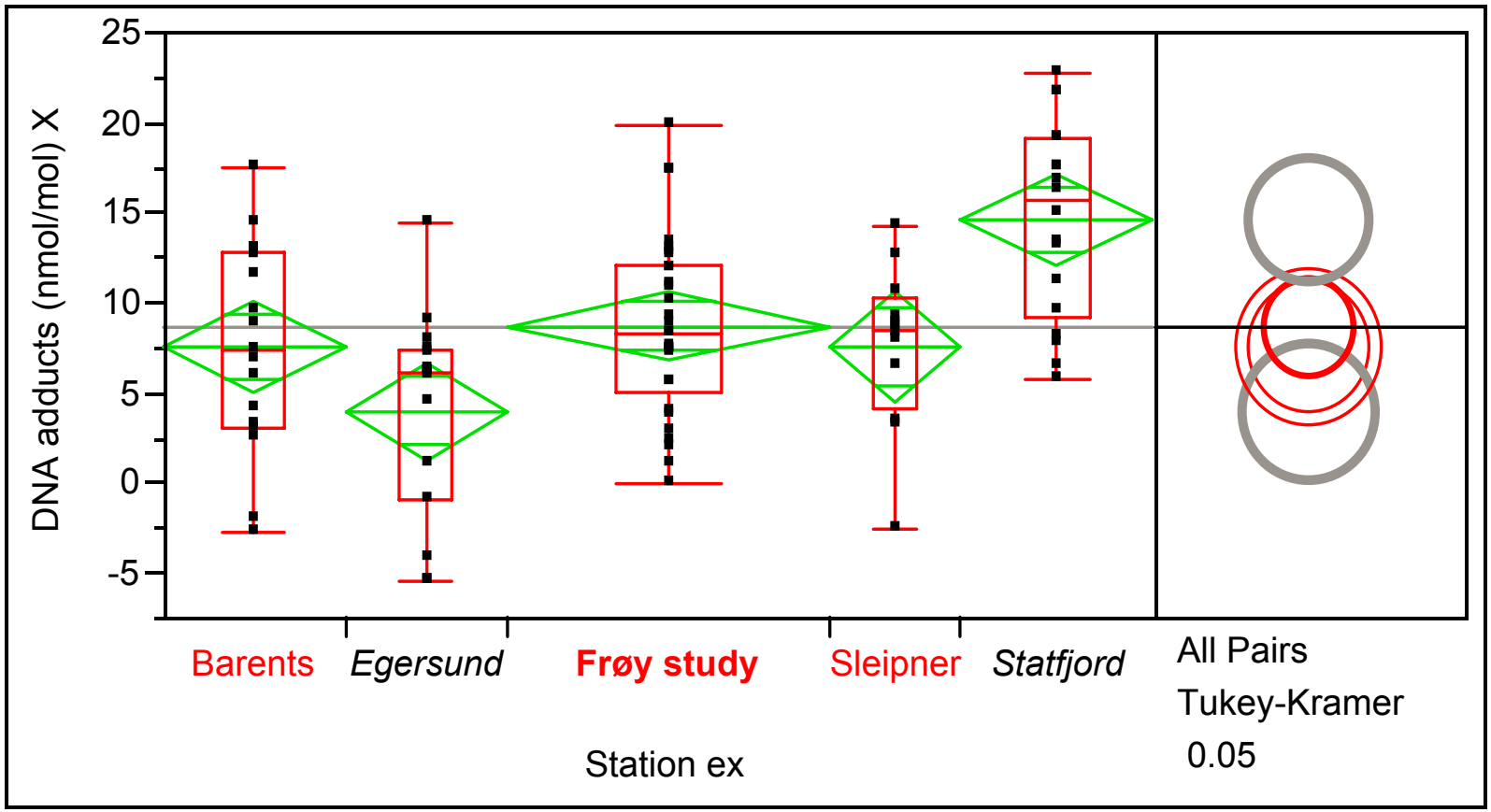
Oneway Analysis of DNA adducts (nmol/mol) By Station



Barents sea data: Biomarker Deep Sea (Cold Water) project – Sundt & Børseth (in prep)

Haddock DNA adducts – Comparison of Frøy with other areas





Statfjord, Sleipner & Egersund data: NFR 152231/720 & TOTAL E&P funding

Barents sea data: Biomarker Deep Sea (Cold Water) project

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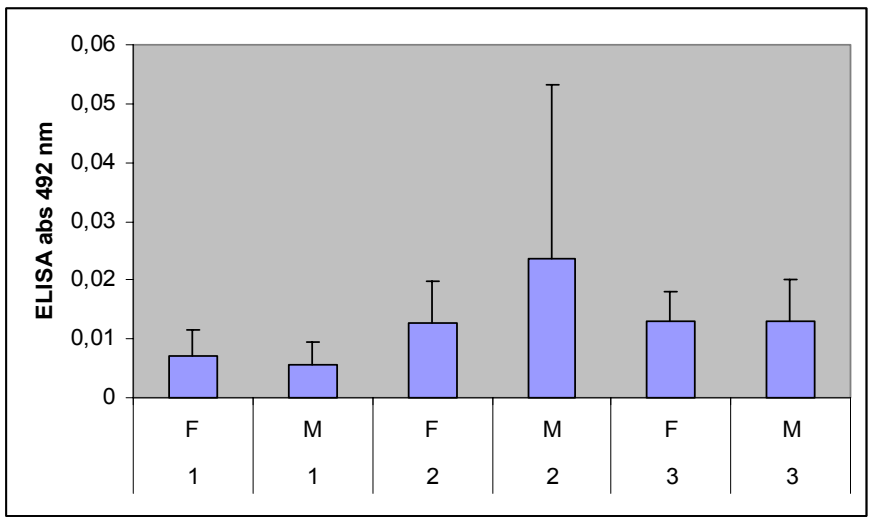
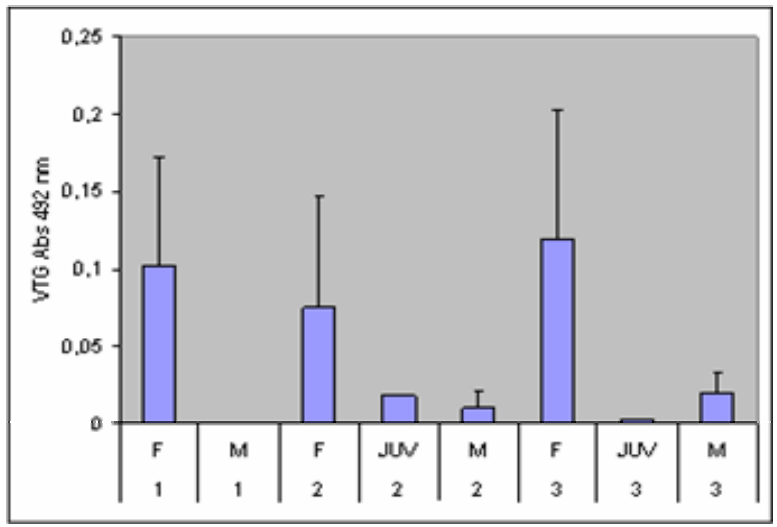
CYP1A and VTG induction in haddock:

No effect at Frøy in comparison to the reference station



CYP1A ELISA
In liver of male and female haddock



VTG ELISA
In plasma of male and female haddock

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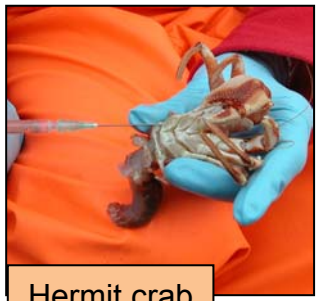
Lysosomal stability condition in invertebrates



Hermit crab

Whelk

Sea star

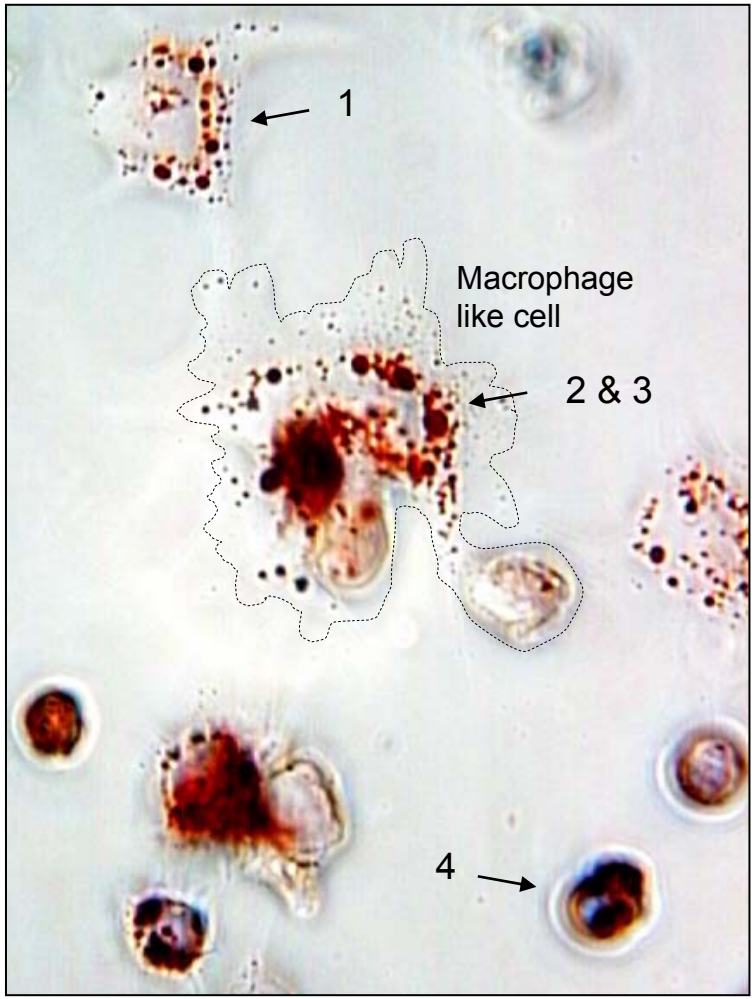
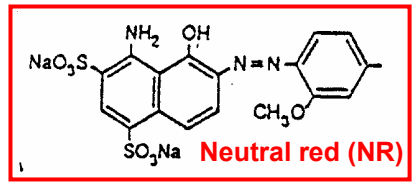


Photo: Anne Bjørnstad

Obtain macrophage like cells and attach them to a microscope slide

Add dye (NR) solution to cells



NR is taken up by cells & accumulates in the lysosome organelles (1)

The lysosomes swell up & the lysosome membrane becomes stressed (2)

Lysosomal membrane breaks and NR leaks into cytosol (3)

The cell rounds up (4) & subsequently dies

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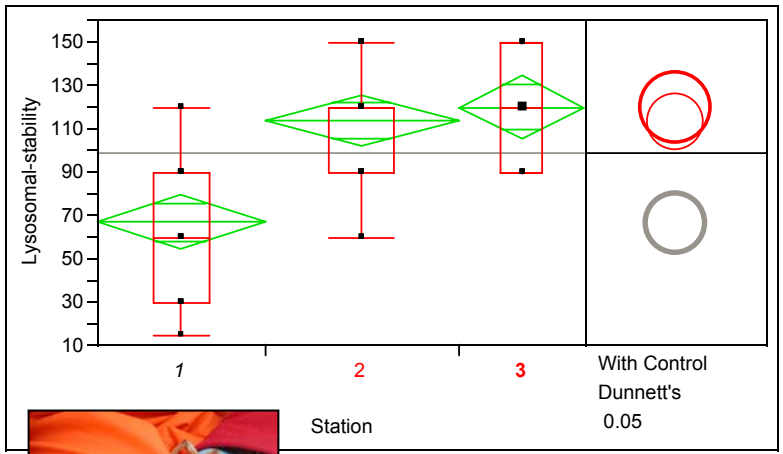
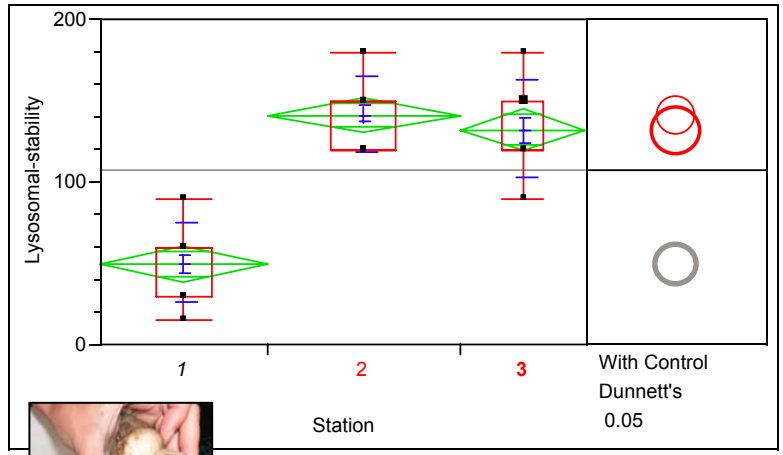
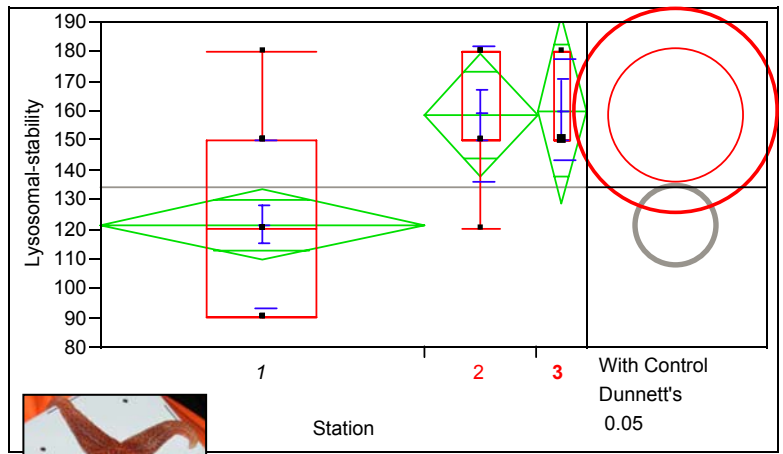
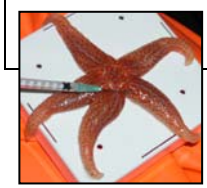
Lysosomal stability in Frøy invertebrates









Significant effect at station 1

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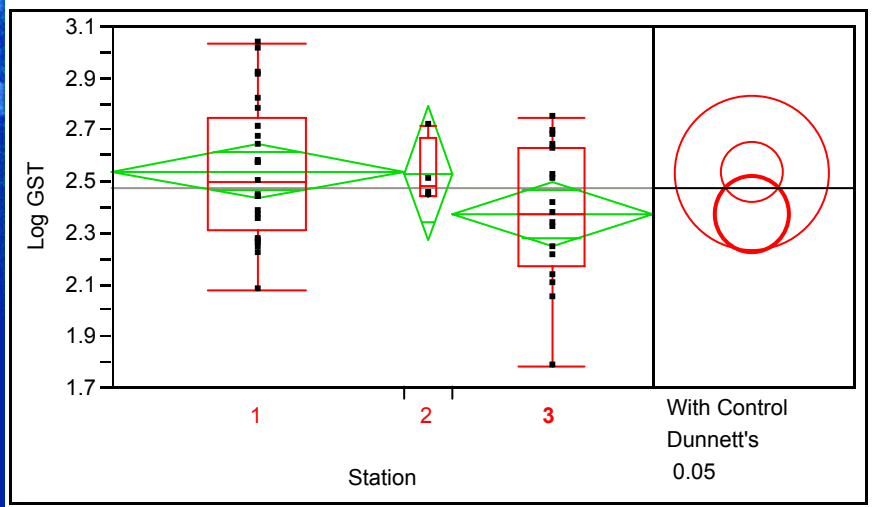
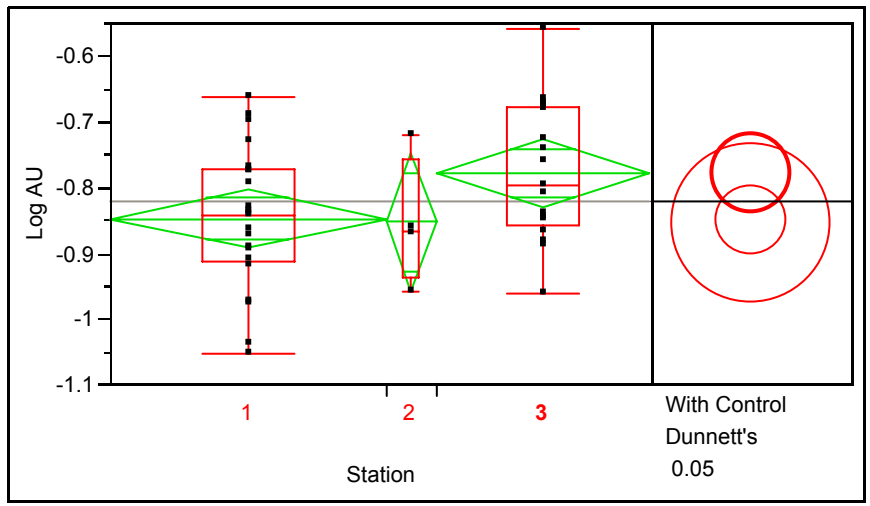
Hermit crab

Other invertebrate biomarkers

GST activity
in hermit crab hepatopancreas



alkaline unwinding
in hermit crab hepatopancreas



Possible weak effect at station 1 & 2

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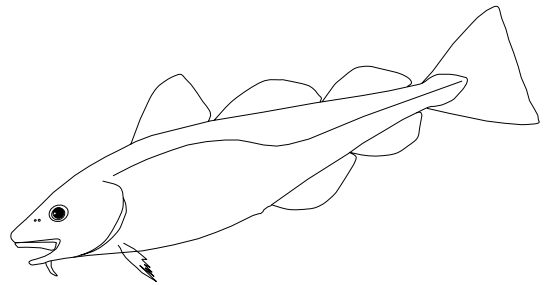
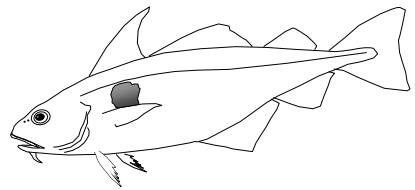
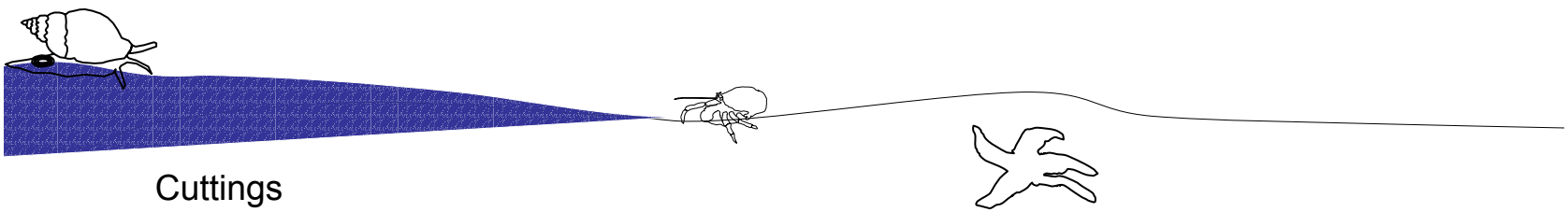
Discussion of approach and findings







Cuttings

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Conclusions of Frøy study

- Biomarkers in Frøy invertebrates
  - Clearest signs of effect was observed for lysosomal stability.
  - Effects was restricted to the of cuttings deposit and ultimate surroundings.
  - Slow moving invertebrates better than fish for effect studies of cuttings
- Biomarkers in Frøy fish
  - In general, no site effect at Frøy in comparison to reference site.
  - DNA adducts in haddock seemed first to be weakly above background, but recent results in Barents sea haddock suggest the Frøy data to be within normal range.
  - A species effect was found on biliary PAH exposure markers in fish with higher signals in benthic species as compared to pelagic.
  - Haddock is apparently a more suitable species than cod for addressing sediment associated pollutant situations.
- The biomarker approach was proven applicable for the task in the Frøy study
- A similar approach may be used to assess possible impact of Offshore installations in general (e.g. drilling discharges, produced water, accidental spills)

Summary of the study cases

The presented study cases have demonstrated how ERA and biomarkers are used as tools for environmental risk and impact assessment related to different phases of E&P offshore activities

The methods are applicable today, and can be further refined to fit different specific purposes

In other words, altogether they constitute a multipurpose environmental assessment toolbox