

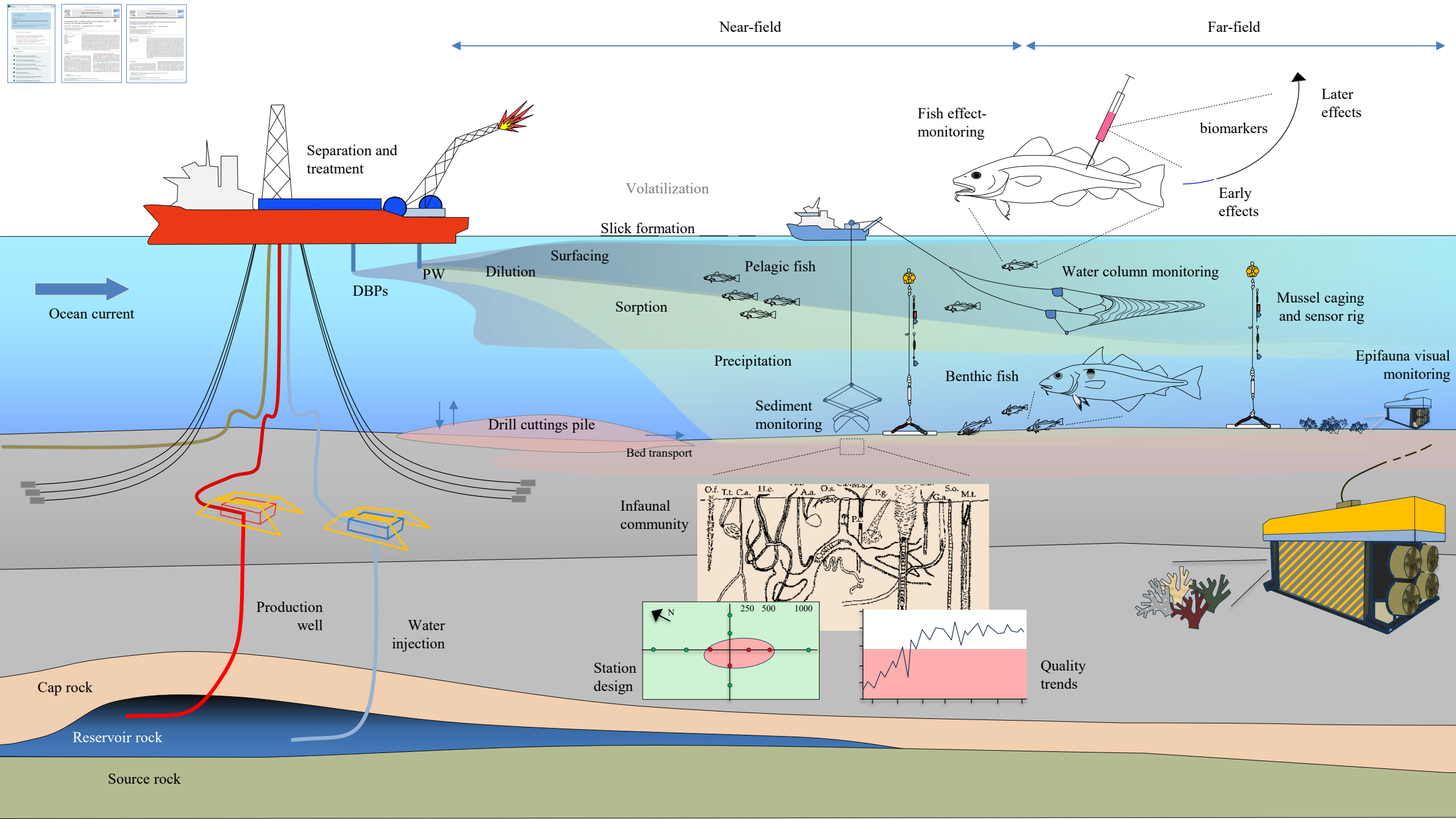
# Effekt-orientert miljøovervåking av produsert vann utslipp innen norsk offshore petroleumsindustri

Jonny Beyer<sup>1,2,3</sup>

<sup>1</sup> Norwegian Inst. for Water Research (NIVA);

<sup>2</sup> Dept. of Biosciences, University of Oslo;

<sup>3</sup> Member of Norwegian Environment Agency offshore monitoring expert advisory group



# Ekspertgruppa: Faglig støtte til Miljødirektoratet i sammenheng med gjennomføring av Norsk offshore miljøovervåking

## [Veileder - miljodirektoratet.no](http://veileder.miljodirektoratet.no)

Miljødirektoratet

Hva leter du etter?

Meny

Forside / ... / Petroleum: Olje og gass / For næringsliv / Miljøovervåking av petroleumsvirksomheten til havs

Bedriftsveilederen

Veileder: | M-300

### Miljøovervåking av petroleumsvirksomheten til havs

Operatørene er pålagt å utføre miljøovervåking på norsk sokkel for å ha kunnskap om hvilke miljøeffekter deres virksomhet har eller kan få.

Veilederen ble oppdatert 21.04.2026. [Selogg](#)

Disse retningslinjene er et resultat av samarbeidet mellom Miljødirektoratet, Direktoratet for strålevern og atomikkerhet (DSA), Miljødirektoratets rådgivende faggruppe, operatører på norsk sokkel og utøvende konsulenter.

Retningslinjene gir detaljerte krav og føringer til gjennomføring av og rapportering fra overvåkingen i vannsøylen, av bunnhabitat (sediment og visuelle undersøkelser) og i forbindelse med avslutningsaktiviteter.

[Retningslinjene ble i 2023 oversatt til engelsk \(M-408\)](#). De er ikke oppdatert i 2025.

### Innhold

Søk i veiledningen

- Hensikten med miljøovervåkingen offshore**  
Få oversikt over tilstanden og trendene i utviklingen i miljøet over tid
- Krav knyttet til miljøovervåking offshore**  
Forurensere må gi forurensningsmyndighetene nødvendige opplysninger
- Beskrivelse av miljøovervåkingen offshore**  
Miljøovervåkingen gjennomføres gjennom hele levetiden til petroleumsinntrengene.
- Kvalitetskontroll av miljøovervåkingen offshore**  
Kvalitetskontrollen bør forankres hos både konsulent og oppdragsgiver.
- Overvåking av vannsøylen**  
Om vannsøylovervåking av marine organismer
- Overvåking av bunnhabitat (sedimentundersøkelser)**

## Effekter av PW utslipp til vannsøyle

Marine Environmental Research 162 (2020) 105155

Contents lists available at ScienceDirect

### Marine Environmental Research

journal homepage: <http://www.elsevier.com/locate/marenv>

### Environmental effects of offshore produced water discharges: A review focused on the Norwegian continental shelf

Jonny Beyer<sup>a,\*</sup>, Anders Goksoyr<sup>b,c</sup>, Dag Øystein Hjermann<sup>a</sup>, Jarle Klungsoyr<sup>c</sup>

<sup>a</sup> Norwegian Institute for Water Research (NIVA), Oslo, Norway  
<sup>b</sup> Department of Biological Sciences, University of Bergen, Norway  
<sup>c</sup> Institute of Marine Research (IMR), Bergen, Norway

**ARTICLE INFO**

**Keywords:**  
Offshore produced water discharges  
Environmental effects  
North sea  
Barents sea  
Sensitivity  
Vulnerability  
Effect-based monitoring  
Risk assessment  
Regulation

**ABSTRACT**

Produced water (PW), a large byproduct of offshore oil and gas extraction, is reinjected to formations or discharged to the sea after treatment. The discharges contain dispersed crude oil, polycyclic aromatic hydrocarbons (PAHs), alkylphenols (APs), metals, and many other constituents of environmental relevance. Risk-based regulation, greener offshore chemicals and improved cleaning systems have reduced environmental risks of PW discharges, but PW is still the largest operational source of oil pollution to the sea from the offshore petroleum industry. Monitoring surveys find detectable exposures in caged mussel and fish several km downstream from PW outfalls, but biomarkers indicate only mild acute effects in these sentinels. On the other hand, increased concentrations of DNA adducts are found repeatedly in benthic fish populations, especially in haddock. It is uncertain whether increased adducts could be a long-term effect of sediment contamination due to ongoing PW discharges, or earlier discharges of oil-containing drilling waste. Another concern is uncertainty regarding the possible effect of PW discharges in the sub-Arctic Southern Barents Sea. So far, research suggests that sub-arctic species are largely comparable to temperate species in their sensitivity to PW exposure. Larval deformities and cardiac toxicity in fish early life stages are among the biomarkers and adverse outcome pathways that currently receive much attention in PW effect research. Herein, we summarize the accumulated ecotoxicological knowledge of offshore PW discharges and highlight some key remaining knowledge needs.

### 1. Introduction

Operational discharges of produced water (PW) from offshore oil and gas platforms are a continuous source of contaminants to continental shelf ecosystems (Fig. 1) (Lee and Neff, 2011). The PW is treated to lower the content of unwanted components (Jimenez et al., 2013) and then reinjected to a geological formation or discharged to the sea. Rejection is considered the Best Environmental Practice for PW management, but these operations are not always technically feasible, making discharge to the sea a very common management solution. In the oceanic area covered by the Oslo-Paris (OSPAR) conventions, about 300 million standard cubic meters (Sm<sup>3</sup>) were discharged to sea annually in recent years; of these the Norwegian discharges were about 130 million Sm<sup>3</sup> (OSPAR, 2019). In 2017, the amount of dispersed oil in these discharges was reported to be about 1600 tons for Norwegian installations, and about 4000 tons for the whole OSPAR area (ibid.). Currently, treated PW is the largest operational waste stream discharged to sea from the offshore oil and gas industry worldwide.

Although large amounts of PW are discharged to the water column offshore, many consider the PW issue to be a classic case of "the solution to pollution is dilution" as a more rapid dilution occurs offshore compared to in freshwater systems affected by land-based oil and gas fields. From early on, the strong dilution of PW when discharged to the sea was considered adequate to mitigate risks for harmful ecological effects at offshore production fields, e.g., (Koons et al., 1977; Middelthiedt, 1984; Somerville et al., 1987; Girling, 1989; Stephenson, 1992). Although it is challenging to characterize all possible biological impacts associated with PW discharges, several earlier summaries of research and monitoring programs have concluded there is little to no evidence that significant impacts occur outside the primary dilution zone several kilometers downstream of PW outfalls (Nilsen et al., 2006; Bakke et al., 2013). But despite these general assessments, some remaining unknowns still create concern. One key concern is the prospect of increasing offshore oil and gas activities in northern regions, such

\* Corresponding author.  
E-mail address: [jonny.beyer@niva.no](mailto:jonny.beyer@niva.no) (J. Beyer).

## Offshore effekt-overvåking av sediment, vannsøyle, og epifaunasamfunn

Marine Environmental Research 209 (2025) 107166

Contents lists available at ScienceDirect

### Marine Environmental Research

journal homepage: [www.elsevier.com/locate/marenv](http://www.elsevier.com/locate/marenv)

### Environmental effects monitoring of offshore oil and gas activities on the Norwegian continental shelf: A review

Jonny Beyer<sup>a,b,\*</sup>, Kari E. Ellingsen<sup>c</sup>, Nigel G. Yoccoz<sup>c,d</sup>, Pål Buhl-Mortensen<sup>e</sup>, Torgeir Bakke<sup>a,1</sup>

<sup>a</sup> Norwegian Institute for Water Research (NIVA), Økernveien 94, N-0579, Oslo, Norway  
<sup>b</sup> University of Oslo, Department of Biosciences, NO-0316, Oslo, Norway  
<sup>c</sup> Norwegian Institute for Nature Research (NINA), Fram Centre, 9296, Tromsø, Norway  
<sup>d</sup> Arctic University of Norway (UiT), 9296, Tromsø, Norway  
<sup>e</sup> Institute of Marine Research (IMR), Nordnagstun 50, 5005, Bergen, Norway

**ARTICLE INFO**

**Keywords:**  
Offshore petroleum industry  
Environmental effect monitoring  
Norwegian continental shelf  
Review

**ABSTRACT**

This review examines the evolution and findings of Norway's offshore environmental monitoring (OEM) program over the past five decades. The program targets soft sediments, water column organisms, and deep-water epifauna across the Norwegian Continental Shelf (NCS) to assess the impacts of offshore oil and gas activities. The program is required by Norwegian authorities and financed by oil and gas companies operating on the NCS. Initially prompted by widespread effects from oil-contaminated drill cuttings (OBM-DC) discharges, the first sediment quality monitoring came in 1973, and grew into a regional sediment quality monitoring program in 1995. A ban on discharge of OBM cuttings on the NCS was implemented in 1993, and the following years saw a clear reduction in areas with impacted sediments. Currently, significant contamination and macrofauna disturbances are typically confined within 250–500 m of DC discharge points. In the 1990s, concerns over increasing produced water (PW) discharges led to development of effect monitoring in the water column, with focus on fish and mussels as bioindicators. These *in situ* effect surveys have shown localized impacts near PW outlets. Other fish surveys have revealed elevated DNA adduct levels in demersal fish (haddock) in several areas on the NCS, but the causality of this phenomenon remains unclear. Deep-water petroleum exploration has necessitated visual surveys to map protected benthic epifauna communities, such as corals and sponges, though the methodology's suitability for assessing biological impact is uncertain. Future recommendations include redesigning sediment surveys to address combined stressors from the petroleum industry, fisheries, and climate change, adopting recent methodological and statistical advancements, and improving integration across program elements. This review describes how the offshore monitoring on the NCS has evolved in response to changing environmental concerns, regulations and industrial practices, providing insights for enhancing ecological protection in offshore petroleum activities.

### 1. Introduction

Since the discovery of the Ekofisk field in 1969, offshore oil and gas activities on the Norwegian Continental Shelf (NCS) have led to development of 123 production fields, of which 92 are producing by the end of 2023 (Norwegian Petroleum, 2024). Over the years, developments of environmental regulations and management have aimed to protect offshore fisheries and other key ecological values which co-exist in the same areas as the oil and gas activities. A central tool in this context is

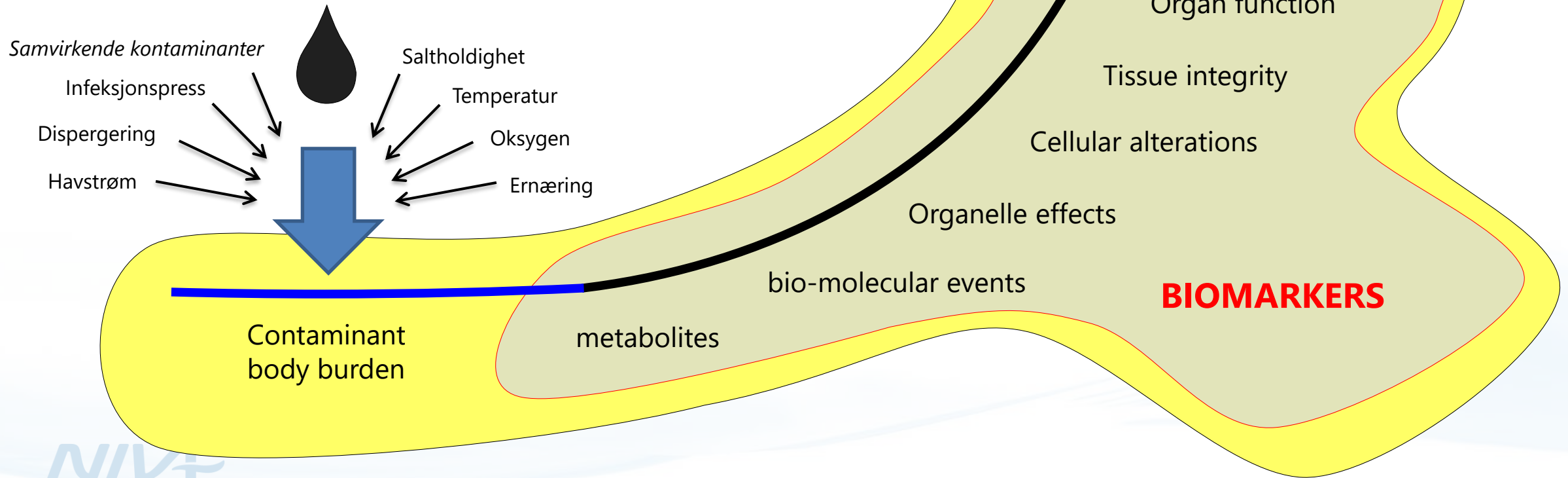
the Norwegian offshore environmental monitoring (OEM) program. The program was developed through collaboration between the Norwegian Environment Agency (NEA, the State Pollution Control Authority, SFT, at the time) and the Oslo-Paris Commission (OSPAR). Its content, including approach, knowledge requirements, parameters, and methods, has been defined and evolved in line with cutting-edge research and international environmental agreements. The OEM program aims to monitor and assess environmental impacts of petroleum activities on the NCS, adhering to OSPAR guidelines and Norwegian

\* Corresponding author. Norwegian Institute for Water Research (NIVA), Økernveien 94, N-0579, Oslo, Norway.  
E-mail address: [jonny.beyer@niva.no](mailto:jonny.beyer@niva.no) (J. Beyer).

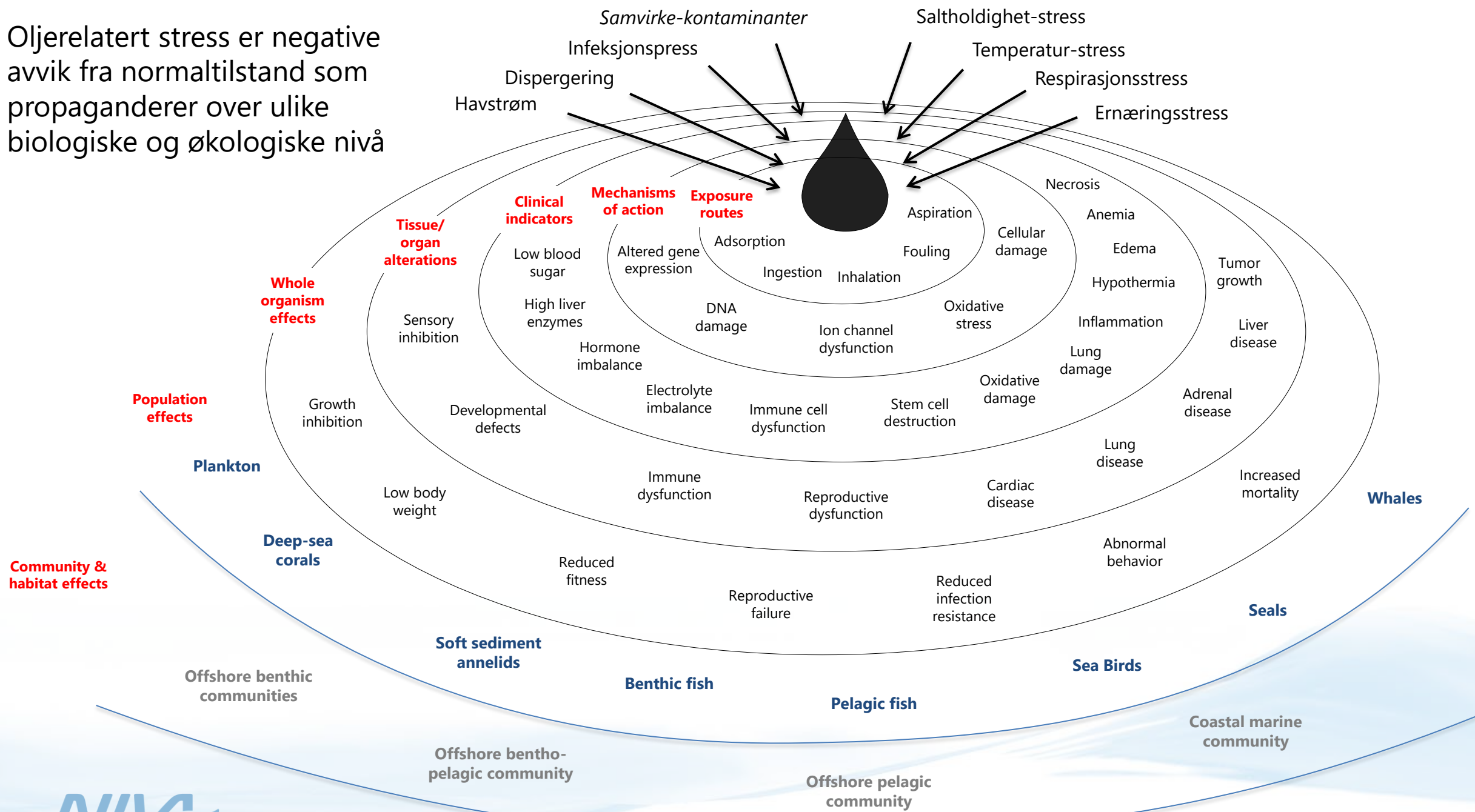
<sup>1</sup> Retired, at emeritus contract in NIVA.  
<https://doi.org/10.1016/j.marenvres.2025.107166>



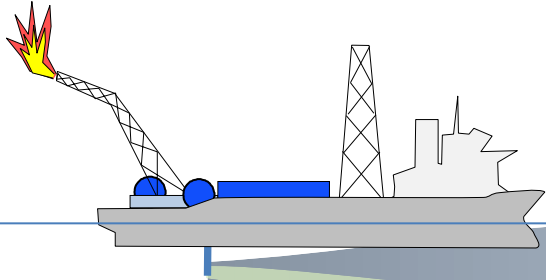
# PW utslipp bidrar til semi-kontinuerlig lav-dose eksponering og mulig påvirkninger/effekter i ulike vannsøyle biota



Oljerelatert stress er negative avvik fra normaltstand som propaganderer over ulike biologiske og økologiske nivå



# Hovedkomponenter av effekt-orientert overvåking i vannsøylen

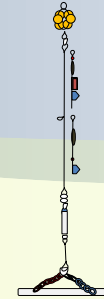


**DREAM & EIF based PW plume fate simulations and risk assessments**

**Sentinel mussel caging, rigs include also sensors and passive samplers**

## Wild fish bioindicators

- Gonad somatic index
- Condition index
- PAH/NPD (liver)
- PAH metabolites (bile)
- Histology alterations (liver)
- CYP1A1-induction (liver)
- DNA adducts (liver)
- Lymphocyte strand breaks (comet)
- Micronuclei (RBCs)
- AChE inhibition (muscle)
- Radio-isotopes (bones/muscles)



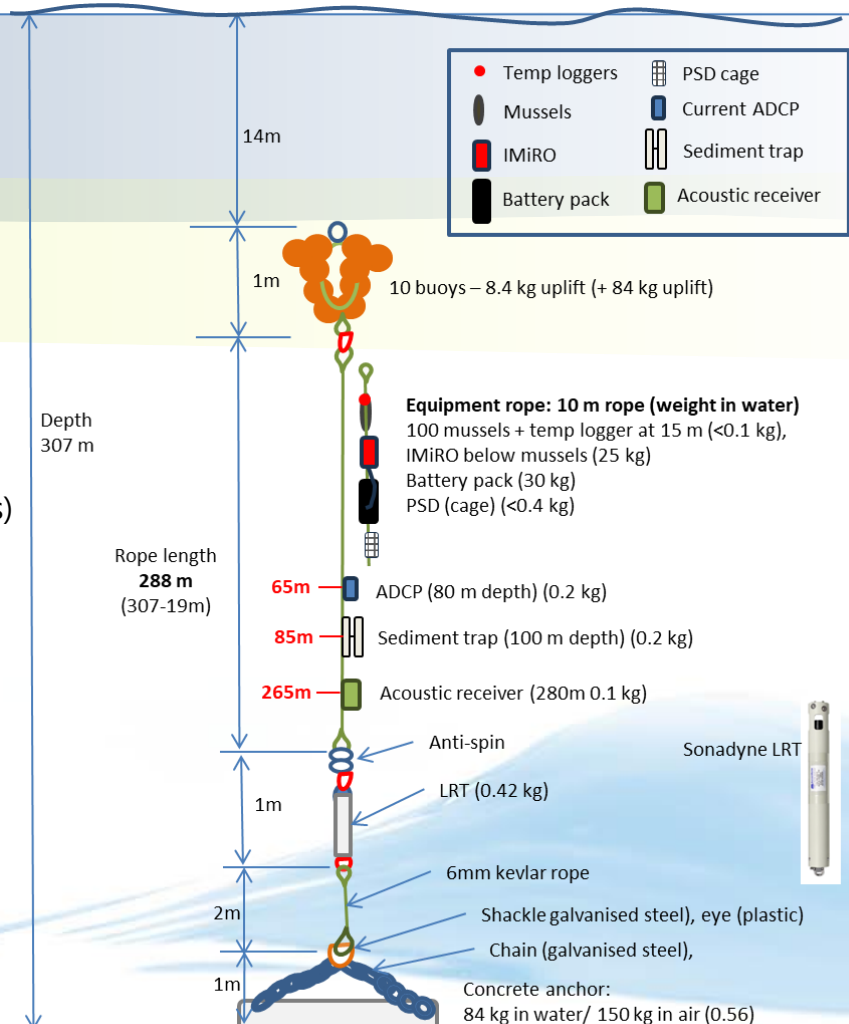
- Size and condition index
- Speciation
- Repro-maturity/spawning (gonads)
- General health status (Stress on stress)
- PAH concentration (soft tissue)
- Metals (soft tissue)
- Micronuclei (haemocytes)
- Lysosomal stability (LMS)

## Example of challenge:

- Risk of suboptimal positioning of rigs
- Sensitivity of biomarkers
- Lack of QC reference samples

## Example of challenge: variable sample groups

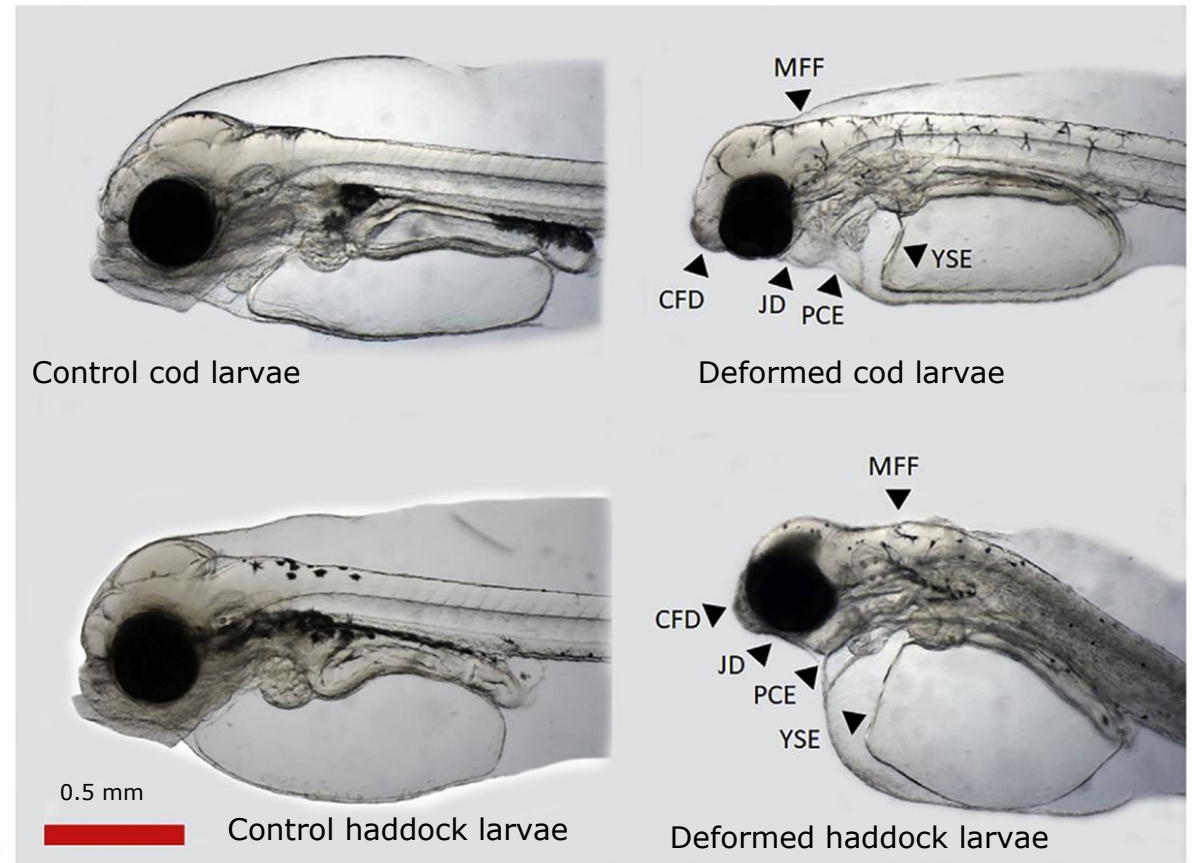
- 2024 (Snorre): ling, tusk, saithe
- 2021 (Ekofisk): cod, dab, haddock, whiting, grey gurnard
- 2017 (Tampen): cod, ling, saithe, whiting, haddock, tusk, pollock
- 2014 (Njård A): ling, tusk, redfish, saithe
- 2012 (Troll) ...



Caging-rig illustration: Steven Brooks

# Aktuelt å måle PAH effekter på utvikling/hjertefunksjon hos fiskelarver (?)

- Råolje inneholder mye 3-rings PAH-er som er utviklings-toksiske og kardiotoxiske hos fiskelarver.
- Påvirkning ses blant annet som svekket pumperefleks, væskeopphopning (ødem) rundt hjertet og plommesekk, redusert hjerte og individfunksjon og økt risiko for hjertesvikt og død.
- Dokumenterte effekter hos viktige kommersielle fiskearter som torsk og hyse.
- Hyse er særlig sensitiv pga. klebrige eggeskall som akkumulerer mer oljedråper og eksponeres kraftigere enn for arter uten klebrige egg.



Normal and deformed 2 days post hatch larvae of cod and haddock.

MFF = Marginal finfold. CFD = Craniofacial deformation. JD = Jaw deformation. PCE = Pericardial edema. YSE = Yolk sac edema.

Both deformed larvae were characterized to have severity degree 3 for CFD and JD and severity degree 2 for PCE and YSE.

Data source: Hansen et al (2019)



Contents lists available at ScienceDirect

Marine Environmental Research

journal homepage: [www.elsevier.com/locate/marenvrev](http://www.elsevier.com/locate/marenvrev)



Embryonic exposure to produced water can cause cardiac toxicity and deformations in Atlantic cod (*Gadus morhua*) and haddock (*Melanogrammus aeglefinus*) larvae

Bjørn Henrik Hansen<sup>a,\*</sup>, Lisbet Sørensen<sup>a</sup>, Trond R. Størseth<sup>a</sup>, Raymond Nepstad<sup>a</sup>, Dag Altin<sup>b</sup>, Daniel Krause<sup>a</sup>, Sonnich Meier<sup>c</sup>, Trond Nordtug<sup>a</sup>

<sup>a</sup>SINTEF Ocean AS, Environment and New Resources, Trondheim, Norway

<sup>b</sup>BioTrix, Trondheim, Norway

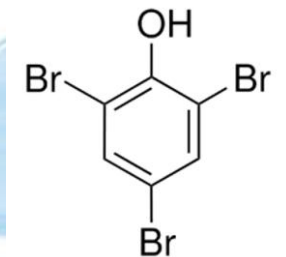
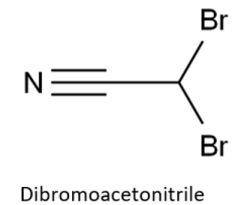
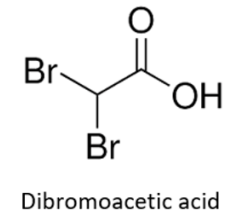
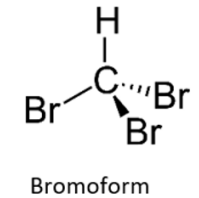
<sup>c</sup>Institute of Marine Research, Bergen, Norway



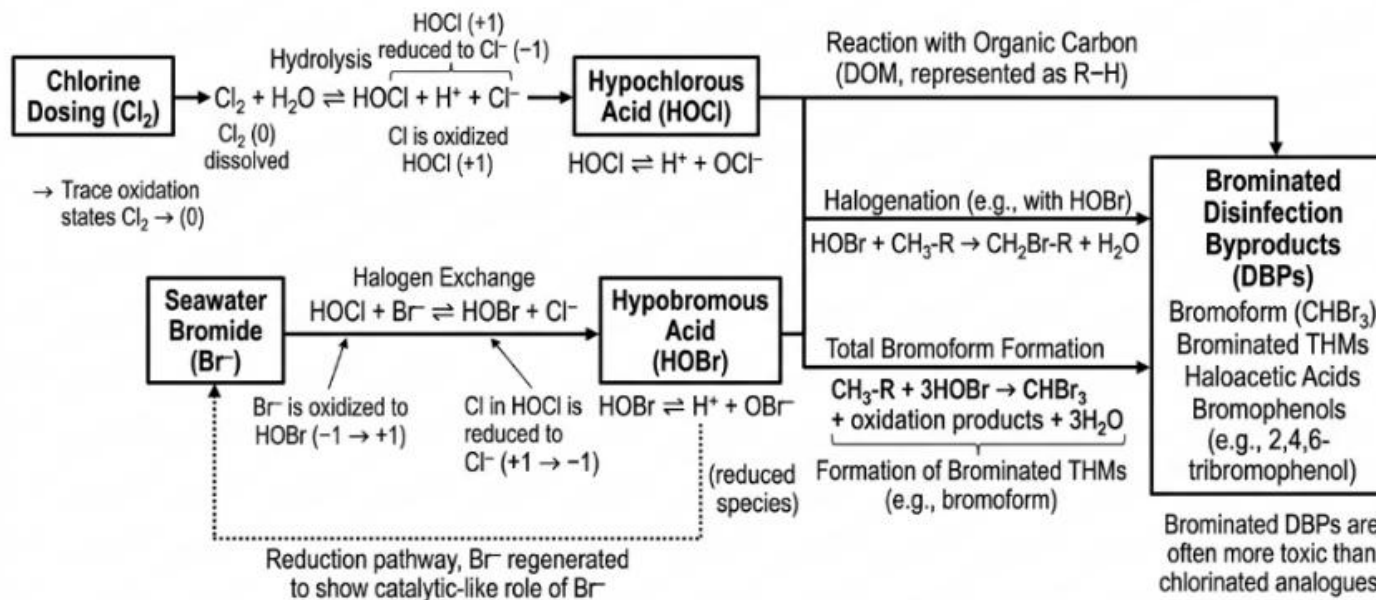
# Bromofenoler – kan være en hittil «oversett» PW risiko

- Utslipp av hypoklorittbehandlet sjøvann skjer typisk nær utslippene av produsert vann.
- Studier fra kystvann tilsier at blanding reaktive bromholdige desinfeksjonsbiprodukter (DBP) og fenol/aromat-rike utslipp kan føre til økt dannelse av miljøgiftige polybromerte aromater.
- Tilsvarende vurderinger/dokumentasjon fra offshore felt mangler.
- Miljødirektoratet vurderer nå om det er behov for bedre kunnskap og dokumentasjon om dette.

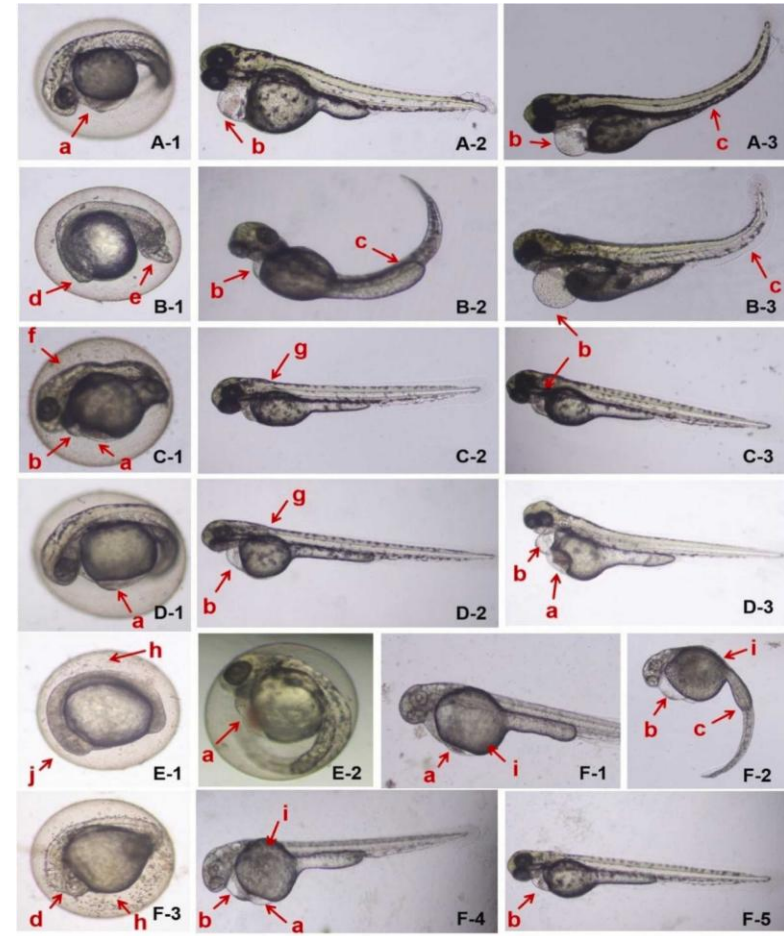
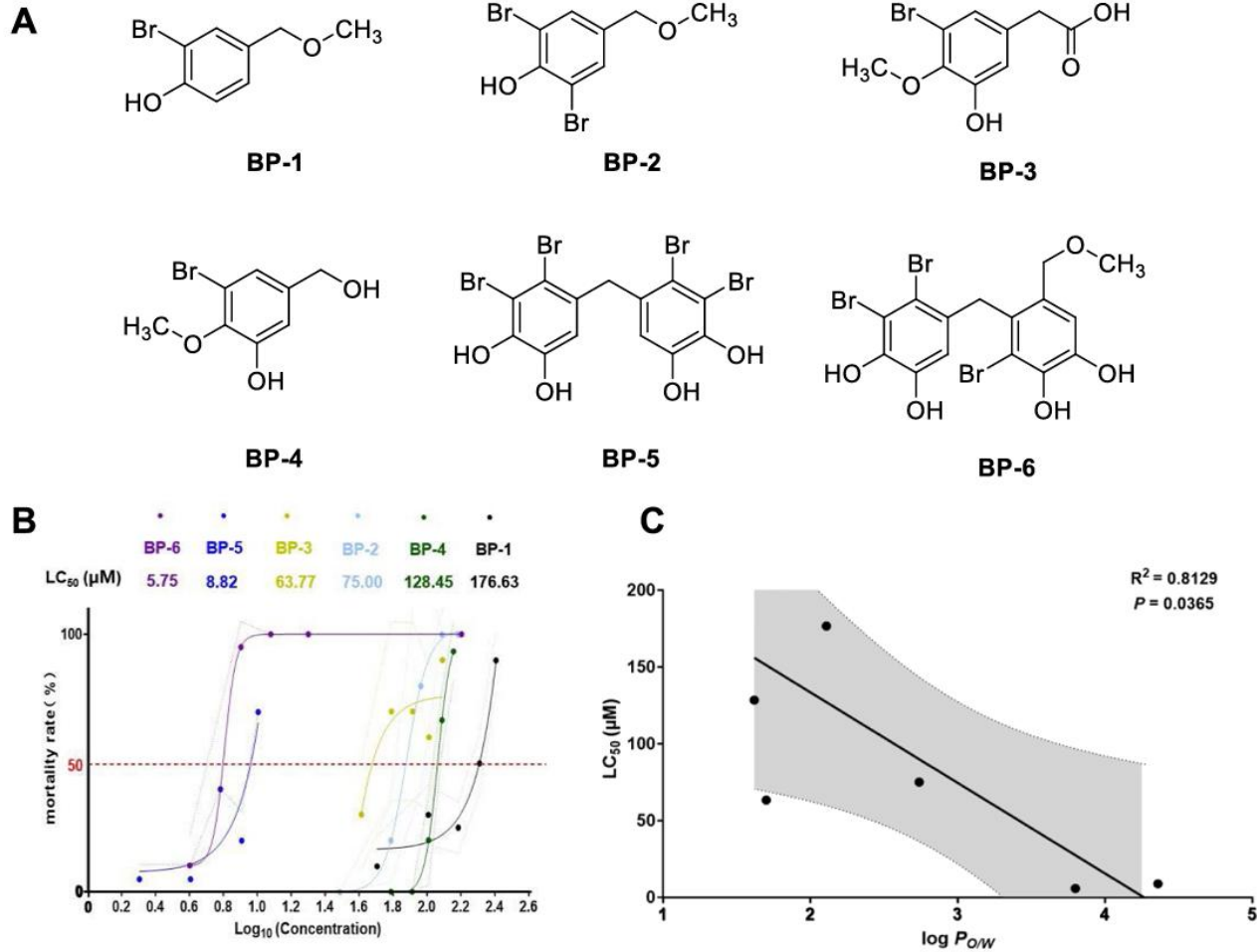
Mulige DBP-  
proxyer for  
vurderinger  
offshore



## Chemical Reaction Scheme for Hypochlorite-based Seawater Disinfection



# Bromofenoler – påvirker også utvikling og hjertefunksjon i fiskelarver



Toxicity biomarkers of bromophenols in zebrafish ELS

Hou, Z. H., et al. (2025). "Organobromine compounds in aquatic environments: Embryotoxicity linked to lipophilicity and molecular structure." *Journal of Hazardous Materials* **489**.

(a) venous sinus edema, (b) pericardial cysts, (c) tail curvature, (d) delayed head development, (e) abnormal tail growth, (f) craniofacial malformation, (g) hydronephrosis, (h) pigment deposition on membranes, (i) delayed yolk sac absorption, and (j) impaired overall embryonic growth.

# Oppsummering

## 1. Vedvarende store utslipp av produsert vann til vannsøylen

- Produsert vann (PW) utslipp inneholder dispergert olje (utgjør den største operative kilde til oljeutslipp til sjø fra offshore petroleumsvirksomhet) og også PAH, NPD, alkylfenoler, BTEX, metaller, lavradioaktive isotoper (NORM) og ulike produksjonskjemikalier.
- Risikobasert tilnærming (RBA), DREAM-EIF-verktøy og myndighetskrav om null-skadelige-utslipp bidrar til streng regulering/håndtering av potensiell miljørisiko knyttet til PW utslippene på norsk sokkel.
- Men pga. "unresolved complex mixtures" problematikk er det vanskelig å identifisere enkeltstoffer/grupper som driver miljørisiko, noe som bidrar til fortsatt usikkerhet om eksponerings- og effektestimater og miljørisikoberegninger.
- Kravene for rapportering av operative utslipp av hypoklor-behandlet sjøvann fra norske installasjoner er skjerpet. Det har gitt økt oppmerksomheten på klorerings-biprodukter i utslipp til vannsøylen, særlig der produsert vann og hypoklor-behandlet sjøvann slippes ut nært hverandre.
- I slike sammenhenger er polybromerte fenoler/aromater potensielt interessante/relevante for effekt- og miljørisikovurdering/overvåking i nærfelt vannsøylen.

## 2. Effekt-orientert forskning og overvåking av offshore PW utslipp

- Erfaringene fra vannsøyleovervåkingen (WCM) viser at PW utslipp gir en målbar lav-dose kontaminering av vannsøyle- biota i nærfeltet.
- Eksponering og biomarkørresponser er påvist flere kilometer nedstrøms for plattformer med store PW utslipp.
- Økte DNA-addukter hos bunnfisk (hyse) har gjentagende blitt påvist, men uten en klar/sikker attribusjon til forurensninger fra produsert vann utslipp og (tidligere) borkaks-utslipp.
- Det er behov for å validere egnethet for biomarkørene som brukes i WCM programmet. Det innebærer kontrollerte og konsentrasjons-realistiske PW effektstudier utført i laboratoriet. Anvendbare markører i sentinelle bioindikatorer skal kunne fange opp miljøfare ved feltrealistiske betingelser.
- Biomarkører for utvikling og hjertefunksjon hos fiskelarver bør gis en særlig oppmerksomhet i slik validering / kontrollert PW effekt-testing.

## 3. Bedre integrering av vannsøyle- og sediment-overvåking?

- Effektundersøkelser innen sediment og vannsøyle dimensjonene har hittil ikke blitt sett i sammenheng.
- Men en økende betydning av økosystem-basert tilnærming og sterkere vektlegging av effekt/miljørisiko for feltenes nærområder tilsier at bedre samarbeid/integrering av disse to delprogrammene vil være hensiktsmessig og ressurseffektivt.